OPAL-RT TECHNOLOGIES

ADVANCING ENERGY SYSTEMS THROUGH CUTTING-EDGE RESEARCH AND INNOVATION

LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY | LIST

Application

- Wide Area Monitoring, Protection and Control

Related Products

- OP4610XG Simulator
- HYPERSIM

Type of Simulation

- Hardware-in-the-Loop (HIL)

SUCCESS STORY

INTRODUCTION

Introducing the Intelligent Clean Energy Systems (ICES) Unit at LIST

The Intelligent Clean Energy Systems (ICES) unit at Luxembourg Institute of Science and Technology (LIST) is at the forefront of developing innovative, market-oriented solutions and services for the energy systems of tomorrow. Their mission is to create clean, efficient, and flexible energy networks that seamlessly integrate all system participants—consumers, suppliers, and other stakeholders—through cutting-edge digital technologies. Their vision is a transparent, democratic energy ecosystem where information flows freely, and operational conditions adapt in real-time to ensure the highest levels of security, reliability, and resilience.

Their Vision: Beyond the Smart Grid

At the heart of the ICES unit is their smart grid vision—an advanced electricity network where consumers and suppliers communicate effortlessly, and the system dynamically responds to real-time conditions. But they don't stop there. They extend this concept to a broader energy portfolio, incorporating other infrastructures such as renewables, heating, transportation etc. By integrating these systems, they aim to elevate the design, planning, and operation of energy solutions to new levels of abstraction and intelligence, paving the way for the future of clean energy.

Focus Areas

The ICES unit is dedicated to addressing key areas in modern energy systems, including:

Integrated Multi-Carrier Systems:

Combining various energy vectors like electricity, heat, and transport for optimized performance.

Virtual Power Plants & Energy Communities:

Facilitating the development of decentralized energy markets and communities.

Hybrid AC/DC Networks & Resilient Grids:

Enhancing grid stability and resilience through innovative network designs.

Electric Transportation & Zero Energy Buildings:

Supporting sustainable transportation solutions and energy-efficient building practices.

Market Applications & Green Economy Regulations:

Promoting new market models aligned with green economy principles.

Research Challenges

Transitioning to a renewable-based, distributed energy model presents several key challenges:

Decarbonization:

Transitioning energy generation to renewable sources and energy consumption to low-carbon alternatives like decarbonized electricity, hydrogen, or heat.

Energy Integration:

Efficiently integrating multiple energy vectors—such as electricity, heat, and water—into a cohesive system.

Digital Transformation:

Implementing large-scale digitalization to enhance system intelligence across all levels, from the edge to the cloud.

Grid Automation:

Improving grid automation for better observability, controllability, and overall system resilience.

AI & Big Data:

Leveraging AI and big data to increase system flexibility, improve forecasting, accelerate decision-making, and enhance automation.

Power Processing:

Advancing power processing capabilities to transition from electromechanical systems to active power converter-dominated systems.

Local Market Innovation:

Developing new, user-centric local markets featuring emerging players like energy communities and aggregators.

"Our mission at ICES is to develop ground-breaking, high-tech, market-oriented solutions and services for clean energy systems, covering the whole value chain. We are committed to strive for new technologies that allow transitioning from current paradigm toward a new sustainable climate-neutral ecosystem in justice and prosperity. The integration of OPAL-RT simulators in our Real-Time Hardware-in-the-Loop (HIL) Lab enables advanced testing and validation of complex systems with high accuracy and reliability. These simulators enhance our ability to model dynamic systems in real-time, reducing development time and costs by identifying issues early in the design process. The flexibility of OPAL-RT tools supports a wide range of applications, from power systems to automotive, making them invaluable for rapid prototyping and optimizing performance in a safe, controlled environment."

Professor / IEEE Fellow / DL, Pedro RODRIGUEZ CORTES, Head of ICES, Luxembourg Institute of Science and Technology (LIST).

SOLUTIONS & DEVELOPMENT

Developed System Architecture

1. Data flow and Communication

Real-time Simulation:

The network modeled in HYPERSIM represents the Transmission Network of Luxembourg. This is a 11-bus transmission network including a distribution feeder in an area having multi-energy assets. The IBRs modeled in this network are a PV plant (4MW), a BESS (1MW) and a multi-energy charging station (2MW) with dynamic models of a wind-turbine system (4.2MW), electrolyser (3MW), and biogas power plant (50MW). The Wide- Area Monitoring & Control System has three physical PMUs at the interconnection buses of Luxembourg with other countries. To analyze and validate the performance of these PMUs, three virtual PMUs (C37.118 Slave in OPAL-RT) are used.

This RT-Simulation system is developed within the framework of HORIZON EUROPE Project i-STENTORE.

"i-STENTORE will explore the integration and co-optimization of diverse storage solutions, focusing on reliability, power quality, cost-efficiency, and asset longevity. The project will introduce a flexible framework to showcase both stand-alone and hybrid storage systems, emphasizing their role not only as energy buffers but also as active grid components. By examining various applications—such as mobility, agriculture, industry, and households—i-STENTORE will create scenarios to select the most effective storage solutions. Additionally, it will design a Reference Architecture for a flexible, technology-agnostic European energy system, promoting innovative business models and new revenue streams to support the energy transition."

Phasor Data Collection:

PMUs deployed across the grid collect phasor data, which is synchronized and transmitted to the Phasor Data Concentrator (PDC).

Control Algorithms:

Based on the simulated and real-time data, control algorithms are developed, tested and deployed to the Beckhoff PLCs.

Grid Control:

Beckhoff PLCs execute the control strategies, sending commands to various actuators in the grid (e.g., switches, relays, and transformers) to maintain stability and optimize performance.

2. Synchronization and Time Management

Time Synchronization:

The phasor measurement units are time synchronized using 1PPS. This ensures that all measurements, simulations, and control actions are accurately time-aligned.

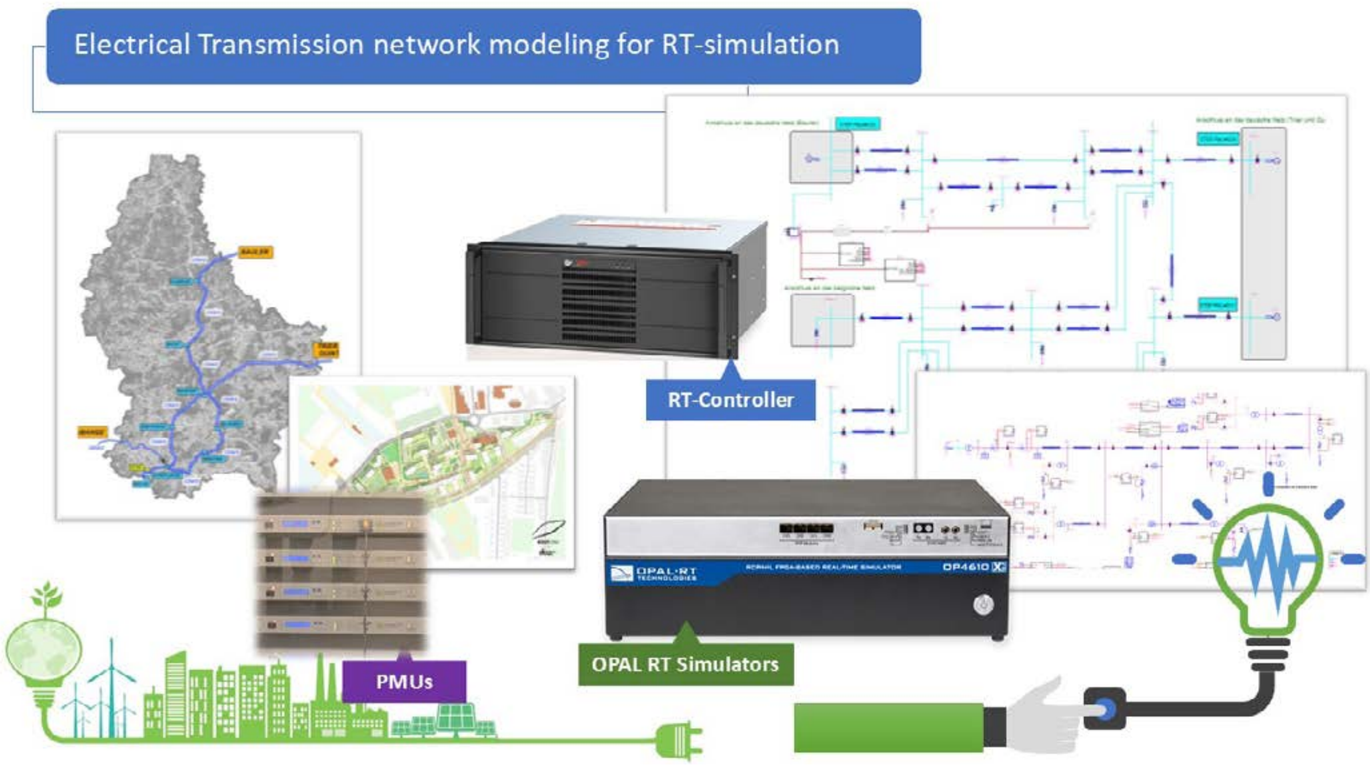
3. System Integration

HIL Testing:

The integration of RT-simulator with the physical components (PMUs and PLCs) allows for Hardware-in-the-Loop (HIL) testing, providing a powerful platform for validating control strategies in a controlled, simulated environment.

Scalability and Flexibility:

The modular nature of the Beckhoff PLCs and the scalable architecture of RT-simulator enable the system to adapt to various grid sizes and configurations.



RESULTS

1. Enhanced Grid Stability

The WAMPACS provides real-time visibility into the grid's state, enabling rapid detection and response to anomalies or faults, thereby enhancing overall grid stability.

2. Optimized Performance

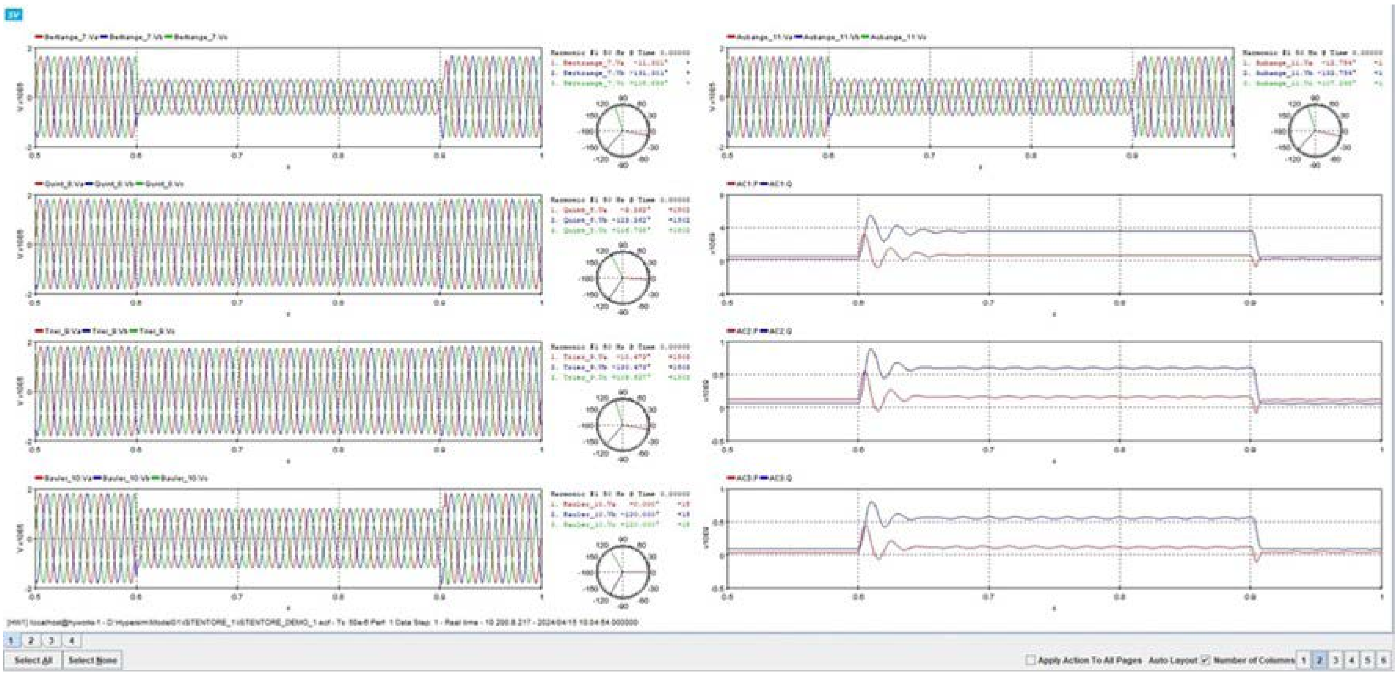
By continuously monitoring and controlling grid parameters, the system optimizes the performance of the power grid, reducing losses and improving efficiency.

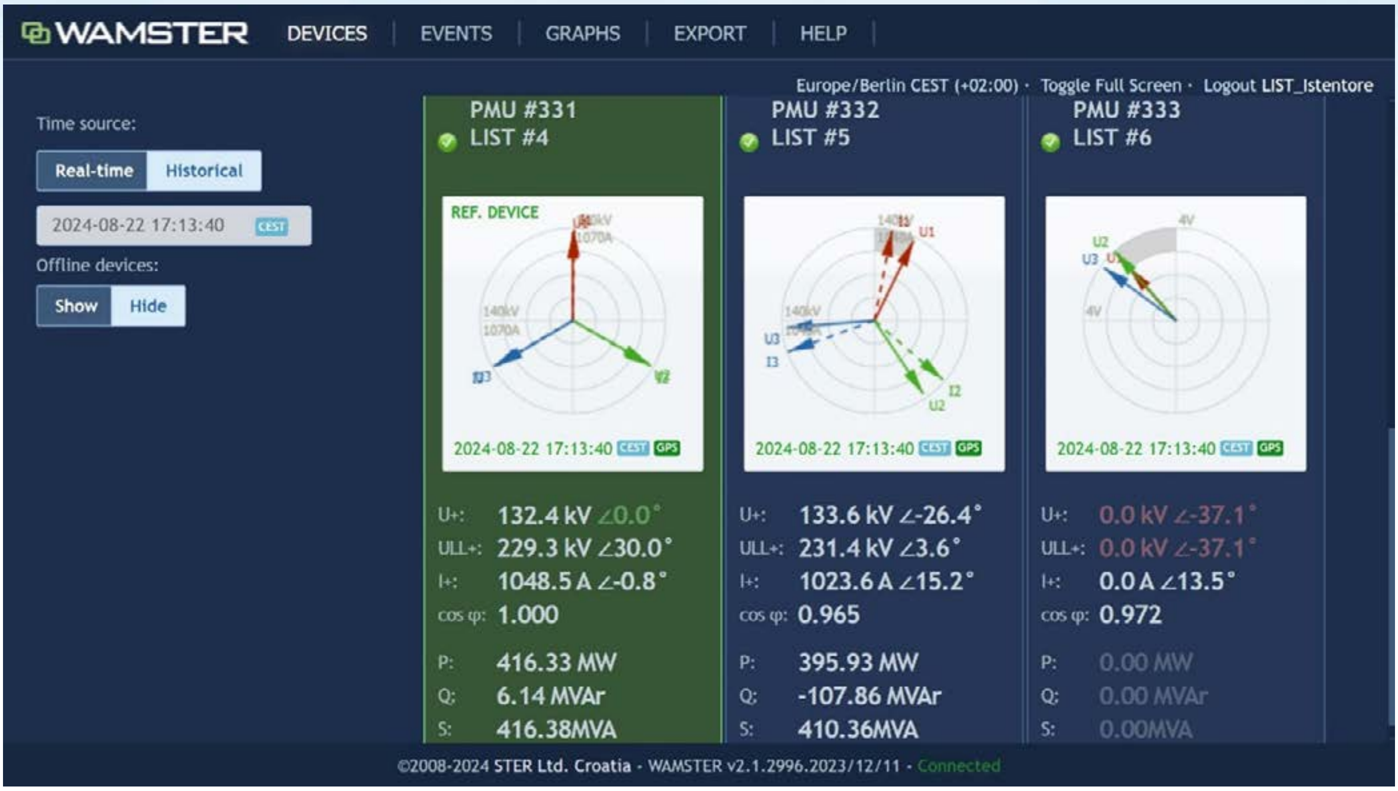
3. Improved Fault Detection and Isolation

The precise and synchronized data from PMUs, combined with real-time simulation in HYPERSIM, allows for accurate fault detection and isolation, minimizing the impact of faults on the grid.

4. Reliable Control and Automation

Beckhoff PLCs ensure reliable execution of control strategies, automating grid operations and reducing the need for manual intervention.

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ULL+: 229.3 kV ∠30.0°
I+: 1048.5 A ∠-0.8°
cos φ: 1.000
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Q: 6.14 MVAr
S: 416.38MVA
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ULL+: 231.4 kV ∠3.6°
I+: 1023.6 A ∠15.2°
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S: 410.36MVA
PMU #333
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I+: 0.0 A ∠13.5°
cos φ: 0.972
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Q: 0.00 MVAr
S: 0.00MVA
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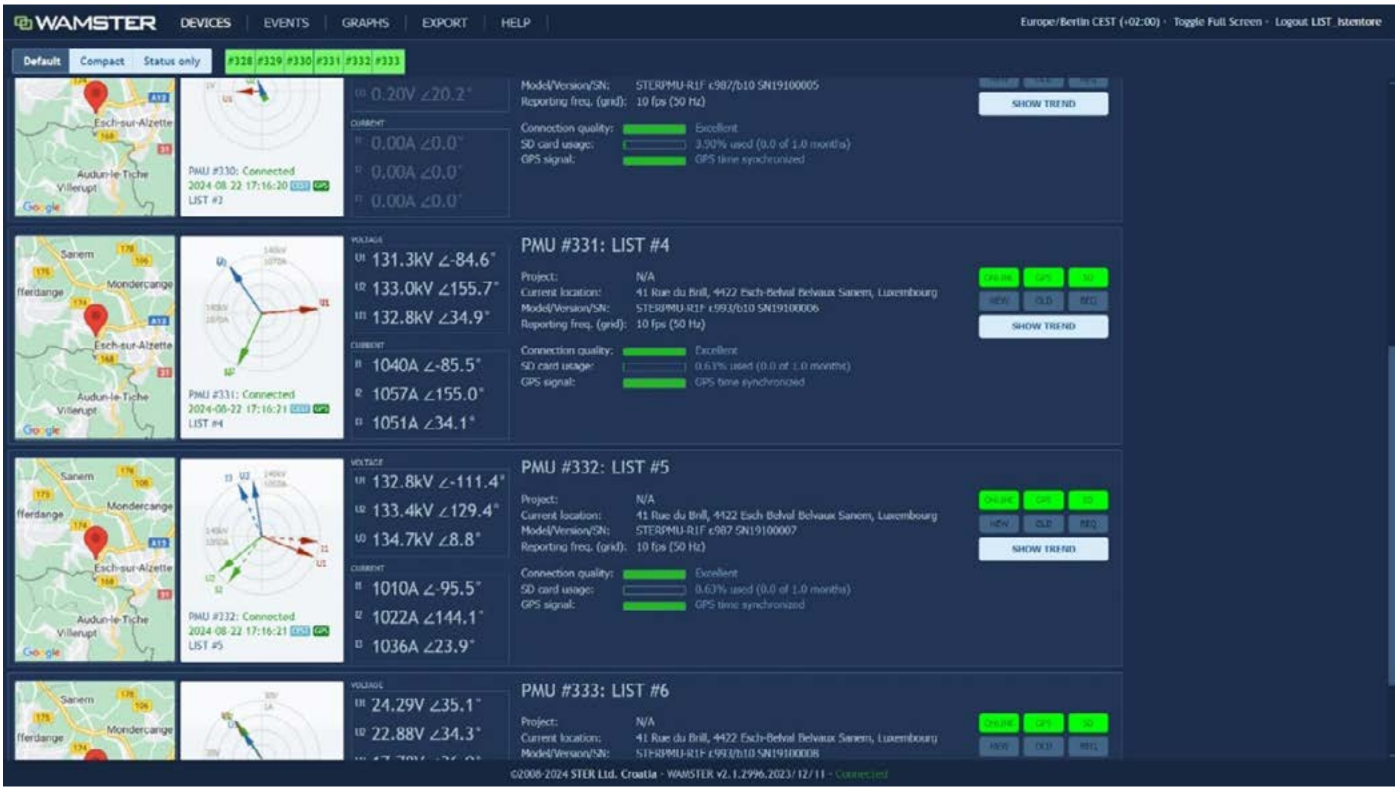
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PMU #331: LIST #4
131.3kV ∠-84.6°
133.0kV ∠155.7°
132.8kV ∠34.9°
1040A ∠-85.5°
1057A ∠155.0°
1051A ∠34.1°
PMU #332: LIST #5
132.8kV ∠-111.4°
133.4kV ∠129.4°
134.7kV ∠8.8°
1010A ∠-95.5°
1022A ∠144.1°
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24.29V ∠35.1°
22.88V ∠34.3°

CONCLUSION

The integration of OPAL-RT Simulator, PMUs, and Beckhoff PLCs in a Wide Area Monitoring, Protection and Control System represents a significant advancement in the management of modern power grids. By combining real-time simulation, precise measurement, and robust control, this system offers a powerful solution for enhancing grid reliability, stability, and performance.

This setup not only supports current grid management needs but also provides a scalable and flexible platform that can evolve with future advancements in power systems technology.

“Our Wide Area Monitoring, Protection and Control System represents a significant leap forward in grid management. By integrating real-time simulation with precise phasor measurements and reliable control, we’ve created a robust platform that enhances grid stability, optimizes performance, and drives innovation in power systems. This setup not only meets the demands of today’s grid but also lays the foundation for future advancements.”

Dr. Shailendra SINGH, Research Engineer R&T, Laboratory Technical Coordinator (ICES), Luxembourg Institute of Science and Technology (LIST)