CONFERENCE

BOOK

DUBROVNIK, CROATIA
OCTOBER 14 - 17
2024

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INNOVATIVE SMART GRID TECHNOLOGIES
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IEEE PES ISGT INNOVATIVE SMART GRID TECHNOLOGIES EUROPE

UNIVERSITY OF ZAGREB Faculty of Electrical Engineering and Computing

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Conference book

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Croatian Transmission System Operator d.d. (HOPS) is the sole independent operator of the electric power system in the Republic of Croatia and the owner of the Croatian transmission network. It carries out the energy activities of electricity transmission as a regulated public service and is responsible for the reliability and availability of the electricity system's supply, the coordination of the electricity generation, transmission and distribution systems in addition to the responsibility for managing the electricity system.

The Croatian electric power system consists of production facilities and plants, the transmission and distribution network and consumers of electricity in the territory of the Republic of Croatia. For the purpose of security and high-quality supply of electricity to customers and the electricity exchange, the Croatian electricity system is connected to the electricity systems of neighboring countries and other systems of ENTSO-E members, which together form the synchronous electricity system of continental Europe. Customers in the Republic of Croatia are supplied with the electricity generated at power plants in Croatia and by the imported electricity.

A well-connected system with the neighboring EPS enables significant exports, imports and transits of electricity through the transmission network, and lays the Republic of Croatia as a very important link of the electricity system of Central and Southeastern Europe.

The role of the electricity transmission system in the energy transition is of key importance, as it enables sustainable and stable transition towards a low-carbon energy system. Investments in the modernization and optimization of the transmission network therefore represent the basis for future of sustainable development and the achievement of common European goals.

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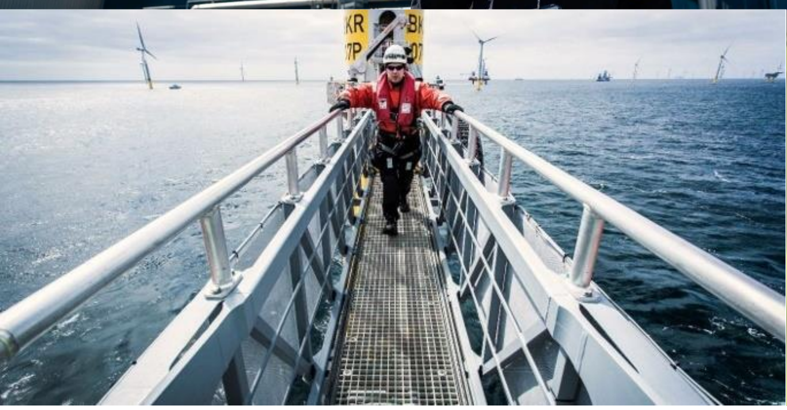

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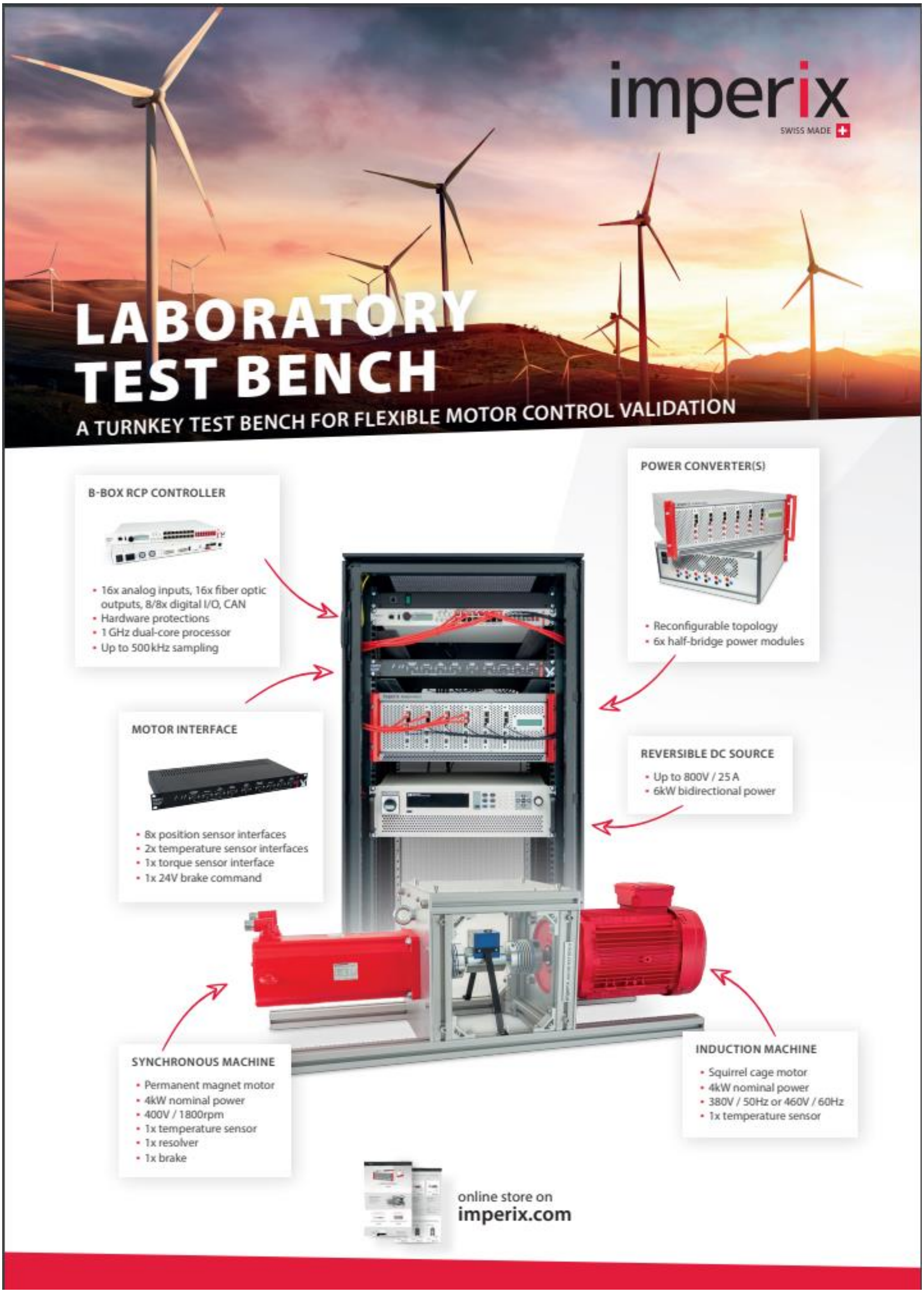
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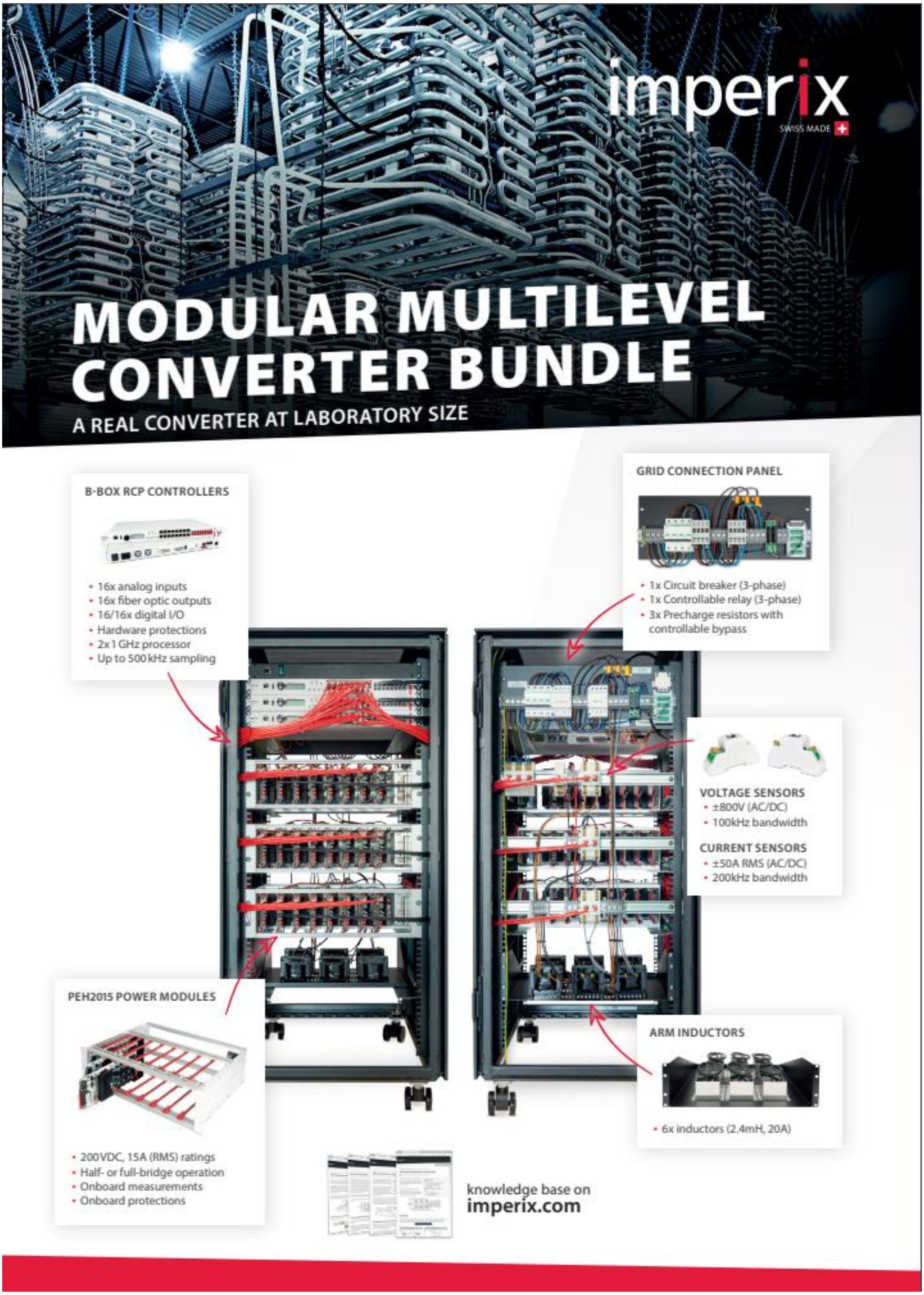
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Contents

Welcome

It is our great pleasure to welcome you to the 2024 IEEE PES Innovative Smart Grid Technologies Europe Conference – ISGT 2024. The conference is an IEEE PES flagship conference organized in Europe. It addresses power grid modernization and the applications for the wide use of information and communication technologies for more intelligent operation of electric power systems and integration of renewable and distributed energy resources.

The IEEE PES ISGT Europe 2024 conference will feature keynotes, plenary sessions, panels, industry exhibits, paper and poster presentations by worldwide experts on smart grid and related technologies. Researchers, practitioners and students worldwide are invited to submit papers for consideration to be presented at the conference and to discuss the latest trends and emerging and innovative technologies for grid modernization..

ISGT2024 Conference offers 3 keynote lectures, 3 tutorial sessions, 3 panel sessions, 7 special sessions, and a total of 52 regular paper sessions. Overall, the conference will host more than 400 papers, each of which was reviewed by at least two reviewers.

This year's ISGT2024 is hosted in Dubrovnik – one of the most beautiful city of Croatia. Dubrovnik Old Town is known as one of the world's finest and most perfectly preserved medieval cities in the world. For centuries, Dubrovnik rivalled Venice as a trading port, with its huge sturdy stone walls, built between the 11th and 17th centuries, affording protection to this former city-state. Today, these walls still enclose Dubrovnik's historic center and it is possible to walk along them to enjoy the best views of the 'Pearl of the Adriatic' and the surrounding lush green islands

For these 4 conference days, you will have a chance to meet, catch up and start collaborations with the experts from all over the world. Please, seize this opportunity as the conference technical and social program is designed for everyone to interact, network, and share ideas to provide everyone with a better future of energy.

We are looking forward to being your hosts,

Your ISGT2024 Organizing Team

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Conference agenda overview

Monday, 14/Oct/2024

8:30am - 9:00am	**OPENING: Opening session** Location: **Orlando 1B** Chair: **Ninoslav Holjevac**, University of Zagreb, Faculty of Electrical Engineering and Computing, Croatia
9:00am - 10:00am	**KEYNOTE01: Damir Novosel** Location: **Orlando 1B** Chair: **Igor Kuzle**, University of Zagreb Faculty of electrical engineering and computing, Croatia
9:00am - 6:00pm	**R8CCM: Region 8 PES Chapter Chairs Training** Location: **Koločep 5**
10:00am -10:30am	**BREAK01: Monday morning coffee break**
10:00am - 2:00pm	**TUT01: Tutorial: Control of HVDC/AC electrical grids: RTDS hardware-in-the-loop approach** Location: **Orlando 1C**
10:00am - 4:00pm	**TUT03: TRANSIT tutorial** Location: **Lovrijenac 3**
10:30am -12:30pm	**SS01: NEWEPS - Nordic Early Warning Early Prevention System** Location: **Orlando 1B**
	SS02: HVDC-WISE special session on tools, modelling, and control for the development of reliable and resilient widespread HVDC grids Location: **Lokrum 4** Chair: **Lukas Sigrist**, Universidad Pontificia Comillas Madrid, Spain
10:30am - 1:00pm	**MON01: Electric vehicles 1** Location: **Orlando 1A**
1:00pm - 2:30pm	**Recess 01: Recess break 01**
2:00pm - 4:00pm	**MON02: Congestion managment** Location: **Orlando 1A**
	PANEL01: Sharing Experiences on Workforce Challenges and Solutions for the Electric Power Industry Location: **Orlando 1B** Chair: **Wayne Bishop**, Quanta, USA
2:30pm - 6:30pm	**TUT02: Tutorial: Utility-Scale Hydrogen Electrolyzers: Dynamic and Steady-State Analysis from Power System Perspective** Location: **Orlando 1C**
4:00pm - 4:30pm	**BREAK02: Monday afternoon coffee break**
4:30pm - 5:15pm	**ERC: European Research Council (ERC) and its research funding programme** Location: **Orlando 1A**
4:30pm - 6:30pm	**PANEL02: ML/AI applications in power systems: Drivers and barriers** Location: **Orlando 1B**
5:15pm - 6:30pm	**MON03: Power system automation techniques** Location: **Orlando 1A**
8:00pm - 11:59pm	**Welcome reception: Welcome reception**

Tuesday, 15/Oct/2024

8:30am - 9:25am	**KEYNOTE02: Vladimir Terzija** Location: **Orlando 1B** Chair: **Igor Kuzle**, University of Zagreb Faculty of electrical engineering and computing, Croatia				
9:25am - 9:30am	**BREAK03: Short break**				
9:30am - 11:00am	**PANEL03: Effective dissemination of research results: Discussion with the Editor-in-Chiefs** Location: **Orlando 1B**	**TUE01: Power system reliability** Location: **Orlando 1A**	**TUE02: Wind turbines** Location: **Orlando 1C**	**TUE03: HVDC** Location: **Koločep 5**	**TUE04: Frequency stability** Location: **Lokrum 4**
9:30am - 1:00pm	**MEET01: TRANSIT project coordination meeting** Location: **Lovrijenac 3**				
11:00am -11:30am	**BREAK04: Tuesday morning coffee break**				
11:30am - 1:00pm	**TUE05: Forecasting techniques** Location: **Orlando 1A**	**TUE06: System protection** Location: **Orlando 1B**	**TUE07: Optimization techniques** Location: **Orlando 1C**	**TUE08: Voltage regulation** Location: **Koločep 5**	**TUE09: Power electronics** Location: **Lokrum 4**
1:00pm - 2:00pm	**Recess 02: Recess break 02**				
2:00pm - 4:00pm	**TUE10: Energy storage systems 1** Location: **Orlando 1A**	**TUE11: Optimal power flow** Location: **Orlando 1B**	**TUE12: Power system stability 1** Location: **Orlando 1C**	**TUE13: Power system development** Location: **Koločep 5**	**TUE14: Integration techniques** Location: **Lokrum 4**
4:00pm - 4:30pm	**BREAK05: Tuesday afternoon coffee break**				
4:00pm - 9:00pm	**DUBROVNIK: Visit to Dubrovnik** Organized buses from the venue hotel entrance.				
4:30pm - 6:30pm	**SS03: Special Session: How Digitalization Supports Flexibility Levers in the Decarbonization of Power Systems** Location: **Orlando 1B** Chair: **Vincent Debusschere**, Grenoble INP UGA, France	**SS04: Digitalization in Power Systems – a Key Enabler of the Energy Transition** Location: **Koločep 5** Chair: **Marina Oluic**, Swedish TSO (Svenska kraftnät), Sweden	**SS05: OPF and REANIMATION projects special session** Location: **Lokrum 4**	**TUE15: Distribution network** Location: **Orlando 1A**	**TUE16: Inverter-based generation** Location: **Orlando 1C**

Wednesday, 16/Oct/2024

Time						
8:30am - 9:25am	**KEYNOTE03: Lina Bertling Tjernberg** Location: Orlando 1B Chair: **Igor Kuzle**, University of Zagreb Faculty of electrical engineering and computing, Croatia					
9:25am - 9:30am	**BREAK06: Short break**					
9:30am -11:00am	**SS07: TRANIST Special Session** Location: Lovrijenac 3	**W00: Computational methods** Location: Koločep 5	**W01: Distribution systems** Location: Orlando 1A	**W02: Grid operation** Location: Orlando 1B	**W03: Transmission systems** Location: Orlando 1C	**W13: Hydrogen storage 2** Location: Lokrum 4
11:00am -11:30am	**BREAK07: Wednesday morning coffee break**					
11:30am - 1:00pm	**SS08: Power Electronic Based Grid: Roadmap Challenges From Modelling To Real Time Monitoring And Control** Location: Orlando 1C	**SS09: IEEE PES Women in Power "Challenges in advanced power system planning and operation"** Location: Lovrijenac 3 Chair: **Mirna Grzanic Antic**,	**SS10: INDUSTRY SPONSOR SPECIAL SESSION** Location: Orlando 1B	**W04: Energy storage systems 2** Location: Orlando 1A	**W05: Smart meters** Location: Koločep 5	**W06: Communications** Location: Lokrum 4
1:00pm - 2:00pm	**RECESS 03: Recess break 03**					
2:00pm - 4:00pm	**W07: Electric vehicles 2** Location: Koločep 5	**W08: EV charging stations** Location: Orlando 1A	**W09: Neural networks in power systems** Location: Orlando 1B	**W10: Demand response** Location: Orlando 1C	**W11: Hydrogen storage 1** Location: Lokrum 4	**W12: Market and cost optimization** Location: Lovrijenac 3
4:00pm - 4:15pm	**BREAK08: Wednesday afternoon coffee break**					
4:15pm - 6:00pm	**POSTER: Poster Session** Location: **Aula** Chair: **Sara Raos**,	**SS06: Cyber-physical perspective of smart grid stability, security and resilience towards a net-zero energy transition** Location: Orlando 1C Chair: **Pudong Ge**,	**W14: Flexibility** Location: Koločep 5	**W15: Machine learning applications in power system** Location: Orlando 1A	**W16: Power system modelling** Location: Lokrum 4	**W17: Measurements** Location: Lovrijenac 3
6:00pm - 7:00pm	**TV01: Technical visit to HPP Zavrelje** Walking distance from the Venue Hotel (500 meters).					
7:30pm - 8:30pm	**JOB FAIR: Sponsor event - Job Fair** Opportunity to hear what the Sponsors have to offer. Leaving the CV in the database and visit card at the entrance grants a free cocktail before the gala dinner starts.					
8:30pm - 11:59pm	**Gala event**					

Thursday, 17/Oct/2024

9:00am - 11:00am	**THU01: Power system management** Location: **Orlando 1A**	**THU02: Optimal control** Location: **Orlando 1B**	**THU03: Reserve markets** Location: **Orlando 1C**	**THU04: Power system equipment** Location: **Koločep 5**	**THU05: Data-driven approach** Location: **Lokrum 4**	
9:00am - 1:00pm	**TRANSIT TRAINING: Distribution network calculation in NEPLAN training** Location: **Lovrijenac 3**					
11:00am -11:30am	**BREAK09: Thursday morning coffee break**					
11:30am - 1:00pm	**THU06: Heat pumps** Location: **Orlando 1A**	**THU07: Multi-energy systems** Location: **Orlando 1B**	**THU08: Reactive power control** Location: **Orlando 1C**	**THU09: Energy markets** Location: **Koločep 5**	**THU10: Energy community 1** Location: **Lokrum 4**	
1:00pm - 2:00pm	**Recess 04: Recess break 04**					
2:00pm - 3:30pm	**ONLINE: Thursday 01 paper session** Location: **Lovrijenac 3** Chair: **Matija Zidar**	**THU11: Energy community 2** Location: **Orlando 1A**	**THU12: Power system inertia** Location: **Orlando 1B**	**THU13: Power system stability 2** Location: **Orlando 1C**	**THU14: Market and metering aspects** Location: **Lokrum 4**	**THU15: Thursday 15 paper session** Location: **Koločep 5**
3:30pm - 4:00pm	**CLOSING: Closing session and Best paper award** Location: **Orlando 1B** Chair: **Ninoslav Holjevac**					
4:00pm - 7:00pm	**TV02: Technical visit to HPP Dubrovnik and substation TS 220/110 kV Plat** Bus departing from the venue hotel main entrance.					

Name: Prof. Vladimir TERZIJA

Email: Vladimir.Terzija@newcastle.ac.uk

Affiliation: Newcastle University, School of Engineering

Country: UK

Biography

Vladimir Terzija received the Dipl-Ing., M.Sc., and Ph.D. degrees in electrical engineering from the University of Belgrade, Belgrade, Serbia, in 1988, 1993, and 1997, respectively. He is a Professor of Energy Systems & Networks at the Newcastle University, UK. He is also a Distinguished Visiting Professor at Shandong University, China, as well as a Guest Professor at the Technical University of Munich, Germany. In the period 2021-2023 he was a Full Professor at Skoltech, Russian Federation. In the period 2006-2020 he was the EPSRC Chair Professor at The University of Manchester, UK. From 2000 to 2006, he was a Senior Specialist for switchgear and distribution automation with ABB, Ratingen, Germany. From 1997 to 1999, he was an Associate Professor with the University of Belgrade, Belgrade, Serbia. His current research interests include smart grid applications, wide-area monitoring, protection and control, multi-energy systems, transient processes, ICT, data analytics, and complex science applications in power systems. He is the Editor-in-Chief of the International Journal of Electrical Power and Energy Systems, Fellow IEEE, Humboldt Fellow and the recipient of the National Friendship Award, China.

On data-driven solutions supporting future resilient power and energy systems

Abstract: The role of data, their acquisition, transmission, collection and processing are becoming more important than ever. The quantity of data is significantly increasing, what is a result of the 4th Industrial Revolution, Industry 4.0, which is significantly changing the shape of processes in the 21st century. Changes are particularly related to technology, industry and society. Through introduction of smart technologies, doors for designing and implementing smart solutions contributing to security, dependability, flexibility and resilience of modern energy systems, are opened. Newly designed “digital substations” are enabling rapid and efficient transfer of information from the physical process, i.e. actual electricity network in which voltage and current transducers are installed, to hierarchically higher centers in which information is processed, e.g. Energy Management Systems, or Distribution Management Systems. Through application of data science-based solutions, integration of renewable energy sources is maximized, different energy vectors are integrated into single multi-energy systems, optimizing processes, making them more efficient and contributing to confident transformation of the existing energy system into a sustainable and low carbon one. Finally, purely data-driven solutions for system monitoring, protection and control are becoming one of the major focuses of the development and innovation. The abovementioned issues will be discussed from the new technology perspective, its impact on new solutions and its expected benefits. Some representative practical examples will be presented, too.

Name: Dr. Damir NOVOSEL

Email: dnovosel@quanta-technology.com

Affiliation: Quanta Technology LLC, President

Country: USA

Biography

Damir Novosel is president and founder of Quanta Technology and was president of Quanta Energized Services. Previously, he was vice president of ABB Automation Products and president of KEMA T&D US. Damir served on various boards and is presently a member of the Sandia National Laboratories Energy and Homeland Security External Advisory Board and Mississippi State University Industry Advisory Board. Dr. Novosel is also an adjunct professor at North Carolina State University.

Damir, a member of the US National Academy of Engineers and IEEE Fellow and Life Fellow, served on the IEEE Standards Board and as IEEE PES president, VP of Technology, and chair of Industry Technical Support Leadership Committee. He is secretary of IEEE PES Executive Advisory Council, and chair of IEEE Strategic and Emerging Standards Committee. He received the IEEE PES Patrick P. Ryan Meritorious Service and Leadership in Power awards. He is the CIGRE US National Committee VP of Nominations and received the CIGRE Philip Sporn and Attwood Associate awards. Dr. Novosel holds 18 US and international patents, published over 200 articles and reports, contributed to 7 books.

Damir holds PhD, MSc, and BSc degrees in electrical engineering from Mississippi State University (where he was a Fulbright scholar), the University of Zagreb, Croatia, and the University of Tuzla, Bosnia and Herzegovina, respectively. Dr. Novosel was selected as Mississippi State University Distinguished Engineering Fellow and received the Distinguished Alumni Award.

Sustainable Electrical Energy Delivery Solutions

Abstract: Resilient, reliable, and affordable electrical grid operation is critical to society. The electrical power and energy industry is changing rapidly to meet the demands of decarbonization society needs. The grid is experiencing significant load growth and continues to face evolving challenges, such as cyber and physical attacks, major weather events and aging infrastructure. Grif flexibility and coordinated transmission, distribution, and resource planning and operation are becoming very important, especially for high levels of EV deployment and data centers. As the impact of EVs and data centers on the grid becoming more prominent, accurate dynamic modelling and forecasting are becoming critical for effective planning and operation of the grid.

As we build the grid of the future with high penetration of inverter-based sources, which complement the grid, addressing dynamic changes through real-time situational awareness, analysis, and automation becomes even more important. New technologies and processes such as advanced monitoring, protection, and control; scenario and probabilistic power system planning and operation; various sensors; device coordination; improved data management; etc. offer significant opportunities for realizing the sustainable energy future. There are various technical, economic, and regulatory challenges as well as need for new market structure and business models.

Identifying the best strategies to ensure reliable, resilient, and cost-effective delivery of electrical energy is needed to set a path to decarbonization. This presentation will discuss success factors for sustainable electrical energy delivery and address how technology and processes help in solving society needs.

Name: Prof. Lina Bertling TJERNBERG

Email: linab@kth.se

Affiliation: Royal Institute of Technology Stockholm

Country: Sweden

Biography

Lina Bertling Tjernberg (Docent, Ph.D., MSc.) is a Professor in Power Grid Technology and Deputy Head of the School of Electrical Engineering and Computer Science at KTH, Royal Institute of Technology, Stockholm, Sweden. She is a Fellow of the Royal Swedish Academy of Engineering, a senior member of IEEE, and serves as an independent expert for the EU Commission. Lina has held various leadership roles in IEEE and received the 2021 Power Woman of the Year award for her contributions to sustainable energy systems. Lina established the Reliability Centered Asset Management (RCAM) framework and has co-authored over 140 scientific articles and several books, including Infrastructure Asset Management with Power System Applications. Her research focuses on applying mathematics to predict and model reliability in electric power systems, with interests in microgrids, battery storage, renewable energy, and electrified transportation. She is an active advisor and expert in several professional organizations and a frequent keynote speaker. Currently, she serves on the board of the Swedish Electromobility Center and the IEEE PES ISGT Europe Steering Group.

Transforming Predictive Maintenance and Condition Monitoring with AI-Based Machine Learning in Asset Management

Abstract: The integration of artificial intelligence (AI) and machine learning (ML) into asset management is revolutionizing the field of predictive maintenance and condition monitoring. This keynote will explore cutting-edge AI-based ML models that enhance the efficiency, reliability, and longevity of critical assets within electric power and energy systems. Attendees will gain insights into how these advanced technologies can predict failures, optimize maintenance schedules, and monitor the condition of assets in real time. Through detailed examples and case studies, the practical applications of AI-driven predictive maintenance and condition monitoring will be demonstrated and, highlighting the significant improvements in operational performance and cost savings.

Tutorial 1: Control of HVDC/AC electrical grids: RTDS hardware-in-the-loop approach

Time: Monday, 14/Oct/2024: 10:00am - 2:00pm **Location:** Orlando 1C

Abstract: The transmission systems are heading towards hybrid using high-voltage AC and DC connections. Power electronic converters contribute to significant changes in the operation and control of the system, its stability, and robustness. For the design of a hybrid electrical grid and preparation for its physical deployment, real-time simulations and hardware-in-the-loop testing are a must.

This tutorial covers the design aspects of the power electronic converters used for DC applications (MMCs) and control of the power systems with the high penetration of renewable energy sources using the real-time hardware, RTDS©. The tutorial will use RSCAD/RTDS open-source libraries during the "hands-on" sessions in RSCAD/RTDS. The participants will be divided into 10 groups, supported by a computer with installed RSCAD and secured access to RTDS cores. Furthermore, one RTDS NovaCor (10 cores) will be present, and the participants will be able to see its operation and connection.

Moderated by:

TBD

Panelists:

1. **Dr. Aleksandra Lekić,** Assistant Professor, Delft University of Technology, Delft, Netherlands, A.Lekic@tudelft.nl
2. **Prof. Dr. Pablo Eguia Lopez,** Professor, University of the Basque County UPV/EHU, Spain, pablo.eguia@ehu.eus
3. **Dr. Vaibhav Nougain,** Postdoc, Delft University of Technology, Delft, Netherlands, V.Nougain@tudelft.nl
4. **Milovan Majstorović,** Ph.D. researcher, University of Belgrade, Serbia, majstorovic@etf.bg.ac.rs
5. **Remko Koornneef,** Technician, Delft University of Technology, Delft, Netherlands, R.N.Koornneef@tudelft.nl

Tutorial 2: Utility-Scale Hydrogen Electrolyzers: Dynamic and Steady-State Analysis from Power System Perspective

Time: Monday, 14/Oct/2024: 2:30pm - 6:30pm **Location:** Orlando 1C

Abstract: There are major discussions worldwide on how the production of clean fuels, such as hydrogen, could facilitate the whole-energy system decarbonization. From a power system perspective, green hydrogen production results in massive grid integration of electrolyzers, that needs to be considered in power system analysis. This tutorial presents the modelling foundations of utility-scale hydrogen electrolyzers with alkaline and proton exchange membrane (PEM) technology, including electrolysis stack models, power electronics interface (PEI) and control, thermodynamics, hydrogen production formulations, and operational constraints in downstream hydrogen process/buffer, required for system-level steady-state and dynamic studies in both transmission and distribution grids. Possible PEIs for grid integration of electrolyzers will be discussed, along with the associated control schemes in particular grid-forming load control. It will be discussed how and to what extent electrolysis plants could impact system stability and operation, from both steady-state and dynamic perspectives.

Moderated by:

TBD

Panelists:

Dr Mehdi Ghazavi Dozein received M.Sc. degree from University of Tehran and Ph.D. degree from The University of Melbourne. After PhD graduation, he worked for two years as an Associate Lecturer in Power Systems with the Department of Electrical and Electronic Engineering, Faculty of Engineering and IT, The University of Melbourne. He is currently a Lecturer (Assistant Professor) at Monash University, Australia. His research interests include power system dynamics and stability, and modelling and control of inverter-based technologies. Mehdi is a Senior Member of IEEE and an active panel member of Australian CIGRE C4 on Power System Technical Performance

Dr Marc Cheah Mañe received the degree in industrial engineering from the School of Industrial Engineering of Barcelona (ETSEIB), Universitat Politecnica de Catalunya (UPC), Barcelona, Spain, in 2013, and the PhD degree in electrical engineering from Cardiff University, Cardiff, the U.K. in 2017. From 2017 to 2020 he was a research associate in CITCEA-UPC, Barcelona, Spain. Since March 2020 he is a Lecturer under the Serra Hunter program at the Electrical Engineering Department of UPC. Since April 2022, he is also a co-founder of eRoots, which is a spin-off company of CITCEA-UPC specialized in innovative tools for modern power system analysis. His research interests include power systems with power electronics, high-voltage direct current systems, wind and photovoltaic generation.

Ms Antonella Maria De Corato received the B.Sc. and M.Sc. degrees in electrical engineering from the Polytechnic University of Bari, Italy, in 2017 and 2019, respectively. She has recently completed her PhD at The University of Melbourne, Australia. Her PhD thesis is now submitted and it is under review. Her research interests include modelling of distributed multi-energy systems and networks and grid integration of renewables and hydrogen technologies.

Tutorial 3: TRANSITion to sustainable future through training and education

Time: Monday, 14/Oct/2024: 9:30am - 11:00am **Location:** Lovrijenac 3

Abstract: TRANSIT (TRANSITion to sustainable future through training and education) is a project funded by the European Union under the program Horizon Europe that aims to provide sustainable training and re-skilling programmes for current and future generations on a multidisciplinary approach in renewable energy.

In achieving this, TRANSIT seeks to enable the societal changes that will encompass the high ambitions of deployment and transformation of the energy sector in the next decades through the design and delivering of an overall educational, retraining and social engagement programme covering different sectoral strategies and stakeholders..

Moderated by:

Tomislav Baškarad, University of Zagreb Faculty of electrical engineering and computing, Croatia

Panelists:

1. **Luis Badesa,** Universidad Politécnica de Madrid, Spain

   Presentation 1: "***How to design economic mechanisms for efficient operation of low-inertia power grids***"

2. **José Miguel Riquelme,** Universidad Politécnica de Madrid, Spain

   Presentation 2: "***Flexible Operation of Storageless Grid-connected Photovoltaic Systems for Frequency Support***"

3. **Dragan Vučković,** University of Niš, Serbia

   Presentation 3: "***The European Green Deal for clean energy transition: Design and Integration of Renewable Energy Sources***"

4. **Petar Krstevski,** Ss. Cyril and Methodius University in Skopje, North Macedonia

   Presentation 4: "***Electricity Balancing Markets - Challenges in Regional Integration and Integration of Flexibility from RES, DSM and Storage***"

5. **Mihailo Micev,** University of Montenegro, Montenegro

   Presentation 5: "***Optimal location of distributed energy sources – problems and experiences from Montenegro***"

Panel Session 1: Sharing Experiences on Workforce Challenges and Solutions for the Electric Power Industry

Time: Monday, 14/Oct/2024: 2:00pm - 4:00pm **Location:** Orlando 1B

Abstract: The Power industry is undergoing a remarkable transformation driven mainly by decarbonization and the resulting intensified electrification and grid modernization. The need for a qualified workforce for tackling these challenges has been pointed out as top priority by major power industry professionals. This Workforce panel is comprised of academic and industry leaders from Europe and the United States who will discuss the challenges, opportunities, unique solutions, and ideas for collaboration between academia, industry, and IEEE. Each person will give a 10 minute presentation, and this will be followed by audience Q&A and discussion. The later will be documented and made part of the formal report that will be issued by the PES Workforce Initiative Committee.

Moderated by:

Wayne Bishop Jr, Chair of Industry Committee for IEEE PES Workforce Taskforce. Vice President, Quanta Technology

Panelists:

1. **Dr. Luka Strezoski,** University of Novi Sad, Serbia
2. **Ambra Sannino,** Vice President R&D Vattenfall, Sweden
3. **Gabriel Bareux,** Head of R&D, RTE, France
4. **Dr. Martha Symko-Davies,** NREL, United States
5. **Annika Moman,** WSP, Gothenburg, Sweden
6. **Pär Lundström,** Senior Policy Advisor, The Swedish Installation Federation
7. **Brittany McKannay,** Director, Electric Engineering, Pacific Gas and Electric Company

Panel Session 2: ML/AI applications in power systems: Drivers and barriers

Time: Monday, 14/Oct/2024: 4:30pm - 6:30pm **Location:** Orlando 1B

Abstract: Application of Machine learning (ML) and Artificial Intelligence (AI) in power systems holds promise based on initial demonstrations. Many journal and conference papers, and panels at different conferences have been promoting future uses across monitoring, control and protection applications. However, most of the proposed applications are tested on synthetic data or ideal data coming from either small or simplified power system models. This did not encounter dealing with bad data and imprecise labels, and large-scale power systems complex dynamics found in the field environment. Furthermore, simplified assumptions also facilitated simplified feature engineering, and algorithm assumptions that proliferated wide use of the off-the - shelf ML/AI solutions. While the results looked promising, many of such applications did not reflect difficulties when implementing solutions to be deployed in a production environment where of-the-shelf algorithms require significant tuning. Also, most of the past solutions where not concerned with the sufficient evaluation that can justify the use of ML/AI over traditional solutions.

This Panel is focusing on experiences from recent developments dealing with real-life problems and applications facing both the opportunities and challenges of scaling such solutions to the cost-effective applications with clear return on investment. The speakers will illustrate the drivers and barriers stemming from their developments aimed at future deployments of ML/AI in the utility environment.

Moderated by:

Mladen Kezunović, Texas A&M University, USA

Bio: Dr. Mladen Kezunovic (Life Fellow, IEEE) has been with Texas A&M University, College Station, TX, USA, for over 35 years, where he is currently a University Distinguished Professor, Regents Professor, Eugene E. Webb Professor, and the Site Director of the ''Power Engineering Research Center'' Consortium. He served for over 30 years as the Principal Consultant of XpertPower AssociatesTM, a consulting firm specializing in power systems data analytics. His expertise is in protective relaying, automated power system disturbance analysis, computational intelligence, data analytics, and smart grids. He is CIGRE Fellow, Honorary and Distinguished Member, registered Professional Engineer in Texas, and member of the US National Academy of Engineering.

Panelists:

1. **Ricardo Bessa,** INESC TEC, Portugal

Bio: Ricardo Bessa earned his Licenciado degree in Electrical and Computer Engineering from the University of Porto (UP) in 2006, followed by an M.Sc. in Data Analysis and Decision Support Systems from UP in 2008. In 2013, he completed his Ph.D. in the Doctoral Program in Sustainable Energy Systems (MIT Portugal) at UP. He is the Coordinator of the Center for Power and Energy Systems at INESC TEC. His research interests include renewable energy forecasting, computational intelligence applied to energy systems, decision-making under risk, and smart grids. He worked on several international projects, such as the European Projects FP6 ANEMOS.plus, FP7 SuSTAINABLE, FP7 evolvDSO, Horizon 2020 InteGrid, H2020 Smart4RES and coordinates the AI4REALNET project. IEEE Senior Member, Associate Editor of Journal of Modern Power Systems and Clean Energy, received the Energy Systems Integration Group Excellence Award in 2022.

Presentation 1: ***"Human-AI frameworks and knowledge representation for AI in control room tasks"***

Summary: This talk will showcase various AI use cases in system operations, highlighting the main benefits driving AI adoption, and it will discuss the need to establish an interdisciplinary framework for AI-based decision systems in critical infrastructures to overcome barriers like algorithm aversion. Additionally, we will emphasize the importance of effective knowledge representation—integrating diverse data sources and human expertise—to fully exploit available information. This approach enhances the interpretability and transparency of models and data for human users and decision-makers.

2. **Jochen Cremer,** Delft University of Technology, The Netherlands

Bio: Dr. Jochen Cremer works as Co-Director of the TU Delft AI Energy Lab, as Assistant Professor at the Faculty of Electrical Engineering, Mathematics, and Computer Science Delft University of Technology and as Principal Scientist at Austrian Institute of Technology. The Delft AI Energy Lab focuses on applying machine learning and data analytics to energy systems operation and control. He holds the PhD from Imperial College London.

Presentation 2: ***"Status quo: Probabilistic Reliability Assessment with Deep Learning"***

Summary: Preparing power systems for large-scale inverter-based resources requires future reliability tools to anticipate uncertainties in monitoring and controlling energy supply. Driven by the first successes in the energy domain, such as renewable or load forecasting, Deep Learning (DL) is promising for other applications. However, applying these DL-based approaches beyond forecasting is challenging as it involves considering multiple existing operating tools. The barrier to inter-operably implementing DL-based methods with other conventional tools requires domain adaptation beyond 'plug-and-play'. Given this barrier, this talk introduces the concept of constraint-driven DL for probabilistic reliability assessment implemented in a security-constrained optimal power flow problem (SCOPF). Recently, a proposed DL approach modelled the loss function as a polynomial, consecutive matrix multiplication of the post-fault power flows with line outage distribution factors improving the scaling with k-outages. The implicit function theorem guarantees the pre-fault power flow is physically feasible, and the DL model learns pre-fault power settings that are N-k secure. Lastly, embedding DL in existing dynamic security assessment tools boosts the computational times to near real-time capabilities.

3. **Panagiotis Papadopoulos,** The University of Manchester, UK

Bio: Panagiotis Papadopoulos is currently a Reader (Associate Prof.) in the Department of Electrical and Electronic Engineering at the University of Manchester and a UK Research and Innovation Future Leaders Fellow working on "Addressing the complexity of future power system dynamic behaviour". He received the Dipl. Eng. and Ph.D. degrees from the Department of Electrical and Computer Engineering at Aristotle University of Thessaloniki, in 2007 and 2014, respectively. From 2014-2017, he was a post-doctoral Research Associate at the University of Manchester and in 2017, he joined the University of Strathclyde as a Lecturer. He is currently the Technical Committee Program Chair for Power System Dynamic Performance committee of IEEE Power and Energy Society. His research interests are in the area of power system stability and dynamics under increased uncertainty, introduced due to the integration of new technologies. He is also interested in power system applications of machine learning to tackle complex problems related to power system stability.

Presentation 3: ***"How can machine learning help with power system security assessment?"***

Summary: The presentation will introduce key challenges linked to increased complexity and uncertainty related to dynamics and stability of modern power systems, and discuss how can machine learning help addressing those. Recent advances going beyond the notion that machine learning models are just powerful black box predictors will be presented, related to explainability/interpretability (understanding and gaining insights from ML models), physics informed (embed known physics in the training of ML models) and graph based (deal with changing topology) methods will be discussed. Remaining challenges related to implementation of machine learning based methods for dynamic security assessment will also be discussed.

4. **Robert Eriksson,** Uppsala University and Svenska Kraftnät, Sweeden

Bio: Robert Eriksson received his M.Sc. and Ph.D. degrees in Electrical Engineering from the KTH Royal Institute of Technology, Stockholm, Sweden, in 2005 and 2011, respectively. He was an Associate Professor at the Center for Electric Power and Energy at the Technical University of Denmark (DTU) from 2013 to 2015. He has several years of experience in operations and system stability development at the Swedish National Grid (Svenska kraftnät), where he has been employed since 2015 and is currently working part-time. He served as an Adjunct Professor at the KTH Royal Institute of Technology from 2020 to 2023. He is currently a Full Professor in the Division of Electricity at Uppsala University. His current research interests include power system dynamics and stability and control; data-driven, AI and machine learning approaches in power system stability; HVDC systems; and wide-area monitoring and control.

Presentation 4: ***"Opportunities and Challenges with AI/ML in the Swedish Power System Operation"***

Summary: The integration of AI and machine learning (AI/ML) technologies in the Swedish power system presents both opportunities and challenges. This presentation will explore how AI/ML can advance load forecasting, enhance frequency and voltage stability, and improve overall system operation. Despite these benefits, implementing AI/ML technologies presents several challenges, which will also be discussed. Key issues include the need for high-quality, sufficient data that is accessible and easily integrated for effective model training, as well as the integration with existing legacy systems. Additionally, the acceptance, transparency, and trust in AI/ML solutions within operational environments impact their effective deployment.

5. **Balthazar Donon,** RTE Research & Development, France

Bio: Balthazar Donon is a researcher at RTE R&D (Réseau de Transport d'Électricité). He is working on designing an AI algorithm that will provide advice to power grid operators on the best actions to take. He completed his studies at École polytechnique and Stanford University, where he obtained a MSc in Civil & Environmental Engineering. Later, he earned a PhD in Computer Science at Université Paris-Saclay and RTE R&D under the guidance of Isabelle Guyon, Marc Schoenauer, and Rémy Clément. Following this, he pursued postdoctoral research at the Université de Liège, collaborating with Prof. Louis Wehenkel on the development of an AI methodology for tertiary voltage control. Balthazar's research interests lie in the energy domain and deep learning, specifically focusing on how graph neural networks can be used to create a true AI assistant for real-time operation. His goal is to create innovative artificial neural network algorithms tailored for real-life and real-time Power Systems applications.

Presentation 5: ***"Topology-Aware Reinforcement Learning for Tertiary Voltage Control"***

Summary: In recent years, transmission systems have seen an increase in the frequency and intensity of high voltage events. Traditional methods for optimal power flow are not well-suited for real-life systems, so there is a pressing need to develop new approaches to help operators improve tertiary voltage control. Fast neural networks could help address this challenge by offloading most of the computational burden to an offline training phase, resulting in extremely fast inference during operation. However, real-life power systems undergo significant topological variations such as asset disconnections and bus-splitting, making it difficult to represent them simply as vectors, which are typically required by feedforward neural networks. In this presentation, we will discuss the concept of hyper-heterogeneous multigraphs for data representation, along with a corresponding graph neural network architecture designed to seamlessly handle real system data. This architecture learns to operate voltages in an unsupervised manner by interacting with an industrial simulator.

Panel Session 3: Effective dissemination of research results: Discussion with the Editor-in-Chiefs

Time: Tuesday, 15/Oct/2024: 9:30am - 11:00am **Location:** Orlando 1B

Abstract: The objective of the Pane/Round table is to present the main Power Engineering journals and discuss the challenges and opportunities of publication of original, theoretical and applied research results with prospective authors. In addition to brief introduction about individual journals, the focus of the round table will be on practices and approaches to presentation of research results and the advantages of effective communication of those to wider audience.

Moderated by:

Prof Jovica V Milanovic, FIEEE, IEEE PES Vice President, Publications & immediate past Editor in Chief of IEEE Transactions on Power Systems, The University of Manchester, UK

Panelists:

1. **Prof Jovica V Milanovic**, FIEEE, IEEE PES Vice President, Publications & immediate past Editor in Chief of IEEE Transactions on Power Systems, The University of Manchester, UK
2. **Prof Claudio Cañizares,** FIEEE, Editor in Chief of IEEE Transactions on Smart Grids, University of Waterloo, Canada
3. **Prof Gianfranco Chicco,** FIEEE, Editor in Chief of ELSEVIER'S International Journal of Sustainable Energy Grids and Networks, Politecnico di Torino, Italy
4. **Prof. Antonio Gomez-Exposito,** FIEEE, Vice Editor in Chief of Modern Power Systems and Clean Energy Journal, University of Seville, Spain.
5. **Prof Vladimir Terzija,** FIEEE, Editor in Chief of ELSEVIER'S International Journal of Electrical Power and Energy Systems, University of Newcastle, UK

Special Session 1: Nordic Early Warning Early Prevention System

Time: Monday, 14/Oct/2024: 10:30am - 12:30pm **Location:** Orlando 1B

Abstract: This panel will present final results of the Norwegian-Swedish research project NEWEPS – Nordic Early Warning Early Prevention System. The research conducted in the NEWEPS project are intended to provide the Transmission System Operators (TSOs) with increased insights into functional and non-functional requirements on Wide-Area-Monitoring-Protection-and-Control (WAMS / WAMPAC) systems. The main focus of the work has been on increased situational awareness for operators, development of novel Energy Monitoring System (EMS) solutions and evaluation of visualization techniques. Towards the end of the NEWEPS project, a road map will be created with the intention to support the development and future implementation of WAMS and WAMPAC systems at the Swedish and Norwegian TSOs.

The main messages of this panel relate to the lessons learned, main conclusions and results, and the proposed way towards implementation. At the panel, the following issues to be addressed:

- Background and needs of a Wide-Area monitoring control and protection system
- Research and development of Voltage stability indicators
- Research and development of identification and classification of Natural and Forced oscillations
- Research and development of Wide-Area-Control concepts
- Research and demonstration of Advanced vizualisation concepts
- Research and demonstration of a Platform for monitoring applications and operator interaction

Moderated by:

Robert Eriksson, Professor & Power system specialist, Uppsala University & Svenska kraftnät, Sweden

Panelists:

1. **Kjell Petter Myhren**, Senior Advisor R&D in System and Market Operation, Statnett, Norway, kjell.myhren@statnett.no
2. **Henrik Ekestam**, Power system specialist, Svenska kraftnät, Sweden, Henrik.Ekestam@svk.se
3. **Valéria Monteiro de Souza**, PhD candidate, NTNU, Norway, valeria.m.de.souza@ntnu.no
4. **David Bergman**, PhD candidate, KTH, Sweden, dabergm@kth.se
5. **Salvatore D'Arco**, Chief Scientist, SINTEF, Norway, salvatore.darco@sintef.no
6. **Erik Weihs**, Research engineer, RISE, Sweden, erik.weihs@ri.se

Special Session 2: HVDC-WISE special session on tools, modelling, and control for the development of reliable and resilient widespread HVDC grids

Time: Monday, 14/Oct/2024: 10:30am - 12:30pm **Location:** Lokrum 4

Abstract: The development of reliable and resilient HVDC dominated power grids in the coming decades presents many challenges, necessitating a range of new analysis tools, models, and control approaches. The Horizon Europe and UKRI funded HVDC-WISE project seeks to address many of these challenges, through the development of an integrated reliability and resilience analysis framework for widespread hybrid AC/DC grids. In this session project participants will discuss methodologies and tool developments, modelling challenges, and control frameworks that have been developed within the project to date.

Moderated by:

Lukas Sigrist, Universidad Pontificia Comillas Madrid, Spain

Panelists:

Name: Lukas Sigrist

Bio: Lukas Sigrist is an associate professor at Instituto de Investigación Tecnológica (IIT) of Universidad Pontificia Comillas, Madrid, and its deputy director of Economic Affairs. His areas of interest are modeling, analysis, simulation, and identification of electric power systems. He has been involved in a large number of research projects related to power-system stability, control and protection and power-system operation.

E-mail: lukas.sigrist@iit.comillas.edu

Presentation 1: ***"Tools for Reliability and Resilience-Oriented Planning and Operation of hybrid AC/DC power systems"***

Authors: Seyedsina Hashemi, Mathaios Panteli, Mateo Baù, Emanuele Ciapessoni, Diego Cirio, Andrea Pitto, Gianni Bakhos, Nicolas Barla, Abdelkrim Benchaib, Boussaad Ismail, Paul McNamara, Callum MacIver, Aurelio García, Saeed Rezaeian, Lukas Sigrist.

Name: Chavdar Ivanov

Bio: Chavdar Ivanov – Managing Director of gridDigIt. He supports TenneT TSO GmbH on various topics. He has M.Sc and PhD degrees in power system engineering. Chavdar has more than 20 years of experience in activities of transmission system operators mainly in the areas of power system analysis, power system modelling, data/model management and R&D. He is a senior member of IEEE, member of Power System Dynamics Performance Committee. He is actively contributing to IEC committees on data exchange and wind modelling related standards. His main field of interest is related to power system modelling, stability studies and data exchanges.
E-mail: chavdar.ivanov@griddigit.eu

Presentation 2: ***"Standardized Model Exchange of HVDC Equipment for RMS and EMT Simulations"***

Authors: Chavdar Ivanov, Georgii Tishenin, Damiano Lanzarotto, Florent Morel, Antonello Monti.

Name: Antoine Knockaert

Bio: Antoine Knockaert joined Tractebel in 2023 as a Power Systems Engineer. He obtained his Master's Degree in Electrical Engineering, with an emphasis on Power Systems, at UCLouvain (Belgium). During his time with Tractebel, Antoine has been working on multiple project around the world including grid compliance studies of renewable and storage units, power system stability studies as well as research projects on HVDC technology. His main interests revolve around HVDC systems and tackling the challenges of mass integration of renewable sources in power systems.

E-mail: antoine.knockaert@engie.com

Presentation 3: ***"Supervisory control of Bipole-based Multi-Terminal HVDC grids using Model Predictive Control including asymmetric operation"***

Authors: Antoine Knockaert, Lampros Papangelis, Pieter Tielens, Karim Karoui

Name: Ying Pang

Bio: Ying Pang is currently working toward his PhD in SuperGrid Institute, focusing on grid-forming control in multi-terminal HVDC systems and its stability analysis. He obtained his M.Sc from Aalborg University, Denmark and since then has been engaged in different research and product development positions in both academia and industry, in the fields of power electronics and control.

E-mail: ying.pang@supergrid-institute.com

Presentation 4: ***"Investigations on the Effects of DC Voltage Control on Inertia Provision in HVDC Converter Stations"***

Authors: Ying Pang, Agustí Egea-Àlvare, Juan-Carlos Gonzalez, Filipe Perez, Abdelkrim Benchaib, Kosei Shinoda

Special Session 3: How Digitalization Supports Flexibility Levers in the Decarbonization of Power Systems

Time: Tuesday, 15/Oct/2024: 4:30pm - 6:30pm **Location:** Orlando 1B

Abstract: Policies are being gradually implemented to address climate change by pushing for the replacement of fossil-fueled generation with distributed renewable energy resources to achieve power systems decarbonization. The massive incorporation of DER presents resilience challenges due to their variability. Flexibility levers, like energy storage systems, can help address some of these challenges, but there are still significant barriers to modeling, integrating, and deploying such solutions. This panel will discuss best practices, state-of-the-art approaches, and key challenges related to the planning and operations of the grid with flexibility levers provided with any kind of flexibility levers. Critical tools such as digital twins or artificial intelligence could be considered to solve issues raised in various applications, from large-scale networks to smaller and more recent grid-connected energy systems, like energy communities.

Moderated by:

Name: Dr Vincent Debusschere
Title: Associate Professor
Affiliation: Grenoble INP UGA
Country: France
E-mail: vincent.debusschere@grenoble-inp.fr

Panelists:

Name: Pr. Geert Deconinck

Title: Professor

Affiliation: KU Leuven

Country: Belgium

E-mail: geert.deconinck@kuleuven.be

Presentation 1: ***"Energy flexibility needs privacy-by-design digital solutions"***

Name: Wicak Ananduta
Title: Researcher
Affiliation: VITO
Country: Netherlands
E-mail:

Presentation 2: ***"Market-based flexibility provision from distribution system resources"***

Name: Dr Nuran Cihangir Martin
Title: Grid Strategist
Affiliation: Stedin
Country: Netherlands
E-mail: Nuran.CihangirMartin@stedin.net

Presentation 3: ***"Network Observability and State Estimation at Low-Voltage Distribution Grids to Exploit Flexibility: Practical Considerations"***

Name: Alejandro Yousef da Silva
Title: Research
Affiliation: Schneider Electric
Country: France
E-mail: alejandro.yousefdasilva@se.com

Presentation 4: ***"Optimizing Microgrid Operations for Effective CO2 Emission Reduction"***

Special Session 4: Digitalization in Power Systems – a Key Enabler of the Energy Transition

Time: Tuesday, 15/Oct/2024: 4:30pm - 6:30pm **Location:** Koločep 5

Abstract: Along with Decarbonization and Decentralization, Digitalization is one of the pillars of successful energy transition. It is enabled by an ever-growing proliferation of monitoring devices and supported by data aggregators and powerful data processors to enhance observability of the energy system, help us understand its response to new operating conditions driven by domination of renewable sources, and extend the lifetime of its assets.

This special session will shed light on the main opportunities and challenges associated with digitalization in the power system, spanning from power system stability assessment and control, and the role of machine learning in facilitating these, to the detection of cyber-attacks in cyber-physical smart grids. An important part of the session will be dedicated to education for the digitalization of power systems, identifying the skill gaps and sharing some good practices in postgraduate courses on digitalization of energy.

Moderated by:

Name: Dr Marina Oluić

Title: Power System Specialist

Affiliation: Svenska kraftnät (Swedish National Grid)

Country: Sweden

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Panelists:

Name: Dr Ambra Sannino

Title: Vice President, Research and Development

Affiliation: Vattenfall

Country: Sweden

E-mail: ambra.sannino@vattenfall.com

Name: Dr Charalambos (Harrys) Konstantinou
Title: Assistant Professor
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Name: Dr Panagiotis Papadopoulos
Title: Reader (Associate Professor)
Affiliation: The University of Manchester
Country: United Kingdom
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Name: Dr Aleksandra Lekić

Title: Assistant Professor

Affiliation: TU Delft

Country: Netherlands

E-mail: A.Lekic@tudelft.nl

Name: Dr Panos Kotsampopoulos

Title: Principal Researcher

Affiliation: Institute of Communication and Computer Systems, National Technical University of Athens

Country: Greece

E-mail: kotsa@power.ece.ntua.gr

Special Session 5: OPF and REANIMATION projects special session

Time: Tuesday, 15/Oct/2024: 4:30pm - 6:30pm **Location:** Lokrum 4

REANIMATION: A system for coordinated provision of flexibility to the power system using advanced households; NPOO.C3.2.R3-I1.02.0002

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REPUBLIKA HRVATSKA Ministarstvo znanosti, obrazovanja i mladih

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Abstract: This session will present the ongoing work and preliminary findings from a project "A system for coordinated provision of flexibility to the power system using advanced households; NPOO.C3.2.R3-I1.02.0002" focused on integrating households into the process of balancing the power system, particularly in managing the variability of renewable energy sources. As renewable energy production continues to grow, driven by weather-dependent sources like solar and wind, it is becoming increasingly important to involve consumers in grid balancing. The project is addressing this challenge by developing two key solutions aimed at enabling households to participate in energy management without affecting their comfort or requiring significant time commitment.

The first solution being developed is an automated system that facilitates interaction between households and energy aggregators. This system will allow households to provide flexibility to energy markets such as day-ahead, intraday, and reserve markets. The goal is to manage household energy consumption efficiently, adjusting appliance use based on grid needs while ensuring user comfort remains unaffected.

The second solution involves household virtualization, which creates a platform for large-scale testing and coordination of household energy consumption. This platform will enable simulations of coordinated energy management across numerous virtual households, using real-time data collected from actual homes. This approach is intended to allow extensive testing and provide insights into how such systems could be applied at a scale in real-world environments.

The discussion will focus on the motivation for involving households in energy system balancing, the current progress in developing automated household energy management systems, and how households could provide flexibility to energy markets. Additionally, the session will include a demonstration of the household virtualization platform, exploring its potential for large-scale testing and coordination of energy use.

Speaker:

Hrvoje Pandžić is a Professor at the University of Zagreb Faculty of Electrical Engineering and Computing. His primary research interests include electricity markets, energy storage and demand response. He published over 80 research papers in top-tier journals and holds a patent Method for Experimental Determination of Battery Parameters and Their Use. He is a recipient of Award Science by the Government of the Republic of Croatia in 2018 and the Award for the highest scientific and artistic achievements in Croatia by the Croatian Academy of Science and Arts for 2018. He has led 8 European research projects and over 20 projects for industry partners as a principal investigator

OPF: Tool for the Power System Preventive Redispatch Based on AC Optimal Power Flow, NPOO – 2021.-2026.

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Abstract: The project develops and refines a method for computing optimal AC power flows and creates a real-time tool for transmission system operators. The advantage of the tool compared to those currently on the market is that the model used solves the exact nonlinear model in a short time while supporting controllable devices modeled in detail according to actual industrial characteristics. The tool supports computations for active and reactive power as well as security redispatch. Parameters of the tool, such as the activation sensitivity limit of controllable devices, are adjustable for efficient and broad use in any transmission network. The expected results are a reduction in active power losses and a decrease in activation costs compared to existing solutions. The project includes a demonstration of the tool's operation on a real system and, for this purpose, develops an interface and processes data from existing software packages available to dispatchers of the transmission system operator.

Speaker:

Karlo Šepetanc is a researcher at his home faculty where he finished Bachelor's, Master's and Doctoral degrees. His research interests include planning, operation and economics of power and energy systems with an emphasis on optimization's computational tractability. Karlo is also involved in teaching activities. He supervises bachelor and master student thesis progress.

Special Session 6: Cyber-physical perspective of smart grid stability, security and resilience towards a net-zero energy transition

Time: Wednesday, 16/Oct/2024: 4:15pm - 6:00pm **Location:** Orlando 1C

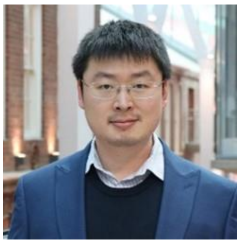
Abstract: Smart grid technologies, such as big data, machine learning, and internet-of-things, are gaining significant attention for their potential to drive the net-zero transition. A crucial development in this area is the emergence of cyber-physical systems, which integrate advanced computational algorithms with physical processes. This innovative approach further standardizes future smart grids in terms of both grid stability and security, as well as linking resilience to future decarbonization pathways.

This special session will offer valuable insights into the opportunities and challenges posed by the cyber-physical revolution in smart grids. Topics will include cyber-physical stability, security, and resilience in smart grid control, operation, and trading, all aimed at achieving a net-zero transition. A key focus will be on the inevitable cyber-physical couplings, examining how can impacts from the cyber layer affect physical layer operations, and further identifying critical components or couplings that could potentially help accelerate the smart grid's decarbonization pathways.

Moderated by:

Pudong Ge, Imperial College London, United Kingdom

Panelists:



Name: Xin Zhang

Title: Chair Professor

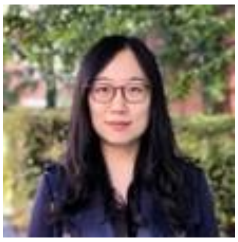
Affiliation: University of Sheffield

Country: UK

E-mail: xin.zhang1@sheffield.ac.uk

Presentation 1: ***"Cyber-Physical Power System Digital Co-Simulation"***

Abstract: This presentation introduces the real-time digital co-simulation platform for cyber-physical power system, which focuses on the co-simulation interface development between power and communication simulators. The co-simulation platform analyses the cyber vulnerabilities in microgrid control, with the optimal co-design of recursive watermarking technique and embedded Unknown Input Observer for the effective cyberattack detection.



Name: Qianwen Xu

Title: Associate Professor

Affiliation: KTH Royal Institute of Technology

Country: Sweden

E-mail: qianwenx@kth.se

Presentation 2: *"Resilient Control of Cyber Physical Microgrids under Cyberattacks"*

Abstract: Ensuring secure and resilient energy systems is essential for a sustainable, cyber-resilient future. This talk will present a novel resilient control approach for cyber-physical microgrids to achieve accepted performance under discrete-time false data injection (FDI) and denial-of-service (DoS) attacks.

Name: Jin Zhao

Title: Assistant Professor

Affiliation: Trinity College Dublin

Country: Ireland

E-mail: zhaoj6@tcd.ie

Presentation 3: *"Adversarial Learning Method for Power Grid Resilient Defense Against Sequential Events"*

Abstract: The presentation introduces a combined adversarial learning and deep reinforcement learning method to realize adaptive resilience defense by network reconfiguration. Accordingly, the survival of critical loads during sequential extreme events (SEE) such as hurricanes and tornadoes is greatly improved.

Name: Pudong Ge

Title: Research Associate

Affiliation: Imperial College London

Country: UK

E-mail: pudong.ge19@imperial.ac.uk

Presentation 4: *"Cyber-Physical Restoration for Power Network Resilience: A Drone-Assisted Communication Coverage Approach"*

Abstract: This talk will propose a jointly cyber-physical framework for post-contingency service restoration aimed at enhancing resilience, which leverages mobile resources that combine both cyber and physical capabilities (i.e., drone communication hub and mobile power source). Within the proposed framework, drones are strategically assigned throughout the power grid to facilitate post-contingency communication coverage..

Name: Dawei Qiu

Title: Research Fellow

Affiliation: Imperial College London

Country: UK

E-mail: d.qiu15@imperial.ac.uk

Presentation 5: *"Smart Grid Decarbonization Technologies"*

Abstract: This presentation introduces a carbon-aware electric vehicles (EVs) power scheduling scheme using a carbon emission flow model in the context of a cyber-physical power-transport network. Utilizing data-driven reinforcement learning algorithm with graph convolutional networks, the scheme facilitates a more informed decision-making process. The findings highlight transport electrification's role in advancing toward net-zero carbon targets.

Name: Weiqi Hua

Title: Assistant Professor

Affiliation: University of Birmingham

Country: UK

E-mail: w.hua@bham.ac.uk

Presentation 6: *"Blockchain-Based Joint Energy and Carbon Trading"*

Abstract: This presentation introduces a blockchain based peer-to-peer trading framework to trade energy and carbon allowance. The bidding/selling prices of prosumers can directly incentivise the reshaping of energy patterns to achieve local energy balance and net-zero energy system transition. A decentralised low carbon incentive mechanism is formulated targeting on specific energy patterns.

Special Session 7: TRANSIT project: Transition Towards Sustainable Power Systems through Education and Skill Enhancement

Time: Wednesday, 16/Oct/2024: 9:30am –11:00pm **Location:** Lovrijenac 3

Abstract: This Special Technical Session examines the crucial role of education and skill development in navigating the pathway to a global energy transition. It will include some results of project TRANSIT funded by the European Union, under the program Horizon Europe, and UKRI.

TRANSIT (which stands for TRANSITion to sustainable future through training and education) aims to provide sustainable training and re-skilling programs for current and future generations on a multidisciplinary approach in renewable energy.

The results shown in the session will focus on innovative educational strategies that empower professionals and students to understand, embrace, and lead the energy transition. It includes an exploration of curricula, training programs, and collaborative initiatives aimed at upskilling and reskilling a workforce capable of steering the world towards a more sustainable and resilient energy future

Moderated by:

Araceli Hernandez Bayo, Universidad Politécnica de Madrid, Spain

Panelists:

1. **Brian Azzopardi**: TRANSIT project overview
2. **Petar Krstevski**: Supporting the process of energy transition: Development of training curriculum for skill augmentation
3. **Markos Asprou**: TRANSIT project Survey on the Societal Impact of the Energy Transition
4. **Brian Azzopardi**: Gamification in renewable teaching
5. **José Miguel Riquelme:** Promoting Renewable Energy to Young Students through an Escape room
6. **Lidija Korunović**: Award to highlight and promote sustainability in renewable energy led by example

Special Session 8: Power Electronic Based Grid: Roadmap Challenges From Modelling To Real Time Monitoring And Control

Time: Wednesday, 16/Oct/2024: 11:30am –1:00pm **Location:** Orlando 1C

Abstract: Nowadays modern power systems are characterized by devices based on power electronics that are structurally different from the so-called traditional power grids. This affect all technical activities related to the power system - from planning and analysis to real time monitoring and control. The intention of the panel is to share the challenges of the comprehensive technical roadmap of the power grid from the experiences of academia and industry.

Moderated by:

Srđan Skok, Team Lead, Pro Integris, Grid Consulting/professor at University North

Panelists:

1. **Vladimir Terzija,** professor, Newcastle University
2. **Charlie Henley,** Senior Manager, at Sandia National Lab
3. **Mario Klaric,** CEO, Professio Energia
4. **Tomislav Plavsic,** HOPS, Assistant Director System Operations
5. **Jody Verboomen,** Global Team Lead, Siemens-Energy, Grid Consulting
6. **Sebastian Schneider,** Siemens-Energy, Grid Consulting

Special Session 9: IEEE PES Women in Power “Challenges in advanced power system planning and operation”

Time: Wednesday, 16/Oct/2024: 11:30am - 1:00pm

Location: Lovrijenac 3

Abstract:

Moderated by:

Name: Mirna Gržanić Antić

Title: Assistant Professor

Affiliation: University of Zagreb Faculty of Electrical Engineering and Computing

Country: Croatia

E-mail: mirna.grzanic@fer.hr

Panelists:

Name: Dr. Martha Symko-Davies

Title: -

Affiliation: National Renewable Energy Laboratory (NREL)

Country: USA

E-mail: -

Presentation 1: ***“Future Flexible Scalable Solutions that Achieve Just Energy Transitions”***

Name: Dženana Tomašević

Title: -

Affiliation: University of Zenica – Faculty of Mechanical Engineering

Country: Bosnia and Herzegovina

E-mail: -

Presentation 2: ***“Machine Learning-Based Short-Term Load Forecasting”***

Name: Qianwen Xu

Title: Associate professor

Affiliation: KTH Royal Institute of Technology

Country: Sweden

E-mail: -

Presentation 3: ***"Safe Deep Reinforcement Learning for Renewable Energy Integrated Power System"***

Name: Carolina Tranchita

Title: Professor

Affiliation: Frankfurt University of Applied Science

Country: Germany

E-mail: -

Presentation 4: ***"Stability Challenges in Modern Power Systems with Extensive Power Electronics"***

Paper Session 1: Electric vehicles 1

Time: Monday, 14/Oct/2024: 10:30am - 1:00pm **Location:** Orlando 1A

Presentations:

Strategic Electric Vehicle Integration: Leveraging Hosting Capacity in Evolving Distribution Grids

Luka Strezoski[1], **Izabela Stefani**[2]
[1]University of Novi Sad, Serbia; [2]Schneider Electric

The integration of electric vehicles (EVs) presents substantial challenges to distribution grid planning and operations due to the strain from increased charging infrastructure. Challenges encompass line and cable overloading, voltage fluctuations, and peak load escalations, among others. Inadequate planning and suboptimal integration strategies for EVs risk grid stability, potentially hindering further EV adoption. This study introduces a Hosting Capacity application within Distributed Energy Resource Management Systems (DERMS), designed to assist Distribution System Operators and engineers in accommodating significant EV integrations. We discuss scenarios where strategic employment of the Hosting Capacity application, as one part of a DERMS planning process, facilitates comprehensive analysis of the distribution grid's capacity to integrate new charging infrastructures. The efficacy of this approach is demonstrated through a real-world case study, examining the integration of three new 3MW charging stations into an existing supply substation region, underscoring the application's potential to support efficient EV grid integration.

LSTM Autoencoder Model to Recognize Electric Vehicles in Grouped Smart Meter Data

Lars Quakernack[1], **Thomas Engelmann**[1], **Valerie Vaquet**[2], **Jens Haubrock**[1]
[1]Hochschule Bielefeld – University of Applied Sciences and Arts, Germany; [2]Bielefeld University

Uncertainty in controllable devices and their power in distribution grids is a considerable problem for grid operators. The corresponding "blind" control of electrical vehicles, heat pumps, heating, ventilation, and air conditioning systems can harm the grid. On the one hand, if not enough controllable devices are available to balance the load, congestion potentially damaging the operating equipment can occur. On the other hand, the incentive of prosumer involvement to provide flexibilities can decrease due to overcontrol of their devices. To analyze how many devices and their respective power are currently in use, the measurement data, for instance, that collected by smart meters, need to be disentangled and split into the household load, the load caused by electrical vehicles, etc. In this contribution, we develop an LSTM-based auto-encoder model to detect electric vehicles charging in household profiles. We test the model by increasing the number of households with respect to the electrical vehicle.Furthermore, we use the minimum controllable power defined in the German Energy Industry Act to increase the classification of relevant charging power. With a precision of 100\% up to 3 households, the LSTM autoencoder can reliably classify electric vehicles in grouped smart meter data.

Controlling Large Electric Vehicle Charging Stations via User Behavior Modeling and Stochastic Programming

Alban Puech[1,2], **Tristan Rigaut**[1], **William Templier**[1], **Maud Tournoud**[1]
[1]Schneider Digital - AI Hub, Schneider Electric, Grenoble, France; [2]École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland

This paper introduces an Electric Vehicle Charging Station (EVCS) model that incorporates real-world constraints, such as slot power limitations, contract threshold overruns penalties, or early disconnections of electric vehicles (EVs). We propose a formulation of the problem of EVCS control under uncertainty, and implement two Multi-Stage Stochastic Programming approaches that leverage user-provided information, namely, Model Predictive Control and Two-Stage Stochastic Programming. The model addresses uncertainties in charging session start and end times, as well as in energy demand. A user's behavior model based on a sojourn-time-dependent stochastic process enhances cost reduction while maintaining customer satisfaction. The benefits of the two proposed methods are showcased against two baselines over a 22-day simulation using a real-world dataset. The two-stage approach demonstrates robustness against early disconnections by considering a wider range of uncertainty scenarios for optimization. The algorithm prioritizing user satisfaction over electricity cost achieves a 20% and 36% improvement in two user satisfaction metrics compared to an industry-standard baseline. Additionally, the algorithm striking the best balance between cost and user satisfaction exhibits a mere 3% relative cost increase compared to the theoretically optimal baseline - for which the nonanticipativity constraint is relaxed - while attaining 94% and 84% of the user satisfaction performance in the two used satisfaction metrics.

Synthetic Load Profile for Electric Bus Depots With Centralized Charging Concept

Amra Jahic, Edvard Avdevicius, Maik Plenz, Detlef Schulz
Helmut Schmidt University, Germany

The load profile of electric bus depots is of crucial interest to fleet and grid operators, as well as other market participants. The analysis and definition of synthetic load profiles for these depots is one of the possible tools that can help gain a deeper understanding of the load profiles and the factors that have an impact on them. This paper analyzes 17 bus depots in the city of Hamburg, Germany. Using k-means-based cluster analysis, the load profiles of the respective bus depots are sorted into three different clusters, showing a distinctive shape of the load profile. The analysis is conducted for a summer and winter scenario, allowing the definition of synthetic load profiles for each cluster and scenario. Additionally, the paper analyzes the factors that can lead to different shapes of the load profile. The proposed synthetic load profiles can be used for the analysis, operation, and optimization of electric power systems involving electric bus fleets and bus depots

Consideration of round-trip electric car-sharing in residential energy system modeling

Julian Achatz, Anurag Mohapatra, Thomas Hamacher
Technical University of Munich, Germany

This paper presents a residential, round-trip, mixed ownership, electric car-sharing scheme with an optimized charging schedule, expressed as a mixed integer linear programming model. Representing the given travel demand as a graph, a mixed (shared and owned cars) ownership fleet configuration, with different trip fulfillment possibilities, is determined using maximal cliques. Next, a car-to-trip allocation model for feasible trip plans, with considerations for equal car utilization and charging price, is used to generate charging profiles for the fleet. The model and the outputs can be variously integrated into existing energy system modeling frameworks. A case study, using data from a test building with a residential car-sharing fleet in Munich, demonstrates the potential of the proposed models to derive meaningful operational insights for fleet and energy system planners. 92\% of the recorded trips at the test building could have been feasibly accomplished with only 60\% of the available cars.

Paper Session 2: Congestion management

Time: Monday, 14/Oct/2024: 2:00pm - 4:00pm **Location:** Orlando 1A

Presentations:

Establishment of On-demand Flexibility Utilization in a Transmission System

Antti Olavi Kuusela, Suvi Peltoketo
Fingrid Oyj, Finland

This paper analyzes establishment of on-demand flexibility utilization in a transmission system. In case of congestion, the short-term rating of power system components provides inherent technical flexibility that allows a time frame to utilize on-demand flexibility as a curative measure. Prerequisites for the on-demand flexibility utilization are the feasibility of technical, economic, and regulatory perspectives that would allow increasing the power system utilization factor efficiently while maintaining system security. This paper elaborates the former studies and proposes amendments to prevailing TSO's company policies and practices enabling methodology establishment. In addition, this paper complements the former analysis by providing a qualitative analysis of different congestion management methods suitability for on-demand flexibility utilization in a transmission system at local and system levels. Based on the analysis the paper provides a recommendation for the methodology large scale deployment.

Developing a Benchmark Grid Model for Future Congestion Management and Stability Analysis

Fabian Meißner, Tobias Sous, Christian Ziesemann, Peter Wirtz, Florian Klein-Helmkamp, Albert Moser
RWTH Aachen University, Germany

The electrical power system is experiencing significant structural changes driven by evolving generation and load dynamics. These transformations necessitate robust grid models to address challenges in congestion management and stability assessment. However, access to high-quality grid models is often limited, particularly in terms of available time series data and technical information on operating devices, thereby constraining the scope of extensive simulations and optimization efforts. This paper presents the development of a benchmark grid model designed to overcome these limitations. The proposed model features a sufficiently large grid size, characteristic grid areas, and a future-oriented scenario. It incorporates a high number of interrelated grid utilization cases, allowing the consideration of annual seasons and the consideration of temporal coupling constraints such as power plant ramp-up and ramp-down gradients. This benchmark grid model is poised to support advanced investigations into future congestion management, curative grid operation, and stability analyses, providing a valuable tool for researchers and practitioners in the field.

Reliability Calculation for Curative Congestion Management in Transmission Grids with Optical Ground Wire Dominated Communication Networks

Bartosz Musiol[1], Christian Thöne[2], Markus Zdrallek[1]
[1]University of Wuppertal, Germany; [2]Amprion GmbH, Germany

Advancements in transmission grid control research suggest further integration of curative congestion management measures (post-fault) to either complement or potentially replace preventive measures (pre-fault) such as precautionary redispatch for both technological and economic reasons. Since curative congestion management no longer relies on a passive resilience against N-1 faults (e.g. a single line failure) in favor of increased loading, the active response mechanisms (i.e. curative measures) are crucially required to exhibit adequate reliability. A model and method for calculation a reliability index for curative congestion management measures given a topology, a set of grid utilization cases and a plan of remedial actions per grid use case are presented. The influence of the communication network through which the required signals are transported is also taken into account. Additionally, the shared topology between energy and communication infrastructure (i.e. usage of optical ground wires) typical to a transmission system operator is utilized within the presented method. The method utilizing the model is demonstrated through a small example.

A Review of Fairness Conceptualizations in Electrical Distribution Grid Congestion Management

Eva de Winkel, Zofia Lukszo, Mark Neerincx, Roel Dobbe
Delft University of Technology, The Netherlands

Fairness has recently gained significant attention in the scientific literature on algorithmic control systems for congestion management. However, many diverse conceptualizations of fairness have been presented. This paper aims to categorize these varying conceptualizations by reviewing existing literature on congestion management. It examines how researchers approach decisions concerning the scoping of fairness problems, the selection of fairness principles, and the choice of evaluation metrics. Findings highlight a need for more justification of fairness conceptualizations in literature as well as a need for standardized evaluation metrics and more

empirical grounding and validation. The insights provided can help researchers and practitioners consider fairness comprehensively in the design of algorithmic control systems for congestion management.

Transmission system reconfiguration for congestion management: DC-AC algorithm and Croatian transmission system case study

Karlo Šepetanc[1], Hrvoje Pandžić[1], Filip Grebenar[2], Renata Rubeša[2], Ana Kekelj[2], Zoran Bunčec[2]

[1]University of Zagreb Faculty of Electrical Engineering and Computing; [2]Croatian Transmission System Operator

Transmission system operators monitor and manage the power network with a goal of achieving secure operation. Contingency analysis lists outage scenarios that can cause line overloading. Operators can activate flexible devices and reconfigure network topology to move the system operating point to achieve N-1 security. This paper analyses the effectiveness of the DC model for solving security constrained optimal power flow (SCOPF) in comparison to the AC model in terms of accuracy and computation time. Then it uses DC-AC algorithm to solve SCOPF problem considering both activation of flexible devices and topology reconfiguration. DC-AC algorithm uses DC model to determine topology and then it resolves with the AC for fixed topology. The results show that the DC model is of fair accuracy, but much faster to solve if model has discrete variables. DC-AC algorithm results in 20\% better objective function than in case of computing just the DC model.

Multi-Actor DSO-TSO Congestion Management and Voltage Control Coordination with a Two-Level ADMM

Nuran Cihangir Martin, Bruno Fanzeres

Pontifical Catholic University of Rio de Janeiro, Brazil

Massive penetration of distributed energy resources (DERs), along with limitations of the network, are increasingly causing congestion or voltage problems in transmission and distribution systems. The interconnectedness of these systems necessitates coordination amongst their operators to assure supply security. This paper proposes a methodology for coordination amongst the Transmission System Operator (TSO) and Distribution System Operators (DSOs) without any hierarchy imposed on the entities. Coordination enables optimal usage of flexibility from Active Distribution Systems (ADSs) by the TSO and mitigation of congestion and voltage problems. This work leverages a two-level ADMM, which guarantees convergence to an approximate stationary solution for multi-block problems involving multiple actors. Tested on a modified IEEE 118-bus transmission system coupled with IEEE 33-bus active distribution test systems, the benefits of the proposal are demonstrated.

Congestion management in HOPS using advanced real time calculations

Marko Rekić[1], Matej Nikola Raič[2], Ana Kekelj[1], Tomislav Stupić[2], Zoran Bunčec[1], Renata Rubeša[1], Igor Ivanković[1]

[1]The independent Transmission System Operator in Croatia, Croatia; [2]Končar, Croatia

To smoothly integrate Renewable Energy Sources (RES) into the transmission power system, the Croatian Transmission System Operator (HOPS) must address potential congestions in the power system promptly, in the day ahead and intraday planning phase as well as in the real-time operation. Therefore, implementing a real-time congestion management system is essential to facilitate easier power system operation management for operators with target to keep the reliability of the power system high. This paper aims to provide a detailed description of the principles of operation and methods for using the redispatch security constrained dispatch function, which is part of the new SCADA/EMS system in the HOPS National Control Center which is used in both real-time and study time calculations. The operational principles and functionality of this redispatch function will be illustrated with concrete example of transmission line congestion in the Croatian transmission power system, highlighting real limitations in its application usage

End-to-End Reinforcement Learning of Curative Curtailment with Partial Measurement Availability

Hinrikus Wolf[1], Luis Böttcher[2], Sarra Bouchkati[2], Philipp Lutat[2], Jens Breitung[1], Bastian Jung[2], Tina Möllemann[2], Viktor Todosijevic[3], Jan Schiefelbein-Lach[4], Oliver Pohl[5], Andreas Ulbig[2], Martin Grohe[1]

[1]Computer Science, RWTH Aachen University; [2]IAEW at RWTH Aachen University, Germany; [3]RWTH Aachen University; [4]E.ON Group Innovation GmbH; [5]Schleswig-Holstein Netz AG

In the course of the energy transition, the expansion of generation and consumption will change, and many of these technologies, such as PV systems, electric cars and heat pumps, will influence the power flow, especially in the distribution grids. Scalable methods that can make decisions for each grid connection are needed to enable congestion-free grid operation in the distribution grids. This paper presents a novel end-to-end approach to resolving congestion in distribution grids with deep reinforcement learning (RL). Our RL-agent learns to curtail power and set appropriate reactive power to determine a non-congested

and, thus, feasible grid state. State-of-the-art methods, such as the optimal power flow (OPF), require high computational costs and detailed measurements of every bus in a grid. In contrast, the presented method enables decisions under sparse information with just some buses observable in the grid. Distribution grids are generally not yet fully digitized and observable, so this method can be used for edge decision-making on the majority of low-voltage grids. On a real low-voltage grid, the approach resolves 100% of violations in the voltage band and 98.8% of asset overloads. The results show that decisions can also be made on real grids that guarantee sufficient quality for congestion-free grid operation.

Paper Session 3: Power system automation techniques

Time: Monday, 14/Oct/2024: 5:15pm - 6:30pm **Location:** Orlando 1A

Presentations:

Observer-Based Discontinuous Communication in the Secondary Control of AC Microgrids

Shahabeddin Najafi[1], Yazdan Batmani[1], Pouya Shafiee[2], Charalambos Konstantinou[3]

[1]University of Kurdistan; [2]Virginia Polytechnic Institute and State University; [3]King Abdullah University of Science and Technology

In the secondary control of microgrids with centralized and distributed structures, the data exchange between distributed generators is inevitable (the decentralized structure is communication-free). This paper proposes an observer-based event-driven approach to decrease the overuse of communication networks. The suggested approach aims to estimate the required data for sharing between units in line with as much communication reduction as possible. In other words, the proposed approach effectively determines which state variables should be shared (observer concept) among the units during specific time intervals (event-triggered concept). This strategy significantly reduces the overall communication load. It is shown that the estimation error remains bounded and Zeno behavior does not occur. The proposed methodology can be systematically applied to any communication-based secondary controller in AC microgrids. Simulation results demonstrate a high degree of precision in estimating the states under the proposed approach. Also, the secondary controller performance under the proposed method is evaluated in MATLAB/Simulink environment.

Concept of a test bench for research into automatic resupply to improve the resilience of critical infrastructure

Fynn Liegmann[1], Katrin Schulte[1], Felix Annen[1], Jens Haubrock[1], Michael Kelker[2], Svenja Joseph[3], Sebastian Raczka[3], Christian Rehtanz[3]

[1]Bielefeld University of Applied Sciences and Arts, Germany; [2]Stadtwerke Bielefeld GmbH; [3]TU Dortmund University

Efficiency and safety are paramount in the ever-changing world of energy supply. Modernising power systems requires the development of new features and extensive testing. Ideally, this should be done under real conditions. Current energy system automation focuses mainly on grid protection, grid frequency control and voltage regulation and is mainly found in high and extra-high voltage grids. However, there is an urgent need for further automation in medium and low voltage grids. Alternatives such as a massive increase in staff and costly grid expansion are difficult to implement. Legal requirements such as German Energy Industry Act (EnWG) also underline the urgency of digitising the energy transition. This paper therefore presents the concept of a test bench for researching and validating automatic resupply for a specific application in the medium-voltage grid. This automation solution automatically restores power to an electrical station following a fault shutdown.

Automated Generation of Urban Medium-voltage Grids using OpenStreetMap Data

Tobias Gebhard[1], Andrea Tundis[1], Florian Steinke[2]

[1]German Aerospace Center (DLR), Germany; [2]Technische Universität Darmstadt, Germany

Realistic geo-referenced electrical distribution grid (DG) models are of great importance for power system analysis and resilience studies. However, DG data are usually not publicly available. In this study, we develop a new process for the automated generation of medium-voltage (MV) grid topologies, specifically for urban areas, based on openly available data and open-source software. OpenStreetMap (OSM) data on power infrastructure, street layouts, and land use, are used as the only input source. In contrast to previous works on DG reconstruction, we use available OSM data on substation locations. Different existing methods are combined in a new, hybrid approach by considering the incompleteness of OSM data, taking the street network into account, and applying the Capacitated vehicle routing problem (CVRP) to find cost-optimal routes for power lines. Our method is tested with a German city as a case study. Furthermore, we verify the result using land use data and evaluate the quality of power-related OSM data. The results demonstrate that our approach can yield realistic geo-referenced MV grid topologies, even with incomplete OSM power data.

Evaluation of Risk of Cascading Outages due to Imperfect Manual Corrective Actions

Shahabeddin Kamyab, Pierre Henneaux, Pierre-Etienne Labeau

Universite Libre de Bruxelles, Belgium

Cascading outages are the leading cause of major disturbances and blackouts. During the slow phase, timely manual corrective actions (MCAs) can halt the cascade. However, perfect execution of MCAs cannot be guaranteed, especially under stressful conditions. Furthermore, recent blackouts and disturbances have highlighted a range of consequences resulting from improper MCAs. In this study, we enhance our previously developed Human Reliability AnalysisOptimal Power Flow (HRA-OPF) framework, which integrates the estimated failure probability of MCAs in the risk analysis of outage scenarios. We expand the framework by introducing additional operator failures scenarios, distinguishing between failures in diagnosis and action phases, and accounting for a broader spectrum of consequences. We apply the HRA-OPF framework to the New England Test System grid. Finally, we evaluate the sensitivity of the results to various assumptions, such as the nominal probability of operator failure and islanding possibilities.

Proposal and Evaluation of Hierarchical EMS using an Adaptive-Robust EMS Method

Masao Shinji[1], Yutaka Iino[1], Tsunayoshi Ishii[1], Yasuhiro Hayashi[1], Satoshi Yamashita[2], Jumpei Doi[2], Takahiro Matsuzaki[2], Jiro Miyake[2], Kentaro Sakamoto[2]

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Distributed energy resources (DER) have recently attracted attention as a new regulating power source, control method for DER, and distributed coordinated Energy Management System (EMS) control, which can optimize an entire region with an edge computer. However, few studies have evaluated and examined these methods in an integrated manner. Therefore, in this study, we propose a hierarchical EMS method with a forecasting function, a robust planning function, and a real-time control function by extending the distributed coordinated DER optimal operation planning method in previous studies. This adaptive-robust EMS method learns the optimal trade-off between robustness against forecast error and cost increase from historical data in a distributed coordinated EMS considering

forecast error. We also performed a sensitivity analysis on a regional power flow through simulation and a cost factor analysis to investigate the effects of the three steps, forecasting, planning, and control. Therefore, we elucidated the trade-off relationship between cost and power flow and confirmed that the real-time control effect and parameter setting during forecasting contribute to cost reduction. These findings provide guidelines for the time-based perspective design of distributed coordinated EMS.

Decision Support for Power System Restoration: Mitigating Risks of Dynamic Phenomena

Joachim Vermunicht[1], Tadej Škrjanc[2], Bence Sütő[3], Dirk Van Hertem[1], Urban Rudež[2], Dávid Raisz[3], Willem Leterme[1,4]
[1]Dept. Electrical Engineering, KU Leuven/Etch EnergyVille, Leuven/Genk, Belgium; [2]Faculty of Electrical Engineering, University of Ljubljana, Ljubljana, Slovenia; [3]Dept. of Electric Power Engineering, Budapest University of Technology and Economics, Budapest, Hungary; [4]Institute of Power Systems and Power Economics, RWTH, Aachen, Germany

Enhancing existing power system restoration procedures is crucial as renewable energy sources, grid-connected converters, and underground cables become more prevalent. Faster power system restoration is key to achieve higher power system resilience. This paper proposes a systematic approach to re-energize the grid using a Markov Decision Process while account for transient and dynamic phenomena during power system restoration. By quantifying risks associated with frequency stability, resonant temporary overvoltages, and converter stability, our method informs operators about problematic states that would lead to critical operation points and ultimately set up the restoration process to fail. Furthermore, it calculates an optimal set of actions from a given state, considering these dynamic factors. The assigned costs for all states during power system restoration guide decision-making, ensuring system stability and power balance.

Paper Session 4: Power system reliability

Time: Tuesday, 15/Oct/2024: 9:30am - 11:00am **Location:** Orlando 1A

Presentations:

Scenario reduction framework to support efficient and accurate power system reliability analysis

Erlend Sandø Kiel, Jørgen Lind Fløystad, Oddbjørn Gjerde, Ivar Bjerkebæk
SINTEF Energy Research, Norway

Reliability analysis is an important part of power system planning and operation. Considering all events and scenarios which can have a significant impact on the reliability of supply to customers can lead to a large computational burden. Scenario reduction techniques can alleviate some of these challenges. A framework for reducing a set of original operating states into a set of representative operating states using clustering techniques is presented in this paper. A case study is performed where different scenario reduction approaches are tested using the proposed framework. It is shown that scenario reduction can decrease the time spent on the associated reliability analysis by several orders of magnitude, with a limited accuracy impact.

The reliability of a resilient power system: Service restoration time in reliability analysis

Erlend Sandø Kiel, Gerd Kjølle, Oddbjørn Gjerde, Sigurd Hofsmo Jakobsen
SINTEF Energy Research, Norway

Neglecting service restoration in reliability analyses can lead to overestimation of energy not supplied (ENS) due to contingencies, and subsequently also the associated interruption costs. Estimating accurate interruption costs is of high importance as it serves as input into power system operation and planning. In this paper a method of accounting for service restoration in reliability analysis is proposed. Literature covering restoration strategies is surveyed, and a minimalistic method of modeling service restoration is developed. The method describes the restoration process in a generalizable manner using steady state analysis. The results of the case study indicate that incorporating service restoration in reliability analysis can have a large impact on the estimated annual expected ENS of the system. The developed method can serve as a platform for further work.

A Decentralised Relational Data Model for Reliability Studies of Medium-Voltage Cables

Konrad Sundsgaard[1,2], Lunodzo Justine Mwinuka[3], Massimo Cafaro[3], Jens Zöega Hansen[1], Guangya Yang[2]
[1]Green Power Denmark; [2]Technical University of Denmark; [3]University of Salento

The distribution grid is evolving into a multilateral cyber-physical system where efficient data sharing and management across stakeholders are fundamental. Consequently, many applications benefit from collecting data from decentralised sources, as in the case of data-driven reliability prediction of medium-voltage cables, where distribution grid operators expect more accurate results through data sharing and joint model development. However, challenges arise when transitioning from centrally stored data to distributed data handled by decentralised peers. Current data collection processes often involve manual and static data requests, requiring additional efforts in data combination or harmonisation. To address these challenges, this study proposes a relational database model tailored for the reliability prediction of medium-voltage cables, and discusses its evolution into a decentralised database design. Eventually, such a setup may not only facilitate the development of ML applications but also guide the way for more standardised and dynamic data sharing among distribution grid operators.

Impact of Distributed Generation Integration on Distribution System Reliability

Mario Vukušić, Damir Šljivac, Predrag Marić, Matej Žnidarec
The Faculty of Electrical Engineering, Computer Science and Information Technology Osijek, Croatia

Ensuring the reliability of electrical power systems is essential for meeting the growing energy demands of modern society. In this paper, we investigate the technical implications of distributed generation deployment, focusing on its influence on system reliability indices such as frequency and duration of distribution grid components failures and resulting expected energy not delivered to the consumers. In order

to assess this impact a reliability analysis is performed for case study distribution network in DIgSILENT PowerFactory software for integration scenarios of variable photovoltaic generation and constant biogas power plants generation focusing on possibility of islanded operation of distributed generation on reliability indices.

Sustainable and cost-effective microgrid sizing methodology for mining operations considering reliability and energy not-served

Shah Mohammad Mominul Islam, **Hossein Ranjbar, S. Ali Pourmousavi, Wen L. Soong**
The University of Adelaide, Australia

Mining industries worldwide consume a significant amount of energy from fossil fuel energy sources, which inevitably increases carbon emission. This study investigates the design of sustainable and cost-effective microgrid systems for mining operations, focusing on integrating renewable energy sources to optimise both environmental and economic outcomes. Through an innovative framework for microgrid sizing, the research evaluates components such as solar PV systems, wind turbines, battery storage, and diesel generators, and conducts scenario-based simulations to analyse trade-offs between the net present cost of energy, emissions per unit energy, and reliability. Key results demonstrate that the incorporation of wind turbines in conjunction with diesel generators significantly reduces both costs and emissions. Additionally, the framework in this study explores the feasibility of certain microgrid configurations with reduced diesel generator capacity at near-perfect reliability. Further analysis shows the practical viability of these configurations, highlighting minimal energy shortfalls that can be safely accommodated with existing flexible mining resources, thereby reducing system cost and emission.

Using Component Risk Models to Guide Future Pathways for Risk-Based Performance Regulation

Roberto Monaco[1], Konrad Sundsgaard[2], Jose Angel Leiva Vilaplana[1]
[1]Denmark Technical University, Denmark; [2]Green power Denmark

The modernization of regulatory frameworks for electricity distribution grids is essential in the ongoing context of the energy transition. Ensuring efficient, secure, and reliable grids is a complex task that requires more proactive regulatory tools leveraging technological advancement. Component risk models lend themselves as useful tools for providing a forward-looking approach to enhance the proactive management of grid asset risks. While some implementations of component risk models exist today, their full potential has yet to be realized, presenting numerous pathways for future adoption. This paper offers a comprehensive analysis of the transition from corrective to proactive regulation and evaluates the role that component risk models can play in this shift. Additionally, it proposes a roadmap outlining incremental steps towards more adaptive, risk-based regulation. The study provides valuable insights for National Regulatory Authorities and Distribution System Operators on the extensive implications and potential benefits of adopting component risk models in the electricity distribution sector.

Paper Session 5: Wind turbines

Time: Tuesday, 15/Oct/2024: 9:30am - 11:00am **Location:** Orlando 1C

Presentations:

Challenges in Protecting Micro-Grids with Inverter-Based Resources: A Focus on Line Differential Protection and Wind Turbine Type-4

Mohammad Rasoulnia, **Akhtar Hussain, Innocent Kamwa**
Laval University, Canada

Abstract— Inverter-based resources (IBRs), such as wind turbines, are increasingly integrated into power grids, presenting challenges for the power system due to their intermittent nature and rapid power fluctuations. This paper assesses the impact of IBRs on power system protection. Specifically, the performance of line differential protection under various scenarios, including load switching, section cut-off, and external faults, is analyzed. This study uses the IEEE 34 bus test system to conduct simulations and examine different protection principles such as percentage and alpha-plane differential characteristics. The results emphasize the need for advanced and adaptable protection mechanisms to ensure grid reliability and efficiency in the face of the challenges posed by fault resistance, unsynchronized phasor measurement units, and IBRs.

A Fractional Controller based VSG Control of PMSG based Wind Turbine to Improve Frequency Response

Ankit Mishra, Abdul Saleem Mir, Narayana Prasad Padhy
Indian Institute of Technology Roorkee, India

The massive incorporation of renewable energy sources (RES) through power electronic converters into the grid leads to a degradation in the power system's frequency response. To address this pressing concern, the paper proposes a fractional controller-based virtual synchronous generator (VSG) control system for a permanent magnet synchronous generator (PMSG) based wind turbine, aiming to enhance the system's frequency response. Initially, the fractional controller is replaced with the conventional integral term of the VSG control. Subsequently, an optimal value for the fractional controller term is determined. By incorporating a fractional controller with VSG control provides an additional degree of freedom, thereby enhancing the frequency response of the system. Several simulation case studies have been demonstrated in the Matlab/Simulink platform to showcase the effectiveness of the proposed approach in contrast to the conventional VSG control for PMSG wind turbines.

Enhancing Grid Stability with Digital Fluid Power-Based Synchronous Wind Turbines

William Mendieta, Damian Flynn
University College Dublin, Ireland

As the integration of renewable energy into power grids expands, ensuring stability becomes increasingly challenging. This paper proposes an innovative approach that utilizes digital fluid power transmission (DFPT) in wind turbines to enhance system stability. DFPT replaces the conventional mechanical gearboxes and power converters in modern wind turbines with a digital displacement hydrostatic transmission, driving a directly grid-connected synchronous generator. This configuration emulates the dynamic response of traditional synchronous machines, which is crucial for managing voltage and frequency disturbances. Various case studies demonstrate the effectiveness of DFPT-based wind turbines in delivering substantial short-circuit currents and natural inertia, addressing challenges related to decreasing system strength and mitigating significant frequency deviations associated with higher shares of renewable energy. Additionally, the paper highlights the potential of DFPT-based wind turbines as a valuable solution in modern wind technology, contributing not only to energy production but also offering diverse system services, thereby emphasizing their pivotal role in the transition towards net-zero energy systems.

A system level lifetime enhancement method for power converters of Type-4 wind turbines

Ibrahim Alisar[1], Erhan Demirok[2], Aydin Akan[1]
[1]Izmir University of Economics, Izmir Turkey; [2]Izmir Katip Celebi University, Izmir Turkey

This study proposes a new system level lifetime enhancement method for back-to-back connected power converters of Type-4 wind turbines. The method is based on adjusting the position and roles of MSC (machine side converter) and GSC (grid side converter) periodically with additional mechanical switches so that the lifetime consumption of electrical switches (IGBTs and diodes) is shared by the inverter and rectifier operating modes. Moreover, the aging effect of the semiconductors have been considered and tested as an additional evaluation. The proposed method is tested with PSCAD (for the simulation of wind turbine) and MATLAB (for the development of thermal models and lifetime calculations) tools. The results show the effectiveness of the proposed method.

Parameter Error Identification for Type-4 Wind Turbine Models using Neural Networks

Fatih Erden[1], Berkay Sağlam[2], Oğuzhan Üstündağ[2], Murat Göl[1]
[1]Middle East Technical University, Turkiye; [2]Siemens Sanayi ve Ticaret A.Ş.

Increasing penetration of inverter-based resources (IBRs) makes the power system more vulnerable to transients and grid events. Therefore, a correct dynamic modeling and simulation of the system is more important than ever. However, the reliability of these simulations is affected by the erroneous parameters and models of the system components. Hence, regular identification and calibration of these defective parameters should be carried out. The offline staged calibration and test for these purposes now can be replaced with online tools. In this paper, a \textbf{sequential} neural network is employed for the identification of the erroneous parameters of Type-4 wind turbine dynamic models. Testing and validation of the proposed method are performed with the generated synthetic data and the identification results reach up to 89\% accuracy rate.

Paper Session 6: HVDC

Time: Tuesday, 15/Oct/2024: 9:30am - 11:00am **Location:** Koločep 5

Presentations:

HVDC Fault Detection Performance in Mixed Overhead Line and Cable Systems

Pedro Miguel Baena Garcia, Geraint Chaffey, Dirk Van Hertem
ETCH - KU Leuven, Belgium

As the use of HVDC for transmission increases and more complex system configurations are developed it becomes more important to understand the fault behavior of mixed overhead line and cable DC systems. The impact of having an heterogeneous transmission medium in protection algorithms has not yet been fully explored in literature. This paper identifies the main challenges for fault detection in mixed underground and overhead systems through the use of a simulation based case study. The analysis of the results show how algorithms can be severely impacted by the transition between sections with different surge impedances. In addition, the most problematic fault cases are singled out along with system parameters that can further reduce protection algorithm performance.

Optimal converter control mode selection for secure offshore HVDC grid operation

Oscar Damanik, Hakan Ergun, Dirk Van Hertem
KU Leuven and Etch of EnergyVille

This paper addresses the incorporation of DC-side converter control modes into a corrective security-constrained optimal power flow (SCOPF) problem for meshed offshore HVDC grids. Two control modes, namely DC power-voltage droop and constant DC power modes, are considered in the SCOPF model. The participation of the offshore wind farms and the onshore grids in balancing the DC grid are determined by their respective converter control modes. The main objective of the paper is to demonstrate the importance of selecting different sets of converter modes in a meshed offshore HVDC grid setup. The different choices are evaluated by assessing their techno-economic performances through the operational decision outcomes such as the onshore and offshore generation setpoints, which are influenced by the converter control mode selections. The assessment is performed using a modified CIGRE B4 DC grid test system representing a meshed offshore HVDC grid connecting multiple AC systems. The results show the significance of selecting appropriate DC-side converter modes for cost-effective and secure operation of offshore HVDC grids.

Large Signal Stability Assessment of MPC-based Control for HVDC Electrical Grid

Rohan Kamat Tarcar, Ajay Shetgaonkar, Marjan Popov, Aleksandra Lekić
TU Delft, The Netherlands

The stability of an HVDC transmission network is very important for the reliable transfer of power from renewable energy resources. Therefore, this paper proposes a region of attraction stability analysis method for grid-forming-based modular multilevel converters. The grid forming control uses a model predictive control-based controller for the inner current loop. The stability analysis is carried out using the direct Lyapunov method. For the model predictive control, the modified version of the cost function is used; the same function is also used as the cost function for the direct Lyapunov method. Furthermore, the boundaries formed by the limiters and Lyapunov function entirely explain transient event behavior.

EMT Modelling Approach for Large Series Parallel DC Windfarm with HVDC Connection

Ibrahim A Shehu, Dragan Jovcic
University of Aberdeen, United Kingdom

This paper studies a novel aggregate Electro Magnetic Transient (EMT) model for system level studies of large DC series-parallel windfarms. This model prioritizes a trifecta of desirable functionalities: accuracy, computational efficiency, and versatility. It facilitates large scale windfarm simulations while enabling studies across various windfarm operations, including DC fault analysis, investigations within individual wind generator, and interaction studies between machines and strings within the windfarm. The model's successful implementation is verified on PSCAD for a two-string 1GW/525kV test windfarm, demonstrating its ability to replicate the dynamics of a single-machine model under diverse operating conditions, and faults.

System Operation Concept for the Curative Use of Thermal Reserves of HVDC Cables

Carsten Thomas Gatermann, Franz Linke, Steffen Schlegel, Dirk Westermann
Technische Universität Ilmenau, Germany

In the light of the energy transition, high voltage direct current (HVDC) cables become increasingly important for energy transmission. Based on the previously unused thermal reserves of the cables, this work proposes a system operation concept for utilising them within curative system operation. To find an analytical solution to describe the heating process, simplified cable modelling with thermal networks is evaluated. To complete the system operation concept, requirements towards a model of the information and communication structure for hybrid power systems are defined. Finally, the structure of this holistic approach is presented.

Frequency-Constrained Coordinated Planning of HVDC and Generation

Yiliu He[1], Haiwang Zhong[1], Guangchun Ruan[2], Baorong Zhou[3], Chao Fu[3], Yingjun Zhuo[3]
[1]Tsinghua University; [2]Massachusetts Institute of Technology; [3]Southern Power Grid Research Institute Co., Ltd

High-voltage direct current (HVDC) technology has been extensively employed for long-distance transmission of renewable energy due to its advantages of high efficiency and controllability. However, large capacity HVDC lines can bring serious challenges to the frequency security of the power grids. Therefore, the planning of HVDC needs to match the frequency regulation capacity of the AC power grid. In this paper, a coordinated planning of HVDC and generation is proposed for renewable energy integration. For the optimal sizing of HVDC, the capacities of candidate HVDC lines are regarded as decision variables, and the investment model for HVDC is considered. The frequency security constraints under HVDC N-1 contingencies are extracted and embedded into the planning model. The case study validates that the proposed planning model can effectively guarantee the frequency security under HVDC N-1 contingencies.

Paper Session 7: Frequency stability

Time: Tuesday, 15/Oct/2024: 9:30am - 11:00am **Location:** Lokrum 4

Presentations:

Extending AC Security Constrained Optimal Power Flow for Low Inertia Systems with Artificial Neural Network-based Frequency Stability Constraints

Mohammad Iman Alizadeh[1], Pedro Pereira Barbeiro[2], Florin Capitanescu[1], José Gouveia[2], Carlos L. Moreira[2], Filipe j. Soares[2]
[1]Luxembourg Institute of Science and Technology, Luxembourg; [2]Institute for Systems and Computing Engineering Technology and Science, Portugal

Frequency stability in inverter-based renewable energy sources (RES)-dominated, low-inertia, power systems is a timely challenge. This paper employs a systematic approach, utilizing an artificial neural network (ANN) and dynamic simulation, to infer two key frequency stability indicators: nadir and rate of change of frequency (RoCoF). By reformulating the ANN mathematical model, these indicators are then integrated as mixed-integer non-linear constraints into a classical AC security-constrained optimal power flow (AC SCOPF), resulting in the proposed AC-F-SCOPF problem. The results of the proposed AC-F-SCOPF on the IEEE 39-bus system show that the problem identifies accurately the synchronous condensers which must run to ensure the frequency stability.

A Sensitivity Analysis of Deployment Time and Reserve Cost of Electrolysers and BESS for using Frequency Stability Constrained Economic Dispatch

Juan Camilo Castaño, Hakan Ergun, Dirk Van Hertem
KU LEUVEN, Belgium

The loss of large power infeeds can lead to significant frequency variations in the power grid, posing a blackout risk and compromising power system resilience. Traditionally, frequency reserve services were provided by generation units. However, the integration of new elements such as battery energy storage systems (BESS) and electrolysers prompts an exploration of their potential benefits in mitigating power imbalances. In this study, a Mixed Integer Second Order Cone economic dispatch model is employed to identify the optimal procurement of frequency reserve from generators, BESS, and electrolysers. A sensitivity analysis of the cost of the procured reserved and deployment time of electrolysers was also carried out. Results indicate that these parameters significantly influence the operational set points, modifying the dimensioning event and the optimal procurement of frequency reserve when it comes to ensuring operational resilience in terms of maximum frequency deviation.

Impact of Installation Location and Active Power Limitation of Grid-Forming Inverters on Frequency Stability

Yui Yoshikawa, Ryosuke Shikuma, Akihisa Kaneko, Hiroshi Suwa, Hideo Ishii, Yasuhiro Hayashi
Waseda University, Japan

The frequency stability has deteriorated due to the penetration of the inverter-based resources and the reduction of synchronous generators. A virtual synchronous generator, which is a major control type of grid-forming inverters (GFMIs), can contribute to the power system stability. However, the output of GFMIs after a disturbance may be suppressed due to their capacity constraints or their reserved power. The time for starting output suppression of GFMIs varies depending on their installation locations because of oscillations between generators that occur in a large-scale bulk power system. The impact of the time taken to reach the active power limitation (APL) of GFMIs on frequency stability should be evaluated to construct a stable power system operation. This study evaluated the impact of differences in the time taken to reach the APL of GFMIs on the center of inertia frequency using a Japanese standard bulk power system model, which is called IEEJ WEST10 grid model. The relationship between the APL of GFMIs and the frequency variation was analyzed based on the swing equation. In addition, the relationship was evaluated quantitatively in terms of the rate of change of frequency and nadir from the numerical simulation results.

Implementation Of Particle Swarm Optimization To Optimize Parameters Of HVDC-VSC In The Aim Of Improving The Frequency Stability

<u>Hung Cuong NGUYEN</u>[1], Quoc Tuan TRAN[2], Yvon BESANGER[1,3]
[1]G2Elab, France; [2]CEA LITEN, INES; [3]Grenoble INP, France

The use of Renewable Energy Sources (RES) and High Voltage Direct Current (HVDC) technology is becoming increasingly common due to their advantages. However, RES have inherent characteristics such as low inertia and intermittency, which can negatively impact the stability of grids. In contrast, HVDC technology has been shown to improve grid stability. This paper demonstrates this improvement using simulation results from the 39-bus New England grid under different scenarios. Additionally, to enhance system reliability, the Particle Swarm Optimization (PSO) technique has been proven effective in determining the parameters of the Voltage Source Converter (VSC) of an HVDC system. By comparing the simulation results of the grid under various circumstances, the authors gained a comprehensive and accurate understanding of the system's operation. The PSO algorithm was implemented using Python and the DigSilent PowerFactory simulation software, making it easily applicable in practical settings.

Comparative Study of Frequency Support Functions of IBRs for Bulk Power System Frequency Stability

<u>Nobuaki Kawashima</u>, Ryoichi Hara, Hiroyuki Kita
Hokkaido University, Japan

Various grid support functions for IBRs have been proposed to improve system stability. Impact analysis of the introduction of IBRs with grid support functions predominantly uses a small-scale or bulk system model, including only a few IBRs due to the computational burden. This paper compares the frequency support function of IBR for frequency stability of a bulk power system interconnected with subsystems including large numbers of IBRs using the reduced-order model method for a distribution system including IBRs. This paper examines the contribution to frequency stability of three types of IBRs: GFL inverters with Frequency-Watt function, droop-controlled GFM inverters and virtual synchronous generator-based GFM inverters. Findings show that the Rate of Change of Frequency (RoCoF) was influenced by the contribution of the frequency support function of IBRs, as well as by the interrelationship between the load-voltage characteristic and the voltage support function of IBRs. The analysis is validated using time-domain simulations in the PSCAD/EMTDC environment.

A Modified AGC for Power System in the Presence of Grid Following Inverters

<u>Siavash Yari</u>[1], Innocent Kamwa[1], Dmitry Rimorov[2]
[1]Laval University, Canada; [2]IREQ, Hydro-Quebec, Canada

Due to the significant growth of the penetration level of inverter-based resources in power transmission grids, the role and impact of these resources in maintaining the stability of the network can no longer be ignored. Therefore, for this category of resources, a role similar to traditional power plants should be considered in controlling the stability of the network. Accordingly, the purpose of this paper is to propose an algorithm to improve the performance of an automatic generation control system (based on a PI controller) in the presence of grid-following inverters to use their maximum potential and ability in network stability in the structure of an automatic generation control system and next to conventional power plants. Therefore, the decoupled-PQ control system (grid-following based) is considered for implementation in a three-area automatic generation control system structure. The dynamic simulation results were performed in an IEEE 39-bus test system using DIgSILENT PowerFactory software and its DSL environment. The results of these dynamic simulations show the effectiveness of this method to improve the automatic generation control system performance and system stability.

Robust Stability Region of PI Controllers for an Interval Time Delayed Load Frequency Control

<u>Majid Ghorbani</u>[1], Komeil Nosrati[1], Aleksei Tepljakov[1], Juri Belikov[2], Eduard Petlenkov[1]
[1]Department of Computer Systems, Tallinn University of Technology, Estonia; [2]Department of Computer Systems, Tallinn University of Technology, Estonia

Transmission delays, load fluctuations, and intermittent output power of renewable energy sources will all have a substantial impact on frequency stability in microgrids (MGs). In response, various types of advanced control techniques were employed to improve the performance of the load frequency control (LFC) systems. Notwithstanding this, the fragility of the current techniques makes LFC systems vulnerable to parametric (interval) uncertainties associated with communication time delay. Inspired by recent breakthroughs in robust control, in this study, we device a novel graphical tuning method of the PI controller for tackling this issue. First, we determine the shape of the value set for the characteristic function of uncertain LFC system. Then, the exposed edges are constructed to the boundary of this set under interval uncertainties. To accomplish this step and thanks to the D-decomposition method, the robust stability region in the parameter space of the controllers are determined. Our devised methodology contributes a family of robust stabilizing

controllers, instead of just one, where it enables a more flexible choice for the controller parameters. The efficacy of the proposed methodology is indicated on a given single-area MG.

Paper Session 8: Forecasting techniques

Time: Tuesday, 15/Oct/2024: 11:30am - 1:00am **Location:** Orlando 1A

Presentations:

Monitoring Hydropower Plants with LSTM-Based Time-series Forecasting

FATEMEH HAJIMOHAMMADALI, **Mauro Tucci, Nunzia Fontana, Emanuele Crisostomi**
University of Pisa, Italy

Data analysis and intelligent monitoring hold notable significance in the new generation of industry, aiming to enhance predictive maintenance and fault detection. This study introduces a predictive system for control within hydropower plants. The approach involves the integration of data gathered from various sensors, based on data processing techniques and deep learning (DL) algorithms. The study explores the efficacy of Long Short-Term Memory (LSTM) algorithms, renowned for their precision in time series prediction, across two different structural configurations.

Forecasting Day-Ahead PV Generation and Load Demand for an Individual Residential Consumer

Elias Mandefro Getie, **Geert Deconinck**
KU Leuven,Belgium

Accurate day-ahead forecasting of PV generation and load demand for an individual consumer gets more attention as the deployment of PV-battery systems increases. The uncertainty in PV generation and load demand for an individual consumer requires optimal operation of batteries to increase flexibility. In this paper, a data-driven, long-short-term memory (LSTM)-based recurrent neural network (RNN) method is used for day-ahead prediction of load demand and PV generation. The proposed method uses historical data of a single consumer collected from a smart meter with a 5-minute time resolution to forecast the next-day PV generation and load demand. The performance of the proposed method is evaluated in terms of RMSE, MSE, and MAE values. The smallest value of RMSE is observed for PV generation prediction in the summer season, whereas for the load profile, it is observed in the winter. Based on the performance evaluation metrics, the data-driven LSTM model improves the accuracy of day-ahead forecasting of solar power output and load demand as compared to the persistence model (PM).

A comparison of machine learning algorithms for the optimization of a day-ahead photovoltaic power forecast

Katrin Schulte, **Lars Engel, Lars Quakernack, Fynn Liegmann, Jens Haubrock**
Bielefeld University of Applied Sciences and Arts, Germany

Model predicitive control (MPC) applications require accurate and reliable forecasts of local photovoltaic (PV) generation. This work presents a novel approach to optimize local PV power forecasts with little measurement data. Different machine learning (ML) methods are compared regarding accuracy for optimizing a day-ahead PV power forecast. With an nMAE of 4.90%, the k-nearest-neighbors (KNN) regression method shows the best results overall and is well below the nMAE of 6.31% compared to the initial forecast. The different ML methods have their advantages in different weather conditions. The optimization of the PV forecast is practicable, as only little measurement data of the PV power is required and the PV power forecast can be used directly in MPC applications.

Forecasting vertical grid load using machine learning algorithms

Marie-Louise Kloubert
Amprion GmbH, Germany

The vertical grid load is one of the main input variables to determine the load flow on the transmission grid in system operation centers. As it depends on a variety of input variables, a method is needed that allows a good forecast despite incomplete and uncertain information about underlying grids, loads and feed-ins. With each underlying distribution grid having its own characteristics, the authors propose to model the vertical grid load individually for each interconnection point between the transmission and distribution grid. The following machine learning algorithms are tested and compared to develop a reliable forecast model: Linear regression, Lasso and Ridge regression, generalized additive regression, Random Forests and XGBoost. The case study shows the results from a German transmission system operator for a forecast horizon of one day ahead.

The Impacts of the Effective Load Data Preprocessing in Long-Term Load Forecasting

Airam Perez Guillen, **Jovica V. Milanović**
The University of Manchester, United Kingdom

Representing the network loading in an appropriate manner to obtain a reliable forecast has been a challenging task for researchers. This study investigates the efficacy of various data resampling strategies for long-term electrical load forecasting using Long-Short Term Memory (LSTM) neural networks, focusing on a dataset with half-hourly measurements from a real UK grid supply point. Given the excessive granularity for long-term forecasting, it was explored to resample the data to a daily scale, evaluating four methods for aggregating active and reactive power, namely maximum active load and maximum absolute reactive load, maximum load with coincident reactive load, mean load with coincident reactive load, and modal (most probable) load with coincident reactive load. These methods were tested under three scenarios: a standard LSTM with varying architectures, a smoothed dataset using a novel uncertainty boundary approach, and a sequence-to-sequence encoder-decoder model. Performance was assessed using mean absolute

percentage error (MAPE). Results indicate that smoothing techniques coupled with maximum daily active power and hour-matched reactive power resampling significantly enhance forecast accuracy by reducing the influence of noise and outliers.

Multi-step ahead wind power forecasting based on N-BEATS model

Luis Fernando Rodrigues Agottani[1], Matheus Melara Girardi[2], Wendel Rafael de Souza Chaves[1], Lucas de Azevedo Takara[3], Leandro dos Santos Coelho[3], Viviana Cocco Mariani[1]

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For wind power systems to operate successfully and efficiently, accurate forecasting is critical. The integration of large wind farms with smart grid technology mainly depend on accurate models for wind power output prediction. This study introduces a neural basis expansion approach named N-BEATS (neural basis expansion analysis for interpretable time series forecasting) for time series multi-step wind power forecasting. N-BEATS is a deep neural network architecture composed of multiple fully connected layers, arranged with both forward and backward residual connections. The performance of N-BEATS was benchmarked using classical approaches including AutoRegressive Integrated Moving Average (ARIMA), Seasonal AutoRegressive Integrated Moving Average (SARIMA), Holt-Winters, and the recurrent neural network named Long Short-Term Memory (LSTM). All models hyperparameters were tuned by Bayesian optimization. The N-BEATS model demonstrated superior forecasting scores and outperformed traditional methods in metrics such as mean absolute error and root mean square error for different forecasting horizons.

Ultra short term power prediction of offshore wind power based on ICEEMD-KPCA-LSTM

Lingling Huang, Zhangjie Fu, Yang Liu, Shurong Wei, Feixiang Ying

Shanghai university of electric power, China, People's Republic of

To improve the prediction accuracy of offshore wind power, an ultra short-term wind power prediction method based on data decomposition and dimensionality reduction of input variables is proposed. First, the original wind speed, wind direction and temperature data are decomposed using the improved complete ensemble empirical mode decomposition (ICEEMD) to mitigate the data fluctuations and extract the internal hidden information. Secondly, in order to strengthen the correlation between the input variables and wind power and eliminate the redundant information, the extracted features were nonlinearly downscaled using Kernel Principal Component Analysis (KPCA) to retain the important feature information. Finally, rolling prediction of the reconstructed power components is carried out using long short term memory (LSTM), and the validity of the combination model proposed in this paper is verified by empirical analysis and selected comparison models. The experimental results show that the prediction method for offshore wind power based on ICEEMD-KPCA-LSTM is able to extract more key information within the wind power data, reduce the dimensionality of the input data, and effectively improve the prediction accuracy.

Paper Session 9: System protection

Time: Tuesday, 15/Oct/2024: 11:30am - 1:00am **Location:** Orlando 1B

Presentations:

Modified Droop-based Fault Current Control for Grid Forming Converter during Network Faults

Irene Henry Masenge, Lie Xu, Yin Chen, Agusti Egea Alvarez

University of Strathclyde, United Kingdom

Reliability and stability of a power system are important aspects for the recent increase in inverter-based resources. Grid forming (GFM) converters have shown to be suitable solution as they can replicate the performance of a synchronous generator. However, since these converters have a characteristic of controlled voltage source behind impedance, they experience overcurrent during network faults. Recent research works have investigated the current limitation of GFM converters, however there is still a gap in the area. In this paper, a droop based GFM control is adopted, and its control is modified to support fault-ride through (FRT) strategies. The FRT strategy that keeps the GFM mode is implemented, where current is limited during fault and winding up of outer control loops is prevented. To evaluate the performance of the proposed technique, the other FRT strategy that switches to grid following (GFL) mode is compared. The performance of the proposed technique is verified and validated through simulations in PSCAD/EMTDC.

System Integrity Protection Schemes in the Nordics — a comparative analysis

Gabriel Malmer[1], Arvid Rolander[2], Emil Hillberg[3], Olof Samuelsson[1], Susanne Ackeby[3], Lars Nordström[2]

[1]Lund University; [2]KTH Royal Institute of Technology; [3]RISE Research Institutes of Sweden

To increase the utilisation rate of the power system and accelerate electrification while providing a high degree of security and reliability, System Integrity Protection Schemes (SIPS) are of great importance. SIPS functions are automatic remedial actions, detecting abnormal conditions or contingencies in the system and taking control action to mitigate these conditions. Design, implementation, maintenance and coordination of SIPS are all important aspects for desired operation. However, different actors have chosen different approaches to using SIPS for capacity enhancement, and there are discrepancies in how capacity is valued in relation to for example complexity, reliability and risk. Additionally, definitions often vary between countries. This paper reports on a joint survey and interview study on SIPS with stakeholders and experts in the Nordic countries – including TSOs, DSOs and industry. Combined with a literature review, a comparison and analysis of how SIPS are used in the Nordics is performed, particularly in relation to ENTSO-E capacity allocation.

Efficient Verification of Protection System Configuration of Electrical Distribution Grids

Francesco Pellei[1], Ahmed Nagy Abdelkhalek Mansour[1], Enrico Ragaini[2], Samuele Grillo[1], Matteo Rossi[1]
[1]Politecnico di Milano, Italy; [2]ABB S.p.A., Bergamo, Italy,

Protection systems are a crucial part of the electric power system. A tool has been developed to formally verify the correct configuration of protection systems in a low-voltage

(LV) distribution grid [1]. It uses a formal model, based on Timed Automaton (TA), representing the relevant elements of an LV distribution grid. The developed tool encountered several challenges related to the limited number of faults it could handle and the significant amount of time required for the verification process. Additionally, the verification output was hard to interpret, and in cases of multiple incorrectly configured

Circuit Breakers (CBs), only the first one detected by the tool was presented to the user. This paper proposes a solution to address these challenges by implementing two versions of the procedure called Automatic Subdivision of Queries (ASQ) in the tool, namely ASQα and ASQΩ to overcome these challenges.

Using the Time Coordination of Definite-Time Overcurrent Protection for the Classification of Grid Topologies in Adaptive Protection Systems

Antigona Selimaj, Immanuel Hacker, Ulbig Andreas
RWTH Aachen University, Germany

This paper introduces an adaptive protection strategy designed to address the challenges posed by varying grid topologies. The strategy is composed of two main stages: an offline stage, where Setting Groups for different grid configurations are predetermined, and an online stage, where protection settings are dynamically adjusted according to the current grid topology. A key contribution of this work is the development of a novel classification method for grid topologies that explicitly incorporates time coordination requirements for the offline stage. This classification is achieved through an optimization model inspired by the bin-packing problem, which organizes grid topologies into distinct classes, allowing for optimized protection settings within each class to ensure time coordination. The effectiveness of the proposed method is demonstrated through simulations on a medium-voltage grid. The results show that the proposed strategy allows for the determination of protection settings for different grid topologies.

Robust Method Based on XGBoost for Inter-Turn Faults Detection in Air-Core Dry-Type Shunt Reactor

Fernanda Soares Vitor Petite[1], Giovanni Manassero Junior[1], Silvio Giuseppe Di Santo[1], Trung Dung Le[2], Demba Diallo[2]
[1]Polytechnic School of University of São Paulo, São Paulo, Brazil; [2]GeePs, CNRS, CentraleSupélec, Université Paris-Saclay, Sorbonne Université, Gif-surYvette, France

This paper presents the development and evaluation of a new scheme based on eXtreme Gradient Boosting (XGBoost) for detecting inter-turn faults in air-core dry-type shunt reactors. The proposed scheme was developed to protect a 230 kV air-core

reactor installed on the Penedo's bar of the "Nossa Senhora do Socorro - Penedo" transmission line in Brazil. To achieve this, the XGBoost model was trained and tested for a set of different faults internal to the reactor, generated in Matlab, using the time domain solution. Furthermore, different levels of noise were added to the dataset, making the method more robust. The results show that the proposed solution based on XGBoost is effective in detecting inter-turn faults in the reactor, even for the most challenging cases in which the overcurrent protections fail to operate due to their low sensitivity.

Event-Triggered Non-Linear Control of Offshore MMC Grids for Asymmetrical AC Faults

Naajein Cherat[1], Vaibhav Nougain[1], Milovan Majstorovic[2], Peter Palensky[1], Aleksandra Lekic[1]
[1]Delft University of Technology, Delft, The Netherlands.; [2]University of Belgrade, Belgrade, Serbia

Fault ride-through capability studies of MMC-HVDC connected wind power plants have focused primarily on the DC link and onshore AC grid faults. Offshore AC faults, mainly asymmetrical faults have not gained much attention in the literature despite being included in the future development at national levels in the ENTSO-E HVDC code. The proposed work gives an event-triggered control to stabilize the system once the offshore AC fault has occurred, identified, and isolated. Different types of control actions such as proportional-integral (PI) controller and super-twisted sliding mode control (STSMC) are used to smoothly transition the post-fault system to a new steady state operating point by suppressing the negative sequence control. Initially, the effect of a negative sequence current control scheme on the transient behavior of the power system with a PI controller is discussed in this paper. Further, a non-linear control strategy (STSMC) is proposed which gives quicker convergence of the system post-fault in comparison to PI control action. These post-fault control operations are only triggered in the presence of a fault in the system, i.e., they are event-triggered. The validity of the proposed strategy is demonstrated by simulation on a ±525 kV, three-terminal meshed MMC-HVDC system model in Real Time Digital Simulator (RTDS).

Safety and Security Dependencies for Gridshield

Reza Soltani[1], Baver Ozceylan[1], Milan Lopuhaä-Zwakenberg[1], Christina Kolb[2], Gerwin Hoogsteen[1]
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Present day cyber-physical systems, such as the Smart Grid, lead to the integration of multiple sub-systems into one single intertwined system. Such systems are characterized by many inter-dependencies between these sub-systems. This makes it complex to correctly assess the impact of new defence mechanisms with respect to the safety and security of the system as a whole. Existing formalisms such as fault and attack trees cannot describe the full system complexity.

This paper presents a novel integrated model, namely the Attack-Fault-Defence Tree (AFDT), and tools to analyse such cyber-physical systems. The presented visual representation allows experts from various disciplines to discuss system dependencies together. In addition, we also present how minimum cut sets can be derived to formally quantify how the safety and security of the overall system is enhanced with the implementation of new defences. The presented AFDT is applied to the Gridshield concept, a novel defence mechanism to prevent grid overloading in power grids due to simultaneous charging of electric vehicles.

Paper Session 10: Optimization techniques

Time: Tuesday, 15/Oct/2024: 11:30am - 1:00am **Location:** Orlando 1C

Presentations:

A Socio-Technical Agent-Based Approach for Optimizing Electrical Vehicle Adoption

Yousra Sidqi, Alba Arias, Simon Läser
Lucerne University of Applied Sciences and Arts, Switzerland

The transition to sustainable transportation systems is a critical component of global efforts to reduce carbon emissions and mitigate climate change impacts. Among various sustainable technologies, electric vehicles (EVs) have emerged as a promising solution. However, the adoption rate of EVs is influenced by a complex interplay of socio-economic factors, technical variables, and infrastructure development. This paper presents a novel application of Agent-Based Modeling (ABM) to analyze and optimize the adoption process of EVs by capturing the dynamics of multiple interacting agents including households, industries, and power generation companies. A Living Lab approach complements the model by providing empirical data through participatory methods, thereby enriching the model's applicability and accuracy.

M5Use: An Optimization Framework for the Multi-Use Operation Scheduling of Large-Scale Battery Storage Systems

Mauricio Celi Cortés[1,2,3], Najet Nsir[1,2,3], Lucas Koltermann[1,2,3], Sebastian Zurmühlen[1,2,3], Jonas van Ouwerkerk[1,2,3], Dirk Uwe Sauer[1,2,3,4]
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Large-scale battery storage systems (BESS) have found widespread application in frequency regulation and spot markets across Europe. However, combined multi-use approaches are necessary to achieve an economically robust operation of BESS. In this context, we present a flexible modeling and optimization framework to find the optimal utilization strategy for BESS in multi-use and single application. Using this framework, we evaluate applications such as energy arbitrage, frequency containment reserve (FCR), and automatic frequency restoration reserve (aFRR) in single and combined operation for the the 6 MW / 7.5 MWh BESS M5BAT located in Aachen, Germany. We found that combined FCR, aFRR, and arbitrage operation results in 136% higher revenues than single FCR operation, which is the current application of M5BAT. Furthermore, we observed synergies between applications that result in revenue without physical delivery. Our results indicate the advantages of multi-use operation of BESS while our framework represents a tool for its realization.

Contribution of storage to adequacy in power systems with a large share of renewable energy resources

Butrint Avdijaj[1,2], Pierre Henneaux[1], Pierre-Etienne Labeau[1]
[1]Université libre de Bruxelles, Belgium; [2]Vrije Universiteit Brussel, Belgium

The variability of renewable energy sources (RES), threatening the adequacy of power systems, could be dampened using storage. Concretely, RES would be stored during periods of excess and used when needed. However, the impact of the operating strategy on the loss of load expectation (LOLE) remains an open question. Therefore, this paper studies the impact of different storage operating strategies on adequacy indicators. To do so, five strategies are defined: yearly costs minimization with single and depth-dependent value of lost load (VoLL), LOLE minimization, and weekly costs minimization, with and without water values. Using Monte Carlo methods, these are applied to three case studies. The various operating strategies give spread results in terms of LOLE, with up to a factor 10 between the lowest and highest value. Weekly minimization gives poorer adequacy indicators. This paper recommends weekly costs optimization, with a depth-dependent VoLL and with water values, in adequacy studies.

Multi-Objective Optimization for a Grid-Connected Hydrogen Integrated Energy Community

Na Li[1], Riccardo Maselli[2], Hesan Ziar[1], Joep van der Weijden[3], Özge Okur[4]
[1]Faculty of Electrical Engineering, Mathematics and Computer Science, Delft university of technology, The Netherlands; [2]AFRY, The Netherlands; [3]The Green Village, Delft University of Technology; [4]Faculty of Technology, Policy and Management, Delft University of Technology

Hydrogen is increasingly recognized for its role in enhancing the electrification of the built environment, particularly as a seasonal storage medium to balance the intermittent nature of renewable generation. Despite its potential, the high investment costs of hydrogen technologies make their integration challenging in current energy systems. This study addresses the gap in research concerning the impacts of hydrogen integration within energy communities, focusing on system performance and grid operations through different grid connection scenarios. We explore three grid connection capacities—unlimited, 24 kW, and 16 kW—using a case study from The Green Village. Our findings indicate that an unlimited grid connection poses a risk of grid congestion, whereas a restricted connection could result in unmet load demands. Our results suggest that aligning the grid connection capacity with the peak demand of the energy community effectively balances the need to reduce grid congestion while meeting energy requirements. This research highlights the need for strategic planning in the integration of hydrogen technologies within energy communities, advocating for a balance that supports both energy independence and grid stability.

Stability Oriented Chance Constrained Optimal Power Flow in Inverter Dominant Microgrids

Jun Wang[1], **Yunhe Hou**[1], **Feilong Fan**[2]
[1]Hong Kong University, Hong Kong S.A.R. (China); [2]College of Smart Energy, Shanghai Jiao Tong University, Shanghai, China

The uncertain nature of renewable energy sources (RESs) always brings negative impacts on the system stability especially in inverter dominant microgrids. In this paper, we propose a stability oriented chance constrained optimization model incorporating the uncertainties of RESs outputs. In this model, the upper level aims to minimize the expected generation cost without violating the stability chance constraint; the lower level concerns about the stability index. Then, we assume that the RES output uncertainties follow Gaussian distribution and hence reformulate chance constraints into linear deterministic versions. With linearized constraints in hand, the bi-level model can be solved by Benders decomposition-based approach. Simulation results on the 33-bus microgrid reveal that compared to other benchmarking approaches, the proposed model has the capability of converging in much shorter CPU time with adopting the sensitivity cuts. The proposed model converges 10 times faster with more accurate solutions. And the stability index is dramatically enhanced as well as the benefit for bus voltage security.

Electric Vehicle Routing Problem with Multiple Resource Constraints

Zhiye He, **Zaiyue Yang**
Southern University of Science and Technology, China, People's Republic of

This paper addresses the Electric Vehicle Routing Problem (EVRP) with multi-resource constraints. We propose a novel mathematical model incorporating multiple resource constraints into the EVRP. While the flexibility of this model is advantageous, it is important to acknowledge that the computational complexity of solving EVRP increases with problem size, as the problem is known to be NP-hard. To tackle this challenge, we propose a two-stage iterative algorithm. The algorithm transforms the original mixed non-linear integer programming problem into two tractable linear programming (LP) subproblems. The first stage focuses on optimizing vehicle routing, and the second stage tackles the resource scheduling problem, ensuring all resource limitations are met. Besides, an iterative optimization process is proposed to improve the performance of the results further. Through numerical experiments, we verify the effectiveness of the proposed algorithm.

Paper Session 11: Voltage regulation

Time: Tuesday, 15/Oct/2024: 11:30am - 1:00am **Location:** Koločep 5

Presentations:

Coordinated Allocation of PV and Capacitors with Var Capability for Voltage Unbalance Mitigation in LV Distribution Grids

Hossam H. H. Mousa[1,2], **Karar Mahmoud**[3], **Matti Lehtonen**[1,4]
[1]Department of Electrical Engineering and Automation, Aalto University, Espoo FI-00076, Finland; [2]Department of Electrical Engineering, South Valley University, Qena 83523, Egypt; [3]Department of Electrical Engineering, Aswan University, Aswan 81542, Egypt; [4]Department of Engineering Sciences in the Electrical Field, Constanta Maritime University, Romania.

Increased penetration of photovoltaic systems (PVs) and unbalanced loads in low-voltage (LV) distribution systems cause adverse impacts on the overall performance of the utility grid (UG). Most importantly, this can lead to voltage unbalance, power losses, thermal overloading of lines, and various power quality issues. To mitigate the voltage unbalance, reactive power control (RPC) techniques are utilized by empowering regulating PV inverters and capacitor banks. This study focuses on coordinating the sizing and placement of PVs with reactive power capability (Var) to reduce the voltage unbalance and uphold the acceptable limits of other power quality indices, particularly in unbalanced three-phase systems. However, during full load conditions, there is insufficient excess capacity available for reactive power injection or absorption by PV inverters. Therefore, in order to improve their reactive power capability, the inverters must be oversized relative to the nominal rating of the installed PV systems, thereby increasing capital costs and harmonic levels within distribution networks. In this regard, both PVs and capacitor banks are optimally allocated using a multi-objective grey wolf optimization (MOGWO) algorithm within IEEE 123-bus unbalanced distribution system using MATLAB and OpenDSS platforms. As a result of this proposed planning, voltage unbalance, power loss and voltage deviation are significantly decreased by 19%, 34%, and 14% (under 100% overloading), respectively, along with a 215% penetration level of PVs. Further, the proposed planning emphasizes that the combination of PVs and capacitor banks can reduce the voltage unbalance mainly which in turn reduces the power losses and thermal line overloading.

Impact of Dynamic Voltage Support on Memory Polarized Mho Relay in Presence of Grid Following PV Generators

Meenu Jayamohan[1], **Sarasij Das**[1], **Jose de Jesus Chavez**[2], **Marjan Popov**[3]
[1]Indian Institute of Science, India; [2]Tecnologico de Monterrey, Mexico; [3]Delft University of Technology, The Netherlands

This paper investigates the influence of dynamic voltage support on Positive Sequence Memory-Polarized (PSMP) mho relays in the presence of Grid-Following (GFOL) Photovoltaic (PV) generators. The widespread integration of Inverter-Based Resources (IBRs) has significantly altered power system dynamics. Traditionally, memory polarization in mho elements has ensured reliable operation during close-in faults. A dynamic expansion of mho characteristics results from the use of memory voltage for polarizing the mho elements, enhancing the resistive reach in systems dominated by Synchronous Generators (SGs). However, the fault current characteristics of IBRs differ from SGs, potentially compromising the dynamic mho expansion behavior. This work explores how dynamic voltage support employed by large-scale PV generators affects the expansion of PSMP mho characteristics. The PV generators used in this study have reactive power priority (Q-priority) and Low Voltage Ride-Through (LVRT)/High Voltage Ride-Through (HVRT) capabilities and are compliant with the IEEE Standard 2800-2022.

TSO-DSO Coordination for Voltage Regulation based on the Distribution Network Reconfiguration and Variable Shunt Reactors

Aghyles Graine[1,2], **Jean-Paul Gaubert**[1], **Didier Larraillet**[2]
[1]Poitiers University, France; [2]SRD

With the growth of Distributed Generation (DG) in both the Transmission Network (TN) and the Distribution Network (DN), voltage management becomes increasingly complex and critical, necessitating more sophisticated tools and methods. Variable Shunt Reactors (VSRs) can, through the modification of their reactive power consumption, contribute to dynamically regulate the voltage. Distribution Network Reconfiguration (DNR) which consists of changing the topology of the DN, can enhance the use of the VSRs, through the creation of a path between them and the nodes where the voltage rises need to be regulated. Furthermore, since the TNs and the DNs are connected, they have the potential to influence each other, positively or negatively. For this reason, a coordination between the Transmission System Operator (TSO) and the Distribution System Operator (DSO) can allow the attainment of a more optimal solution. In this paper, the combination of the DNR with the VSRs to regulate the voltage of the TN, while taking into consideration the constraints of the DN, through an iterative method, is presented. The method is assessed on a 103-bus network and shows a high level of precision after few iterations.

A Hardware-in-the-Loop Testbench for Voltage Control in Active Distribution Networks

Bastien Ewbank, Clément Moureau, Antonin Colot, Mevludin Glavic, Bertrand Cornélusse
University of Liège, Belgium

Recent studies introduce new controllers that leverage the flexibility of inverter-interfaced generation for voltage regulation. However, only few discuss the practical implementations of such controllers. Bridging this gap between theoretical designs and real-world deployment is crucial to validate the results obtained in numerical simulations. In this paper, we present a hardware-in-the-loop test bench for assessing the performance of a feedback-based controller in a high-fidelity simulation. The feedback-based controller, developed in [1] pursues the optimal solution of an AC optimal power flow problem, while ensuring the satisfaction of the operation constraints, using voltage and power measurements. We evaluate the performance of this controller on a 20-node distribution network with a realistic setting, considering modeling uncertainties and communication delays. We highlight the benefits of feedback-based controllers compared to omniscient controllers, especially in the presence of modeling uncertainties.

Implementing Deep Reinforcement Learning-Based Grid Voltage Control in Real-World Power Systems: Challenges and Insights

Di Shi[1], **Qiang Zhang**[2], **Mingguo Hong**[2], **Fengyu Wang**[1], **Slava Maslennikov**[2], **Xiaochuan Luo**[2], **Yize Chen**[2]
[1]New Mexico State University, Las Cruces, NM, United States of America; [2]Department of Advanced Solution Technologies, ISO New England, Holyoke, MA, United States of America

Deep reinforcement learning (DRL) holds significant promise for managing voltage control challenges in simulated power grid environments. However, its real-world application in power system operations remains underexplored. This study rigorously evaluates DRL's performance and limitations within actual operational contexts by utilizing detailed experiments across the IEEE 14-bus system, Illinois 200-bus system, and the ISO New England node-breaker model. Our analysis critically assesses DRL's effectiveness for grid control from a system operator's perspective, identifying specific performance bottlenecks. The findings provide actionable insights that highlight the necessity of advancing AI technologies to effectively address the growing complexities of modern power systems. This research underscores the vital role of DRL in enhancing grid management and reliability.

A Robust Incremental Volt/VAR Control for Distribution Networks

Antonin Colot[1], **Elisabetta Perotti**[2], **Mevludin Glavic**[1], **Emiliano Dall'Anese**[2]
[1]University of Liège, Belgium; [2]University of Colorado Boulder, USA

This paper proposes an incremental Volt/VAR control for voltage regulation in distribution networks with high penetration of distributed energy resources. The Volt/VAR controller coefficients are obtained by solving a robust optimization problem, where reactive power is minimized. The proposed optimization problem is solved using a Successive Convex Approximation method. Communication requirements are minimal and restricted to the offline stage since the local controllers share the same gains. Numerical studies on a 42-node low voltage network demonstrate the improved performance of our local controllers against a

traditional static Volt/VAR control strategy.

Enhancing Voltage and Frequency Control in Islanded VSC-Based Microgrids: A PSO-Driven Multilayer Perceptron Approach

Yared Bekele, **Getachew Biru Worku**, **Lina Bertling Tjernberg**
Addis Ababa University

This paper proposes a novel design approach using the particle swarm optimization-trained multilayer perceptron neural network (PSO-MLPNN) for inner current and voltage controllers in voltage source converter (VSC)-based islanded AC microgrids. Unlike conventional controllers that depend on line parameters, our intelligent control structure operates independently of these parameters. The PSO-MLPNN controller effectively replaces the traditional PI control, achieving accurate power-sharing and excellent dynamic performance across various load scenarios. Simulation results validate the effectiveness of our proposed controller.

Paper Session 12: Power electronics

Time: Tuesday, 15/Oct/2024: 11:30am - 1:00am **Location:** Lokrum 4

Presentations:

Impedance Modelling and Stability Criteria of LCL-type Inverters Operating at Higher Switching Frequencies Enabled by SiC MOSFETs

Jieyu Yao, Michael Merlin, Paul Judge
University of Edinburgh, United Kingdom

While the reduced switching losses of Silicon Carbide (SiC) MOSFETs has enabled higher switching frequencies, their impact on the stability of LCL-type converters has not been studied thoroughly. This paper presents the sequence impedance modeling and system stability analysis for an LCL-type grid-tied inverter with SiC MOSFETs, considering various PWM frequencies and controller bandwidths. The average analytical model and simulation model are built and compared in this paper. The discrete simulation model of the inverter is built by appropriately selecting the sampling frequency corresponding to different switching frequencies with proper LCL design. By comparing the Bode plots and applying stability criteria for different PWM frequencies and controller bandwidth, their impact on system stability is analysed. The results show that the reasonable controller bandwidth can reduce the impact of noise from Pulse Width Modulation (PWM) modulation. Besides, the lower PWM frequency will potentially worsen the system stability for the same controller bandwidth. Different controller bandwidth does not significantly impact on the system stability, but it may affect the damping of the converter impedance at the LCL filter around resonance frequency.

Interlinking Converter Operation with Enhanced Hybrid and Inverse Q-V Droop

Shwetank Agrawal[1], Barjeev Tyagi[1], Vishal Kumar[1], Pawan Sharma[2]
[1]Indian Institute of Technology Roorkee, Roorkee, India; [2]University of Tromso, Tromso, Norway

This paper introduces an enhanced hybrid and inverse Q-V droop control for the interlinking converter (ILC) in a hybrid microgrid (HMG). A hierarchical control approach is utilized to control the HMG. The primary control for both AC and DC sections employs the virtual synchronous generator (VSG) concept to provide inertia support, thereby improving the rate of change of frequency (ROCOF) and voltage (ROCOV). Secondary control employs a centralized method to restore the frequency and voltages of the PCC bus in both sections. The proposed control incorporates an integrator in the hybrid and inverse Q-V droop control for effective power balancing between the AC and DC sections. Simulation studies demonstrate that the proposed control outperforms traditional methods in maintaining power balance under both primary and secondary control, exhibiting superior performance and capability.

Optimized Positioning of DC Links in Medium-Voltage Grids

Maxim Müllender, Julian Saat, Timo Schumacher, Andreas Ulbig
IAEW at RWTH Aachen University, Germany

The demand for grid expansion at the medium-voltage level is expected to increase due to the growing penetration of decentralized generation plants and increasing electrification. In addition to the conventional expansion measures in medium-voltage grids, an alternative expansion with DC links is possible, which enables the possibility of power flow control and is becoming increasingly economically attractive due to the further cost degression of power electronics. Within this paper, a method based on a genetic algorithm is presented to optimize the positioning of DC links concerning the total cost of expansion in medium-voltage grids, as well as to optimize the set points of these DC links. For the resulting hybrid AC/DC grids, an economic evaluation of these grids is carried out compared to an estimation of a conventional expansion for different assumptions of converter costs.

Improved Accuracy in Calculation of Initial Fault Current in Converter-based Power Systems

Deepak Deepak[1], Krzysztof Rudion[1], Christoph John[2], Hans Abele[2]
[1]University of Stuttgart, Germany; [2]TransnetBW Gmbh, Germany

Initial short-circuit current is an important charac- teristic parameter (operational and planning) for the classical power system and is calculated as per the VDE/IEC 60909 standard. However, with synchronous generators being replaced with converter-interfaced generators, the short-circuit current profile is changing. Therefore, the question is: How to update the static modeling of generating units to calculate initial fault current with high penetration of converter-interfaced generators in the power system? This paper contributes by investigating the accuracy of currently valid VDE/IEC standard with respect to the assumptions made and modeling of fault contributing units. Then an extended approach is proposed for the calculation of initial fault current for better accuracy. This is achieved by characterizing the initial fault response of converters and then considering the complex contribution instead of scalar contribution as in the existing norm. This extended approach is further investigated and sensitivity analysis with respect to system impedance, fault location, and proportion of synchronous generators is presented.

Paper Session 13: Energy storage systems 1

Time: Tuesday, 15/Oct/2024: 2:00pm - 4:00pm **Location:** Orlando 1A

Presentations:

Predicting Battery Cycle Life with Few-Shot Transfer Learning over Heterogeneous Datasets

Runyao Yu[1,2,3], Jiaqi Wang[1], Yongsheng Han[1], Chi Zhang[1], Teddy Szemberg O'Connor[3], Jochen L. Cremer[1,2]
[1]Delft University of Technology; [2]Austrian Institute of Technology; [3]Rimac Technology

This paper presents an efficient approach to battery cycle life prediction through few-shot transfer learning, addressing the challenges of costly and limited battery aging data. Leveraging freely available datasets, a multi-layer perceptron (MLP) model was pretrained on diverse battery aging datasets to adapt to new prediction tasks with minimal training samples through few-shot fine-tuning techniques on the target data. The proposed fine-tuning strategy was validated using a heterogeneous aging dataset of 347 batteries, with cycle lives ranging from 144 to 4,052 cycles, incorporating batteries with lithium iron phosphate (LFP), lithium cobalt oxide (LCO), nickel cobalt aluminum oxide (NCA), and nickel manganese cobalt oxide (NMC) chemistries, which ensures robust validation of our methods. The results show that even with few samples of data from a target task, a comparable generalization performance to training from scratch with 100% data can be achieved, thus demonstrating its effectiveness in utilizing available resources for accurate cycle life prediction.

Redesign of Large-Scale Irrigation Systems for Flexible Energy Storage

Sergi Costa-Dilmé, Juan Carlos Olives-Camps, Paula Muñoz-Peña, Pau Garcia-Motilla, Oriol Gomis-Bellmunt, Eduardo Prieto-Araujo
CITCEA-UPC, Spain

The increase of energy storage is a key factor in the development of modern energy systems. The flexibility provided by energy storage allows for greater robustness in the face of increasing uncertainty derived from the essence of renewable energy sources. In this context, we focus on large-scale irrigation systems as a new actor managing the energy available in stored water. This article describes the main features of an open-source Python-based optimisation tool developed to redesign irrigation systems as large energy accumulators while maintaining their primary function. The tool provides the size of the new equipment to be installed, taking into account optimal system operation. The effectiveness of the proposed tool is illustrated by a study case based on a real irrigation system. The results show the potential for using this energy with low investment costs.

Electrical Storage Design in Multi-Energy Systems: Impact of Component Model Choice

Philipp Glücker[1,2,3], Sleiman Mhanna[3], Thiemo Pesch[1], Pierluigi Mancarella[3,4], Andrea Benigni[1,2,5]
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The transition towards coupled energy vectors within multi-energy systems (MES) requires explicit modelling of more components and thus requires careful decisions on the level of modelling details. The focus commonly lies on one energy sector, with strong simplifications for the remaining coupled energy sectors. However, the impact of model choice on the MES planning solution is largely unexplored. This work therefore sets out to investigate the impact of component model choice in an MES with electricity and heat for sizing a community battery energy storage system (BESS). Our analysis examines the impact of the choice of model of the power grid, the heating network, the heat pump, and the thermal building. Our results show a 31% increase in BESS size when using the convex second-order cone formulation compared to the exact nonlinear AC OPF equations for the power grid. The linear formulation results in 39% oversizing and suboptimal placement of the BESS. Furthermore, neglecting the heating network results in an 11% undersizing of the BESS. Different heat pump models show minimum impact on the BESS design and location, thus our findings suggest that linear models for the heat pump are suitable. However, omitting thermal demand and storage capabilities overestimates the BESS size by 42%. This further emphasizes the necessity of explicitly modelling the coupled heating sector and its thermal inertia for realistic electrical storage designs.

Battery Storage Considerations for Mitigating the Impact of Increased Integration of Renewable Sources: Case Study for Spain

Alicia Mortera-Canga[1,2], Diego Iribarren[1], Milan Prodanovic[1]
[1]IMDEA Energy, Spain; [2]Rey Juan Carlos University, Spain

At the European level, significant efforts have been made to mitigate the effects of climate change. Following the adopted directives, several member states have developed National Energy Climate Plans (NECP) and prospective studies have been conducted using different approaches. One of the most ambitious plans is proposed by the Spanish Government that will be used as a starting point in this study. Given that the Spanish network is poorly interconnected, the main objective of this work is to obtain reliable information where to install battery systems in order to integrate the growing renewable capacity and whether

the existing power lines should be reinforced. The PyPSA-Eur software has been selected to perform the analysis. Two case studies have been developed for this purpose. The obtained results directly link the necessary battery capacity with transmission line constraints, providing lessons relevant to a large number of regions with similar contexts.

Optimal Planning of Large-Scale Wind-Storage Power Plant Considering AC Power Flow Based on Stackelberg Game Theory

Miao Cheng[1,2], Qinfei Long[1,2], Yunhe Hou[1,2], Liang Liang[3], Xiaodong Xu[4]
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The imperative for decarbonization of power systems has accelerated the development of renewable energy sources. The inherent variability of these new energy sources necessitates the integration of energy storage, leading to an increase in the number of large-scale wind-storage power plants(WSPP) connected to the transmission network(TN). To enhance the profitability of these wind-storage facilities, this paper establishes a Stackelberg game model to study the optimal capacity planning of large-scale WSPP. Unlike previous models that utilized direct current optimal power flow(OPF), this study considers the alternating current(AC) OPF within the TN when making WSPP construction decisions. Additionally, a dictionary-assisted Particle Swarm Optimization(PSO) algorithm is proposed to solve the presented model. The paper discusses the necessity and challenges of including AC OPF and validates the effectiveness of the proposed model and algorithm through case studies.

Energy Management of Large-Scale Battery Storage Systems: Field Evaluation of Battery Aging and System Efficiency

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Large-scale battery energy storage systems (BESS) are rapidly gaining share in the electrical power system and are used for a variety of applications, including grid services and intraday trading. The energy management system (EMS) of BESS has a strong influence on the system efficiency and battery aging. This study presents a comprehensive evaluation of the system efficiency and battery stress factors that cause aging within the BESS M5BAT with a focus on EMS development. M5BAT is a 5 MW/7.5 MWh hybrid research storage system mainly used for frequency containment reserve but is also prequalified for automatic frequency restauration reserve and used for intraday trading. The results of the efficiency evaluation show a steady increase in BESS efficiency up to 78% round trip efficiency based on the 2023 version of the EMS. The influence of the EMS on the energy throughput, SOC and C-rate of the individual battery units was used to reduce battery stress and consequently battery aging. The test results provide insight into the flexibility of the EMS for different applications and the resulting effects on the batteries. With the knowledge gained from this study, it will be possible to improve EMS development and increase the profitability of BESS.

A Novel Deep Learning Method for Real-Time Estimation of Lithium-Ion Battery Capacity

Zihuan Zhang, ZHONG FAN, Cesar Ruiz

Exeter University, United Kingdom

Accurate prediction of lithium-ion battery states in electric vehicles (EVs) is crucial for enhancing safety, economic efficiency, and environmental sustainability. However, current research on real-time, on-board estimation of battery states is limited. This paper aims to bridge this gap by introducing a method that employs an Auto-BiLSTM algorithm coupled with an innovative data preprocessing technique using a low-pass filter (LPF) to accurately predict battery capacity. Initially, data from the NASA dataset were pre-processed with the LPF to mitigate measurement noise and smooth oscillations caused by capacity self-generation, thereby stabilizing the input for neural network processing. After optimizing the autoencoder settings, this refined data, and the encoder output were used to evaluate the most effective predictive model among four widely used architectures. The results indicate that an autoencoder with 50-dimensional hidden units paired with a BiLSTM model offers the highest accuracy and the smallest model size, making it suitable for hardware implementation. Finally, a comparative analysis with the latest deep learning-based prediction models demonstrates that our model achieves top-level accuracy currently available in the field.

Optimizing Second-Life Battery Use in Renewable Energy Storage: A Deep Reinforcement Learning Approach

YUANHAO WU, ZHONG FAN

Exeter University, United Kingdom

With the rising global prevalence of electric vehicles, a significant influx of end-of-life (EOL) lithium-ion batteries is anticipated in the recycling market. Although no longer meeting the performance standards for electric vehicles, these batteries can be repurposed for less demanding applications like stationary storage for renewable energy. This addresses the disposal of second-life batteries and supports the development of clean energy, contributing to sustainable development and climate change mitigation. This paper presents a machine learning model employing Deep Reinforcement Learning (DRL) to aid energy merchants in decision-making regarding battery charging/discharging and energy market bidding, thus maximizing profitability while considering battery wear and tear costs. The methodology combines Long Short-Term Memory (LSTM) networks with Proximal Policy Optimization (PPO) algorithms to manage the complex dynamics of energy pricing and battery state of charge (SoC). Experimental results demonstrate the model's effectiveness in enhancing the profitability of energy storage using second-life batteries, offering a novel contribution to the field of renewable energy storage and battery reuse.

Linear energy storage and flexibility model with ramp rate, ramping, deadline and capacity constraints

Md Umar Hashmi[1], Dirk Van Hertem[1], Aleen van der Meer[2], Andrew Keane[2]

[1]KU Leuven & EnergyVille, Genk, Belgium; [2]University College Dublin, Dublin, Ireland

To harness the full potential of energy storage and flexibility, we will need better models representing these assets. In the absence of such models, the true capability of such resources might be over or under-estimated. In this work, we propose a new energy storage and flexibility model that not only considers the ramp (power) and capacity (energy) limits but also accurately models the ramp rate constraint. The proposed models are linear in structure and efficiently solved using off-the-shelf solvers as a linear programming problem. We also provide an online repository for wider application and benchmarking of these models. Finally, numerical case studies are performed to quantify the sensitivity of ramp rate constraint on the operational goal of profit maximization for energy storage and flexibility. The results are encouraging for assets with a slow ramp rate limit. We observe that for resources with a ramp rate limit of 10% of the maximum ramp limit, the marginal value of performing energy arbitrage using such resources exceeds 65% and up to 90% of the maximum possible profit compared to the case with no ramp rate limitations.

Paper Session 14: Optimal power flow

Time: Tuesday, 15/Oct/2024: 2:00pm - 4:00pm **Location:** Orlando 1B

Presentations:

Analyzing Data Characteristics for Learning OPFs

Hugo Lugmania, Jocellyn Luna, Xavier Rodriguez-Veliz, Jose Cordova-Garcia
Escuela Superior Politécnica Del Litoral, ESPOL

Renewable energy sources have caused a change in the generation and loading characteristics of modern electrical power systems, which is why finding the solution to the Power Flow Problem (OPF) has increased in complexity and the need to solve it more frequently. Despite increasing complexity, the OPF has a known structure presenting characteristics that allow the use of Machine Learning (ML) to find the solution to that problem. This paper sets out to investigate the effects of varying specific characteristics of the input data used to train ML models of the OPF, particularly the load. We investigate how the sample size, the load correlation coefficient and the maximum load deviation impact the performance of a neural network trained to predict an OPF solution. The results of this research demonstrate a clear correlation between these variations in the training dataset and the performance of different ML models.

A Machine Learning-Based Privacy-Preserving Approach to Incorporate Distributed Generators in AC Optimal Power Flow

Burak Dindar[1], Can Berk Saner[2], Dogukan Yigit Polat[3], Hüseyin Kemal Çakmak[1], Veit Hagenmeyer[1]
[1]Institute for Automation and Applied Informatics, Karlsruhe Institute of Technology, Germany; [2]Department of Electrical and Computer Engineering, National University of Singapore, Singapore; [3]School of Computing, National University of Singapore, Singapore

In order to achieve the goal of a carbon-neutral power system, significant changes to the power grid are underway, necessitating enhanced interoperability between Transmission System Operators (TSOs) and Distribution System Operators (DSOs) for effective grid operation, particularly in light of the growing number of distributed generators (DGs). Data privacy concerns, however, complicate decision-making processes, particularly when integrating DGs into system-wide dispatch decisions. In this paper, we propose a machine-learning (ML)-based method to incorporate DGs located within the distribution system (DS) into dispatch decisions, adhering to data privacy by mitigating the exchange of sensitive data, such as system topology and demand profiles, between TSOs and DSOs. The methodology involves training three ML models to represent the behavior of the DS, thereby replacing the standard power flow model that contains sensitive information. Notably, we utilize a novel tailored neural network (NN) architecture to enhance computational efficiency in mapping the feasible region of the DS. Additionally, we employ open-source data to construct the Baden-Württemberg (Germany) electricity grid, allowing to test our method not only on standard systems but also on a model that more accurately represents real-world power systems. The numerical case studies verify that the proposed method achieves results comparable to standard AC optimal power flow (AC-OPF) in both cost-optimality and computational time.

An AC OPF based Clearing Mechanism for Local Flexibility Markets

Benoit Couraud[1], Sonam Norbu[1], Merlinda Andoni[1], Valentin Robu[2], David Flynn[1]
[1]University of Glasgow, United Kingdom; [2]Intelligent and Autonomous Systems Group, Centrum Wiskunde & Informatica (CWI), Amsterdam, The Netherlands

Local flexibility markets have emerged as an alternative option to expensive grid reinforcement and curtailment and propose a low-cost solution to solve local voltage excursion and cables overload at the distribution grid level. In this paper, we propose a local flexibility market framework based on optimal power flow (OPF) computation to allow a Community Distributed System Operator (C-DSO) to coordinate local flexibility provided by distributed generators and residential consumers. This local flexibility market allows the Distributed System Operator (DSO) to select the most cost-effective mix of flexible assets that addresses voltage excursions and grid congestions. It builds on an OPF formulation applicable only to energy markets, and extends it to the coordination of electrical flexibility. It considers active and reactive power while being suitable for imbalanced distribution grids analysis. Finally, it is implemented on the European low voltage distribution network with real consumption data and with large solar PV penetration to solve local grid constraints. The formulation optimises the flexibility effort while the power flow accuracy presents an error below 2.9% as compared with OpenDSS.

Enhanced Optimal Power Flow Based Droop Control in MMC-MTDC Systems

Hongjin Du, Rashmi Prasad, Aleksandra Lekic, Pedro P. Vergara, Peter Palensky
Delft University of Technology

In Multi-Terminal Direct Current (MTDC) transmission systems, achieving optimal operation set points for modular multilevel converters (MMCs) is critical for efficient power distribution and control performance. This paper presents an advanced Optimal Power Flow (OPF) model tailored specifically for MMC-MTDC systems, integrating an adaptive voltage droop control strategy. The strategy aims to simultaneously minimize generation costs and DC voltage deviations while ensuring the stable operation of the MTDC grid by dynamically adjusting the MMCs' operation points. The modified Nordic 32 test system with an embedded 4-terminal DC grid is modeled in Julia and the proposed control strategy is implemented based on the power model. The results demonstrate the feasibility and effectiveness of the proposed droop control scheme in power sharing, affirming its potential value in enhancing the performance and reliability of complex AC-DC power systems.

Risk-based Stochastic Optimal Power Flow for AC/DC Grids Using Polynomial Chaos Expansion

Kaan Yurtseven[1,2], Hakan Ergun[1,2], Dirk Van Hertem[1,2]
[1]KU Leuven, Electrical Engineering, Leuven, Belgium; [2]EnergyVille, Energy Transmission Competence Hub (Etch), Genk, Belgium

Renewable energy sources (RES) are increasingly integrated into power systems, introducing operational uncertainties that challenge the way we manage the grid. These uncertainties necessitate strategies to address the risks in grid reliability and economic performance. This paper introduces a framework to simultaneously manage the risk associated with economic performance and grid reliability under

non-Gaussian uncertainty. The framework utilizes Polynomial Chaos Expansion to solve the risk-based and chance-constrained Stochastic Optimal Power Flow for hybrid AC/DC grids. The risk associated with the costs is addressed by introducing the Value-at-Risk parameter, derived through moment-based calculations, to facilitate risk-averse decision-making. Numerical studies illustrate the impact of risk-neutral versus risk-averse decision-making on the probability distribution functions of RES curtailment and operational costs. Additionally, analyzing efficient frontiers for various confidence levels showcases the framework's capability to construct a portfolio of strategies that effectively balance risk and operational costs under varying confidence levels of non-Gaussian uncertainty.

Multi-Period Optimal Power Flow: Convex Relaxations and Parallel Algorithms

Tianshu Yang[1,2], Daniel Kuhn[1], Gabriela Hug[2]
[1]Risk Analytics and Optimization, EPF Lausanne, Switzerland; [2]EEH - Power Systems Laboratory, ETH Zürich, Switzerland

We develop efficient methods for solving multi-period optimal power flow (MPOPF) problems. The class of MPOPF problems is NP-hard due to the non-convexity of power flow equations, and due to the temporal coupling of the decision variables introduced by ramp constraints. To comprehensively address these challenges, we extend a conic relaxation, originally developed for single-period optimal power flow problems, to convexify the MPOPF problem, and develop a customized alternating direction method of multipliers to solve it in parallel. The proposed method is guaranteed to converge and provides a tighter lower bound than standard second-order cone relaxations. We assess the performance of our method on standard systems.

Coordinated Optimal Power Flow and Control of a DC Overlay Grid over Asynchronous AC grids

Giacomo Bastianel[1], Oscar Aristo Damanik[1], Dirk Van Hertem[1], Yin Chen[2], Lie Xu[2], Gavin Nevin[3], Shahab Sajedi[3], Eoin Hodge[3]
[1]KU Leuven/Etch by EnergyVille, Leuven/Genk, Belgium; [2]University of Strathclyde, Glasgow, Scotland; [3]SuperNode, Dublin, Ireland

Power systems are shifting towards a sustainable and interconnected future, where renewable power is transmitted over long distances to demand centers. This paper describes the role of a High Voltage Direct Current (HVDC) overlay grid in a proposed 6-zones AC/DC grid inspired by the European power system. The test case is analyzed with Optimal Power Flow (OPF) and Electromagnetic Transient (EMT) models both in normal operations and for two contingency scenarios, namely loss of a DC branch in the meshed AC/DC grid and loss of a radial HVDC link. The results of the simulations confirm the importance of the DC overlay grid from a power system stability perspective. Furthermore, a robust control philosophy is developed in hybrid AC/DC grids and helps to maintain the power balance and ensure stable power flows under various operational conditions.

Scalable Multi-Voltage-Level Optimal Power Flow for Curative Grid Curtailment Measures

Julian Bigalke, Chris Martin Vertgewall, Andreas Bong, Luis Böttcher, Andreas Ulbig
IAEW at RWTH Aachen University, Germany

In the course of the energy transition, an increase in controllable units in the distribution grids is to be expected, which can be used to delay or avoid grid expansion. The determination of an optimal power flow can be used to efficiently eliminate grid bottlenecks by curtailing these controllable units. The effort required to solve an optimal power flow (OPF) problem to curtail loads or generators increases greatly with the number of controllable grid participants and the complexity of the grid. In order to determine the optimal use of controllable grid participants in higher voltage levels, the flexibility of the lower voltage levels must also be taken into account. Therefore grids with several voltage levels must be considered. This complexity leads to high computing times. To solve this problem, we developed a method that makes it possible to curtail controllable participants in multi-voltage level grids in the event of limit violations considering (N-1)-safety by calculating the optimal power flow for different sub-grids separately. With the developed procedure, a runtime improvement of a factor of up to 358 can be achieved while receiving similar results as from a conventional OPF when applied on controllable loads in a medium and low voltage grid.

Acceleration of a decentralized radial AC-OPF on GPU

Beatrice THOMAS[1,2], Roman LE GOFF LATIMIER[2], Abdelhafid EL OUARDI[1], Hamid BENAHMED[2], Samir BOUAZIZ[1]
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Distribution networks are currently hosting a major share of the energy transition and require the development of new management mechanisms. Their tuning requires numerous simulations to get closer to the optimal performance set by optimal power flow results. In radial networks, this problem admits specific resolutions. However, these algorithms are still hampered by prohibitive computing times for large-scale prob- lems, which is typically the case for a distribution network. Specific implementations are, therefore, crucial to make the most of heterogeneous CPU GPU computing architectures. This contribution focuses on two distributed OPF algorithms in radial networks. The speed-up by a factor of 3 is observed, particularly on the largest systems. Nevertheless, in several study cases, GPU methods failed to converge due to the lack of numerical stability of the algorithms.

Paper Session 15: Power system stability 1

Time: Tuesday, 15/Oct/2024: 2:00pm - 4:00pm **Location:** Orlando 1C

Presentations:

Advanced Angle Estimation using Kalman Filter for high impedance Grid-following Inverters Stability

Phuoc Sang Nguyen, Ghavameddin Nourbakhsh, Gerard Ledwich
Queensland University of Technology, Brisbane, Australia

Frequency and phase angle are important factors in maintaining stability of power systems integrated with Grid-following inverters. This has led to the development of various grid synchronisation techniques. In practice, high grid impedance presents a significant challenge to the stability of power systems. However, most existing methods neglect to consider this issue. This research proposes an Advanced Angle Estimation using Kalman Filter technique, which incorporates grid impedance terms into state space models as part of the Kalman Filter approach. This is used to estimate instantaneous phase angle and frequency using Synchronous Reference Frame equations in alpha and beta frames. Using the proposed approach in this paper, the stability performance of a two-source system is applied and validated, using eigenvalue analysis. The results demonstrate improved performance of this technique over the Conventional Angle Estimation using Kalman Filter and Conventional Phase-Locked Loop methods, in terms of accuracy, distortion reduction, and convergence time under conditions of sudden increases in grid impedance.

Robustness Analysis of Grid-Forming Inverter with Linear Quadratic Integral Controller

Chamanie Dinuwanthi Welmilla Welmillage Don, Don Mahinda Vilathgamuwa, Yateendra Mishra
Queensland University of Technology, Australia

The black start capability of grid-forming (GFM) inverters and their autonomous operation enhance the performance of inverter-based power grids. In the context of GFM inverters, the voltage and frequency have to be autonomously maintained as per the grid codes. This paper proposes a linear quadratic integral (LQI) controller for a small-scale GFM inverter supplying power to a load. A LCL filter is integrated to enhance the GFM inverter's output. The proposed controller demonstrates a robust performance under a situation when the parameters of the LCL filter degrade by 70% of its original value. The Nyquist stability criterion is incorporated to analyze the designed LQI controller in both original and degraded plants. Furthermore, the effectiveness of the controller is validated through the simulated results in the MATLAB Simulink environment.

Time delay-induced control cross-coupling in VSC-MMC systems: Implications in harmonic mitigation, passivity and stability

Eros Avdiaj, Jef Beerten
KU Leuven, Belgium

As renewable energy integration accelerates, so does the demand for voltage source converters, particularly Modular Multilevel Converters. However, control time delays --inherent to such converters-- pose a significant challenge, threatening system stability. This paper investigates the impact of dq-frame time-delay-induced cross-coupling on AC-side control of MMCs. Traditional control designs in the dq-frame may overlook these cross-couplings arising from time-varying signals in the abc-frame, leading to unexpected performance outcomes.

To address this challenge, we propose a method to compensate for time-delay-induced cross-coupling and validate it through comparative analysis between conventional high-frequency models and detailed MMC models. The analysis reveals the benefits of compensating for time-delay-induced cross-coupling to improve stability and performance.

The paper elucidates the mechanism behind time-delay-induced cross-couplings, outlines the MMC model and control strategy, and introduces the compensation method. Additionally, it discusses a framework for the passivity-based design via a high-frequency model and presents results validating the compensation method.

Automated Frequency-Domain Small-Signal Stability Analysis of Electrical Energy Hubs

Francisco Javier Cifuentes Garcia, Thomas Roose, Özgür Can Sakinci, Dongyeong Lee, Lokesh Dewangan, Eros Avdiaj, Jef Beerten
KU Leuven, Dept. Electrical Engineering (ESAT-Electa), Leuven & Etch EnergyVille, Genk, Belgium

Energy hubs will be crucial infrastructures in future power systems, enhancing renewable energy integration and flexibility. However, their stability analysis is demanding as they incorporate many converters supplied by multiple vendors, for which only black-box models are available. We address this challenge by introducing the first openly available frequency-domain stability analysis tool based on Electromagnetic Transients (EMT) software models. An efficient and reliable frequency-domain identification procedure is presented and validated, which enables the application of state-of-the-art multi-terminal stability assessment methods. The capabilities of frequency-domain methods to provide valuable stability insights are demonstrated for the novel case study of a multi-terminal hybrid energy hub, thus paving the way for their safe deployment into modern power systems.

Stability Analysis of Grid with High Renewable Energy Sources Under Uncertainty Conditions

Hung Cuong NGUYEN[1,3], Quoc Tuan TRAN[2], Yvon BESANGER[1,4]
[1]G2Elab, France; [2]CEA-INES; [3]Vietnam Maritime University; [4]Grenoble Alpes University

Renewable Energy Resources (RES) have been become an inevitable choice for the future. However, RES can decrease the inertia of grids to which they are connected. Moreover, their power generation depends on weather conditions, making it intermittent and uncertain. These two inherent characteristics of RES negatively impact the stability of connected power systems. Forecasting RES power output and loads demand is one of the most effective solutions to improve stability of grids integrated with high penetration. However, predictive methods have not yet achieved perfect accuracy. To address the gap, this paper presents a novel stochastic simulation based on

forecasting, form which operators can identify extreme scenarios and prepare solutions to ensure the safety and reliability of grid operations in these situations. This paper introduces stochastic simulation techniques, demonstrating their application in identifying severe scenarios based on global stability of a grid. Furthermore, the study proposes solutions to enhance overall stability of the grid after identifying these extreme conditions.

Impact of Inertia Reduction on Small-Signal Stability and Controllability of Interconnected Synchronous Generators

Antonija Šumiga[1], Jožef Ritonja[2], Boštjan Polajžer[2]

[1]Croatian Transmission System Operator; [2]Faculty of Electrical Engineering and Computer Science, University of Maribor

The integration of renewable energy sources inherently reduces power system inertia, which can result in a higher rate of change of frequency. Moreover, reduced inertia also affects the small-signal stability and controllability of the interconnected synchronous generators (SGs). In this paper, we use the linear state-space model to show the impact of SGs' inertia constants on eigenvalues, participation factors, and Gramian-based controllability metrics. Both a single-machine and an IEEE 9-bus system were analyzed. The results for the IEEE 9-bus system with three SGs show an optimal range of inertia constants to increase the damping of a specific mode and increase controllability. Thus, a framework for multi-objective optimization combining large-signal stability, small-signal stability, and controllability is proposed that can be applied to grid-forming converters.

Analyzing Dynamic Stability in Power Systems with High Penetration of Grid-Forming Inverters

Kevin Ramiro Mendoza Moreira, Carolina Tranchita Rativa

Frankfurt University of Applied Science, Germany

The growing integration of Inverter-Based Resources (IBR) in electric power systems worldwide presents a significant challenge, which is the loss of inertia, due to the replacement of synchronous generators with inverters. This shift necessitates inverters to take on a more active role in the voltage and frequency control of the grid. It has led to the development and ongoing research of multiple control strategies and technologies. This paper addresses the dynamic stability of a power system with high penetration of IBR grid-forming inverters (GFMI), utilizing droop control and virtual synchronous machines (VSM) as control methods. Additionally, current limiting methods, such as Virtual Impedance (VI) and Current Limiting (CL) are employed to manage over-current conditions typically encountered during faults, thereby ensuring the secure operation of GFMI under various control configurations. The simulation results show that the performance of IBRs and their impact on the power system dynamic stability significantly depends on the chosen control methods, underscoring the need for effective power control and current limiting techniques to ensure reliable grid operation.

Assessment of Harmonic Stability of Grid-connected Inverter and Harmonic Limits in IEC TS 61000-3-16

Hiro Nakayama, Naotaka Okada

Central Research Institute of Electric Power Industry, Japan

Increasing integration of grid-connected inverters can cause harmonic disturbances in distribution systems. In order to maintain power quality in a reasonable way, IEC TS 61000-3-16, which is a technical specification (TS) deals with the harmonic limits for the grid-connected inverter, was prescribed by IEC in November 2023. Because the dynamic characteristics of the current controller influence both the harmonic emissions and the harmonic stability of the inverter, complying with limits in the TS would affect the harmonic stability of the inverter.

In this study, an electromagnetic transient simulation of an inverter following the measurement procedures defined in the TS is shown. The comparison between the simulation results and limits in the TS illustrate that the gain of the current controller can be constrained into a particular range for the purpose of compliance with the TS.

Investigation of Operating Point Setting and Stability Behavior of LVDC Arc Flashes

Sebastian Glaser, Dirk Westermann

Power systems group,Technische Universität Ilmenau, Germany

Short circuits in electrical power systems often lead to arc flashes, prompting increased demands for protection, especial-ly in LVDC systems. Static equivalent circuit models are com-monly used to estimate arc flash characteristics under steady-state conditions. However, these models typically overlook dynamic behavior around the operating point and its impact on arc fault stability. Laboratory measurements in a DC test circuit with various parameters were conducted to investigate operating point setting and arc fault extinguishing tendencies. Insights into dynamic stability and stability indicators were derived, aiding in the selection of appropriate personal protec-tive equipment (PPE) during hazard assessments.

Paper Session 16: Power system development

Time: Tuesday, 15/Oct/2024: 2:00pm - 4:00pm **Location:** Koločep 5

Presentations:

Development and Deployment of Generic Models for Grid Code Compliance Studies

Stephen James Sommerville, Gareth A. Taylor, Maysam Abbod
Brunel University, United Kingdom

A challenge faced by many Transmission System Operators (TSO) is how to adequately represent Inverter Based Resources (IBR) within TSO network models. At present most TSOs require a series of Grid Code compliance studies to be provided as part of the connection process, which use detailed vendor models. These are often encrypted and require detailed understanding to implement into existing TSO network models, which become a significant time and cost constraint. This paper demonstrates that the majority of IBR plant and the associated performance requirements, can be adequately represented using generic open source aggregated WECC models. A 50 MW, Battery Energy Storage System (BESS) plant connected to the UK network, following the UK Grid Code / RfG requirements, is studied by developing and deploying a aggregated Western Electricity Coordinating Council (WECC) model in DIgSILENT Powerfactory and is presented as a benchmark system.

Towards Explainable and Trustworthy Autonomous Models for Power Systems: a Retrospective Case Study Analysis

Maria Cassidy[1], Blair Brown[1], Stephen Stephen D. J. McArthur[1], Sakuntala Devi Vidhyasankar[2], Damon Kirk[2], Bruce Stephen[1]
[1]University of Strathclyde, United Kingdom; [2]ScottishPower

Currently, power systems are undergoing a digitalization shift to manage an increasingly heterogeneous and volatile network, incurred by the energy transition, which directly impacts control centres. However, trust in automated infrastructure management through an understanding of the model behaviour is decisive in making operational and scalable decisions. Therefore, there is a need for transformative changes aided by trustworthy, explainable automation, particularly through human-centred design, to empower control room operators. This paper assesses the expected shift towards trustworthy industries based on recent policies and standards development, supported by research. Through a switchgear asset management case study, it evaluates the trustworthy challenges and expected processes to provide recommendations.

Evaluating grid development strategies for a regional grid using dynamic line rating sensors

Susanne Sandell, Iver Bakken Sperstad
SINTEF Energy Research, Norway

Traditionally, regional power grid planning relies on grid reinforcement and present value calculations to evaluate alternative grid development plans, as well as strict adherence to the N-1-criterion. However, it is now becoming possible to use dynamic line rating sensors to operate the grid closer to its real capacity, as well as adapting probabilistic security constraints. This work proposes a grid development methodology which considers static, ambient adjusted and sensor-based dynamic line rating of regional grid overhead lines: First, an operational model proposes grid development strategies given various load development scenarios. Then, the strategies are evaluated by quantifying both the values and risks. The methodology is demonstrated in a case study of a real Norwegian regional grid (132 kV). The results will demonstrate that in order to realize the option value of using DLR as a measure in grid development, the grid company should reduce the risk margins used in the operation of the grid.

Integrating Distribution Grids in Power System Optimization with a Feasible Planning Region

Luis Böttcher, Steffen Kortmann, Simon Braun, Julian Saat, Christian Fröhlich, Andreas Ulbig
IAEW at RWTH Aachen University, Germany

The shift towards clean energy brings about notable transformations to the energy system. In order to optimally plan a future energy system, it is necessary to consider the influence of several sectors as well as the interaction of the transmission grid and distribution grid. The concept of Feasible Operation Region (FOR) is a detailed approach to representing the operational dependencies between the transmission and distribution grid. However, in previous planning procedures, only a simplified expansion of the distribution grids can be taken into account. With the method presented in this paper, a Feasible Planning Region (FPR) is developed, which represents the operational boundaries of the distribution grids for several expansion stages and thus represents an admissible solution space for the planning of distribution grids in systemic planning approaches. It hence enables a more detailed representation of the necessary distribution grid expansion for the integration of distributed technologies in an optimized energy system of the future. In this paper, we present the method by which the FPR is formed and its integration into an energy system planning formulation. In the results, the FPR is presented for different voltage levels, and its use in power system planning is demonstrated.

Impact of Evolving EV charging profiles on Distribution Grid Reinforcement: A Case Study

Tilman Weckesser[1], Mikhail Skalyga[1], Casper Bjerregaard[2,3]
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The number of Electric Vehicles (EVs) is rapidly growing in several parts of the world and particular in Scandinavia. A large share of the EV chargers are expected to get connected to the distribution grid. This together with the ongoing electrification of other consumption, e.g. heating, will likely require reinforcement of the existing grids. Consequently, Distribution System Operators need to consider the impact of EV charging in their grid planning. Contrary to conventional consumption, the EV charging patterns are highly dependent on consumer behaviours and preferences. Hence, technical developments and behavioural changes may impact grid reinforcement needs. In this paper, in a Danish case study, we investigate how the evolution of EV charging impacts grid reinforcement needs. Furthermore, we present a generic and transparent framework for analyzing reinforcement needs of the distribution grid, due to changes in the expected consumption. The case study is based on actual distribution grid data and EV charging profiles from the UK from 2017 and Denmark from 2023. The results show that the grid reinforcement needs are severely impacted by the evolution of charging profiles.

A Generation Expansion Planning using the PSO-GA algorithm to Reduce Carbon Emissions

Mahmoud Zadehbagheri[1], Igor Kuzle[2]
[1]Islamic Azad University, Iran, Islamic Republic of; [2]University of Zagreb Faculty of electrical engineering and computing

Generation expansion planning (GEP) is a part of network development planning in which the goal is to determine the characteristics of new power plants that are used to develop the existing productive system. In this article, reducing the number of greenhouse gases in the power system is considered in the long-term planning horizon. In addition, much effort has been made to minimize production costs and maximize power plant profits. According to the results obtained in this paper, the following points can be deduced: Oil power plants are beneficial in both scenarios. For this reason, in both cases, many of these power plants enter the circuit. In the 12-year planning horizon, many LNG power plants have entered the circuit. Nuclear power plants have a large capacity. Also, the maintenance cost of these power plants is low, that's why these power plants are used at the beginning of planning. In the second scenario, fewer LNG power plants are built due to a high tax on LNG plants. Reducing the number of power plants reduces the amount of carbon produced

Real-Time Load Estimation and Graph-Based Modelling for Load Shedding in Rural DSO Digital Twin Frameworks: A Case Study from NE Spain

Ignacio Glenny-Crende[1,2], Francesca Rossi[2], Vinicius A. Lacerda[2], Eduardo Prieto-Araujo[2], Yolanda Castellón-Lalanza[1]
[1]iGrid T&D; [2]CITCEA-UPC UPC BarcelonaTech

The electrification of energy demand and the challenges associated with the energy transition pose significant uncertainties for rural distribution system operators (DSOs). Digital twin (DT) frameworks can provide real-time analysis, modeling, and simulation capabilities. However, traditional DT applications rely heavily on data, presenting challenges for rural DSOs with limited monitoring coverage and constrained data availability. The proposed load shedding application combines the DT framework's data-driven load estimation and graph-based grid modeling offering operator assistance in reduced data availability scenarios, as seen with real distribution grid implementation in North-Eastern Spain.

A Review of Small Hydro Electricity Generation Potential in Iceland

Egill Benedikt Hreinsson
University of Iceland, Iceland

While Iceland has in recent decades developed its power system based on large hydro and geothermal projects, the current development faces environmental concern and some opposition. In addition, wind energy has had difficulties in the initial phase of its development process, for the same reason. Therefore small hydro presents an interesting option to satisfy future demand in the coming energy transition. The immediate need is to replace fossil fuel in the transportation sector with renewable, emission free energy. Small hydro as a resource may contribute to such future electricity needs, especially if its environmental impact is viewed to be more benign than the large scale hydro development or new wind generation. This paper surveys and summarizes Iceland's small hydro potential with estimated streamflow, power capacities, location and other attributes for integration it into the present Icelandic power system.

Estimation of LCOE and LCCA for a Renewable Energy and Energy Efficiency Project in India's Paper Industry: A comparison between Rooftop Solar and Steam Expander for Power Generation

Dhipankumar Kanakasabapathi, Sumant Bansal, Dhanavaradhan M, Prof. Satyanarayanan Seshadri, Prof. Santosh Kumar Sahu
Indian Institute of Technology Madras, India

The paper industry in India, exemplified by M/s. Sattur Venkateshwara Paper Mills plays a crucial role in the country's Gross Domestic Product (GDP). Facing rising energy costs, environmental concerns, and the need for sustainability, there is a growing imperative for the industry to cut down their carbon emissions either by integrating suitable renewable energy options or energy efficiency technologies and measures. This study estimates the Levelized Cost of Energy for rooftop solar PV systems and steam expanders, assessing their economic feasibility as alternative energy sources. Factors such as initial capital investment, discount rate, operating and maintenance costs, energy generation, and project lifespan are considered. The research also evaluates the Levelized Cost of Carbon Abatement for these technologies, providing insight into their potential for reducing carbon emissions within the industrial sector. Additionally, the study examines energy consumption patterns, fossil fuel dependence, and emissions associated with the paper industry.

Paper Session 17: Integration techniques

Time: Tuesday, 15/Oct/2024: 2:00pm - 4:00pm **Location:** Lokrum 4

Presentations:

Lowering barriers to a large-scale implementation of grid booster projects by introducing a hybrid concept

Jonas Lotze[1,2], **Marvin Dorn**[2], **Veit Hagenmeyer**[2]
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The future of power systems belongs to renewables. And to integrate them, the expansion of the electricity grids is undoubtedly necessary. Furthermore, power systems cannot operate without reserves and flexibilities. For these to be efficient, system-serving, and economical, holistic concepts are needed. This paper describes the grid booster concept and presents the major barriers to a large-scale implementation in electric power systems. A proposal for enhancing economic viability and multi-applicability is presented through the discussion of a hybrid grid booster concept.

The Potential of Small Modular Reactors to Provide System-Bearing Services in the Future Power Grid

Jonas Kristiansen Nøland[1], **Martin Hjelmeland**[1], **Magnus Korpås**[1], **Lina Bertling Tjernberg**[2]
[1]Norwegian University of Science & Technology (NTNU); [2]Royal Institute of Technology KTH, Sweden

The future power grid comprises large shares of inverter-based resources (IBRs) dominated by solar and wind power. As a result, the grid's resilience in terms of voltage and frequency regulation capabilities can be significantly reduced. To deal with this unsolved challenge, there is a potential for small modular reactors (SMRs) to provide, in addition to electricity and heat, system-bearing services that, at a reduced cost, can enable higher penetration of renewables. This paper shows that the alternative system-wide ancillary service cost for physical inertia and short-circuit capacity can be approximately $20/MWh when using synchronous condensers (SCs) to enable a 100 % renewable energy system. SMRs can avoid these additional system costs and, in addition, significantly increase the grid strength when compared to the use of SC devices. Moreover, it is shown that multiple SMR units instead of large nuclear power plants significantly reduce the needed frequency reserves.

Determining Candidate Renewable Energy Sources for G&TEP using Data Envelopment Analysis

Amin Moghimy Fam, **Janne Seppänen**, **Mahdi Pourakbari-Kasmaei**
Aalto university, Finland

Renewable energy sources (RESs) are becoming more and more dominant energy sources in many countries and are replacing conventional power plants. Furthermore, the electricity demand is rising due to sector coupling and moving toward carbon neutrality. Hence, a new framework for generation and transmission expansion planning (G&TEP) based on the intermittent output of RESs is introduced. Since G&TEP has a high computational burden, currently, expert-based or high-level approaches are used to determine the candidate units for each location. This paper proposes a systematic approach based on data envelopment analysis (DEA) to determine candidate RES combinations for G&TEP. The proposed method helps to benchmark different possible combinations of distinct PV panels and wind turbines locally. This results in reducing the number of integers in G&TEP and introduces a systematic approach to decision-making. To achieve this goal, first, the output of different PV panels and wind turbines based on meteorological data is calculated. Then, a local sizing problem for each combination, considering the transmission side constraints is solved. Finally, by applying DEA with parameters aligned with G&TEP, the relative efficiency of all combinations with respect to each other is determined. Based on the relative efficiencies, the candidate units for G&TEP can be selected. The results reveal that expert-based candidate selection can yield inefficiency. For instance, it is shown that using hybrid PV panels and wind turbine plants in Nordic countries, where solar irradiation is low, results in higher efficiency in contrast to what experts used to believe.

Assessing Regional Capacity Expansion: The Role of Quasi-Dynamic Thermal Ratings in a Changing Climate

Sergio Montana, **Andrea Michiorri**
PSL, France

Proposing practical solutions to mitigate the effects of climate change on the electricity system requires thorough understanding and quantification. This paper introduces a new method of quantifying dynamic network capacity at the transmission level, using established thermal models and a set of regional expansion plan tools. The results suggest this approach can increase component capacity by up to 21% during winter and up to 16% during nighttime hours for overhead lines. This approach offers a viable option for electricity operators to address the challenge of balancing the need to reduce failure rates and capacity loss with the crucial demand for new investment in transmission assets, reducing more than 1% of system cost expansion by 2050.

A multi-year Renewable Amounts assessment for Grid Portions: the Italian case

Chiara Giordano, Enrico Maria Carlini, Corrado Gadaleta, Alessandra Zagnoni, Alfonso De Cesare, Michela Migliori, Luca De Bellis, Marco Rigobello, Francesca Ferretti, Francesca Longobardi
Terna, Italy

The increasing penetration of renewable energy sources (RES) in the Italian electricity system requires an evaluation of the integration capacity in the National Transmission Network. In this paper, a novel methodology to assess the maximum RES capacity (wind and solar photovoltaic) that can be integrated into different grid portions of the Central-South Italy is presented. The network constraints, the real distribution of RES connection applications, the sub-transmission network operation islands and the grid development projects progress are the main parameters considered in an integrated multi-year iterative approach. The results show that the RES integration capacity increases significantly with the network reinforcements implementation, and that the main limitations are due to line congestion and system stability. The importance of a coordinated planning between the network and the RES is also highlighted, in order to optimize the use of renewable resources and ensure the security and efficiency of the electricity system.

An Integrated High-Speed Railway Electrification Framework for Reducing Embodied Carbon

Archita Vijayvargia, Abhijit R. Abhyankar
Indian Institute of Technology Delhi, India

High-speed railways (HSR) have emerged as a promising mode of sustainable transportation, requiring comprehensive simulations throughout the project electrification process. However, the development of an integrated framework for HSR electrification that focuses on reducing embodied carbon remains a notable gap. This paper proposes an integrated framework for HSR electrification, compliant with the European standard for railway applications (EN 50388:2012), which aims to advance sustainable HSR network development. The proposal first designs the power supply installations based on critical HSR schedules. It is followed by optimizing the traction power supply systems (TPSS) design for the economically viable placement of autotransformers and traction substations (TSS) using the interior point method. The feasibility of TPSS is then assessed using the fundamentals of traction load flow study. The effectiveness of the proposed framework is demonstrated on a real track in India, showing significant embodied carbon reduction in TPSS design, equivalent to eliminating one TSS.

A Holistic Assessment Framework for Evaluating Buildings' Green and Digital Readiness Level

Nearchos Stylianides, Lenos Hadjidemetriou, Charalambos Charalambous, Christos Panayiotou
University of Cyprus

Smart buildings assessment methodologies are important tools utilized across all stages of transitioning towards a greener, smarter, and energy-efficient building sector. Existing assessment methods either focus only on specific building aspects, or consider buildings with particular technical characteristics, or require explicit technical knowledge by the users to evaluate building performance. Consequently, this paper proposes a holistic and flexible assessment framework that encompasses all facets of a building, including green factor, energy efficiency, occupants' comfort, and digitization levels. The proposed framework does not require strong technical knowhow to perform the assessment and can be generally applied for evaluating different buildings by providing basic information about their main characteristics. The assessment framework was applied to a real commercial building, demonstrating its effective use in evaluating overall building performance and analyzing the score in each individual impact category or domain. In addition, two potential action plans were formulated by utilizing the proposed framework to explore different pathways for enhancing the building's performance.

Long-term storage expansion planning considering uncertainty and intra-annual time series

Tiago João Abreu, Leonel Carvalho, Vladimiro Miranda
INESC TEC, Portugal

Long-term storage expansion planning has usually employed representative days and intra-annual time series aggregation methodologies to reduce the computation complexity. This paper proposes a shift on the approach to the economic evaluation of these systems by implementing an intra-annual time series cost evaluation that considers different uncertainty trajectories. This methodology aims to determine the best possible investment strategies for the available computational budget using strategy game-based decision-making models, as Monte Carlo tree search. The proof of concept is illustrated by a single-bus equivalent test system and compared to a deterministic evaluation for a limited uncertainty model.

Limiting grid exchange applying PV curtailment and EV charging coordination on an LVDC backbone

Hakim Azaioud, Jos Knockaert, Lieven Vandevelde, Jan Desmet
Ghent University, Belgium

An LVDC backbone offers a promising solution for the efficient integration of Battery Energy Storage Systems (BESS), photovoltaics (PV), and Electric Vehicle (EV) chargers. Furthermore, dynamically optimized backbone voltage could further enhance efficiency and simplify the grid by eliminating PV DC/DC converters. This study extends the framework to include dynamic curtailment and EV coordination. Curtailment is considered as a necessary measure to address congestion issues. With the dynamic curtailment proposed in this article, PV curtailment only occurs when it cannot directly be consumed by EVs or be stored in the BESS, thereby increasing efficiency and reducing inverter size.

Paper Session 18: Distribution network

Time: Tuesday, 15/Oct/2024: 4:30pm - 6:30pm **Location:** Orlando 1A

Presentations:

A Voltage-Approximated Three-Phase Distribution Network Model with Comprehensive Applications

Qijun Liang, Cuo Zhang, Jianguo Zhu
The University of Sydney, Australia

The increasing integration of distributed energy resources (DERs), such as photovoltaics (PVs), poses significant challenges for active network management in unbalanced distribution systems. An accurate and applicable three-phase distribution network model is essential. This paper proposes a voltage-approximated network model for three-phase distribution networks, which can be applied to optimal power flow problems. Unlike conventional approaches that use squared voltages as state variables, the proposed model directly incorporates voltage magnitudes, offering high efficiency and accuracy for wide applications such as Volt/Var control and conservation voltage reduction problems. Comprehensive studies utilizing a modified IEEE 123-bus test system validate the effectiveness of the proposed model in these applications.

An Integer Program based Appliance Identification and Load Disaggregation Method

Haozhe Li, Qiaozhu Zhai, Yuzhou Zhou, Yingming Mao
Xi'an Jiaotong University, China, People's Republic of

Obtaining information on electricity consumption and operating habits of appliances on the user side of the grid is crucial for optimizing energy rationing and promoting smart grid development. This paper focuses on the household scenario and proposes a two-step non-intrusive appliance load monitoring (NIALM) model, targeted on low-frequency (around or less than 1 Hz) load data using event detection and integer program. The first step is to detect appliance switchover and to reshape the load curve into a step-like curve. Based on the reshaped curve, an unsupervised appliance identification model is proposed, combining integer program and event-based method. In the second step, integer program is used for load disaggregation. Our method is tested on a private dataset and the Reference Energy Disaggregation Dataset (REDD). Experiments demonstrate that our method can successfully identify appliances from load profiles and disaggregate them from the load curve. The performance of our method is computationally efficient and promising for practical use.

Predicting Distribution Reliability Indices based on exogenous data

Xavier Weiss, Patrik Hilber, Sanja Duvnjak Zarkovic, Lars Nordström
KTH Royal Institute of Technology, Sweden

Reliability indices like the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) serve as the Key Performance Indicators (KPIs) for Distribution System Operators (DSOs). They effectively measure the frequency and impact of outages on end users. Given the criticality of the electrical grid to many functions of the modern world, minimizing these values has been and continues to be a priority for DSOs. SAIDI and SAIFI can, however, be influenced by many factors including but not necessarily limited to the network topology, the type of installed components and the quantity of customers connected to the grid. In this work we thus attempt to predict the reliability indices of a DSO based on financial, customer and grid composition statistics reported to regulatory bodies by DSOs in Sweden between 2010 and 2021. By decomposing which features are the strongest predictors for SAIDI and SAIFI, DSOs can see how changes in their customer base and grid composition impact their reliability KPIs. In addition these indices can potentially be used to indicate which parts of the grid are most vulnerable to outages and thus prioritize mitigations at those locations.

Feasible Operating Regions of Distribution Network Buses in Networks with Different Renewable Energy Sources

Ester Thomas Marcel, Jovica V. Milanović
The University of Manchester, United Kingdom

The increase in the number of variable renewable energy source (RES) generation poses a significant risk to distribution networks' operation when their power injections into the network are uncontrolled. This paper demonstrates how specifying day-ahead feasible operating regions for distribution network buses in terms of real and reactive power injections in the network controls the RES generations' power injections into the network, hence eliminating overvoltages and line congestion challenges that may occur. The study was performed on a test network with solar photovoltaics (PVs) and wind RES generations. The operating envelopes were calculated using Latin Hypercube Sampling (LHS) based probabilistic load flow simulation and convex hull estimation in DIgSILENT and MATLAB environments. The results demonstrated that the presence of different types of RES in the network (PV, wind, batteries) facilitates the calculation of operating regions (envelopes) across the entire 24-hour period and, therefore, more flexible network operation.

Distribution network reconfiguration for operational objectives: reducing voltage violation incidents and network losses

Geert Mangelschots[1], Sari Kerckhove[1,2], Md Umar Hashmi[1,2], Dirk Van Hertem[1,2]
[1]KULeuven, Belgium; [2]EnergyVille, Belgium

As the share of low-carbon technologies in the low-voltage distribution network (DN) is expected to rise, a higher and more variable electric load and generation could stress the DNs, leading to increased congestion and power losses. To address these challenges, DSO's will have to make a lot of investments in strengthening the network infrastructure in the coming decade. This paper looks at one possible strategy to do so through dynamic DN reconfiguration. Typically, in European DN, usually, the network has only manual switches. Hence, the network configuration is set for longer periods of time. Therefore, an opportunity is missed to benefit from more short-term dynamic switching. In this paper, a method is proposed which identifies the best static switches to replace with reconfigurable

switches based on their performance in terms of avoided voltage congestion incidents and DN power losses. The developed method is an exhaustive search algorithm which divides the problem into 3 subsequent parts, i.e., radial configuration identification, multi-period power flow and impact assessment for reconfigurable switch replacement on DN operation. A numerical evaluation shows that the replacement of the first 2 switches in the test case had the highest influence on the power losses and on the voltage constraint violations. Investing in additional reconfigurable switches only slightly improved the operation of the DN.

Distribution Network Reconfiguration Considering Nodal Pricing

Andreas Gatos, Athanasios-Rafail Lagos, Aris Dimeas, Nikos Hatziargyriou
National Technical University of Athens, Greece

In this paper, a novel Distribution Network Reconfiguration (DNR) method for the cost effective operation of the Distribution Network (DN) is presented. We focus on the maximization of the welfare of the consumers and producers connected to the DN, where we consider that nodal pricing is applied on the Transmission System (TS) and as a result the price of purchasing or selling energy varies per HV/MV substation. The proposed model initially focus on the consumers' cost minimization and the producers' profit maximization separately and it is extended to a multi-objective problem taking into account both objectives simultaneously. For this problem, the Pareto Front solutions are computed, which indicate the trade-off between consumers' cost and producers' profit in each optimal network topology. The results of the proposed algorithm are very promising since either a reduction of cost of 2.87% or a profit increase of 7.69% are achieved.

A Constraint Enforcing Imitation Learning Approach for Optimal Operation of Unbalanced Distribution Networks

Neda Vahabzad, Pedro Vergara, Peter Palensky
Delft University of Technology, The Netherlands

Addressing the optimal operation of modern distribution networks has become a computationally complex problem due to numerous network constraints and the integration of various distributed energy resources (DERs). Although data-driven methodologies offer potential in handling the non-linearity and non-convexity of such optimization problems, they often struggle to meet system constraints. This paper proposes integrating imitation learning (IL) with a surrogate optimization model (SOM) to minimize both cost and active power losses within the system, bypassing the complexities of the original nonlinear problem while ensuring feasible solutions. The effectiveness of the proposed IL-SOM in accurately predicting the decision variables of the optimization problem is demonstrated using a 25-bus unbalanced three-phase distribution network test case. Furthermore, the predicted variables fully comply with the system's crucial constraints, including active and reactive power balance constraints, as well as line current and phase voltage magnitude limits.

Evaluation of Grid Connection Points on the Basis of Hosting Capacity in High-Voltage Distribution Grids

Simon Braun[1], Franca Lohse[1], Steffen Kortmann[1,2], Andreas Ulbig[1,2]
[1]IAEW at RWTH Aachen University, Germany; [2]Digital Energy, Fraunhofer FIT, Aachen, Germany

In the context of the energy transition and the associated expansion of renewable energies, the energy system of the future faces major challenges. As the grids are increasingly overloaded, grid connection issues for project planners of renewable generation plants can sometimes only be realized with a delay, since grid expansion measures have to be taken. This paper presents a method for evaluating individual grid requests based on hosting capacity. For this purpose, an OPF-based model is set up which can be used to calculate the hosting capacity of a power grid. By changing the objective function, the connection potential of individual nodes can be calculated, allowing grid connection requests to be simulated. The individual connection requests can then be compared with the results at the single nodes of the hosting capacity of the entire grid. The results for a model region in northern Germany show that the transformers are limiting elements for calculating the hosting capacity. Furthermore, it can be shown that the hosting capacity can be exploited in particular if connections are realized close to the transfer points to the transmission grid level.

Preprocessing Distribution Network Topology for Improved Performance of Network Reconfiguration

Özgür Arda Kucukaslan[1], Tugay Gül[1], Murat Göl[2]
[1]ODTÜ-GÜNAM, Turkey; [2]Middle East Technical University, Turkey

Voltage regulation is a prominent issue in distribution networks as distributed generation and electrical vehicle chargers become more popular. However, solving these issues in the distribution networks becomes challenging as the system is operated radially and due to the lack of equipment installed. To solve the voltage regulation issues, distribution network reconfiguration methods are developed. There are several approaches to this problem, and some of these sacrifice finding global optimal solution capability for shorter computation times, while the other approaches can take extremely long times. To find the best network topology for voltage regulation with improved computational performance, a method that uses a numerical approach and benefits from preprocessing the topology is proposed. The preprocessing method intends to decrease the size of the optimization problem by detecting independent rings and branches for parallel computation, and also by determining feasible networks. The optimization method for demonstration purposes depends on brute force, ensures global optimum without linearization of the constraints, and is a good example for observing the decrease in computation time caused by preprocessing.

Paper Session 19: Inverter-based generation

Time: Tuesday, 15/Oct/2024: 4:30pm - 6:30pm **Location:** Orlando 1C

Presentations:

On the damping of power systems during inverter-based blackstart

Adolfo Anta Martinez, Diego Cifelli
AIT Austrian Institute of Technology GmbH, Germany

The massive deployment of inverter-based generation poses several challenges to system operators but also offers new opportunities. In the context of grid recovery, inverter-based generation is expected to take over new responsibilities, as conventional generation that are blackstart capable are being decommissioned. Grid-forming converters, being very flexible and controllable, have the ability to contribute during grid restoration, although it is still unclear how to deal with the limited ratings of batteries, PV, etc. and how to address nonlinear effects such as inrush currents or harmonics. In this direction, the requirements of grid-forming inverters to comply with black start capabilities are still to be defined. During the first steps of a grid restoration process the dynamics of the grid largely vary from the grid behaviour under normal operation. In particular, the grid is nearly unloaded and therefore poorly damped. Indeed, overvoltages and resonances are a common concern during the energization of long transmission lines. In this work we analyse the spectral properties of unloaded transmission lines, and describe the impact of voltage controllers on the damping of the system. As a byproduct, this analysis can be leveraged to propose high level requirements for grid-forming devices, in order to provide adequate damping during the early stages of a grid restoration process.

Applying Dynamic Mode Decomposition for Real-Time Modal Identification of Converter-Driven Oscillation

HOCK LIM CHENG[1], Janne Seppänen[2], Matti Lehtonen[2]
[1]Fingrid Oyj, Finland; [2]Aalto University

The integration of inverter-based resources (IBRs) into power systems is a critical step towards a sustainable energy future. However, this integration introduces new challenges for grid stability, particularly through converter-driven oscillations that can threaten the integrity of power systems. The complexity of converter dynamics and non-availability of accurate mathematical model poses significant challenge for power system engineers and researchers to analyze them. Dynamic Mode Decomposition (DMD) emerges as a valuable tool for power system engineers to overcome the challenge of dynamic modelling complexity of these large-scale power systems. DMD is now gaining traction in power system analysis for its ability to identify complex system behaviors without relying on detailed equations. This technique is particularly adept at identifying modal characteristics of converter-driven oscillations, which is crucial for the development of strategies to mitigate their impact. As DMD is still in the early stages of application in power systems, its full potential is yet to be realized. Nevertheless, its promise lies in its capacity to enhance grid security and resiliency by providing a deeper understanding of the spatial-temporal dynamics introduced by large-scale sparse renewable integration. This study explores the application of DMD in modal identification of converter-driven oscillation, highlighting its relevance and adaptability in addressing the challenge of converter-driven oscillation in IBR dominated grid.

An Improved Dual Grid-Forming MMC with Port-Hamiltonian Structure

Arkaitz Rabanal[1], Salvatore D'Arco[2], Elisabetta Tedeschi[1,3]
[1]NTNU, Norway; [2]SINTEF Energy Research; [3]University of Trento

The operation of ac and dc grids interconnecting converters in future inertia-free and weak networks poses significant challenges. Modular multilevel converters applying dual grid-forming techniques are able to effectively synchronize to weak grids and control the dc voltage levels simultaneously. This paper proposes an enhanced dual grid-forming strategy based on an equivalent voltage representing the converter's internal energy. The converter's control variables have been redesigned in order to improve system stability margins, which, at the same time, preserve the macroscopic port-Hamiltonian structure of the converter. The correct operation of the converter at different grid inertia constants has been proved through small-signal and time-domain simulations, including inertia-free system. Moreover, the system is stable at both very weak and strong grid conditions, with short circuit ratios from 1 to 30.

Coordinative Operation for Grid-interactive Efficient Buildings Considering Thermal Dynamic

Ruizhang Yang, Minxin Zhang, Yunhe Hou
The University of Hong Kong, Hong Kong S.A.R. (China)

Rapid urbanization has led to a surge in urban building loads, while the penetration of large amounts of renewable energy has increased the demand for grid operational flexibility. As an important part of the building load, Heating, Ventilation and Air Conditioning (HVAC) systems have unique heat storage capabilities, thus providing a new approach to improving the flexibility of the utility grid. To this end, considering the effect of solar thermal radiation and the thermal effect of human flow, this paper proposes an HVAC thermal-electrical dynamic model to quantify the heat energy storage capacity and cooling effect of the HVAC system. By integrating the model into the grid-interactive efficient building, a coordinative operation strategy considering thermal dynamic effects is proposed, and the impact of prediction deviation is further reduced through model predictive control. Based on the data from the urban rail transit station, the accuracy of the proposed model is verified. The flexibility and the cost-efficiency of the proposed operating strategy are analyzed in different solar radiation conditions and building materials. The result verifies that the method significantly improves the economic benefits of GEB while improving the temperature comfort of the building environment.

Impact of Grid-Connected Inverters on Medium-Voltage Grid Currents During Phase-to-phase Faults

Lainser SKLAB[1], Bertrand RAISON[1], Manuel BILLAUD[2], Benjamin SCHULER[2]

[1]University of Grenoble Alpes, Grenoble INP, CNRS, G2ELab, Enedis; [2]Enedis

The growing incorporation of renewable energies (RE) into France's Enedis medium-voltage grid via static converters necessitates a thorough assessment of their impact, both under typical operating conditions and in the event of faults. Understanding this issue is vital for ensuring the effective operation of protection relays at the substation level, distinct from those at the electrical energy producers sites due to variations in behavior and contribution arising from different control mechanisms compared to synchronous machines. This project has two primary objectives. Firstly, it aims to ensure that the grid-connected inverter (GCI) we intend to deploy adheres strictly to the medium-voltage grid codes, including Low Voltage Ride Through (LVRT) and potential dynamic voltage support during grid faults. This is imperative as these requirements may not be part of Enedis technical specifications, and compliance may vary among electrical energy producers. Thus, it is pertinent to investigate this scenario. Secondly, we seek to analyze the behavior of the GCI and its influence on the measured current at the source substation during phase-to-phase faults on the medium voltage network. This is significant as the settings of the overcurrent protection on the Enedis side rely on phase-to-phase fault currents. By gaining insights into the GCI's operation and its effects on the overcurrent relay (OC) of the electrical network during faults, we aim to enhance the resilience and efficiency of electrical systems. Preliminary findings indicate that the GCI can impact the source substation's contribution to faults by reducing current injection. This phenomenon may lead to relay blinding and malfunction if the influence of GCI is not appropriately considered.

Experience of Dynamic Performance Assessment of Hybrid Inverter Based Resources in India

Himanshi Sagar, Anil Kumar Meena, V Thiagrajan, Ashok Pal, P C Garg

Central Transmission Utility of India Ltd, India

Hybrid renewable projects which include a mix of wind, solar and/or energy storage are being developed in order to provide procuring utilities with higher load factors and also some measure of dispatchability. Resource developers in India submit grid interconnection requests to Central Transmission Utility which assesses the compliance of the new resource to the prescribed standards through various simulation studies. The paper analyses the dynamic performance of one such hybrid renewable power plant and compares it with the performance of a standalone wind plant, based on the simulation studies carried out on the models submitted by plant developers at pre-connection stage. The key points of difference in terms of the dynamic performance of the plants observed from the simulations have been discussed. It is observed that the hybrid plant provides better dynamic performance as well as better controllability than the standalone wind plant owing to installation of higher inverter capacity.

Surrogate Models for Investigating Dynamic Security Regions of Renewables-Dominated Grids

Junyi Lu[1], Jonathan Fallman[1], Blair Brown[1], Bruce Stephen[1], Panagiotis Papadopoulos[2], Stephen McArthur[1]

[1]University of Strathclyde, United Kingdom; [2]University of Manchester, United Kingdom

Conventional grid operational planning usually entails dynamic security assessment performed by running time-domain simulations. This requires detailed modelling and is computationally burdensome. An alternative is to use a machine learning approach as a lightweight surrogate to evaluate stability for a set of operational inputs. Any supervised learning approach used will only be as good as the exemplar data it has been trained on. In this paper we propose the use of synthetic resampling to deal with lack of operational edge case examples and super resolution to improve coverage without additional samples. The contribution demonstrates improved accuracy in security assessment for an illustrative transmission network test case over a number of scenarios.

Enhancing Photovoltaic Module Fault Detection and Diagnosis Skills through Experiential Learning

Carlos Meza[1], Brian Azzopardi[2], Bernhard Kubicek[3], Ana Gracia Amillo[4], Melodie de l'Epine[5], Aritz Legarrea[4], Steve Zerafa[6], Carmel Azzopardi[2], Brian Bartolo[2]

[1]Anhalt University of Applied Sciences, Germany; [2]The Foundation for Innovation and Research, Malta; [3]Austrian Institute of Technology, Austria; [4]Fundación CENER, Spain; [5]Becquerel Consulting, Belgium; [6]PIXAM Ltd, Malta

Fault detection and diagnosis (FDD) techniques play an essential role in optimising the performance and reliability of photovoltaic (PV) modules, given that they allow the understanding of the degradation process in PV module technology. Conducting outdoor inspections of PV modules is the preferred method for fault identification due to its practicality and efficiency. This paper presents an experiential learning activity for university students to introduce them to photovoltaic module fault detection and diagnosis techniques. The experiential learning activity, conducted as part of the PROMISE project's Advanced School, focuses on three fault identification techniques—thermography, electroluminescence, and UV fluorescence. Through hands-on activities, students are exposed to these techniques, enhancing their skills in detecting and diagnosing faults in PV modules. The paper concludes by highlighting the pedagogical benefits of experiential learning in PV reliability, contributing valuable insights into fault detection principles and enhancing critical thinking skills among students.

Paper Session 20: Computational methods

Time: Wednesday, 16/Oct/2024: 9:30am - 11:00am **Location:** Koločep 5

Presentations:

Harmonic Anomalies Due to Geomagnetically Induced Currents as a Potential Cause of Protection Mal-Trips at the South Atlantic Anomaly Area

Roger Alves de Oliveira[1], **Rafael Salles**[1], **Sarah Rönnberg**[1], **Roberto Leborgne**[2], **Miguel Carli**[3]

[1]Luleå University of Technology; [2]Universidade Federal do Rio Grande do Sul; [3]Eletrobras

Geomagnetically induced currents (GIC) cause the half-cycle saturation of transformers that inject high harmonic distortion into the grid. Most of the studies cover the analysis of GIC for extreme latitude locations. However, GIC might also impact power grids at mid and low latitudes. Solar energetic particles at the South Atlantic Anomaly (SAA), which covers latitudes between 15° and 45° South, can penetrate deeply into Earth's atmosphere and even reach surface level. Therefore, GIC signatures might be found in harmonic measurements in power grids at SAA. Moreover, the high harmonic distortion can even lead to the mal-trip of protection relays at SAA. This work extracts anomalies in long-term harmonics measurements in a transmission grid (525 kV) in the South of Brazil (latitude 33° South) to evaluate the possible impact of GIC inside SAA. The anomalies are extracted by a deep learning method in combination with expert rules. The harmonic anomalies are validated by cross-checking with Space Weather data and the simultaneity with anomalies in Sweden (latitude 63° North). The main contributions of this work are: (a) validating that the signatures of harmonics due to GIC at SAA are similar to the ones extracted in high latitude; (b) demonstrating that anomalies in harmonics due to GIC are a potential cause of protection mal-trips at SAA.

Event-informed Identification and Allocation of Distribution Network Planning Candidates with Influence Scores and Binary Linear Programming

Juan J. Cuenca[1,2], **Marta Vanin**[3], **Md. Umar Hashmi**[3], **Arpan Koirala**[4], **Hakan Ergun**[3], **Barry Hayes**[5]

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This article presents a novel numerical approach aimed at finding a distribution network expansion plan that prevents future congestion and voltage issues. Forecasted duration and intensity of thermal and voltage violation events are used to determine a pool of potential candidates for infrastructure (i.e., line/cable) upgrade, voltage regulator, and energy storage system installations. This is complemented with an algorithm to obtain the minimum-cost list of these candidates that solves all constraint violation events using binary linear programming. This approach is validated using the modified IEEE 33-bus network and a real 1171-bus feeder in the West of Ireland through numerous high-resolution quasi-static time series simulations. Three pools of candidates and three cost projections were considered to explore the method's sensitivity to different scenarios. Results show that the proposed methodology is a versatile tool for designers, planners and policymakers. The methodology can ensure that the investment plan solves all forecasted violation events. Nevertheless, we show that accepting a marginal degree of violations may be admissible and would significantly reduce investment costs.

Sensitivity Region-Based Optimization for Maximizing Renewable Generation Hosting Capacity of an Islanded Microgrid

Daichen Liu[2], **Cuo Zhang**[1], **Yan Xu**[3], **Zhaoyang Dong**[3], **Yuan Chi**[4]

[1]The University of Sydney, Australia; [2]The University of New South Wales, Australia; [3]Nanyang Technological University, Singapore; [4]Chongqing University, China

Renewable energy based distributed generators are key components in islanded microgrids. However, their power intermittency and uncertainty may impair power quality and cause system operating constraint violations. It is imperative to evaluate and maximize the hosting capacity of an islanded microgrid for renewable generation. Besides, conventional optimization methods focus on improving the solution

robustness on constraints under uncertainties but ignoring that on the optimization objective. To address these unsolved issues, a sensitivity region (SR) based optimization method for maximizing renewable generation hosting capacity of an islanded microgrid is proposed. This paper firstly proposes an optimization model considering microgrid frequency variation and microturbine droop control functionality. Secondly, SR and feasibility-SR are adopted to quantify solution robustness against

uncertainties of renewable generation and load. It is expected to enlarge these two regions to cover all the possible uncertainty realizations, thus providing robust solutions. Last, this paper develops an SR based optimization method with a new solution algorithm. Through comprehensive numerical simulations, the proposed SR based hosting capacity maximization method is verified with high solution robustness on both objective and operating constraints.

Efficient State of Health Estimation of Lithium-ion Batteries Using Differential Thermal Voltammetry Analysis

Elaheh Sadat Ahmadi Mousavi[1], **Farzaneh Adbollahi**[2], **Farshad Barazandeh**[3], **Hortensia Amaris**[4]

[1]Amirkabir University of Technology, Iran; [2]Amirkabir University of Technology, Iran; [3]Amirkabir University of Technology, Iran; [4]University Carlos III of Madrid, Spain

An innovative approach for evaluating the state of health (SOH) of lithium-ion batteries (LIBs) is presented by integrating linear regression, density-based spatial clustering of applications with noise (DBSCAN), and differential thermal voltage (DTV) analysis. DTV analysis provides extensive insights. into the thermal and electrochemical behavior of LIBs during charge and discharge cycles, facilitating the monitoring of degradation processes while DBSCAN effectively finds high density regions in DTV data, revealing significant electrochemical changes within the battery. The proposed approach is emphasized for its efficiency and simplicity, making it

suitable for applications in Battery Management Systems (BMS) with restricted hardware. Significant benefits are offered by this method compared to machine learning techniques such as Long Short-Term Memory (LSTM) and Gaussian Process Regression (GPR), including reduced computational and memory requirements, which are critical for real-time applications in constrained environments. Employing the experimental data, Mean Squared Error (MSE) consistently below 0.065% was achieved. The results demonstrate how well this novel approach maps a state of health (SOH) to a health index (HI), with low computational overhead and promising accuracy.

Crossover-BPSO Driven Multi-Agent Technology for Managing Local Energy Systems

Hafiz Majid Hussain[1], Ashfaq Ahmad[2], Pedro H. J. Nardelli[3]
[1]Lappeenrannan–Lahden teknillinen yliopisto LUT, Finland; [2]Air University, Pakistan; [3]Lappeenrannan–Lahden teknillinen yliopisto LUT, Finland

This article presents a new hybrid algorithm, crossover binary particle swarm optimization (crBPSO), for allocating resources in local energy systems via multi-agent (MA) technology. Initially, a hierarchical MA architecture in a grid-connected local energy setup is presented. In this architecture, task specific agents operate in a master-slave manner. Where, the master runs a well-formulated optimization routine aiming at minimizing the total cost of the system considering costs of energy procurement, battery degradation, and load scheduling delay. The slaves function hierarchical manner unless specified otherwise. Simulation results demonstrate that the proposed algorithm outperforms selected existing ones by 21\% in terms average energy system costs while satisfying customers' energy demand and maintaining the required quality of service.

Paper Session 21: Distribution systems

Time: Wednesday, 16/Oct/2024: 9:30am - 11:00am

Location: Orlando 1A

Presentations:

Dispatch of High-Performance Compressed Air Energy Storage in Distribution Networks

Xuecen Zhang, Sunku Prasad Jenne, Jihong Wang
University of Warwick, United Kingdom

The compressed air energy storage (CAES) system is considered as one of the major solutions to address challenges associated with integrating non-dispatchable wind power into the power system. To effectively tackle the limitations of conventional CAES systems, such as low energy conversion efficiency and high carbon emissions, we propose an innovative High-performance Compressed Air Energy Storage (Hi-CAES) technology that hybridises the CAES system with a high-temperature thermal energy storage (HTES) unit. In this study, we develop a linearized Hi-CAES model for the optimal operation of distribution networks with wind power penetration. The dispatch of Hi-CAES in the distribution network is formulated as a bi-objective optimisation model, with the aim of minimising network loss and wind curtailment. The ε-constraint method is utilised to search for Pareto solution sets. A case study on a modified radial IEEE 33-bus system is carried out to assess the performance of the proposed Hi-CAES system. The results demonstrate that Hi-CAES can significantly reduce the worst wind curtailment and network loss by 39% and 76% during the bi-objective optimisation process. Furthermore, the HTES unit enhances the charging power capacity of the Hi-CAES system and extends the discharging duration. The developed Hi-CAES model can be readily used in a wide range of power system operation scenarios.

Maximizing Hosting Capacity of Single-Phase Rooftop PVs in Unbalanced Distribution Systems

Hossam H. H. Mousa[1,2], Karar Mahmoud[3], Matti Lehtonen[1,4]
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Increased installation of single-phase rooftop photovoltaic (PV) systems (SPPVs) and unbalanced loads in low-voltage distribution networks (LVDNs) may cause deterioration in the overall network performance. Major impacts includes voltage unbalance, power losses, thermal overloading of lines, and other power quality issues. Therefore, it is crucial for robust integration coordination of SPPVs with proper sizing and placement to sustain the acceptable limits of power quality indices especially in unbalanced three-phase systems. In this paper, an optimal capacity allocation of SPPVs method is proposed which not only aids in minimizing the voltage unbalance, power losses, and lines' overloads but also increases the hosting capacity (HC) of LVDNs. Such HC boosting enables to accommodate an excessive capacity of SPPVs besides reducing the exchanged power through the utility grid. This work is demonstrated using IEEE 123-bus unbalanced distribution system and simulated using daily and stochastic curves of PV generations and load demands by co-simulation between MATLAB and OpenDSS platforms. Initially, the LVDN is divided into five operational zones, each zone has aggregated bulk generation of SPPVs switched only on single-phase. Then, the multi-objective grey wolf optimization (MOGWO) algorithm is operated to select the appropriate capacity, connected phase, and location of SPPVs at each operational zone. As a result, the voltage unbalance, power losses, and imported grid power, are declined by 10%, 32% (31 kW at 100% overloading), and 26%, respectively. Further, the HC of LVDNs is increased by 185%, which highlights that the integration of SPPVs can improve power quality using accurate capacity allocation for bulk generation.

Increasing the Fairness of Photovoltaic Curtailments for Voltage Management in Distribution Grids

Andreas Kotsonias, Lenos Hadjidemetriou, Markos Asprou, Christos Panayiotou
University of Cyprus, Cyprus

The increasing penetration of photovoltaic systems (PV) in distribution grids can create significant over-voltage conditions due to intense reverse power flow. In addition to reactive power control, PV curtailments are often employed for voltage regulation to ensure compliance with the regulatory limits. However, reducing the output power of a PV system results to a revenue drop for the owners, raising concerns about fairness. Relevant works often address this issue through penalty terms in the objective function, but most works neglect the trade-off between fairness and total curtailments, i.e., increasing fairness leads to an increase of total curtailments. This paper proposes a

novel methodology to enhance the fairness of PV curtailments for voltage regulation while ensuring that the increase in total curtailments is within a specified acceptable limit. In this direction, the Jain's fairness index is used to quantitatively measure fairness, which is incorporated in the optimization process as a second order cone program constraint. An iterative algorithm based on the bisection method is then developed to increase fairness until the allowable total curtailments are reached. Simulation results demonstrate the capability of the proposed method to improve the fairness of PV curtailments, considering different levels of allowable total curtailments.

Topology and Parameter Identification in Electrical Distribution Systems using Spatial Priors

Steven de Jongh[1], **Felicitas Mueller**[1], **Claudio A. Cañizares**[2], **Thomas Leibfried**[1], **Kankar Bhattacharya**[2]
[1]Karlsruhe Institute of Technology (KIT), Germany; [2]University of Waterloo, Canada

This manuscript presents novel methods that allow the consideration of spatial priors derived from Geographic Information Systems (GIS) for System Identification (SI), i.e., Topology Identification (TI) and Parameter Identification (PI), in electrical distribution systems. The proposed methods are designed to allow flexibility in the assumed measurement devices and the integration of micro-Phasor Measurement Units (μPMU) and Non-Phasor Measurement Units (NPMU), based on power flow approximations and GIS data associated with the location of measurement devices to deduct topological priors and cable and line parameter ranges based on spatial relationships between measurements. Based on a Mixed-Integer Quadratic Programming (MIQP) optimization problem, the proposed SI approach can handle measurement errors and noise. The presented method is demonstrated on a benchmark 17-node Low Voltage (LV) grid for three different scenarios, analyzing errors with respect to topology and parameters, as well as the computational effort. It is shown that by using spatial priors, the proposed SI method performs better than existing techniques.

Angular Reference Models for Optimization-based Unbalanced Distribution System State Estimation

Mohamed Numair[1,2], **Marta Vanin**[1,2], **Dirk Van Hertem**[1,2]
[1]Research Group ELECTA, Department of Electrical Engineering, KU Leuven, 3001 Heverlee, Belgium; [2]EnergyVille, Thor Park 8310, 3600 Genk, Belgium

The importance of state estimation has surged for distribution networks, given their increased digitalization and measurement availability. However, distribution system state estimation (DSSE) implementations still encounter several practical challenges. One of them is defining unbalance at the reference bus. Existing three-phase DSSE methods usually assume reference buses with equally spaced voltage phase angles. This assumption does not hold in general in low voltage (LV) distribution networks, due to their imbalance. Although recent publications proposed alternatives to the balanced reference bus assumption, several aspects of such alternatives have not been explored. This paper benchmarks DSSE using the balanced angle approach and two recently proposed alternatives. Our DSSE implementation leverages optimization concepts that are not featured in conventional DSSE. These allow to model unbalanced reference angles, while overcoming the numerical challenges that were reported in prior literature. Accuracy trade-offs with the different reference angle models are demonstrated on a realistic LV feeder across various scenarios.

Phase imbalance impact on operating envelope for low-voltage distribution grid

Lionel Delchambre[1,2], **Patrick Hendrick**[1], **Pierre Henneaux**[1], **Hamada Almasalma**[2]
[1]ULB, Belgium; [2]VITO, Belgium

Distribution System Operators must ensure safe operation of the Low Voltage distribution grid in the face of upcoming challenges posed by new assets (e.g. photovoltaic panels, electric vehicles) and new activities (e.g. energy sharing, frequency reserves). This task is further complicated by the fact that end-users may be unevenly connected to the phases without Distribution System Operators being aware of it. This can lead to unexpected voltage or current congestions. This paper presents an innovative method, a relaxed unbalanced three-phase optimal power flow, to compute the maximum day-ahead flexibility per end-user that can be unlocked while ensuring safe use of the low voltage grid, i.e. the operating envelope. Additionally, the paper shows results that controlling reactive power on the LV network could not increase flexibility potential and counteract imbalances caused by unevenly distributed phase connections.

Paper Session 22: Grid operation

Time: Wednesday, 16/Oct/2024: 9:30am - 11:00am

Location: Orlando 1B

Presentations:

A fuzzy logic approach for economic energy-efficient heat pump operation in thermal building control

Jovana Kovačević, Anne-Christin Süß, Hüseyin K. Çakmak, Veit Hagenmeyer
Karlsruhe Institute of Technology, Germany

Advanced thermal control has great potential to decrease energy consumption in buildings. Thereby, encountering the balance between thermal comfort, and electricity load reduction is a challenge. For this, advanced control systems need to be developed that can respond to external signals such as electricity prices and are robust to different types of buildings to be widely utilized. In this paper, we propose and investigate two fuzzy control systems, an economic-energy-efficient controller and a comfort controller. The comfort controller focuses on thermal comfort, whereas the economic-energy-efficient controller is attentive to electricity prices and the energy efficiency of the heat pump. For the simulation, we use a reduced-order building model identified by measurements of a real-world building. Furthermore, we compare the proposed controllers with a hysteresis controller as a lower benchmark control strategy. Simulation results reveal that an economic-energy-efficient controller can reduce electricity consumption by 14.92 % and costs by 18.41 % when compared to a benchmark controller and with mean thermal discomfort of 0.216 °C over an evaluation period of two months. The comfort controller has slightly smaller costs and electricity consumption than the hysteresis one, but less zone temperature fluctuations, enhancing the quality of controlled zone temperature and occupants' comfort.

Microgrid Connector Controller Prototype

Hanwen Gu[1], Behnam Tamimi[2], Claudio Canizares[2]
[1]Xi'an Jiaotong University, China, People's Republic of; [2]University of Waterloo, Canada

The integration of Microgrids (MGs) into Active Distribution Networks (ADNs) to enhance grid resiliency requires a flexible, economical, and reliable MG-ADN interface. In this context, the Microgrid Connector Controller (MGCC) discussed in this paper has been demonstrated through simulations to offer a more cost-effective alternative than a Back-to-Back (B2B) interface while delivering similar performance. Therefore, the design and testing of an experimental MGCC prototype is presented here, proposing a three-stage start-up strategy to eliminate the need for an external dc source initially proposed for charging the controller's DC Link capacitor, making the MGCC more practical and cost-effective. Based on the MGCC power flow characteristics, a charging resistor is required to provide a current path during the start-up process and divide the converter input voltage to match the low ratings of the MGCC components. The presented results from testing the MGCC prototype under several relevant conditions demonstrate the technical and practical feasibility of the MGCC topology and controls, as well as the effectiveness of the proposed start-up strategy.

A Computational Platform to Assess the Integration of Renewable Distributed Generation in Chile

Ignacio Pérez, Bernardo Severino, Luis Gutierrez-Lagos, Daniel Olivares
Universidad Adolfo Ibañez, Chile

Chile enjoys one of the largest solar irradiance levels globally. Although large-scale photovoltaic (PV) plants have flourished, the integration of medium-scale PV plants in medium-voltage (MV) distribution networks, only account for a quarter of Chile's installed PV capacity. One of the main barriers for its deployment is the sluggish connection assessment process. To breach the gap, this paper presents a computational platform, VisionDERRED, that leverages the capabilities of open-source software Julia and OpenDSS, for the connection assessment of distributed generation (DG) projects to MV networks, following specific regulations from Chile. This contributes not only to automating the connection assessment process, but also by enabling finding the theoretical maximum admissible DG size per MV node. This allows building a nodal hosting capacity map, useful for project developers and policy makers. The capabilities of the platform are demonstrated in a real MV feeder case study in Osorno, Chile.

Predictions and Decision Making for Resilient Intelligent Sustainable Energy Systems

Martin Braun[1,2], Christian Gruhl[1], Christian A. Hans[1], Philipp Härtel[1,2], Christoph Scholz[1,2], Bernhard Sick[1], Malte Siefert[1,2], Florian Steinke[3], Olaf Stursberg[1], Sebastian Wende-von Berg[1,2]
[1]University of Kassel, Germany; [2]Fraunhofer IEE, Kassel, Germany; [3]Technical University of Darmstadt, Germany

Future energy systems are subject to various uncertain influences. As resilient systems they should maintain a constantly high operational performance whatever happens. We explore different levels and time scales of decision making in energy systems, highlighting different uncertainty sources that are relevant in different domains. We discuss how the uncertainties can be represented and how one can react to them. The article closes by summarizing, which uncertainties are already well examined and which ones still need further scientific inquiry to obtain resilient energy systems.

Power Management in Smart Parking Systems: Addressing Battery Degradation

Jordan P. Sausen[1], Carlos H. Barriquello[1], Alzenira R. Abaide[1], Bruno K. Hammerschmitt[1], Joelson L. Paixão[1], Paulo S. Sausen[2]
[1]UFSM, Brazil; [2]UNIJUI, Brazil

This research addresses the growing importance of rechargeable battery technology in urban mobility solutions amid concerns over environmental impact. Electric Vehicles (EVs) emerged as a disruptive distributed energy resource, with the potential to revolutionize the electricity sector's dynamics. While private chargers remain popular, the availability of infrastructure for opportunity charging during business hours is crucial for promoting electric mobility, especially in emerging markets like Brazil. This study focuses on optimizing charging processes in smart parking facilities to meet recharging needs, reduce costs, and preserve battery life on bidirectional applications. Challenges related to uncoordinated EV charging and battery degradation are discussed, with a proposed comprehensive optimization model aiming to address these concerns while minimizing operational costs. The research highlights the importance of considering battery compensation to users in optimizing EV charging strategies.

AI-Based Assessment of Power System Resilience under Climate Change-Induced Extreme Weather Events

Luca Pizzimbone
Tractebel Engineering GmbH, Germany

Power system resilience analysis methods aim to assess the ability of a power system to withstand and recover from high-impact, low-probability events, such as natural disasters. These methods often entail performing AC Optimal Power Flows (OPF) using nonlinear optimization algorithms for numerous sequential Monte Carlo (MC) iterations, which require high computational resources. This may restrict the number of feasible simulations, with the risk of reducing the reliability on the analysis outcomes and limiting the scope of the resilience assessment. This paper introduces the use of Artificial Intelligence (AI) to enhance the computational performance of power system resilience analysis. The paper proposes to use artificial neural networks (ANN) as a surrogate model to approximate the OPF solution for different scenarios and contingencies. The case study demonstrates that ANN provide an interesting solution, reducing the computational burden to a fraction of a classical OPF approaches, while keeping remarkable accuracy in the estimation of resiliency KPIs, such as energy not served (ENS) and survivability. A case study of resiliency analysis with ANN application is presented. The analysis is conducted with reXplan, a novel tool for climate power system resilience analysis, and an ANN built on Pytorch framework. SimBench, an open dataset for network analysis, provides the grid data, generation, and demand profiles. A comparison of the KPIs calculated with ANN and simulated results with OPF is provided, showing the effectiveness and efficiency of the proposed approach.

Synthetic Scenario Generation for Microgrid Design: A Methodological Approach Using TimeGAN

Haje Ebnou[1,2], Anne Blavette[3], Florian Dupriez-Robin[2], Anthony Roy[1], Salvy Bourguet[1]
[1]Nantes University, IREENA; [2]France Energies Marines; [3]CNRS, SATIE/IETR, ENS Rennes, Univ. Rennes

Generating synthetic scenarios for time-series data is crucial for various applications, including predictive modeling, data augmentation, and scenario analysis. In this study, we focus on creating scenarios for the optimal sizing of renewable energy systems within microgrids by testing two methods: directly generating photovoltaic production data and generating meteorological data scenarios followed by calculating the production. Our goal is to evaluate how well the TimeGAN artificial intelligence tool performs in generating realistic synthetic scenarios for both approaches. TimeGAN, a type of Generative Adversarial Network (GAN), is known for its ability to capture temporal patterns and maintain data distribution. We use TimeGAN to generate synthetic scenarios for renewable energy production and compare the feasibility and quality of the scenarios produced by each method. Our comparative analysis highlights the benefits and limitations of both approaches, offering valuable insights into scenario generation in energy systems, especially within microgrids

Paper Session 23: Transmission systems

Time: Wednesday, 16/Oct/2024: 9:30am - 11:00am

Location: Orlando 1C

Presentations:

5-phases solution and series compensation: a cost-effective strategy for OHLs power transfer capacity increase under stability margin

Michela Migliori, Enrico Maria Carlini, Maria Rosaria Guarniere, Corrado Gadaleta, Roberto Spezie, Francesco Palone, Luca Buono, Gianfranco Luongo, Davide Monno
Terna S.p.A., Italy

In the light of the decarbonization process, modern power systems pose multiple challenges to transmission network planners. In the Italian context, increasing network congestions are expected in the medium/long-term horizon across long corridors from South, where connection applications for new renewable power plants are concentrated, to North, where main load consumptions are located: in these scenarios, the angle stability constraint become an additional subject to be addressed in the EHV transmission system planning. For this purpose, the reduction of equivalent reactance of strategic transmission paths enables operational limits extension and becomes a crucial topic in planning framework. In this paper, the innovative "5-phases" solution, developed by Terna (the Italian TSO), is combined with the capacitive series compensation in a wider pilot network affected by stressful power transfer conditions. The main benefits in terms of transfer capacity increase between relevant market section and voltage phase shifts reduction are assessed in different cases study both in normal conditions and during critical contingencies.

Approach to Assessment and Analysis of Distribution-Transmission Network Interactions at Grid Supply Point

Saad A. Alyoubi, Jovica V. Milanovic
The University of Manchester, United Kingdom

A probabilistic method has been proposed to study the interaction between the active distribution network and the transmission network at the grid supply point. The Monte Carlo method has been adopted to account for uncertainty arising from renewable energy generation. Subsequently, the probabilistic load flow has been run to identify all operating points in terms of active and reactive power. Following this, the operating envelope at the point of interaction (grid supply Point) is plotted in the P-Q plane using the convex hull method. Four types of load models (static, dynamic, and composite) have been considered to observe the importance of choosing a realistic load model and its influence on the operation envelope. The results show that the proposed method is highly efficient for creating the parameter space to assist with studying distribution-transmission network interactions at the interface point.

Impact Of Climate Changes On Overhead Transmission Lines

Goran Levačić, Igor Lukačević, Krešimir Mesić, Mate Lasić, Petar Končar, Igor Ivanković
Croatian Transmission System Operator Plc.

The consequences of climate change are felt everywhere, especially in power systems and overhead lines as one of its most exposed elements. It is expected that impact of climate changes will be even more expressed in the coming decades, with an increasing possibility of occurrence of extreme conditions in the form of storms, winds, snow, ice, high temperatures, fires, etc. Therefore, it is essential to ensure the safe and stable operation of power networks. In this paper, an experience with two strong storms which appeared within only two days in July, 2023 affecting larger part of Croatian transmission network is presented, in order to discuss whether it is necessary to change valid requirements at design phase of new overhead lines. Also, it shows a huge significance of neighbouring transmission system collaboration, especially in terms of modular emergency restoration tower exchange in cases of unpredictable weather phenomena.

Quantum-Compatible Unit Commitment Modeling through Logarithmic Discretization

Tyler Christeson[1], Amin Khodaei[1], Rozhin Eskandarpour[2]
[1]University of Denver, United States of America; [2]Resilient Entanglement, United States of America

The unit commitment (UC) problem is essential to operating the power system in an efficient and reliable manner. However, modern power systems are growing increasingly complex with the growing penetration of distributed energy resources, making classical approaches to the UC problem computationally inefficient. Quantum computing approaches have been investigated for the UC problem due to the potential to outperform classical solutions. In many quantum models, including quadratic unconstrained binary optimization, or QUBO, the problem must be reformulated by discretizing continuous variables into "bins" or "segments" to ensure compatibility with the quantum processing unit (QPU). This would increase the number of variables due to discretization and lead to sub-optimal solutions.

In this paper, we propose a new reformulation strategy for converting optimization problems into QPU-compatible binary quadratic models while creating significantly fewer binary variables, resulting in faster computation, increased efficiency, and further scalability. The performance of this approach is examined in terms of computation time and solution optimality to demonstrate its advantages and to illustrate the potential capability to solve the UC problem more efficiently than classical solutions.

A New Notion of Reserve for Power Systems With High Penetration of Storage and Flexible Demand

Georgios Tsaousoglou
TECHNICAL UNIVERSITY OF DENMARK, Denmark

Modern power systems face important demand uncertainties due to increasing penetration of behind-the-meter renewable generation. System operators need to account for such uncertainties when solving the unit commitment and economic dispatch problem. The research literature has proposed advanced methods for decision making under uncertainty but, in practice, actual system operators put more trust in the tried-and-true approach of dealing with future uncertainty by committing reserves. In this paper, the unit commitment and economic dispatch problem is formulated for a system with high penetration of storage and the inadequacy of methods based on the traditional notion of reserves is exposed. Namely, in contrast to a generator, a storage unit can provide reserve capacity in a number of timeslots but it cannot provide an analogous reserve activation in all of those timeslots due to the battery's energy being depleted. After discussing two plausible but inadequate approaches, a new, generalized notion of reserves is proposed, which addresses these issues while not abandoning the practical, reserve-based approach for the operator's problem, thus making the best of both worlds. The proposed scheme enables storage units to provide reserves, without putting the system at risk of energy scarcity, which is shown to result in substantial cost savings.

A Practical Approach for Circle Power Flow Detection Using the Floyd-Warshall Algorithm

Teng Jiang[1], Matthias Kahl[1], Olaf Brenneisen[1], Jonas Lotze[1], Hui Cai[2], Dirk Westermann[2]
[1]TransnetBW GmbH, Germany; [2]Ilmenau University of Technology

Due to the uneven geographical distribution of renewable energy sources (RES), the fluctuating generation from RES needs to be transported to demand centers, often covering substantial distances and potentially causing congestion on transmission lines. The deployment of Flexible AC Transmission Systems (FACTS) provides transmission system operators with the ability to influence power flows. However, the unfavorable control of voltage angle and magnitude may create conditions conducive to circular power flows, placing unnecessary strain on the transmission system. This research contributes by presenting a practical approach to detect circle power flows using the Floyd-Warshall algorithm from graph theory. It introduces essential terminology, discusses the method's adaptation in network planning tools, and validates its effectiveness through simulations on the IEEE 39 system.

Paper Session 24: Hydrogen storage 2

Time: Wednesday, 16/Oct/2024: 9:30am - 11:00am

Location: Lokrum 4

Presentations:

Effects of Temperature Variation on the Capacity of Gas Networks to Receive Injections of Green Hydrogen

João Fontoura, Filipe Soares, Zenaida Mourão
INESC TEC, Portugal

The literature on the isothermal model gas flow is extensive, but the effect of temperature variation on the hydraulic characteristics has been rarely addressed. Additionally, the impact of hydrogen blending on the thermal condition of NG pipelines is also an emergent topic that requires new approaches to the gas flow problem formulation and resolution. In this paper, a model for the gas flow problem was developed to optimise the operation of natural gas distribution networks with hydrogen injection while maintaining pressure, gas flows, and gas quality indexes within admissible limits. The goal is to maximise the injection of hydrogen and investigate the influences of thermal variations in the gas blending. Also, this model enables the calculation of the maximum permitted volume of hydrogen in the network, quantifying the total savings in natural gas usage and carbon dioxide emissions in different temperature conditions.

Cost-Effective Green Hydrogen Production: A Simulation Study on Energy Mix Optimization

Giuseppe Graber[1], Vito Calderaro[1], Vincnzo Galdi[1], Lucio Ippolito[1], Fabrizio De Caro[1], Alfredo Vaccaro[2]
[1]University of Salerno, Italy; [2]University of Sannio, Italy

The European regulatory framework establishes that the production of green hydrogen (H2) must be supported either from the electricity grid through a power purchase agreement (PPA), or from intermittent renewable energy sources (IRES) plants owned by the hydrogen producer. In this paper, a mixed-integer linear programming (MILP) problem, assuming as objective function the overall cost minimization of the allowed energy mix for green hydrogen production, has been formulated. Through simulation results on different scenarios considering hydrogen production targets, IRES production, and cost for PPAs, we estimated the cost for green H2, and it is compared with that of grey H2, i.e. generated from natural gas, or methane.

Optimal planning of a green hydrogen fueling station

António Coelho[1], Filipe Soares[1], José Iria[2]
[1]INESC TEC, Portugal; [2]Australian National University, Australia

As the global community transitions towards decarbonization and sustainable energy, green hydrogen is emerging as a key clean energy carrier. This paper addresses the role of hydrogen in transportation, emphasizing the European Union's additionality principle for renewable energy sources in green hydrogen production. It introduces a model for optimally designing hydrogen fueling stations, considering electrolyzers, hydrogen storage, fuel cells, PV systems, and batteries. This model also considers the participation in electricity (energy and secondary reserve), hydrogen, and oxygen markets, and it is evaluated under different additionality policy scenarios. Results indicate that stricter additionality policies reduce the internal rate of return. However, participation in secondary reserve markets significantly boosts operational revenues and compensates for higher investment costs.

Wind Farm Capacity Assessment for Hydrogen Production: A Case Study in Finland

Amin Salehi, Mahdi Pourakbari-Kasmaei
Aalto University, Finland

Renewable energy-based generations are steadily playing a pivotal role in the global energy supply, and power-to-gas (P2G) technologies are recognized as a viable option for storing the excess power generated by renewable energy sources. In this context, hydrogen is one of the several potential alternative fuels produced by P2G equipment, and its favorable environmental effects make it a suitable option. Motivated by the aforementioned facts, this paper assesses wind farm capacity in Finland as a key driver for hydrogen production. To this end, an interconnected power and hydrogen network considering various scenarios in 2030 and 2040 is designed and implemented in SAInt. Subsequently, factors such as electrolyzer efficiency and geographical data are incorporated into the model to shed light on the critical role of wind farm infrastructure in facilitating Finland's transition, considering hydrogen as an extension of energy systems. Detailed simulations and assessments indicate a significant need in developing wind farm infrastructures in Finland. As a result of this development, Finland will be positioned as a major player in the emerging hydrogen market across Europe. Moreover, it can be traced that improving electrolyzer efficiency would be an imperative action for manufacturers, given that this enhancement could significantly reduce the investment costs associated with wind turbines' installation.

Probabilistic analysis of integrated electricity and gas network with Power-to-Hydrogen

Dimitrios Lagos, Athanasios-Rafail Lagos, Aris Dimeas, Nikos Hatziargyriou
School of Electrical and Computer Engineering National Technical University of Athens, Greece

The decarbonization process of traditionally high emitting sectors imposes drastic practices as the hydrogen injection in the gas network infrastructures. However, uncertainties in renewable generation, electricity and gas demand can have a negative impact in the operation of both networks and in the quality of the delivered gas. This work performs a probabilistic analysis of an Integrated Electricity and Gas System (IEGS), where surplus electricity from renewable units is used to produce hydrogen in a Power-to-Hydrogen (PtH) unit and directly inject it to the gas network. The correlations among the random variables are considered and the analysis is carried out via Monte Carlo simulations. The outcomes include the distributions of power-to-hydrogen's and networks' operational variables and the composition of the produced blend. The suggested modelling and methodology can be adopted by network operators for designing and assessing the viability of such integrated systems.

Comparative analysis of centralized and decentralized offshore electrolysis in the North Sea

Laurens Frowijn[1], Riccardo Travaglini[2], Kenneth Bruninx[1], Zofia Lukszo[1]
[1]Technical University Delft; [2]Università degli Studi di Firenze

his study estimates the levelized cost of hydrogen (LCOH) of three hydrogen production configurations: onshore centralized electrolysis, offshore centralized electrolysis, and off- shore decentralized electrolysis. Using a broad range of projected parameters for key components and cost assumptions for key components for 2030, we find LCOH values for onshore electrolysis from 1.9 to 10.1 €/kg, offshore centralized electrolysis from 1.7 to 10.8 €/kg, and offshore decentralized electrolysis 1.5 to 10.4 €/kg. This wide range reflects the current uncertainty on the evolution of the cost of key components. Decentralized offshore electrolysis may be more cost-effective compared to centralized electrolysis due to higher efficiency assumptions, hence, reduced conversion losses (≈1% of the LCOH), minimized material requirements in wind turbines (≈1%), minimized infrastructure (≈6-19%), combined development processes (≈1-3%), and decentralized brine disposal (≈0.2-0.6%). Offshore decentralized electrolysis may present promising opportunities for large-scale hydrogen production from offshore wind, but the expected LCOH today is uncertain. Research and experimentation are required to assess whether the cost reductions and efficiency gains above can be realized.

Decentralised Secure Modelling of Electrolyzers with Federated and Transfer Learning

Syrine Ben Aziza, Athanasios Trantas
TNO

The rapid evolution of electrolyzer technologies demands efficient and secure methods for exchanging sensitive information among distributed stakeholders. In this paper, we propose a novel solution for secure exchange of information between electrolyzer Operators while preserving data privacy. Our approach leverages Federated and Transfer Learning tech- niques, incorporating local predictive models and a central global model as a two-tier learning system. By training local models on individual electrolyzer system, we enable the central global model to aggregate the learned features without directly accessing the sensitive data. This approach not only alleviates issues gen- erated by anti-competitiveness regulations, as many businesses don't want to share data, but also enables efficient information exchange among electrolyzer operators in a distributed context. We demonstrate the effectiveness of our proposed methodology through comprehensive experiments, showcasing its potential to model and optimize electrolyzer performance without compro- mising data confidentiality. Our solution has broad implications for the development and deployment of electrolyzer systems, pro- viding a secure and efficient means for stakeholders to collaborate and advance sustainable hydrogen production technologies.

Paper Session 25: Energy storage systems 2

Time: Wednesday, 16/Oct/2024: 11:30am - 1:00pm

Location: Orlando 1A

Presentations:

Experimental Investigation of Inverter-Battery System Efficiency for Energy Scheduling

Lysandros Tziovani, Lenos Hadjidemetriou, Stelios Timotheou
KIOS Research and Innovation Center of Excellence, University of Cyprus, Cyprus

Battery energy storage systems (BESSs) are widely used in energy management applications to maximize arbitrage profits. The consideration of the power losses from both battery and inverter components in optimization schemes is vital to ensure the economic BESSs scheduling. Towards this direction, this work develops two optimization models that consider the combined inverter-battery efficiency. The first model represents the non-linear efficiency curve of the inverter using a piece-wise linear approximation, resulting in mixed-integer linear programming formulations. The second model approximates the nonlinear efficiency curve using a constant term, resulting in linear programming formulations which can be fast and reliably solved. Moreover, an experimental investigation is performed to derive the efficiency curve of a real inverter-battery system, where the parameters of the two models are identified. Simulation results highlight the necessity to consider the efficiencies from both battery and inverter components to reduce modelling inaccuracies and hence to maximize profits. The results also show the capability of the linear programming model to yield high-quality solutions with an approximation error of less than 1%.

Scalable Charging Optimization of Battery Energy Storage Systems with Deep Reinforcement Learning

Amir Hossein Heydarian-Ardakani[1], Kianoush Aqabakee[2], Farzaneh Abdollahi[2], Elham Shirazi[1]
[1]University of Twente, Enschede, The Netherlands; [2]Amirkabir University of Technology, Tehran, Iran

This paper presents a scalable data-driven methodology that leverages deep reinforcement learning (DRL) to optimize the charging of battery units within smart energy storage systems (ESS). Battery charging is formulated as an optimization problem for individual battery units. A novel DRL-based architecture based on local data is proposed to derive the optimal policy for each battery unit while ensuring scalability across the entire storage system. This architecture features a shared buffer to aggregate experiences from all agents, enabling the synthesis of centralized training with decentralized execution. The efficacy and scalability of this approach are substantiated through a comprehensive evaluation, demonstrating enhanced performance across various configurations of battery units. The inherent scalability of this methodology facilitates its integration into modular and reconfigurable storage systems, proving the potential for widespread practical applications.

Economics and Optimization Analysis of On-grid Hybrid Energy Systems with Controlled Battery Storage towards Net-zero Households - A Case of Different Solar Radiation Profile Zones.

Samuel Cudjoe[1,2], Marten Van Der Laan[1,2]
[1]Hanze University of Applied Sciences; [2]Center of Expertise Energy

The global clean energy transition goals require commitment from every country. Different locations however present different technical and economic viability for increasing the penetration of variable renewable energy (VRE) resources to meet national targets. This work presents a comparative economic and system sizing analysis of PV/wind/battery hybrid energy systems in two different residential locations and climate zones (Ansen, Netherlands (NL)) and Mpoase, Ghana (GH)) to measure and compare the fraction of self-consumption. The system aimed to achieve net-zero energy transfer using a battery with self-consumption (SC) control. The System Analysis Model (SAM) integrated with a multi-parametric economic model was used for system simulations and sizing. The study found that for the same optimum hybrid system size in two different locations, higher SC and cheaper system costs were achieved when the consumption and generation profiles of the VRE were more closely matched in time. Increasing the battery size increases SC and the system cost non-linearly. However, increasing the PV capacity resulted in a non-linear decrease in the SC, the unit installed cost, and the LCOE. For the same PV size of 5 kW, GH and NL had the highest SC of 0.71 and 0.64 respectively. However, with this fraction, the LCOE of NL exceeded its reference LCOE by 100% as the battery size and the installed cost were 2.5 and 1.5 times more than that of GH respectively. In GH, the highest achievable fraction of SC for return on investment was 0.59 and consisted of a 5 kW PV and 10 kWh battery capacity. This gave a simple payback of 18.6 years at an LCOE of 0.18 €/kWh. NL required an additional 1 kW wind turbine to meet the demand and to make the system financially viable at an LCOE of 0.17 €/kWh and an installed cost of 6.6 €/W.

Modeling of Multi-Use Operation of BESS with EA, SCO and FCR Applications

Steffen Kortmann[1,2], Johannes Jeup[1], Florian Schmidtke[1,2], Andreas Ulbig[1,2]
[1]RWTH Aachen University, Germany; [2]Fraunhofer FIT, Germany

Nowadays, battery energy storage systems (BESS) are on track to become a central pillar of the energy transition, as they are a cornerstone in balancing the energy paradigm of matching imbalances between load and volatile generation by renewable energy resources. Yet, the economic feasibility remains unstable due to falling but still high initial investment costs without sustainable business models. However, BESS offer operational behavior for stacking applications that can be deployed on the same system. Therefore, decisions on the applications are to be made on operational dispatching. As such, optimization yields an opportunity to address potential challenges from the operational conditions while maximizing revenue potential. This work analyzed the modeling of BESS for the selected applications of energy arbitrage (EA), self-consumption optimization (SCO) and frequency containment reserve (FCR). Apart from the operational constraints, the economic value will be determined and compared for different market conditions.

Second Life EV Battery Repurposing for Stationary Energy Storage

Tommaso Reschiglian, Kristian Sevdari, Mattia Marinelli
Denmark Technical University, Denmark

As the global adoption of electric vehicles (EVs) increases, the need for sustainable solutions to manage end-of- life EV batteries becomes more pressing. This paper presents a Battery Energy Storage System (BESS) that represents a novel approach to sustainable energy storage through repurposing end- of-life Tesla battery modules for stationary applications. The modules have been assembled and controlled in a robust and scalable design that offers versatile deployment options and economic benefits. Various use cases for these types of applications are described, such as Energy Management, Backup Power Supply, Demand Response, Grid Support, and Price Arbitrage. Emphasis is placed on the grid services and benefits for end users. The system architecture is discussed in detail with focus on the main components as the BMS, the battery modules and the inverter, and preliminary test protocols are outlined, including charge-discharge cycles and performance under different load conditions. These tests aim to evaluate the system's reliability, efficiency, and energy storage capabilities, providing insights into its feasibility for real-world applications. The paper discusses potential challenges and opportunities as- sociated with second-life batteries, such as battery degradation and safety considerations.

Linear Reinforcement Learning for Energy Storage Systems Optimal Dispatch

Shuyi Gao[1], Shengren Hou[1], Edgar Mauricio Salazar Duque[2], Peter Palensky[1], Pedro P. Vergara[1]
[1]Delft University of Technology, Delft, The Netherlands; [2]Eindhoven University of Technology, Eindhoven, The Netherlands

Reinforcement Learning (RL) has emerged as a promising solution for defining the optimal dispatch of Energy Storage Systems (ESS) in distributed energy systems. However, a notable gap exists in the literature: a lack of comprehensive and fair comparisons between different RL algorithms, particularly between linear and nonlinear approaches. This study critically evaluates the trade-offs between computational efficiency and operational accuracy among various Linear RL (LRL) strategies and compares them against the nonlinear Deep-Q-Network (DQN) algorithm. Through a comprehensive analysis, this study benchmarks the model-based Mixed-Integer Linear Programming (MILP) results to assess and compare these algorithms' convergence, training efficiency, and optimization accuracy. Results indicate that while LRL approaches the operational cost accuracy of DQN, it faces significant trade-offs in computational efficiency and struggles with generalization across larger and varied datasets. The results illuminate critical areas for further development in LRL methodologies, particularly in enhancing their adaptability and generalization capabilities.

Comparison of Field Test and Controller Hardware-in-the-Loop Simulation Results of Utility-Scale Battery Energy Storage System

Yasuaki Mitsugi, Takahiro Terazono, Hiroshi Hashiguchi
TMEIC Corporation, Japan

The Battery Energy Storage System (BESS) is expected to mitigate the power supply-demand imbalance induced by the fluctuation of power generation from the variable renewable energy resources and the reduced system inertia caused by decreased number of synchronous generators. Since the BESS can quickly adjust its power output according to the grid frequency fluctuations, it is regarded as one of the most important resource providing the fast frequency response (FFR) service, which requests the resource to adjust its active power output according to the grid frequency fluctuations. From a point of view of the utility-scale BESS project development, estimating the dynamic performance criteria of utility-scale BESSs, such as response speed and control accuracy, in advance of the field commissioning is important. However, it is challenging since their power rating is more than MW scale. Based on the above awareness, controller hardware-in-the-loop simulation (CHILs) is regarded as the method enabling the verification of the expected dynamic performance of the utility-scale BESS at the initial stage of the project development. This paper compares the control response time and control accuracy of the BESS in three test environments consisting of CHILs , reduced-scale facility, and the actual utility-scale BESS built in GB.

Paper Session 26: Smart meters

Time: Wednesday, 16/Oct/2024: 11:30am - 1:00pm **Location:** Koločep 5

Presentations:

Multi-dimensional flexibility potential quantification of household appliances from smart meter data

Emilio J. Palacios-Garcia[1], Geert Deconinck[3], Barry P. Hayes[2,1]
[1]MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland; [2]School of Engineering, University College Cork, Cork, Ireland; [3]KU Leuven, Dept. of Electrical Engineering, ESAT-ELECTA, Leuven, Belgium

Demand response programmes are essential for the stability of a power system with increasing penetration of renewable generation. However, before the necessary technologies are deployed, the flexibility potential that consumers can offer to the grid operator must be evaluated. Although smart meters can support this process, aggregated consumption profiles do not provide insights into the individual appliances. Non-intrusive load monitoring techniques are an alternative, but most recent works only focus on increasing the performance of primarily supervised learning algorithms, reducing the applicability of their results. This paper proposes an end-to-end methodology to quantify flexibility potential and emissions intensity of large household appliances. The process relies solely on local aggregated measurements and low-complexity unsupervised learning techniques to identify major power blocks. This information is combined with information on wholesale market prices and electricity production mix to derive three novel metrics, dubbed peak price, peak emissions, and critical peak score. The results show that relatively simple unsupervised techniques can help characterise major consumption blocks from aggregated consumption, providing the per appliance flexibility potential.

Demonstrating Electrical Model-Free Voltage Calculations with Real Smart Meter Data

Vincenzo Bassi[1,2], Luis F. Ochoa[1,2], Tansu Alpcan[1], Christopher Leckie[1], Michael Z. Liu[1,2], Orlando Pereira[1], Eshan Karunarathne[1]
[1]Faculty of Engineering and Information Technology, The University of Melbourne, Melbourne, Australia; [2]VoltMind, Melbourne, Australia

Voltage calculations are key for most distribution network analyses. However, the challenge in low voltage (LV) networks is that electrical models are not readily available and, therefore, accurate voltage calculations (via power flows) are not possible. Alternatively, regression methods can be used to capture the relationships among the historical smart meter data of customers (P, Q, V) and the corresponding LV network. This paper improves a previously proposed methodology to carry out electrical model-free voltage calculations based on Neural Networks (NNs) so it can be used with real smart meter data. The effectiveness of the improved methodology is demonstrated using data from 6 Australian LV networks. The results show that the improved methodology significantly reduces the computing time required to produce the NN, making it an accurate and extremely fast alternative for distribution companies to calculate voltages without electrical models.

Smart Meter Insights: Identifying and Projecting Electric Vehicle Loads in Reykjavik

Laurentiu Lucian Anton[1], Kári Hreinsson[2], Ragnar Kristjánsson[1]
[1]Reykjavik University; [2]Veitur ohf.

Time series data from 24,500 smart meters in the Greater Reykjavik Area (GRA) were analyzed to evaluate grid impacts in an Electric Vehicle (EV) integration scenario. Features from Type 2 chargers were identified and used to classify meters that likely serviced EVs. EV power consumption was integrated and annualized to compute EV equivalents behind each meter, estimated at 3 MWh/year for the average driver in Reykjavik. An algorithm was developed to create synthetic data with a target EV per capita ratio of 0.6, corresponding to a 100% EV loading scenario. The algorithm synthesized a dataset corresponding to 85% EV loading scenario before filling in data for all metered connections in the service area. Data was aggregated by secondary substations to identify transformer overloading under peak demand. This data-centered approach provided temporally- and geospatially- resolved insights and can be adopted by other utilities with unlabeled smart meter data to prepare for future transport electrification.

Feature-based identification of distributed energy resources in buildings from aggregated smart meter data

Ada Canaydin, Joris Depoortere, Hussain Kazmi
Department of Electrical Engineering, KU Leuven, Belgium

Distributed energy resources (DERs), including electric vehicles, heat pumps and rooftop solar photovolatic systems, are becoming increasingly common-place in Europe. On the one hand, these developments drastically alter the net load, making it imperative for distribution system operators to be cognizant of their proliferation. On the other, they can provide cost-effective energy flexibility to mitigate the worst side effects of distributed generation and demand electrification. However, most of these new installations are not recorded in a centralized database, making planning and operation tricky. The simultaneous proliferation of smart meters is also inadequate to track this in and of itself since there is little visibility on behind the meter loads. In this paper we utilize a detailed corpus of data from 1,300 residential buildings in Flanders, Belgium to create strategies which can automatically detect different DERs in these settings. Using two interpretable feature extraction methodologies (domain informed and domain agnostic), we show strong predictive performance (macro-F1 score exceeding 0.87) in accurately categorizing buildings based on the DERs present behind the meter, without having this information up front. Such a strategy can help distribution grid operators (DSOs) better identify the proliferation of DERs in their control region without the investment and privacy issues related to sub-metering.

Privacy-Preserving Load-Shaping Strategies for Smart Meters using Deep Reinforcement Learning

Ruichang Zhang[1], Kaiyue Wu[1], Youcheng Sun[1], Mustafa A. Mustafa[1,2]
[1]The University of Manchester, United Kingdom; [2]KU Leuven, Belgium

Smart meters are important for improving households' energy management and efficiency, but they raise significant privacy concerns by potentially revealing detailed user behaviors through energy consumption patterns. Recent work have proposed methods using physical energy resources to modify smart meter readings; however, they neglect the importance of keeping the energy storage device's electricity level consistent after the protection cycle. In this paper, we present PLS-DDPG, a novel proactive load-shaping strategy based on the deep deterministic policy gradient (DDPG) algorithm. The proposed method enhances privacy by creating artificial load patterns and masking original load signatures by incorporating a novel reward-shaping mechanism to incentivize privacy-centric behaviors. We also present a battery consistency mechanism to ensure efficient energy management. The proposed method is evaluated on a state-of-the-art adversary algorithm: TCN-based non-intrusive load monitoring (NILM). We trained two NILM algorithms for kettle and toaster usage disaggregation because these two appliances are commonly used and can reflect user life cycles. The performance of our proposed method is compared with other baseline algorithms. The evaluation results indicate that our proposed algorithm is on par with the previous DQN-based work in privacy protection, with both demonstrating top-tier performance among all baselines evaluated. However, PLS-DDPG retains 96.55\% of the electricity capacity compared to 67.24\% for the DQN-based work, highlighting its superior efficiency in managing energy resources while upholding privacy.

Model-Free Voltage Estimation of Low Voltage Electrical Power Distribution Systems using Smart Meter Data

Anthony O'Malley[1], Emilio J. Palacios-Garcia[2], Barry P. Hayes[1,2]
[1]School of Engineering, University College Cork, Cork, Ireland; [2]MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland

Increasing penetration of low carbon technologies in residential low voltage (LV) networks increases the need for modelling their state to preempt voltage issues. Due to the challenges in modelling vast numbers of feeders, LV network models are often simplified, incomplete, or even absent. The large-scale roll-out of smart meters (SMs), creates the opportunity for generating accurate LV network models at scale at low cost. In this paper, a methodology for voltage estimation in LV networks without an electrical model is proposed and tested across 127 real distribution feeders. The approach uses machine learning and historical active power and voltage data from SMs to predict voltage at a node of interest. This approach shows promising results, particularly in its capability to generalise to different loading scenarios and estimate voltage under higher electric vehicle and solar photovoltaic penetration levels.

Active and Reactive Power Sequences for Energy Disaggregation with Deep Learning Models

Jean-Luc Timmermans, **Pierre Henneaux**
Université Libre de Bruxelles, Belgium

Non-Intrusive Load Monitoring (NILM) aims to decompose the aggregated power signal of a household smart meter into the power consumption of individual appliances. This information about consumption can potentially lead to energy savings by changing consumer behavior or facilitating the development of flexibility at the residential level. Deep learning methods have been shown to be the most successful in solving this problem. Nevertheless, these methods focus, most of the time, only on the measurement of the active power neglecting other available information such as reactive power. This paper evaluates the impact of adding reactive power sequences in such methods. In particular, we evaluate the impact of reactive power sequences in two state-of-the-art methods: one updated sequence-to-point Convolutional Neural Network (CNN) that we designed and one Variational Autoencoder (VAE) from the literature. Our experiments show that the addition of reactive power improves the performance of both algorithms on the UK-DALE dataset.

Paper Session 27: Communications

Time: Wednesday, 16/Oct/2024: 11:30am - 1:00pm

Location: Lokrum 4

Presentations:

Implementing Secure Layer 2 Tunneling Protocols for IEC 61850-90-5 Based Routable and Non-Routable GOOSE and SV Message

Stephen Ugwuanyi[1], Kinan Ghanem[2], Ibrahim Abdulhadi[3]
[1]PNDC, United Kingdom; [2]PNDC, United Kingdom; [3]PNDC, United Kingdom

In this paper, the performance of layer 2 tunnelling for IEC 61850 inter-substation communication is presented for a teleprotection function use case. Generic object Oriented Substation Events (GOOSE) and Sampled Value (SV) packets routed over layer 2/3 VPN using Multiprotocol Label Switching (MPLS) network and the end-to-end timing and

latency of packets were evaluated. The performance and impact of using MACsec and IPsec security schemes are also presented. The paper also aims to show the minimal if not negligible, impact of end-to-end encryption of securing GOOSE and SV Messages over layer 2 VPN.

Modelling Latencies of Broadband Powerline Communication Networks for Smart Grids

Philipp Leonard Lutat, Jasmin Girbig, Sarra Bouchkati, Andreas Ulbig
RWTH Aachen University, Germany

The intense integration of Advanced Metering Infrastructure into distribution grids leads to an increasing demand for appropriate ICT networks. Broadband Powerline Communication is a technology that is well-suited for the task of last-mile connection for deep-indoor coverage. Research is focused on the technology's capabilities to fulfill increasing requirements and its future role in Smart Grid connectivity. An important Quality-of-Service parameter for network planning is the end-to-end latency. Although real-time meter reading and grid operations are crucial tasks in the near future, planning tools are not capable to take latencies into account yet. Our work introduces a software model for quasi-stationary latency calculation that enables planning tools to estimate the average link performance. To provide first insights into latency dependencies and bottlenecks in Powerline networks, we performed a case study including a sensitivity analysis towards the network properties.

Encryption-Aware Anomaly Detection in Power Grid Communication Networks

Ömer Sen[1], Mehdi Akbari Gurabi[2], Milan Deruelle[3], Andreas Ulbig[4], Stefan Decker[5]
[1]Fraunhofer FIT; [2]Fraunhofer FIT; [3]RWTH Aachen University; [4]IAEW at RWTH Aachen University; [5]Fraunhofer FIT

The evolution of the electrical power grid into a smart grid has integrated these critical systems into broader networks, increasing their vulnerability to sophisticated cyber threats. Holistic security measures that encompass preventive, detective, and reactive components are required, including traffic encryption and intrusion detection. However, traditional intrusion detection methods struggle with encrypted traffic. Our research addresses this issue by developing methods for anomaly detection within the low-level communication layers of encrypted power grid systems. Utilizing statistical and machine learning techniques, we aim to identify irregular patterns indicative of cyberattacks, focusing on real-time monitoring and evaluation of encrypted communications in power grids. Our results indicate that a harmonic security concept based on encrypted traffic and anomaly detection can be reliably achieved in smart grids, but further research is needed to improve detection quality.

Line protection systems with 5G communications

Santiago Sanchez-Acevedo[1], Tesfaye Amare Zehirun[1], Mohammad khalili Katoulaei[2], Hans Kristian Høidalen[2], Thomas Zinner[2]
[1]SINTEF Energi AS, Norway; [2]Norwegian University of Science and Technology, Norway

This paper analyses communications-assisted accelerated line protection scheme using 5G communication between two substations. The aim of using the 5G technology is to remove the wired communications typically required for accelerating line protection trips during fault conditions at the opposite end of the line. The study employs a hardware-in-the-loop setup, featuring hardware Intelligent Electronic Devices and an OPAL-RT real-time simulator to model virtual Merging Units of the substations. A realistic operational private 5G network is utilized as the communication infrastructure for the accelerated distance protection. Experimental results in a laboratory environment demonstrate the feasibility and effectiveness of implementing 5G technology for line protection.

Investigation of characteristics of cables in high frequency for power line communication using finite element Analysis

Amirali Mahjoob, Yuwan Liu, Sarra Bouchkati, Andreas Ulbig
IAEW at RWTH, Germany

The increasing use of PLC modems in smart grids highlights their vulnerability to signal attenuation influenced by cable shape and material properties. While cable design significantly impacts signal transmission, the complex relationships between cable characteristics and performance at varying frequencies are less understood. This study uses finite element analysis to address signal attenuation and transmission anomalies in low-voltage (LV) cables, especially under high-frequency conditions in smart grid communications. Using COMSOL Multiphysics, detailed simulations of electrical and magnetic properties for various LV cable designs aim to optimize cable characteristics, reduce attenuation, and enhance signal integrity. The research compares Coaxial and NAYY cables, offering recommendations to improve smart grid communications infrastructure.

IT/OT challenges and opportunities to improve cyber resiliency for utilities: a review paper

Mansi Negi, Mazaher Karimi
University of Vaasa, Finland

As utilities increasingly rely on interconnected digital systems, the integration of IT and OT has become crucial for ensuring cybersecurity. However, this integration presents significant challenges due to differing priorities, governance models, and the inherent complexities of disparate technologies. This paper evaluates the effectiveness of the report's proposed strategies, which are grounded in the National Institute of Standards and Technology (NIST) Cybersecurity Framework, to mitigate these challenges. The review identifies the report's comprehensive approach to presenting risks and recommendations, alignment with existing cybersecurity practices, and its practical implications for utility companies. By comparing the report's content with existing literature, this paper assesses its contributions to the field and suggests areas for further research, particularly the need for empirical validation of the recommended strategies. This study proposes solutions including the use of automated tools for continuous monitoring, blockchain for data integrity, and AI-driven supply chain risk management to address these vulnerabilities. Additionally, we explore the potential of machine learning for predictive analytics, quantum-resistant encryption, and advanced network segmentation to secure critical infrastructure. This research contributes to the academic discourse by providing a comprehensive framework that utilities can adopt to mitigate risks and leverage technological opportunities for improved security.

Paper Session 28: Electric vehicles 2

Time: Wednesday, 16/Oct/2024: 2:00pm - 4:00pm **Location:** Koločep 5

Presentations:

Towards Low-Carbon Power Grid: Integrating Electric Vehicles for Multi-Service Provisions

Chutian Su, Yi Wang, Goran Strbac
Imperial College London, United Kingdom

In recent years, the power system has witnessed an increased integration of electric vehicles (EVs) and renewable energy sources (RESs), which helps address the climate crisis and accelerate decarbonisation. However, the intermittent nature of RESs poses new stability and security challenges to the power system, such as voltage fluctuations and harmonics. To mitigate these challenges, vehicle-to-grid (V2G) has gradually become a key technology for demand-side management due to EVs' ability to provide ancillary services. As a result, assessing the potential impact of EV integration on multi-service provisions and its impact on carbon reduction and trading becomes crucial to the system operation and market trading. This paper addresses a multi-period carbon and electricity co-optimization problem to minimise electricity generation, carbon emission and battery degradation costs. A case study is conducted based on the IEEE 15-bus network to assess the impact of EVs on providing carbon-related service, voltage management and power balancing. The co-optimisation problem is solved through a centralised control strategy over 24 hours with data resolution set at 60 minutes.

Enhancing phase balance in electric vehicle clusters: a smart charging approach using phase mode switching

Xihai Cao, Jan Engelhardt, Charalampos Ziras, Mattia Marinelli
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European low voltage distribution systems are primarily three-phase four-wire networks, where the three phases have uneven load connections. With the rising number of electric vehicles (EVs) in the market, the charging behaviors of the single-phase EVs are inevitably leading to a more severe phase unbalance issue in the grid. To address such concerns, this paper proposes a smart charging control scheme that utilizes phase mode switching functions of electric vehicle supply equipment (EVSE). The connected three-phase EVs can be switched to single-phase charging mode by charging only at the first phase, hence alleviating the congestion on the other phases of the cluster. A case study using charging data from a real-world situation in a public working place in Athens is conducted, to demonstrate the functionality of the proposed phase mode switching method. The simulation outcomes reveal that the phase mode switching scenario reduces collective charging time by 8.4% and improves phase power unbalance by 31% on the average value compared to the benchmark scenario. The results indicate that the smart charging control manages to effectively mitigate the phase power unbalance issues among three phases and allows the cluster to charge with more flexibility.

Implementation of priority-based scheduling for electric vehicles through local distributed control

Kristoffer Laust Pedersen, Simone Striani, Jan Engelhardt, Mattia Marinelli
Technical University of Denmark, Denmark

Distributed load management systems can become a crucial enabler for the widespread adoption of electric vehicles (EVs). The present paper experimentally demonstrates a priority-based scheduling algorithm that enables all chargers of an EV parking lot to coordinate

their charging processes in a distributed manner. The distributed approach provides decreased control delays and a management complexity that does not scale up with the number of EVs. A system is developed in which each electric vehicle supply equipment (EVSE) makes local decisions individually, sharing only their priorities with the other EVSEs of the cluster. The approach controls the total cluster consumption to a connection capacity while prioritizing the charging of EVs with the highest urgency. The scheduling algorithm is implemented in a real-life charging cluster, and its working principle is demonstrated through field tests. The system successfully shows the scheduling of two EVs to charge on a shared connection of 9 kW. The common capacity of the cluster showed a utilization ratio of 0.86 without critically overloading the grid connection.

Electric Vehicle Batteries and Storage: A Literature Review of Current and Future Solutions

João Ferreira[1], António Jorge Gouveia[1,4], Cristiano Pendão[1,2], Arsénio Reis[1,3], Tiago Pinto[1,3], João Barroso[1,3]
[1]Universidade de Trás-os-Montes e Alto Douro, Portugal; [2]ALGORITMI; [3]INESC-TEC; [4]C-MADE/UTAD

With the progressive increase in electric vehicles and the carbon neutrality goals set for 2050, it is important to commit to optimizing batteries and their lifespan. Studies have been conducted to improve and understand storage systems and to determine the best ones to use in specific situations. Combining battery lifespan, the number of charging cycles, specific energy, and power can sometimes be challenging for the optimal functioning of an electric vehicle. This article aims to facilitate the understanding of how batteries truly influence the choice of an electric vehicle, and how some of them have more capacity than is commonly known.Additionally, advancements in battery technology, such as fast-charging capabilities, are being explored to address these challenges and enhance overall performance. Moreover, this paper highlights the importance of sustainable battery production, which are crucial for minimizing the environmental impact of increased electric vehicle adoption. By understanding these aspects, consumers and manufacturers can make more informed decisions that support both technological progress and environmental sustainability.

Potentials, Challenges and Incentives for Vehicle-to-Home in Shared Neighborhoods: a Multidisciplinary Analysis

Andre Leippi[1,2], Melina Zernickel[3], Michael D. Murphy[2]
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This paper examines the potential, challenges, and incentives of implementing vehicle-to-home (V2H) in a shared residential neighborhood. A multidisciplinary approach is employed, comprising an analysis of user acceptance of V2H by using data of a survey and a data-based potential analysis of a V2H use case of energy arbitrage in a residential neighborhood. The simulation-based analysis enabled the investigation of charging requirements, load flows, and energy transactions as part of an investment decision in a bidirectional smart grid. The paper analyzed energy arbitrage, where electric vehicles (EV) could be charged at a low cost in the workplace and the stored energy could be discharged in the residential area. The results show there is a generally positive attitude towards vehicle-to-everything (V2X) technologies. However, concerns exist in relation to uncertain battery state-of-charge and degradation. Additionally, equitable financial compensation remains a significant challenge for participation in V2X applications. The study found that a price difference of 5 - 10 ¢/kWh between home and workplace charging prices would make it economically feasible to invest in V2H bidirectional charging infrastructure in a residential area. Furthermore, the research revealed that EVs with larger batteries are more cost-effective and suitable for V2H applications than smaller EVs.

Vehicle-to-grid dynamic modeling in a neighborhood of Utrecht municipality

Renos Rotas, Petros Iliadis, Nikos Nikolopoulos, Paschalis A. Gkaidatzis, Konstantinos Grigoropoulos, Dimosthenis Ioannidis, Dimitrios Tzovaras, Athanasios Tamvakos, Mary Panou
Centre for Research and Technology Hellas, Greece

Vehicle-to-grid (V2G) technology is a promising addition to power systems, and its widespread adoption could enhance the provision of advantageous services. The accurate representation of the dynamic operation of such systems aids in addressing technical challenges and, thus, accelerates their implementation. This work focuses on the development of a dynamic model for V2G power transactions, including all of the key interacting components, i.e. the EV battery, the power converter, and the bidirectional charger control unit. Modelica language is utilized. The integration of the developed models into a broader system has been tested through simulations of an area of a Utrecht distribution grid. The results indicate that the examined V2G system could ensure a reliable and stable operation by supplying the requested power. The maximum deviation between requested and supplied power equals 0.23 kW for active and 0.18 kVAr for reactive power, respectively.

Reinforcement Learning for Optimized EV Charging Through Power Setpoint Tracking

Yunus Emre Yılmaz, Stavros Orfanoudakis, Pedro Vergara
Intelligent Electrical Power Grids, Delft University of Technology, Delft, The Netherlands

Decarbonizing the transportation sector involves adopting electric vehicles (EVs); a shift that introduces significant challenges in energy distribution management and raises concerns about grid stability. Charge Point Operators (CPOs) are important in this transition as they control the EV charging process by balancing the needs of EV users and the grid. This study presents a smart-charging model from the perspective of CPOs for handling EVs located in a commercial parking lot to minimize the Power Setpoint Tracking (PST) error. To solve this sequential decision-making problem, a Markov Decision Process (MDP) model is designed and solved using Deep Deterministic Policy Gradient (DDPG), a Deep Reinforcement Learning (DRL) algorithm. The proposed model can effectively manage the uncertainties associated with EV arrivals and fluctuating charging demands by structuring the action and state space to incorporate power constraints. The experimental evaluation using realistic EV behavior data shows that the proposed approach significantly outperforms uncontrolled charging, reducing PST error while effectively managing multiple EV chargers and EVs with varying battery capacities and power limitations.

V2G Contribution to Reducing Renewable Energy Curtailment and to Improving Duck Curve

Shigeru Tamura, Taiyo Inoue
Meiji University, Japan

Massively introduced renewable energy to achieve carbon neutrality by 2050 causes many problems in the power systems. Among the problems, surplus generation in the daytime by photovoltaic generation and steep ramps in the evening in the duck curve are tackled in this paper. As electric vehicle is becoming popular all over the world, vehicle-to-grid is utilized with the real car owners' profiles to reduce the renewable energy curtailment and to improve the duck curve in this paper. Two approaches are proposed and simulated. One is maximizing the daily net load factor with constraints of photovoltaic curtailment and the other formulates weighted two objective functions composed with maximizing the daily net load factor and minimizing the renewable energy curtailment. The simulation results show that the latter approach is more effective in reducing the renewable energy curtailment than the former one.

Analysis of EVCS Switching Attack Impact on Power Grid Operation

Michael Bonadonna, Jianhua Zhang, Tuyen Vu
Clarkson University, United States of America

As the Electric Vehicle (EV) and Electric Vehicle Charging Station (EVCS) footprint continues to grow, the electrical grid faces a new wave of security threats. Existing attack strategies such as switching attacks, benefit from a new class of vectors. Preliminary investigations of the impact of EVCS-based switching attacks exist and detection methodologies have been conducted but make assumptions about the availability and composition of load. This paper 1) analyzes EVCS-based switching attacks to identify the impact on the power grid caused by different load characteristics and 2) investigate the impact of real-world constraints on attack feasibility and strategy. Combining the two demonstrates the true challenges not only faced by attackers, but with defending the new cyber-physical grid, as threat actors endlessly work to develop or alter strategies to bypass detection and protection mechanisms.

Paper Session 29: EV charging stations

Time: Wednesday, 16/Oct/2024: 2:00pm - 4:00pm **Location:** Orlando 1A

Presentations:

Receding horizon optimization for distributed control of electric vehicle charging stations

Anna Malkova[1], Jan Martin Zepter[1], Mattia Marinelli[1], Herbert Amezquita[2], Hugo Morais[2]
[1]Technical University of Denmark, Denmark; [2]Instituto Superior Técnico, Universidade de Lisboa, Portugal

With the continuous increase of electric vehicle (EV) adoption, deploying smart charging techniques offer a practical solution to mitigate the impact of grid overloading caused by simultaneous EV charging. At the same time, smart charging can help to stabilize the fluctuations in the production from local renewable energy sources (RES). This article introduces a receding horizon optimization model for the distributed control of EV charging stations, focusing on maximizing the profit of the charging station, while enhancing the utilization of local PV generation. The proposed model operates in 5-minute intervals, determining the power reference for the EV cluster at the charging station. Results demonstrate that the proposed model effectively lowers electricity cost for charging stations, while ensuring more than 90% energy delivery for charging EVs. Future research will be focused on integrating wind energy and refining the model in controlled lab tests for practical implementation and validation.

A Bilevel Programming Approach to Model the Charge Curve for EV Charging Scheduling at Capacity-Constrained Fast Charging Stations

Can Berk Saner, Jaydeep Saha, Dipti Srinivasan
Department of Electrical and Computer Engineering, National University of Singapore, Singapore

DC fast charging is a key enabler for removing barriers to the widespread adoption of electric vehicles (EVs), offering rapid recharging solutions that alleviate range anxiety. However, at capacity-constrained fast charging stations (FCSs) with multiple ports, where the aggregate power is limited by technical or economic factors, it may not be possible to simultaneously charge all EVs at maximum power. This necessitates the implementation of EV charging scheduling schemes to distribute the available power capacity among connected EVs while ensuring high quality-of-service and fairness. Moreover, efficiently and accurately integrating the non-linear charge curve of EVs, which defines the maximum charging power as a function of state-of-charge, into an EV charging scheduling optimization problem remains a formidable challenge. In this work, we propose a modeling approach for EV charge curves using multi-segment piecewise linear (PWL) regression. We adopt a bilevel programming scheme to identify optimal breakpoints, slopes, and intercepts of the segments in the PWL model by minimizing the sum of absolute residuals error. The resulting PWL model is then efficiently integrated into a mixed-integer linear program to solve the charging scheduling problem. Case studies confirm the superiority of the framework, achieving up to 11.72% improvement over the best performing of three benchmark methods. Additionally, the solution time remains below 2.5 seconds for up to 200 simultaneously connected EVs, demonstrating its computational efficiency and scalability.

Optimal Microgrid Scheduling with Synthetic Inertia Provision from Electric Vehicle Charging Stations

Yixun Wen[1], Zhongda Chu[2], Fei Teng[2], Boli Chen[1]
[1]University College London; [2]Imperial College London

This paper presents a microgrid (MG) scheduling problem involving frequency dynamic constraints with the provision of Synthetic Inertia (SI) via electric vehicles (EVs). The model of EV charging stations involving EVs' arriving/departure and charging/discharging dynamics is implemented. SI provision from EVs is incorporated into the frequency constraints, and the value of SI provided is constrained by the number of EVs in charge, the EVs' arrival state of charge, and the charging/discharging range of the chargers. To tackle the forecast errors from EVs, distributionally robust chance constraints are implemented. The Bonferroni approximation method is then utilized to separate the joint constraints into individual ones, which can be reformulated into convex forms. The MG scheduling problem can be formulated as an MILP problem. The effectiveness of the method is validated based on a modified IEEE 14-bus system.

Charging Stations vs. Battery Swapping Stations Considering Battery-to-Grid Injections

Hilmi Cihan Güldorum[1,2], **Pablo Diaz-Cachinero**[3], **Gregorio Muñoz-Delgado**[1], **Javier Contreras**[1]
[1]Universidad de Castilla-La Mancha, Ciudad Real, Spain; [2]Yildiz Technical University, Istanbul, Turkiye; [3]University Carlos III de Madrid, Leganés, Spain

Battery swapping stations (BSSs) have been increasingly attracting the attention of researchers. The advantages of BSS over conventional charging stations (CS) have not been sufficiently investigated. In this work, an optimization model for the BSS operation that aims to maximize its revenue is proposed. Charging and discharging management is allowed by considering time-varying electricity tariffs and by taking part in ancillary services to the grid via battery-to-grid. In addition, photovoltaic (PV) power generation is considered in the proposed approach. The social effects of the proposed optimization model are investigated by examining the comfort effect for each EV owner. Additionally, the proposed model for the operation of a BSS is compared to a conventional CS model, in which the swapping feature is disregarded. The proposed model is developed in the form of mixed-integer linear programming (MILP) and solved using the CPLEX solver in the General Algebraic Modeling System (GAMS) environment. The findings revealed that BSS outperformed CS in terms of profits.

Optimizing Electric Vehicle Charging Through a Real-Time Control Mechanism

Jacco Reuling, **Bart Nijenhuis**, **Gerwin Hoogsteen**, **Johann L. Hurink**
University of Twente, Netherlands, The

This paper explores an integrated approach combining real-time and predictive control mechanisms to manage electric vehicle charging in alignment with solar energy availability. By utilizing predictive control and a Real-Time Control Mechanism (RCM), the challenges posed by the variability of solar power and the increasing demand for EV charging are addressed. Through simulations and field tests, the proposed strategy demonstrates its ability to reduce peak grid loads, enhance self-sufficiency, and improve self-consumption, while maintaining user satisfaction. The findings indicate that integrating real-time adjustments with predictive EV charging scheduling can significantly contribute to a more stable and efficient grid.

Top-Down Approach for Modeling of Aggregated Electric Vehicle Charging Load based on Real Data

Nelly-Lee Fischer[1], **Johannes Beck**[1], **Svenja Bayer**[1], **Krzysztof Rudion**[1], **Nikita Maksymchuk**[2], **Rainer Enzenhöfer**[3]
[1]University of Stuttgart, Germany; [2]smartlab Innovationsgesellschaft mbH, Germany; [3]TransnetBW GmbH, Germany

To investigate the effects of the future integration of electric passenger cars on the power grid, methods are needed to adequately consider this additional load in the simulation. Mainly agent-based approaches based on historic mobility data of conventional passenger cars are used in the literature to calculate a charging profile specifically for each car. Thus, the total load profile of a larger grid area has to be estimated in a bottom-up process considering a high number of individual charging profiles, which can be complex and time consuming. In contrast, this paper presents a new top-down approach, in which the total energy demand expected from the electric passenger cars is first determined based on their assumed mileage, their temperature dependent consumption as well the charging efficiency. This resulting total energy demand is then split up into different charging location types. The proposed method includes charging at home, in public and at the workplace. Furthermore, standard load profiles for each charging location type are derived based on real usage data. These can then be scaled based on energy demand, which may be dependent on the degree of electrification and other factors. The presented approach is characterized by a high computing efficiency, since there is no need for the generation of a high amount of individual charging profiles. This is shown in an exemplary case study that examines the impact of electric passenger cars within the state of Baden-Wuerttemberg, Germany.

A Comparative Analysis of Early Departure Buttons in Coordinated Control of EV Charging

Baver Ozceylan, **Gerwin Hoogsteen**, **Johann L. Hurink**
dept. of Electrical Engineering, Mathematics and Computer Science, University of Twente, Enschede, the Netherlands

The increasing adoption of electric vehicles (EVs) necessitates the efficient management of large EV parking facilities to prevent them from exceeding grid capacity and to improve the overall user experience. This paper introduces a data-driven approach for coordinated control of EV charging in an office parking facility, integrating Early Departure Buttons (EDB) into the system. These buttons provide a binary option for users to indicate an earlier departure than a predefined time. We employ the EDB data to improve departure time estimations and to address issues where EVs receive no or only very low energy. We utilize three datasets originating from different geographical locations. One dataset displays a user pattern where users leave shortly after completing their charging, unlike the other datasets which follow typical working hours. Our simulations show that the unique user pattern significantly increases fairness among users, and integrating EDBs improves fairness for the other datasets to levels similar to those of quick station turnover.

Use of probabilistic distribution functions for EV fast-charging infrastructure planning for highways

Verónica Anadón Martínez, **Andreas Sumper**
Department d'Enginyeria Elèctrica, CITCEA-UPC, Spain

The widespread adoption of electric vehicles (EVs) has brought about a change in transportation, requiring advanced planning and infrastructure development to meet the growing demand. This research presents an innovative approach to model EV charging demand on highways, which is critical for strategically deploying fast-charging infrastructure to support the increasing adoption of EVs. The aim is to develop the charging infrastructure in accordance with the variable demand for EV charging, thus reducing grid congestion and improving the quality of service for EV users. Through the use of probabilistic distribution functions (PDFs) based on traffic flow and EV characteristics, the study offers a dynamic and data-driven framework for accurate predictions of EV charging demand. This methodology provides accurate, stochastic predictions of EV charging demand by integrating real-time data on vehicle flows and directions on different highway segments. The approach aims to align infrastructure planning with mobility trends, enhancing the reliability and accessibility of charging stations, reducing congestion, and promoting the widespread use of EVs. As a result, our contribution to estimating and forecasting EV charging profiles to improve highway EV infrastructure planning provides a solid foundation for deploying fast-charging stations.

Optimal EV charger placement considering technical uncertainties

Paschalis A. Gkaidatzis, Konstantinos Grigoropoulos, Renos Rotas, Petros Iliadis, Athanasios Tamvakos, Josep Maria Salanova Grau, Angelina D. Bintoudi, Ioannis Moschos, Dimosthenis Ioannidis, Nikos Nikolopoulos, Mary Panou, Dimitrios Tzovaras
Centre for Research and Technology - Hellas, Greece

In this paper, the integration of Electric Vehicle (EV) chargers problem is contemplated, regarding their optimal placement in a distribution network. Loss minimization is considered as the objective, while networks technical features as the constraints. Renewable Energy Sources (RES) and traffic and mobility patterns are also considered in terms of uncertainty. The proposed approach is tested upon CIGRE Low and Medium Voltage testing networks. v0g, v1g and v2g scenarios are considered. A significant improvement can be observed in terms of loss minimization, voltage profile improvement and network congestion, especially when applying the v2g scenario.

Paper Session 30: Neural networks in power systems

Time: Wednesday, 16/Oct/2024: 2:00pm - 4:00pm **Location:** Orlando 1B

Presentations:

Neural Network-Driven State Estimator for European-Type Unbalanced LV Grids

Yamen Alsyoufi, Jose Manuel Cano Rodriguez, Gonzalo Alonso Orcajo
University of Oviedo, Spain

The imperative to swiftly estimate the state of unbalanced low voltage distribution grids is paramount for effective flexibility management, where machine learning presents an efficient possibility suitable for real-time applications. This research focuses on the design and evaluation of a neural network-based state estimator tailored for unbalanced LV distribution grids. In addition, an approach to generate training datasets utilizing real-world grid profiles is proposed. The estimator's performance undergoes thorough evaluation across various simulated scenarios conducted on a real grid located in northern Spain. These assessments showcase its resilience and precision under diverse operational conditions.

Physics-Informed Neural Networks for Privacy-Preserving Model Sharing in Power Systems

Ilayda Canyakmaz[1], Can Berk Saner[2], Antonios Varvitsiotis[1]
[1]Singapore University of Technology and Design, Singapore; [2]National University of Singapore, Singapore

Data privacy concerns in the power systems sector significantly complicate the sharing and integration of sensitive operational data among various independent entities. This challenge is particularly pronounced when developing system-wide mathematical models, as the reluctance to share sub-system models parametrized by sensitive data hinders effective system analysis and decision-making. To address this issue, this work introduces the application of Physics-Informed Neural Networks (PINNs) to develop surrogate models that accurately replicate power system dynamics without exposing sensitive data, enabling privacy-preserving model sharing. By embedding physical laws into the training process, PINNs utilize both available data and inherent system physics, making them particularly suitable for modeling complex dynamics. We propose a framework for model development, including dataset generation and integration of the physics knowledge during PINN training. As a proof-of-concept, we apply this framework to a simplified Single Machine Infinite Bus (SMIB) system. Case studies demonstrate that the trained PINN model closely follows ground-truth dynamics and consistently achieves higher accuracy compared to generic neural networks, highlighting the potential for accurate, privacy-preserving model sharing and system-wide dynamic simulations in power systems.

Energy Price Prediction with Hybrid Neural Network using Time2Vec Attention-based CNN-biGRU

Edvard Avdevičius, Mina Eskander, Detlef Schulz
Helmut Schmidt University / University of the Federal Armed Forces Hamburg, Germany

In dynamic energy markets, accurate energy price prediction is crucial for risk management, resource allocation, efficient and fast decision-making. This study proposes a novel hybrid neural network architecture combining Time2Vec coding method, convolutional neural networks (CNNs), attention mechanism (AM) and bidirectional gated recurrent units (biGRUs). This architecture is complemented by input data processing techniques using complete ensemble empirical mode decomposition with adaptive noise (CEEMDAN) and seasonal and trend decomposition using locally estimated scatterplot smoothing (STL). CEEMDAN captures nonlinear and nonstationary patterns inherent in the input data. STL is widely used to isolate seasonal components. The Time2Vec encoding method is effectively utilized to capture temporal patterns, transforming time-related features into continuous embeddings. CNN block extracts the features of the data and AM improves the interpretability of the model by focusing on significant features. Further, biGRUs read data dependencies from past and future steps. The Time2Vec-CNN-AM-biGRU architecture learns hierarchical representations of data features, exploiting spatial and temporal dependencies in the data. Experimental open-loop evaluations on real electricity price datasets demonstrate the superiority of the proposed approach over baseline models in terms of prediction accuracy.

Hybrid Quantum Physics-Informed Neural Networks for Power Flow Analysis

Zeynab Kaseb, Peter Palensky, Pedro P. Vergara
Delft University of Technology, Netherlands, The

In this paper, we develop a hybrid quantum physics-informed neural network (QPINN) for power flow analysis. QPINN includes two important modifications contributes to the enhanced performance of QPINN: (i) a parameterized quantum circuit is integrated within the neural network architecture, and (ii) a modified loss function is developed based on the power flow equations. Experiments are conducted using a small-size dataset based on a 4-bus test system. Two state-of-the-art models are used to perform a systematic performance comparison, which are a linear regression model (LR) and a multilayer perceptron (MLP). The comparison is based on the (i) training error, (ii) validation error, (iii) generalization ability, and (iv) robustness. The results show that QPINN outperforms both LR and MLP. Hence, QPINN can improve deep learning-based power flow analysis in the noisy-intermediate-scale quantum (NISQ) era.

Improved Physics-Informed Neural Network based AC Power Flow for Distribution Networks

Victor Eeckhout[1], Hossein Fani[1,2], Md Umar Hashmi[1,2], Geert Deconinck[1,2]
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Power flow analysis plays a critical role in the control and operation of power systems. The high computational burden of traditional solution methods led to a shift towards data-driven approaches, exploiting the availability of digital metering data. However, data-driven approaches, such as deep learning, have not yet won the trust of operators as they are agnostic to the underlying physical model and additionally have poor performances in regimes with limited observability. To address these challenges, this paper proposes a new, physics-informed model. More specifically, a novel physics-informed loss function is developed that can be used to train (deep) neural networks aimed at power flow simulation. The loss function is not only based on the theoretical AC Power Flow equations that govern the problem but also incorporates real physical line losses, resulting in higher loss accuracy and increased learning potential. The proposed model is used to train a Graph Neural Network (GNN) and is evaluated on a small 3-bus test case both against another physics-informed GNN that does not incorporate physical losses and against a model-free technique. The validation results show that the proposed model outperforms the conventional physics-informed network on all used accuracy metrics. Even more interesting is that the model shows strong prediction capabilities when tested on scenarios outside the training sample set, something that is a substantial deficiency of model-free techniques.

Deep Learning-Based Probabilistic Forecasting of Household Energy Consumption in Smart Grids

Lucas de Azevedo Takara[1], Luis Fernando Rodrigues Agottani[2], Cesar Vinicius Züge[1], Wendel Rafael de Souza Chaves[2], Leandro dos Santos Coelho[1], Viviana Cocco Mariani[2]
[1]Graduate Program in Electrical Engineering, Federal University of Parana, Brazil; [2]Graduate Program in Mechanical Engineering, Federal University of Parana, Brazil

Smart grids, enhanced by advancements in electronics and communication technologies, have transformed energy distribution and management, necessitating accurate predictions of energy consumption to optimize grid reliability and efficiency. This paper proposes a probabilistic forecasting approach for one-day and one-week-ahead household energy consumption using deep learning models. Neural Hierarchical Interpolation Time Series (NHITS), Neural Basis Expansion Analysis (NBEATSx), Gated Recurrent Unit (GRU), and Long Short Term Memory (LSTM) models are trained on energy consumption data from households in London, United Kingdom, collected via smart meters. These models are optimized using a multi-quantile loss function to account for forecast uncertainty. The forecasting performance is evaluated using Mean Absolute Error (MAE), Mean Squared Error (MSE), Mean Absolute Percentage Error (MAPE), Average Interval Width (AIW), and Prediction Interval Coverage Probability (PICP) metrics, with prediction intervals set at 80\% and 90\%. An expanding window cross-validation approach is employed for performance evaluation. The results show that the NBEATSx model outperforms all others in one-day-ahead forecasting, achieving a 1.3\% lower MAE, while the NHITS model performs best, with a MAE of 0.986 kWh, for one-week-ahead forecasting. Additionally, NHITS excels in one-day-ahead forecasting with a PICP of 96.10\% at the 80\% interval and 99.56\% at the 90\% interval. However, for one-week-ahead predictions, NBEATSx surpasses NHITS, achieving a PICP of 90.48\% and 97.40\%, respectively.

Accelerating Power Flow Calculations in LV Networks Using Physics-Informed Graph Neural Networks

Furqan Azam[1,2], Chris Hermans[1], Thijs Becker[1], Reinhilde D'hulst[1], Koen Vanthournout[1], Geert Deconinck[2]
[1]VITO, Belgium; [2]KU Leuven, Belgium

Precise calculations of network states and parameters are crucial for the modeling, monitoring, and operation of the distribution grid. AC power flow calculations are the preferred method for determining grid operating limits and analyzing the utilization of grid assets during planning processes. Traditional power flow solving techniques often rely on iterative algorithms, which can be computationally expensive, especially for large electrical networks. In this context, we propose a physics-informed graph neural network technique for the fast calculation of low-voltage network states, such as voltages and currents. Our approach leverages the inherent physical knowledge of power systems through the integration of different physical constraints inside model architecture and loss function. By incorporating physical laws such as Kirchhoff's law and active power balance as prior knowledge, the proposed method maintains high accuracy while significantly reducing computational complexity. The results show that the proposed model achieves better performance and higher.

Paper Session 31: Demand response

Time: Wednesday, 16/Oct/2024: 2:00pm - 4:00pm **Location:** Orlando 1C

Presentations:

Advanced Energy Management System for Demand Response in the Cement Industry

Bruno Laurini[1], Yi Zong[1], Chresten Træholt[1], Shanmugam Perumal[2]
[1]Technical University of Denmark; [2]FLSmidth Pvt Ltd

As heavy industries strive to reach net-zero targets, the demand for efficient energy management tools becomes increasingly imperative. The power flexibility of energy-intensive processes, such as cement manufacturing, has the potential to reduce energy-related costs and emissions. Moreover, through the implementation of Demand Response (DR), these large industrial loads can help balance intermittent sources of power supply and, thus, actively contribute to integrating renewable energy sources into the grid. In this paper, we develop an Energy Management System (EMS) for DR in a cement plant. The EMS is designed for day-ahead scheduling, optimizing not only electricity costs but also addressing CO2 costs and mitigating undesired voltage levels within the plant's power distribution network.

Addressing myths of residential consumers regarding demand response

Araavind Sridhar[1,2], Jan Stoklasa[1], Samuli Honkapuro[1], Fredy Ruiz[2], Salla Annala[1], Annika Wolff[1]
[1]LUT University, Finland; [2]Politecnico di Milano, Milan, Italy

The rising need for energy flexibility has paved the way to explore different solutions in various sectors. The residential sector represents one group of consumers who have very low individual flexibility, but due to their large numbers when coupled together, can help the energy system during times of need. This study investigates residential consumers' preferences for Demand Response (DR) programs,

aiming to debunk prevalent myths and provide insights for stakeholders. Analyzing data across demographic divisions like gender, age, education level, household composition, and type, our findings challenge the existing literature, highlighting the need for tailored strategies to effectively promote residential DR adoption. This study not only offers valuable insights into residential DR motivators but also underscores the importance of adapting strategies to reflect the consumer background and meet evolving consumer needs.

Optimising Demand Response Considering Different Load Types and Payback Potentials

Lois Efe, Eduardo A. Martínez Ceseña
The University of Manchester, United Kingdom

In a distribution network (DN), when loads offer flexibility during demand response (DR) optimisation, they often require additional supply to restore services, such as heating, requiring extra power for system restart. Capturing this impact requires considering not only the payback effect but also diverse load characteristics and their payback requirements. Although payback has been partially addressed, load diversity remains inadequately considered, potentially undermining the value of flexibility, or expecting unfeasible additional services from consumers. This paper aims to tackle this issue by proposing a day-ahead optimisation approach for DR planning, incorporating load diversity, and comprehensively assessing payback potential. The payback potential metric for different load types has been introduced to enable detailed modelling based on required reconnection schemes (i.e., load payback), facilitating optimised DR scheduling to meet load preferences and network needs. This methodology is illustrated through case studies using a modified IEEE 33 bus DN model. The findings demonstrate how optimised activation of flexible demands across different load types, each with distinct reconnection schemes, provides a more realistic reflection of DR planning's impact on the DN and improves DN performance metrics.

Methods for studying policies and regulations impacting demand response in Dutch wholesale day-ahead power market

Sugandha Chauhan[1], Sebastiaan Hers[2], Milos Cvetkovic[1], Laurens de Vries[1]
[1]Delft University Of Technology; [2]TNO

Decarbonisation of the electricity sector has led to the adoption and deployment of a large number of consumersited flexible assets. Simultaneously, consumers are becoming increasingly aware of their consumption patterns and are eager to reduce their energy expenses making demand response a significant source of flexibility in energy markets. In this paper, we discuss the policy measures that influence a consumer's ability to respond to price signals and offer flexibility in the day-ahead market. We propose two methods to quantitatively analyse these policy instruments through their inclusion in market clearing models for the Dutch day-ahead power market. A single-level optimisation model with social welfare maximisation objective can be used to perform a simplified assessment of changes in demand bids due to policy-based financial influences. This model is suitable for studying policies governing taxes and network tariffs but unsuitable for complex schemes such as net-metering and SDE++. A bi-level optimisation model with social welfare maximisation on the upper level and consumer surplus maximisation on the lower level allows more sophisticated modelling of policies. It can be used to study taxes and tariffs as well as net-metering and subsidy schemes. The two methods can be compared on the basis of their ability to incorporate different policy instruments and market design choices and model consumer bidding behaviour, their computational complexity and obstacles to implementation.

Approach for Investigating Demand Profile Compatibility for Possible Co-Localisation of High Electricity Demand Customers

Stine Fleischer Myhre, Jan Erik Farbrot, Hans Olav Randem, Terje Bodal
Institute for Energy Technology (IFE), Norway

The green shift has resulted in a growing volume of electricity connection requests for power grid operators in Norway. The grid is however in most areas congested, and investments are needed. This paper utilises data-driven approaches to investigate the feasibility of co-localising high electricity end-use customers in grid connection request queues to reduce grid investments in congested grids for a distribution grid operator in Norway. This is performed by matching clusters of real electricity demand profiles to investigate the compatibility between the different customer groups. The results show promising opportunities for co-localising different customer groups. Especially the demand profile for charging stations is compatible with most of the other profiles.

Pricing Mechanisms versus Non-Pricing Mechanisms for Demand Side Management in Microgrids

Cassia Regina Santos Nunes Almeida, Arun Narayanan, Majid Hussain, Pedro Nardelli
Lappeenranta-Lahti University of Technology LUT, Finland

In this paper, we compare pricing and non-pricing mechanisms for implementing demand-side management (DSM) mechanisms in a neighborhood in Helsinki, Finland. We compare load steering based on peak load-reduction using the profile steering method, and load steering based on market price signals, in terms of peak loads, losses, and device profiles. We found that there are significant differences between the two methods; the peak-load reduction control strategies contribute to reducing peak power and improving power flow stability, while strategies primarily based on prices result in higher peaks and increased grid losses. Our results highlight the need to potentially move away from market-price-based DSM to DSM incentivization and control strategies that are based on peak load reductions and other system requirements.

Optimizing Grid Services: A Deep Deterministic Policy Gradient Approach for Demand-Side Resource Aggregation

Liangcai Zhou[1], Yi Zhou[1], Zhehan Yi[2], Di Shi[3], Zhilong Huang[1]
[1]East China Branch of State Grid Corporation, Shanghai, China; [2]CPS America, Pleasanton, CA, United States; [3]New Mexico State University, Las Cruces, NM, United States

The new types of demand-side controllable resources in recent years, such as smart home appliances, portable power stations, and electric vehicles, have introduced newfound opportunities for power system control. Aggregating a large volume of these resources can provide a substantial amount of ancillary services for the grid, such as voltage and frequency control. Nevertheless, the integration of such a large and highly distributed amount of controllable resources for grid services has posed significant challenges for grid operators as well as aggregators, primarily due to the uncertainties, load characteristics, computational complexity, and scalability. This paper aims to devise an efficient distributed aggregation system targeting the optimal control and integration of diverse controllable resources for power system services. This is achieved through a model-free deep reinforcement learning-based approach, which not only maximizes the total profits of the distributed resource owners to incentivize participation but also improves the control performance. The efficacy of the proposed system is validated through case studies utilizing real-world data.

Paper Session 32: Hydrogen storage 1

Time: Wednesday, 16/Oct/2024: 2:00pm - 4:00pm **Location:** Lokrum 4

Presentations:

Analysis of Hydrogen Storage for Seasonal Leveling of Renewable Energy Generation in Scenarios of Japan's Generation Mix

Yuna Oishi, Shoki Okawara, Takuto Komuro, Yusuke Manabe, Nobuyuki Yamaguchi
Tokyo University of Science, Japan

The power sector is being decarbonized to achieve carbon neutrality in 2050, and the Group of Seven (G7) has decided to phase out coal-fired power generation by 2035. In this study, we set up coal phase-out scenarios for 2030, 2040, and 2050 and conducted a simulation analysis by unit commitment with an expanded introduction of renewable energy. In this study, we estimate the optimal capacity of hydrogen storage system (HSS) for various future supply scenarios in Japan through an inter-seasonal energy supply-demand leveling simulation. The proposed method is a time series simulation of unit commitment (UC) and inter-seasonal hydropower storage systems using mixed integer linear programming (MILP). As a result, the HSS significantly contributed to reducing the amount of Variable Renewable Energy (VRE) output suppression and effectively utilizing VRE in all future scenarios.

A Multi-Stage Energy Management Approach Incorporating Seasonal Hydrogen Storage in a PV-BESS-Electrolyzer-Fuel Cell System

Aihui Fu, Milos Cvetkovic
TU Delft, Netherlands, The

This paper introduces a novel four-stage energy management strategy, harnessing receding-horizon optimization to manage energy consumption to facilitate a photovoltaic (PV)-battery (BESS)-electrolyzer-fuel cell residential energy community in the urban environment. Our approach uniquely sequences four optimization stages: yearly, monthly, day-ahead, and intraday. This integration blends both long-term and short-term strategies in energy management system (EMS) development, positioning hydrogen produced by electrolyzers as seasonal storage and batteries for daily utilization. The algorithm presents three modes, each defined by a distinct objective function, catering to different user preferences: self-sufficiency, profit maximization in the energy market, and provision of balancing services to grid operators and external entities. The method's efficacy is demonstrated through simulations and a detailed analysis of a real-world PV-BESS-electrolyzer-fuel cell lab setup, encompassing algorithm efficiency assessment and a comparative performance review across the different operational modes.

Software and Hardware-Based Decoupling Control Comparison of Multiport-Isolated DC-DC Converters for Hydrogen Energy Storage Systems

Oyedotun E Oyewole, Khaled H Ahmed
University of Strathclyde, United Kingdom

Hydrogen energy storage systems (HESS) offer a promising green solution for energy storage, producing only water and oxygen as byproducts, unlike fossil fuels which have harmful environmental impacts. HESS efficiency is closely related to the efficiency of the power converter. Multiport-isolated DC-DC converters are ideal for HESS applications owing to their high power density and flexibility. However, they suffer from cross-coupling effects, which compromise their performances. This paper presents a comprehensive comparison of software and hardware-based decoupling control strategies for multiport-isolated DC-DC converters, with the aim of mitigating these cross-coupling effects. Linear active disturbance rejection control (LADRC) and inherent decoupling control (IDC) are implemented as software and hardware-based solutions, respectively. Simulations are carried out to validate the performance of these controllers. This paper provides valuable insights for enhancing the performance of multiport-isolated DC-DC converters in HESS applications.

Profit maximization opportunities of co-located intermittent generators and hydrogen energy storage in Germany

Oleksandr Prokhorov, Dina Dreisbach, Robert Bach
Faculty of Electrical Engineering South Westphalia University of Applied Sciences, Germany

In this paper we analyze potential economic benefits of a collocated renewable energy production facility containing photovoltaic generators with hydrogen energy storage (HES). We consider a data modelling approach which is based on real-world company data from a local commercial PV installation in NRW, Germany. Using non-linear programming, we model potential profit gains from the generator perspective. A retrospective optimization is conducted based on the German-Luxembourg intraday continuous price index from EPEX and company generation data. The optimization aims to determine the best possible profit that a company could have achieved with a 200.00 MW HES availability in 2023. Our results indicate an extra profit premium of 4.86 percent from the reference. Despite positive financial results, the intensity of HES utilization appeared to be moderate, as the HES was operated on 13.70 percent of the days in the year. Our analysis suggests a theoretical possibility of the usage of HES as energy storage for generating elevated profits. However, these results were generated under an optimistic assumption of the relative maturity of the technology. This study offers insights for strategic aspects of the integration of hydrogen energy systems into the national energy grid, optimizing resource allocation, and aligning with Germany's long-term sustainability goals. The analysis also contributes to the literature that so far remains relatively scarce in the domain of the commercialized HES dispatch optimization.

Optimal Design of Hydrogen Supply Chain Infrastructure in the Kingdom of Saudi Arabia

Abubakr Hassan, Ali Al-Awami, Mohamed Makawi
King Fahd University of Petroleum and Minerals, Saudi Arabia

This study develops an optimization framework for the hydrogen supply chain in Saudi Arabia, utilizing a Mixed-Integer Linear Programming (MILP) model executed in the General Algebraic Modeling System (GAMS). The research aims to minimize total daily costs incurred through production, storage, and distribution of hydrogen across three evaluated scenarios: hydrogen compressed at 100 bar, at 200 bar, and in liquid form. Results indicate that the scenario utilizing pipelines for hydrogen compressed at 100 bar is the most cost-effective, primarily due to the absence of labor and fuel costs, which are typically incurred with other transportation modes. Additionally, the liquid hydrogen scenario demonstrates reduced transportation costs, benefiting from the higher density of liquid hydrogen which allows for the transport of larger volumes in fewer trips. Each scenario reveals significant trade-offs between capital and operational expenditures, emphasizing the need for strategic planning in the development of hydrogen supply infrastructure.

Feasibility Investigation of Thermal Management and Heat Recovery of Low-Temperature Hydrogen Electrolysis Systems

Xin Jin, Chunjun Huang, Bruno Laurini, Aneesh Chandra Nunna, Shi You
Technical University of Denmark, Denmark

Electrolysis systems can satisfy various demand responses by transferring energy from renewable energy sources, such as solar power and wind, towards hydrogen production. Green hydrogen can be further employed as a low-carbon fuel for transportation and industry sectors, delivering a promising alternative to conventional energy sources. However, the high cost of electrolysis technology remains a practical challenge. Effective thermal management is required to improve the overall energy efficiency of electrolysis systems and heat recovery techniques have been applied to sell heat as a byproduct, making them more economically competitive. An overview of the potential of thermal management and heat recovery for electrolysis systems is given in this study. Temperature control assists in keeping the stack operating at a higher efficiency while ensuring system safety, providing an optimal operation environment for electrolysis systems. The heat recovered from electrolysis systems can be effectively used to preheat the incoming feedstock or to integrate into district heating. Existing strategies for managing excess heat generated by electrolysis systems, including temperature control and heat recovery, are introduced. The electrolyser technology still requires further improvements and could be better planned based on the information collected in this study.

Paper Session 33: Market and cost optimization

Time: Wednesday, 16/Oct/2024: 2:00pm - 4:00pm **Location:** Lovrijenac 3

Presentations:

Seasonal Dynamics in Energy Cost Optimization of Commercial Buildings with Integrated Photovoltaic and Battery Storage Systems

Samar Fatima, Ilkka Jokinen, Verner Püvi, Matti Lehtonen, Mahdi Pourakbari-Kasmaei
Aalto University, Finland, Finland

This paper presents an energy management system (EMS) for commercial customers in southern Finland, equipped with photovoltaic (PV), battery energy storage systems (BESS), and electric vehicles (EVs). The model manages EV charging schedules and explores vehicle-to-grid (V2G) dynamics, effectively reducing energy procurement costs and accommodating seasonal variations. The energy management problem is implemented in GAMS as a mixed-integer linear programming model that utilizes real load, PV generation, EV driving patterns, and temperature variation across various seasons. Moreover, the customer's BESS is investigated to explore the export potential in an urban environment under a significantly high load demand. Results show percentage cost savings for three customers at 3.46%, 4.07%, and 9.26%, with export potential up to 878 kW, 757 kW, and 428 kW, respectively, highlighting the benefits of renewable sources and storage systems for energy management in similar large-scale facilities.

Value evaluation and price calculation of regulating power for grid constraints in simultaneous market

Yuki Kamei[1], Tsuyoshi Okada[1], Taisuke Masuta[1], Yusuke Manabe[1], Nobuyuki Yamaguchi[2]
[1]Meijo University, Japan; [2]Tokyo University of Science, Japan

In recent years, renewable energy integration into the electrical grid has significantly increased. Consequently, adjustments must be made in the electricity market to accommodate this shift. In Japan's current electricity market, grid constraints are often overlooked, raising concerns about potential grid congestion when a substantial amount of renewable energy is introduced. This necessitates the consideration of security-constrained unit commitment (SCUC). In this study, we have devised a plan for SCUC and identified issues related to trading in the current market. Particularly, in the simultaneous market, we have conducted a comprehensive analysis of profit and loss scenarios between unit commitment (UC) and SCUC, focusing on the management of regulating power for grid constraints. By delving into these aspects, we aim to provide valuable insights into optimizing the integration of renewable energy and ensuring grid stability within Japan's evolving electricity market landscape.

Operating envelopes for the grid-constrained use of distributed flexibility in balancing markets

Abhimanyu Kaushal, Wicak Ananduta, Luciana Marques, Tom Cuypers, Anibal Sanjab
VITO NV, Belgium

The increasing share of distributed energy sources enhances the participation potential of distributed flexibility in the provision of system services. However, this participation can endanger the grid-safety of the distribution networks (DNs) from which this flexibility originates. In this paper, the use of operating envelopes (OE) to enable the grid-safe procurement of distributed flexibility in centralized balancing

markets is proposed. Two classes of approaches for calculating OEs (one-step and two-step methods) are compared in terms of the level of distribution grid safety they can provide, the impact they can have on the market efficiency, and the volume of discarded flexibility they can yield. A case study considering different system scenarios, based on Monte Carlo simulations, highlights a trade-off between the market efficiency, DN flexibility resource utilization, and the grid safety delivered by the different OE methods. The results showcase that the use of the two-step OE approach results in a more grid-secure albeit less-efficient use of distributed flexibility.

P2P Energy Trading in Energy Communities with local PV and Community Energy Storage Systems

Elnaz Davoodi, André Guimaraes Madureira
Luxembourg Institute of Science and Technology, Luxembourg

In order to properly accommodate the proliferation of small-scale renewable generation in residential settings and the challenges posed by reduced feed-in-tariffs, a paradigm shift towards Peer-to-Peer (P2P) energy trading is required to enhance the financial benefits for prosumers by facilitating direct energy exchange among end-users and contributing to the resilience of energy systems. The participation of Distributed Energy Resources (DER) in P2P trading within the context of Energy Communities reduces energy costs for participants while optimizing renewable energy usage. Community Energy Storage Systems (CESS) are leveraged to mitigate the variability of DER and are gaining traction due to economies of scale. This paper proposes a comprehensive market-based scheme for energy communities incorporating P2P energy trading, transactions with utility companies, and the integration of CESS to maximize benefits. Realistic market policies are defined to encourage community participation, ensuring fair profit distribution. Simulation results demonstrate the efficacy of the proposed model in minimizing costs for end-users and maximizing revenue for DER producers within an energy community. With increasing community participation, P2P energy trading can significantly reduce energy costs, while enabling efficient utilization of CESS and facilitating transactions with utility companies.

Real-Time Market Mechanism With Jointly Considering Electricity and Carbon Markets

Xiemin Mo[1,2], Tao Liu[1,2]
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This paper develops a real-time market mechanism by jointly considering the electricity and carbon markets to simultaneously achieve economic optimality, regulate frequency, and further reduce carbon emissions for power systems with high penetration of renewables. The target of the proposed mechanism is to solve an optimization problem that aims to minimize the total generation and penalty costs of electricity and carbon market entities subjecting to the constraints of both markets. To integrate frequency regulation into the proposed mechanism, the optimization problem is reformulated into an equivalent counterpart. The feedback-based optimization and partial primal-dual gradient dynamics method are used to develop the real-time market mechanism that includes bidding behaviors of market entities and clearing procedures of electricity and carbon markets. Finally, case studies on a modified IEEE 57-bus system demonstrate the effectiveness of the proposed mechanism.

Economic Challenges in V2G Implementation: an Italian Market Analysis

Fabrizio De Caro[1], Giuseppe Graber[1], Vito Calderaro[1], Lucio Ippolito[1], Alfredo Vaccaro[2], Vincenzo Galdi[1]
[1]University of Salerno, Italy; [2]University of Sannio

The growth in recent years of electric vehicle (EV) fleets represents a valuable resource for enhancing grid flexibility. Indeed, Vehicle-to-Grid (V2G) technology can provide peak load-shaving services and reduce variability in renewable power generation. Despite V2G being commercially available, its adoption is still lower than expected due to factors such as users' willingness to share their EV batteries and the lack of robust V2G market platforms. Moreover, existing research has primarily focused on maximizing aggregator benefits without adequately considering the economic conditions that trigger the V2G services in the market. Therefore, this work aims to address these overlooked aspects through sensitivity analysis based on real-world data, where considered economic conditions involve the needs of all stakeholders, including aggregators, the grid, and EV users. Additionally, aspects such as the impact of load forecasting errors on aggregator income have not received sufficient attention, and they are investigated in the paper.

Grid-Impact Aware P2P Trading and Implications on Flexibility Markets

Anibal Sanjab[1,2], Gonçalo De Almeida Terça[1,2]
[1]Flemish Institute for Technological Research (VITO), Genk, Belgium; [2]EnergyVille, Genk, Belgium

This paper investigates the impact of peer-to-peer (P2P) markets on the safe operation of local distribution grids, and proposes control instruments, which can be applied by distribution system operators (DSO) to ensure grid safety while enabling P2P trading.

The grid impact is captured through quantified modifications to the network states, and thus the DSO's flexibility needs, that can result from P2P trades. In this regard, a P2P market formulation modeled as a generalized Nash equilibrium problem is adopted, in addition to a local flexibility market (LFM) formulation, through which the DSO can procure flexibility for congestion management. Two DSO control instruments are then proposed: (i) a preventive blocking method, through which the DSO can block (ex-ante) the possibility of trades if they are deemed to harm the grid, and (ii) an incentive scheme, through which the DSO provides incentives to encourage the realization of P2P trades that are deemed helpful to the grid. A structured comparison of these methods, as compared to free P2P trading (i.e., without DSO intervention) is then conducted. The results showcase the varying impacts that P2P trades can have on the grid, being at instances helpful (resolving congestions) and at others harmful (exacerbating congestions). The results showcase that the proposed preventive blocking method, outperforms the alternatives for ensuring grid-safety while abiding by regulatory and practical requirements.

Virtual Energy Storage Systems and their Participation in Day-ahead and Flexibility Markets

Farid Hamzehaghdam[1], Aleksandr Zavodovski[1], Mehdi Rasti[1,2], Eva Pongracz[1]
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The rising concept of the Virtual Energy Storage System (VESS) within the energy storage systems (ESSs) landscape is indicative of its innovative features, marked by exceptional efficiency and reliability. The unpredictable and stochastic nature of renewable energy sources (RESs) has posed challenges to the grid's flexibility. Utilizing ESSs can contribute to overcoming this issue. In response to this, this research puts forth a framework designed to optimize the operation of a multi-carrier VESS. The VESS consists of batteries, thermal

storage systems and responsive loads. The responsive loads contain both electrical and thermal loads, leveraging its similarities to the behavior of physical ESS. From a market perspective, the study considers the involvement of three key participants: the electrical market, the thermal market, and the flexibility market, reflecting the multifaceted nature of energy storage requirements. Operational constraints are factored in during the optimization, allowing for a comprehensive evaluation of the operational costs linked to different ESS configurations. The culmination of these efforts involves simulations conducted within the GAMS environment, offering a detailed and insightful analysis of the proposed VESS framework. Through this approach, the study contributes valuable knowledge to the ongoing discourse on optimizing energy storage systems in the context of evolving smart grids.

A Dynamic Price Policy Method for Electricity Grids with Flexible Thermal Loads using Grey Box Model and Differential Evolution Optimization

Carlos E. Gil Simancas[1], Chris Develder[2], Lina Bertling Tjernberg[3], Johan Driesen[1]
[1]KU Leuven - EnergyVille, Belgium; [2]Ghent University - imec, Belgium; [3]KTH, Sweden

The electricity grids have become a key component in the energy transition and decarbonization of industries due to increasing electrification of different loads, such as heating. This paper presents the overview and validation of a new method for electricity retailers or Virtual Power Plants operators to match their portfolio dominated by Renewable Energy Resources (RES) with electrical demand of thermal loads (heat pumps) via a price control mechanism. This research proposes a novel three-step framework to exploit the flexibility of Thermostatically controlled loads (TCLs) by estimating the governing physical parameters of the household and controlling the heat pump electric power via a dynamic price policy; for parameter estimation and price policy a Differential Evolution (DE) optimization algorithm is used. The proposed method performs well for a large number of parameters and reduced training data (prediction errors around 2.5% on the power average and standard deviation) and it effectively controls the loads via a dynamic price policy reducing total price for the household owner or customer compared to a tariff without demand response (DR) (reduction of up to 53.63 %), and respecting the technical constraints of the grid.

Paper Session 34: Flexibility

Time: Wednesday, 16/Oct/2024: 4:15pm - 6:00pm **Location:** Koločep 5

Presentations:

On Reserve Markets in the Era of High Storage and Flexibility Penetration

Georgios Tsaousoglou[1], Jakob Hviid[2], Hanne Binder[2], Henrik Madsen[1]
[1]TECHNICAL UNIVERSITY OF DENMARK, Denmark; [2]Energinet, Denmark

The transition to renewable energy sources poses unique challenges to power system operators, particularly in efficiently procuring reserves. This paper investigates the discrepancies between existing reserve procurement frameworks and the capabilities of emerging players such as storage and flexible demand in systems with high renewable penetration. Using a characteristic example, we expose the inability of current reserve products to enable the new players to express their capabilities, which leaves them exposed to systemic risks. We proceed to present a solution where a new type of reserve allows to bridge this discrepancy, enhancing the reliability and flexibility of the power system. Our findings underscore the urgent need for a revised regulatory framework to accommodate the growing demand for ancillary services and harness the full potential of emerging technologies in renewables-and-flexibility driven power systems.

Cloud – Edge Grid Control : Advanced Flexibility for Aggregated Local Communities

Yara ABDUL SAMAD EL SKAFF[1], Hugo JOUDRIER[1], Raphael CAIRE[2], Quoc Tuan TRAN[1]
[1]Univ.Grenoble Alpes, CEA LITEN, INES, France; [2]G2Elab – Grenoble INP Univ. Grenoble Alpes

Control models of power grids are rapidly evolving. New control models are adopting hierarchical distributed strategies in which local energy communities are involved in the decision-making process. In such control models, local energy communities are able, through demand response strategies, to provide aggregated flexibility services to the grid. However, this requires the implementation of available flexibility computation strategies capable of maximizing flexibility when required, while considering local preferences. This paper proposes an advanced local flexibility computation strategy adapted for hierarchical distributed control models. The strategy is applied to a proposed grid control model, at a distribution level, referred to as 'cloud –edge'.

Flexibility provision from battery storage and PV inverters using IoT platform: Real-life demonstrations at Chalmers campus

Ioannis Bouloumpasis[1], Kyriaki Antoniadou-Plytaria[1], Nima Mirzaei Alavijeh[1], Rohini Sharma[1], David Steen[1], Anh Tuan Le[1], Minh-Quan Tran[2], Phuong Nguyen[2], Carmen Oana[3]
[1]Chalmers University of Technology, Sweden; [2]Eindhoven University of Technology, The Netherlands; [3]SIMAVI, Romania

In this paper the real-life demonstrations for grid control and flexibility intervention based on advanced controllability of flexible resources that were performed at Chalmers University of Technology campus are presented. The demonstration activities were facilitated by the implementation of an IoT platform, which was also used for the visualization and assessment of the results. Through the demonstrations, the successful integration of the required tools to the IoT platform, as well as the efficient employment of the platform for real-life applications have been validated. The evaluation of the results against the defined key performance indicators (KPIs) shows that the coordinated voltage control by solar PVs through model predictive control (MPC) efficiently keeps voltage within the desired limits, while the optimization algorithm for battery energy storage systems (BESs) dispatch for flexibility service (FS) provision, provides financial benefits to the energy cluster that includes the BES, minimizing its energy cost.

Forecasting Demand-side Flexibility of a Household with Dynamic Consumer Behavior Analysis

Argum Shahid, Roya Ahmadiahangar, Argo Rosin, Tarmo Korõtko
Tallinn University of Technology, Estonia

Demand-side flexibility is considered an efficient concept for enhancing grid stability and optimizing energy resources amidst increasing renewable energy integration and fluctuating consumption patterns. A challenging task in demand-side flexibility adaptation is to forecast its availability while considering consumer comfort to assist aggregators in efficient energy management. This paper proposes a novel machine learning-based approach to address this issue by quantifying the demand side flexibility of household appliances and utilizes this quantification to forecast next-day flexibility, incorporating dynamic consumer behavior analysis. To achieve this, various flexibility metrics are employed, and temporal and energy variations are analyzed across flexible appliances, enabling a better comprehension of their interaction with the environment. K-means clustering is used to analyze consumer behavior, and XG-Boost is applied to forecast flexibility. Accurate forecasting of the flexibility profile is required to avoid penalties for not meeting the contracted capacity and to minimize the risk of failing to provide flexibility reserve due to overestimation of production by the aggregator. The results show that the proposed approach can be used to forecast flexibility with high accuracy.

Flexibility of Distributed Power-to-Gas in Interconnected Electricity-Gas Distribution Network Including Pressure Management

Thomas Swarts[1], Johan Morren[1], Wouter van den Akker[1], Arjan van Voorden[2], Han Slootweg[1]
[1]Eindhoven University of Technology; [2]Delft University of Technology

This study investigates the impact of pressure limits in natural gas (NG) distribution networks on the economic effectiveness of Power-to-Gas (P2G) systems in alleviating congestion and associated reinforcement investments in electricity distribution networks. A joint optimal planning and operational model integrating P2G facilities within interconnected electricity-gas distribution networks is developed, incorporating investment decisions in the electricity network formulated as a Mixed-Integer Second Order Cone Program (MI-SOCP). Results demonstrate that pressure constraints in the gas grid significantly curtail the flexibility and efficacy of P2G in mitigating congestion issues, resulting in an annualized reinforcement cost in the electricity grid of 0.9 million compared to 0.4 million without gas-grid constraints. Implementation of pressure management (PM) strategies enhances the flexibility of P2G systems, facilitating increased upstream hydrogen flow during periods of low demand. Static pressure management (SPM) effectively alleviates gas-grid congestion under stable hydrogen demand conditions, leading to reduced reinforcement costs in the electricity grid. Dynamic pressure management (DPM) proves highly effective in mitigating gas-grid congestion, although operational constraints persist for distributed P2G systems during summer and spring days. Transitioning passive NG distribution grids to Active Gas Distribution Networks (AGDNs) with pressure management is essential to overcome gas-grid congestion stemming from distributed P2G system return flows. This transformation significantly enhances the flexibility and efficacy of P2G systems in reducing congestion within electricity distribution grids

Ancillary Services Provision by Cross-Voltage-Level Power Flow Control using Flexibility Regions

Christian Holger Nerowski, Zongjun Li, Christian Rehtanz
TU Dortmund University, Germany

The large-scale integration of distributed renewable energy sources into the electricity grid requires the investigation of new methods to ensure stability. For example, Active Distribution Networks (ADNs) can be used at (sub-) transmission levels for emergency operation, provided robust and efficient control is available. This paper investigates the use of Feasible Operating Regions (FORs) and Flexibility Regions (FRs) for Cross-Voltage-Level Power Flow Control (CPFC). The enhancement of network stability due to the provision of ancillary services is illustrated, as is the need for strengthened cooperation between Transmission (TSOs) and Distribution System Operators (DSOs). Optimal power flow methods are considered, focusing on computational advances through PieceWise Linearization (PWL) and convex relaxation techniques aiming to speed up runtime while keeping high accuracy. To illustrate the algorithms' benefits and drawbacks, they are analyzed using exemplary medium voltage grids.

Scheduling Strategy for Industrial Energy Flexibility and Self-consumption

Isabella Bianchini[1], Alexander Sauer[2]
[1]Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Germany; [2]Institute for Energy Efficiency in Production EEP, University of Stuttgart, Germany

The transition towards climate neutrality profoundly affects the industrial sector. In Germany, industry presently accounts for approximately 29 % of final energy consumption, primarily for process heat provision, with only a small fraction supplied by renewables. Industrial energy flexibility emerges as a key solution for integrating renewables, decarbonizing the industrial sector, and reducing production costs. This paper proposes an energy management strategy for scheduling industrial energy flexibility explicitly considering multiple energy carriers and prioritizing self-consumption. Results indicate that integrating self-consumption goals into the optimization process leads to significant improvements in CO2 emissions without imposing energy cost disadvantages.

Paper Session 35: Machine learning applications in power system

Time: Wednesday, 16/Oct/2024: 4:15pm - 6:00pm **Location:** Orlando 1A

Presentations:

LSTM-based Active and Reactive Load Forecasting and its Replicability in Large Geographical Areas

Dzenana Tomasevic[1], **Jelena Ponocko**[2], **Tatjana Konjic**[3]
[1]University of Zenica, Bosnia and Herzegovina; [2]University of Manchester, UK; [3]University of Tuzla, Bosnia and Herzegovina

The day-ahead load forecast is essential for the efficient planning and operation of electric power systems, especially in the context of smart grids. This task is becoming increasingly important with the growing integration of variable renewable energy sources. Among the various machine learning-based load forecasting methods, Long Short-Term Memory (LSTM) networks have shown to be particularly effective. This paper analyses the impact of reactive load as an exogenous variable on active load forecasting and vice versa, employing LSTM networks with hyperparameters optimized through Gaussian Process Regression (GPR). The results, validated using dataset from Bangalore, India, demonstrate that including exogenous variables enhances forecasting accuracy. Additionally, the effect of different training/(validation+test) percentage ratios on prediction performance is evaluated finding that a 70%:30% ratio yields a satisfactory balance of accuracy and training efficiency. Finally, a combined forecasting model is used to analyse the forecasting accuracy of a model that is trained using data from one location (Bangalore) and tested using data from another location (Itanagar), proving there is no overfitting in the forecasting model.

Evaluating the Impact of Data Availability on Machine Learning-augmented MPC for a Building Energy Management System

Jens Engel[1], **Thomas Schmitt**[1], **Tobias Rodemann**[1], **Jürgen Adamy**[2]
[1]Honda Research Institute Europe GmbH, Germany; [2]Control Methods and Intelligent Systems Laboratory, Technical University of Darmstadt

A major challenge in the development of Model Predictive Control (MPC)-based energy management systems (EMSs) for buildings is the availability of an accurate model. One approach to address this is to augment an existing gray-box model with data-driven residual estimators. The efficacy of such estimators, and hence the performance of the EMS, relies on the availability of sufficient and suitable training data. In this work, we evaluate how different data availability scenarios affect estimator and controller performance. To do this, we perform software-in- the-loop (SiL) simulation with a physics-based digital twin using real measurement data. Simulation results show that acceptable estimation and control performance can already be achieved with limited available data, and we confirm that leveraging historical data for pretraining boosts efficacy.

Scalable and Lightweight Machine Learning Based Load Forecast: Netload versus Disaggregrated Forecast

Alexander N. Ndife, **David Steen**, **Anh Tuan Le**
Chalmers University of Technology, Sweden

This paper develops lightweight and adaptive demand forecast models for a residential building integrated with solar photovoltaics using scalable and adaptive deep learning algorithms, i.e., long short-term memory (LSTM) and gated recurrent units (GRU). First, the forecast models have been trained using the real measurement data from a residential building. Then, the models have been used in case studies using the real-time data for two forecasting approaches: i) netload forecast; ii) disaggregated forecasts, i.e., forecasting the load and PV generation separately. The performance of the two forecasting approaches have been compared. The results from case studies showed that disaggregated forecast approach was superior (with an overall RMSE of 2.03 kW for the building with max demand of 10.53 kW) than the aggregated forecast approach (with an overall RMSE of 2.63 kW). Case studies results have also demonstrated that the models are scalable with more data, and are lightweights, hence, suitable for resource-constraint devices. Although LSTM shows advantages in accuracy, GRU shows better scalability in terms of computational efficiency. The models can be utilized by various stakeholders, such as building owners, grid operators, etc., and can be adapted to other types of buildings.

Machine Learning-based Model to Estimate the Dynamic Hosting Capacity in Distribution Network

Meysam Asadi, **Kamran Jalilpoor**, **Robbert Claeys**, **Jan Desmet**
EELab/Lemcko, Department of Electromechanical, Systems and Metal Engineering, Ghent University, Kortrijk, Belgium

The efficient and reliable operation of electrical distribution networks (EDNs) relies on enhancing their hosting capacities (HCs). This paper introduces a machine learning (ML) model to estimate the dynamic hosting capacity of an EDN, focusing on the seamless integration of air source heat pumps (ASHPs) and their interaction with demand response programs. A predictive model has been developed using optimization techniques coupled with ML algorithms, including the Multilayer Perceptron. This model can dynamically adapt to parameter variations, such as substation capacity, outdoor temperatures, customer engagement, and load flexibility. The methodology has been implemented on the IEEE 33-bus test EDN, demonstrating the model's proficiency in precisely evaluating the impact of uncertain parameters on the HC. The results prove the high accuracy of the designed model to enhance the planning and operation of modern power systems, facilitating more effective integration of ASHPs and optimizing grid performance under diverse scenarios.

Machine Learning-Driven Prediction of Load Shedding During Cascading Outages

George Paphitis[1], **Balaji Venkateswaran Venkatasubramanian**[2], **Mathaios Panteli**[1]
[1]Department of Electrical and Computer Engineering, University of Cyprus, Nicosia, Cyprus; [2]School of Technology, Woxsen University, Telangana, India

The complexity of modern power systems makes predicting and mitigating cascading outages challenging. Quantifying their impact requires extensive simulations, which are computationally expensive and impractical for real-time applications. To address this issue, we introduce a novel methodology that integrates different machine learning regressors to create a stacking ensemble regressor along

with a cascading failure model enabling rapid quantification of cascading-driven nodal load shedding through prediction. The effectiveness of the proposed model is evaluated using the R2 metric, with studies conducted on the IEEE 39-bus system. Additionally, the model is tested on the IEEE 24-bus Reliability Test System to demonstrate the effect of network reliability on cascading failures and its impact on model fitness. The outcomes of this study indicate that the proposed model fits better on the IEEE 39-bus system, achieving an R2 of 0.88. In contrast, on the IEEE 24-bus Reliability Test System, the R2 is 0.42; the reasons behind this discrepancy are examined and discussed.

Pioneering Roadmap for ML-Driven Algorithmic Advancements in Electrical Networks

Jochen Cremer[1,2], Adrian Kelly[3], Ricardo J. Bessa[4], Milos Subasic[5], Panagiotis N. Papadopoulos[6], Samuel Young[7], Amar Sagar[8], Antoine Marot[9]

[1]Delft University of Technology, Netherlands; [2]Austrian Institute of Technology, Austria; [3]Electric Power Research Institute, Ireland; [4]nstitute for Systems and Computer Engineering, Technology and Science, Portugal; [5]Hitachi Energy, Germany; [6]The University of Manchester, United Kingdom; [7]Energy Systems Catapult, United Kingdom; [8]Arizona State University, United States of America; [9]Réseau de Transport d'Électricité, France

Advanced control, operation, and planning tools of electrical networks with ML are not straightforward. 110 experts were surveyed to show where and how ML algorithms could advance. This paper assesses this survey and research environment. Then, it develops an innovation roadmap that helps align our research community with a goal-oriented realization of the opportunities that AI upholds. This paper finds that the R&D environment of system operators (and the surrounding research ecosystem) needs adaptation to enable faster developments with AI while maintaining high testing quality and safety. This roadmap may interest research centre managers in system operators, academics, and laboratories dedicated to advancing the next generation of tooling for electrical networks.

Play With Me: Towards Explaining the Benefits of Autocurriculum Training of Learning Agents

Eric MSP Veith[1], Torben Logemann[1], Arlena Wellßow[1], Stephan Balduin[2]

[1]Carl von Ossietzky University Oldenburg, Germany; [2]OFFIS - Institute for Information Technology

Deep Reinforcement Learning (DRL) has firmly established itself in the smart grid domain in numerous applications, such as voltage control, Electric Vehicle (EV) charging control, real power distribution, or energy markets. Yet, many results presented suffer from an out-of-distribution sampling problem because the scenarios the agents have been trained with are usually highly abstract and often benign. This limits the general applicability of results as the agents can not be meaningfully judged on their performance in more realistic or adverse conditions. Autocurriculum training settings are assumed to remedy this since the DRL-based adversary agent forces its counterpart to a more comprehensive sampling of the available state/action space and, subsequently, to develop a more comprehensive policy. However, until now, this assumption can only be inferred from the agent's reward curve and other metrics stemming from the simulated environment. In this paper, we present an approach that uses an equivalent representation of an DRL agent's policy network, which we then analyze to show the effects of autocurriculum training training. We also present an initial case study to demonstrate the our approach.

Paper Session 36: Power system modelling

Time: Wednesday, 16/Oct/2024: 4:15pm - 6:00pm **Location:** Lokrum 4

Presentations:

A Hybrid Approach for Enhancing Line Parameter Estimation in Power Systems

Markos Asprou[1], Andreas Stavrou[2], Christos Panayiotou[1]

[1]KIOS Research and Innovation Center of Excellence, University of Cyprus; [2]Electricity Authority of Cyprus

Accurate modeling of power systems is crucial for various control center applications. One of the key components in a power system model is the transmission lines. The line model includes parameters such as series impedance and shunt admittance, which are typically assumed to be time-invariant. However, these parameters vary based on the ambient and operating conditions of the system. Therefore, it is essential for the different monitoring and protection applications of the power system to have an accurate visualization of the line parameter variance throughout the day. In this context, this paper develops a hybrid line parameter estimation scheme that makes use of the available Phasor Measurement Unit (PMUs) measurements and Neural Network (NN) estimations to calculate the series line parameters of the transmission lines. The developed scheme was tested in the IEEE 14-bus system under realistic ambient and operating conditions, showcasing its practical applicability and enhanced accuracy.

Analyzing parameter estimation methods for RC models in the modelling of heat dynamics of residential buildings

Mark Timmerman, Edser Apperloo, Syrine Ben Aziza

TNO, Netherlands, The

The growing use of heat pumps contributes significantly to energy consumption and is thus a suitable focus for flexibility solutions. Maximizing the flexibility of a single heat pump requires an accurate model of a building's heat dynamics, ensuring that the heat pumps can be controlled appropriately. These dynamics are unique to each building and continuously evolve as a result of a variety of factors such as weather, home remodelling, and building usage. Resistor-capacitor (RC) models are a proven way to model such dynamics, but require parameters to be tuned to the building represented by the model. Training algorithms can be applied to learn these parameters based on observational data. This paper qualitatively compares three such algorithms: a genetic algorithm, a neural network and a sequential Monte Carlo algorithm. The quality of the learning algorithms is assessed on the accuracy, its adaptability, explainability, and the amount of time and data required to converge. This serves as the foundation regarding the practical usability of such an algorithm in a real-world environment.

Efficient modelling of external network dynamics for converter controller design

Dimitri Nesterov
TRACTEBEL, Belgium

This paper proposes a method allowing to integrate the super-synchronous dynamics of an external network into a linearized model, which can be used for designing the control system of a converter. The modelling method is found efficient as it is easily implementable, while remaining accurate for balanced systems. It is shown that the resonances of the external network might be reflected in open-loop transfer functions corresponding to phase-locked loop and d− and q− axes controllers. Therefore, these resonances might impact on the choice of parameters and on the dynamic performance of a converter. The proposed modelling method consists in expressing the dynamics of the external network under the form of two transfer functions, which can be calculated by formulas provided in this paper. These two transfer functions can then be integrated directly into a block diagram representing the converter and its control system, opening door to control system design techniques using linear analysis. The proposed method is illustrated by an example, presenting a block diagram, Bode plots, and validation of the latter by time-domain simulations.

Demonstrating probabilistic operational planning on the full Norwegian power system model

Sigurd Hofsmo Jakobsen[1], Matias Vistnes[2], Oddbjørn Gjerde[1]
[1]SINTEF Energy Research, Norway; [2]Norwegian University of Science and Technology

In this paper, we demonstrate probabilistic operational planning on the power system model used by the Norwegian TSO. It is a detailed model with thousands of lines and buses. By using load and price data from publicly available sources, we demonstrate that probabilistic operational planning can be performed sufficiently fast on a realistic model. Moreover, we compare the probabilistic and the classical deterministic approach where the probabilistic approach gives lower operational costs by higher tie-line flows.

Black-boxing of Converter State-Space Models for Power System Eigenvalue Analysis

Andrew Macmillan Smith[1,2], Trond Tutturen[3], Salvatore D'Arco[1], Jon Are Suul[1,3]
[1]SINTEF Energy AS, Norway; [2]Department of Electric Energy, NTNU; [3]Department of Engineering Cybernetics, NTNU

State-space models are useful for a wide range of power system analyses such as eigenvalue-based small-signal stability assessment. However, state-space models for detailed analysis of power converter dynamics are typically not provided to third-parties due to intellectual property (IP) concerns. This work illustrates how diagonalization of a state-space model will effectively obscure sensitive information about the system structure and parameters. Thus, diagonalization can be utilized as a safe method for providing black-boxed state-space models. The process is performed on an example system to clearly demonstrate that the information revealed in a diagonalized model is no more than what can be determined from system identification of a black-boxed time-domain model. A practical method of implementing this technique to provide linearized small-signal models across the full range of operating points in a compiled application is presented.

Model order reduction of converter-based ac power systems based on interaction modes identification

Goran Grdenić[1], Marko Delimar[1], Jef Beerten[2,3]
[1]University of Zagreb Faculty of Electrical Engineering and Computing, Croatia; [2]KU Leuven, Belgium; [3]Energyville, Belgium

The considerable integration of renewable energy sources into modern power systems has led to the widespread application of power-electronics devices. Fast-acting controllers of voltage source converters (VSCs) that are employed in many applications can potentially interact mutually, as well as with the resonances of the ac grid, giving rise to new stability problems commonly named converter-driven or harmonic stability. New stability issues require modeling guidelines redefinition for proper analysis. Phasor-based ac grid modeling is adequate for the study of conventional stability phenomena. However, it becomes insufficient for the analysis of converter-related stability issues. Electromagnetic (EMT) ac line modeling is therefore required for modeling the parts of the network in the vicinity of power electronics devices. This paper presents the model order reduction methodology of the ac grid model that determines the boundary between the phasor- and EMT-based grid model, including the complexity level of the EMT part of the model. The methodology is established on the eigenvalues analysis and the interaction modes identification between VSC and ac grid state variables, and it is demonstrated on the IEEE 39 bus grid.

Modeling Impact of Panel Configuration and Ambient Conditions on PV Generation System Outputs for Aggregate Power Flow Studies

Zafar Iqbal, Jaime Alcazar Fernandez, Sasa Djokic
The University of Edinburgh, United Kingdom

Higher power outputs from increasing numbers of grid-connected PV generation systems necessitate use of simple yet accurate models for evaluating their aggregate impact on the grid. This paper presents simplified generic efficiency-based models of the four main types of PV panels and compares them with commonly used, but computationally intensive single-diode model. The presented generic models take into account not only ambient temperature, but also wind speed and configuration (open or closed) of PV panels. Measurements from an actual PV installation are used to illustrate modelling procedure and demonstrate its accuracy.

Paper Session 37: Measurements

Time: Wednesday, 16/Oct/2024: 4:15pm - 6:00pm **Location:** Lovrijenac 3

Presentations:

Noisy PMU Data Recovery in Transient Conditions through Self-Attention Neural Networks

Ramin Bahmani[1], **Mousa Afrasiabi**[2]
[1]Interdisciplinary Centre for Security, Reliability and Trust (SnT), University of Luxembourg; [2]Electrical Engineering Department, Cyient

This paper utilizes the self-attention-based Imputation method to effectively manage missing data in Phasor Measurement Units (PMUs) during transient power system disturbances. By employing self-attention neural networks, this method adeptly processes multivariate noisy datasets. This method significantly enhances the accuracy and operational reliability of the grid performance during disturbances under three different missing data patterns and various missing data ratios. We conducted a comprehensive comparative analysis with other imputation methods using the IEEE 39-bus New England system. As inputs for the imputation, we employed voltage magnitudes and angles. Results demonstrate the superiority of this method in maintaining data integrity and ensuring system stability. In comparative testing, this method reduced Mean Absolute Error (MAE) by approximately 5% to 50% across different cases compared to the best result from other methods in most scenarios, although it underperformed slightly in highly sparse data conditions with a missing ratio of 0.9. The method demonstrated robustness through its high imputation accuracy and fast performance, confirming that it is well-suited for real-time applications in smart grid monitoring, thanks to its ability to process data in parallel.

The resolution drives the conclusion: insights from low-energy co-housing measurements

Lies Debruyne, **Cas Lavaert**, **Bert Herteleer**, **Jan Cappelle**
Research group ELECTA Ghent Faculty of Technology Engineering, KU Leuven Leuven, Belgium

Consumption patterns of electricity by residential customers are rapidly changing through the uptake of PV systems, new large consumers such as heat pumps and electric vehicles. The emergence of digital meters give distribution system operators (DSOs) and households a more detailed look at these consumption patterns. These meters provide a standard time resolution of 15min for remote access, while higher resolution data (e.g. 1s) can be captured through physical access to the meter. In this work, electricity consumption measurements at 1s resolution have been captured at a low-energy co-housing community for analysis. The load profiles from these households give insights into future demand patterns and are compared against 15min data of Flemish households. The importance of time resolution is shown to affect the magnitude and timing of peak loads during the year and day, which is of importance for DSOs and households to make appropriate investment decisions for battery storage and grid upgrades.

Real Time Hardware Validation of Conservation Voltage Reduction Strategy with Measurement based Load Estimation for Optimal Energy Saving

Saehwan Lim[1,2], **Hyeong-Jun Yoo**[1], **Jin-Oh Lee**[1], **So-seul Jeong**[1], **Gyeong-Hun Kim**[1]
[1]Korea Electrotechonology Research Institute, Korea, Republic of (South Korea); [2]Yonsei University,Korea, Republic of (South Korea)

In this paper, the measurement based load estimation for optimal energy saving is proposed. For optimal energy reduction, the system model must be precise. If not, the system may become unstable or energy consumption may increase. In the proposed strategy, accurate estimation of load parameters was achieved using curve fitting and kernel density estimation method based on the data obtained from advanced metering infrastructures (AMI) of each load. After the load parameter estimation, the proposed method aims to minimize the sum of the load, line losses and photovoltaic (PV) inverter's internal losses by controlling the voltage through reactive power compensation of PVs. The performance of the proposed strategy is validated by hardware platform consisting of real time digital simulator, server, PV emulator and AMIs using hardware in the loop simulation based on Korea Electric Power Corporation single-phase low-voltage system. Simulation results indicate that the proposed strategy can improve the energy efficiency of network.

A Platform for Development and Testing of WAMPAC Applications based on Kafka Streaming

Hallvar Haugdal[1], **Salvatore D'Arco**[1], **Kjetil Uhlen**[2]
[1]SINTEF; [2]Norwegian University of Science and Technology (NTNU)

In this paper a platform for developing and testing Wide Area Monitoring, Protection and Control (WAMPAC) applications is presented. The fundamental idea is that individual applications operate as microservices. Each application access and process data (e.g. data from Phasor Measurement Units) and produces results which can be further elaborated by other microservices, or directly presented to the operators. Streaming of data between microservices is handled by a Kafka streaming server which handles the complete information flow. The platform has been tested both on data streams from a lightweight real-time simulator (with hundreds of measurement channels), and on PMU streams generated from recorded data from the Nordic system (with thousands of measurement channels). The platform is characterized by low need of computational resources and easy installation (only requiring basic Python programming skills). Experience from this work indicates that the chosen approach is suitable for streamlining the process of development and testing of WAMPAC applications, with the aim of raising the technology readiness level of already existing applications in the literature or for future applications.

The Impact of Stealthy Data Integrity Attacks on Wide-Area Monitoring System Applications

Denys Mishchenko, **Irina Oleinikova**, **Laszlo Erdodi**, **Basanta Raj Pokhrel**
Norwegian University of Science and Technology, Norway

Cybersecurity has become a paramount concern in light of the potential consequences of disruptions within the energy sector, such as widespread outages resulting from successful cyber-attacks. To meet this challenge this paper aims to delve into the impact of data integrity attacks on the Wide-Area Monitoring System (WAMS) at the application level. The study outlines various models of data integrity

attacks that substitute original data. Using these attack models, the consequences of attacks on WAMS are simulated and analyzed. These attacks are designed with complex behavior to mimic real processes in power systems, potentially misleading related systems and operators. The performed case studies use cyber-physical testbed facilities with industrial WAMS applications to showcase the impact of these stealthy attacks.

A semi-supervised anomaly detection approach applied to solar energy generation

Luis Fernando Rodrigues Agottani[1], Reginaldo Ferreira[2], Rafael Sapia Teixeira[3], Lucas Roveroni de Lima[4], Leandro dos Santos Coelho[5], Viviana Cocco Mariani[6]

[1]Graduate Program in Mechanical Engineering, Federal University of Parana, Brazil; [2]Graduate Program in Mechanical Engineering, Pontifical Catholic University of Parana, Brazil; [3]PLIN Energia S.A., Maringá, Brazil; [4]PLIN Energia S.A., Maringá, Brazil; [5]Graduate Program in Electrical Engineering, Federal University of Parana, Brazil; [6]Graduate Program in Mechanical Engineering, Federal University of Parana, Brazil

As the electrical grid grows and becomes more efficient, the need for better integration with solar power generation data progressively increases. It is important, for example, to robustly detect anomalies in solar energy generation systems, especially when observing the susceptibility of energy generation through measuring equipment, climate data, and measurement failures. Such failures compromise the accuracy of predictions and accentuate the urgency of effective anomaly detection methodologies. This paper presents a semi-supervised anomaly detection framework built for solar power generation data. As an alternative to unsupervised frameworks, the suggested method uses the patterns of typical solar power generation behavior using manually labeled data to train the models exclusively at health points, minimizing training execution time and improving anomaly detection results. The methodology is evaluated using meteorological data obtained from solar plants, demonstrating its effectiveness in identifying and categorizing anomalous events based on the evaluation of several models. The models are from PyOD library and the anomaly detection is evaluated using accuracy, precision, recall, the area under the curve, and F1-score, with prediction intervals at 70%, 80%, and 90% levels. The results demonstrate that the KNN and HBOS models outperform other models, and execution time in semi-supervised frameworks demonstrates a 60% of reduction when compared to unsupervised frameworks.

Paper Session 38: Power system management

Time: Thursday, 17/Oct/2024: 9:00am - 11:00am **Location:** Orlando 1A

Presentations:

Relation between Electrical Grid Congestion and Bus Characteristics

Flin Verdaasdonk, Maria Vlasiou, Gerwin Hoogsteen, Johann Hurink

University of Twente, Netherlands, The

Electrical grids are increasingly congested, which causes stability and safety risks. To get more insights in how congestion can be managed, this paper analyses whether bus characteristics exist that have a consistent influence on grid loading. To study this, a metric for quantifying bus influence on grid loading is introduced and applied in two case studies. The first case study investigates if there are characteristics that correlate with congestion consistently, regardless of grid topology. The results from this case study suggest that none of the evaluated characteristics consistently correlate with grid loading. These results imply that topology should be explicitly considered in congestion management. The second case study investigates the variance in the correlation between bus characteristics and influence, within a single topology, over a variety of conditions. The results of the second case study suggest that this correlation is robust to reasonable changes in bus loads.

Secondary Control of Hybrid AC/DC Microgrids Interfaced with the Distribution Grid by Multiport Grid-Forming Smart Transformers

Angel Navarro-Rodriguez[1], Carlos Gómez-Aleixandre[1], Behnam Daftary[2], Marius Langwasser[2], Marco Liserre[2]

[1]University of Oviedo, Spain; [2]Christian-Albrechts-Universität zu Kiel, Germany

Smart Transformers (ST) have become one of the most promising solutions for the integration of hybrid microgrids (MGs) into the medium voltage distribution grid. However, in most of the control approaches presented for ST based MGs, the frequency and voltage control of each ST port are decoupled. In addition, integration of ST based MGs in the primary and secondary frequency and voltage regulation of the medium voltage distribution grid has not been deeply explored. This paper presents a multidelay compensator based secondary control strategy for ST based AC/DC hybrid distribution grids operated under previously proposed primary and inertial control with multiport Grid Forming capabilities. The presented strategies cover both the MG and the MV distribution grid secondary control for the integration of ST based MGs, and takes into account the effect of the multiple delays present in the centralized secondary control.

Two-Stage Stochastic Optimal Energy Management of Microgrids for Participation in Flexibility Markets

Stefano Massucco[1], Gabriele Mosaico[1], Matteo Saviozzi[1], Pablo Almaleck[2], Marina Santarelli[2], Pietro Serra[2]

[1]University of Genoa, Italy; [2]Hitachi Energy Italy S.p.A., Genoa, Italy

The increasing importance of flexibility markets has arisen in empowering distributed energy resources to assist grid operators in balancing the electricity system. This necessitates new optimization algorithms capable of optimally computing flexibility for day-ahead flexibility markets and implementing flexibility requests in intraday operations. This paper proposes a two-stage (day-ahead and intraday) flexibility optimization formulation for a Microgrid (MG). Chance constraints with separation constraints approximation, tuned by a risk aversion parameter, handle uncertainties. An experiment involving a diverse set of energy assets is performed, simulating a relevant energy flexibility request, which is successfully satisfied, demonstrating the capabilities of the proposed solution.

Impact of Time Resolution and Window Length on Capture of Frequency Variations and Events

Boštjan Polajžer[1], Younes Mohammadi[2], Amin Saremi[2]
[1]University of Maribor, Faculty of Electrical Engineering and Computer Science, Maribor, Slovenia; [2]Umea University, Department of Applied Physics and Electronics, Umea, Sweden

Power-quality standards provide limited guidance on frequency quality for short time scales, such as less than one hour. Capturing frequency variations and events requires high time resolutions, e.g., 0.1 seconds or less, resulting in significant data storage requirements. However, power-quality monitors typically report averaged values at intervals of 10 minutes, 15 minutes, or one hour, depending on the disturbance type. To address these challenges, we propose calculating statistic indices from high-resolution data within a 15-minute or one-hour window length, thus avoiding storing high-resolution data. We apply the basic statistic indices to frequency data measured in Finland for a single day in June 2023, demonstrating their effectiveness in capturing frequency variations and two significant events during that day.

Onsite testing for assessment of Primary Frequency Response in Thermal generating Units

Aman Gautam, Rahul Shukla, Himanshu Kumar, Manas Rajan Chand, Vivek Pandey, S.C. Saxena
Grid-India, India

This paper presents a thorough study of the Primary Frequency Response (PFR) in thermal power units, focusing on its vital role in maintaining grid stability. The study utilizes extensive findings based on onsite testing of thermal generation plants in Indian power system which was carried out to evaluate PFR performance across various thermal units. Key aspects analyzed include droop characteristics, response stability, response activation , rate of response and turbine-governor model validation. The methodology involved simulated frequency injections at different load levels, capturing critical data on active power, frequency, steam pressure, and valve positions. The findings reveal significant insights into the effectiveness of current PFR implementations and highlight areas for improvement. Recommendations are provided to enhance PFR capabilities, ensuring compliance with regulatory standards and improving overall grid reliability

Datacenter Infrastructure health visualization for Grid Operation and development of an Index to Signify the Health Status of Infrastructure using open-source tools

TAPOBRATA PAUL, GURMIT SINGH, RITIK PAL, RAJIB SUTRADHAR
GRID CONTROLLER OF INDIA LTD, India

Information Technology applications and software are nowadays works as backbone of modern-day Grid Operation. Datacentre infrastructure at control center hosts all these critical interlinked applications software and automations. Most of the applications are customised and resource requirements of these applications varies widely. Thus, monitoring of the underlined infrastructure where the critical application services are hosted becomes essential. Real time monitoring of critical servers and network of data center is done using multiple tool such as network monitoring systems (NMS), Virtual platform monitoring tools, security information and event management (SIEM) etc. However, there is a need of comprehensive dashboard for monitoring of various parameters, which are some time not possible with off-the-shelf monitoring tools. Regional LDC of India has developed and implemented open source tools based visualizations for comprehensive monitoring of data center infrastructure of grid control center. However, as there are huge number of servers and multiple parameters of each servers need to be monitored, this causes information overload for any dashboard. Further, with the increasing requirement of comprehensive monitoring and quick fault detection, there is a need for crafting a index to evaluate the health status of hardware infrastructure within datacenters of grid control center. Recognizing the criticality of maintaining operational availability of critical services in grid control center environments, this paper presents noble methods and analysis aimed at empowering system administrators with mechanisms for hardware health assessment. The objective of developing an index to signify the overall health status of hardware infrastructure is to provide system administrators with a holistic view of system health and facilitate informed decision-making. Various approaches, including statistical methods, machine learning techniques, and other expert systems, have been explored for developing health status index in this paper. The paper elaborates the dashboards developed for effective monitoring of hardware infrastructure and methodologies adopted for development for health index with nuanced understanding of the complexities inherent in assessing hardware health within dynamic grid control datacenter.

Sequentially Pruning Phase Rebalance Schedule: Load Profile Learning Approach

Miroslav Kosanic[1], Hongbo Sun[2], Shunsuke Kawano[3], Arvind Raghunathan[2], Shoichi Kitamura[3]
[1]Massachusetts Institute of Technology, United States of America; [2]Mitsubishi Electric Research Laboratories, United States of America; [3]Mitsubishi Electric Corporation, Japan

As low-voltage (LV) distribution networks evolve with the rise of prosumer behavior, traditional reactive load management strategies fall short of addressing the voltage phase imbalances caused by unpredictable load variations. Voltage imbalances pose significant risks including inefficiency, power outages, and equipment failures. Existing optimization solutions lack the adaptability to address this problem extensively with such dynamic environments due to the computational time budget limit. In response, this paper presents a novel method utilizing an Imitation Learning (IL) framework implemented through Ensemble Random Forests to prune the process of sequential load phase swapping, previously determined by solely running at all times costly multi-objective optimization. We maximize classifier recall performance to ensure reliable pruning. Tested across various Solar Photovoltaic (PV) penetration levels (30- 100%) on a standard 13-bus LV test feeder, our method demon- strates substantial improvements in mitigating voltage imbalance, reducing operational costs, and decreasing feeder testing time by 83%. This marks a significant step forward in smart grid technology, offering utilities a robust tool to enhance system reliability with considerable time efficiency.

Network Reduction Assisted Acceleration of Risk-Aware Islanding for Distribution System Resiliency

Jishnudeep Kar, Ji Hyun Yi, Ashwin Shirsat, Muhammad Jawad, Lena Peter
Hitachi Energy Research

This paper presents a computationally efficient method to solve optimization problem for power network resiliency applications, which can have many binary variables. One of such applications is microgrid formation in the distribution grid, which enables to optimally form islands to enable operation of the distribution grid without relying on risk prone assets. To make the solution faster, we propose the use of network reduction algorithm to remove the non-critical information from the network without masking the presence of essential components, such as switches and critical loads that are needed to make the island formation decisions. The proposed method reduces

both, the number of nodes and lines, while accounting for the load criticality of the aggregated loads placed at the nodes of the reduced network. Subsequently, this reduced network can be used to solve the islanding optimization problem. We validate the proposed method on the IEEE 123-bus and 8500-bus systems.

Spatial dependency on flexibility value considering stacked transformer overload cost

Kasper Emil Thorvaldsen, Stian Nessa, Susanne Sandell, Maren Istad
SINTEF Energy Research, Norway

Distribution grids in industrial areas are under pressure to increase the utilization of the existing grid and to build more grid due to electrification of existing industries and new power-intensive industries. Distribution system operators (DSOs) are currently considering if and how they can use power system flexibility, such as demand response, to simultaneously avoid overloading their grid assets and avoid investing in new grid. The DSO may choose to operate an asset, such as a transformer, beyond its rated load. However, this accelerates the aging of the transformer, hence decreasing its remaining life. In this work, a methodology is developed which relates the cost of transformer overload to the value of power system flexibility, to determine the DSO's willingness to pay for a flexibility service. The methodology finds the spatial dependency of a flexibility services' value by optimizing load shedding in the grid to minimize transformer loss of life (LoL). The methodology is demonstrated in a case study using real grid and load data measured in an industrial area in Norway that includes both medium voltage (MV) and low voltage (LV) transformers.

Paper Session 39: Optimal control

Time: Thursday, 17/Oct/2024: 9:00am - 11:00am **Location:** Orlando 1B

Presentations:

Modeling Battery Aging for Optimal Control

Ricarda Monja Hogl[1], Arne Groß[2], Jakob Harzer[2], Nils Reiners[1], Moritz Diehl[2]
[1]Fraunhofer Institute for Solar Energy Systems, Germany; [2]University of Freiburg, Germany

When optimizing the operation of stationary batteries using optimal control in a time-of-use application, aging costs can have a strong influence on the economic outcome. Thus, it is beneficial to consider aging costs in the controller design. First, we give a detailed explanation of how to include varying stress factors into a lab-based aging model, even with non-linear dependencies on time and full equivalent cycles (FEC). We state and motivate the discrete dynamics and formulate an optimal control problem for a time-of-use scenario. As a result, we find a control strategy for the battery that provides clear benefits. Unlike the aging-unaware controller and a controller with light aging-awareness, the fully aging-aware controller manages to recoup the battery investment. Compared to a base case without any batteries, the aging-unaware and aging-light controller lose 3657 € and 710 € in every year of their operation, while the aging-aware controller gains 627 € per year because it increases the battery lifespan by 345%.

A Robust H∞ Control Based on LMI for PMSG-based Grid-connected Wind Energy System

Veeranna KURUVA, Amir H. ABOLMASOUMI, Vinu THOMAS, Bogdan MARINESCU
Ecole Centrale de Nantes, France

Enhancing the integration of renewable energy sources into electrical grids via grid-connected converters requires robust control schemes to ensure the stable behavior of these converters during disturbances on the grid side. In this paper, a robust control strategy for a grid-connected Permanent Magnet Synchronous Generator (PMSG) is designed for variablespeed wind applications. The controlled variables include the electromagnetic power generated by the machine, dc-link voltage, and reactive power that is injected to the grid side. This paper proposes a robust H∞ control scheme enhanced by the D-stability technique using a Linear Matrix Inequality (LMI) approach, which takes into account the detailed model of the back-to-back converter system to which the PMSG is connected. The control scheme is validated on an OPAL-RT-based real-time simulator and the results indicate that, in different conditions, the robust H∞ control scheme provides a superior response during shortcircuit faults and PMSG speed variations, compared to those of the standard PI vector control scheme. This control scheme shall be extended to implement the decentralized control method for each of the generating units of the Dynamic Virtual Power Plant, a concept introduced in the H2020 POSYTYF project

Bidirectional Substation Control for Smart Thermal Grids: Experimental Evaluation of a Weighted Proportional-Integral Approach

Ulrich Ganslmeier, Lorenz Lukas, Thomas Hamacher, Thomas Licklederer
Technical University of Munich (TUM), Germany

When transforming district heating networks into smart thermal grids, a crucial part is the integration of distributed energy resources and prosumers, coordinated by an overarching management system. Central to this transformation are bidirectional substations that technically facilitate flexible energy exchange between prosumers and the network. Novel control approaches are required that are capable of meeting temperature requirements, implementing power setpoints from overarching management, and mitigating the mutual thermohydraulic influence among prosumers simultaneously. A recently proposed control strategy to mitigate those challenges is based on combined and weighted errors as inputs for proportional-integral controllers; However, it was tested only using simulations so far. In this paper, we experimentally test the control approach using a realistic hardware setup, where two bidirectional substations exchange heat between two emulated prosumers. The investigated control approach achieved the control objectives within a stabilization time of approximately six minutes after step changes in the power setpoints. The controller successfully reflects the application-specific prioritization of different temperature objectives, confirming simulation results from prior work. Minor performance issues arose from hardware limitations, particularly in power transfer capabilities due to actuator sizing, highlighting their significance for practical applications. Overall, our experiments demonstrate for the first time the suitability of a control approach for prosumer-based district heating contexts with realistic hardware, laying a foundation for the practical implementation of smart thermal grids and contributing to a sustainable transition in heat supply.

MPC-based Optimal Control of Battery Management System in Residential Application

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[1]Tallinn University of Technology, Estonia; [2]Technion---Israel Institute of Technology, Israel

In the evolving field of residential energy management, optimizing energy use while minimizing costs has become increasingly critical. This paper explores the problem of optimizing a home energy management system by using Model Predictive Control (MPC) to boost economic efficiency and battery longevity. By integrating market prices, historical energy demand, and solar data into the MPC algorithm, it manages energy storage predictively. Additionally, the incorporation of the parameter that controls the discharge rate allows for the smoothing of the control signal. The study examines operational parameters, disturbance responses, and system configurations. The developed algorithm minimizes electricity costs and extends battery life, offering homeowners predictive savings and energy management insights with a minimal user interface.

Low-Voltage Grid Control Based on Data-Driven State Estimation and Online Feedback Optimization

Jano Schubert[1,2], Edwin Mora[1], Mathias Duckheim[1], Stefan Niessen[1,2]
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The operation of low-voltage distribution grids is facing increasingly complex challenges with the integration of Distributed Energy Resources (DERs).To ensure secure grid operation, Distribution System Operators can utilize active network management with autonomous monitoring and control systems. In this paper, we propose a novel two-stage controller for LV grids that combines data-driven state estimation and model-free Online Feedback Optimization (OFO). The first stage is a data-driven state estimator that leverages real-time measurements at the substation and historical smart meter data to compute real-time voltage estimates at smart meter nodes.The second stage is an OFO algorithm fed with the voltage estimates obtained in the first stage. The OFO algorithm is designed to mitigate voltage band violations while minimizing DER intervention actions. Simulation experiments conducted on a benchmark LV grid with high DER penetration and realistic load and generation profiles demonstrate the ability of the proposed controller to mitigate both undervoltage and overvoltage situations while maintaining DER control interventions at a minimum.

A Fuzzy Control Strategy for Coordination of Solar PV and Battery System in a Microgrid

Ali Karimi[1], Mahmoud Zadehbagheri[1], Ali Reza Abbas[2], Igor Kuzle[3]
[1]Islamic Azad University, Iran, Islamic Republic of; [2]Faculty of Engineering, Fasa University; [3]University of Zagreb Faculty of electrical engineering and computing

In this paper, a robust fuzzy control strategy is proposed for the coordination of photovoltaic system with maximum power point tracking control and battery storage control to support the voltage and frequency in an island grid. Control strategies, shows an effective coordination among Voltage control and frequency of converter, Control of Maximum Power Point Tracking, Charging and discharging the battery. Regarding to be fix of integrator controller and Proportional controller gain coefficients in different modes, the system should adjust the value of these controllers to a specific value that can improve performance in different operating modes. Considering the capabilities of the fuzzy algorithm in setting variables with changing conditions, in this paper, using the fuzzy algorithm, we set the integral and proportional gain coefficient of the PI controllers based on the error rate. Setting these coefficients based on the type of system mode and using the fuzzy algorithm is one of the objectives of this plan for precise control of the controller coefficients to improve the performance of the system in various operating situations. The results show an effective coordination between DGs in the micro-grid, taking into account the variability of the solar radiation system and the status of the battery charging constraint.

Reinforcement Learning for FACTS Setpoint Control with Limited Information

Magnus Tarle[1,3], Mats Larsson[2], Gunnar Ingeström[3], Mårten Björkman[1]
[1]KTH, Stockholm, Sweden; [2]Hitachi Energy, Baden-Dättwil, Switzerland; [3]HItachi Energy, Västerås, Sweden

A coordinated control of Flexible AC Transmission Systems (FACTS) reference setpoints is often absent in real systems. Despite the power quality gains demonstrated in studies, this absence can partly be derived from challenges with model-based control. As promising alternative methods of control, data driven approaches based on reinforcement learning (RL) have been considered. In this work, we study the potential gains in power quality using RL while recognizing the increasing number of installed Phasor Measurement Units, providing limited but reliable information. We demonstrate on the IEEE 14-bus and IEEE 57-bus systems that by adding a few measurements per FACTS device and a constraint violation signal, an RL scheme may significantly improve power quality compared to a baseline of fixed setpoints. To evaluate robustness, several configurations are simulated and for larger systems, we identify unobserved constraint violations as the main risk and propose a potential path for new research.

Flexible operation model of a tidal range scheme with pumping turbines

Tong Zhang, Meysam Qadrdan, Reza Ahmadian, Man Yue Lam
Cardiff University, United Kingdom

Tidal range energy is a renewable energy source that harvests the gravitational potential energy of seawater derived from tide level variation. Tidal energy generation is highly predictable and can be used as a reliable energy source. The generation capability of a tidal range scheme could be increased by utilising reversible turbines with pumping functions that increase the water level difference. Furthermore, adopting an adjustable number of active turbines during generating and pumping can help the TRS better regulating its electricity generation. Therefore, this paper proposed an optimal operation model of a tidal range scheme with reversible turbines, in which the tidal range scheme could work with a flexible generation plan to maximise its total energy generation or daily revenue. A case study is conducted to demonstrate how the operation profiles, generation and revenue vary when the tidal range scheme incorporates the pumping turbines and adopts a flexible operation plan.

Comparison of Hierarchical MPC-Based Energy Management Strategies for Residential Microgrids

Wenyan Ye[1], Hao-Husan Chang[1], Ping Zhang[1], Lars Quakernack[2], Michael Kelker[2], Jens Haubrock[2]
[1]Institute of Automatic Control, University of Kaiserslautern-Landau, Germany; [2]Institute for Technical Energy Systems, Bielefeld University of Applied Sciences and Arts, Germany

This paper compares three structures of model predictive control (MPC) approaches to address challenges in residential microgrids, mainly due to the incoincident time slot of available energy production and energy consumption. The control objective is to minimize the building energy consumption while fulfilling various constraints. The optimization problem takes into account the fluctuations in the energy demand. Through simulations, we evaluate the control performance under each approach, highlighting their trade-offs and suitability for different microgrid configurations. The simulation results offer valuable insights into the potential of MPC in optimizing residential energy management, guiding the selection of energy management system approaches that best align with specific operational goals.

Paper Session 40: Reserve markets

Time: Thursday, 17/Oct/2024: 9:00am - 11:00am **Location:** Orlando 1C

Presentations:

Optimized Bidding Strategies for Industrial Steam Networks in Multiple Energy and Reserve Markets

Luciana Marques[1], Lina Silva-Rodriguez[1], Brida V. Mbuwir[1], Carlo Manna[1], Roman Cantu Rodriguez[2], Tom Cuypers[1]
[1]VITO/Energyville, Belgium; [2]KU Leuven/Energyville, Belgium

To increase the flexibility available from the industrial sector, this paper proposes an optimization model to valorize the flexibility from a steam network in a multi-market (gas, day-ahead electricity, balancing capacity and balancing energy). The model determines the optimal bidding behavior of the industrial process considering all markets constraints and the steam network operational limits. We run the model using 2023 real prices from the Belgian electricity and balancing markets, and steam demand profiles from a Belgian chemical industry. Results showcase that the strategic decision between the position in the day-ahead market (as a consumer or as a generator) and later provision of flexibility (upward or downward) should take into account the expected relation between the day-ahead, capacity and energy markets prices, which is established by the unit revenue parameter that we propose.

Management Strategies for Battery Storage Systems Participating in Joint Energy and Reserve Markets

Ahmed MOHAMED[1,2], Rémy RIGO-MARIANI[1], Vincent DEBUSSCHERE[1], Lionel PIN[2]
[1]Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, 38000 Grenoble, France; [2]Atos Worldgrid Solutions for Energy and Utilities, Grenoble, 38130, France

Battery Energy Storage Systems (BESS) are increasingly recognized as crucial participants in the energy market, offering versatile grid services. To maximize profitability, this paper explores the opportunity to stack services while participating in the Day-Ahead market (DA) and the provision of Frequency Containment Reserve (FCR). Look-ahead optimization is proposed assuming that energy and reserve prices and requirements are known in order to examine the interplay between DA and FCR products. Especially, two management strategies are proposed to provide the two services and hence evaluate the maximum theoretical profits assuming perfect price forecast. Strategy (a) allows the participation in only one service at each hour of the day. Strategy (b) enables the simultaneous provision of the two services all the time. Additionally, a baseline case is introduced while allowing the BESS to participate only in one market. The simulations use historical data to compute the DA energy and FCR schedule. Furthermore, a storage degradation analysis is performed to evaluate the effect of the predicted operations on the battery lifetime, considering both cycling and calendar aging.

Development of an Instantaneous Reserve Market and Storage Park Based on Inertia Safety Levels

Christoph Sauer, Christian Rinne, Martin Wolter
Otto von Guericke University Magdeburg, Germany

This paper introduces an instantaneous reserve (IR) market to meet the demand for IR at a low cost. It provides initial insights into trading prices that will emerge in the new electricity market. The German power plant park is used as the basis for the methodology of the day-ahead market and the new IR market. Taking load and generation forecasts into account, a new storage park is optimized for the IR market. The hourly security level has a significant influence on the size and costs of the IR market. It is shown that wind turbines with storage systems, synchronous condensers as well as battery storage systems can benefit from this market. In addition, forecasts for future IR requirements and the associated storage costs are presented.

Decision-Focused Learning for Optimized Participation of an Industrial Consumer in Energy-Only and Reserve Markets

Chloé Dupont[1,2], Pietro Favaro[1], François Vallée[1], Bruno Francois[2], Jean-François Toubeau[1]
[1]Power Systems and Markets Research Group, University of Mons, Mons, Belgium; [2]Univ. Lille, Arts et Metiers Institute of Technology, Centrale Lille, Junia, ULR 2697 - L2EP, F-59000 Lille, France

Many decision-making applications in modern power systems involve solving two sequential problems: (i) predicting unknown parameters and (ii) optimizing decisions under prediction uncertainty. Conventionally, these two stages are applied independently: prediction tools are trained to minimize statistical errors (with the true observations), without considering their impact on the downstream decision-making problem. In contrast, this paper investigates Decision-Focused Learning which aims at integrating the optimization model into the training pipeline with the ambition to minimize the sub-optimality of the decisions arising from forecast inaccuracies. This end-to- end learning approach is applied to the day-ahead scheduling problem of a flexible consumer participating in both energy-only and reserve markets. A machine learning model is used to forecast the day-ahead energy prices under a price-taker assumption. This forecaster is trained using a value-oriented loss function, referred to as regret which evaluates the quality of the operation decisions. Results demonstrate the ability of Decision-Focused Learning to improve decision quality, leading to economic benefits for the consumer. Outcomes also reveal initializing training with a conventional least-squared-error, before using the regret, enhances model performance.

Impact of Uncertain Data in Robust Optimal Bidding of RVPP in Energy and Reserve Markets

Hadi Nemati, **Pedro Sanchez-Martin, Lukas Sigrist, Alvaro Ortega**
Comillas Pontifical University, Spain

Different probability distributions yield different outcomes of optimization problems under uncertainty such as the optimal bidding problem of RES-only Virtual Power Plant (RVPP). Robust Optimization represents uncertainties by sets, which are parameterized according to the assumed underlying probability distributions. This paper analyzes the impact of uncertain data related to energy and reserve market prices as well as non-dispatchable renewable production and demand on the outcomes of the optimal RVPP electricity market bidding problem. Different parameters related to the accuracy and shape of data forecast are analyzed and their impact on the RVPP bidding strategy is obtained by sensitivity analysis.

Optimal Sizing and Economic Valuation of an Energy Storage System Participating in Joint Energy and Reserve Markets

Ahmed MOHAMED[1,2], Rémy RIGO-MARIANI[1], Vincent DEBUSSCHERE[1], Lionel PIN[2]
[1]Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, 38000 Grenoble, France; [2]Atos Worldgrid Solutions for Energy and Utilities, Grenoble, 38130, France

This paper evaluates the participation of a gridconnected Battery Energy Storage System (BESS), in the Day ahead (DA) and Frequency Containment Reserve (FCR) markets in Europe. Through annual simulations, the study demonstrates the substantial revenue potential of providing multiple services (DA+FCR) by a single battery, resulting in a significant 74% increase compared to the sum of individual markets' participation. Furthermore, a comprehensive sensitivity analysis is conducted to determine the optimal sizing of the battery, revealing the advantages of higher power-to-energy ratios in terms of profitability and payback periods. An oscillation penalty is introduced to mitigate the battery degradation by reducing the battery's depth of discharge. This leads to a reduction of battery capacity fade behavior by 7 % while incurring only a marginal 9 % loss in the annual revenues. These findings contribute valuable insights for decision-making in deploying grid-connected batteries, considering revenue optimization and battery performances.

Operation of an industrial green amonnia fuel hub participating in secondary reserve markets

António Coelho, Filipe Soares
INESC TEC, Portugal

Green ammonia production stands as a pivotal component in the transition towards sustainable energy and agriculture, poised to revolutionize numerous industries. This paper presents a model predictive control framework for industrial green ammonia fuel hubs to engage in electricity, hydrogen, and oxygen markets, addressing both economic and technical considerations. By evaluating scenarios with and without battery storage, this study demonstrates the potential for increased profitability and energy independence through secondary reserve market participation, alongside insights into the economic viability of photovoltaic investments. These findings underscore the importance of considering market dynamics and technological integration in the sustainable operation of green ammonia production hubs.

Quantifying the Impact of Multi-area Policies on Operational Reserve Adequacy and Market Prices: a Sequential Monte Carlo-based Approach

Inês Alves[1,2], Sanja Duvnjak-Zarkovic[3], Leonel Carvalho[2], Vladimiro Miranda[2,4], Mauro Rosa[4,5], Pedro Vieria[4,6]
[1]FEUP, Portugal; [2]INESC TEC, Portugal; [3]KTH Royal Institute of Technology, Sweden; [4]INESC P&D Brasil, Brazil; [5]UFSC, Brazil; [6]IFSC, Brazil

This paper addresses the challenges associated with integrating large shares of renewable energy sources into the power system, focusing on managing operational reserves in multi-area systems and their long-term adequacy. Unlike previous studies, this paper investigates the long-term impact of procurement and activation of operational reserve in adjacent areas, considering energy scheduling and interconnection line constraints. Three procurement schemes for multi-area energy and reserve exchanges are proposed and analyzed through Sequential Monte Carlo Simulation. These schemes vary in their approach to interconnection line capacity constraints and the simultaneous or phased procurement of energy and synchronized reserve. The mathematical operationalization of these schemes is achieved through simple linear programming models, facilitating the quantification of marginal prices for both products. The impact of these schemes on operational reserve adequacy, marginal prices, and interconnection line utilization is demonstrated using configurations of the IEEE RTS 96 system. This analysis incorporates long-term uncertainty and diverse operational conditions and provides valuable insights into the interplay between energy and reserve procurement strategies in multi-area systems.

On Short-Term Variations of RES Power Generation and Associated Secondary Regulation Demand

Dubravko Sabolic, Igor Ivankovic, Antun Andric, Alan Zupan
HOPS, Zagreb, Croatia

Incorporating Renewable Energy Sources (RES) into power systems typically focuses on ensuring adequate energy production, but the variability in this production sometimes may get underestimated. Our research deals with 15-minute production data from RES available on the ENTSO-E Transparency platform, concentrating on Germany, Austria, and Hungary. Spanning nearly eight years of continuous data, our findings reveal that as more RES capacity is added, the marginal need for additional regulation reserve capacity per unit of new RES diminishes. This indicates that portfolio diversification statistically mitigates short-term variability to a significant, but limited extent.

Paper Session 41: Power system equipment

Time: Thursday, 17/Oct/2024: 9:00am - 11:00am **Location:** Koločep 5

Presentations:

Determining Cost-Efficient Sequence of Condition Inspection Based on Estimated Condition Data

Guido Andreesen[1], **Madis Leinakse**[1], **Jako Kilter**[1], **Mart Landsberg**[2]
[1]TalTech, Estonia; [2]Elering AS

Commonly, the known data about the equipment condition is used in asset management of substations. If not having sufficient data or it can be limited, asset management becomes less efficient and can not avoid the potential failures with significant consequences. For these cases, the process proposed in this paper is intended. It is based on the usage of known data (Health Index values) to estimate the condition of equipment with unknown data. Next, it is implemented in a process to determine the cost-efficient sequence of equipment inspections. The process has four beneficial outcomes, such as decreasing the uncertainty of data, avoiding failures with higher cost, reducing the overall inspection cost and obtaining exact data for inspected equipment. The methodology is tested on the IEEE 39-bus power system. The obtained results indicated the reduction of inspection cost by 80 \% in the example case, and avoiding failures with higher cost. The process is mainly intended for equipment with unknown or limited data.

Maximum Risk Calculation Process for Individual Substation Equipment in Primary Side

Guido Andreesen[1], **Madis Leinakse**[1], **Jako Kilter**[1], **Mart Landsberg**[2]
[1]TalTech, Estonia; [2]Elering AS

Commonly, the risk is obtained for specific equipment groups in the substations. Yet, there are many other equipment groups, which can also have higher risk. This paper presents the hybrid solution to calculate the maximum risk of all the individual equipment of substation primary side. It combines the power flow with contingency analysis done in PSSE and dedicated risk calculation logic developed in Python. In PSSE, load curtailment values are obtained in accordance to the contingency descriptions. These represents a part of an equipment failure consequences. The main risk calculation logic is in Python. It uses the power system data and contingency analysis results to combine them with individual substation equipment. It includes also inputs for failure probability, replacement times, replacement costs, load curtailment cost and substation types. It is tested on the IEEE 39-bus power system. The results indicated the different impact to the equipment risk based on the changes in inputs. Based on that, it is possible to determine the parameters sensitivity to individual equipment and adjust the asset management decisions accordingly.

The weather impact on corona losses of 330 kV aging transmission lines

Pradeep Kumar Gupta, **Kaur Tuttelberg**, **Jako Kilter**
Tallinn University of Technology, Estonia

The main objective of this work is to investigate the characteristics of different weather parameters on corona losses for aging overhead transmission lines using synchronized phasor measurements. The study is conducted for a long-term assessment using two years of data based on PMU measurements collected from Estonian TSO and weather data from the Estonian Environmental Agency. This research gives insight into information about weather factors influencing corona loss for two different aged transmission lines using a statistical graphical study. It is generally believed that aged transmission lines are more sensitive as they are exposed to different environmental conditions, leading to the deterioration of the line performances. Therefore, it would seem appropriate to investigate the factors influencing corona loss in an overhead transmission line. These results can be the basis for transmission system operators to reduce the power loss purchase and improve corona loss management under complex weather conditions to increase power grid efficiency.

Feasibility Study of a Medium Voltage 12 kV, 1 kA, LC DC Circuit Breaker

Dragan Jovcic
University of Aberdeen, United Kingdom

The paper studies design options for a 12 kV, 1 kA LC DC Circuit Breaker with multiple possible applications in future MV DC systems. The stresses on all main components are analysed under conservative assumptions, and evaluation of their implementation is provided. The ultrafast disconnector is the key component that is assumed to have 6 break points with 2.5 m/s rod velocity and 2 ms opening time. The peak current stress is obtained on detailed PSCAD simulation model as Icp=4.7 kA, with conservative assumptions for protection system. The parallel capacitor is the largest component, with the calculated main parameters VCs=18 kV, Cs=250 µF, and estimated weight of m=80 kg. The total energy dissipation is 220 kJ, that can be accommodated with 2 standard 5 kV railway arresters (210 kJ), while Cs takes another 10 kJ. The low-voltage pre-charged film capacitor Cch =6mF, 0.8 kV is of modest weight. It is concluded that the design is feasible with expected competitive performance and cost, relative to the commercial HV DC breakers.

Capacitor-based Medium Voltage Test System for DC Circuit Breakers

Ibrahim A. Shehu, Dragan Jovcic
University of Aberdeen, United Kingdom

This paper studies the design of a capacitor-based 12 kV test circuit for evaluating the performance of DC Circuit Breakers (DCCB) in Medium Voltage DC (MVDC) applications. The proposed circuit offers a cost-effective solution for realistic testing in research laboratories. It also accommodates current reversal during interruption, as required with latest DCCB technologies. The paper details the key test circuit requirements, component selection process, and a comprehensive PSCAD simulation model. The simulation model analyzes the operation of both the test circuit and DCCB under various test conditions, including charging circuit performance, discharge circuit response with the DCCB closed, and fault current interruption with different current thresholds. The results demonstrate that the MV DCCB test circuit achieves the desired peak current, it's derivative, and energy, while post-fault voltage stress is lower than in real circuits.

High Voltage Circuit Breaker Health Index Evaluation Considering Measurement Accuracy

Sajjad Asefi[1], **Jako Kilter**[1], **Ebrahim Shayesteh**[2], **Patrik Hilber**[2], **Tommie Lindquist**[3]
[1]Tallinn University of Technology, Estonia; [2]KTH Royal Institute of Technology, Sweden; [3]RISE – Research Institutes of Sweden, Sweden

The reliable operation of high voltage circuit breakers (HVCBs) is crucial for ensuring the security of the power system. Therefore, the accurate calculation of the health index (HI) for proper maintenance of HVCBs is essential. However, existing methods often neglect two key challenges: proper signal preprocessing for feature extraction and incorporating measurement accuracy into the HI model. This paper addresses these shortcomings by proposing a methodology for improving HI representation for HVCBs. We account for measurement accuracy by considering the varying precision of different monitoring schemes. Furthermore, the impact of signal preprocessing on the condition monitoring data is analyzed. Finally, a case study exhibits how the HI based failure rate can affect the reliability centered maintenance scheduling in the power system.

Transformer-based Drum-level Prediction in a Boiler Plant with Delayed Relations among Multivariates

Gang Su[1], **Sun Yang**[2], **Zhishuai Li**[1], **Ziyue Li**[3]
[1]SenseTime Research, China; [2]Peking University, China; [3]University of Cologne, Germany

The steam drum water level is a critical parameter that directly impacts the safety and efficiency of power plant operations. However, predicting the drum water level in boilers is challenging due to complex non-linear process dynamics originating from long-time delays and interrelations, as well as measurement noise. This paper investigates the application of Transformer-based models for predicting drum water levels in a steam boiler plant. Leveraging the capabilities of Transformer architectures, this study aims to develop an accurate and robust predictive framework to anticipate water level fluctuations and facilitate proactive control strategies. To this end, a prudent pipeline is proposed, including 1) data preprocess, 2) causal relation analysis, 3) delay inference, 4) variable augmentation, and 5) prediction. Through extensive experimentation and analysis, the effectiveness of Transformer-based approaches in steam drum water level prediction is evaluated, highlighting their potential to enhance operational stability and optimize plant performance.

Analytical models to quantify the vulnerability of overhead line towers to scouring due to flash floods

Andrea Pitto[1], **Emanuele Ciapessoni**[1], **Diego Cirio**[1], **Silverio Casulli**[2], **Federico Falorni**[2], **Francesca Scavo**[2]
[1]Ricerca sul Sistema Energetico RSE S.p.A.; [2]Terna Corporate S.p.A.

Hydrogeological phenomena may represent a serious threat for the power system. Transmission System Operators (TSOs) in countries exposed to hydrogeological phenomena could benefit from methodologies and models to quantify the risk of load disruptions due to this kind of threats, in order to assess and enhance the resilience of their systems. In this context, the paper proposes a physics-inspired, analytical model to quantify the vulnerability of overhead line tower footings to mechanical instability induced by a flood-related mechanism i.e. scouring (removal of terrain from the top of tower footing due to flash floods). Simulations on a simple case study show that the model represents a good tradeoff between accuracy and scalability, and its outcome, i.e. the conditional failure probability of footing instability, is sensitive to relevant features such as soil characteristics, intensity of the flood-related phenomena, foundation design criteria.

Context-Driven Framework for Maintenance Optimization in Power Stations

Sarala Mohana Naidu[1], **Ning Xiong**[2], **Juergen Schuderer**[3], **Mohammad Ghomi**[1]
[1]HitachiEnergy, Mälardalens University; [2]Mälardalens University; [3]Hitachi Energy, Turgi Aargau, Switzerland

In the power industry, effective maintenance decisionmaking is crucial for ensuring reliability and availability of assets. This paper proposes a practical framework that addresses the challenge of aligning desired expectations on Availability metric, with the integration of existing practices and the extension to data-driven methods. The framework incorporates key contextual factors as elements, from maintenance maturity levels to business case justification, and offers a structured approach to navigate two strategies: business pull and technology push. While the business pull strategy prioritizes outcome-driven approach and aligns with the compatible data, the technology push strategy derives the outcome by focusing on the data-driven predictive methods. Additional value add from the technology push is to support the design and engineering with the identification of design margins for effective optimization. Enabling early failure detection weeks ahead of failure allowing scope of planning and preparation for maintenance, reduces costs involved. A discussion on the choice of the path based on context is also presented. Indicating that data-driven predictive methods offer potential solutions when traditional methods fall short, particularly due to the complexity of new problems, decision-making uncertainties, and constantly evolving environment in the domain.

Paper Session 42: Data-driven approach

Time: Thursday, 17/Oct/2024: 9:00am - 11:00am **Location:** Lokrum 4

Presentations:

Data-driven Approach for High Loss Detection in LV Networks

José Pedro Paulos[1], **Pedro Macedo**[1], **Ricardo Bessa**[1], **José Nuno Fidalgo**[1,2], **José Oliveira**[3]
[1]INESC TEC, Portugal; [2]University of Porto; [3]ENEIDA

This article proposes a methodology for high loss detection in LV network, based on a very small set of commonly available data/metadata from networks connected to an MV/LV substation. The approach is based on a combination of predictors from several distinct categories, including network data, metadata, and measured smart meter data. Several independent groups of unranked real networks were simulated, and it was possible to find the top ten networks with the highest level of losses with a very satisfactory success rate (76% to 98%), depending on selected groupings folds. Due to the impracticability of analyzing all LV networks, the identification of the highest loss ones is essential for the definition of loss reduction planning since, with this list filtering, it is possible to determine with a good degree of certainty which networks require maintenance or upgrade.

Practical Real-Time Data-Driven Approach for District Cooling Plant Operational Optimization

Ivan Sukhanov[1,2], **Ahmet Köse**[1,2], **Lauri Loo**[1], **Aleksei Tepljakov**[2], **Eduard Petlenkov**[2], **Juri Belikov**[2]
[1]R8 Technologies OÜ, Estonia; [2]Tallinn University of Technology, Estonia

The real estate sector has a dramatic impact on global carbon dioxide emissions, approximately 70\% of the emissions are produced by or are due to building operations. With rising global electricity costs and climate change mitigation, there is a significant interest in energy-efficient solutions for building operations. Although comprehensive cooling systems are widespread throughout Europe, most of them lack robust machine learning-based applications in practice. This work presents an application that optimizes in real-time the operation of the district cooling plant based on a machine-learning model. A more than 35\% reduction in energy costs is achieved by implementing the model with optimization including hourly electricity market prices, weather forecasts, and estimated demand in buildings. The application is deployed during the cooling season and is driven by real data collected at 15-minute intervals.

Data-driven Approaches for Anomaly Detection in Low-Voltage Grid Net Power

Razieh Balouchi Anaraki, Rajkumar Palaniappan, Ulf Häger, Christian Rehtanz
TU Dortmund, Germany

This paper examines the anomaly in low-voltage (LV) grids, which are becoming more complex due to the widespread adoption of distributed energy sources such as electric vehicles, electrical heat pumps, and increasing photovoltaic installations. A variety of data-driven techniques, from statistical analysis to artificial intelligence, are used to analyze data from the grid. The focus of the research is on detecting unexpected changes in energy usage, unauthorized photovoltaic installations, and sudden changes in grid loads, to identify significant deviations from expected patterns. The results show that the suitability of each method depends on the specific objectives of grid operators and effectively differentiates between short-term and long-term anomalies. The anomaly detection capability improves network operators' understanding of current network dynamics and enables them to better anticipate and manage emerging patterns in the future.

A data-driven architecture for adaptive decentralized charging and energy management

Dominik Ascher, **Sahin Albayrak**
Technical University Berlin

Distributed energy resources (DER), renewable energy sources (RES) and electric vehicles (EV) pose considerable challenges with respect to their efficient integration within the power system. Operation and control strategies for energy management systems (EMS) and charging station management systems (CSMS) are required to be highly adaptable and able to rapidly incorporate information received about power system supplies and demands to maintain efficient system operation. Here, information integration and monitoring is particularly crucial in use cases such as smart charging of EV and vehicle-to-grid (V2G) interactions. For this, standardization is a key challenge, as communication standards such as OCPP and EEBus facilitate interoperability, as well as monitoring and controlling aligned devices using shared data models and protocols. In this work, a data-driven architecture for integrated and adaptive charging and energy management is presented, which allows for mapping of logical system states and actions to concrete protocol data models. Based on actual and predicted information received with respect to system state, control strategies can be derived and adapted during run-time to address changed system requirements, behavior or system topologies of DER and charging stations (CS).

Islanding Detection In Bulk Power Systems: A Data-Driven Approach

Hêmin Golpîra[1], **Igor Kuzle**[2]
[1]University of Kurdistan, Iran; [2]University of Zagreb, Croatia

An attempt is made to propose a data-driven approach for detecting islanding in large-scale power systems. The method utilizes data collected by phasor measurement units (PMUs) to develop an equivalent model of the system. In this model, the system is represented by multiple centers of inertia (COIs) linked to a central point known as the center of gravity (COG) through fictitious reactances. These reactances, which are interpreted as the electrical distances between the local COIs and the COG, serve as a valuable indicator for detecting islanding. The occurrence of islanding can be identified by comparing the temporal trends of electrical distance variations across different areas. The effectiveness of the proposed methodologies is evaluated using simulated data from the 73-bus IEEE test system.

Data-Driven Topology Generation with Physics-Guidance in LV Distribution Networks

Dong Liu[1], Juan Giraldo[2], Peter Palensky[1], Pedro Vergara[1]

[1]Intelligent Electrical Power Grids, Delft University of Technology, The Netherlands; [2]Energy Transition Studies, Netherlands Organisation for Applied Scientific Research, The Netherlands

Low-voltage distribution networks (LVDNs) topology is significant for distributed energy resources (DERs) integration, and network operation management, among others. However, LVDN topology is a difficult task due to the outdated recordings of networks, the uncertainty of DERs and data privacy. To address this issue, a data-driven topology generation approach for LVDNs is proposed based on open GIS and voltage magnitude data. The proposed approach aims to generate a topology with an accurate number of main feeders and sub-branches for adjacent substations. The boundaries between adjacent substations are first identified by using the hierarchical clustering algorithm to cluster normalized voltage magnitude. Given the boundaries and the location of LV transformers, a simplified hierarchical minimum spanning tree algorithm is adopted to generate graph topologies using pre-processed GIS data, which simultaneously verifies the number of cables under the streets. Finally, the endpoints of each feeder are estimated by hierarchically clustering the transformed Pearson correlation coefficient of voltage magnitude. The feasibility and robustness of the proposed approach are evaluated on two real radial LVDNs in the Netherlands.

Training Data Generation Strategies for Data-driven Security Assessment of Low Voltage Smart Grids.

Juan J. Cuenca[1,2], Emanuel Aldea[3], Eloann Le Guern-Dall'o[2], Raphaël Féraud[4], Guy Camilleri[1], Anne Blavette[2]

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Control of small-scale resources in low and medium voltage electricity networks is being decentralised, which increases the need and frequency of use of smart grid security assessment tools. This paper compares three data-driven approaches to classify if a smart grid is “safe” or “unsafe” (i.e., if grid constraints are respected) given an operational point as input: decision trees, gradient tree boosting and deep neural networks. Five novel training data generation strategies are proposed as alternatives to the standard random generation approach, aiming for data-driven models that generalise realistic scenarios better. Simulations are conducted using the IEEE European low voltage test network. Trained models are tested following trends from the literature and using realistic scenarios from the test network documentation, and electric vehicle charging patterns. Our results highlight the inadequacy of the current training data generation strategy, and offer better-performing alternatives. At last, we report on computational times dedicated to training our models, and discuss potential implications for future data-driven smart grid applications.

Anomaly Detection in Low-Voltage Grids with LSTM Autoencoders: A Study on Future Scenario Impacts

Razieh Balouchi Anaraki, Rajkumar Palaniappan, Ulf Häger, Christian Rehtanz

TU Dortmund, Germany

This paper presents a method using Long Short-Term Memory (LSTM) autoencoders for anomaly detection in time series net power data, specifically focusing on low voltage (LV) grids. The rapid integration of distributed energy resources (DERs) and new loads introduces significant operational challenges, such as reverse power flow and pattern changes. The data-driven approach, such as LSTM autoencoders, effectively identifies significant deviations in patterns without the need for labeled data. Due to the unsupervised nature of the problem, traditional labels for training are unavailable. The study highlights the model's ability to detect anomalies by considering future scenarios in the grid, such as unaccounted photovoltaic (PV) systems and new loads. Evaluations on real LV grid data, characterized by high PV power generation, show that this method detected 107 out of 128 anomalies. These results highlight the potential of LSTM autoencoders to enhance anomaly detection, providing a robust solution for managing and analyzing large energy usage datasets.

Data-Driven Validation of Photovoltaic Performance in the Climatic Context of Malta

Brian Bartolo[1,2,3,4], Brian Azzopardi[1,4], Kenneth Scerri[1,4]

[1]The Foundation for Innovation and Research - Malta, Malta; [2]Malta College of Arts, Science and Technology (MCAST); [3]Azzopardi & Associates; [4]The University of Malta (UM)

Optimizing photovoltaic (PV) performance in regions with challenging climates is essential for maximizing energy efficiency. This study addresses the unique environmental conditions in Malta, such as high temperatures and atmospheric salinity, that impact PV systems. The framework developed aims to validate the accuracy and reliability of PV data using advanced acquisition techniques. By correlating solar irradiance with DC current and applying statistical tests including the T-test, anomalies such as shading and system faults are identified. Results highlight the effectiveness of this approach in detecting performance issues, ensuring data accuracy, and enhancing PV system reliability. This scalable solution not only improves fault and shading detection but also contributes to optimizing PV performance in Malta and other regions with similar climates.

Paper Session 43: Heat pumps

Time: Thursday, 17/Oct/2024: 11:30am - 1:00pm **Location:** Orlando 1A

Presentations:

Response Allocation of Domestic Hybrid Heat Pumps Flexibility for Congestion Management

Lingkang Jin[1], Xin Li[1], Stefan de Lange[1], Han Slootweg[1,2], Nikolaos G. Paterakis[1]
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Congestion management is crucial for maintaining the required reliability and efficiency of the electrical distribution grid. In this context, the use of electricity-natural gas hybrid heat pumps which can offer great potential flexibility, is worthy of more research. To quantitatively assess the flexibility of hybrid domestic heat pumps in a cluster of residential users and to investigate management strategies to allocate the required response among them, an optimization model has been developed in this paper. The model determines the energy carrier that is used by the hybrid heat pumps such that a collective response to electrical power limitations can be achieved. Results obtained for a cluster of eighteen residential users indicate that various response management strategies, while offering similar levels of flexibility and incurring comparable additional costs at the aggregate level, can lead to significant disparity in fairness. Specifically, the Jain's fairness index is found to increase by 44.6% when employing a power-driven response management approach compared to a case without response management.

Demand-Side Flexibility through Real-Time Control of Heating Systems using Digital Twin

<u>Thien Phong Tran</u>[1], Quoc Tuan Tran[1], Minh Tri Le[2], Raphael Caire[2]
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In the scope of energy transition, the increasing penetration of intermittent renewable energy generation has put the electrical system against a great challenge: real-time power balance between supply and demand. In this context, heating systems stand out as one of the most decisive controllable loads in commercial buildings and residential households. Managing peak load consumption by controlling electric heaters has excellent potential in demand-side management. This paper presents a method to reduce peak load consumption using a fuzzy-logic-based real-time control of heating systems while minimizing the rebound effect. The proposed solution is evaluated based on a digital twin of a real low-voltage distribution network containing 50 houses under different conditions of desired power exchange. This technique falls within the framework of the smart grid concept in order to make load consumption more active and intelligent, thereby increasing flexibility on the demand side.

Flexible operation of heat pumps in a decarbonised power system

<u>Qikun Chen</u>, Meysam Qadrdan
Cardiff University, United Kingdom

Heat pumps emerge as a potential solution, leveraging the thermal inertia of building materials to provide flexibility to the power system. This paper presents a model of the power transmission system with flexible heat pumps, using the Great Britain in 2050 scenario as a case study. Four scenarios with different indoor temperature constraints are defined, to clarify the value of heat pump flexibility. Results reveal that allowing variations within the thermal comfort enables adaptive heat pump operation, avoiding energy consumption during peak times and hence reducing 28\% cost. This is attributed to minimised reliance on costly hydrogen-fired generation compared to a scenario with stricter temperature constraints. Consequently, the Locational Marginal Price (LMP) of the power system with adequate flexibility is lower. Furthermore, this paper analyses the operational impact of heat pumps on other flexible units like electrolysers and energy storage units, finding a marginal effect on the latter. This is ascribed to these units' ability to alternate between charging and discharging states, ensuring operational stability. Additionally, the study highlights the benefits of heat pump flexibility in adapting to ambient temperature fluctuations. The results illustrate that heat pumps with higher flexibility can better mitigate cost increases caused by lower temperatures.

Droop Control of Heat Pumps in Integrated Electricity and District Heating Systems in Remote Community Microgrids

<u>Muhammad Abuelhamd Mahmoud Muhammad</u>, Claudio Adrián Cañizares
University of Waterloo, Canada

This paper proposes a droop control of Heat Pumps (HPs) in Integrated Electricity and Heating Systems (IEHSs) to manage energy exchanges between these networks to provide frequency regulation services in microgrids. Thus, demand management control of HPs is proposed to enhance primary frequency regulation, which facilitates the integration of variable Renewable Energy Sources (RESs). The developed droop control is applied, tested, and validated in a realistic community microgrid based on a remote community Electric Power Network (EPN) located at Kasabonika Lake First Nation (KLFN) in Northern Ontario. It is shown that the District Heating Network (DHN) facilitates the proper integration of RESs in isolated microgrids.

Comparative analysis of heat pump energy consumption patterns for residential buildings in the UK and Ireland

Dervla Scully, Adamantios Bampoulas, Eleni Mangina
School of Computer Science, University College Dublin, Ireland

Heat pumps can play a crucial role in achieving a decarbonised economy by replacing traditional combustion appliances and electrifying heating systems. Their ability to reduce carbon emissions and promote sustainability can significantly contribute to decarbonising Ireland's energy system. This transition requires increased electrification, changes in electricity usage patterns, investment in grid and generation capacity, and government support for household retrofitting. Optimised electricity usage can boost the share of renewable

energy.Irish energy providers often rely on UK energy data for decision-making, which raises concerns about its accuracy for Ireland. This paper addresses this issue by comparing energy consumption patterns in the UK and Ireland using the When2Heat dataset. It analyses the coefficient of performance, heat demand, and heat profiles of heat pumps. The simulation results indicate that the trends and distributions of the analysed figures are quite similar for both countries. Overall, the study provides insights into the potential for heat pumps to contribute to decarbonising the economy, as well as the importance of accurate energy data analysis for informing energy usage profiling in Ireland and the UK. The findings could inform policy decisions related to promoting the adoption of heat pumps and supporting the necessary grid and generation capacity needs for increased electrification.

Paper Session 44: Multi-energy systems

Time: Thursday, 17/Oct/2024: 11:30am - 1:00pm **Location:** Orlando 1B

Presentations:

Toward a Digital Twin of the Dutch EHV Network: Analyzing Future Multi-Energy Scenarios

Jonathan Aviles Cedeno, Jose Rueda, Anouk de Roos
Delft University of Technology, Netherlands

The integration of variable renewable energy sources (VRES) into the Dutch transmission network is imperative for transitioning to a sustainable energy future. However, incorporating large-scale VRES poses significant monitoring and control challenges, such as fluctuating power flows and grid stability concerns. This manuscript examines the role of digital twins as modern tools for supervising and controlling power systems. This work also presents the development of a synthetic digital model of the Dutch extra-high-voltage (EHV) network to analyze steady-state performance under high VRES penetration scenarios for 2030. Using DIgSILENT PowerFactory, automated by Python scripting, this study offers insights into the impacts of VRES and electrolyzers in power networks. By creating and analyzing various future scenarios, this research evaluates the effectiveness of digital models in scenario analysis, marking a significant step toward the implementation of comprehensive digital twins for future energy system planning and optimization.

Quantification of the Flexibility Enhancement with Micro-Scale Multi-Energy Coupling

Carlo Tajoli[1], Philipp Heer[2], Gabriela Hug[1]
[1]ETH Zurich, Switzerland; [2]Swiss Federal Laboratories for Materials Science and Technology, Switzerland

The rise of distributed and non-dispatchable generation in the distribution network presents challenges in maintaining voltage and power limits. Demand response has great potential to tackle those issues, particularly with thermal loads due to the thermal inertia of buildings and heat storage systems. Residential buildings are currently heated through different energy carriers, such as gas, electricity, and district heating, with each building usually having its own heating system. However, there is the possibility to connect neighboring buildings through hot water connections. The improvement of the system's flexibility by such micro-scale multi-energy coupling is analyzed using a model predictive control approach for the operation of the buildings and the concept of flexibility envelopes.

On the effect of thermal models on the operation of Multi-Energy Systems providing flexibility services

Simone Polimeni, Riccardo Lazzari
RSE SpA - Ricerca sul Sistema Energetico, Italy

Multi-Energy Systems (MES) are acknowledged for their potential to enhance energy system flexibility. However, they pose several challenges to the conventional optimization models in addressing local flexibility market interactions and fulfilling internal thermal demands. Given these considerations, the paper introduces a novel Energy Management System (EMS), with a hierarchical architecture that comprehensively addresses the thermal sub-section within a MES framework. The proposed methodology integrates an intra-hour Model Predictive Control (MPC) strategy, leveraging a linearized thermal model to balance heat equations and accurately describe thermal energy storage dynamics, incorporating considerations for delivery temperature to thermal loads during the provision of flexibility services. The results show that the conventional optimization model underestimates the operational cost of a MES by an amount ranging from 2% to 12%, depending on the delivery temperature to the thermal loads. Moreover, the proposed MPC can operate the MES in real-time with a reduced impact when compared to a rule-based thermal control (with savings of up to 7%), while ensuring commitment to local flexibility markets.

Coordinated flexibility scheduling in multi-carrier integrated energy systems: a model coupling approach

Christian Doh Dinga[1], Sander van Rijn[2], Laurens de Vries[3], Milos Cvetkovic[1]
[1]Electrical Sustainable Energy, Delft university of technology, The Netherlands; [2]Netherlands eScience Center, The Netherlands; [3]Engineering Systems and Services, Delft University of Technology, The Netherlands

Coordinating the interactions between increasingly interconnected energy sectors and carriers can lead to an efficient integration of variable renewable energy (VRE) resources, and a more cost-efficient energy transition. This paper proposes a model coupling approach that uses a market-based mechanism to efficiently coordinate the interactions among electricity, heat, and (hydrogen) gas systems, and (near) optimally schedule flexibility to maximize social welfare. The proposed approach is benchmarked against traditional co-optimization, and is shown to achieve comparable results with a moderate "optimality gap" in terms of reduction in system costs, peak load, and VRE curtailment. Its added value is the ability to enable each system to interact in an integrated energy system and locally optimize their decisions without sharing confidential information. The practical implication of this new approach is to provide a modeling environment where system operators and flexibility aggregators can obtain insights into the impacts of decarbonization of other parties on their systems - thereby avoiding myopic operational or investment decisions.

Global forecast models for the Belgian combined heat and power plant stock

Joris Depoortere[1], Xavier Weiss[2], Johan Driesen[1], Lars Nordstrom[2], Hussain Kazmi[1]
[1]KU Leuven, Belgium; [2]Royal Institute of Technology (KTH), Sweden

Decentralized energy generation, often in the form of industrial Combined Heat and Power (CHP) units, meets a significant part of the global energy demand. The power production from these units has to be forecast, both individually and collectively, to ensure balance and avoid congestion events on the power grid. However, despite its importance, forecasting CHP generation remains an under-studied problem. With increasing proliferation of renewable energy sources, large forecast errors for CHP generation are rapidly taking center-stage as well. In this paper, we propose a global, ensemble-based machine learning (ML) method to improve short-term forecasting accuracy. We demonstrate its efficacy using data from one hundred largest (industrial) CHP units in Belgium, showing a forecast error reduction of up to 27\% compared to the baseline method. This can greatly reduce balancing needs and costs, as well as congestion issues. Our results also highlight several nuances that must be kept in mind by grid operators and market players alike, including fitting global models that leverage data from many CHPs can lead to better forecast accuracy while incurring potential data privacy issues. Additionally, our analysis shows that there is no single best forecast model for all CHPs.

Scheduling Optimization of Integrated Electricity and Green Hydrogen Storage System for Transmission-Distribution Coordination

MIAORUI MA[1], Jin Yang[1], Chengwei Lou[1,2]
[1]University of Glasgow, United Kingdom; [2]China Agricultural University, China

This paper presents a new economic-oriented optimization for the coordinated scheduling of transmission and distribution systems, with a particular focus on integrating green hydrogen storage with offshore wind energy. The designed objective is to maximize annual revenue by considering both electricity and hydrogen revenues while reducing electricity purchase costs. With a case study, the optimal results of the coordinated system are obtained and analyzed. This is compared with results for a system that employs a single storage system located only at the production side. This comparison highlights the economic advantages of situating electrolyzers and hydrogen storage systems at both the production and consumption ends, and improved coordination between electricity transmission and distribution.

Paper Session 45: Reactive power control

Time: Thursday, 17/Oct/2024: 11:30am - 1:00pm **Location:** Orlando 1C

Presentations:

Optimal reactive power control for 3-phase EMT SVC grid-connected converter

Kouki Mohamed, Trajin Baptiste, Vidal Paul-etienne
UNIVERSITY OF TECHNOLOGY TARBES OCCITANIE PYRÉNÉES, France

Nowadays, the integration of power electronics into power systems has increased significantly. As a result, power grids were subject to numerous transformations. Hence, operations, power factor corrections, and voltage control of the grid-connected converters have become challenging tasks subject to enhancing the stability, reliability, and performance of the power grid. For this, we propose in this paper an advanced state-feedback control using the linear quadratic regulator (LQR) optimized by the metaheuristic method for a 2-level 3-phase voltage source converter (VSC) connected to the utility grid through an output L-type or LCL-type filter. The proposed methodology avoids the empirical trial-and-error technique for adjusting the weighting values of matrices Q and R respecting multi-objectives: (i) minimize control loop errors, (ii) minimize the overshoot, and (iii) respect suitable time constant. Thus, the optimal weighting matrices are provided using the multi-objectives Tunicate Swarm Algorithm-TSA. The effectiveness of the proposed methodology is tested on Electromagnetic Transients (EMT) VSC grid-connected systems and compared to standard vector control and advanced control (H_\infty). The proposed methodology permits important performance regulation of reactive power for the feasible VSC operation range and under perturbation conditions (short circuits,...).

Reactive Power Retrieval at the TSO-DSO Interface in Germany: Identifying Approaches and Challenges

Nadja Isabelle Belz, Steffen Schlegel, Jannes Grünberg, Dirk Westermann
Technische Universität Ilmenau, Germany

The decommissioning of conventional power plants in Germany leads to the reduction of reliable reactive power sources available in the transmission grid. The rising grid volatility and voltage sensitivity make it more difficult to predict critical voltage-related congestions and events. The use of the reactive power provided by renewable energy plants at the distribution grid level is proving to be promising for the congestion management of transmission system operators. The paper presents a testbed to evaluate, if procedures and regulations from existing congestion management instrument such as the German Redispatch 2.0 Process is suitable for reactive power. While previous research in the literature has been methodologically focused, the emphasis of this paper is on the presentation of the entire process in the testbed, to investigate the methodological and processual challenges during the retrieval at the TSO-DSO interface in C2RT. For this, relevant case studies are defined.

Navigating Grid Challenges: Voltage-Reactive Power Control in the Integration of Power-to-X Facilities

Jonathan Riofrio, Shi You, Tilman Weckesser
Technical University of Denmark - DTU, Denmark

This paper reviews the technical requirements for inverter-based facilities in modern power systems, focusing on Photovoltaic Power Plants (PVPPs), Wind Power Plants (WPPs), and Energy Storage Facilities (ESFs), with an emphasis on voltage-reactive power (V-Q) control. Case studies from in-force grid codes in Denmark and the United Kingdom are analyzed due to their high share of renewable energy and potential for Power-to-X (PtX) projects. Our findings suggest that existing requirements may apply to electrolysers, key components in PtX facilities, provided that their capability curves are properly defined, considering their electrochemical behavior, the

absence of DC-side energy generation, and inverter operation. The paper highlights the need for harmonizing grid codes, particularly for PtX equipment and electrolysers. Transmission System Operators (TSOs) are urged to establish mandatory V-Q control requirements, focusing on connection levels. Moreover, the proposed solutions indicate that electrolysers could mitigate voltage issues in large power systems with appropriate regulation, and future grid codes should define contribution grades for inverters in multi-energy systems to ensure compliance and seamless integration.

Damping Sensitivity Based Droop Control Strategy for Self-Stabilizing Microgrid Realization and Improved Reactive Power-Sharing

Prashant Pant[1], **Thomas Hamacher**[1], **Vedran Peric**[2]
[1]Technical University of Munich, Germany; [2]Aarhus University

This paper proposes an event-triggered adaptive droop control strategy that tunes the reactive droop coefficient in real-time to maintain microgrid stability and enhance reactive power-sharing. First, a damping sensitivity formula is presented to quantify the impact of each inverter on system damping relative to changes in its reactive droop coefficient. Based on this formula, the proposed strategy continuously estimates the damping sensitivity for each inverter and updates the reactive droop coefficient accordingly. This approach ensures that each inverter contributes to grid stabilization in proportion to its own impact on system damping. Simulation results confirm the efficacy of the proposed droop control scheme in enhancing inverter reactive power-sharing and microgrid stability.

Paper Session 46: Energy markets

Time: Thursday, 17/Oct/2024: 11:30am - 1:00pm **Location:** Koločep 5

Presentations:

Energy Sharing Concepts - Comparing Large Scale Local Energy Markets and Collective Self Consumption

Klemens Schumann[1,2], **Oliver Banovic**[1], **Andreas Ulbig**[1,2]
[1]IAEW at RWTH Aachen University, Germany; [2]Fraunhofer FIT, Germany

End customers can perform energy sharing through Collective Self Consumption (CSC) and in Local Energy Markets (LEMs). While CSC is often performed in energy communities collectively investing in a PV system, LEMs can be applied to communities with distributed generation systems. To compare both concepts, we introduce a model that simulates CSC and LEMs for large-scale energy communities with distributedly owned generation systems. The model solves a linear optimization problem representing all participants with their generators, loads, and flexibility. Each participant can self-consume electricity, buy or sell it to an energy supplier, or share energy with other participants. We apply our model to a large-scale energy community with 1300 participants. The results show that CSC and LEMs benefit all participants. Analyzing the participants' behavior in detail, CSC provides significant consumer benefits, while LEMs are more beneficial to generators.

Leader-Follower Dynamics in P2P Energy Markets: A Bilevel Stochastic Optimization Approach

Sweta Malik, Mel T. Devine, Andrew Keane
University College Dublin, Ireland

Peer-to-peer (P2P) energy trading has emerged as a solution for facilitating direct energy transactions between peers within a local energy community. The role of an aggregator in this context is crucial, as it facilitates these transactions and maximizes economic benefits according to current market conditions and future uncertainties. Aggregator-peer dynamics are important in P2P energy trading because they enable efficient coordination and pricing strategies that reflect both market conditions and individual peer preferences. To address this, we use a leader-follower bilevel stochastic approach, where the aggregator acts as the leader and the peers as followers. This research implements a stochastic bilevel optimization framework, where the aggregator aims to maximize social welfare by optimizing profits from energy transactions at the upper level, and the peers minimize their net energy expenditure while maximizing revenue from selling excess energy, responding to the aggregator's pricing strategy at the lower level. The stochastic nature of renewable energy is handled by considering different scenarios in the model, capturing uncertainties in solar PV generation, energy demand profiles, and market prices. Additionally, we compare this bilevel optimization approach with a single-level optimization function to demonstrate the advantages of the leader-follower dynamic in achieving more efficient and economically viable outcomes. A case study is conducted to demonstrate the model's applicability and effectiveness in optimizing P2P energy transactions. These findings underscore the model's relevance to the evolving future energy market and its capacity to meet the challenges posed by the integration of renewable energy sources.

Day-ahead Optimal Scheduling of Microgrids Participating in Multiple Energy Markets

Mohsen Mohammadpour Kivi[1,3], **Asma Achnib**[2], **Gilney Damm**[2], **Alessandro Bosisio**[3], **Rouzbeh Shirvani**[3]
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Local flexibility markets (LFMs) have emerged as a promising solution for integrating Distributed Energy Resources into the distribution network, helping to address challenges such as grid stability and congestion. However, the optimal strategies for Microgrids (MG) and aggregators to effectively participate in these markets remain largely unexplored. This paper presents a multi-objective optimization approach for the day-ahead scheduling of MG in LFMs and day-ahead (DA) energy markets. By developing a detailed MG model with various distributed energy resources and storage systems, the study aims to minimize operational costs while maximizing market participation and revenue. A comparative case study highlights the economic benefits of dual-market participation over a single DA market strategy.

Optimal Economic Dispatch Scheduling in Competitive Energy Market Utilizing a Greedy Q-Learning Algorithm

Athanasios Ioannis Arvanitidis, Miltiadis Alamaniotis
University of Texas at San Antonio, United States of America

In the realm of deregulated electricity markets, selection of power plant units for electricity generation is considered crucial for their optimal operation. In this study, an agent involved model simulating a competitive energy market consisted of two generation companies aiming to cover load demand and maximize revenue is examined. The agent is trained through the utilization of the Q-Learning algorithm embedded with a greedy reward system. The results clearly illustrate that the agent

driven supplier attains the optimal economic dispatch schedule, underscoring the effectiveness of a single training session, which enables the agent to learn the most cost-effective approach to cover maximum capacity while simultaneously minimizing testing errors. Finally, the findings of this study emphasize the potential for improved decision-making for more autonomous economic dispatch processes in the dynamic landscape of competitive energy markets.

Exploiting Data Centres and Local Energy Communities Synergies for Market Participation

Ángel Paredes[1], Yihong Zhou[2], Chaimaa Essayeh[3], José A. Aguado[1], Thomas Morstyn[4]
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The evolving energy landscape has propelled energy communities to the forefront of modern energy management. However, existing research has yet to explore the potential synergies between data centres and energy communities, necessitating an assessment on their collective capabilities for cost efficiency, waste heat optimisation, and market participation. This paper presents a mixed integer linear programming model to assess the collaborative performance of energy communities, data centres and energy markets. The evaluation focuses on the efficient use of waste heat and the flexibility of job scheduling while minimising system energy costs and maintaining quality of service requirements for data centres. Our results, based on realistic profiles of an energy community and a data centre, showcase significant benefits of these synergies, with a 38% reduction in operating costs and an 87% decrease in heat demand.

The Impact of Independent Aggregators on the Electricity Market – Slovenian Case Study

Matej Pečjak[1], Edin Lakić[2], Tomi Medved[1], Andraž Kordeš[3]
[1]Faculty of Electrical Engineering, University of Ljubljana; [2]Institute for Innovation and Development of University of Ljubljana; [3]Borzen, operater trga z elektriko, d. o. o., Ljubljana, Slovenia

Independent aggregators are new entrants in the electricity market. Their operation may cause deviations to other market participants, notably electricity suppliers, which may lead to compensation obligations. Different models already exist to regulate the relationship between independent aggregators and suppliers, each with advantages and disadvantages. This paper discusses the current state of independent aggregation in Slovenia, including a Cost-Benefit analysis of the independent aggregator operation in the Slovenian electricity market. Based on an estimate of the quantities that an independent aggregation could offer on the market through demand response, the impact of lower prices on the wholesale market is determined for the day-ahead and intraday markets, considering the actual supply and demand curves. Given the different models, for managing supplier-independent aggregator relationships, which are also presented in the SWOT analysis, the impact on the balance of market participants, including end users involved in the demand response, is also assessed.

An Example of Spurious Granger Causality in Electricity Market Data

Sven Barac[1], Karlo Kovačić[2], Dubravko Sabolic[3]
[1]University of Zagreb, Faculty of Electrical Engineering and Computing; [2]University of Zagreb, Faculty of Economics and Business; [3]Croatian Transmission System Operator, Ltd., Zagreb, Croatia, Croatia

This paper investigates the validity of Granger causality in the context of the Croatian power system by analyzing time series data for electricity production from gas and renewable sources. We assess the correlations between production variables and market prices using data from the ENTSO-E Transparency Platform and the Croatian Transmission System Operator. A Vector Autoregression (VAR) model is applied to evaluate the causal relationships among these variables. Our findings suggest that the observed Granger causality is spurious, indicating potential flaws in relying solely on statistical causality tests without understanding the underlying power system organizational dynamics. Future research should focus on examining other components and regions to validate these findings and refine causality detection methods.

Paper Session 47: Energy community 1

Time: Thursday, 17/Oct/2024: 11:30am - 1:00pm **Location:** Lokrum 4

Presentations:

Adaptive Learning Control for Smart Local Energy Community

Ibrahim Brahmia, **Bernd kloeckl**
Vienna University of Technology, Austria

This paper presents a novel Adaptive Learning Control (ALC) approach for optimizing energy management in Smart Local Energy Communities (LECs). The framework com- bines advanced Reinforcement Learning (RL) with Distributed Model Predictive Control (DMPC), enabling real-time adapta- tion to fluctuations in energy demand, generation, and pricing. A key feature of this method is the use of data-driven algo- rithms to handle uncertainties in renewable energy sources, such as generation. While optimizing energy dispatch among prosumers. The energy management system employs an on- line trained neural network with stochastic weights that are continuously trained and updated in real-time using incoming data such as load, renewable output, and electricity prices, which are then used to optimize control actions. Additionally, a Hyperparameter Optimization (HPO) was integrated to ensure a balance between the rapid learning rate and the model sta- bility. Decision-making across LECs enhances overall system efficiency and resilience. Simulations and case studies demon- strate that this approach improves energy demand predictions and robust self-learning, outperforming the conventional RL method. It maintains stable grid performance under dynamic, stochastic conditions and significantly advances self-learning. A comparison between the robust prediction capabilities of ALC-EMS versus the conventional RL-EMS approach high- lights the benefits of this innovative method.

A Transactive Energy Architecture for Integration of Energy Communities in Virtual Power Plants

Mehrdad Salimitari[1], Ali Arabnya[1,2], Amin Khodaei[1], Julio Romero Aguero[2]
[1]University of Denver, United States of America; [2]Quanta Technology, United States of America

Energy communities (ECs) are at the core of the Virtual Power Plant (VPP) ecosystems. While ECs can coordinate small-scale decisions on energy trading, grid control, and ancillary services among neighboring prosumers, VPPs can leverage the data from different ECs for larger-scale decisions. However, a lack of a comprehensive architecture that considers energy market rules and the communication and computation limitations of the grid and edge devices, while guaranteeing grid security and users' privacy, is an obstacle to the implementation and adoption of ECs. In this paper, we present a decentralized architecture where prosumers within an EC can securely reach a consensus about local scheduling and energy trading decisions. These data can be processed by VPPs for participation in the wholesale electricity markets, or by Independent System Operators (ISOs) for decision-making regarding grid management. We propose a novel consensus method called Local Consensus and a Sybil resistance method called Proof of Demand Response (PoDR) as the underlying components of our architecture that can address the limitations of current blockchain-based solutions. This method is precisely tailored for ECs by considering specific limitations and requirements of existing grid infrastructure.

Quantifying, Activating and Rewarding Flexibility in Renewable Energy Communities

Julien Allard[1], Thomas Stegen[2], Mevludin Glavic[2], François Vallée[1], Bertrand Cornelusse[2], Zacharie De Grève[1]
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Demand-side flexibility from renewable energy community members maximizes the benefits of local production and exchanges. To effectively harness this flexibility, end-users must be rewarded for their efforts regarding the shifted energy volumes and the associated discomfort. In this work, these last two quantities are quantified. Then, a two-step model is proposed which first optimally activates the offered flexibility and then shares the benefits of this activation among the renewable energy community members either through a rule-based or an optimization-based approach. Results show that the community framework can further increase the benefits brought by flexible demand. Additionally, a sharing scheme is proposed to adequately and fairly allocate benefits among the community members.

What makes an Energy Community? Features Impact in Collective Benefits and Self-consumption

Maria Victoria Gasca Segura[1], Remy Rigo-Mariani[1], Vincent Debusschere[1], Yousra Sidqi[2]
[1]University Grenoble Alpes, CNRS, Grenoble INP, G2Elab, Grenoble, France; [2]Lucerne University of Applied Sciences and Arts, Switzerland

Energy communities (ECs) aggregate users within proximity, which have diverse assets and consumption/generation power profiles. Such a variety of user arrangements significantly influences the benefits expected from the organization in ECs. From a vast pool of EC configurations, this paper investigates the composition of ECs regarding the impacts of members' profiles on collective benefits. To that end, clustering is performed for major features to characterize what makes a community. Features are defined based on the battery, PV capacity ratios, and self-sufficiency capacity. Two performance metrics, self-consumption ratio and bill savings, are computed for the defined categories of managed EC. The paper discusses how the community setup impacts its performance, which enables defining the most relevant features to create a community in the first place. Hence, 1000 ECs are formed from 10 initial users. In order to illustrate the importance of selected features and performance metrics for ECs, two study cases are tested, one with 100% of users with PV and battery (i.e., only prosumers) and the second with 50% of prosumers. The results suggest that the photovoltaic installed capacity is a more significant asset than storage capacity concerning investments within the community, regardless of the end-users profiles.

Co-locating PV and BESS in an energy community of commercial and industrial prosumers

Ville Sihvonen, **Salla Annala, Samuli Honkapuro**
LUT University, Finland

Energy communities (ECs) have strong potential to improve the integration of renewable energy and support regional climate targets. The novelty of this paper is in evaluating the role of co-located photovoltaic (PV) and battery energy storage system (BESS) in enabling EC of commercial and industrial prosumers. The study found that the co-located PV and BESS enabled improvement of the local

utilization of PV production, further reducing the need for purchasing electricity. Consecutively, the BESS also reduced the grid feed-in of the electricity, reducing the income from the PV production. In conclusion, a PV-only system in the case area would promote a stronger investment case, than a PV-BESS system. On the other hand, BESS could be used for added technical and social benefits, such as improving energy independence in the EC and increasing the role of energy end-users in the energy transition.

Risk-Averse Bidding Strategy for Energy Community Trading in the Spot Market

Inoussa Habou Laouali[1], Mateo Toro-Cárdenas[1], Ângelo Casaleiro[1], Ricardo Cartaxo[1], Nuno Pinho da Silva[1], Hao Yuan[2]
[1]R&D Nester, Centro de Investigação em Energia REN – State Grid, S.A., Portugal; [2]Power Automation Department China Electric Power Research Institute Co., Ltd. Nanjing, China

This paper presents a risk-averse bidding strategy designed to optimize the operational planning of aggregated demand-side flexibility. The framework aims to coordinate peer-to-peer electricity trading within the European day-ahead and intraday markets. The goal is to maximize the social welfare of the community while minimizing the risk of deviation from a target buying or selling position to retailers. To address the uncertainty surrounding the production of renewable energy and spot prices, a two-stage framework based on linear programming approaches is proposed. The approach leverages distributionally robust optimization to manage uncertainty in the forecast error distribution. It optimizes the decision-making process by considering the expectation of the worst-case uncertainty distribution within an ambiguity set, based on the conditional value-at-risk (CVaR). A case study based on data collected from a Portuguese system operator demonstrates the effectiveness of the proposed approach.

Paper Session 48: Energy community 2

Time: Thursday, 17/Oct/2024: 2:00pm - 3:30pm **Location:** Orlando 1A

Presentations:

Assessment of Distributed and Centralized PV Production in an Energy Community

Mikko Nykyri, Jouni Haapaniemi
LUT University, Finland

Energy communities are a method for organizing energy sharing between prosumers. This paper studies the economic viability of different scenarios of energy communities that consist of single-family homes: the homes either have a single PV installation which production they share, or have individual installations and share the possible excess energy each of them may produce. The energy allocation within the community can be realized with a blockchain-based balance settlement ledger that allows the prosumers to remain in the open retail electricity market. When comparing the economic performance of the studied scenarios, no significant difference is found between them. The scenario that has multiple installations can provide the individual prosumers increased direct benefit, but it is more complex and more expensive to build.

Towards Explainable Renewable Energy Communities Operations Using Generative AI

Amal Nammouchi[1], Cyrine Chaabani[2], Andreas Theocharis[1], Andreas Kassler[1,3]
[1]Karlstad University, Sweden; [2]Center for Digital Technology and Innovation, Germany; [3]Deggendorf Institute of Technology, Germany

Renewable Energy Communities (RECs), characterized by decentralized energy networks, are a key enabler for enhancing renewable energy utilization, cost-efficient planning and clean energy transition. However, optimizing RECs operations is challenging due to the complex interplay of different stakeholders with conflicting requirements. The complexity of managing such systems often leads to a lack of transparent and reliable decision-making, creating barriers for actors within the community. This paper explores the integration of Generative AI into Renewable Energy Communities (RECs) to enhance the transparency, explainability and accessibility of energy management systems (EMSs) that depend on solving optimization problems. We propose a novel framework, Chat-SGP, which uses generative AI to synthesize optimization modeling code to provide actionable, explainable insights for managing the REC operations. Our approach allows us to interact with the EMS through natural language queries, enhancing the system's accessibility and user-friendliness. Our evaluation shows that using GPT-4 with in-context learning performs 96.72\% accuracy on average in generating correct answers.

Renewable energy communities and business models: a review

Dani Vidal[1], José Baptista[1,2], Hugo Morais[3], João Ferreira[1], Tiago Pinto[1,2]
[1]Universidade de Trás-os-Montes e Alto Douro, Portugal; [2]INESC-TEC; [3]Instituto Superior Tecnico, and INESC-ID, Lisbon, Portugal

Renewable energy communities are increasingly becoming a field of great interest. This is mainly due to the advancement of technology but also the global concern to reduce carbon emissions and also create economic and social benefits. Business models play a crucial role in these communities, as a well-structured business model can facilitate the integration of innovative technologies, optimize the use of renewable energy sources, and promote economic and environmental sustainability. Therefore, it is a topic whose research is of great importance. This article presents an investigation and discussion on different aspects relating to renewable energy communities with special attention to Europe, concentrating in certain parts the focus on Portugal. This study was carried out with the aim of understanding which business models already exist and later understanding whether they can be improved or even considering the creation of new models.

EnFoBench: A community-driven energy forecasting benchmark

Attila Balint[1], Chun Fu[2], Johan Driesen[1], Hussain Kazmi[1]
[1]KU Leuven, Belgium; [2]National University of Singapore, Singapore

Forecasting plays a crucial role in the energy domain, including long-term investment planning, and short-term operational optimization. However, there is little clarity as to which algorithms perform best in which conditions, with different studies reporting different, often conflicting, results. Researchers have attempted to address this by relying on forecasting competitions. However, despite their increasing prevalence, forecasting competitions often face challenges in generalizing beyond the competition settings. They also struggle with properly evaluating model performance due to limited datasets and forecast horizons, along with focusing on pre-selected error metrics. In this paper, we introduce EnFoBench, a novel open-source benchmarking toolkit designed to address these challenges and facilitate comprehensive evaluation of energy forecasting models in a transparent and reproducible manner. EnFoBench provides a dynamic framework to benchmark energy forecasting models across various scenarios, by providing homogenized training datasets for building energy demand and generation, and a continuously updated dashboard showcasing how different models perform on a wide variety of metrics for unseen test datasets. This evaluation provides more holistic insights into model performance, ranging from relative forecasting skill compared to baseline models as well as the computational costs of different models.

Hybrid Market Design Considering Heterogeneous System Operator Preferences

Benjamin Cajna[1,2], Roman Le Goff Latimier[1], Hamid Ben Ahmed[1], Jean-Yves Bourmaud[2], Gerald Vignal[2]
[1]SATIE, ENS Rennes, CNRS, Bruz, France; [2]RTE, Paris, France

Integration of distributed renewable energy sources presents new challenges in managing electrical networks. We propose a hybrid market model that addresses network constraints. Recognizing that the optimal solution from the power system's perspective may not always be the fairest, we introduce a heterogeneous preference term for the system operator, which allows for the resolution of network congestion according to a preference criterion. We test our model on a case study and demonstrate that physical constraints can be met with varying responses from energy communities. Moreover, we show that these responses are influenced by the heterogeneous preferences of the system operator. This approach provides a flexible framework for balancing network constraints and fairness considerations, enabling more efficient and equitable management of power networks in the presence of distributed renewable energy sources and energy communities.

Paper Session 49: Power system inertia

Time: Thursday, 17/Oct/2024: 2:00pm - 3:30pm **Location:** Orlando 1B

Presentations:

Power System Dynamic Properties after Implementation of PSS and Inertia Decrease

Ružica Kljajić, Predrag Marić
University J.J. Strossmayer in Osijek, Croatia, Faculty of Electrical Engineering, Computer Science and Information Technology

Low inertia of the power system combined with low damping impairs the power system's ability to cope with disturbances that can significantly affect system stability. In such a case, in addition to speed or frequency deviations of the generator, low-frequency oscillations also occur and suitable ways must be found to mitigate them. In this paper, an oscillatory stability as well as the time domain generator's speed deviations were ob-served in an IEEE 14-bus system in four simulation scenarios after improving the system damping by implementing a Power System Stabilizer (PSS) and the system inertia was changed by integrating wind farm with fully rated converter interfaced wind generators.

Consensus + Innovations Approach for Online Distributed Multi-Area Inertia Estimation

Nicolai Lorenz-Meyer[1], Hans Würfel[2], Johannes Schiffer[1,3]
[1]Brandenburg University of Technology Cottbus-Senftenberg; [2]Potsdam Institute for Climate Impact Research; [3]Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems (IEG)

The reduction of overall system inertia in modern power systems due to the increasing deployment of distributed energy resources is generally recognized as a major issue for system stability. Consequently, real-time monitoring of system inertia is critical to ensure a reliable and cost-effective system operation. Large-scale power systems are typically managed by multiple transmission system operators, making it difficult to have a central entity with access to global measurement data, which is usually required for estimating the overall system inertia. We address this problem by proposing a fully distributed inertia estimation algorithm with rigorous analytical convergence guarantees. This method requires only peer-to-peer sharing of local parameter estimates between neighboring control areas, eliminating the need for a centralized collection of real-time measurements. We robustify the algorithm in the presence of typical power system disturbances and demonstrate its performance in simulations based on the well-known New England IEEE-39 bus system.

Coordinated Inertial Response Service Provided by Virtual Power Plants Based on Grid-Forming Converters

Juan Diego Rios-Peñaloza, Javier Roldán-Pérez, Milan Prodanovic
IMDEA Energy, Spain

Power systems have become more exposed to frequency excursions, emphasising the importance of dynamic ancillary services such as inertial support and fast frequency response to mitigate them. Virtual power plants (VPPs) are seen as suitable candidates for provision of these services and each generation technology within the plant should contribute to the aggregated response according to its own characteristics. However, most VPP studies focus on their steady-state contribution and only a few explore their potential to provide dynamic ancillary services. Moreover, the influence of power reserves (i.e., climatological conditions, state of charge of batteries, etc.) is rarely taken into consideration. This paper presents a centralised controller for a VPP that allows the provision of dynamic ancillary services, considering different generation technologies and their power reserves. The proposed controller helps manage and select the contribution of each individual technology according to the power reserves and the type of energy source. In contrast to existing solutions that depend on continuous adjustment of control parameters, the proposed controller selects the control parameters from predefined subsets that comply with grid codes. The proposed approach is validated by performing numerical simulations.

Considering Disturbance Scenarios in Clustered Inertia-Aware Generation Expansion Planning

Oussama Alaya, Taiseer Alhaj Ali, Benedikt Jahn, Hendrik Lens
University of Stuttgart, Germany

The transition to a carbon-neutral power system requires replacing conventional generation with distributed renewable energy (RE) sources. This poses challenges related to reduced system inertia and large and long-distance power transmission in the system. This paper presents a novel generation expansion planning (GEP) methodology called inertia-aware clustered generation expansion planning (I-CGEP). The I-CGEP approach integrates spatial clustering and generator clustering to optimize discrete generation expansion options while avoiding overestimation of system inertia. The model incorporates advanced Rate of Change of Frequency (RoCoF) constraints that, in addition to standard constraints following predefined outages, also account for the expected power imbalance resulting from large disturbance scenarios such as regional islanding. The proof of concept of the methodology is demonstrated using the open European transmission system model PyPSA-Eur. The results show its suitability for maintaining the required RoCoF under different scenarios.

Estimating Synchronous Inertia in Power Systems Using Equal Area Criterion and Artificial Intelligence

shiva Amini[1], Hêmin Golpîra[2], innocent Kamwa[1]
[1]Laval university, Canada; [2]University of Kurdistan, Iran

This paper introduces an algorithm that uses artificial neural networks (ANN) to estimate the inertia of synchronous generators (SGs). The algorithm incorporates a modified equal area criterion method and kinetic energy concept to calculate the maximum mechanical power (Pmax). This Pmax value is then included as a new input feature in the ANN. In addition to the contributions outlined in this paper, a supplementary proposal entails the introduction of a novel index for identifying the most optimal fault location Finally, to assess the efficiency of the proposed algorithm, testing was conducted on the IEEE 39-bus New England test system, and comparisons were made with other methods. The simulation results demonstrated an impressive estimation error of below 1% in determining the inertia of the generators in the system.

Hybrid Power Plants' Contribution to Alleviate Frequency Nadir in Low-Inertia Power Systems

Soheil Pouraltafi Kheljan[1], Moataz Moataz El-Seid[2], Mustapha-Amine Rahmani[2], Kaushik Das[1], Poul Ejnar Sørensen[1]
[1]Dept. of Wind And Energy Sytems, Technical University of Denmark; [2]TotalEnergies

The anticipated extensive integration of renewable energy sources will decrease inertia in future grids. This will lead to a higher frequency change rate and lower frequency nadirs. Hybrid power plants (HPP) are growing globally, driven by their considerable advantages and potential service capabilities. These advantages include increasing energy availability, mitigating intermittency and uncertainty in power production, and laying the groundwork for grid enforcement. Frequency containment reserves and fast-frequency response emerge as a potential revenue stream for HPPs, provided they can demonstrate reliable delivery capability. This frequency service has been implemented in the hybrid power plant controller. This study evaluates the impact of HPPs on the frequency nadir of continental Europe's synchronous area. The inertia of the studied grid varies for different converter-based resource share scenarios. Simulation results demonstrate that introducing a significant percentage of hybridization can alleviate the frequency nadir challenges associated with high shares of renewable generation.

Paper Session 50: Power system stability 2

Time: Thursday, 17/Oct/2024: 2:00pm - 3:30pm **Location:** Orlando 1C

Presentations:

Performance of IBR Power Oscillations Damper according to power system operating conditions

Marta Gomis-Domènech[1,2], Thai-Phuong Do[2], Raphaël Caire[1]
[1]Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab; [2]Univ. Grenoble Alpes, CEA, Liten, Campus Ines

This paper analyses the performance of a Power Oscillations Damping (POD) controller through small-signal stability analysis. The POD is installed in a photovoltaic (PV) power plant controlled in conventional grid-following (GFL) mode. During frequency transients, the POD modifies the reactive power reference of the GFL control, in order to damp electromechanical power system oscillations. The transmission power grid Western System Coordinating Council (WSCC) 9-bus benchmark has been analysed using the DIgSILENT PowerFactory software. The PV plant capacity, its location in the network, and the power system operating conditions are considered. Particularly, the analysis of a few specific consumption and generation conditions shows that the electromechanical oscillatory modes of the system are more critical in case of peak load, as it happens for 100~\% synchronous generation. The main result is the significant contribution of the POD to damping electromechanical modes in the scenario of winter evening peak consumption, when the PV plant does not inject active power to the grid, which coincides with the most poorly damped electromechanical modes.

Analysis of Tie-Line Impact on Frequency Response in Multi-Area Power Systems

Tomislav Baškarad, **Ninoslav Holjevac, Igor Kuzle**

University of Zagreb Faculty of Electrical Engineering and Computing Zagreb, Croatia

This work primarily focuses on investigating how the frequency response of a power system may change due to the addition or failure of tie-lines. The proposed method enables the analysis of two specific scenarios: firstly, assessing the potential enhancement in frequency response by adding an extra tie-line between two areas, and secondly, evaluating the deterioration in frequency response when one tie-line is disconnected. One notable advantage of the proposed method is its reliance solely on actual frequency response measurements from individual areas, thereby eliminating the need for extensive knowledge of system parameters. The effectiveness of this method is evaluated by comparing the analytically derived frequency responses with those obtained through simulation

Assessment of Interactions of Multiple Converters and Network Considering Impedance Change

Tesfu Gebremedhin[1], Lie Xu[1], yin chen[1], Dong chen[2]

[1]university of Strathclyde; [2]UK National HVDC Centre

This paper addresses the stability challenges arising from the integration of multiple converters into an AC network, spotlighting on potential instabilities generated by the interplay between converter control loops and the network's passive components. Employing an impedance-based approach that incorporates impedance ratio (IR) and examining a different control configuration such as active and reactive Power (PQ) and active Power and AC voltage (PV), alongside other parameters like phase-Locked loop (PLL), this work examines methodically the dynamic interactions. Through IR, it evaluates the individual impacts of converter (remote converter) on network equivalents, thereby elucidating how the interaction between converters and the broader network influences overall system stability. Ultimately, the proposed methodology aids in identifying impedance variations and potential instabilities in grid-tied converters, offering a roadmap for the perceptive design of converters and network parameter configurations.

Frequency Control in EV Clusters: Experimental Validation and Time Response Analysis of Centralized and Distributed Architectures

Pietro Zunino, **Jan Engelhardt, Simone Striani, Kristoffer Laust Pedersen, Mattia Marinelli**

Technical University of Denmark, Denmark

The increased penetration of Renewable Energy Sources and of Electric Vehicles (EVs) in the electrical grid poses challenges to the stability and performance of the electrical system. To mitigate these problems, ancillary services can be provided by clusters of EVs during the charging process. The delay in the provision of frequency services from a cluster of EVs is analyzed, considering both a centralized and a distributed control architecture. The distributed architecture was tested on a cluster of EVs in the DTU Risø facilities. The communication delays in the system have been quantified. Both the centralized and distributed architectures have been modeled on Simulink® using the estimated delays, and the average delay following the grid frequency has been determined. After comparing the results, the distributed architecture was found to be faster in following the reference than the centralized architecture. Moreover, different aspects of the control system have been identified to be responsible for an increased delay, including saturation in the power setpoint for each EV, and presence of instability in the control system.

Performance of Grid Forming Compared to Grid Following STATCOM in Weak Power Systems

Arun Kannan[1], Kamil Lipiec[1], Lutz Hanel[1], Klaus Würflinger[1], Mykola Shevchenko[1], Anna Soergel[1], Pascal Winter[2], Tobias Neumann[2], Klaus Vennemann[2], Tobias Hennig[2], Benedikt Sand[2], Marc Großmann[2]

[1]Siemens Energy Global GmbH & Co. KG, Germany; [2]Amprion GmbH

With the increase in high penetration of inverter-based generation, the power system's features are evolving swiftly, leading to various challenges. Among numerous issues, this paper addresses specific grid challenges such as dynamic reactive power support during weak grid situations. To provide such grid support service during weak grid situations, a new type of STATCOM control has emerged known as grid forming. This control has a unique capability of providing instantaneous reactive power support against the change in voltage magnitude irrespective of the grid strength. This paper aims to compare the behavior of grid-forming and grid-following STATCOMs in real network model under extreme grid conditions, providing insights to determine the most suitable STATCOM type for specific grid situations, ultimately contributing to the enhancement of power system stability and reliability.

Boundary Estimation of Vulnerable Areas in Bulk Power Systems using Electrical Distance

Illia Diahovchenko[1,2], Andrew Keane[2]

[1]Sumy State University, Ukraine; [2]University College Dublin

Electric power plants and bulk substations are vital for modern society's functioning across various sectors. Their disruption can lead to widespread blackouts, cause economic losses, and jeopardize public safety. Given the increased risk of terrorist and military attacks on the elements of critical energy infrastructure in recent times, swift preparation and operational solutions are crucial for power systems' stability and resiliency. This paper proposes a method to form clusters within large power systems, based on the electrical proximity of the buses and the graph theory. By forming these clusters, simulations can be conducted only for the relevant areas of interest, optimizing computational resources and time, and fostering planning and operational decision-making. The proposed approach has the potential to improve stability and resiliency against potential attacks and can be employed by transmission system operators (TSOs) or grid planners to enable more efficient and prompt responses to threats on critical energy infrastructure.

Paper Session 51: Market and metering aspects

Time: Thursday, 17/Oct/2024: 2:00pm - 3:30pm **Location:** Lokrum 4

Presentations:

Automated Market Maker-based Batch Auction for Decentralized Customer-centric Local Energy Sharing

Tom Celig, Saber Talari, Wolfgang Ketter, Detlef Schoder
University of Cologne, Germany

Traditional marketplaces, like order book solutions, for Peer-to-Peer (P2P) energy trading are often unable to efficiently manage decentralized trading, especially when faced with low liquidity and limited participants. To address this challenge, this paper introduces the Automated Market Maker (AMM)-based batch auction (AMMBA) trading mechanism, designed to improve the efficiency and fairness of P2P energy markets. AMMBA combines the strengths of both batch auctions and AMMs by taking frequent clearing and uniform pricing from batch auctions and decentralized algorithmic pricing from AMMs. The batch auction clearing method is replaced by a sigmoid price function. In each market window, producers generate energy tokens from surplus production. Buyers add stablecoins to the liquidity pool reflecting their energy requirements, with the clearing price adjusted at the window's end using the sigmoid function. Ultimately, stablecoins and energy tokens are distributed to sellers and buyers, respectively. Simulation results show that AMMBA not only secures significant gains for all parties involved but also exhibits high adaptability to real-time demand and supply fluctuations.

Deep Causal Learning to Explain and Quantify Natural Gas Market Shocks

Philipp Kai Peter, Yulin Li, Ziyue Li, Wolfgang Ketter
University of Cologne, Germany

Natural gas demand is a crucial factor for predicting natural gas prices and thus has a direct influence on the power system. However, existing methods face challenges in assessing the impact of shocks like in the case of the outbreak of the Russian-Ukrainian war. In this context, we apply deep neural network-based Granger causality to identify important drivers of natural gas demand. Furthermore, the resulting dependencies are used to construct a counterfactual case without the outbreak of the war, providing a quantifiable estimate of the overall effect of the shock on various German energy sectors.

From Hourly to Quarter-Hourly: Effects of Metering Intervals on Self-Consumption Ratios and Economic Viability of Solar Photovoltaic Systems in Finnish Residential Buildings

Aki Kortetmäki[1], Juha Koskela[2], Juho Ylipaino[1], Kari Kalliohariu[1], Pertti Järventausta[2]
[1]Tampere University of Applied Sciences, Finland; [2]Tampere University, Finland

The adoption of solar photovoltaic (PV) systems in Finnish residential buildings has significantly increased, reflecting broader global trends. A crucial element in the investment evaluation of these systems is the self-consumption ratio (SCR). Self-consumed energy reduces costs on energy purchases, taxes, and distribution system operator (DSO) fees, thus linking the SCR with profitability. This study explores the effects of transitioning from hourly to 15-minute metering intervals on SCR and the consequent financial outcomes. This research utilizes actual consumption data from 10 detached and 10 multi-dwelling buildings (MDB) in Finland and simulated production in 15-minute intervals to evaluate SCR impacts across various system sizes. Detached buildings (DB) were analyzed with system sizes of 3 kWp, 5 kWp, and 7 kWp, and MDBs with 10 kWp, 20 kWp, and 30 kWp. Results reveal SCR decreases from -0.60% to -4.52% across all DB's PV system sizes, with corresponding financial benefits decreasing by -1.02% to -3.67%. In MDBs, SCR decreases ranged from -0.01% to -4.61%, with financial impacts decreasing by -0.01% to -3.41%. These findings underscore the variability of SCR influenced by metering intervals and site-specific factors such as production and consumption patterns, providing substantial data to the discourse on sustainable energy practices in residential settings.

Load Profiling using Grey Relational Analysis for Power System State Estimation

Hanshan Qing, Abhinav Kumar Singh, Efstratios Batzelis
School of Electronics and Computer Science, University of Southampton, Southampton, United Kindom

Power system state estimation (PSSE) is a critical tool for power system operation. Load/generation profiles are essential for performing accurate PSSE, and enable PSSE algorithms to handle errors in real and pseudo measurements. The classic approach of modelling the measurement error in PSSE is applying the mixture reduction algorithm to Gaussian mixture models (GMMs) fitted to existent load/generation profiles. However, this approach has inherent limitations in the mixing process. We propose a novel algorithm based on grey relational analysis (GRA) to derive a smaller load/generation profile from the original extensive profiles based on the forecast results of the next day. Our algorithm addresses the issues of mixture reduction and is applied before mixture reduction to improve PSSE accuracy. A case study is presented to evaluate the performance of the proposed algorithm in improving the accuracy of PSSE.

Dynamic Time-Series Clustering for Improving Appliances Forecasting in Smart Homes

Rameez Raja[1], Surender Redhu[2], Nga Dinh[1]
[1]Østfold University College; [2]Kongsberg Digital AS

Energy consumption forecasting for smart home appliances is a crucial area of research due to its potential to optimize energy consumption and reduce costs. However, accurate Energy forecasting remains challenging due to the evolving nature of energy consumption patterns. This paper addresses these challenges by proposing Dynamic Time-Series clustering techniques to enhance more accuracy in energy and load forecasting for smart home appliances. The focus of this study is on the correlation between the energy consumption of different household appliances. Energy consumption data from these appliances is recorded as time-series data, offering valuable insights for analysis. Our research centers on clustering the time-series data of multiple appliances within a household, with the aim of improving the performance of forecasting algorithms. Specifically, We improve forecasting accuracy by using clustering information. This involves organizing time-series data from various appliances into clusters, which are then used as input for forecasting algorithm. To achieve this, we employ the k-shape algorithm for time-series clustering on household appliances data. This algorithm effectively extracts time series shapes and computes pairwise cross-correlation for clustering purposes. Moreover, our proposed Dynamic time-series clustering approach incorporates time of the day information, enabling the identification of patterns and variations in appliance behavior across various periods.

Economic assessment and grid impact of different sharing keys in collective self-consumption

Kjersti Berg[1,2], Rubi Rana[2], Henning Taxt[2], Marthe F. Dynge[1]

[1]Norwegian University of Science and Technology; [2]SINTEF Energy Research

Collective self-consumption (CSC) is a way to increase the profitability of distributed renewable energy. In CSC schemes, a sharing key is used to virtually distribute the renewable energy production. The sharing key will impact the cost reduction for each household, and if households are flexible, it will also have an impact on the physical grid exchange. The aim of this article is to investigate how the new CSC scheme in Norway will impact the cost reduction for the energy community members and the physical exchange with the distribution grid. Two sharing keys are investigated: equal and yearly consumption based. We find that the largest cost reductions are obtained for the yearly consumption-based key, especially when households are assumed to be flexible. When introducing flexibility, however, the maximum import at the point of common coupling was increased by 9.6%, due to each household individually optimising against spot price variations. Comparing the grid impact and grid related costs in the different cases, we conclude that the CSC scheme is likely to shift costs over to other end-users in the grid.

Poster Session

Time: Wednesday, 16/Oct/2024: 4:15pm - 6:00pm **Location:** Aula

Posters:

1. Uncertainty Quantification for Branch-Current State Estimation in Power Distribution Systems

Florian Thorsten Lutz Strobel, Davood Babazadeh, Simon Stock, Christian Becker
Institute of Electrical Power and Energy Technology, Hamburg University of Technology

The growing number of prosumers in the distribution grid pushes the system to the edge of its operational capacities. This makes it essential to assess the current state of the system. However, the availability of grid measurements is often times not sufficient. To achieve observability, inaccurate pseudo measurements can be included in the state estimation. The obtained results are subject to high uncertainty. This paper proposes an algorithm for quantifying the uncertainty of the branch current and node voltage estimate in a branch currentbased weighted least squares state estimation. The algorithm uses the same inputs as the state estimation, including the measurement vector, its standard deviation, and the grid parameters. The uncertainty quantification is twofold: first, the uncertainty of the currents is estimated using the diagonal of the gain matrix. Second, the voltage uncertainty is obtained using a novel error propagation calculation. The proposed algorithm is based on a modified version of the branch current state estimation algorithm. We evaluate the proposed algorithm in a variety of scenarios with different measurement availabilities and pseudo measurement uncertainty distributions. As a guiding example, we utilize a benchmark distribution system from the Simbench dataset. The algorithm demonstrates high accuracy when dealing with Gaussian distributed input uncertainty.

2. Influence of Measurement Uncertainties on the Quality of Grid Topology Identification in Three-Phase Systems

<u>Franziska Tischbein</u>, Dominik Kubon, Markus Stroot, Andreas Ulbig
IAEW RWTH Aachen, Germany

Due to the increase in decentralized generation plants and the emergence of new customer types, distribution grid operators will face an increased need to perform grid status analyses based on measurement data collected by smart metering systems. The necessary grid topology, however, is not available to distribution grid operators in sufficient quality in many cases. This paper presents an extension of an existing topology identification method based on measurement data of three-phase systems. Within the scope of sensitivity analyses, the influence of measurement uncertainties is investigated and compared with the current state of deployed measurement technology in Europe.

3. Influence of Local Reactive Power Control on the Quality of Grid Topology Identification

<u>Franziska Tischbein</u>, Christoph Hölscher, Florian Klein-Helmkamp, Andreas Ulbig
IAEW RWTH Aachen, Germany

Due to the increasing integration of decentralised generation plants and new types of consumers, distribution grid operators must switch to active grid operation based on digital grid models, which in many cases are not known in sufficient quality. Therefore, different methods for measurement-based topology identification are currently being developed. In order to develop and test these methods, realistic synthetic measurement data is required that represents the characteristics of different grid users. This paper presents a method for the creation of realistic, synthetic measurement data, which in particular represents the reactive power control of PV systems accordingly, and quantifies the influence of Local Reactive Power Control on a method for topology identification based on voltage correlation analysis. The results demonstrate that the algorithm is sensitive to the consideration of different local reactive power control strategies, explicitly indicating the relevance of representing the active and reactive power behaviour of grid users accordingly when creating synthetic data sets.

4. Equitable Distribution of Community Energy Resources for Underprivileged Households

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Community energy resources (such as shared or donated photovoltaic generation and energy storage) are considered a viable option to enhance the access of underprivileged communities to green energy. However, equitable distribution of these resources among different community members is challenging. To address these challenges, this article presents an analysis of the performance of three well-known allocation rules for distributing energy from community energy resources: equal energy allocation, equal loss allocation, and proportional energy allocation. For each rule, we formulate a quadratic programming model with generalized constraints and specific objective functions. The performance of all rules is evaluated for a residential community with shared photovoltaic generation and energy storage, and the equitability of energy allocation for each rule is assessed using Jain's fairness index. The results show that proportional allocations are the most equitable, while equal loss-based allocations are deemed the least equitable.

5. Hosting Capacity of Electric Vehicles under Consideration of Grid Integration Measures

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The current ramp-up of electric vehicles raises the question of how many vehicles can be integrated into today's electrical distribution grids and how this can be accurately determined. Current methods do not take all relevant aspects into account, therefore we propose

a method to determine the hosting capacity of electric vehicles in realistic distribution grids and to evaluate grid integration measures. A probabilistic approach is chosen in which the mobility requirements are precisely modelled in order to significantly increase the validity of the simulation. The results show that the hosting capacity is largely dependent on the charging power of the vehicles. For example, if all vehicles are charged with 3.7 kW, the analysed grid can supply around eight times more vehicles than with a charging capacity of 11 kW. However, every grid integration measure influences the mobility of the participating vehicles. Among the grid integration measures, balanced charging, in which the entire duration of the stay is used for charging, has established itself.

6. Analysis of zero-sequence current injection response in compensated distribution networks

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ABB Distribution Solutions, Finland

The zero-sequence current injection is an essential method that is applied to various complex applications in compensated distribution networks. This paper introduces the necessary current injection theory, including the equations that describe the system's response to current injection and parameters affecting it. The parameters are especially considered in terms of basic parameters of compensated networks including system damping, detuning, and asymmetry, so that the outcome of the current injection can be easily understood intuitively. This allows easy analysis of current injection response using the basic earth fault parameters. The influence of current injection frequency is further described, and concept of resonant frequency is introduced, illustrating its advantages. Finally, PSCAD simulations are used to visualize and verify the validity of the presented current injection theory.

7. A Review of Condition Monitoring of Offshore Wind Turbines

Mohammad Moradzadeh
ULB, Belgium

Wind energy has the largest share among renewables playing a very important role in the global energy mix. Wind turbines consist of complex mechanical and electrical systems with hundreds of moving parts which must be kept in good working order through appropriate maintenance and condition monitoring programs. Effective and timely maintenance is crucial to deter and avoid expensive downtimes. This paper aims at performing a systematic literature review on the condition monitoring of (offshore) wind turbines and providing comprehensive insights towards diagnosis and prognosis of related faults and failures.

8. Decarbonize energy sharing strategy for multi-microgrids considering uncertainty

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The multiple uncertainty of microgrids (MG) makes it challenging to establish an efficient, accurate, and environment-friendly transaction model. To address the challenge, this paper investigates a decarbonized energy sharing strategy based on the non-cooperative game model for multi-microgrids to achieve a sound benefit sense in the economy and environment. We formulate the energy sharing process as two parts: i.e., the equivalence publication of price and aggregation of the supply-demand information. To incentivize the energy sharing between microgrids, we generate the energy sharing price according to the aggregation information from each microgrid. Moreover, for environmental benefits, the energy sharing price is driven by carbon emissions. Since establishing an accurate uncertainty modelling is the key to optimal dispatch for the multi-microgrid system, the energy sharing model proposed in this paper considers uncertainty via a distributed robust chance constraint (DRCC) model based on the Wasserstein metric. Finally, through case simulation analysis, it is verified that the proposed model can promote energy complementarity among multi-microgrids, and enhance the overall environmental and economic benefits.

9. Accurate and Robust Inertia Estimation Using Limited Measurement Data

Dmitry Shchetinin, Mats Larsson
Hitachi Energy Research, Switzerland

Increased penetration of renewable energy sources and phase out of synchronous generators lead to reduced levels of grid inertia. This poses a serious concern for system operators, who are becoming increasingly interested in estimating the grid inertia. Existing estimation approaches typically assume extensive measurement infrastructure, which might not be always available.

To address this problem, this paper proposes a robust method for estimating inertia of the grid or its area while only requiring a limited amount of measurement data. It uses an autoregressive-exogenous model and replaces unmeasured components of the power mismatch by proxy values. Simulation results corroborate the algorithm's effectiveness. The paper also analyzes the impact of geographical distribution of inertia and disturbance location on the frequency response using an analytical model and introduces the concept of local inertia. The role of local inertia is studied to demonstrate the need for a zoning approach when estimating the inertia value.

10. Enhancing Fraud Detection in Renewable Energy Grids through Behind-the-Meter PV Disaggregation

Marc Jené-Vinuesa, Abdullah Abdullah, Mònica Aragüés-Peñalba, Andreas Sumper
Universitat Politècnica de Catalunya, Spain

Detecting non-technical losses (NTL) in electrical grids with high renewable energy penetration presents unique challenges. This study proposes a methodology that combines a two-step behind-the-meter (BTM) photovoltaic (PV) disaggregation algorithm with an unsupervised fraud detection model to improve the detection rate in renewable energy grids. The methodology is validated using real-world data from the Ausgrid dataset, comprising several prosumers with BTM PV systems. The disaggregation algorithm accurately estimates the PV capacity with a Mean Average Percentual Error (MAPE) of 7.85%. Applying the disaggregation model improves fraud detection performance, increasing the Matthews Correlation Coefficient (MCC) from 0.654 to 0.747. These services have been developed and tested within the OMEGA-X European project.

11. Moebius-Strip for High Voltage AC Switchyards of High Availability

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Ex-Koeppl-Power-Experts, Switzerland

HV (high voltage) ac switchyards are core elements of any hv ac grid and should be permanently available. Switchyard designs such as ring- or breaker-and-a-half-structures try to fulfill these requirements. Another scheme – the crossed-ring arrangement – is to be counted into this category too. It also needs 1½ circuit-breakers per feeder and has the physical appearance of a closed strip. By twisting this strip into a Moebius-strip the availability of the feeders of such an hv ac switchyard is further increased. This is demonstrated by comparing the three switchyard types of Moebius-strip, crossed- ring and breaker-and-a-half based on non-available feeders and non-available circuit breakers respectively. The Moebius-strip arrangement clearly provides the best feeder availability, followed by the crossed-ring – and at a great distance - the breaker-and-a-half arrangement. Therefore, it might be a solution for central grid nodes and strategically important hv ac substations.

12. Peak Management and Voltage Regulation using Demand Response from Green Data Centers

Pouria Nouri, Carolina Tranchita Rativa
Frankfurt University of Applied Sciences, Germany

As demand for digital services, such as social media, business management, communication, and various online-based functions continues to increase, so does the need for additional Data Centers to store and process data. The growth of Data Centers in number and size raises significant concerns regarding power consumption, land use, and environmental impact. However, with the capability to control and optimize their electricity generation and consumption, Data Centers can effectively manage their own power demand. Additionally, combining flexible loads in Data Centers with the integration of both thermal and electrical storage and Renewable Energy Sources (RES) has the potential not only to optimize the facility's energy management but also to provide support to the power grid when needed. By leveraging these capabilities, the overall power flexibility provided by Data Centers can offer Demand Response (DR) to meet the diverse needs of stakeholders in the electricity market, while simultaneously reducing energy consumption and environmental impacts. This paper focuses on leveraging DR from Green Data Centers (GDC) for peak load management and voltage regulation of the electric power grid. The strategies for using power flexibility within GDCs and their impact on the power grid are assessed through Quasi-Dynamic Simulation.

13. Identification of Technical Limits of Mini Run-of-River Hydro Power Plants During Frequency Containment Reserve Provision

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As an effect of Germany's energy transition, the amount of Decentralized Energy Resources (DERs) is increasing not only worldwide, but especially in Europe. For stable power grid operation, renewable DERs should as well be considered for ancillary services, such as Frequency Containment Reserve (FCR). Previous works assume a potential water level flexibility of mini Run-of-River (RoR) Hydro Power Plants, which could be used for that. This paper investigates the limits of mini RoR Hydro Power Plants as FCR providers with a simulation and a field test experiment. The goal is to identify, which technical characteristics could have a limiting effect on FCR provision and thus also indicate which modelling aspects are needed for the assessment of FCR provision capability of these DERs. The results show, that continuous FCR provision over multiple hours is technically possible, while the requirements for response time and accuracy in an operational step response test can not entirely be fulfilled for some types of small-scale RoR Hydro Power Plants.

14. A Gramian-based tool for modeling converter-dominated power systems

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Tallinn University of Technology

The increasing integration of renewable energy sources and high voltage direct current (HVDC) connections has led to a proliferation of power electronic devices within the grid, thereby transforming the power system dynamics. The applicability of traditional power system modeling approaches, based on the distinction between fast and slow dynamics, became limited due to the introduction of converter dynamics. Consequently, it becomes critical to determine the minimum level of modeling details required for accurately representing these systems. The paper aims to demonstrate how a Gramian-based model reduction method can be used to develop a tool for MATLAB/Simulink that allows the visualization and identification of the model components that contribute to the system dynamics. This tool is beneficial to understand the boundaries between EMT and RMS models and how far a complex model can be simplified while retaining all the relevant dynamics.

15. Scenario-Oriented Multi-Cut Generalized Benders Decomposition-Based Distributed OPF for AC/DC Hybrid Grids

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In this paper, a distributed optimal power flow (OPF) for the AC/DC hybrid grid, composed of the AC grid, renewable energy system (RES), and voltage source converter (VSC)-multi-terminal DC (MTDC) grid, is presented. Firstly, we take a series of linear approximations/convex relaxations to construct a mixed-integer convex AC/DC OPF model. Then, to address the uncertainties from RESs, we illustrate scenario-oriented decision-making regarding the constructed AC/DC OPF model. Next, we verify that considering arbitrary possible scenarios can be replaced by a small set of extreme scenarios if the OPF model is (mixed-integer)convex. Furthermore, we develop the scenario-oriented multi-cut generalized Benders decomposition to achieve more efficient distributed problem-solving in the constructed AC/DC OPF model. Finally, numerical results are provided to validate the effectiveness of our constructed AC/DC OPF model and our developed distributed problem-solving approach.

16. Implications of EU Battery Regulation on Circular Economy: Barriers and Opportunities for Repurposing Electric Vehicle Batteries

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This paper presents a study of the impact of EU battery regulations, specifically Regulation (EU) 2023/1542, on end-of-life batteries, primarily focusing on repurposing within the supply chain. Qualitative data was gathered from stakeholders in the battery supply chain using a combination of surveys and interviews. Interviews provide deeper insights into aspects beyond the survey's scope, enhancing our understanding of how EU regulations influence the supply chain. The findings reveal a nuanced landscape where EU regulations bring advantages through defined producer responsibilities, improved safety standards, and facilitated data sharing. The study explores various circular business models within this context, emphasizing the need for a functional value network and effective stakeholder coordination. This research contributes valuable insights as the EU pursues circularity in the battery supply chain. By addressing barriers, capitalizing on opportunities, and promoting collaboration, it supports a sustainable and circular future in the EV battery supply chain, optimizing initial investments and aligning with the energy transition goals.

17. Synergizing Energy Management System and Electric Vehicle Charging Infrastructure in a microgrid for a commercial building: A Case Study from EU project FLOW

Sergio Orlando, Leon Gritsyuk, Oleksij Chumak, Stefan Costea
Eaton European Innovation Center

This paper introduces a pilot demonstration of Energy Management System (EMS) based control of Electric Vehicle Charging Infrastructure (EVCI) and the integration with a DC power system addressing the use case of commercial building. The research is carried out within the Horizon EU funded project FLOW which will be introduced by providing an overview on a project demonstrator and the status, as well as a detailed description of the infrastructure built for the testbed. The goal of this paper is to introduce to the first phase of the pilot demonstrator and to provide with information of the future development by describing the case study.

18. Diffusion-based reinforcement learning for flexibility improvement in energy management systems

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We introduce an online diffusion-based reinforcement learning approach for enhancing flexibility in energy systems. Leveraging diffusion models, the framework is able to learn the complex dynamics underlying energy systems that are subject to continuous stochastic processes. The flexibility actor, guided by a Q-value based critic, employs a diffusion-based consistency policy, enabling tracing of trajectory points back to initial actions in a single step. The method is applied to optimize the flexibility of grid connected photovoltaic systems. Results indicate improved learning efficiency and system flexibility compared to standard RL algorithms, including a notable 38.46% increase in final episodic reward, although with a higher computational demand.

19. Evaluating Temporal and Spatial Characteristics of Wind Energy for Enhanced Synthetic Inertia Provision in Power Systems

Guoxuan Cui, Zhongda Chu, Fei Teng
Imperial College London, United Kingdom

As renewable energy continues to grow globally, system inertia, essential for resisting frequency changes and ensuring power system stability during power imbalance events, is decreasing due to the shutdown of spinning generators and the widespread use of power electronic devices. Variable Speed Wind Turbines (VSWTs) can provide Synthetic Inertia (SI) to help restore system frequency during under-frequency events. However, the variability of wind resources introduces significant errors in predicting SI capacity with existing wind speed forecasting methods, which often neglect the temporal and spatial characteristics of wind energy. This paper investigates the impact of time sampling resolution and Wind Turbine (WT) distribution within a Wind Farm (WF) on the availability of inertia provision. A novel probabilistic approach for SI capability assessment is proposed, incorporating the study of temporal and spatial characteristics of wind energy to ensure conservative SI provision. Case studies demonstrate that this framework significantly reduces the unavailability of SI provision, highlighting its effectiveness in enhancing power system stability.

20. Performance of the pattern search direct search method for load estimation in distribution grids

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Accurate load estimation plays a key role in efficiently planning and managing electric distribution systems. This study introduces a novel load estimation methodology utilizing a Matlab dataset and simulations executed within the Open Electric Power Distribution System Simulator (OpenDSS). The dataset comprises diverse demand profiles of residential, commercial, and industrial consumers across three standard distribution feeders: IEEE 13-bus, 37-bus, and 123-bus, encompassing at least 96 individual scenarios. A custom-fit mathematical approach employs the pattern search technique to estimate loads by optimizing predefined objective functions with and without constraints. The authors evaluated the effectiveness of the proposed methodology in load estimation using quality indices, offering valuable insights into its performance across various scenarios. Additionally, the paper delves into the significance of load information in electrical systems, distinguishes load estimation from alternative methodologies, and explores the intricacies of direct search methods with a specific focus on pattern search. A thorough analysis of pattern search in specific power systems underscores its efficacy in load estimation. The dataset and findings presented herein serve as a valuable asset for future investigations into load estimation techniques, facilitating comparisons and advancements in this field.

21. Modeling Work Processes and Decisions in Grid Operation

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Grid operations plays a critical role in ensuring a reliable power supply ranging from the control center to the field units. Developments due to the decarbonization of the energy, transport and heat sectors are leading to a more complex power grid and an increasing workload for grid operations staff. The increasing workload needs to be addressed by optimizing the grid operations work processes. This can be done by assessing the optimization potential of each process with all the underlying process steps. An important step in this assessment is the description and analysis of the work processes. This paper presents an approach to model work processes in grid operations. The model aims to describe work processes, their components and function in the context of grid operations. The model consists of a mathematical definition, a visualization approach and a decision model. The decision model allows the estimation of decision outcomes based on the available information. Accompanying our model, we introduce an evaluation method by defining different metrics for evaluating and comparing multiple processes. Finally, we demonstrate the application of our model on a case study. For our case study we collaborated with two grid operators and created a model for the fault management process in distribution grids. Based on that, we evaluate the influence of information source outages on the process.

22. A Self-adaptive Digital Twin with Broad Learning System: an Example of Heat Pump

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This paper introduces a novel self-adaptive digital twin (DT) based on broad learning system (BLS), which has potential to be evolved in the power and energy sectors. Traditional data-driven DT approaches in these sectors struggle with the requirement for extensive historical data and flexibility in adapting to changes in operating conditions. By integrating BLS, our method notably decreases the volume of initial training data required and improves the system's ability to adjust to new conditions uncovered in initial training data. As an example, the proposed method is applied on a 5 kW air-source heat pump system. Finally, the effectiveness of the proposed method is demonstrated through comparison with a benchmark model calibrated with experimental data.

23. Harmonic Distortion in Large-Scale Heat Pump Systems with Active Filters: An Experimental Case Study on a University Campus

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A heat pump is an efficient ventilating equipment that has been used more regularly in recent years. However, these devices cause harmonic distortion in the electric grid, which should be controlled based on the standards. This paper investigates the harmonic performance of a commercial large-scale heat pump. In order to limit harmonic distortion, an active filter is also installed at the Point of Common Coupling (PCC) so that it can comply with IEEE 519 harmonic standard. The practical results of an installed active filter in a heat pump substation are also recorded and demonstrated which clearly verifies the necessity of the active filter for a heat pump.

24. Smart Charging for Future Electric Vehicle Adoption in Office Areas and Flexibility Assessment

Parnian Alikhani, Till Cordes, Gudo Borger, Ioannis Lampropoulos, Wilfried van Sark
Utrecht University, Netherlands

The integration of Photovoltaic (PV) systems with Electric Vehicle (EV) charging infrastructure is growing, providing substantial benefits for the power grid and consumers. This paper proposes a model to assess the flexibility of various charging station adoption rates, exploring the application of EV smart charging and stationary battery management in an office area. It introduces a method for analyzing and simulating the time-dependent flexibility of EV demand, respecting the interdependencies among transaction parameters. The smart charging algorithms aim to minimize electricity costs and maximize PV self-consumption by evaluating unidirectional and bidirectional EV charging scenarios. The results demonstrate that incorporating vehicle-to-grid (V2G) technology does not provide substantial improvements in achieving either objective compared to unidirectional charging. This is primarily due to factors such as EV availability and the costs associated with EV battery degradation. Given the workplace context with frequent daytime EV charging sessions, cost optimization proves to be more effective, as the optimal solution already achieves significant PV electricity self-consumption. Moreover, the potential for expanding the adoption of charging stations is analyzed due to the spare capacity of the existing transformer in the case study. Utilizing PV-based V2G optimization can further enhance the potential rate of adoption.

25. Measurement-based Harmonic Current Modeling of Agricultural Heat Pumps with Active Filters

Kyohei Kawamura, Kentaro Fukushima, Naotaka Okada
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Harmonic disturbances occur in power distribution systems because of the intensive connection of agricultural heat pumps (AHPs). An effective countermeasure is to equip AHPs with active filters (AFs). However, no harmonic model exists for analytically examining the harmonic suppression effect of AFs. In this study, we measured the harmonic characteristics of an AHP (and an air conditioner) equipped with AFs; the results were used to develop corresponding harmonic current models. AFs are not activated until the active input power of the AHP (and air conditioner) increases to some extent. Thus, a model was developed for the case with an AF and that without an AF; these models are switched according to the effective input power of the AHP. These models can be used for harmonic calculation to prevent harmonic disturbances in distribution systems.

26. Temporal resolution of EV connection data for forecast of V2G frequency services

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This paper investigates the temporal resolution of electric vehicle (EV) connection data required to forecast aggregate frequency response (FR) capacity of vehicle-to-grid (V2G) for FR market participation. This is necessary as there is a mismatch between the temporal resolutions of EV event datasets and the temporal resolutions needed in ancillary services markets. Here, we demonstrate for

the first time that 1 Hz event data provides limited added value for aggregate V2G connection forecasting as the fluctuations found in aggregate EV connection time series and distributions of aggregate EV connection time series can be well-represented by minutely data. This opens up the possibility to utilise widely available minutely data to support V2G connection forecasting for ancillary services markets. An additional investigation into the impact of further downsampling of minutely aggregate EV connection time series indicates that filtering the time series prior to downsampling may reduce information loss.

27. Optimal Hydro Scheduling and Schedule's Automatic Execution in Generation Center Dalmatia in Croatia

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The paper describes the principles and usage of two very important functionalities in generation centers for hydropower plants: optimal scheduling and schedule's automatic execution. As case study, a generation center in Croatia is used. There, hydro scheduling application is used to calculate optimal generation schedule for power units, while respecting basin's and units' physical, technical and operational constraints. A separate module for schedule's execution ensures that the units automatically track the approved schedule. Results recorded during operation in real power system are provided in the paper

28. Reinforcement Learning for Optimal Renewable Energy Sources Scheduling

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The increasing penetration of renewable energy sources (RES), such as wind and PV, in distribution systems, introduces challenges, such as optimal scheduling, due to their intermittent nature. This paper presents a reinforcement learning (RL) algorithm to address the optimal scheduling of RES in distribution systems. The primary objective is to improve the system's technical parameters such as voltage profile and power loss. Additionally, the environmental performance index (CO_2 emission) has been assessed for the case. The presented approach is carried out with the IEEE 33-bus radial distribution network. Simulation results demonstrated that the proposed RL-based approach effectively balanced these objectives. Importantly, it also exhibited adaptability to sudden changes in system conditions, resulting decrease in the system losses.

29. Efficient Sampling for Data-Driven Frequency Stability Constraint via Forward-Mode Automatic Differentiation

Wangkun Xu, Qian Chen, Pudong Ge, Zhongda Chu, Fei Teng
Imperial College London, United Kingdom

Encoding frequency stability constraints in the operation problem is challenging due to its complex dynamics. Recently, data-driven approaches have been proposed to learn the stability criteria offline with the trained model embedded as a constraint of online optimization. However, random sampling of stationary operation points is less efficient in generating balanced stable and unstable samples. Meanwhile, the performance of such a model is strongly dependent on the quality of the training dataset. Observing this research gap, we propose a gradient-based data generation method via forward-mode automatic differentiation. In this method, the original dynamic system is augmented with new states that represent the dynamic of sensitivities of the original states, which can be solved by invoking any ODE solver for a single time. To compensate for the contradiction between the gradient of various frequency stability criteria, gradient surgery is proposed by projecting the gradient on the normal plane of the other. In the end, we demonstrate the superior performance of the proposed sampling algorithm, compared with the unrolling differentiation and finite difference. All codes are available at https://github.com/xuwkk/frequency_sample_ad.

30. Comparative AC-DC Interaction Analysis for Grid-Following and Grid-Forming HVDC Converters

Yonggang Zhang[1], Christian Hachmann[1,2], Nils Wiese[1,2], Martin Braun[1,2], Yahya Lamrani[3], Xavier Guillaud[3]
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AC-DC interactions in modular multi-level converters (MMCs) tend to play a critical role in the small-signal stability of HVDC systems, particularly when considering grid-forming (GFM) control, as required by German grids codes for future HVDC applications. This paper utilises the multiport admittance model of a MMC to evaluate the impacts of GFL and GFM control and the (connected) AC/DC grid strengths on the level of AC-DC interactions and their effects on small-signal stability. Assessment metrics like relative gain array (RGA), self-dominance factor (SDF), and participation factor (PF) considering only the MMC admittance or also the AC/DC grid admittances are partially extended for suiting the assessment and used for comparative analysis. The results highlight the needs of considering potential AC-DC interactions from GFM MMCs in HVDC stability analysis, particulary at between 1-100 Hz, and when current control is included in GFM control. Time-domain simulation in MATLAB/Simulink verifies the frequency-domain analysis.

31. Economic Assessment of Vehicle to Energy Communities

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This paper investigates the commercial viability of bidirectional electric vehicle charging within V2X (Vehicle to Everything) technologies. It explores revenue streams and business cases for households and residential communities. The study assesses concerns regarding battery degradation and the potential of V2G (Vehicle-to-Grid) services. Simulation results reveal saving potential for different household archetypes, especially in urban areas with high energy consumption. Innovative business models are proposed to overcome adoption barriers. The findings stress the significance of routine usage patterns and integration with renewable energy systems for enhancing V2X technologies' commercial value.

32. Techno-economic analysis of superconducting circuit breakers for HVDC grids

Marene Larruskain, Agurtzane Etxegarai, Araitz Iturregi, Oihane Abarrategi, Pablo Eguia, Unai Villena
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This paper presents a comprehensive techno-economic analysis of superconducting circuit breakers (S-DCCBs) for high voltage direct current (HVDC) grids, in comparison to hybrid circuit breakers. The design of the proposed S-DCCB focuses on the superconductor dimensions. Then, the performance of an S-DCCB is evaluated and compared with a hybrid circuit breaker (H-CB) in a four-terminal HVDC grid. The analysis demonstrates that the technical performance of the designed S-DCCB versus H-CB is similar in terms of breaking capability but with remarkably lower costs. The findings contribute to the development of more reliable and efficient HVDC grid protection strategies.

33. Enhancing Grid Resilience with the Integration of Frequency Response in Renewable Energy Systems

Bwandakassy Elenga Baningobera, Irina Oleinikova, Kjetil Uhlen
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Frequency Response (FR) strategies play a pivotal role in modern power systems by enabling grid operators to manage electricity production patterns and balance supply and demand in real-time. This paper investigates the potential of hybrid wind power plants with integrated energy storage systems and their efficacy in enhancing grid resilience during high load demand. Simulation studies and case analyses explore the dynamics of high and low load demand and their impact on system reliability and renewable energy integration. The results are validated using the Nordic 44 model and underscore the importance of frequency response from wind power plants as a flexible tool for addressing grid challenges during periods of high load demand and promoting the efficient utilization of renewable energy resources.

34. An Innovative Digital Twin of Integrated Transportation and Power Networks for Efficient Scheduling of Autonomous Electric Vehicles

Reza Razi, Haider Ali, Frédéric Colas, Bruno Francois
L2EP, France

The use of autonomous electric vehicles has gained significant attention due to the growing interest in sustainable transportation solutions. Shared autonomous vehicles also have the potential to minimize market investments, improve transit systems, and reduce local environmental impact. To address the challenges of scheduling and coordinating shared AEV fleets while considering their integration with power networks, a digital twin-based platform is proposed. The digital twin concept involves creating a virtual replica of a complex system, enabling real-time monitoring, analysis, and optimization. This paper introduces an adaptive digital twin model falling within the third phase of digital twin evolution, integrating transportation and power networks for efficient shared AEV scheduling. The platform utilizes real-time simulators for transportation and power networks, connected through communication protocols. The proposed system aims to enhance scheduling algorithms, consider power grid conditions, and optimize AEV charging infrastructure.

35. A Co-simulation Platform for Wireless LTE Networks in Smart Distribution Systems

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Wireless long-term evolution (LTE) networks are considered as a viable option for deployment in smart distribution systems due to their reliability, scalability, and cost-effectiveness. Yet, co-simulation platforms with the ability to analyze the performance of wireless LTE networks are lacking in the existing literature. This paper, for the first time, presents a real-time co-simulation platform based on Typhoon HIL and OMNeT++ for wireless LTE networks in smart distribution systems. The performance of the wireless LTE networks in smart distribution systems is investigated using the proposed co-simulation platform. A case study related to distribution automation is used to demonstrate the usefulness of the proposed co-simulation platform for examining the performance of wireless LTE networks.

36. Non-Convex AC/DC Static Transmission Expansion Planning Considering Energy Storage Systems and Uncertainty

Santiago Torres[1], Jorge Idrovo[1], Mateo Llivisaca[1], Edgar Morquecho[1], Jose Jara-Alvear[2], Miguel Torres[3], Hakan Ergun[4], Dirk Van Hertem[4]
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The integration of non-dispatchable renewable energy sources increases demands for the inclusion of modern technologies, such as High Voltage Direct Current (HVDC) links and Energy Storage Systems (ESS), in the network expansion planning. Also, the current and future power network complexity demands the use of more accurate models to provide more realistic solutions for the transmission expansion planning problem. However, there are no approaches that allow the selection of the proper technology in a unified and accurate TNEP formulation. In this article, a non-convex formulation to solve the problem, using AC/DC transmission links and ESS, is proposed. The Iterated Greedy (IG) algorithm to find good quality solutions is employed as an optimization technique. Since uncertainty in load and generation scenarios impact significantly the Transmission Network Expansion Planning (TNEP), the Monte Carlo Simulation (MCS) technique is used to deal with their stochastic behavior. The advantages of the proposed approach are illustrated using a modified 6-bus Garver test system.

37. Integrated Planning of Generation and Hybrid AC/DC Transmission Networks

Jose Eduardo Chillogalli[1,2], Santiago Torres[2], Ruben Romero[1], Wilson Chumbi[1], Fabian Astudillo - Salinas[2], Danny Ochoa - Correa[2]
[1]Sao Paulo State University - Ilha Solteira Campus; [2]Universidad de Cuenca, Ecuador

Currently, there is a growing interest in highvoltage DC lines (HVDC) for transmitting power from remote renewable energy projects. However, it is difficult to evaluate the suitability of those technologies, when compared to other generation and transmission expansion options, due to the lack of proper expansion planning approaches. Therefore, to deal with that issue, Generation Expansion Planning (GEP) and Transmission Network Expansion Planning (TNEP) models have been proposed. Those planning approaches have been

traditionally addressed sequentially using linearized models, which do not consider important features such as HVDC links, network power losses, reactive power constraints, or voltage variables. That approach can lead to costly proposals due to oversized transmission expansion plans or high energy production and investment costs. In this research, a new methodology to assess the integrated Generation and Transmission Network Expansion Planning (GTNEP) is proposed, which takes into account the integrated planning of new power plants, and AC and DC transmission lines, for which the AC/DC optimal power flow (OPF) is used. The Iterated Greedy Algorithm (IGA) and a hybridization of Archimedes Optimization Algorithm with the Tabu Search (AOA-TS) meta-heuristic were implemented as a solution method. Important savings were obtained with the 6- bus Garver test system using the proposed planning approach.

38. Investigating Balance Responsible Party Mismanagement through Comprehensive Schedule Analysis: Day-Ahead to Day-After

Devanand Yadav[1], Patrali Majumder[3], Jens Götze[3], Marcel Gaber[2], Dr.-Ing. Marc Richter[3], René Felber[2], Prof. Dr. -Ing. Ines Hauer[1]

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The proper management of balancing groups in the energy sector is essential for a stable electricity supply system. Nevertheless, high balancing group deviations occur repeatedly, for unclear causes. In this paper, a methodology is presented that integrates correlation analysis, feature-based analysis, and linear regression to examine discrepancies in generation and load forecast schedules across day-ahead, intraday, and day-after timeframes. The robust approach includes daily and monthly Key Performance Indicators (KPIs) as the basis for analysis. Applied to over 2 million schedule notifications across more than 900 balancing groups, and generating 6 million schedule-related evaluation metrics, the methods were extensively tested and refined. The top-down approach facilitated a comprehensive assessment of management behaviors at the monthly, daily, and individual schedule-version levels, with support from visual aids and data exports

39. Coordinated Operation of Electrified Transportation Networks Considering Road Capacity Drop

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This paper proposes an optimal transportation-power flow (OTPF) model to manage electrified transportation networks (ETNs) with dynamic wireless charging (DWC) facilities. The transportation network (TN) model, considering the road capacity drop, is adopted for traffic flow assignment. The Distflow model is used to calculate the power flow in the power distribution network (PDN). Energy storage systems (ESSs) and flexible loads (FLs) are integrated into the coordinated operation of ETNs to enhance the economy and security of the system. To address fluctuations and variations in renewable energy generation, model predictive control (MPC) is adopted. The proposed MPC-based OTPF model is formulated as a nonlinear and non-convex problem. To obtain the global optimal solution, it is further transformed into a mixed-integer second-order cone programming (MISOCP) problem by using second-order cone (SOC) relaxation, piecewise linearization, and the Big-M method. Case studies verify the significant influence of road capacity drop on the operation of ETNs.

40. A Method for Identifying the Active Characteristics of Low Voltage Stations Based on Digital Twin

Hao Dai[1], Kang Yao[1], Liwei Liu[1], He Yang[2], Li Cai[1], Jia Li[1], Shuiqiang Gu[1]

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With the deepening of the construction of new power systems, the increasing frequency of user-side participation in grid interactions has led to a rapid evolution of the morphological structure and dynamic characteristics of the distribution system, which has brought new problems and challenges to the low-voltage system. At present, the situation of user-side active equipment is a "black box" for the grid company, which is unable to accurately grasp the situation of user-side active equipment and its characteristics; it poses a greater risk to the operation and maintenance of low-voltage platforms, and restricts the auxiliary planning of the distribution network as well as the precise customer service. This paper proposes a data-driven method based on the identification of active characteristics of LV (low-voltage) platforms, which firstly uses the digital twin technology to simulate the steady-state and transient simulation of the operating state of LV platforms with different topologies, different new energy access modes, and different typical daytime scenarios, and forms a massive simulation scenario dataset. Then it proposes the regular working condition uncertainty learning and abnormal working condition identification technology based on probability distribution modelling, and applies the GMM (Gaussian Mixture Model) to the active identification of low-voltage stations, and constructs the joint probability distribution model of multi-dimensional measurement data of low-voltage stations by using the historical operation data of low-voltage stations, and then compares the similarity between the model horizontally (among other distribution stations) and vertically (among the historical data) by calculating the JS (Jensen-Shannon) dispersion of the joint probability distribution model, so as to judge the existence of the access to the distributed power supply and storage equipment in the low-voltage station area.

41. Multidimensional binary variable-based AC/DC hybrid offshore electrical system optimization of an offshore wind farm cluster

Lingling Huang, Feixiang Ying, Yang Liu, Shurong Wei, Zhangjie Fu

Shanghai University of Electric Power

The exploration of offshore wind power has shown a definite trend of clustering and rapid development from the shore to the far ocean. This has created new challenges for offshore electrical system (OES) planning for offshore wind farm clusters (OWFCs) because high-voltage alternating current (HVAC) transmission is no longer the only optimal choice. The limitations of transmission capacity and distance restrict the applications of HVAC transmission systems and have led to research on AC&DC hybrid OES. Distributed offshore wind farms (OWFs) in the OWFC and nonpredetermined AC/DC transmission systems for OWFs demonstrate some new features. This paper presents a mixed-integer linear programming (MILP) model for the OES optimization of the OWFC. Based on a definition of a set of 0–1 decision variable matrices and the linilization of nonlinear variables with auxiliary binary decision variables, CPLEX is introduced to solve the problem. The case results show the effectiveness of the proposed methodology. Some suggestions for the AC/DC hybrid OES planning of the OWFC have also been proposed.

42. Power transformers winding deformation diagnostic using a fast and affordable method for measuring leakage inductance

Vladimir Valentić, Tomislav Plavšić, Ivica Petrović, Robert Noskov
Croatian Transmission System Operator Ltd., Croatia

Due to the increasing number of transformers owned by different companies e.g. power plants, production facilities and tourist companies the main aim of this paper is to enable quick, reliable and cheap transformer winding diagnostics using the U-I method. Furthermore, the winding deformation test is described, based on the detailed description, recommended power transformer's measuring connections and threshold values. Because power transformer unavailability could lead to large and hard-to-recover losses, undelivered energy and even blackouts, U-I method results are verified with a more complex and expensive frequency analysis (FRA) method.

43. Grid-Oriented Control of Vehicle Batteries in a Cellular Grid Setup Based on Fuzzy Logic

Lars Quakernack, Melina Gurcke, Katrin Schulte, Jens Haubrock
Hochschule Bielefeld – University of Applied Sciences and Arts, Germany

The electrification of various sectors and the expansion of renewable energy resources leads to a change from the historically established and planned vertical load flow in the electrical power system to a horizontal one. This is placing a particular strain on the distribution grids to which the new loads and decentralized generators are connected. The cellular energy system approach is expected to work with a high proportion of renewable energies and ensure a high level of supply security. This paper investigates an autonomous control of vehicle batteries for a cellular grid approach. The hierarchically lowest cell manages loads at household level, in this case the bidirectional charging of electrical Vehicles. The higher entity ensures safe grid operation at transformer level. The aim is to optimize the utilization at transformer and supply line level to avoid congestion. The concept is validated on a test low voltage grid using three scenarios based on the grid expansion plan in Germany. The results show that a cellular grid approach can help reduce the utilization of operational resources and avoid overload with an unknown action space at household level. For a future scenario, the overload at the transformer is reduced by 0.31 pu and the overload at the supply line is reduced by 0.45 pu in a future scenario (2037).

44. Application of Dual-Grid-Forming MMC for Seamless Transition between Grid Connected and Islanded Operation in Microgrids

Arkaitz Rabanal[1], Salvatore D'Arco[2], Elisabetta Tedeschi[1,3]
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This paper presents a control strategy based on dual-grid-forming applied to modular multilevel converters. The goal is to ensure seamless transitions between grid-connected and island operations in AC microgrids. This control strategy is tested on a case where back-to-back multilevel converters interconnect the microgrid to a system with a low short-circuit ratio. While conventional approaches rely on islanding detection algorithms and control mode switches, the proposed technique eliminates the need for such mechanisms, thereby averting potential instabilities. The dual-grid-forming approach synchronizes the grid frequency with the converter's internal energy while enabling concurrent dc voltage regulation. This paper explores the design, implementation, and performance of such control strategy showcasing its effectiveness in enhancing grid stability and ensuring reliable operation at several grid strengths.

45. Impacts of probabilistically sized reserves on the operation of the Senegalese electrical grid

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This paper aims at providing insights into the evolution of the operation costs of Senegal's electrical grid and the fulfillment of system reserve needs while frequency control reserves are sized probabilistically. Control Reserves are used by Transmission System Operators (TSO) to cope for disturbances and limit frequency deviation from nominal set point as small as possible. Historically they have been sized in a deterministic manner. However, with the advent of more intermittent Renewable Energy Sources (RES), there is a need of paradigm shift towards a probabilistic sizing methodology which enables a better coverage of weather-induced disturbances. Such a probabilistic sizing method entails a choice of percentile defining the span of disturbances to cover. Afterwards, the reserve needs sized must be partitioned between the different control reserves. Using historical data of Senegal's electrical grid, we will assess how grid operation is impacted by the percentile choice as well as the partition of reserve needs if a probabilistic sizing approach were to be used.

46. Investigation of a user-centred heating network expansion path compared to a decentralised supply in the context of the municipal energy transition

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In order to achieve greenhouse gas neutrality by 2045 in accordance with the EU Commission's climate targets, it is essential to switch to a sustainable energy supply in the building sector. One strategy for this is the use of heating networks that can ensure an efficient and sustainable heat supply. Considering limited resources and urban planning restrictions, it is necessary to evaluate this added value compared to a decentralised supply. To this end, a modelling process was developed that enables staggered expansion steps, taking expansion restrictions into account. In a first step, the decision-making behaviour of building owners is analysed and then integrated into the planning of the expansion path of heating networks. The results of the study show that heating networks that are operated with renewable energy sources can achieve a positive net present value. It is predicted that by 2045, over 50% of the heat demand can be covered by the heating network, achieving a connection rate of 71%. Buildings that are not connected to the heating network are mainly heated with air source heat pumps.

47. An AC OPF based Clearing Mechanism for Local Flexibility Markets

Benoit Couraud[1], Sonam Norbu[1], Merlinda Andoni[1], Valentin Robu[2], David Flynn[1]

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Local flexibility markets have emerged as an alternative option to expensive grid reinforcement and curtailment and propose a low-cost solution to solve local voltage excursion and cables overload at the distribution grid level. In this paper, we propose a local flexibility market framework based on optimal power flow (OPF) computation to allow a Community Distributed System Operator (C-DSO) to coordinate local flexibility provided by distributed generators and residential consumers. This local flexibility market allows the Distributed System Operator (DSO) to select the most cost-effective mix of flexible assets that addresses voltage excursions and grid congestions. It builds on an OPF formulation applicable only to energy markets, and extends it to the coordination of electrical flexibility. It considers active and reactive power while being suitable for imbalanced distribution grids analysis. Finally, it is implemented on the European low voltage distribution network with real consumption data and with large solar PV penetration to solve local grid constraints. The formulation optimises the flexibility effort while the power flow accuracy presents an error below 2.9% as compared with OpenDSS.

48. Bridging the gap between theory and practice in local energy sharing - energy communities in Croatia

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The European directives put the focus on unlocking the potential of final customers in the clean energy transition. With the recent trend of skyrocketing electricity prices and petrol together with reduced investment costs in low-carbon technologies, the installation of photovoltaic solar panels at the final customer's side became more profitable compared to the previous years resulting in reduced return of investment period. Moreover, to enhance the citizen engagement in renewable energy sources integration, different forms of local energy sharing models are discussed in the literature. The paper will elaborate the regulatory framework and policies on the European level for renewable energy communities, citizen energy communities, and collective self-consumption with the focus on Croatian prospective highlighting the steps needed for accelerating energy communities realization in practice. Based on the current regulation in Croatia, the profit achieved from selling surplus of community energy to the supplier cannot be directly remunerated to the community members. The results show that community members could achieve 20% lower electricity costs on the annual level if the surplus of energy is directly remunerated. In order not to loose the potential profit from excess energy, the paper models investment in the community-owned battery storage system to increase the community self-consumption and minimize the amount of energy sold to the supplier. It is shown that with static sharing scheme the cost is decreased between 11% and 16% for individuals community members and with dynamic key up to 20% in the case the profit from excess energy cannot be renumerated directly to the community members.

49. Innovative Strategy for the Socioeconomic Variables Impact Evaluation on Non-Technical Losses

Leonardo Nogueira Fontoura da Silva[1], Natalia B. Sousa[1], Vinicius J. Garcia[1], Alexandre B. Richter[1], Kamila Stromm[1], Antônio Kaminski Jr.[1], Alzenira da Rosa Abaide[1], Otacílio O. Carneiro Filho[2]

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Non-technical losses (NTL) comprise one of the main negative impacts on energy and economic efficiency of the distribution sector since it has an exogenous source. Thus, the NTL pattern identification provides tools to recognize inspection points and to understand the main reasons and how to mitigate future energy theft and connection fraud. In previous studies, the relationship between NTL in low-voltage consumer environments and socioeconomic aspects is clear. However, these relations cannot be directly obtained due to the different data sources and the lack of accurate measures and information on distribution systems. Based on these premises, this paper presents an innovative strategy for NTL spatial analysis data treatment. Georeferenced socioeconomic sectors and distribution systems crossed layers return feeder vertexes, consumer units, and energy consumed. These three variables compose an NTL contribution index to allocate the global estimated feeder NTL along socioeconomic sectors. It was applied to a Brazilian case study, comparing different scenarios. The results showed a general advance in feature selection, increasing the Mutual Information and Spearman Correlation indexes, mainly for higher feeder vertexes and energy consumed coefficients.

50. A Fixed Point Method for the AC Power Flow Calculation

Miguel Jiménez Carrizosa[1], Dionysios Moutevelis[2]

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This paper presents an AC power flow algorithm using a fixed point method based on the contractive mapping the- orem. The method guarantees the algorithm convergence a priori and the uniqueness of the solution, if it exists, while requiring less computational efforts compared to classical methods. The proposed algorithm is firstly applied for the solution of the the power flow problem for the IEEE 14-bus system under load stress scenarios. Then, its performance is compared against a classical Jacobian matrix-based method and the continuation power flow method. The results show that the proposed method provides better accuracy and convergence properties in the vicinity of the critical voltage point, compared to the standard Jacobian matrix-based, Newton-Raphson method

51. Improved Identification of Natural Frequencies of Fault-Originated Travelling Waves

Zhaoyang Wang[1,2], Renke Wang[2], Pier Luigi Dragotti[2]

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This paper explores the electromagnetic transient travelling waves initiated by faults in electrical power networks with a focus on identifying their associated natural frequencies. Prior research has introduced fault-inferred mother wavelets to address the limitation that traditional mother wavelets typically only detect initial natural frequencies. This paper analyses how the alternative use of L1 normalization, together with modifications to the Q factor, enables traditional mother wavelets to attain performance comparable to that of fault-inferred mother wavelets in identifying all expected natural frequencies. In this way, this approach also mitigates the dependency on specific cases and the additional complexity involved in constructing fault-inferred mother wavelets.

52. Continuous Monitoring System and Method for Detection and Localisation of the Cell-to-Ground Short Circuit for the Battery Cell Packs

Kerim Obarcanin, Miroslav Petrovic, Vedran Mulic
DV Power, Sweden

The battery development and application surge in industry and academia is driven by the dual pressure of environmental pollution and energy shortage. To ensure safety, reliability and optimize the utilization of batteries as an energy storage system, a wide variety of approaches, health indicators and condition assessment methods and safety policies are available nowadays. This paper presents the approach for the detection and localisation of the cell-to-ground short-circuit that is a common potential issue in battery packs. The method is supplemented with the developed measurement and data acquisition system which is used for experimental validation. Moreover, the starting premise is validated in the simulated environment as well.

53. Hydrogen in the Distribution Grid for Capacity Planning and Flexibility

Torgeir Hauso, Irina Oleinikova
NTNU, Norway

By 2050, Norway plans to become a low-emission society, eliminating 90-95 % of greenhouse gases. The government has outlined a hydrogen roadmap that includes both green and blue hydrogen production. This research reviews plans for hydrogen production through electrolysis and examines hydrogen modeling, including storage capabilities. It presents various scenarios focusing on capacity planning and grid integration with flexibility considerations. The implications for the electric grid, when used to provide electricity for hydrogen production via electrolysis, are explored. The study aims to investigate how electrolysers and hydrogen storage can contribute to a flexible power supply in distribution networks. The study shows that flexible operation of electrolysers can mitigate grid stress and postpone costly upgrades by adjusting energy consumption during peak demand periods.

54. Modified Distflow: Novel Power Flow Model for Distribution Grid

Shubhankar Kapoor[1], Johannes Hendriks[1], Adrian Wills[2], Lachlan Blackhall[1], Masoume Mahmoodi[1]
[1]The Australian National University, Canberra, Australia; [2]University of Newcastle, Newcastle, Australia

As the adoption of distributed energy resources (DERs) increases, it introduces several challenges to the distribution grid (DG), including reverse power flow, voltage instability, and grid congestion. These challenges necessitate active distribution grid management, which requires the development of accurate power flow models. This paper proposes a novel, explicit, non-recursive power flow model that incorporates line losses, called the modified Distflow model. The proposed model can be easily integrated into optimization, state estimation, and parameter identification problems. Its performance is evaluated against the widely used Distflow and linearized Distflow (LinDistflow) models on a single-phase IEEE 37-node test feeder, utilizing real-world consumer load data. The results demonstrate that the proposed model achieves comparable accuracy to the Distflow model while being six times faster. Additionally, it offers improved accuracy over the LinDistflow model.

55. Effect of the European Union Emission Trading System on promoting industrial electrification

ESTIBALITZ RUIZ, IVAN PAVIC
University of Luxembourg, Luxembourg

The European Union designed the Emission Trading System (EU-ETS) aiming to achieve climate neutrality by 2050. Theoretically, this mechanism should incentivise consumers to emit less CO2 and invest in green technologies. While there is evidence that it helped reduce CO2 emissions, it is unclear whether it helped promote green investments. This paper answers such a question based on a large European industry. We demonstrate that historical EU-ETS prices have not been incentive enough for this industry to transition from gas to electricity to produce steam. Our calculations show that companies would have to pay at least 30,57\% more for operational costs when using only electricity for heat generation compared to natural gas, even with the addition of EU-ETS prices. We argue that using both conventional and green technologies might be the way to proceed since such a hybrid solution can reduce energy costs by up to 1,68\% and CO2 emissions by 16,23\%. These savings could pay back the investment in the electric boiler until the lifetime of the gas boiler is terminated. Nevertheless, even with the addition of the EU-ETS cost, the operational cost of the electric boiler in 2030 is expected to be higher than that of gas unless the electricity spot prices are controlled.

56. Single-Diode Solar Cell Models: Review and Comparison

Mihailo Micev, Martin P Calasan, Milovan Radulovic
Faculty of electrical engineering, Montenegro

This paper provides an in-depth analysis of single-diode models for solar cells, comparing various models and their accuracy. It will specifically focus on comparing two different solar cell types and estimating parameters using the equilibrium optimizer (EO) algorithm. The findings demonstrate that modified single-diode models offer greater accuracy in representing the current-voltage characteristic of solar cells compared to the classic single-diode model.

57. Power Flow Control using multiple Phase-Shifting Transformers

Ivana Hrgović, Ivica Pavić
University of Zagreb Faculty of Electrical Engineering and Computing, Croatia

When multiple phase-shifting transformers (PSTs) are installed in a meshed electrical grid, careful coordination of these devices is crucial. Poor coordination can result in inefficient infrastructure use and may even compromise the security of supply. This paper aims to explore how PSTs can be controlled to achieve an optimal or near-optimal configuration for a given network. The Croatian transmission network is used as a case study. Expert knowledge is applied alongside an iterative algorithm based on power flow sensitivity analysis. The objective is to determine the PST phase angles and voltage ratios to prevent transmission network overloads under both normal and N-1 contingency conditions during the planning phase.

58. Evaluating the possibilities of inverter-based technologies to ensure system dynamic stability

Matija Kostelac, Tomislav Baškarad, Matija Zidar, Ninoslav Holjevac, Igor Kuzle
University of Zagreb Faculty of Electrical Engineering and Computing, Croatia

Modern power systems have seen increased integration on converter-based electricity production units, mostly photovoltaics and wind. Main consequence of converter-connected generation is decrease of synchronous grid inertia. The inertia of the rotating masses helps to minimize the frequency drift in case of power variation, however if the grid is mostly dominated by power electronic converters, this inertial effect can be severely weakened. Some additional or modified control loops can be added to the converter to emulate the primary and secondary frequency control of standard synchronous machines, thus introducing virtual inertia to the system. Possibilities of such technologies will be explored in this paper..

Online Session

Time: Thursday, 17/Oct/2024: 2:00pm - 3:30pm **Location:** Online

Presentations:

Machine Learning Based Short-Term Forecasts for Wind Power Generation in Denmark

Preeti Grewal[1], **Debasish Ghose**[2]
[1]Østfold University College, Norway; [2]Kristiania University College

Forecasting wind power generation is critical for optimizing energy market operations and ensuring grid stability. Accurate short-term predictions facilitate better scheduling, reduce operational costs, and enhance the integration of renewable energy sources into the smart grid ecosystem. This paper explores multiple machine learning models to predict short-term wind power generation in Denmark, using aggregated data from offshore and onshore wind farms, along with meteorological data from the North Sea, including wind speed and direction. The dataset covers the period from January 2023 to May 2024. The study compares the performance of different models, including XGBoost, CatBoost, LightGBM, Gradient Boosting Regressor, and Random Forest Regressor, demonstrating the importance of comprehensive weather data in achieving accurate forecasts. The results underscore the efficacy of these models in capturing the intricate dependencies in wind power generation data, providing insights that are crucial for future energy management strategies.

Power System Stability Improvements Through Grid Forming Inverters for Systems with High Penetration of Grid Following Inverters

Viduruwan Geekiyanage, **Janne Seppänen**
Aalto University

The power transmission system is rapidly changing due to the integration of renewable sources such as wind and solar power. However, these additions are converter-based hence their behavior is different from traditional synchronous generator-based power systems. In addition, the majority of the converters are grid-following inverters and a high share of grid-following inverters can have adverse effects on the power system stability. To mitigate the adverse effects, a new concept called grid-forming inverters is emerging. This paper studies the ability of the grid-forming inverters to maintain the power system stability under high inverter-based resource scenarios up until 100% inverter-based resource share. The research identified that the two-area Kundur model is stable up to 50% grid following inverter share and with the use of a sufficient share of grid-forming inverters, the system can reach up to 100% inverter-based resource share. Furthermore, the location sensitivity of the grid-forming inverter and the effects of different power flow scenarios at high inverter-based resource share were studied.

Pilot Nodes Clustering Using Sensitivity Analysis for Frequency-Constant Grid Operation in Power Systems with Zero Inertia

Nizam Halawi, Hassan Alhomsi, Franz Linke, Steffen Schlegel, Dirk Westermann
Ilmenau University of Technology, Germany

A new method for power balancing in a converter-dominated power system is angle control of pilot nodes. Voltage angle control allows instantaneous activation of control power based on angle changes. In addition to conventional voltage angle control, the pilot node approach allows higher utilization and avoids overloading of transmission lines. Furthermore, the pilot node approach reduces computational complexity and minimizes measurement equipment costs by selectively measuring voltage phasors only at pilot nodes, rather than at each voltage source converter. This paper presents a full concept of a voltage angle control for pilot nodes in the grid. The functionality of this approach is evaluated on a modified 39-bus New England system as a case study.

Optimal Active and Reactive Power Flow Management in Microgrid : Moroccan VS Time of Use System Tariff

saad GHEOUANY, **Hamid OUADI, Saida EL BAKALI**
National Higher School of Arts and Crafts, Mohammed V University in Rabat, Rabat, Morocc, Morocco

This paper introduces an innovative Active and Reactive Energy Management System (AR-EMS) tailored for optimizing power flow within a Moroccan smart microgrid. It investigates how different electricity price profiles influence energy flow distribution, Battery Storage System (BSS) longevity, and financial gains. Specifically, it compares two tariffs: the Moroccan Tiered Tariff (TTS), which is based on consumption bands over a 30-day horizon, and the European Time of Use Tariff (TOU), which varies hourly according to peak and off-peak hours. The proposed AR-EMS computes optimal active and reactive power setpoints for each energy source over 30 days and relates to forecasted load consumption and PV power output. Its primary objectives include reducing energy bills, mitigating BSS degradation costs, optimizing the Peak-to-Average Ratio (PAR), and minimizing environmental impact. These objectives are optimized through Multi-Objective Particle Swarm Optimization (PSO). Through critical comparative analysis using real-world data, the study highlights the advantages of the AR-EMS over existing strategies that only manage active power flow (A-EMS). Notably, the AR-EMS demonstrates a 29% reduction in both total energy bills and carbon emissions, while also improving the power factor by 26% compared to the A-EMS.

Improving Grid Resiliency with Active Management of Electric Vehicles Charging in Low Voltage Distribution Network

Hafiz Aqib Nazir[1], Muhammad Zubair Iftikhar[2], Shahid Nawaz Khan[1], Naveed Arshad[1], Muhammad Yousuf Jamal[2]

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With the growing concern about climate change and the rapid advancement of technology, integrating electric vehicles (EVs) into power systems, particularly within low voltage (LV) distribution networks, is becoming increasingly vital to ensure reliable and sustainable grid operation. This significant paradigm shift necessitates careful consideration of the impact of home charging on the grid, including potential issues such as power quality degradation, voltage deviation, and the overloading of distribution transformers. Under-voltages, especially at the far end of the feeder, can significantly undermine the network's hosting capacity. An active voltage constraint management approach for EVs has been implemented to effectively manage the clustering of EVs within residential power distribution networks, aimed at enhancing the grid's hosting capacity while accounting for realistic household electricity demand. Additionally, the substantial impact on transformer health and power losses is carefully analyzed. The results indicate that the hosting capacity of the studied network could be notably increased through the proposed EV charging demand-shifting strategy. Moreover, the negative impacts on transformer health could be significantly mitigated, leading to a 34.57% improvement in life expectancy.

Optimal Operation of a Building with Electricity-Heat Networks and Seasonal Storage

Eléa Prat[1], Pierre Pinson[2,3,1,4], Richard M. Lusby[1], Riwal Plougonven[5], Jordi Badosa[5], Philippe Drobinski[5]

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As seasonal thermal energy storage emerges as an efficient solution to reduce CO2 emissions of buildings, challenges appear related to its optimal operation.

In a system including short-term electricity storage, long-term heat storage, and where electricity and heat networks are connected through a heat pump, it becomes crucial to operate the system on two time scales. Based on real data from a university building, we simulate the operation of such a system over a year, comparing different strategies based on model predictive control (MPC). First, we determine the minimum prediction horizon to retrieve the results of the full-horizon problem. We then evaluate a method that combines MPC with setting the long-term storage level at the end of the prediction horizon to the optimal values from the previous year. For a prediction horizon of 6 days, the suboptimality gap with the full-horizon results is 3.28%, compared to 10.07% when using a prediction horizon of 42 days and fixing the final level to be equal to the initial level, which is a common approach.

Quantifying the flexibility at the TSO-DSO Interface Under Uncertainties

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With the increasing penetration of distributed energy resources (DERs) into power systems, overall grid uncertainty and variability have increased significantly. The transmission and distribution networks both find it challenging to maintain grid stability and security. To address these challenges, flexibility within the distribution network can be crucial in supporting various grid or ancillary services, such as frequency control, voltage control, or congestion management. Hence, this paper focuses on developing an algorithm to assess feasible and flexible regions from the distribution network at the interface of Transmission System Operators (TSOs) and Distribution System Operators (DSOs). This work includes multiple case studies demonstrating the effects of different constraints like line flows, upper and lower voltages, ramp rates, and market dispatch points on estimated flexible charts. Additionally, the impact of load uncertainty on feasible regions is investigated using a robust optimization technique. The proposed methodology under different scenarios is validated through simulation on a modified IEEE 33-bus system.

Hotel function areas

General information

Registration desk hours

Monday, October 14th	7:00 am – 4:00 pm
Tuesday, October 15th - Thursday, October 17th	8:00 am – 4:00 pm

Name Badge

The admission to all conference sessions is by name badge only. Please be sure to wear your badge at all times.

Responsibility

The Organizing Committee assumes no responsibility for accident, losses, damage, delays, or any modifications to the program arising from unforeseen circumstances. It accepts no responsibility for travel or accommodation arrangements.

The participant acknowledges that he or she has no right to lodge damage claims against the Organizing Committee should the conference proceedings be hindered or prevented by unexpected political or economic events or generally by acts of God or should the non-appearance of speakers or other reasons necessitate program changes.

Internet Access

Wireless internet access is available in the hotel.

Conference venue & Accommodation

The conference will be held in Sheraton Dubrovnik Riviera Hotel. This hotel is a perfect destination for all holidaymakers and event organizers, located between the Airport and the old town, in a secluded surroundings with an amazing and private view over Srebreno's bay.

Transfer services

If you wish to schedule a transfer service to the airport or downtown Dubrovnik please let us know at the registration desk. Pre- and post-conference travel options – Our touristic **Partner Concorda** will help you with your travel and accommodation arrangements.

Currency

The official currency in Croatia is EUR. Credit cards (Eurocard / Mastercard, Visa, American Express and Diners) are accepted in all hotels, marinas, restaurants, shops and cash machines.

Emergency Telephone Numbers

Emergency – Police, Ambulance, and Fire: 112

This number can be reached any time, day or night, regardless of where you are in the Republic of Croatia. Calls to this number are free of charge. Calls can be made through all operators and all telephone devices by dialing 112.

Lost and found

All materials lost or found in the auditoriums are brought to the Registration Desk located in the main lobby of the hotel.

Parking

Hotel provides parking for all its guests.

Welcome Reception

Monday, October 14th, 8:00 pm – 11:59 pm

Sheraton Dubrovnik Riviera Hotel – hotel terrace

Reception with snacks and drinks

The ISGT2024 Welcome Reception will take place on the hotel terrace with the Tesla coil musical performance.

This will be a perfect setting for delegates, students and companions to enjoy a social evening of food, drinks, and conversation.

Gala Dinner

Wednesday, October 17th, 8:30 pm – 11:50 pm

Sheraton Dubrovnik Riviera Hotel

The gala dinner at the Conference are (Orlndo).

Technical visit 1

Time: Tuesday, 15/Oct/2024: 6:00pm - 7:00pm **Location:** HPP Zavrelje

Walking distance from the Venue Hotel (500 meters).

HEP Zavrelje was constructed in 1953 in Župa Dubrovačka, about 10 km east of Dubrovnik, Croatia. It uses water from the Zavrelje spring in Župa Dubrovačka. This typical karstic spring is located at 82 m a.s.l., and 620 m far from the sea where it inflows in the settlement of Mlini. Water is taken from the spring by a 322 m long open canal (4.2 m × 2 m), a small dam, where a 320 m penstock of 1.3 m in diameter begins, taking water to the power house with two Frances turbines located on the coast. Water from the turbines is discharged into coastal sea. HEP Zavrelje is directly connected to EPS to which all produced electric energy is given.

Technical visit 2

Time: Thursday, 17/Oct/2024: 4:00pm - 7:00pm **Location:** HPP Dubrovnik

Bus departing from the venue hotel main entrance.

A technical visit to the hydroelectric power plant, **HPP Dubrovnik** (2×126 MW) has been planned for **October 17, 2024**. Dubrovnik hydropower plant was built in 1965. As the HPP Dubrovnik accumulation lake is located on the territory of Bosnia and Herzegovina, one of its units generates electricity for the electric power system of Bosnia and Herzegovina. During 50 years of its operation, this hydropower plant has generated almost 60 billion kWh, 30 billion of which was delivered to the Croatian electric power system – almost double the amount of Croatia's overall annual consumption. HPP Dubrovnik is also the first hydropower plant which was renovated as part of the comprehensive multi-year renovation and revitalisation programme of HEP's hydropower plants. The 3.6 billion kuna worth revitalisation programme will ensure about 120 MW of new capacity, which equals the production of a new hydropower plant, sixth by capacity among 26 existing HEP's hydropower plants.

The second part of the trip will involve a visit to the TS 220/110/35/20(10) kV PLAT substation.

The 220/110/35/20(10) kV substation (SS) Plat is situated at the southern access to the town of Dubrovnik, above the Adriatic main road, near the village of Plat, approximately 800 m north of the present 220 and 110 kV switchyard of the Dubrovnik hydro power plant. To the north-east, on the open space behind the high voltage switchgear building, the 220/110/35/20(10) kV switchgear is situated, comprising two 220/110 kV autotransformers, **150 MVA** (AT1 and AT2), a 110/35 kV, **20 MVA** (TR1) and a 110/20 kV, **20 MVA** (TR2) transformer, and an 35/20(10) kV, 16 MVA interconnecting transformer. Unit auxiliary transformers 35/0.4 kV, 630 kVA and 20(10)/0.4 kV, 630 kVA are situated on the ground floor of the management and control facility.