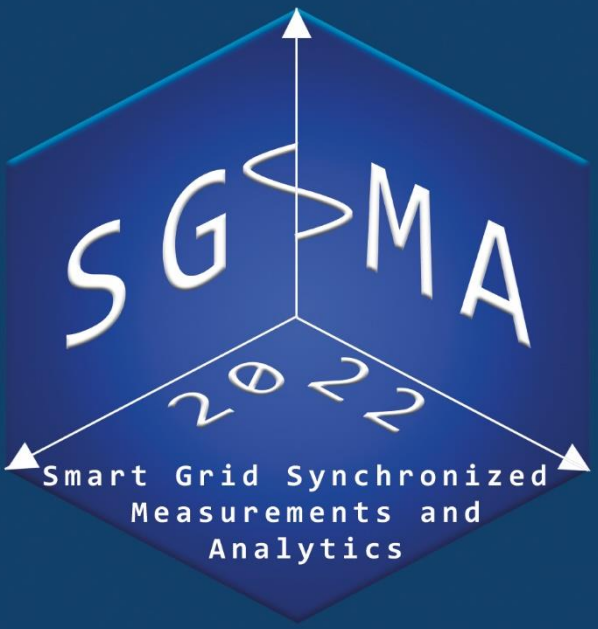
# The 2022 International Conference on Smart Grid Synchronized Measurements and Analytics (SGSMA2022) Conference Book




24th - 26th May 2022, Split, Croatia

# Conference book

# The 2022 International Conference on Smart Grid Synchronized Measurements and Analytics – SGSMA, Split, Croatia, May 24h - 26th 2022

## Conference book

SGSMA 2022

24-26 May 2022

Split, Croatia

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**Editors:**

**Ninoslav Holjevac, Igor Kuzle, Igor Ivanković, Tomislav Baškarad**

Organized by:

UNIVERSITY OF ZAGREB

Faculty of Electrical Engineering and Computing

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# Welcome

It is our great pleasure to welcome you to the 2022 International Conference on Smart Grid Synchronized Measurements and Analytics – SGSMA 2022. The conference provides a leading forum for disseminating the latest research in Synchronized Measurements and Analytics. The SGSMA brings together leading researchers and developers from academia, research, and industry from all over the world to facilitate innovation, knowledge transfer and the technical progress in addressing synchronized measurements and analytics to advance smart grids.

The theme of the conference will be focused particularly on synchronized sampling and synchrophasors. The conference will attract scientific and applied research findings in Smart Grid Synchronized Measurements and Analytics. The attendees will get the opportunity to present their findings, learn about the recent research results from others, and be able to network with some of the leading luminaries, academics, researchers and practitioners in this area.

SGSMA 2022 Conference offers 1 keynote lecture, 1 tutorial session, a total of 10 panel sessions, and a total of 9 regular paper sessions. Overall, the conference will host 36 papers, each of which was reviewed by at least two reviewers. Authors of accepted papers at SGSMA2022 will have the opportunity to submit extended versions of their papers to a special issue of the International Journal of Electric Power Systems (IJEPS) on synchronized measurements and analytics.

This year's SGSMA2022 is hosted in Split - the second largest city of Croatia. It lies on the eastern shore of the Adriatic Sea and is spread over a central peninsula and its surroundings. Split is known for ancient sights, sandy beaches, and rich nightlife options. Alongside Dubrovnik, Split is the most important part of Croatia tourism, featuring millions of visits every year.

For these 3 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 a better future of energy.

We are looking forward to being your hosts,

Your SGSMA2022 Organizing Team

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# Keynote Speaker

**Name of the speaker:** Renata Rubeša, PhD

**Email**: renata.rubesa@hops.hr

**Organization**: Head of the Department SCADA/EMS applications, Croatian Transmission System Operator HOPS, Croatia

## Biography

Renata Rubeša received her B.Sc.E.E degree in 2005. in electrical engineering from the Faculty of Electrical Engineering and Computing University of Zagreb in 2005, and the PhD degree in Electrical Engineering from the University of Zagreb, Croatia in 2015. Since 2005. she has been with the Croatian transmission system Operator, where she started working as a relay protection engineer. Since 2007 she is with the Department for support to power system control, responsible for maintenance, development and integration of SCADA, EMS, AGC and WAM systems. She is currently head of department for the support to power system control in HOPS. She has participated in several projects and conferences involving development of WAM system in Croatia and international CIGRE working groups for the integration of WAMS in the control room. She is Member of IEEE, member of CIGRE Croatia study committee C2 Power system operation and control and chair of Croatian CIGRE study committee B5 Protection and automation. She has participated in several research and development projects funded by the EU. Since 2017 she is technical lead for the integration and development of an automated Volt Var control system in Croatia, as part of the Sincro.Grid project co-funded by the European Commission in the field of smart grids. Her main topics of interest are transmission system protection, wide area monitoring and energy management systems.

## WAMS in the control room, a TSO perspective

**Abstract:** The literature is full of different, proposed applications, which use sychrophasor data. Currently, there is no singular, 'master' application or system, which would cover all the possible usages. Different utilities usually have niche use cases to cover their needs. Considering this, the usage of WAM data in a TSO depends on the issue to be monitored or solved. The applications can be divided into those used in the control room for real time operations, those used for planning purposes and those for disturbance analysis. TSOs usually have a long path to introduce the benefits of the synchrophasor technology in the control room. The integration issues are usually of technical or non-technical nature. Data communication protocols, visualization, alarm thresholds, cyber security are usually some of the main technical integration issues. Confidence gap and unknown countermeasures to mitigate unsecure operation of the power system are one of the main non-technical barriers for a more vast usage of synchrophasors in the control room. The presentation will deal with paths, issues and solutions how TSOs face the challenges of integrating the benefits of a WAM system.

# Program overview

| Monday<br>23rd May | Tuesday<br>24th May | Wednesday<br>25th May | Thursday<br>26th May |
|---|---|---|---|
| | 7:30am - 8:30am<br>**Registration** | 7:30am - 8:30am<br>**Registration** | 7:30am - 8:30am<br>**Registration** |
| | 8:30am - 9:00am<br>**Opening session** | 8:30am - 10:00am<br>**Parallel paper session: SES5 and SES6**<br>Room: Ruzmarin and Oleandar | 8:30am - 9:50am<br>**Paper session: SES9**<br>Room: Oleandar |
| | 9:00am - 10:00am<br>**Keynote**<br>Room: Ballroom | | |
| | 10:00am - 10:30am<br>Coffee break | 10:00am - 10:30am<br>Coffee break | 10:00am - 10:15am<br>**Closing session** |
| | | | 10:15am - 10:30am<br>Coffee break |
| | 10:30am - 12:00pm<br>**Parallel paper session: SES1 and SES2**<br>Room: Ruzmarin and Oleandar | 10:30am - 12:00pm<br>**Parallel panel session: SES5 and SES6**<br>Room: Ruzmarin and Oleandar | 10:30am - 6:00pm<br>**Technical visit** |
| | 12:00pm - 1:00pm<br>Lunch | 12:00pm - 1:00pm<br>Lunch | |
| 1:00pm - 5:00pm<br>**Registration** | 1:00pm - 1:30pm<br>**SEL Sponsorship**<br>Room: Ruzmarin | 1:00pm - 1:30pm<br>**Pro Integris Sponsorship**<br>Room: Ruzmarin | |
| | 1:30pm - 3:00pm<br>**Parallel panel session: SES1 and SES2**<br>Room: Ruzmarin and Oleandar | 1:30pm - 2:50pm<br>**Parallel paper session: SES4 and SES8**<br>Room: Ruzmarin and Oleandar | |
| 3:00pm - 6:00pm<br>**Tutorial**<br>Room: Oleandar | 3:00pm - 4:20pm<br>**Parallel paper session: SES3 and SES7**<br>Room: Ruzmarin and Oleandar | 2:50pm - 4:20pm<br>**Parallel panel session: SES7 and SES8**<br>Room: Ruzmarin and Oleandar | |
| | 4:20pm - 4:45pm<br>**EPG Sponsorship**<br>Room: Ruzmarin | 4:20pm - 4:45pm<br>**Zaphiro Sponsorship**<br>Room: Ruzmarin | |
| | 4:45pm - 5:00pm<br>Coffee break | 4:45pm - 5:00pm<br>Coffee break | |
| | 5:00pm - 6:30pm<br>**Parallel panel session: SES3 and SES4**<br>Room: Ruzmarin and Oleandar | 5:00pm - 6:30pm<br>**Parallel panel session: SES9 and SES10**<br>Room: Ruzmarin and Oleandar | |
| | 6:30pm -7:00pm<br>**Quanta Technology Sponsorship**<br>Room: Ruzmarin | 6:30pm -7:30pm<br>**SGSMA Association meeting**<br>Room: Palma | |
| | 8:00pm -11:00pm<br>**Welcome reception** | 8:00pm -11:00pm<br>**Gala Dinner** | |

| | |
|---|---|
| **1:00pm - 5:00pm** | **Registration** |
| **3:00pm - 6:00pm** | **Tutorial 1 -** CPOW Analysis: Data processing techniques for extracting insights from continuous point-on-wave measurements<br><br>Room: **Oleandar** |

## Tuesday, 24/May/2022

| | | |
|---|---|---|
| **7:30am - 8:30am** | **Registration**<br>Registration desk will stay open throughout the whole day until 17:30 | |
| **8:30am - 9:00am** | **Opening session**<br>Room: | |
| **9:00am - 10:00am** | **KEYNOTE: Renata Rubeša -** WAMS in the control room, a TSO perspective<br>Room: **Ballroom** | |
| **10:00am - 10:30am** | **Coffee Break** | |
| **10:30am - 12:00pm** | **Parallel Paper Session** | |
| | **S1 -** Distribution level PMU applications<br>Room: **Ruzmarin** | **S2 -** State Estimation<br>Room: **Oleandar** |
| **12:00pm - 1:00pm** | **Lunch** | |
| **1:00pm - 1:30pm** | **SEL Sponsorship** - Time Synchronization in Power System Protection Applications – Current Technologies and Future Trends<br>Room: **Ruzmarin** | |
| **1:30pm - 3:00pm** | **Parallel Panel Session** | |
| | **S1 -** PMU- and AI-based analysis for a resilient operation of future power systems<br>Room: **Ruzmarin** | **S2 -** Utilization of transmission system data for enhancement and preservation of its secure operation<br>Room: **Oleandar** |
| **3:00pm - 4:20pm** | **Parallel Paper Session** | |
| | **S3 -** Platforms and architectures I<br>Room: **Ruzmarin** | **S7 -** Power System Oscillations<br>Room: **Oleandar** |
| **4:20pm - 4:45pm** | **EPG Sponsorship -** Synchrophasor Technology for Managing and Operating Power Grids<br>Room: **Ruzmarin** | |
| **4:45pm – 5:00pm** | **Coffee Break** | |
| **5:00pm - 6:30pm** | **Parallel Panel Session** | |
| | **S3 -** Monitoring, Analysis and Mitigation of Power System Oscillations Using Synchronized Measurements<br>Room: **Ruzmarin** | **S4 -** Data-Driven Analytics and Use Cases for Synchronized Waveform Measurements<br>Room: **Oleandar** |
| **6:30pm – 7:00pm** | **Quanta Technology Sponsorship -** Successful and Practical Synchronized Measurement Applications and Deployment<br>Room: **Ruzmarin** | |
| **8:00pm – 11:00pm** | **Welcome reception**<br>Location: **Hotel outdoor pool area** | |

## Wednesday, 25/May/2022

| | | |
|---|---|---|
| **7:30am - 8:30am** | **Registration**<br>Registration desk will stay open throughout the whole day until 17:30 | |
| **8:30am - 10:00am** | **Parallel Paper Session** | |
| | **S5 -** Industry experiences<br>Room: **Ruzmarin** | **S6 -** Machine learning applications<br>Room: **Oleandar** |
| **10:00am - 10:30am** | **Coffee Break** | |
| **10:30am - 12:00pm** | **Parallel Panel Session** | |
| | **S5 -** Wide area monitoring and control challenges in the Nordic power system<br>Room: **Ruzmarin** | **S6 -** Analysis of the two systems splits and one inter-area oscillation within the Continental European Synchronous Area in year 2021<br>Room: **Oleandar** |
| **12:00pm - 1:00pm** | **Lunch** | |
| **1:00pm - 1:30pm** | **Pro Integris Sponsorship** – Solving communication challenges in IEC 61850 based substations<br>Room: **Ruzmarin** | |
| **1:30pm - 2:50pm** | **Parallel Paper Session** | |
| | **S4 -** Platforms and architectures II<br>Room: **Ruzmarin** | **S8 -** Event detection and identification<br>Room: **Oleandar** |
| **2:50pm - 4:20pm** | **Parallel Panel Session** | |
| | **S7 -** PMU testing and synchrophasor system life-cycle management<br>Room: **Ruzmarin** | **S8 -** Enabling Technologies for Enhancing Power System Resiliency by Wide Area Monitoring Protective and Control Systems<br>Room: **Oleandar** |
| **4:20pm - 4:45pm** | **Zaphiro Sponsorship -** PMU rollout at EPFL campus – A real-scale laboratory for synchrophasor applications<br>Room: **Ruzmarin** | |
| **4:45pm – 5:00pm** | **Coffee Break** | |
| **5:00pm - 6:30pm** | **Parallel Panel Session** | |
| | **S9 -** Towards a Zero Inertia Grid thanks to Synchrophasor Measurements<br>Room: **Ruzmarin** | **S10 -** Synchronized Measurement in The Control Room of The Future<br>Room: **Oleandar** |
| **6:30pm – 7:30pm** | **SGSMA Association meeting**<br>Room: **Palma** | |
| **8:00pm – 11:00pm** | **Gala Dinner**<br>Location: **Restaurant at venue hotel** | |

## Thursday, 26/May/2022

| | |
|---|---|
| **7:30am - 8:30am** | **Registration**<br>Registration desk will stay open throughout the whole day until 17:30 |
| **8:30am - 9:50am** | **Paper Session S9 -** Frequency and phasor estimation<br>Room: **Oleandar** |
| **10:00am - 10:15am** | **Closing Session** |
| **10:15am - 10:30am** | **Coffee Break** |
| **10:30am - 6:00pm** | **Technical Visit -** A technical visit to two hydroelectric power plants, HPP Zakučac (544 MW) and HPP Kraljevac (67.2 MW) |

## Paper Sessions

## Paper Session 1: Distribution level PMU applications

*Time:* **Tuesday, 24/May/2022: 10:30am - 12:00pm** *Location:* **Ruzmarin**

Chair**: Mario Paolone**

### Presentations

**A hardware in the loop testbed for adaptive protection of non-inteconnected island systems with high RES penetration**

**George Gkiokas, Dimitrios Lagos, George Korres, Nikos D. Hatziargyriou**
National Technical University of Athens, Greece; gkorres@cs.ntua.gr

**Dynamic Performance Comparison and Prediction based on Distribution-level Phasor Measurement Units**

**Yuru Wu[1], He Yin[1], Yilu Liu[1,2], Shengyou Gao[3]**
[1]University of Tennessee; [2]Oak Ridge National Laboratory; [3]Tsinghua University; ywu70@vols.utk.edu

**Technical solutions for automation of distribution networks based on SPM technology**

**Sergey Aleksandrovich Piskunov[1], Aleksej Vladimirovich Mokeev[2], Aleksandr Igorevich Popov[2], Dmitrij Nikolaevich Ulyanov[1], Andrej Vyacheslavovich Rodionov[1]**
[1]Engineering Centre Energoservice, Russian Federation; [2]Northern (Arctic) Federal University; s.piskunov@ens.ru

**Roadmap for Distribution Synchronized Measurements**

**Rich Hunt[1], Sean Kantra[1], Damir Novosel[1], Julio Romero Aguero[1], Daniel Dietmeyer[2], Tariq Rahman[2]**
[1]Quanta Technology, United States of America; [2]San Diego Gas & Electric, United States of America; DNovosel@quanta-technology.com

## Paper Session 2: State estimation

*Time:* **Tuesday, 24/May/2022: 10:30am - 12:00pm** *Location:* **Oleandar**

Chair**: Joe Chow**

### Presentations

**Metrological Significance and Reliability of On-Line Performance Metrics in PMU-based WLS State Estimation**

**Guglielmo Frigo, Federico Grasso-Toro**
Swiss Federal Institute of Metrology, METAS; guglielmo.frigo@gmail.com

**Physics-Conditioned Generative Adversarial Networks for State Estimation in Active Power Distribution Systems with Low Observability**

**Mohasinina Kamal[1], Wenting Li[2], Deepjyoti Deka[2], Hamed Mohsenian-Rad[1]**
[1]University of California, United States of America; [2]Los Alamos National Laboratory, United States of America; hamed@ece.ucr.edu

**A Practical Model for Optimal PMU Placement**

**Mohammadreza Maddipour Farrokhifard, Gang Zheng, Manu Parashar, Vijay Sukhavasi**
GE Digital, United States of America; mohammadreza.maddipourfarrokhifard@ge.com

**Optimizing D-PMU deployment for distribution system state estimation**

**Themistoklis Xygkis, George Korres**
National Technical University of Athens, Greece; txygkis@power.ece.ntua.gr

## Paper Session 3: Platforms and architectures I

*Time:* **Tuesday, 24/May/2022: 3:00pm - 4:20pm** *Location:* **Ruzmarin**

Chair: **Mehrdad Ghandhari**

### Presentations

**A Reconfigurable Synchrophasor Synchronization Gateway & Controller Architecture for DERs**

**Prottay M. Adhikari[1], Luigi Vanfretti[1], Chetan Mishra[2], Kevin Jones[2]**
[1]Rensselaer Polytechnic Institute, United States of America; [2]Dominion Energy, Richmond, VA, USA; prottaymondaladhikari@gmail.com

**Characterization of a Low Power Instrument Transformer with Digital Output in Low-Inertia Power Systems**

**Guglielmo Frigo, Marco Agustoni**
METAS, Switzerland; marco.agustoni@metas.ch

**A Software Toolchain for Real-Time Testing of Synchrophasor Algorithms in MATLAB**

**Lalit Kumar[1], Shehab Ahmed[1], Luigi Vanfretti[2], Nand Kishor[3]**
[1]KAUST, Saudi Arabia; [2]RPI New York, USA; [3]Østfold University College, Norway; Lalitnbd@gmail.com

**Investigation of PMU Limitations in Monitoring Fast Dynamics Through Real-Time Hardware-In-The-Loop Experiments**

**Hossein Hooshyar, Aboutaleb Haddadi, Evangelos Farantatos, Mahendra Patel**
Electric Power Research Institute, United States of America; hhooshyar@epri.com

## Paper Session 4: Platforms and architectures II

*Time:* **Wednesday, 25/May/2022: 1:30pm - 2:50pm** *Location:* **Ruzmarin**

Chair: **Lars Nordström**

### Presentations

**Slipstream: High-Performance Lossless Compression for Streaming Synchronized Waveform Monitoring Data**

**Steven Blair, Jason Costello**
Synaptec, United Kingdom; steven.blair@synapt.ec

**Analytical Approach to Phasor-based Line Parameter Estimation Verified Through Real PMU Data**

**Evgeniy Satsuk[1], Andrey Zhukov[1], Dmitrii Dubinin[1], Igor Ivanov[2], Andrey Murzin[2]**
[1]SO UPS; [2]Ivanovo State Power Engineering University; satsuk-ei@so-ups.ru

**Iterative Quadrature Demodulation for Harmonic Synchrophasor Estimation**

**Dahlia Saba[1], Miles Rusch[1], David M. Laverty[2], Alexandra von Meier[1]**
[1]University of California, Berkeley, United States of America; [2]Queen's University Belfast, Belfast, United Kingdom; dahliasaba@berkeley.edu

**Non-Homogeneous Sampling Rate Wide Area Backup Protection using Synchrophasors and IED Data**

**Jose Chavez[1], N Veera Kumar[1], Marjan Popov[1], Enrique Melgoza[2], Sadegh Azizi[3], Vladimir Terzija[4], Peter Palensky[1]**
[1]Delft University of Technology, The Nehterlands; [2]The National Technological Institute of Mexico; [3]University of Leeds, UK; [4]School of Electrical Engineering, Shandong University, China; j.j.chavezmuro@tudelft.nl

## Paper Session 5: Industry experiences

*Time:* **Wednesday, 25/May/2022: 8:30am - 10:00am** *Location:* **Ruzmarin**

Chair: **Robert Eriksson**

### Presentations

**Load frequency response in The Chilean Power System**

**Juan Quiroz[1], Carlos Fuentes[2], Héctor Chávez[3]**
[1]University of Santiago of Chile, Chile; [2]University of Santiago of Chile, Chile; [3]University of Santiago of Chile, Chile; juan.quiroz@usach.cl

**Synchrophasor-based Fault Location with Class M Fault Capture and Built-in Line Parameter Estimation**

**Andrey Zhukov[1], Dmitrii Dubinin[1], Igor Ivanov[2], Andrey Yablokov[2], Andrey Tychkin[2], Filipp Kulikov[2], Anton Panaschatenko[2]**
[1]SO UPS, Russian Federation; [2]Ivanovo State Power Engineering University, Russian Federation; zhukov@so-ups.ru

**Monitoring of the dynamics of changes in the kinetic energy of power plants to improve the reliability of power system control**

**Dmitrii Dubinin, Andrey Zhukov, Evgeny Satsuk, Vladimir Vasilev**
SO UPS, Russian Federation; dubinin@so-ups.ru

**Centralised system for overfrequency real-time dynamic settings for generators**

**Tadeja Babnik[1], Bojan Mahkovec[1], Srdjan Subotic[2]**
[1]ELPROS d.o.o., Slovenia; [2]Elektromreza Srbije, Serbia; tadeja.babnik@elpros.si

# Paper Session 6: Machine learning applications

*Time:* **Wednesday, 25/May/2022: 8:30am - 10:00am** *Location:* **Oleandar**

Chair: **Mladen Kezunovic**

## Presentations

### Real-time Coherency Identification using a Window-Size-Based Recursive Typicality Data Analysis

**Lucas Lugnani Fernandes[1], Daniel Dotta[1], Mario R A Paternina[2], Joe Chow[3]**

[1]University of Campinas, Brazil; [2]University of Mexico, Mexico; [3]Rensselaer Polytechnique Institute, USA; lugnani@dsee.fee.unicamp.br

### Transfer Learning for Event-Type Differentiation on Power Systems

**Haoran Li[1], Zhihao Ma[1], Yang Weng[1], Evangelos Farantatos[2]**

[1]Arizona State University, United States of America; [2]Electric Power Research Institute; lhaoran@asu.edu

### Machine Learning Using a Simple Feature for Detecting Multiple Types of Events From PMU Data

**Tatjana Dokic[1], Rashid Baembitov[1], Ameen Abdel Hai[2], Zheyuan Cheng[3], Yi Hu[3], Mladen Kezunovic[1], Zoran Obradovic[2]**

[1]Texas A&M University, Collage Station, United States of America; [2]Temple University, Philadelphia, United States of America; [3]Quanta Technology, Raleigh, United States of America; kezunov@ece.tamu.edu

### Big Data Platform for Real-Time Oscillatory Stability Predictive Assessment Using Recurrent Neural Networks and WAProtector's Records

**Jaime Cepeda[1], Ignacio Gomez[2], Fabian Calero[3], Angel Vaca[3]**

[1]CENACE, System Operator of Ecuador, Ecuador; [2]Universidad Europea Miguel de Cervantes; [3]ARCERNNR, Ecuadorian Agency of Regulation and Control of Energy; cepedajaime@ieee.org

## Paper Session 7: Power System Oscillations

*Time:* **Tuesday, 24/May/2022: 3:00pm - 4:20pm** *Location:* **Oleandar**

Chair: **Kjetil Uhlen**

### Presentations

**Confidence Metrics for Regional Forced Oscillation Source Localization**

**Jim Follum[1], Joseph H. Eto[2]**

[1]Pacific Northwest National Laboratory (PNNL); [2]Lawrence Berkeley National Laboratory (LBNL); james.follum@pnnl.gov

**Examples of processing low-frequency oscillations in Russia and ways to improve the analysis**

**Aleksandr Popov[1], Kirill Butin[2], Dmitry Dubinin[3], Andrey Rodionov[1], Alexey Mokeev[2], Sergey Piskunov[2]**

[1]Engineering Centre "Energoservice"; [2]Northern (Arctic) Federal University; [3]System Operator of the United Power System; a.popov@ens.ru

**Real-time execution of linear ringdown analysis methods for identifying dominant modes**

**Felix Reyes[1], Miguel Juarez[1], Alejandro Zamora-Mendez[1], Jose Ortiz[1], Juan Carlos Silva[1], Mario Arrieta[2], Carlos Toledo[3]**

[1]Universidad Michoacana de San Nicolás de Hidalgo, Mexico; [2]Universidad Nacional Autonoma de Mexico; [3]UIS; 1614878b@umich.mx

**A Python-based Ringdown Analysis Toolbox for Electromechanical Modes Identification**

**Rodrigo Reyes[1], José Antonio de la O[2], Mario R. Paternina[6], Joe Chow[4], Alejandro Zamora Mendez[3], José Ortiz[5]**

[1]Universidad Autónoma de Nuevo León; [2]Universidad Autónoma de Nuevo León; [3]National Autonomous University of Mexico, Mexico; [4]Rensselaer Polytechnic Institute; [5]Universidad Michoacana de San Nicolás de Hidalgo; [6]Universidad Michoacana de San Nicolás de Hidalgo; rodrigo.reyesd@uanl.edu.mx

## Paper Session 8: Event detection and identification

*Time:* **Wednesday, 25/May/2022: 1:30pm - 2:50pm** *Location:* **Oleandar**

Chair: **Marjan Popov**

### Presentations

**Tracking of Power Systems Events: PMUs, Reporting Rate and Interpolation**

**Guglielmo Frigo[1], Paolo Attilio Pegoraro[2], Sergio Toscani[3]**

[1]Swiss Federal Institute of Metrology, Switzerland; [2]University of Cagliari, Italy; [3]Politecnico di Milano, Italy; paolo.pegoraro@unica.it

**Using Synchrophasor Status Word as Data Quality Indicator: What to Expect in the Field?**

**Zheyuan Cheng[1], Yi Hu[1], Zoran Obradovic[2], Mladen Kezunovic[3]**

[1]Quanta Technology, Raleigh, NC, USA; [2]Temple University, Philadelphia, PA, USA; [3]Texas A&M University, College Station, TX, USA; yhu@quanta-technology.com

**Enhanced PMU-based Wide Area Measurement System with Integrated Power Quality and Fault Analysis**

**Paolo Castello[1], Carlo Muscas[1], Paolo Attilio Pegoraro[1], Davide Sitzia[1], Sara Sulis[1], Giorgio Maria Giannuzzi[2], Martina Pede[2], Camilla Maiolini[2], Pietro Pau[2], Fabio Bassi[2], Claudio Coluzzi[2]**

[1]University of Cagliari, Italy; [2]Terna Rete Italia, Italy; paolo.pegoraro@unica.it

**Wide-Area Event Identification in Power Systems: A Review of the State-of-the-Art**

**Mohammad Rezaei Jegarluei[1], Jesús Sánchez Cortés[1], Vladimir Terzija[2], Sadegh Azizi[1]**

[1]University of Leeds, United Kingdom; [2]Skolkovo Institute of Science and Technology, Russia; elmrj@leeds.ac.uk

## Paper Session 9: Frequency and phasor estimation

*Time:* **Thursday, 26/May/2022: 8:30am - 9:50am** *Location:* **Oleandar**

Chair: **Carlo Muscas**

### Presentations

**Non-Gaussianity in Frequency Distribution: FNET/GridEye's Observation of Worldwide Grids**

**Chujie Zeng[1], Wei Qiu[1], Weikang Wang[1], Kaiqi Sun[1], Chang Chen[1], Yilu Liu[1,2]**

[1]The University of Tennessee, Knoxville, United States of America; [2]Oak Ridge National Laboratory, Oak Ridge. United States of America; czeng8@vols.utk.edu

**A Dynamic Wideband Multi-Component Phasor Estimator Using Matrix Theory**

**Dongfang Zhao, Fuping Wang, Shisong Li, Wei Zhao, Songling Huang**

Tsinghua University, China, People's Republic of; zdf18@mails.tsinghua.edu.cn

**Step Change Detection for Improved ROCOF Evaluation of Power System Waveforms**

**Alexandra Karpilow[1], Asja Derviškadić[2], Guglielmo Frigo[3], Mario Paolone[1]**

[1]EPFL; [2]Swissgrid Ltd.; [3]METAS; alexandra.karpilow@epfl.ch

**Experimental Evaluation and Systematic-Error Reduction of Frequency Estimation Using the Zero-Crossing Technique for Dynamic Power Grids**

**Ellen Förstner, Richard Jumar, Orhan Delil Tanrikulu, Heiko Maaß, Uwe Kühnapfel, Veit Hagenmeyer**

Karlsruhe Institut of Technologie (KIT), Germany; ellen.foerstner@kit.edu

# Panel Sessions

Panel I: PMU- and AI-based analysis for a resilient operation of future power systems

Panel II: Utilization of transmission system data for enhancement and preservation of its secure operation

Panel III: Monitoring, Analysis and Mitigation of Power System Oscillations Using Synchronized Measurements

Panel IV: Data-Driven Analytics and Use Cases for Synchronized Waveform Measurements

Panel V: Wide area monitoring and control challenges in the Nordic power system

Panel VI: Analysis of the two systems splits and one inter-area oscillation within the Continental European Synchronous Area in year 2021

Panel VII: PMU testing and synchrophasor system life-cycle management

Panel VIII: Enabling Technologies for Enhancing Power System Resiliency by Wide Area Monitoring Protective and Control Systems

Panel IX: Towards a Zero Inertia Grid thanks to Synchrophasor Measurements

Panel X: Synchronized Measurement in The Control Room of The Future

## Panel Session I: PMU- and AI-based analysis for a resilient operation of future power systems

*Time:* **Tuesday, 24/May/2022: 1:30pm - 3:00pm** *Location:* **Ruzmarin**

### Panel chair

**Name**: Prof. Marjan Popov

**Organization:** Delft University of Technology, Netherldands

**Email:** M.Popov@tudelft.nl

**Short biography of the chair**: Marjan Popov (M'95–SM'03-F'22) obtained his Ph.D. degree in electrical power engineering from Delft University of Technology, Delft, The Netherlands, in 2002. In 1997, he was an Academic Visitor at the University of Liverpool, Liverpool, U.K., working in the arc research group on modeling SF6 circuit breakers. His major fields of interest are future power systems, large-scale power system transients, intelligent protection for future power systems, and wide-area monitoring and protection. He has been given invited lectures at many universities and keynote speeches at several conferences. Prof. Popov is a member of CIGRE and actively participated in WG C4.502 and WG A2/C4.39. In 2010 he received Hidde Nijland Prize for extraordinary research achievements. He is IEEE PES Prize Paper Award and IEEE Switchgear Committee Award recipient for 2011 and associate editor of the Elsevier's international journal of electric power and energy systems.

**Panel Abstract:** This panel deals with several essentials related to resilient operation of future power systems. The first one is intentional controlled islanding of power systems, which is important for blackout prevention and based on the principle of isolating a part of the power system, which is affected by a severe disturbance allowing the rest of the system to safely operate. One of the ways to implement this is to determine the islands by identifying slow coherent groups of generating units. This information serves as a preventive-step of several emergency control schemes to identify power system control areas and improve transient stability. For this purpose, it will be elaborated on an efficient method (open-source available algorithm), capable of online and near real-time tracking of grouping changes of the slow coherent generators in a power system. Here, we will also look into the algorithm's performance during various grid conditions. The panel also deals with is Artificial Intelligence (AI) application. Future power systems are subjected to faster dynamics, more fluctuations, more possible contingencies, more data, and as such more uncertainties. Therefore, the operating safety margins (and the economic costs) may increase as we lack future-ready operating tools. Here, the development of future methods by using operating (and synthetic) data to train AI models for real-time Dynamic Security Assessment (DSA) will be presented.

It will be shown: how AI methods correlate with physics resulting in reduced errors for DSA; how to train interpretable AI models, considering changing topologies, selecting the

best model with minimal training data, and how to quantify risks when using them for real-time DSA. The limits and possible promising future works will also be addressed. Furthermore, we are keen to put attention on protection and stability phenomena caused by high penetration of converter interfaced generation (CIG), more specifically short-term voltage stability.

The phenomenon as such is rather complex and requires deep understanding of EMT processes, as well as high fidelity modelling of the system components involved into the nature of this new type of instability. Next to representative EMTP examples, we are putting our attention to data driven approaches to short-term voltage instability detection and monitoring. In this context we introduce Maximum Lyapunov Exponent-Based approach supported by wide area voltage measurements, traditionally obtained using Phasor Measurement Units. The entire approach will be presented and discussed from the perspective of its applicability and efficacy. Finally, increased penetration of distributed generation on distribution level results in a gradual change of distribution grids from passive to active. Hence there is increased necessity for monitoring and control of the distribution networks to ensure secure and reliable operation of the distribution grid. For this purpose, State Estimation (SE) is a crucial tool to provide the best system estimate for many downstream applications, such as optimal power flows, contingency analysis and dynamic stabilities.

The next part of the panel also deals with the implementation of distribution system state estimation (DSSE) algorithms, which takes into account the anomaly detection discrimination and identification (ADDI), in a distribution network. Both normal and abnormal operation scenarios occurring in a power system are simulated to validate the algorithms. Here, a Forecasting-aided State Estimator (FASE) using extended Kalman filter technique will be presented on the real-life 50 kV ring distribution grid, which makes use of PMUs. The developed platform can accurately and successfully estimate the system states under both normal and abnormal operations.

## Panelist 1

**Name:** Dr. Ir. Jochen Cremer

**Organization:** Delft University of Technology, the Netherlands

**Email:** J.L.Cremer@tudelft.nl

**Short biography**: Jochen Cremer is Co-Director of the Delft AI Energy Lab and Assistant Professor Intelligent Electrical power Grids at the Technical University of Delft. His expertise is on AI and ML technology for use cases in energy systems, ranging from demand response, distributed real-time control over centralised coordinated operations in real-time. His novel algorithms can process very large amounts of data and advance energy systems operations from societal, sustainable, and economic perspectives. Before he worked on Machine Learning technology at Imperial College London, control theory at Carnegie Mellon and MIT. He worked in the chemical and energy industry, in China and Germany. He holds an M.Sc. in Chemical Engineering, a B.Sc. in Electrical Engineering, and a B.Sc. in Mechanical Engineering from RWTH Aachen University, Germany. He is member of the IEEE PES Taskforces for Big data processing, members of CIGRE C2 working groups.

**Title of presentation**: AI Methods For Realtime Dynamic Security Assessment

**Abstract**: "The future has faster dynamics, more fluctuations, more possible contingencies, more data and more uncertainty. As we lack future-ready operating tools for the future, larger operating safety margins may be needed which raises economic costs. This talk will summarize the development of future methods by using operating (and synthetic) data to train AI models for real-time Dynamic Security Assessment (DSA). In more detail, this talk will show how AI methods can function together with conventional offline DSA. The talk then touches on how to train interpretable AI models, considering changing topologies, selecting the best AI model with minimal training data, and how to quantify risks when using them for real-time DSA. The talk will close by discussing the limits and possible promising future works.

## Panelist 2

**Name:** Dr. Matija Naglic

**Organization:** TSO TenneT, the Netherlands

**Email:** Matija.Naglic@tennet.eu

**Short biography:** Matija Naglic received Uni. Dipl. Ing. degree in Electrical Engineering, study filed Telecommunications from the Faculty of Electrical Engineering, University of Ljubljana, Slovenia in 2011. In 2020 he received Ph.D. degree in Power System Engineering from the Faculty of Electrical Engineering, Mathematics and Computers Science, Delft University of Technology, The Netherlands. He is experienced with the implementation of IEEE std. C37.118 specifications, both the measurement and the telecommunication parts. He developed a cyber-physical platform for closed-loop control testing of WAMPAC applications, and two algorithms for online detection of disturbances and slow-coherent generators in a power system. He is a member of CIGRE WG C2.18. Currently, he works as an advisor for TenneT TSO, with a focus on the Control Room of the Future.

**Title of presentation:** Online Identification Of Slow Coherent Generators

**Abstract:** In a power system, slow coherency can be applied to identify groups of the generating units, the rotors of which are swinging together against each other at approximately the same oscillatory frequencies of inter-area modes. This information serves as a prerequisite step for several emergency control schemes to identify power system control areas and improve transient stability. First I will discuss the challenges related to model and measurement-based coherency identification of generators. Next, I will elaborate on a recently developed and open-source available algorithm, capable of online and near real-time tracking of grouping changes of the slow coherent generators in a power system. Here, we will also look into the algorithm's performance during various grid conditions. The talk will be concluded with possible further research directions.

## Panelist 3

**Name:** Prof. Dr. Vladimir Terzija

**Organization:** Skoltech, Russian Federation

**Email:** v.terzija@scoltech.ru

**Short biography:** Vladimir Terzija (M'95–SM'00-F'16) was born in Donji Baraci (former Yugoslavia). He 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 the Engineering and Physical Science Research Council Chair Professor in Power System Engineering with the School of Electrical and Electronic Engineering, The University of Manchester, Manchester, U.K., where he has been since 2006. From 1997 to 1999, he was an Assistant Professor at the University of Belgrade, Belgrade, Serbia. From 2000 to 2006, he was a senior specialist for switchgear and distribution automation with ABB AG Inc., Ratingen, Germany. His current research interests include smart grid application of intelligent methods to power system monitoring, control, and protection; wide-area monitoring, protection, and control; switchgear and fast transient processes; and digital signal processing applications in power systems.

**Title of presentation:** Data-driven and PMU-based solutions for short-term voltage instability detection and monitorin

**Abstract:** Protection and stability phenomena caused by high penetration of converter interfaced generation (CIG) are today in the focus of a number of studies and practical, industry driven, activities. One of phenomena, identified as a recognizable challenge is short-term voltage stability. The phenomenon as such is rather complex and requires deep understanding of EMT processes, requiring high fidelity modelling of the system components determining the nature of this new type of instability. Next to representative EMTP examples, we are putting our attention to data driven approaches for short-term voltage instability detection and monitoring. In this context we introduce Maximum Lyapunov Exponent-Based approach supported by wide area voltage measurements, traditionally obtained using Phasor Measurement Units. The entire approach will be presented and discussed from the perspective of its applicability and efficacy

## Panelist 4

**Name:** Prof. Marjan Popov

**Organization:** Delft University of Technology, Netherlands

**Email:** M.Popov@tudelft.nl

**Short bio and photo:** included above in the Panel Chair section

**Title of presentation:** Anomaly Detection by Applying using Real-time State Estimation

**Abstract:** Increased penetration of distributed generation on the distribution level results in a gradual change of distribution grids from passive to active. Hence there is an increased necessity for monitoring and control of the distribution networks to ensure secure and reliable operation of the distribution grid. For this purpose, State Estimation (SE) is a crucial tool to provide the best system estimate for many downstream applications, such as optimal power flows, contingency analysis, and dynamic stabilities. The next part of the panel also deals with the implementation of distribution system state

estimation (DSSE) algorithms, which take into account the anomaly detection discrimination and identification (ADDI), in a distribution network. Both normal and abnormal operation scenarios occurring in a power system are simulated to validate the algorithms. Here, a Forecasting-aided State Estimator (FASE) using an extended Kalman filter technique will be presented on the real-life 50 kV ring distribution grid, which makes use of PMUs. The developed platform can accurately and successfully estimate the system states under both normal and abnormal operations.

## Panel Session II: Utilization of transmission system data for enhancement and preservation of its secure operation

*Time:* **Tuesday, 24/May/2022: 1:30pm - 3:00pm** *Location:* **Oleandar**

### Panel chair

**Name of the organizer**: Dr Rafael Segundo

**Organization:** Zurich University of Applied Sciences ZHAW, Switzerland

**Email:** segu@zhaw.ch

**Short biography of the chair**: Rafael Segundo received the PhD degree from Imperial College London, United Kingdom in 2013. From 2007 to 2008, he worked in the Automation and Control group in the Corporate Research Centre of ABB, in Switzerland. From January 2013 to July 2014, Dr Segundo was a postdoctoral research fellow at the school of electrical engineering of the KTH Royal Institute of Technology in Stockholm, Sweden. Since 2014, he is research associate in the Electric Power Systems and Smart Grid Lab at the Zurich University of Applied Sciences in Switzerland. Dr. Segundo is Senior Member of the IEEE, chair of the IEEE Task Force " Application of Big Data Analytic on Transmission System Dynamic Security Assessment" and chair of the international annual workshop DynPOWER. He is the principal investigator of different projects funded by the Swiss National Science Foundation, the Swiss Federal Office of Energy, Innosuisse and the European Commission. His areas of interest include dynamic stability and control of power systems with low inertia and application of data-driven techniques for transmission system phenomena.

**Panel Abstract:** Electrical power systems are evolving into low-inertia networks where utilities are staring to face challenges associated to the dramatic increase of inverter connected devices. To support the decision making and consequently reinforce the security of the system, utilities rely more than ever on monitoring infrastructure in order to gain a higher degree of observability in the network. Consequently, the increasing use of high frequency synchronized devices such as Phasor Measurement Units (PMUs) on transmission systems is not only contributing to a more reliable dynamic security assessment but also to introduce additional challenges such as data storage, visualization and data handling. Motivated by this issues, the objective of the panel is to open a forum of discussions associated to alternative solutions in relation to the accuracy of these measurements, incorporation of innovative compression methods, artificial intelligence based solutions for real time implementation, visualization tools to gain situational awareness and emphasize the relevance that the location of the inertia plays with respect to frequency response

### Panelist 1

**Name:** Prof. Sara Sulis

**Organization:** University of Cagliari, Italy

**Email:** sara.sulis@unica.it

**Short biography**: Sara Sulis received the M.S. degree in electrical engineering and the Ph.D. degree in industrial engineering from the University of Cagliari, Cagliari, Italy, in 2002 and 2006, respectively. She is currently an Associate Professor of electrical and electronic measurements with the University of Cagliari. She has authored or coauthored more than 100 scientific articles. Her current research interests include distributed measurement systems designed to perform state estimation and harmonic sources estimation of distribution networks. She is an Associate Editor of the IEEE Transactions on Instrumentation and Measurement

**Title of presentation:** Measurement challenges in low inertia power grids

**Abstract:** Measurements can be an enabling technology for Smart Grids. For this to happen, the entire measurement chain must guarantee measurements with given accuracy performance also in the presence of dynamic signals. The challenge is therefore to describe the result of the measurement process with a properly evaluated accuracy even in the presence of complex architectures and frequent transients, which will be typical of low inertia power grids. Phasor Measurement Units (PMUs) and Smart Meters are new generation devices expected to spread worldwide for new designed monitoring systems. Nevertheless, the behaviour of these devices in the presence of dynamics must be carefully characterized, particularly if they are fed by traditional instrument transformers. For example, PMU compliance tests are described in the standards also considering dynamics, but the combination of realistic events can induce significantly degraded performance. The presentation will focus on these main aspects and aims at describing a measurement perspective and suggest possible design strategies for a new generation of effective monitoring system.

## Panelist 2

**Name:** Prof. Hector Chavez

**Organization:** University of Santiago de Chile USACH

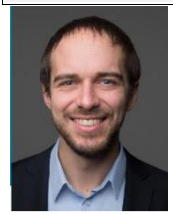
**Email:** hector.chavez@usach.cl

**Short biography:** Hector Chavez (Member, IEEE) received the Licenciado, Ingeniero Civil en Electricidad, and Magister degrees in electrical engineering from the University of Santiago, Santiago, Chile, in 2004, 2006, and 2006, respectively, and the Ph.D. degree in electrical engineering from The University of Texas at Austin, Austin, TX, USA, in 2013. In 2013, he was a Postdoctoral Fellow with the Department of Electric Power Systems, School of Electrical Engineering, KTH Royal Institute of Technology, Stockholm, Sweden. From 2006 to 2009, he was an Instrumentation Engineer with WorleyParsons Minerals and Metals, Santiago. He is currently the head of the Department of Electrical Engineering, University of Santiago.

**Title of presentation:** Power system data-driven, reduced-order models for look ahead frequency analysis

**Abstract:** The reduction in system inertia and frequency response has increased the need for real time tools to increase control room situation awareness. This talk exposes how data-driven reduced-order models can help real time operation by performing fast frequency stability assessments based on historical data and parameter identification frameworks.

## Panelist 3



**Name:** Prof. Jochen Cremer

**Organization:** TU Delft, Netherlands

**Email:** j.l.cremer@tudelft.nl

**Short biography:** Jochen Cremer is Co-Director of the Delft AI Energy Lab and Assistant Professor Intelligent Electrical power Grids at the Technical University of Delft. His expertise is on AI and ML technology for use cases in energy systems, ranging from demand response, distributed real-time control over centralised coordinated operations in real-time. His novel algorithms can process very large amounts of data and advance energy systems operations from societal, sustainable, and economic perspectives. Before he worked on Machine Learning technology at Imperial College London, control theory at Carnegie Mellon and MIT. He worked in the chemical and energy industry, in China and Germany. He holds an M.Sc. in Chemical Engineering, a B.Sc. in Electrical Engineering, and a B.Sc. in Mechanical Engineering from RWTH Aachen University, Germany. He is member of the IEEE PES Taskforces for Big data processing, members of CIGRE C2 working groups.

**Title of presentation:** On Dynamics and Artificial Intelligence for Power Systems

**Abstract:** Power systems must undertake a significant shift toward considering shorter dynamics in operations. Interestingly, the intersection of modelling dynamical systems and AI has experienced significantly progresses in recent years showing interesting synergies. In a bidirectional way, AI can be used to study data from dynamical systems and the theory of dynamical systems can be used to investigate AI. My talk will investigate these synergies and show whether AI becomes more or less suitable with the increase of power-interfaced dynamics introducing coupling effects with very short-time dynamics. I then introduce a method based on artificial neural networks to predict the dynamics with maximized accuracy, suitable for real-time predictions of power system dynamics analyzing PMU data for contingencies

## Panelist 4

**Name:** Prof. Kjetil Uhlen

**Organization:** Norwegian University of Science and Technology, Norway

**Email:** kjetil.uhlen@ntnu.no

**Short biography:** Kjetil Uhlen received the master's and Ph.D. degrees in control engineering in 1986 and 1994, respectively. He is currently a Professor of power systems with the Norwegian University of Science and Technology, Trondheim, Norway, and a Special Adviser with STATNETT (the Norwegian TSO), Oslo, Norway. His main research and education interests include within control and operation of power systems, grid integration of renewable energy, and power system dynamics.

**Title of presentation:** Methods for monitoring and presenting modal information in a power system

**Abstract:** Various methods have been proposed, tested and implemented for identification and characterization of low damped electro-mechanical modes in power systems. This presentation will discuss some of these methods that are mostly based on streaming data from Phasor Measurement Units (PMUs). When critical modes are identified, it is further important how the information is presented to operators. The presentation aims at comparing what information is obtained from different methods and how this information can be visualized and presented to gain situational awareness in an operational setting.

## Panelist 5

**Name:** Dr Luis Badesa

**Organization:** Imperial College London, United Kingdom

**Short biography:** Dr Luis Badesa is a Research Associate with the Department of Electrical and Electronic Engineering at Imperial College London. His research aims to facilitate a cost-effective integration of renewable energies, developing mathematical models to operate electricity grids and markets efficiently. His main body of work is focused on the economics and stability of low-inertia power grids.

**Title of presentation:** Regional stability needs in low-inertia power grids

**Abstract:** As renewable generation replaces thermal plants, system inertia is increasingly scarce. Furthermore, the typically remote location of the best renewable resources creates a non-uniform distribution of inertia across the grid. This effect leads to inter-area oscillations in frequency following a generation outage, therefore frequency can no longer be consider as a system-wide magnitude. In this work we demonstrate that the location of inertia and frequency response is key to guarantee frequency stability. We also highlight the need to move to a regional N-1 reliability requirement, rather than the current practice of system-wide N-1 reliability. This talk is based on a two-part paper recently published in IEEE Transactions on Power Systems

## Panel Session III: Monitoring, Analysis and Mitigation of Power System Oscillations Using Synchronized Measurements

*Time:* **Tuesday, 24/May/2022: 5:00pm - 6:30pm** *Location:* **Ruzmarin**

### Panel chair

**Name**: Evangelos Farantatos

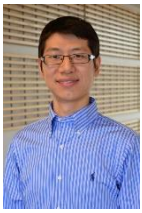
**Organization:** EPRI, USA

**Email:** efarantatos@epri.com

**Short biography of the chair**: Evangelos Farantatos received the Diploma in Electrical and Computer Engineering from the National Technical University of Athens, Greece, in 2006 and the M.S. and Ph.D. degrees from the Georgia Institute of Technology, Atlanta, GA, USA, in 2009 and 2012, respectively. He is a Senior Project Manager with the Grid Operations and Planning R&D Group at EPRI, Palo Alto, CA. He is managing and leading the technical work of various R&D projects related to synchrophasor technology, power systems monitoring and control, power systems stability and dynamics, renewable energy resources modeling, grid operation and protection with high levels of inverter-based resources. He is a Senior Member of IEEE. In summer 2009, he was an intern at MISO.

**Panel Abstract:** Poorly damped or undamped oscillations present a significant threat to the secure and economic operation of power grids. The number of oscillation events and their severity have been increasing, due to stressed and atypical grid operating conditions and changing resource mix with the increasing integration of renewables and retirement of conventional generators. In conventional power grids, power system stabilizers (PSS) on conventional generators have been used to suppress oscillations. However, the retirement of conventional plants is expected to result in insufficient stabilizing capability from the remaining generators, the location of which may also render them inappropriate to suppress these oscillations. Phasor Measurement Units (PMUs) and Synchrophasors is an emerging technology for grid monitoring and control. With PMUs due to the high resolution and GPS synchronized measurements, oscillations can be monitored and controlled. This panel will discuss latest technologies and ongoing activities from academia and industry on the topic of oscillations mitigation using synchronized measurements

### Panelist 1



**Name:** Lin Zhu

**Organization:** EPRI, USA

**Short biography**: Lin Zhu (EPRI, US): Dr. Lin Zhu is currently a Technical Leader at Electric Power Research Institute. He was a Research Assistant Professor at The University of Tennessee at Knoxville. He received his B.S. degree and Ph.D. degree from Huazhong University of Science and Technology in 2005 and 2011, respectively, both in Electrical Engineering. His research interests include power system dynamic, renewable energy integration, smart distribution grid, and microgrid. Many of his research accomplishments have been translated into actual products or product prototypes ready for commercialization. He led a team and developed an adaptive power grid oscillation damping controller, which was recognized with R&D 100 Awards in 2021. He has been the co-PI of two NSF awards and the lead PI of 20+ industry projects. Dr. Lin Zhu is a Senior Member of IEEE and CIGRE member

**Title of presentation:** GridDamper: An Adaptive Power Grid Oscillation Damper

**Abstract:** Recently, multiple severe oscillation events have occurred in the interconnected power grids in Continental Europe and North America. With the increasing integration of renewables and the retirement of conventional generators, more severe and more frequent oscillation events could be experienced if not sufficiently controlled. This presentation will introduce GridDamper, a field-deployment-ready technology to mitigate three major categories of oscillations (natural, forced, and sub-synchronous) and allow more renewable integration in power grids. GridDamper adaptively updates its parameters, sensors, and actuators to guarantee power grid stability and reliability. The performance of GridDamper has been validated in four realistic large-scale power grid models with actual events through simulations and controller hardware-in-the-loop testing. GridDamper earned the R&D 100 Awards for 2021.

## Panelist 2

**Name:** Yi Zhao

**Organization:** University Tennessee Knoxville, USA

**Short biography:** Yi Zhao (University Tennessee Knoxville, US): Dr. Yi Zhao received her B.S. degree from Southwest Jiaotong University, Chengdu, China in 2008 and her Ph.D. degree from Tsinghua University, Beijing, China in 2013. She worked as a Postdoc at Tsinghua University before she joined the Electrical Engineering and Computer Science Department at the University of Tennessee in March, 2017. Currently, she is a Research Associate at the University of Tennessee. Her main research interests include power system stability analysis and control, large-scale system simulation. She has investigated the application of wide-area damping control system in several realistic power grids around the world, including China Southern Grid, US Eastern Interconnections, Continental European power grid, and Great Britain Power Grid. She is a winner of R&D 100 Awards of 2021 for her contributions to adaptive wide-area oscillation damping controller design, development and implementation

**Title of presentation** Implementation and Demonstration of a Wide Area Oscillations Damping Controller with Real Time Simulators in a Hardware In the Loop Setup

**Abstract:** Real Time Simulators (RTS) and Hardware In the Loop (HIL) experiments can help accelerate the advancement and deployment of Wide Area Monitoring, Protection and Control (WAMPAC) systems. This presentation will focus on the development of a Wide Area Oscillations Damping Controller (WADC) on a generic hardware platform, and its testing using RTS (e.g RTDS and OPAL-RT) in a HIL setup, for various power grid models. The performance of the developed WADC has been validated on the HIL test setup under different scenarios, including measurement error/noise, constant and stochastic time delays, consecutive and stochastic data package loss. The experiment results demonstrate that the developed WADC can provide sufficient damping to suppress the targeted oscillation mode.

## Panelist 3

**Name:** Cosimo Pisani

**Organization:** TERNA, Italy

**Short biography:** Cosimo Pisani (TERNA, Italy): Cosimo Pisani was born in Benevento, Italy, in 1985. He received the M.Sc. degree with honors in Energy Engineering from the University of Sannio, Benevento, in 2010 and the Ph.D. degree in Electrical Engineering from the University of Naples “Federico II,” Naples, Italy, in 2014. During his PhD in collaboration with Terna, the Italian Transmission System Operator, he investigated some dynamic stability issues of large interconnected power system such as the European one (i.e. European Network of Transmission System Operator). From May 2014 to March 2016 he was Research Fellow at University of Sannio. From March 2016 he is with Terna. Currently, he is head of Stability and Network Calculations at Dispatching and Switching Department. He is project manager or however directly involved in several project covering network stability studies, real time algorithm and tool development for monitoring and control of electrical power systems, design of Special Protection Schemes to counteract instability phenomena, High Voltage Direct Current systems.

**Title of presentation** Field Implementation, Deployment and Demonstration of a Wide Area Oscillations Damping Controller at TERNA

**Abstract:** Low frequency oscillations have been a significant threat to the secure and economic operation of the Continental European grid. Several severe oscillation events with low damping ratio have occurred in the past, for instance, on December 3rd 2017, undamped low frequency oscillations between the South and North Italian power system. Wide Area Monitoring Protection and Control (WAMPAC) systems that rely on PMU measurements can be used to mitigate such oscillations. This presentation will summarize the field implementation, deployment and demonstration of a Wide Area Oscillations Damping Controller (WADC) at TERNA’s control center and at a selected substation. The WADC control architecture and infrastructure will be summarized. System commissioning and Site Acceptance Test (SAT) procedures will be described. Preliminary results from field testing will be also shown.

## Panelist 4

**Name:** Gilles Torresan

**Organization:** RTE, France

**Short biography:** Gilles Torresan (RTE, France): Gilles Torresan received the degree in electrical engineering from Grenoble INP, France. He joined Réseau de Transport d'Electricité (RTE), the French Transmission System Operator (TSO), in 2001. He worked in the Operation department for 18 years, mainly involved in power system stability studies. He is currently working for the Research and Development department and his main fields of interest are power system stability, grid code for generators and oscillation monitoring

**Title of presentation** RTE's Oscillation Monitoring Tool

**Abstract:** RTE (French Transmission System Operator) is going to put in operation its oscillation monitoring tool. This presentation will introduce the concept and the challenges of such a tool:

- History of the project
- Project framework
- Algorithms used
- Practical examples

## Panel Session IV: Data-Driven Analytics and Use Cases for Synchronized Waveform Measurements

*Time:* **Tuesday, 24/May/2022: 5:00pm - 6:30pm** *Location:* **Oleandar**

### Panel chair

**Name**: Professor Hamed Mohsenian-Rad

**Organization:** University of California, Riverside, USA

**Email:** hamed@ece.ucr.edu

**Short biography of the chair**: Dr. Hamed Mohsenian-Rad is a Professor of Electrical and Computer Engineering and a Bourns Family Faculty Fellow at the University of California, Riverside, USA. His research interests include developing data-driven and model-based techniques for monitoring, control, and optimization of power systems and smart grids. He is the author of an upcoming textbook on smart grid sensors: principles and applications. Dr. Mohsenian-Rad has received the NSF CAREER Award, a Best Paper Award from the IEEE PES General Meeting, and a Best Paper Award from the IEEE Conference on Smart Grid Communications. Two of his papers are currently ranked as the two most cited articles in the IEEE Transactions on Smart Grid. Dr. Mohsenian-Rad is the author of *Smart Grid Sensors: Principles and Applications*, a textbook on smart grid sensors and data-driven applications. He is the Associate Director of the Winston Chung Global Energy Center, an endowed research center in the area of energy and sustainability at UC Riverside. Dr. Mohsenian-Rad is currently an Associate Editor of the IEEE Transactions on Power Systems. Previously, he served as Associate Editor of the IEEE Transactions on Smart Grid. He has served as the PI for over $10 million smart grid research projects. He received his Ph.D. in Electrical and Computer Engineering from the University of British Columbia, Vancouver, Canada in 2008. Dr. Mohsenian-Rad is a Fellow of the IEEE.

**Panel Abstract:** Waveform measurement units (WMUs) are an emerging class of smart grid synchronized measurement technologies that provide synchronized measurements for voltage and current waveforms. Since WMUs provide synchronized waveform measurements, as opposed to synchronized phasor measurements that are provided by phasor measurement units (PMUs), the data from WMUs is much more granular than the data from PMUs. This calls for fundamentally new methodologies to analyze WMU data. In this panel, we cover the advancements in this field, in various areas, including sensor technologies, data collection and compression, data analytics, and use cases. The speakers on the proposed panel are experts in this field with diverse representations, coming from academia, industry, and government.

### Panelist 1

**Name:** Wilsun Xu

**Organization:** University of Alberta, Edmonton, Canada

**Email:** wxu@ece.ualberta.ca

**Short biography:** Dr. Wilsun Xu received Ph.D. from the University of British Columbia, Vancouver, BC, Canada, in 1989. He worked in BC Hydro, Vancouver, BC, Canada, for seven years before he joined the University of Alberta, Edmonton, Alberta, Canada, in 1996. He is currently a professor at the University of Alberta. Dr. Xu's main research area is power quality. He was awarded IEEE Fellow in 2005 for contributions to power quality research. In recent years, Dr. Xu has been researching the application of disturbance waveforms to support equipment and system condition monitoring. These activities have helped to form the Power Quality Data Analytics Working Group in 2014, under the Power Quality Subcommittee of the IEEE Power & Energy Society.

**Title of presentation:** Applications of Synchronized Waveform Data to Power System and Apparatus Monitoring

**Abstract:** Voltage and current waveforms contain the most authentic and granular information on the behaviors of power systems. In recent years, it has become possible to synchronize waveform data measured from different locations of a power system. Thus, large-scale coordinated analyses of multiple waveforms over a wide area are within our reach. This presentation provides an overview on the developments in this fascinating direction and proposes three platforms for applying the data. It further presents several strategies to discover and develop synchronized waveform-based applications for both power system and power apparatus monitoring.

## Panelist 2

**Name:** Professor Hamed Mohsenian-Rad

**Organization:** University of California, Riverside, USA

**Email:** hamed@ece.ucr.edu

**Short biography**: Dr. Hamed Mohsenian-Rad is a Professor of Electrical and Computer Engineering and a Bourns Family Faculty Fellow at the University of California, Riverside, USA. His research interests include developing data-driven and model-based techniques for monitoring, control, and optimization of power systems and smart grids. He is the author of an upcoming textbook on smart grid sensors: principles and applications. Dr. Mohsenian-Rad has received the NSF CAREER Award, a Best Paper Award from the IEEE PES General Meeting, and a Best Paper Award from the IEEE Conference on Smart Grid Communications. Two of his papers are currently ranked as the two most cited articles in the IEEE Transactions on Smart Grid. Dr. Mohsenian-Rad is the author of *Smart Grid Sensors: Principles and Applications*, a textbook on smart grid sensors and data-driven applications. He is the Associate Director of the Winston Chung Global Energy Center, an endowed research center in the area of energy and sustainability at UC Riverside. Dr. Mohsenian-Rad is currently an Associate Editor of the IEEE Transactions on Power Systems. Previously, he served as Associate Editor of the IEEE Transactions on Smart Grid. He has served as the PI for over $10 million smart grid

research projects. He received his Ph.D. in Electrical and Computer Engineering from the University of British Columbia, Vancouver, Canada in 2008. Dr. Mohsenian-Rad is a Fellow of the IEEE.

**Title of presentation:** Synchro-Waveforms in Power Distribution Systems: Field Data, Data-Analytics, and Innovative Use Cases

**Abstract:** Synchronized waveform measurements, a.k.a, synchro-waveforms, provide the ultimate measurement resolution for voltage and current in advanced power system monitoring. Analysis of synchrophasors has important applications in power distribution systems, such as to detect, identify, and locate incipient faults in power distribution systems. In this talk, we start by looking at a few examples of real-world waveform and synchro-waveform measurements in power distribution systems. We will then discuss some recent advancements in data-driven methodologies in this field, covering both model-based and model-free methods, as we as emerging and future use cases for synchro-wavform measurements.

## Panelist 3

**Name:** Steven Blair

**Organization:** Synaptec Ltd, Glasgow, Scotland, UK

**Email:** steven.blair@synapt.ec

**Short biography**: Steven Blair is the Head of Power Systems Technologies at Synaptec, UK. He has extensive experience in the fields of power system measurement, protection, and communications technologies. He holds a PhD in power system protection from the University of Strathclyde, where he has been both researcher and academic including holding the Nokia lectureship position. Steven is a member of IEC TC57 WG10 which manages the IEC 61850 standards, and is also a member of CIGRE WG C4/C2.62/IEEE on Review of Advancements in Synchrophasor Measurement Applications

**Title of presentation:** Applications of wide-area synchronised waveform measurements

**Abstract:** Fundamental changes in power grids due to decarbonisation require advanced monitoring and automated analysis. Synchronised waveform data from voltage and current sensors offers several new capabilities beyond synchrophasors from Phasor Measurement Units (PMUs). This presentation will describe new applications which are enabled by this approach, including: deeper classification of events (e.g., for root cause identification for electrical faults), detailed wide-area power quality investigations, and post-event analysis of major system-wide disturbances. However, the obvious drawbacks in manipulating, transferring, and storing waveform data are the high data bandwidth and storage requirements. This presentation also reports on a platform to address these issues by using a high-performance lossless data compression method designed for streaming waveform data, which significantly reduces data bandwidth requirements and improves end-to-end efficiency and latency. An implementation of the scheme, called Slipstream, has been open sourced to enable industry adoption (available at https://github.com/synapteltd/slipstream). The presentation will demonstrate the performance of the data compression method, which removes the barriers for utilities to stream, record, and analyse synchronised power system waveform data.

## Panelist 4

**Name:** Alvaro Furlani Bastos

**Organization:** Sandia National Laboratory, Albuquerque, USA

**Email:** afurlan@sandia.gov

**Short biography:** Dr. Alvaro Furlani Bastos is a Senior Member of the Technical Staff at Sandia National Laboratories, New Mexico, US. He received his MS and PhD degrees in Electrical and Computer Engineering from The University of Texas at Austin in 2015 and 2020, respectively. His current work is focused on the application of data analytics and optimization to the planning, modeling, and control of energy storage systems; other research interests include power quality, renewable energy integration, and microgrids.

**Title of presentation:** Challenges and their potential solutions in implementing synchronized waveform applications

**Abstract:** This presentation will discuss several procedures that enable the successful application of synchronized waveform measurements. These procedures aim at improving the data quality of the synchronized measurements before they are utilized in the desired applications; for example, it is not uncommon to encounter datasets where the phase ordering of the voltage measurements and/or the polarity of the current measurements are inconsistent among the measurement locations due to improper connection of the measurement devices. Further, an algorithm for detecting abnormal/novel waveforms within large synchronized waveform datasets is presented. Finally, we will illustrate how inaccurate timestamps in the synchronized waveform measurements affect some applications.

## Panel Session V: Wide area monitoring and control challenges in the Nordic power system

*Time:* **Wednesday, 25/May/2022: 10:30am - 12:00pm** *Location:* **Ruzmarin**

### Panel chair

**Name**: Salvatore D'Arco, Senior scientist

**Organization:** Sintef energy research, Norway

**Email:** salvatore.darco@sintef.no

**Short biography of the chair**: Salvatore D'Arco received the M.Sc. and Ph.D. degrees in electrical engineering from the University of Naples "Federico II," Naples, Italy, in 2002 and 2005, respectively. From 2006 to 2007, he was a postdoctoral researcher at the University of South Carolina, Columbia, SC, USA. In 2008, he joined ASML, Veldhoven, the Netherlands, as a Power Electronics Designer consultant, where he worked until 2010. From 2010 to 2012, he was a postdoctoral researcher in the Department of Electric Power Engineering at the Norwegian University of Science and Technology (NTNU), Trondheim, Norway. In 2012, he joined SINTEF Energy Research where he currently works as a Senior Research Scientist. He is the author of more than 130 scientific papers and is the holder of one patent. His main research activities are related to control and analysis of power-electronic conversion systems for power system applications, including real-time simulation and rapid prototyping of converter control systems.

**Panel Abstract:** The panel will present wide area monitoring and control challenges in the nordic power system results and possible solutions obtained in Nordic cooperative projects. The panel will focus on WAMPACS and on the application of PMUs to improve the operation of the power system. The objective is to showcase research activities and development progress in the Nordic area.

### Panelist 1

**Name:** Robert Eriksson

**Organization:** Swedish National Grid (Svenska kraftnät), Sweden

**Short biography**: Robert Eriksson received the M.Sc. and Ph.D. degrees in electrical engineering from the KTH Royal Institute of Technology, Stockholm, Sweden, in 2005 and 2011, respectively. From 2013 to 2015, he held a position as an Associate Professor with Center for Electric Power and Energy, Technical University of Denmark – DTU, Kongens Lyngby, Denmark. He is currently Team Leader at the Swedish National Grid (Svenska kraftnät), Department of Power Systems. Since 2020, he holds a position as an Adjunct Professor at the KTH Royal Institute of Technology.

**Title of presentation:** Interarea oscillations and recent observations in the Nordic power system

**Abstract:** Phasor Measurement Units (PMUs) are installed to monitor inter-area and local power oscillations. Various sources excite oscillations in power systems and, too low damping or sustained oscillations may jeopardize the stability. Visualization tools and mitigation measures are needed to maintain the stability. The presentation will go through observations and key findings from recent events of natural and forced oscillations seen in the Nordic power system.

## Panelist 2

**Name:** Knut Hornnes

**Organization:** Statnett, Norway

**Short biography:** MSc and PhD in Electrical Engineering from NTNU in 1983 and 1995 respectively. From 1984 to 2001 he worked at SINTEF Energy Research with optimization models and system analysis in Nordic and European power systems. The PhD thesis was focused on integration of market models and power flow models. From 2001 to 2011 he worked in Powel, now Volue, as consultant and developing of optimization models for hydropower. From 2011 he have worked at the Norwegian TSO Statnett with power system development and operation.

**Title of presentation:** An introduction to the NEWEPS project as a joint Nordic initiative

**Abstract:** MSc and PhD in Electrical Engineering from NTNU in 1983 and 1995 respectively. From 1984 to 2001 he worked at SINTEF Energy Research with optimization models and system analysis in Nordic and European power systems. The PhD thesis was focused on integration of market models and power flow models. From 2001 to 2011 he worked in Powel, now Volue, as consultant and developing of optimization models for hydropower. From 2011 he have worked at the Norwegian TSO Statnett with power system development and operation, both in Norway and in the Nordic synchronous system. He have also attended various work groups within Entso-E.

## Panelist 3

**Name:** Sigurd Jakobsen

**Organization:** SINTEF Energy Research, Norway

**Short biography:** Sigurd Hofsmo Jakobsen is currently a researcher at SINTEF Energy Research (2013-. He received his master degree from the Norwegian University of Science and Technology (NTNU) on modelling of power electronic in 2013 and his PhD in electric power engineering at NTNU in 2019. His research interests include power system reliability, stability and model validation.

**Title of presentation:** Model learning for power system operation

**Abstract:** In the Sparc project model learning is used for localising the source of forced oscillations. Some initial findings are presented as well as outlines for further work.

## Panelist 4

**Name:** Lars Nordström

**Organization:** KTH – The Royal Institute of Technology, Sweden

**Short biography:** Lars Nordström is Professor in Information Systems for Power System Control at KTH – The Royal Institute of Technology, Stockholm, Sweden. He is head of the division of Electric Power and Energy Systems at KTH and deputy head of the school of electrical engineering and computer science, with specific responsibility for faculty development. His research and teching is focused on issues at the crossroads of control, communication and power systems. His research interests include future architectures, functionality and quality aspects of Information and communication systems used for power system control, operation, automation and protection. He has served as director of the Swedish centre of Electric Power Engineering and as Thematic leader for Smartgrids and electric storage in KIC InnoEnergy In 2014 he was visiting professor at Washington State University.

**Title of presentation:** SPARC project: Automated identification of distribution grid equivalent models from PMU streams

**Abstract:** Offline use of PMU data to validate models of power system components improves dynamic studies of power systems by enhancing the models of components. Given the dynamic nature of active distribution grids, equivalent models of such grids may need frequent updating to accommodate changes in generation and possibly even topology. In the SPARC project a method that sequentially processes PMU data to identify system events and classify them as informative or noninformative for model identification and parameter estimation has been developed. The method provides automatic updating of distribution grid dynamic equivalents and estimated parameters thereby providing up to date dynamic equivalents for power system dynamic analysis.

## Panelist 5

**Name:** Seppänen Janne

**Organization:** Aalto University, Finland

**Short biography:** Janne Seppänen received the M.Sc. (Eng.) and D.Sc. (Tech.) degrees in electrical engineering from Aalto University, Finland, in 2011 and 2017, respectively. Currently, he is working as a Professor of Practice at Aalto University, Espoo, Finland, and as a Senior Expert at Fingrid Oyj Strategic Grid Planning unit, Helsinki, Finland. Previously, he has worked in several different roles at Fingrid Oyj and at ABB Corporate Research in Switzerland. His main research interests are related to power system dynamics and stability, transmission system planning and analysis as well as transmission system operation and control.

**Title of presentation:** Changing power system dynamics with converter connected generation – observations and challenges

**Abstract:** Fingrid's observations on how the large increase of wind power is affecting the system properties: varying inertia, changing oscillatory dynamics, control instability of wind power (e.g. with low system short circuit power near large wind power parks).

## Panel Session VI: Analysis of the two systems splits and one inter-area oscillation within the Continental European Synchronous Area in year 2021

*Time:* **Wednesday, 25/May/2022: 10:30am - 12:00pm** *Location:* **Oleandar**

### Panel chair

**Name of the organizer**: Asja Derviskadic

**Organization:** Swissgrid, Switzerland

**Email:** asja.derviskadic@swissgrid.ch

**Short biography of the chair**: Asja Derviškadić received the B.Sc. and M.Sc. degrees (Hons.) in electrical engineering from the University of Rome "La Sapienza," Rome, Italy, in 2012 and 2015, respectively, and the Ph.D. degree in electrical engineering from the Swiss Federal Institute of Technology of Lausanne (EPFL), Lausanne, Switzerland, in 2019. In 2019-2020 she was a Postdoctoral researcher at the Distributed Electrical Systems Laboratory (DESL) of EPFL and her research interests focused on synchronized sensing technologies for wide-area situational awareness of electrical grids operating in non-stationary conditions. She is currently with the short-term network modeling team of Swissgrid, the Swiss transmission system operator, where she works as grid studies engineer. She is a member of the ENTSO-E SubGroup System Protection and Dynamics.

**Panel Abstract:** During year 2021, the Continental European (CE) Synchronous Area faced several incidents that seriously challenged its interconnected nature. Thanks to the close collaboration of European TSOs through the ENTSO-E, and thanks to the inherent resilience of such a large power system, none of these events lead to catastrophic consequences and the system was brought back into a safe operating mode after few hours. First, on January 8th due to a large power flow from South-East to North-West Europe, cascaded trips of several transmission elements split the system into two separate regions, with the separation line crossing Croatia, Serbia, and Romania. Then, on July 24th the Iberic Peninsula was separated form the rest of the CE power system due to a wildfire in the eastern French double circuit near the Spain-France interconnection that triggered the automatic protection devices of the tie-lines and led to further cascaded trips. Finally, on October 11th a long-lasting undamped oscillation excited the East-West mode. The ENTSO-E SubGroup System Protection and Dynamics had a leading role in carrying out the technical investigations that followed these events and actively contributed to the definition of future recommendations. The tutorial/panel expands on the methods and tools that were used during such investigations, with a particular focus on dynamic stability criteria.

### Panelist 1

**Name:** Asja Derviskadic

**Organization:** Swissgrid, Switzerland

**Email:** asja.derviskadic@swissgrid.ch

**Short bio and photo:** included above in the Panel Chair section

**Title of presentation**: Analysis of the two systems splits and one inter-area oscillation within the Continental European Synchronous Area in year 2021

**Abstract**: During year 2021, the Continental European (CE) Synchronous Area faced several incidents that seriously challenged its interconnected nature. Thanks to the close collaboration of European TSOs through the ENTSO-E, and thanks to the inherent resilience of such a large power system, none of these events lead to catastrophic consequences and the system was brought back into a safe operating mode after few hours. First, on January 8th due to a large power flow from South-East to North-West Europe, cascaded trips of several transmission elements split the system into two separate regions, with the separation line crossing Croatia, Serbia, and Romania. Then, on July 24th the Iberian Peninsula was separated from the rest of the CE power system due to a wildfire in the eastern French double circuit near the Spain-France interconnection that triggered the automatic protection devices of the tie-lines and led to further cascaded trips. Finally, on October 11th a long-lasting undamped oscillation excited the East-West mode. The ENTSO-E SubGroup System Protection and Dynamics had a leading role in carrying out the technical investigations that followed these events and actively contributed to the definition of future recommendations. The tutorial/panel expands on the methods and tools that were used during such investigations, with a particular focus on dynamic stability criteria.

## Panelist 2

**Name:** Agustín Díaz García

**Organization:** REE, Spain

**Email:** agustindiaz@gmail.com

**Short biography**: Agustín Díaz García is Industrial Engineer (Electricity) of Universidad Politécnica de Madrid (Spain). During his years at university he made collaborations with Physics and Automatics departments. He began his career working as electrical consultant for Network Studies and Wind Power departments at Iberdrola Engineering. On 2007 he entered Network Studies Department in Red Electrica de España (Spanish TSO) as senior engineer. Since that, his work has been focused on system stability, renewable power impact in the electricity system, requirements for generators, network studies for conventional generator access to the network, power quality, etc. Nowadays Agustin is co-convenor of the System Protection and Dynamics group of Continental Europe at ENTSO-E.

**Title of presentation**: Power system separation of the Iberian Peninsula from Continental Europe on 24 July 2021

**Abstract**: On 24 July 2021 at 16:36 CET, due to a major incident in France, the transmission systems of Portugal and Spain, together with a small part of the French

transmission system, were disconnected from the synchronous area Continental Europe for just over 30 minutes. During the disturbance, the frequency deviation of the large part of the Continental Europe was kept within a safety margin, whereas in the Iberian Peninsula the deviation was more substantial and involved further emergency measures according to the predefined plans. The panel presents the results of the incident investigations, providing a comprehensive analytical overview of the incident – the causes and the consequences – and proposing recommendations to prevent and mitigate the consequences of similar events in the future.

## Panelist 3

**Name:** Walter Sattinger

**Organization:** Swissgrid, Switzerland

**Email:** walter.sattinger@swissgrid.ch

**Short biography:** Walter Sattinger has extensive experience in power system dynamic analysis. He has been working for 34 years in the field of power system modelling and power system control. In several studies he has worked in all required project stages from the on-site data collection to the organisation and execution of system tests, dynamic model identification, system modelling, performing of studies, reports and finally the presentation of the study results. Currently he is working as a project engineer at the interface between planning and operation and he is responsible for the implementation of concepts to enhance system security. He is currently co-convenor of the System Protection and Dynamics group of Continental Europe at ENTSO-E and CIGRE convenor for C2.18 WG. He has received his PhD in 1995 and degree of electrical engineer in 1988 from the Univ. of Stuttgart, Germany.

**Title of presentation**: Analysis of the Continental European inter-area oscillations on 11 October 2021

**Abstract**: On 11 October 2021 at 9, an unexpected opening of a tie-line interconnecting the French and the Spanish grids, triggered an oscillatory incident in Continental Europe electricity system. The East-Center-West mode was excited, characterized by undamped oscillations at 0.18 Hz. The oscillation was mitigated by changing the control mode of the interconnecting DC HVDC links. The panel presents the results of the event analysis, identifies the causes of the incident, describes the countermeasures taken to stop the oscillation and proposes recommendations on how to avoid long-lasting undamped oscillations

## Panelist 4

**Name:** Giorgio Giannuzzi

**Organization:** Terna, Italy

**Email:** giorgio.giannuzzi@terna.it

**Short biography:** Giorgio Giannuzzi (1967) received his Electric Engineering degree from the University of Rome. Until December 2000 he worked for ABB, where he was in charge of network studies, protection and control applications, with special reference to RTU apparatus and data engineering issues. Since 2001 he serves TERNA as expert in defense plans/systems, dynamic studies, protection, telecontrol and substation automation. Between years 2004 and 2011 he coordinated the study, design and activation of Wide Area Defence system (including Interruptible Customers System) and Wide Area Monitoring System. Until 2009 he was a member of a UCTE Expert Group on Power System Stability. In 2010 he joined ENTSO-E System Protection and Dynamics Group and starting from 2014 is the co-Convenor, coordinating the European evaluation over Dispersed Generation impact on system security, Defense Systems and Power System dynamics studies for ENTSO-E. Currently is responsible of the Engineering Department of National Dispatching Centre.

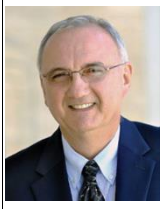
**Title of presentation**: Separation of the Continental Europe power system on 8 January 2021

**Abstract**: On 8 January 2021 at 14:05 CET the synchronous area of Continental Europe was separated into two parts due to outages of several transmission network elements in a very short time, with the separation line crossing Croatia, Serbia, and Romania. The system separation resulted in a deficit of power (approx. -6.3 GW) in the North-West Area and a surplus of power (approx. +6.3 GW) in the South-East Area, resulting in turn in a frequency decrease in the North-West Area and a frequency increase in the South-East Area. The panel presents the results of the investigations after the incident, provides a comprehensive analytical overview of the incident, including its causes and its consequences, and proposes recommendations to prevent and mitigate the consequences of similar events in the future.

# Panel Session VII: PMU testing and synchrophasor system life-cycle management

*Time*: **Wednesday, 25/May/2022: 2:50pm - 4:20pm** *Location:* **Ruzmarin**

## Panel chair



**Name**: Mladen Kezunovic, Regents Professor

**Organization:** Texas A&M University, USA

**Email:** kezunov@gmail.com

**Photo and short biography of the Chair**: Dr. Mladen Kezunovic has been with Texas A&M University, College Station, TX, USA since 1986, where he is currently Regents Professor, Eugene E. Webb Professor, and the Site Director of "Power Engineering Research Center" consortium. For over 30 years he has been the Principal Consultant of XpertPower Associates, 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 has authored over 600 papers, given over 120 seminars, invited lectures, and short courses, and consulted for over 50 companies worldwide. He served as a Convener of the CIGRE WG that prepared the CIGRE Technical Brochure 843, "Life Cycle Testing of Synchrophasor Based Systems used for Protection, Monitoring and Control" published in 2021. Dr. Kezunovic is a CIGRE Fellow, Honorary and Distinguished member. He is Registered Professional Engineer in Texas and a Life Fellow of IEEE.

**Panel Abstract:** Deployment of phasor measurement units (PMUs) in the US grid has surpassed 3,000. Other countries such as China, Russia and Brazil are deploying PMUs at a rapid pace widely as well. Combined, the mentioned countries have deployed or are planning to deploy over 10,000 PMUs so far. This panel will be focused on the discussions of how the synchrophasor systems are to be maintained during their life cycle, starting from the type and conformance testing for PMUs to the commissioning, regular maintenance and troubleshooting testing of the entire synchrophasor system. The Panelists from the USA, China, Russia and Brazil will discuss their experiences and share the lessons learned. Also, summary of the relevant issues from the recently approved IEEE standard C37.242.2021 "Guide for Synchronization, Testing, Calibration and Installation of PMUs", and CIGRE Technical Brochure 843, "Life Cycle Testing of Synchrophasor Based Systems used for Protection, Monitoring and Control", both published in 2021, will be given.

## Panelist 1

**Name:** Mladen Kezunovic, Regents Professor

**Organization:** Texas A&M University, USA

**Email:** kezunov@gmail.com

**Short bio and photo:** included above in the Panel Chair section

**Title of presentation:** Why PMU testing and lifecycle management of PMUs matter

**Abstract:** The deployment of synchrophasors in the USA has surpassed 3000 units in the transmission system and deployment in the distribution system is foreseen as taking a rapid development in the next 10 years. The assessment of the needs for testing and life cycle management of PMUs and synchrophasor systems was addressed by a CIGRE WG that prepared the CIGRE Technical Brochure 843, "Life Cycle Testing of Synchrophasor Based Systems used for Protection, Monitoring and Control" published in 2021. This presentation will focus on two issue: highlights of the findings included in the CIGRE report, and experiences from examining recording from close to 500 PMUS placed in all three US interconnections over the period of two years.

## Panelist 2

**Name:** José Eduardo da Rocha Alves Junior

**Organization:** Centro de Pesquisas de Energia Elétrica (CEPEL), Brazil

**Email:** alves@cepel.br

**Short biography**: J. E. R. Alves, Jr. received the B.Sc., M.Sc., and D.Sc. degrees in electrical engineering, in 1986, 1991 and 1999, respectively, from COPPE/Federal University of Rio de Janeiro. He is Associate Professor at the Federal Fluminense University since 1991. Since 1995, he has been with CEPEL, the largest Energy Research Center in Brazil, as a Researcher. His main areas of research are: synchrophasor measurements, systems automation and experimental research. He is senior member of IEEE (SM'05) and also CIGRE member.

**Title of presentation:** Testing Practices in Brazil

**Abstract:** The Brazilian system operator ONS is implementing a large phasor measurement system, comprising more than 200 PMUs with a forecast of more than a thousand PMUs. All PMUs used in this system were evaluated at Synchrophasor Measurement Laboratory in CEPEL, the largest electric energy research center in South America. More than 8 PMU models, involving 5 manufacturers, were evaluated, bringing valuable comparative information about PMUs, especially regarding the differences between their performances and the impact at foreseen PMU applications. Based on this experience, a reference PMU for field tests was developed, providing even more reliability for the Brazilian phasor measurement system. Besides that, tests were also carried out on PMUs having digital signals as inputs, in accordance with the IEC 61850-9-2 standard, coming from SAMUs (Stand Alone Merging Units), providing interesting results.

## Panelist 3

**Name:** Tianshu Bi

**Organization:** North China Electric Power University, China

**Email:** tsbi@ncepu.edu.cn

**Short biography:** Prof. Tianshu Bi received her Ph. D degree from the University of Hongkong in 2002 and currently is a Professor of Electrical Engineering at North China Electric Power University. She also serves as the Vice President of North China Electric Power University and Executive Director of the State Key Lab of Alternate Electrical Power System with Renewable Energy Sources. She got the honor of “Distinguished Young Scholars supported by NSFC(National Natural Science Foundation of China)” in 2017. Her main area of expertise is synchronized measurement technology and its applications, power system protection and control. She is PI of NSFC projects, including National Major Research Instrument Development Project, Major International Joint Research Project and MOST (Ministry of Science and Technology) Projects, including 973, 863 and Key Basis Research Subprojects. And she has published over 200 academic papers. One National Science and Technology Progress Awards (2nd class), three Ministry and Provincial Science and Technology Progress Awards (1st class), and four Ministry and Provincial Science and Technology Progress Awards (2nd class) have been conferred. She also got the honor of Outstanding Contribution Award for Chinese Power Industry Science and Technology Development. She has established broad research collaborations with research institutes and universities in US and EU.

**Title of presentation:** PMU Calibrator Development and Testing Practices in China

**Abstract:** In China, there are more than 4000 PMUs in transmission networks at present. Due to the integration of large-scale of renewables and increasement of power electronics, hundreds of micro PMUs have been installed in distribution networks and new energy generation. In the future, more and more PMUs will be deployed in power-electronics-enabled power grids to monitor system behavior. To improve the measurement performance and data quality of PMUs in China, a PMU test platform based on a highaccuracy calibrator has been developed for PMU testing. Some techniques are proposed to make the PMU calibrator provide the reference values. An adaptive synchronized sampling method based on phaselocked loop technology are put forward to reduce hardware errors. A high-accuracy phasor measurement method based on a general nonlinear fitting model is proposed to ensure measurement accuracy. Up to now, this PMU test platform has been used to test PMUs from 7 manufactures in China.

**Panelist 4**

**Name:** Kenneth Martin

**Organization:** Electric Power Group, USA

**Email:** martin@electricpowergroup.com

**Short biography:** Kenneth Martin is a principal engineer with the Electric Power Group (EPG). He has 45 years of experience in the electric utility industry in communication, precise timing, instrumentation, and testing, first at the Bonneville Power Administration (BPA) and currently at EPG. He started working with synchrophasor measurement with the original PMUs in 1987 and led development in their deployment and testing including implementing the measurement system at BPA and building the first PDC. He continues to work with synchrophasor measurement applications, managing development of real-time data quality, linear state estimation, real-time contingency analysis, and area-angle monitor applications. Mr. Martin led development of many standards for synchrophasors. He chaired the development of the IEEE C37.118 Synchrophasor standard series and convened the IEC-IEEE 60255-118-1 synchrophasor measurement standard. Mr. Martin has authored/co-authored more than 100 technical papers and articles, is a registered Professional Engineer in Oregon and Washington, and is a Life Fellow of the IEEE.

**Title of presentation:** Synchrophasor Measurement Testing in the USA

**Abstract:** Since its introduction in the 1980's, synchrophasor measurement has become the primary source of information of power system dynamic performance both for real-time operation and off-line analytics. Standards have been developed to assure that the measurements are accurate and compatible and also that data reporting is consistent. Testing then closes the circle to assure compliance with standards. The current international standard IEC/IEEE 60255-118-1 covers PMU measurement of phasor, frequency, and ROCOF under both steady-state and dynamic operating conditions. The guide C37.242-2021 details implementation of tests that assure compliance with this standard. The IEEE provides certification for compliance with this standard under its ICAP program. In addition to measurement qualification, phasor measurement systems need continual monitoring to assure that the data reporting is accurate and reliable. These services are provided by commercial applications that both support reliable operation and prompt notification when service where needed. Initial PMU qualification coupled with continual system monitoring assures utilities of reliable information for analysis, operation and control of the power system.

## Panel Session VIII: Enabling Technologies for Enhancing Power System Resiliency by Wide Area Monitoring Protective and Control Systems

*Time*: **Wednesday, 25/May/2022: 2:50pm - 4:20pm** *Location:* **Oleandar**

### Panel chair

**Name**: Alfredo Vaccaro, University of Sannio and Giorgio M. Giannuzzi, Terna SpA, Italy

**Email:** vaccaro@unisannio.it

**Short biography of the chair**:

**Alfredo Vaccaro** (Senior Member, IEEE) received the M.Sc. (Hons.) degree in electronic engineering from the University of Salerno, Salerno, Italy, and the Ph.D. degree in electrical and computer engineer- ing from the University of Waterloo, Waterloo, ON, Canada. From 1999 to 2002, he was an Assistant Researcher with the Department of Electrical and Electronic Engineering, University of Salerno. From March 2002 to October 2015, he was an Assistant Professor of electric power systems with the Department of Engineering, University of Sannio, Benevento, Italy, where he is currently an Associate Professor of electrical power system. His research interests include soft computing and interval-based method applied to power system analysis, and advanced control architectures for diagnostic and protection of distribution networks. Prof. Vaccaro is Associate Editor of the IEEE trans. on Power Systems, IEEE trans. on Smart Grids, and he is the Chair of the IEEE PES Awards and Recognition Committee.

**Giorgio M. Giannuzzi** received the degree in electric engineering from the University of Rome. Till December 2000, he worked with ABB, where he was in charge of network studies, protection, and control applications, with special reference to RTU apparatus and data engineering issues. Since 2001, he has been working with TERNA as an Expert in defense plans/systems, dynamic studies, protection, telecontrol, and substation automation. From 2004 to 2011, he coordinated the study, design, and activation of Wide Area Defense system (including interruptible customers system) and a Wide Area Monitoring System. In addition under his guidance, the main security Energy Management Systems were designed and coded, they are actually in use with the National Control Centre (optimal power flow security and market constrained, optimal reactive power flow, dynamic security assessment tool, dynamic and static security verification software, and operator training simulator). He supervised the revision of main Italian Grid Code technical enclosures (primary and secondary frequency regulation, load shedding, protection and automation, and defense plans). Till 2009, he was a member of the UCTE Expert Group on power system stability. In 2010, he joined the ENTSO-E System Protection and

Dynamics Group. Starting from 2014, he is the Convener, coordinating the European evaluation over dispersed generation impact on system security and load shedding guidelines. He is currently responsible for the Engineering Department of National Dispatching Centre.

**Panel Abstract:** In order to increase power system resilience, wide area monitoring protection and control techniques are being increasingly applied to monitor power systems. Based on measured data smart algorithms are also applied by means of which, decisions will timely take place to protect power systems and to avoid large blackouts. In this panel, the latest experience from manufacturers, specialists and academia will be presented on different Wide area monitoring strategies, and how they can be applied to obtain safe and resilient grid in system with low inertia. A special attention will be given to blackout prevention methodologies by using synchrophasors and some results on disturbance detection by applying synchrophasors and pattern recognition techniques will be presented

## Panelist 1

**Name:** Damir Novosel

**Organization:** Quanta Technology, USA

**Email:** DNovosel@quanta-technology.com

**Short biography**: Damir Novosel (Fellow, IEEE) received the B.S., degree from the University of Tuzla, Tuzla, Bosnia and Herzegovina, the M. Sc. degree from the University of Zagreb, Zagreb, Croatia, and the Ph.D. degree from Mississippi State University, Starkville, MS, USA, respectively, all in electrical engineering.,He is the President of Quanta Technology, Raleigh, NC, USA, a subsidiary of Quanta Services. He was a Vice President of ABB Automation Products, and a President of KEMA T&D, Chalfont, PA, USA. He has authored or coauthored more than 100 articles in transactions, journals, and proceedings. He holds 16 U.S. and international patents, and has led or participated in numerous IEEE standards, publications, and other initiatives, such as keynotes and panels.,Dr. Novosel was elected to the National Academy of Engineers in 2014 and was the President of the IEEE Power and Energy Society. He is also a member of the CIGRE US National Committee and was the recipient of the CIGRE Attwood Associate and Distinguished Service awards. He is currently a member of the IEEE Standards Board and chairs IEEE Industry Technical Support Leadership Committee.

**Title of presentation:** Importance of Synchronized Measurements to Address Changing Electrical Power Delivery

**Abstract:** Power grids have become more complex to plan and operate. With grid changes arise new challenges: renewable generation, energy conservation, electric vehicles, energy storage, and load growth. Challenges facing the electric industry today include balancing capacity, reliability, economics, environmental, and other public objectives. Recent cascading outages have demonstrated the challenges faced when operating a system near its limits. These outages over the last few years have had large social and economic impacts. In this complex scenario the large-scale deployment of advanced measurement and monitoring system has led to increased operational knowledge and a foundation for improved reliability. The advances gained from understanding real-time monitoring will lead to increased efficiency of the modern grid. In

this context, this talk discusses novel synchrophasor-based approaches that integrate protection, control, and monitoring using high-performance computing, and concludes with a discussion on emerging and future technologies for improving the resiliency of a sustainable grid.

## Panelist 2

**Name:** Kwok Cheung

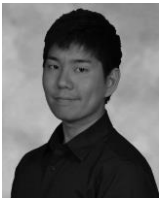
**Organization:** GE Digital, USA

**Short biography:** Kwok W. Cheung (S'87–M'91–SM'98–F'14) received the Ph.D. degree in electrical engineering from Rensselaer Polytechnic Institute, Troy, NY, USA, in 1991,He joined GE Grid Solutions (formerly ALSTOM Grid Inc.) in 1991 and is currently the Director R&D of Network Management Solutions focusing on innovation and technology. His current interests include electricity market design and implementation, smart grid, renewable energy integration, energy forecasting, power system stability and microgrid. Dr. Cheung has been a registered Professional Engineer of the State of Washington since 1994.

**Title of presentation:** WAMS technologies and stability applications for low Inertia Grids

**Abstract:** Due to the growing capacity of variable renewable generation, the operation of the power grid is continuing to grow in complexity. This has led to a massive displacement of traditional synchronous power generation with high rotational Inertia, by more distributed inverter-based renewable energy generation in modern grids. Transmission system operators (TSO) and independent system operators (ISO) around the world now require enhanced visibility and understanding of the power system to deliver fast-acting response services for maintaining system reliability and dynamic security. Development of phasor measurement unit (PMU) technology, which provides synchronous timestamp, high-resolution data not previously available in traditional SCADA, has given utilities the ability to implement wide area measurement system (WAMS) techniques for assessment and control of power system stability. WAMS is an augmented key subsystem in advanced energy management systems (AEMS) to complement the traditional model-based approach based on time-domain simulation and energy analysis. This talk presents a holistic framework of WAMS within AEMS and provides an overview of the state-of-art WAMS technologies. Some advanced and emerging applications related to WAMS and system stability for control centers are highlighted with illustrated use cases.

## Panelist 3



**Name:** Kenta Kirihara

**Organization:** Hitachi, Japan

**Short biography:** Kenta Kirihara is with Hitachi Ltd., Development Group, Hitachi-shi, Ibaraki, Japan

**Title of presentation:** The Importance of Reliable Data on WAMPAC and How Data Reliability Can Be Improved

**Abstract:** The large scale pervasion of Phasor Measurement Units allows acquiring and storing large quantity of synchrophasor data. However, the efforts to process these

massive data-sets to meet very high operator trust expectations has been challenging. This talk analyzes the effects of synchrophasor data quality in the Trustworthy Cyber Infrastructure for the Power Grid project, and the enabling technologies aimed at improving the resilience of WAMPACs to imprecise and uncoherent data.

## Panelist 4

**Name:** Evangelos Farantatos

**Organization:** EPRI, USA

**Email:** efarantatos@epri.com

**Short biography:** Evangelos Farantatos received the Diploma in Electrical and Computer Engineering from the National Technical University of Athens, Greece, in 2006 and the M.S. and Ph.D. degrees from the Georgia Institute of Technology, Atlanta, GA, USA, in 2009 and 2012, respectively. He is a Senior Project Manager with the Grid Operations and Planning R&D Group at EPRI, Palo Alto, CA. He is managing and leading the technical work of various R&D projects related to synchrophasor technology, power systems monitoring and control, power systems stability and dynamics, renewable energy resources modeling, grid operation and protection with high levels of inverter-based resources. He is a Senior Member of IEEE. In summer 2009, he was an intern at MISO

**Title of presentation:** Hierarchical Decentralized Frequency Control in Inverter Dominated Grids

**Abstract:** With the increasing number of inverter based resources (IBRs) and the displacement of synchronous generators that have been traditionally performing frequency control, renewable energy resources are expected to perform such controls in the future. Frequency control of IBR dominated grids needs to be automatic and fast. The reason is the expected faster system dynamics and potential stability issues that can manifest in a short time in which operator action might not be feasible. Further, local active controls are needed to respond to such fast changes. The reason is that with traditional centralized controls, the time required for monitored data to reach the control center, systems to detect a reliability threat, and control action to be determined and implemented may be too long for the issue at hand. Furthermore, the control system needs to have a wide-area visibility to ensure secure and efficient operation of local controls. The implementation of such controllers requires high resolution measurements which may not be provided by today's SCADA systems, thus necessitating a more advanced monitoring technology. Towards this goal, this talk analyzes a decentralized hierarchical control architecture that takes advantage of the fast control capabilities of IBRs and the highresolution synchronized measurements provided by Phasor-Measurement Unit (PMU) technology. The hierarchical architecture comprises a combination of local-distributed and wide area-central controllers to achieve secure and efficient operation. Such a hierarchy allows the local controllers to quickly mitigate local disturbances while the central controller coordinates the local controllers and provides them with wide area visibility. Such a controller facilitates transition from the centralized control paradigm of today's power system with EMS and SCADA towards a hierarchical decentralized control paradigm to address potential reliability issues of an IBR dominated power system. The presentation will summarize the development of the proposed control architecture,

simulation case studies using a benchmark test system, and validation using real-time Hardware-Inthe- Loop (HIL) tests.

## Panelist 5

**Name:** Cosimo Pisani

**Organization:** Terna, Italy

**Short biography:** Cosimo Pisani was born in Benevento, Italy, in 1985. He received the M.Sc. degree with honors in Energy Engineering from the University of Sannio, Benevento, in 2010 and the Ph.D. degree in Electrical Engineering from the University of Naples "Federico II," Naples, Italy, in 2014. During his PhD in collaboration with Terna, the Italian Transmission System Operator, he investigated some dynamic stability issues of large interconnected power system such as the European one (i.e. European Network of Transmission System Operator). From May 2014 to March 2016 he was Research Fellow at University of Sannio. From March 2016 he is with Terna. Currently, he is head of Stability and Network Calculations at Dispatching and Switching Department. He is the author or coauthor of over 60 scientific papers published in reviewed journals and presented at international and national conferences. His research interests include the applications of dynamic stability of power systems, Wide Area Monitoring and Protection systems, Special Integrity Protection Schemes, High Voltage Direct Current Systems, Power system restoration. He is leader of WAMS task force within ENTSO-E System Protection and Dynamic group as well as member of CIGRE C2.17 working group Wide Area Monitoring Systems – Support for Control Room Applications and currently member of the CIGRE C2.18 working group Wide Area Monitoring Protection and Control Systems – Decision Support for System Operators.

**Title of presentation:** Oscillations Damping Control using Measurement Derived Transfer Function Model – Terna Applicative Case Study

**Abstract:** Oscillation damping controllers are usually designed and tuned based on the power system circuit model around a particular operating point using offline simulations. The limitations of this approach are that a) the accuracy of the control design depends on the accuracy of the power system dynamic model which is limited by its size and its complexity and b) the actual operating conditions are constantly changing rendering the design of the control optimal only for specific conditions. The increasing deployment of Phasor Measurement Units (PMUs) and Wide-Area Measurement Systems (WAMS) makes it possible to derive a measurement-based transfer function model describing the input and output relationships within a power system. The measurement-based transfer function model can represent power system oscillatory behavior and can be used for control design. The advantage of this approach is that the measurement-based model doesn't rely on the circuit model of each component and can be updated in real time to reflect the changes in power system operating conditions. Terna and EPRI worked together in the past years to design and validate a wide-area damping controller (WADC) using a measurement-driven transfer function. Then the WADC was implemented on a generic-purpose hardware platform (Compact RIO) and tested in a hardware-inthe- loop (HIL) setup, where the ENTSOE model was emulated on a real-time digital simulator (i.e. OPAL-RT). Realistic operating conditions were emulated to evaluate the performance of

the WADC including random time measurement delays, data package loss, measurement noise, and multiple PMUs as backup. At the current stage the project is in the field implementation, deployment and demonstration by using as actuators two augmented inertia synchronous condensers installed in two Terna substations.

## Panel Session IX: Towards a Zero Inertia Grid thanks to Synchrophasor Measurements

*Time*: **Wednesday, 25/May/2022: 5:00pm - 6:30pm** *Location:* **Ruzmarin**

### Panel chair

**Name**: Panayiotis (Panos) Moutis

**Organization:** Carnegie Mellon University, USA

**Email:** pmoutis@andrew.cmu.edu

**Short biography of the chair**: Panayiotis (Panos) Moutis, PhD, has been Special Faculty with the Scott Institute for Energy Innovation at Carnegie Mellon University (CMU) since August 2018 (postdoc at Electrical & Computer Engineering, CMU, 2016-18). His recent grants include one from the national system operator of Portugal, REN, for the development of a transmission expansion planning platform, and another from the moonshot factory of Google, X, for the digital twin of the electrical grid. Between 2018-20 he served as a Marie Curie Research Fellow with DEPsys, Switzerland, on distribution grid synchronized measurements and state estimation. In 2014 he was awarded a fellowship by Arup UK (through the University of Greenwich), on the "Research Challenge of Balancing Urban Microgrids in Future Planned Communities". In 2013 he won the "IEEE Sustainability 360o Contest" on the topic of Power. Throughout 2007-15, as part of Prof. Nikos Hatziargyriou's research group he contributed to over a dozen R&D projects funded by the European Commission. Panos received both his diploma (2007) and his PhD (2015) degrees in Electrical & Computer Engineering at the National Technical University of Athens, Greece, and has published more than 30 papers and contributed to 5 book chapters. He has accumulated over 10 years of industry experience on projects of Renewable Energy Sources and Energy Efficiency, and serves in energy start-ups as advisor and executive. He is a senior member of multiple IEEE societies, member of the IEEE-USA Energy Policy Committee and NASPI, associate editor of IEEE & IET scientific journals, active contributor to IEEE standards working groups, chair of the IEEE Smart Grid Publications Committee and editor-in-chief of the "IEEE Smart Grid Newsletter". Personal Website for more information: https://panay1ot1s.com/

**Panel Abstract:** Renewables and battery storage systems gradually displace conventional generators with large rotating inertias. Rotating inertias have allowed system operators to respond to critical grid events in times of a few seconds, while the severity of the grid events themselves has been dampened by the collective grid inertia. As the energy portfolios change in the pursuit of the decarbonization of the electricity sector, the reduction of rotating inertia will limit the system operators' response time to milliseconds and the grid criticalities will gradually become more severe. Clearly, we need faster and more granular grid status monitoring, to enable faster remedial responses. This means that we will require from synchrophasor measurements (at the timescales of sub-period detail) to detect the rigidness of the grid and inform the controllers of fast acting inverter-interfaced resources. This panel will review the current stage of research in estimating grid inertia and enabling inverter control action thanks to synchrophasor measurements. We will also attempt to draw a roadmap towards a zero-inertia grid and

what are the expectations from phasor measurement units, the supporting IT set-ups and their interactions with the most crucial grid components and stakeholders.

## Panelist 1

**Name:** Panayiotis (Panos) Moutis

**Organization:** Carnegie Mellon University, USA

**Email:** pmoutis@andrew.cmu.edu

**Short bio and photo:** included above in the Panel Chair section

**Title of presentation:** What is the Zero Inertia Grid and what affects its stability

**Abstract:** As an introduction to the panel and the ensuing discussions, several studies on the instability concerns introduced by high amounts of inverter-interfaced resources are reviewed. The studies focus on the contribution of two factors: the frequency control droop on the active power setpoint of the inverter and the size of the grid impedance at the inverter output. Both of these concerns are in turn functions of the grid operating status and characteristics. System inertia in a low-inertia grid may vary considerably under very typical system operation, while grid impedance may change as faults occur or system reconfiguration actions are performed. Given the fact that the time constants of grid phenomena will be shifting to those of electrical time scale (a few ms), the value of synchrophasor measurements and the applications they enable is particularly crucial.

## Panelist 2

**Name:** Evangelos Farantatos

**Organization:** Electric Power Research Institute, USA

**Email:** efarantatos@epri.com

**Short biography**: Evangelos Farantatos received the Diploma in Electrical and Computer Engineering from the National Technical University of Athens, Greece, in 2006 and the M.S. and Ph.D. degrees from the Georgia Institute of Technology, Atlanta, GA, USA, in 2009 and 2012, respectively. He is a Senior Project Manager with the Grid Operations and Planning R&D Group at EPRI, Palo Alto, CA. He is managing and leading the technical work of various R&D projects related to synchrophasor technology, power systems monitoring and control, power systems stability and dynamics, renewable energy resources modeling, grid operation and protection with high levels of inverter-based resources. He is a Senior Member of IEEE. In summer 2009, he was an intern at MISO.

**Title of presentation:** Online Inertia Estimation & Monitoring – Needs, Challenges, Industry Practices and R&D

**Abstract:** As power systems are transitioning towards decarbonization, there are increased concerns around system reliability and especially frequency security. With increasing penetration of inverter based renewable energy resources that continue to displace conventional synchronous machines, the overall system inertia is reducing and this directly impacts the rate of change of frequency (RoCoF) that the power system is exposed to immediately following a disturbance. Higher RoCoFs allow less time for

frequency responsive services to act and hence threaten under frequency load shedding (UFLS) or in more severe cases, system separation. Utilities around the world have established planning procedures and operational constraints in the form of RoCoF constraints or critical inertia floors to accommodate existing equipment withstand and available reserve capabilities. In this context, system operators are monitoring system inertia in their control rooms in real time and also looking at forecasts. The ability to estimate or measure inertia accurately in real time allows system operators to manage the grid and procure frequency response services in an efficient manner. However, most of the control room inertia monitoring at this time is based on online EMS telemetered generating stations. Estimates from EMS monitored generation does not account for the demand side inertia contribution from large industrial loads and demand side generation (e.g. embedded synchronous generation). To address this challenge, measurement based techniques for system inertia estimation are emerging. This presentation will summarize state-of-the-art methods and industry practices for system inertia estimation, as well as R&D activities that investigate the use of synchronized measurements provided by phasor measurement units (PMUs) for system inertia estimation.

## Panelist 3

**Name:** Deepak Ramasubramanian

**Organization:** Electric Power Research Institute, USA

**Short biography:** He received the M.Tech. degree from the Indian Institute of Technology Delhi, New Delhi, India, in 2013, and the Ph.D. degree from Arizona State University, Tempe, AZ, USA, in 2017. He is currently a Senior Engineer Scientist in the Grid Operations and Planning Group, Electric Power Research Institute, Knoxville, TN, USA. He is a recipient of the North American SynchroPhasor Initiative Outstanding Graduate Student Award and the POSOCO Power System Award. His research interests include modeling, control, and stability analysis of the bulk power systems with recent focus on the associated impacts of large-scale integration of converter interfaced generation.

**Title of presentation:** Modeling and analysis of systems with newer forms of inverter control

**Abstract:** The growth of inverter-based resources (mostly based on renewable energy) are changing the electrical grid physics. Even though inverter-based resources (IBRs) have already been operating harmoniously with with conventional units, in some cases, IBRs approach a 100% contribution to the local power demand. Grid-forming inverters are a category of controls and coordination strategies for systems with the aforementioned characteristics and could enable renewable integration at scale with added security, resilience, efficiency, and affordability. Over the next five years, the UNIFI consortium will develop the methods and assess the challenges in ensuring interoperability and meeting functional requirements for these technologies, by integrating research capabilities and project objectives. The UNIFI consortium will demonstrate how the next-generation power systems will operate using federated hardware test beds. The value of accurate, synchronized and highly granular system measurements is key to enabling the stable, secure and efficient control of grid forming inverters in a low or zero inertia grid. Some preliminary yet fundamental aspects of this consideration will be discussed.

## Panelist 4

**Name:** Qiteng Hong

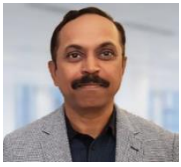
**Organization:** University of Strathclyde, Glasgow

**Short biography:** He received the B.Eng. (Hons.) and Ph.D. degrees in electronic and electrical engineering from the University of Strathclyde, Glasgow, U.K., in 2011 and 2015, respectively. He is currently a Lecturer (Strathclyde's Chancellor's Fellow) with the University of Strathclyde. His main research interest includes power system protection and control of future networks with high penetration of renewable generation. Dr. Hong is a Regular Member CIGRE Working Group B5.50 and IEEE Working Group P2004. He was the Technical Lead at the CIGRE UK Next Generation Network (2014-2019) and the Secretary of IET Scotland Southwest Committee (2015-2018).

**Title of presentation:** Enhanced Frequency Control for Future Power Network with Low Inertia Using Synchrophasor Measurements

**Abstract:** The clean energy shift in power systems has led to a massive decrease of system inertia, which makes frequency control challenging, due to the small response times before frequency drops to unacceptable levels. Network operators must, thus, procure increased power reserves representing higher operational costs. Moreover, since renewable generation is arbitrarily dispersed in a power system, there are differences in the inertia across interconnected regions and, as a result, to their frequency behavior. Novel wide-area monitoring and control topologies that are capable of dispatching fast and coordinated response from a variety of distributed resources are necessary. A novel system, termed "Enhanced Frequency Control Capability (EFCC)", considers the regional impact of frequency disturbances and is capable of deploying much faster response compared with conventional primary response schemes (from a few seconds to within one second), thus enhancing the frequency control in future power systems with low inertia. The overall architecture of the EFCC system and the design of the key components within it to realise the enhanced frequency control objectives will be discussed, including case studies on distinguishing frequency events from pure electrical faults to avoid unnecessary operation.

## Panelist 5



**Name:** Krish Narendra

**Organization:** Electric Power Group LLC, USA

**Short biography:** Krish Narendra, Ph.D, is the COO and Technology Lead of Electric Power Group LLC (EPG). Krish joined EPG in September 2017 and has over 30 years of experience and is a prominent expert in power system protection, monitoring, control and analysis. Krish works on real time grid monitoring, visualization and analytics to address industry needs for asset health monitoring, digital solutions for power grid automation, and control. Krish's expertise spans innovative design, commercialization of protective relays and disturbance monitoring recorders, and use of advanced digital

signal processing technologies on embedded systems to enable real time grid security, analytics, asset health and automation. K

**Title of presentation:** Real-Time Inertia Monitoring Using Synchrophasors

**Abstract:** With the increasing penetrations of renewable generation in the North American power grid the “low inertial response” of the power grid is becoming a growing concern. In such types of grids it is difficult to estimate the time varying inertia constant during major infeed loss or disturbances because of the complexities of identifying the number of machines participating including the load (which may also contribute to the rotational inertia). The overall inertia constant and hence the rotational kinetic energy, if available for each of the balancing authorities (Operators) in near real time (online), would help them in accessing the next course of action to recover the system faster avoiding stability issues. Planners can also use the estimated inertia constant and do the system model validation for better evaluation of the planned contingencies. The presentation aims at the conceptual aspects of the “inertial response of electrical grid” with growing renewables.

## Panelist 6

**Name:** Dr. Yilu Liu

**Organization:** University of Tennessee Knoxville and Oak Ridge National Lab, USA

**Email:** Liu@utk.edu

**Short biography:** Yilu Liu received her M.S. and Ph.D. degrees from the Ohio State University, Columbus, in 1986 and 1989. She received the B.S. degree from Xian Jiaotong University, China. Dr. Liu is currently the UT-ORNL Governor’s Chair at the University of Tennessee and Oak Ridge National Laboratory. She is also the deputy director of the DOE/NSF engineering research center CURENT (curent.utk.edu). She led the effort to create the North American power grid Frequency Monitoring Network FNET/GridEye (fnetpublic.utk.edu, powerit.utk.edu). Dr. Liu is an expert in large grid dynamic modeling, simulations, and monitoring. Dr. Liu is a member of National Academy of Engineering, a member of the National Academy of inventors, a fellow of IEEE. She can be reached at Liu@utk.edu.

**Title of presentation:** Benefit of Grid Edge Synchronized Measurements

**Abstract:** The talk will provide an overview on the effort of power grid wide-area monitoring and observations that were made possible from the grid edge synchronized data. The critical roles of wide-area phasor measurement in situation awareness, operation, and control will be discussed. The concept of electromechanical wave propagation in power grid will be demonstrated using measurement data collected from the actual grids. Applications of time synchronized data in event location, oscillation location detection, model validation, and high renewable grids will be discussed.

# Panel Session X: Synchronized Measurement in The Control Room of The Future

*Time*: **Wednesday, 25/May/2022: 5:00pm - 6:30pm** *Location:* **Olenadar**

## Panel chair

**Name of the organizer**: Damir Novosel, President

**Organization:** Quanta technologies, USA

**Email:** DNovosel@quanta-technology.com

**Short biography of the chair**: Damir Novosel is president and founder of Quanta Technology, a subsidiary of Quanta Services, a Fortune 250 company. He was also president of Quanta Energized Services which achieved a perfect safety record during his tenure. Previously, he was vice president of ABB Automation Products and president of KEMA T&D US. Dr. Novosel is also an adjunct professor of Electrical Engineering at North Carolina State University. Damir was elected to US National Academy of Engineers in 2014. He served as president of the IEEE Power and Energy Society, VP of Technical Activities, and chair of Industry Technical Support Leadership Committee. Damir is a member of the IEEE Standards Association Standards Board and chair of Strategic and Emerging Standards Committee. He is a member of the CIGRE US National Committee and received the CIGRE Attwood Associate and the Distinguished Member awards. Damir holds 17 US and international patents, published over 200 articles and reports, and contributed to 6 books. Damir, an IEEE Fellow since 2003, 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 in 2015.

**Panel Abstract:** As the electric grid fast evolving towards a grid of the future, the real-time control room operations will face increasing new challenges, such as reduced system inertia, fast changing system transient and voltage stability margins. Existing tools (e.g., EMS/SCADA systems) would become either less effective or unable to address some of the upcoming operation challenges. System operators and utilities worldwide have embarked on their journey of planning and implementing new systems and tools toward a control room of the future (CROTF). This panel will focus on the discussions of how to evolve current control room operations to a CROTF operation in which synchronized measurement will play an increasingly critical role. The global industry leaders will discuss their current efforts towards a CROTF and share the challenges faced and lessons learned.

## Panelist 1

**Name:** Matija Naglič, Advisor

**Organization:** TenneT TSO, Netherlands

**Email:** matija.naglic@tennet.eu

**Short biography**: Matija Naglic received Uni. Dipl. Ing. degree in Electrical Engineering, study filed Telecommunications from the Faculty of Electrical Engineering, University of Ljubljana, Slovenia in 2011. In 2020 he received Ph.D. degree in Power System Engineering from the Faculty of Electrical Engineering, Mathematics and Computers Science, Delft University of Technology, The Netherlands. He is experienced with the implementation of IEEE std. C37.118 specifications, both the measurement and the telecommunication parts. He developed a cyber-physical platform for closed-loop control testing of WAMPAC applications, and two algorithms for online detection of disturbances and slow-coherent generators in a power system. He is a member of CIGRE WG C2.18. Currently, he works as an advisor for TenneT TSO, with a focus on the Control Room of the Future.

**Title of presentation:** Evolving of EMS/SCADA with synchro-measurements: user needs, challenges, and early stage developments

**Abstract:** In the last decade, the power system complexity and the number of large-scale power system blackouts have increased significantly. To cope with the new system requirements, the conventional EMS/SCADA system and tools need to be improved. This presentation addresses the typical challenges of the conventional EMS/SCADA system from the design perspective, elaborates the limitations of the conventional monitoring system for dynamic phenomena, and focuses of the early stage developments to improve the existing EMS/SCADA functionality with synchro-measurements. The special attention is paid to interfacing synchro-measurements with SCADA, and their use in Sate Estimation and Load Frequency Control applications.

## Panelist 2

**Name:** Matthew Gardner, Director

**Organization:** Dominion Energy, USA

**Email**: matthew.gardner@dominionenergy.com

**Short biography:** Matt Gardner is Director, System Protection with Dominion Energy's Power Delivery Group. In this role, Matt oversees the company's System Protection organization, including both engineering and field operations responsibilities. His organization also includes Dominion Energy's T&D Protection and Control Standards, Data Engineering and Analytics, and Operations Engineering Studies groups. Since joining Dominion in 2008, Matt has held various roles in planning, operations, and engineering. Outside of Dominion Energy, Matt has a range of experiences spanning industry, academic, and regulatory domains. As an IEEE Senior Member, Matt stays deeply involved in industry groups such as the IEEE Power and Energy Society, Cigré, EPRI, and the North American Transmission Forum, to name a few. Matt also has a passion for the development of future generations of technical talent for our industry and is actively involved with a broad number of academic institutions and

consortia, including Virginia Tech. Speaking of Virginia Tech, Matt received his PhD degree in Electrical Engineering from Virginia Tech where he was a Bradley Fellow. He also holds BS and MS degrees in Electrical Engineering from Virginia Tech. Matt is a licensed Professional Engineer in the Commonwealth of Virginia.

**Title of presentation:** Unpacking the Value of Synchrophasors – Decades of Discovery, Growth, Evolution, and Execution

**Abstract:** This presentation will serve as an exposé of Dominion Energy's synchrophasor technology deployment and utilization. The talk will traverse the arc of State Estimation, Situational Awareness, and System Restoration. Organizational concepts and changes required to maximize the utility of synchronized measurements will be outlined. A realistic overview of synchronized measurement data quality requirements will be discussed. Finally, the presentation will demonstrate how a combination of analytics capabilities and operations intelligence have become pivotal to Dominion Energy's real-time operations.

## Panelist 3

**Name:** Tariq Rahman, Principal Engineer

**Organization:** San Diego Gas & Electric (SDG&E), USA

**Email:** TRahman@sdge.com

**Short biography:** Tariq Rahman, P.E., is a Principal Engineer in the Electric Engineering Department at San Diego Gas & Electric Company (SDG&E), California. He obtained his BSEE in 1980 and MSEE in 1985. Tariq has 35+ years' electric utility industry working experience in Electric Grid Control Room Operations, Generation Planning, and System Protection & Control Engineering. In addition to his current system protection engineering functions, Tariq has been leading SDG&E's Transmission Synchrophasor-based Wide Area Situational Awareness (WASA) System Deployment Project since 2010. In 2017 his effort and the accomplishment of SDG&E has earned him the NASPI "Synchrophasor Technology Champion" award, and SDG&E the "NASPI 2017 Outstanding Utility" award. Tariq led the development of an advanced Visualization Software System (VSS) for SDG&E's next generation WASA system (WASA2) that is currently being commissioned in SDG&E's Grid Control Room for real-time operations complementing the EMS system. Tariq also led SDG&E's transition from TDM/SONET to MPLS communication for teleprotection, WASA/WAMPAC systems and SCADA. He has been presenting/speaking at many protective relay conferences, NASPI, NERC SMS, WECC JSIS, IEEE and SMART conferences and working groups as panelist or guest speakers. He is a licensed Professional Engineer in the states of New York and California and is a Senior Member of IEEE.

**Title of presentation:** SDG&E's Experience in Deploying Synchronized Measurements for Grid Control Room Operations

**Abstract:** The presentation will review SDG&E's experience so far in deploying its synchrophasor-based WASA System for grid control room real-time operations, and discuss SDG&E's view on building a fully integrated next generation EMS+WASA system centered around the synchronized measurement for future grid control room operations

## .Panelist 4

**Name:** Yi Hu, Director-WAMPAC

**Organization:** Quanta Technology LLC, USA

**Email:** YHu@quanta-technology.com

**Short biography:** Dr. Yi Hu, an IEEE Fellow, is a Director of WAMPAC at Quanta Technology. He has over 30 years of experience in electric power system protection, control, and analysis. Since 2005, Yi has been supporting U.S. and international utilities in their deployment of large-scale synchrophasor systems for control room situational awareness, protection and control. He chaired the PES PSRC WG that developed the "IEEE Guide for Engineering, Implementation, and Management of System Integrity Protection Schemes" (C37.250), and currently chairs a PSRC WG C43 to develop an IEEE report for a "Use of Artificial Intelligence and Machine Learning for Power System Protection and Control". Dr. Hu obtained his BSc from Southeast University and MSc from Nanjing Automation Research Institute in China, and PhD from University of Manitoba in CANADA.

**Title of presentation:** Managing Future Control Room Operation Challenges

**Abstract:** The presentation will overview emerging operation challenges brought about by the drives towards a carbon-neutral future grid, and discuss the critical roles that synchronized measurement based applications and tools will play in assisting operators to manage these new challenges.

## Panelist 5

**Name:** Bas Kruimer, Business Director Digital Grid Operations

**Organization:** DNV Energy Systems, USA

**Email:**

**Short biography:** Bas Kruimer is Business Director Digital Grid Operations at DNV Netherlands Energy Advisory focusing on digital grid operations, automation strategy & deployment and with special attention to cyber security in operational environments. With a background in SCADA, Substation Automation, Smart Metering and Utility Cyber Security Bas works with a team of experts/consultants in the Northern Europe region supporting utilities and grid operators in their diverse Next Generation Grid Operations, network control, grid automation and digital transition challenges. With the rapid rise of renewables, decentralization and digitalization facing the industry, the DNV Energy Systems & Renewables group helps utility companies respond to emerging opportunities, to ensure continued grid reliability and resiliency through responsible and sustainable operations during all phases of the energy transition. As a graduated power engineer from Delft University of Technology end 80's Bas started his international career in the electrical power transmission and distribution markets over 30 years ago at ABB Network Control & Protection, followed by KEMA, Eneco/Joulz, Quanta Technology and Accenture/Accenture Security

**Title of presentation:** New PMU data transfer solutions and interoperability of WAM Systems

**Abstract:** PMUs are increasingly being deployed and integrated into data collection networks supporting the grid operations to better manage the many new large and distributed renewable generators into the system. The PMU data is to be used in analytics applications as part of the Grid Operations System in the Control System of the Future. Questions addressed will be how to manage the real-time transfer of increasing amount of PMU data using scalable streaming solutions, how to manage this data in real-time within the Next Generation Grid Operations System (data machine), and finally how to achieve interoperability of different devices within the system from both a communication as well as from a data structuring perspective. And did anyone mention cyber security?

## Tutorial 1: CPOW Analysis: Data processing techniques for extracting insights from continuous point-on-wave measurements

*Time*: **Monday, 23/May/2022: 3:00pm - 6:00pm** *Location:* **Online**

### Tutorial chair

**Name of the organizer**: Alexandra von Meier

**Email:** vonmeier@berkeley.edu

**Short biography of the chair**: Sascha von Meier is an Adjunct Professor in the Department of Electrical Engineering and Computer Science at the University of California, Berkeley, and Director of the Electric Grid Research program at the California Institute for Energy and Environment. She is also a Faculty Scientist at the Lawrence Berkeley National Laboratory. Her research focuses on advanced measurements, data analytics and control strategies in electric grids to support resilience and the decarbonization of the energy sector.

**Tutorial Abstract:** This online only workshop will introduce techniques and tools for analyzing continuous point-on-wave (CPOW) measurements from electric grid sensors, on the PredictiveGrid platform. After a general introduction to CPOW data, participants will have the opportunity to work hands-on in applying algorithms to CPOW data sets consisting of field measurements of primary and/or secondary distribution system voltages. Breakout rooms will focus on specific topic areas including oscillation detection, waveform/harmonic analysis, and multi-resolution data, allowing small groups to work together on coding challenges.

### Part 1

**Name of the speakers:** Sascha von Meier and Laurel Dunn

**Short biography:**

**Sascha von Meier** is an Adjunct Professor in the Department of Electrical Engineering and Computer Science at the University of California, Berkeley, and Director of the Electric Grid Research program at the California Institute for Energy and Environment. She is also a Faculty Scientist at the Lawrence Berkeley National Laboratory. Her research focuses on advanced measurements, data analytics and control strategies in electric grids to support resilience and the decarbonization of the energy sector.

**Laurel Dunn** is a project manager leading PingThings ARPA-E project *A National Infrastructure for AI on the Grid*. She received her engineering PhD at the University of California, Berkeley where she specialized in data-driven decision analysis for utilities. She specializes in bridging interdisciplinary perspectives and areas of expertise to advance the use of big data and AI/ML tools for grid modernization.

**Title of presentation:** Introduction to continuous point-on-wave measurement (40 min)

**Abstract:** Much of the sensing instrumentation on the grid reports phasors or time-averaged values which are often derived from higher frequency measurements. These raw waveform data include information that is lost in aggregation. This portion of the tutorial will examine the information contents of CPOW data compared with other data streams, motivating the need for more widespread collection and analysis of CPOW data. We will also discuss computational challenges and requirements for processing this volume of data.

## Part 2

**Name of the speakers:** Mohini Bariya and Theo Laughner

**Short biography:**

**Mohini Bariya** leads the data & applications team at PingThings. Her work focuses on the use of novel, high-resolution measurements for improved situational awareness in the electric grid. She has worked extensively with real PMU datasets and has also taught science and engineering concepts to different audiences. She holds a PhD in electrical engineering and computer science from UC Berkeley.

**Theo Laughner** is the Director of Engineering at Lifescale Analytics. Previously, Mr. Laughner spent 21 years at TVA where he was responsible for the Power Quality program at TVA. He has a passion for helping utilities and their stakeholder maximize investment in data for the contemporary grid. Cyber security and data analytics are at the center of this focus. Mr. Laughner is a registered professional engineer in the state of Tennessee.

**Title of presentation:** Applications and data analysis techniques (60 min)

**Abstract:** This portion of the course will cover data processing techniques relevant to extracting different types of insights from CPOW data. Analytical methods focus on extracting features of the data (such as the power density, or fault analysis) to characterize dynamics that would not be evidenced by low-frequency sensor telemetry streams. These methods offer a foundation for data exploration and synthesis aimed at drawing attention to time-intervals where relevant dynamics are present, and provide a basis for targeting downstream workflows to diagnose and address possible issues.

## Part 3

**Name of the speakers:** Laurel Dunn

**Short biography:** Laurel Dunn is a project manager leading PingThings ARPA-E project *A National Infrastructure for AI on the Grid*. She received her engineering PhD at the University of California, Berkeley where she specialized in data-driven decision analysis for utilities. She specializes in bridging interdisciplinary perspectives and areas of expertise to advance the use of big data and AI/ML tools for grid modernization.

**Title of presentation:** : Coding challenge: Exploratory data analysis and visualization (60 min)

**Abstract:** This portion of the tutorial will include guided data analysis exercises designed to give attendees the experience of working with point-on-wave data. Presenters will disseminate data and code necessary to replicate analytics described earlier in the session. This portion of the tutorial will include a series of breakout room sessions targeted at building familiarity with point-on-wave workflows needed to develop exploratory data analysis workflows of their own.

## Part 4

**Title of presentation:** Conclusion, discuss interim results (20 min)

**Abstract:** The workshop will culminate with attendees and panelists re-grouping to discuss highlights and challenges associated with processing

# Sponsor presentation

SCHWEITZER ENGINEERING LABORATORIES

**Date:** Tuesday, May 24 **Time:** 1:00 pm – 1.30 pm (CEST)

**Name**: Veselin Skendzic

**Email**: Veselin_Skendzic@selinc.com

**Short biography:** Veselin Skendzic is a fellow engineer at Schweitzer Engineering Laboratories, Inc. He earned his BSEE. from FESB, University of Split, Croatia; MSc. from FER (ETF), Zagreb, Croatia; and PhD. from Texas A&M University, College Station, Texas. Veselin is an IEEE Fellow, has written multiple technical papers, has over 25 patents, and is actively contributing to IEEE and IEC standard development. Veselin is a convenor of TC38 WG37 (electronic instrument transformers), member of the IEEE Power Engineering Society (PES) and the IEEE Power System Relaying Committee (PSRC).

**Title:** Time Synchronization in Power System Protection Applications – Current Technologies and Future Trends

**Abstract:** Time synchronization and network based communications are gaining an increasing role in power system protection and automation. While the IEC 61850-9-2 Sampled Values and communication based protection promise to bring system wide benefits, power engineers are justifiably concerned about ensuring that time distribution and communication problems do not interfere with protection system performance. Presentation asks: “Can time be made mission critical?”

PRO INTEGRIS

**Date:** Wednesday, May 25 **Time:** 1:00 pm – 1:30 pm (CEST)

**Name**: Marko Gamberger

**Email**: marko.gamberger@prointegris.hr

**Short biography:** Marko Gamberger, relay protection specialist employed in Pro Integris with over 18 years of successful experience in hydro, thermal and nuclear powerplants and 110 kV to 1150 kV transmission systems. This highly qualified professional specialized in generator and substation protection and control systems was engaged in many projects around the world. Interested in protection studies and fault analysis, Marko is currently involved with project development and protection studies. With a strong technical background and demonstrated success he provides trainings in the field of Power utility communication segment such as Cyber Security tools and IEC61850 testing tools in power system facilities.

**Title:** Solving communication challenges in IEC 61850 based substations

**Abstract:** Equipment and systems are able to exchange data, commands and measured values using a set of standardized protocols. The IEC 61850 standard forms the basis for communications in electrical substations and also supports the further development of existing protection and process control concepts. It also permits new approaches, including digital substations. IEDs (Intelligent Electronic Devices) are employed as secondary technical equipment in the IEC 61850 environment. The IEDs of different manufacturers communicate with each other and access data models with the help of standardized elements. How to simplify the process of testing the automation, control, and SCADA communication in SAS utilizing IEC 61850 and how to visualize and analyze the communication relationships and depict the system topology in an intuitive manner is described. There has been an increase in recent years in the number of cyber attacks against critical control systems in production facilities and energy supply companies. Many utilities are, therefore, introducing processes to reduce the risk of cyber attacks. Until now, these measures mainly concentrated on IT networks and control centers. However, substations and their networks also represent critical attack vectors. As a consequence, the operation and maintenance processes of these substations must also be included in the cybersecurity risk assessment. A solution is presented which offers in-depth analysis and presents a completely new approach for detecting cyber attacks but also offers functional monitoring possibilities, asset inventory and IED version management. In addition, we present challenges in SCL engineering and solutions to those challenges, because better SCL engineering eases the commissioning and enables common language in operation and maintenance activities in IEC 61850 based substation.

**Date:** Wednesday, May 25 **Time:** 4:20 pm – 4:45 pm (CEST)

**Name**: Lorenzo Zanni

**Email**:

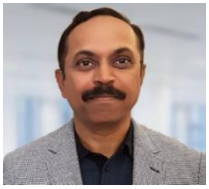
**Short biography:** Lorenzo Zanni is a co-founder and Chief Product Officer at Zaphiro Technologies. He received his PhD from the Swiss Federal Institute of Technology of Lausanne (EPFL) in 2017. He has written a number of technical papers in power-system monitoring, control, and protection by using PMUs, with focus on state estimation and fault location.

**Title:** PMU rollout at EPFL campus – A real-scale laboratory for synchrophasor applications

**Abstract:** Zaphiro presents the roll-out of a PMU monitoring infrastructure in the entire medium-voltage grid of the EPFL university campus in Lausanne, Switzerland. The presentation elaborates on the technical challenges and solutions developed by Zaphiro's engineers as well as field measurements and relevant outcomes. In particular, the presentation focuses on three main aspects: (1) deployment of a non-invasive sensing infrastructure, (2) wide-area PMU synchronisation via PTP, (3) field results of Zaphiro's state estimation and fault location techniques.

Electric Power Group

**Date:** Tuesday, May 24 **Time:** 4:20 pm – 4.45 pm (CEST)



**Name**: Krish Narendra, PhD

**Email**: Narendra@electricpowergroup.com

**Short biography:**Krish Narendra, Ph.D, is the COO and Technology Lead of Electric Power Group LLC (EPG). Krish joined EPG in September 2017 and has over 30 years of experience and is a prominent expert in power system protection, monitoring, control and analysis. Krish works on real time grid monitoring, visualization and analytics to address industry needs for asset health monitoring, digital solutions for power grid automation, and control. Krish's expertise spans innovative design, commercialization of protective relays and disturbance monitoring recorders, and use of advanced digital signal processing technologies on embedded systems to enable real time grid security, analytics, asset health and automation. Krish has published over 40 papers in various IEEE/IEC journals and conferences, and holds several patents. He is a member of the IEEE PRSC working groups, the PRTT of NASPI, the CIGRE C4-B5 working group and NERC SMS committee.

**Title:** Synchrophasor Technology for Managing and Operating Power Grids

**Abstract:** The use of Synchrophasor technology by ISO's and Utilities is increasing. The portfolio of applications has expanded beyond WAMS. The presentation will cover use cases of synchrophasors for oscillations, linear state estimation, integration with SCADA information to provide operators with actionable intelligence. Presentation will present examples of technologies in use by ISOs and Utilities in Control Centers as well as for Advanced Analytics.

**Date:** Tuesday, May 24 **Time:** 6:30 pm – 7.00 pm (CEST)

**Name**: Damir Novosel and Yi Hu

**Email**: DNovosel@quanta-technology.com; YHu@quanta-technology.com

**Short biography:**

**Damir Novosel** (Fellow, IEEE) received the B.S., degree from the University of Tuzla, Tuzla, Bosnia and Herzegovina, the M. Sc. degree from the University of Zagreb, Zagreb, Croatia, and the Ph.D. degree from Mississippi State University, Starkville, MS, USA, respectively, all in electrical engineering.,He is the President of Quanta Technology, Raleigh, NC, USA, a subsidiary of Quanta Services. He was a Vice President of ABB Automation Products, and a President of KEMA T&D, Chalfont, PA, USA. He has authored or coauthored more than 100 articles in transactions, journals, and proceedings. He holds 16 U.S. and international patents, and has led or participated in numerous IEEE standards, publications, and other initiatives, such as keynotes and panels.,Dr. Novosel was elected to the National Academy of Engineers in 2014 and was the President of the IEEE Power and Energy Society. He is also a member of the CIGRE US National Committee and was the recipient of the CIGRE Attwood Associate and Distinguished Service awards. He is currently a member of the IEEE Standards Board and chairs IEEE Industry Technical Support Leadership Committee.

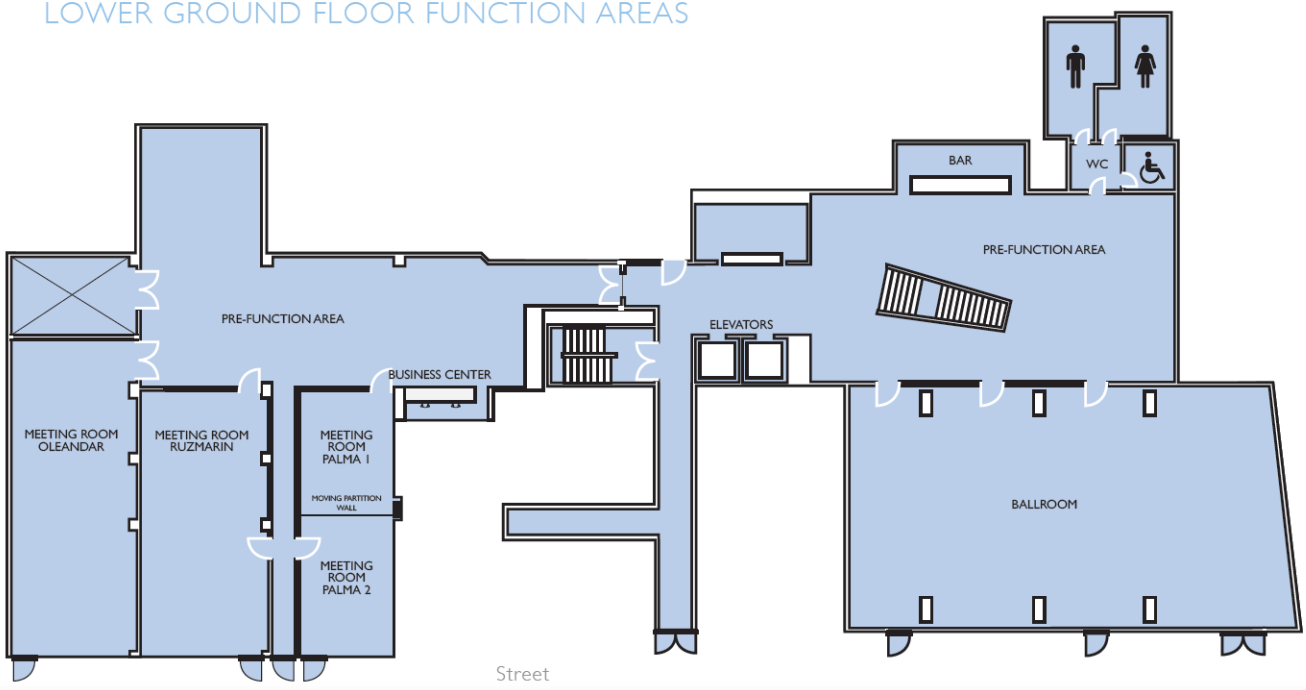
**Dr. Yi Hu**, an IEEE Fellow, is a Director of WAMPAC at Quanta Technology. He has over 30 years of experience in electric power system protection, control, and analysis. Since 2005, Yi has been supporting U.S. and international utilities in their deployment of large-scale synchrophasor systems for control room situational awareness, protection and control. He chaired the PES PSRC WG that developed the “IEEE Guide for Engineering, Implementation, and Management of System Integrity Protection Schemes” (C37.250), and currently chairs a PSRC WG C43 to develop an IEEE report for a “Use of Artificial Intelligence and Machine Learning for Power System Protection and Control”. Dr. Hu obtained his BSc from Southeast University and MSc from Nanjing Automation Research Institute in China, and PhD from University of Manitoba in CANADA.

**Title:** Successful and Practical Synchronized Measurement Applications and Deployment

**Abstract:**

# Venue information

## LOWER GROUND FLOOR FUNCTION AREAS



# General information

## REGISTRATION DESK HOURS

| | |
|---|---|
| Monday, May 23rd | 1:00 pm – 5:00 pm |
| Monday, May 24th | 7:00 am – 8:30 am |
| Monday, May 25th | 7:00 am – 8:30 am |
| Monday, May 26th | 7:00 am – 8:30 am |

## 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 Hotel Radisson Blu Resort & Spa, Split. Overlooking the Adriatic Sea with the ritzy islands of Hvar and Brac directly in front of us, the hotel puts you at the heart of Dalmatia. Situated only 3 kilometres from the city centre, this hotel sits in scenic surroundings on a white pebble beach that runs along the aquamarine waters of the Adriatic Sea.

## TRANSFER SERVICES

If you wish to schedule a transfer service to the airport or downtown Split 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 the kuna (1 kuna = 100 lipa). Foreign currency can be exchanged in banks, exchange offices, post offices and in the majority of tourist information offices, hotels and campsites.

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.

## PRESENTATION GUIDELINES

All paper session are predicted to last 80 minutes and constitute of 4 papers with related topic. The predicted presentation time for each paper is 12-15 minutes maximum with additional up to 3-5 minutes for discussion.

The IEEE SGSMA 2022 conference does not require presenters to use any specific presentation template but it is required to do the following:

- Use the title page from the template to allow the unified show of basic information about each paper;
- Add the simple text footer to your presentation: “The 2022 International Conference on Smart Grid Synchronized Measurements and Analytics – IEEE SGSMA, Split, Croatia, May 23th – 26th 2022”

SGSMA slide template can be downloaded from SGSMA 2022 web page.

## WELCOME RECEPTION

Tuesday, May 24th, 8:00 pm – 11:00 pm

Hotel Radisson Blu Resort & Spa – hotel outdoor pool area

Reception with snacks and drinks


The SGSMA 2022 Welcome Reception will be held at the Restaurant at venue hotel. Overlooking the Adriatic Sea with the ritzy islands of Hvar and Brac directly in front of us, the hotel puts you at the heart of Dalmatia.

This will be a perfect setting for delegates, students and companions to enjoy a social evening of food, drinks, and conversation.

## GALA DINNER

Wednesday, May 25th, 8:00 pm – 11:00 pm

Hotel Radisson Blu Resort & Spa

The gala dinner at the restaurant at the venue hotel.

# Technical visit

Allocated time: Thursday, May 26th, 11:00 am – 6:00 pm

A technical visit to two hydroelectric power plants, **HPP Zakučac** (544 MW) and **HPP Kraljevac** (67.2 MW) have been planned for May 26, 2022.

1. Departure from the hotel Radisson Blu Resort & Spa at 10.30 am
2. Arrival to HPP Zakučac at 11.00 am
3. Sightseeing of HPP Zakučac – 2 hours
4. Departure from HPP Zakučac at 1.00 pm
5. Arrival to HPP Kraljevac at 1.30 pm
6. Sightseeing of HPP Kraljevac – 2 hours
7. Departure from HPP Kraljevac – 3.20 pm
8. Arrival at the Restaurant Radmanove Mlinice – 3:30 pm
9. Return to the hotel – 6.00 pm

The price is:

**375 HRK** (50 EUR, 60 USD) – for participants

**225 HRK** (30 EUR, 36 USD) – for students

and includes refreshments, the lunch in traditional Croatian restaurant, bus transportation, and entrance tickets for HPPs. Registrations can be done online through the Conference registration system or on the spot until Tuesday 24.05.2022. until 22:00.

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# NOTES

# NOTES