Volume 10

Summer 2025

POWER IN MIND

Winning the **Renewable Energy Integration Battle** Together

AN INTERVIEW WITH ENTERGY'S THOMAS FIELD

Inverter-Based Resource Integration & Modelling Challenges

LEVERAGING ADVANCED GRID SUPPORT CAPABILITY FROM INVERTER-BASED RESOURCES

By Deepak Ramasubramanian
EPRI

OPAL-RT TECHNOLOGIES

A Word from the Editor

There's a quiet irony in how we speak of renewable energy integration, as if it were merely a technical upgrade. In reality, it's a test of coordination, trust, and collective will. A battle not just for electrons, but for shared understanding.

The energy landscape is shifting fast. Inverter-based resources (IBRs) are no longer outliers, they are the new backbone. But their seamless integration into the grid isn't guaranteed. It requires more than faster control loops or clever algorithms. It requires open collaboration across manufacturers, system operators, utilities, researchers, and regulators. It calls for a shared foundation, where models, standards, and expectations converge.

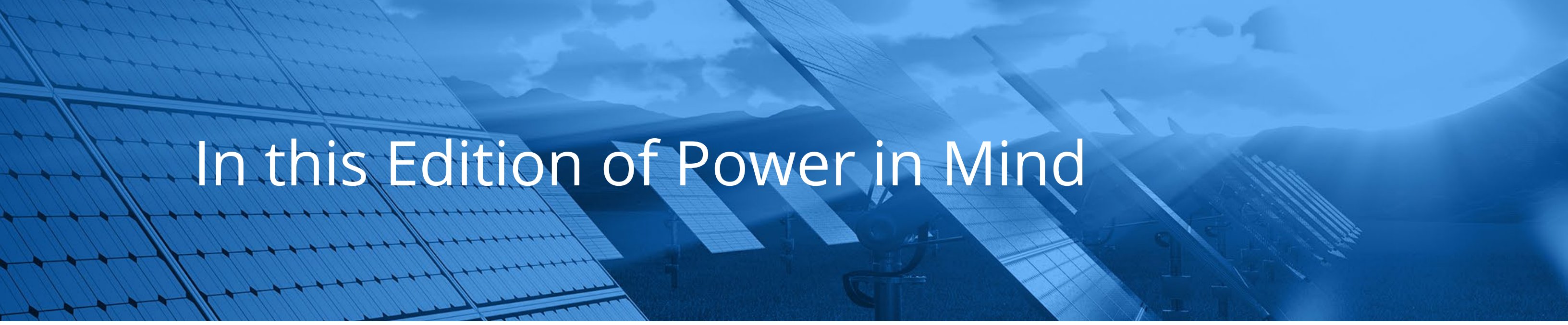
At OPAL-RT, we've long believed that real-time simulation is more than a testing environment, it is a meeting ground. A space where proprietary models and public infrastructure can interact safely. A space where real code from manufacturers meets real-world operating scenarios. And most importantly, a space where interoperability is not theoretical, but proven.

If there's a battle to be won, it's the battle against fragmentation. Against models that can't be shared, systems that can't connect, and ideas that stop at institutional boundaries. And this battle is not won alone. Every successful integration, whether it involves a blackbox controller, a grid-forming inverter, or a multi-vendor HVDC system, is proof that cooperation is more powerful than complexity.

This issue of Power in Mind celebrates those who are making this cooperation real. Not just by pushing technology forward, but by choosing to build bridges across the boundaries of what was once proprietary and siloed. Let's keep building that future, together.

Etienne Leduc,
Director of Product Strategy

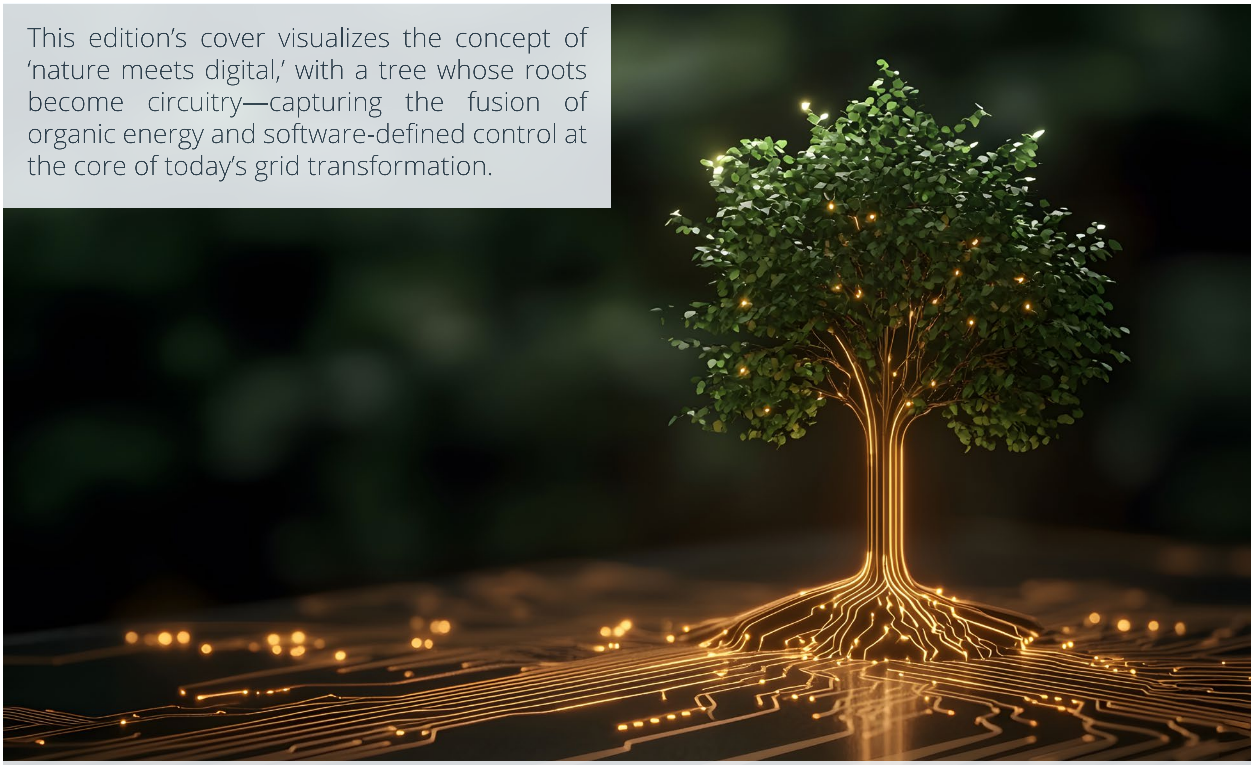
Etienne Leduc is a highly accomplished professional in electrical engineering and power systems at OPAL-RT TECHNOLOGIES. With expertise in real-time simulation and hardware-in-the-loop testing, Etienne has made significant contributions to power system simulation and control technologies. He is dedicated to promoting green energy solutions, particularly in renewable energy integration and grid modernization.



In this Edition of Power in Mind

Behind the Cover

This edition's cover visualizes the concept of 'nature meets digital,' with a tree whose roots become circuitry—capturing the fusion of organic energy and software-defined control at the core of today's grid transformation.

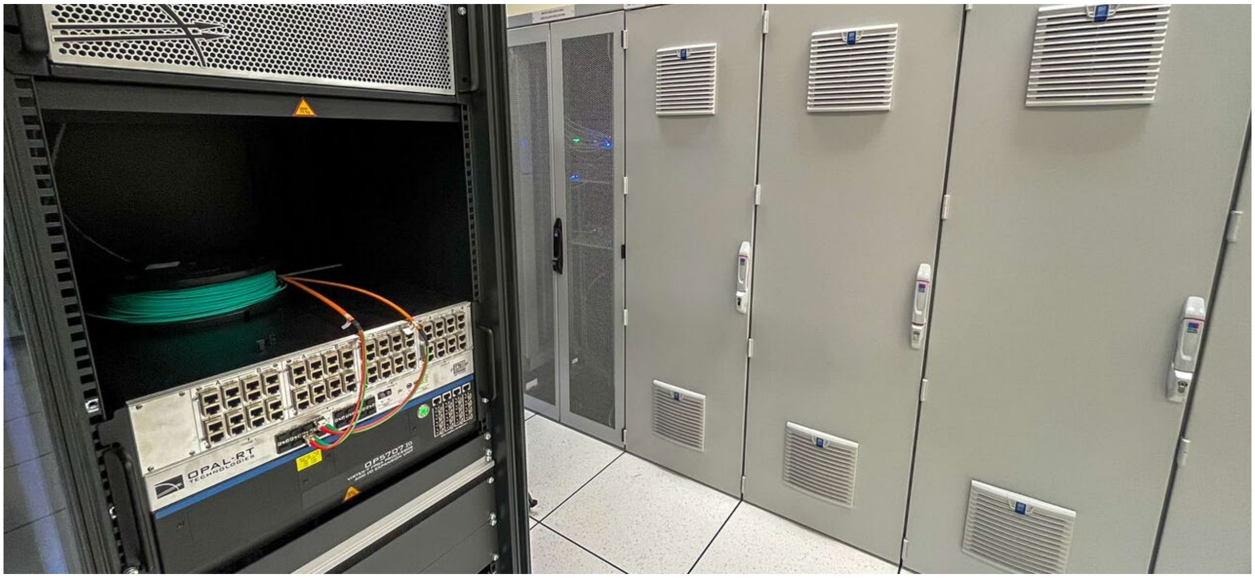


Featured article by: Elisabeth Madingou

Editors: *Etienne Leduc, Nadine Hariri, Elisabeth Madingou, and Sofía Escalera Eguíluz*

Design and layout: Sofía Escalera Eguíluz, Maija Baroni and Tania Gray

Multi-terminal, Multi-vendor Interoperability: A Cornerstone of the European Union’s InterOPERA project



Europe Tackles Offshore Wind with Smart, Interconnected Grids

The European Union has set an ambitious target for 2050: to deploy 300 GW of offshore wind capacity. This initiative aims to meet the continent’s climate objectives and reduce reliance on fossil fuels. To achieve this goal, the development of advanced offshore transmission systems is crucial. These systems must not only deliver electricity to shore but also function as interconnectors between member states. Multi-purpose, multi-terminal high voltage direct current (HVDC) systems are identified as the most efficient means to achieve this. They are seen as essential for enhancing the integration of renewables, improving market security, and bolstering resilience.

However, a major challenge lies ahead: ensuring interoperability between components and systems supplied by different manufacturers. Without standardized functional specifications and interfaces, integrating diverse technologies into a cohesive and efficient grid becomes complex and costly. This is precisely where the InterOPERA project comes in.

The InterOPERA Project’s Ambitious Goals

Officially titled “Enabling Interoperability of Multi-Vendor HVDC Grids”, InterOPERA is a flagship initiative under the European Union’s Horizon Europe research and innovation program. Coordinated by the SuperGrid Institute, this ambitious project aims to establish the necessary technical frameworks and standards to facilitate the integration of renewable energy sources into Europe’s electricity transmission system. Launched in January 2023, InterOPERA will run for 52 months, concluding in April 2027.

As the integration of renewables accelerates, major HVDC projects are being commissioned across the world. To make these projects more robust and flexible, multi-vendor, multi-terminal links are being developed, making interoperability absolutely indispensable. The primary objective of InterOPERA is therefore clear: to develop and implement standardized frameworks that ensure the interoperability of multi-vendor HVDC grids.

Here are some of the project's specific goals:

- Create common functional specifications and standard interfaces to enable the integration of modules based on different technologies from various manufacturers.
- Improve the grid-forming capabilities of both offshore and onshore converters to support stable and reliable grid operations.
- Agree on procurement, commercial, legal, and regulatory frameworks to facilitate the tendering, building, and operation of full-scale HVDC multi-terminal, multi-vendor, multi-purpose real-life applications anticipated by 2030.

An Unprecedented European Coalition

InterOPERA brings together a diverse consortium of over 20 European partners. This pan-European collaboration includes key players from across the entire value chain:

- Transmission System Operators (TSOs) such as Amprion, Energinet, RTE Réseau de Transport d'Electricité, Statnett, TenneT, Terna, and 50Hertz.
- Offshore Wind Developers, including Equinor, Ørsted, and Vattenfall.
- HVDC Equipment Manufacturers such as GE Renewable Energy, Hitachi Energy, Siemens Energy, and SCiBreak.
- Wind Turbine Manufacturers Siemens Gamesa and Vestas.
- Sector Associations such as T&D Europe and WindEurope
- Academic Institutions including Delft University of Technology and the University of Groningen.

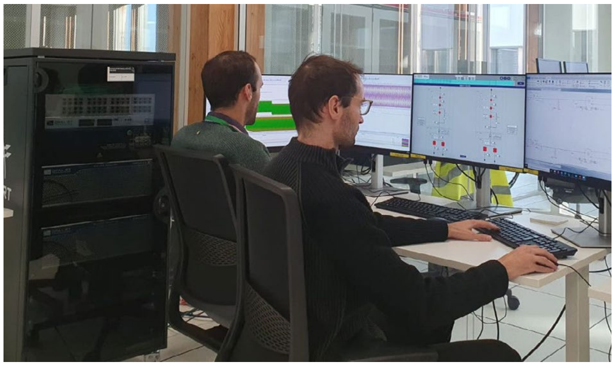
This collaborative approach ensures comprehensive expertise and alignment of interests.

Real-Time Simulation's Essential Role in the Validation Process

A key component of the project is the development of a real-time simulation-based physical demonstrator to validate the interoperability of control and protection systems. This involves analyzing planned HVDC projects. In collaboration with RTE's HVDC group in Lyon, France, OPAL-RT is providing one of the real-time simulation platforms for the demonstration project. To date, controllers from Siemens Energy, Scibreak, and Supergrid Institute have been integrated. Work is ongoing to integrate controllers from Hitachi Energy, GE Vernova, Siemens Gamesa and Vestas, covering both offshore and onshore stations.

"Through collaboration among key industry players InterOPERA seeks to pave the way for efficient, interoperable, and scalable HVDC grid systems by 2030.

Ravinder Venugopal
Vice President Business Development & R&D-EUROPE and MIDDLE EAST (EMEA)



Siemens Energy's Control and Protection Systems for InterOPERA including Converter Control communicating with the MMC model and the Measuring System interfaced with the OPAL-RT simulator

For example, Siemens Energy's Control and Protection Systems for InterOPERA, including Converter Control, communicate with the MMC (Modular Multilevel Converter) model within the HYPERSIM simulation and the Measuring System is interfaced with the OPAL-RT simulator. The hardware basis for these two subsystems is the Siemens Energy PLUSCONTROL™. This demonstration is a significant step in establishing flexible testing of HVDC controls to accelerate the deployment of robust and reliable renewable energy systems.

Another crucial aspect is the integration of converter and controller real code models in the real-time simulators. These models are often "blackboxed" (compiled) to protect the intellectual property of the converter manufacturer. This approach allows for Software-in-the-Loop (SIL) simulation or a combination of SIL and Hardware-in-the-Loop (HIL). OPAL-RT is notably working with Siemens Gamesa and other InterOPERA partners to integrate their models on its simulation platform within the InterOPERA project.

Some key advantages of OPAL-RT's Linux-based systems are that they allow integrating hundreds of blackboxes without the need for additional hardware, enabling full controller fidelity, and even support multiple rates for high-speed control loops below 5 µs. HIL testing has also been critical in de-risking HVDC link commissioning, as well as for maintenance and fault analysis.

A Major Advancement for the European Energy Transition

By enabling interoperable HVDC technologies, InterOPERA aspires to be a key enabler for the meshed connection of offshore wind farms to the European power grid. This will significantly enhance the integration of renewable energy sources, improve market security, and contribute to Europe's climate and energy targets. Through collaboration among key industry players, research institutions, and academic bodies for the development of standardized frameworks, InterOPERA seeks to pave the way for efficient, interoperable, and scalable HVDC grid systems by 2030. ■

Read the project announcement featuring OPAL-RT, RTE and Siemens Energy: CLICK HERE

OPAL-RT TECHNOLOGIES PRESENTS

FUNFAIR & DEMO NIGHT

DEMOS • GAMES • MUSIC • REFRESHMENTS

On July 30, OPAL-RT is bringing the fun to the 2025 IEEE PES General Meeting in Austin, TX!

Join us at Fareground from 6-11PM for a thrilling evening of innovation. Experience four exciting demos and unwind with six fairground games, tasty treats, and live music!

JULY 30th

REGISTER NOW

CLICK HERE!

OPAL-RT TECHNOLOGIES **SPECIAL INVITATION**

Shaping the Future of Real-Time Simulation with OPAL-RT

2025 CIGRE International Symposium
September 29 – October 2
Palais des Congrès, Montréal

Explore the latest in real-time power system simulation at our booth and see how OPAL-RT is driving electric grid innovation.

OPAL-RT Open House

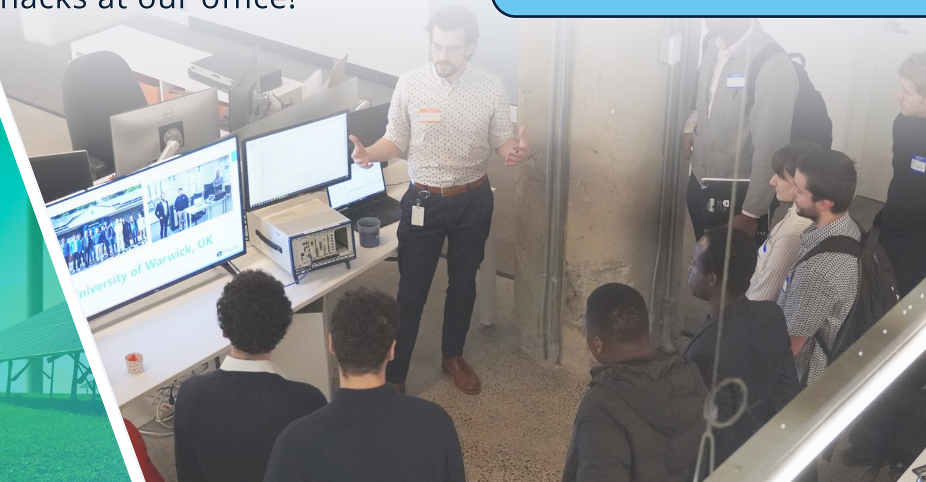
September 30th | 4 to 9pm

Step inside our advanced labs and get exclusive access to our latest real-time simulation demos.

Connect with our experts and industry peers over drinks and snacks at our office!

SPOTS ARE LIMITED!

CLICK HERE
TO REGISTER



MANUFACTURER BLACKBOX CONTROLS - FROM LAB TO GRID

Test What Matters. Accelerate the Energy Transition.

OPAL-RT's **Blackbox Interface** enables key energy stakeholders to accelerate inverter-based resource model validation, de-risk commissioning, and make more confident planning decisions.

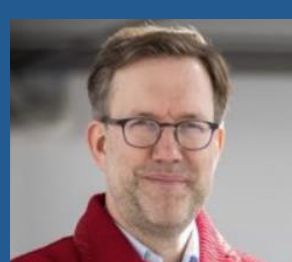
Manufacturers can validate black-box controller models against real control hardware

Integrators can simulate complex plants with flexibility, combining physical and software replicas

System Operators can run planning and transient stability assessment studies using high-fidelity controller behavior—without needing access to proprietary hardware

Take the path to safer inverter-based resource integration.

"With OPAL-RT's blackbox controller integration and high-performance simulators, we successfully implemented our Sunny Central Storage UP inverter controller. In a real-world use case, 32 inverter controllers ran in real-time on a single core—while dedicating just four additional cores to the full plant model. This allowed to validate large-scale IBR behavior with full control fidelity and exceptional scalability."



↑
Christian Hardt
System Architect - Business Unit Large Scale & Project Solutions at SMA Solar Technology

Why it matters.

FOR MANUFACTURERS

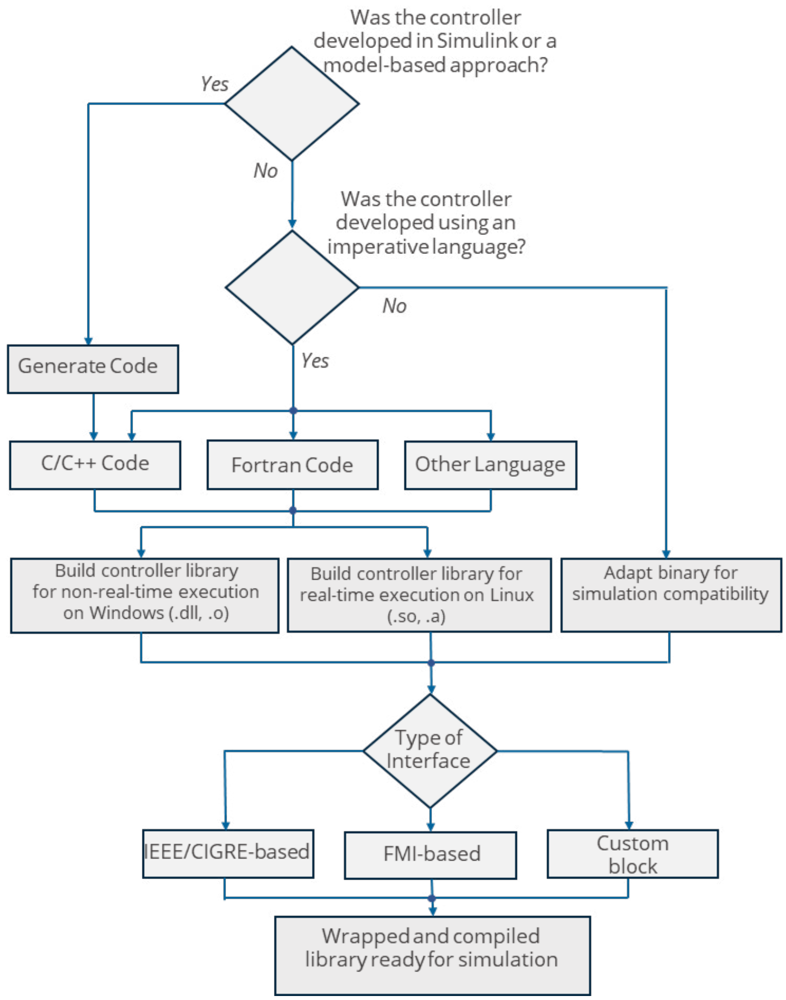
- Reuse the same control code in lab and in simulation
- Accelerate development cycles and gain early validation
- Prepare for grid code compliance certification (e.g. IEEE 2800, UL 1741)
- Protect IP with blackbox deployment

FOR INTEGRATORS

- Simulate control interactions across different manufacturers
- Combine blackbox and physical controllers in the same simulation
- Accelerate commissioning and reduce late-stage surprises

FOR SYSTEM OPERATORS

- Perform plant interaction studies using real manufacturer control behavior
- Improve model credibility for interconnection and stability studies
- Plan grid expansions with reliable control response forecasts



How it works.

No matter the format — **DLL, FMU, Simulink model, Fortran, C++**, or even other source code — **we've got you covered**.

Whether the controller was developed using a model-based environment or handwritten code in an imperative language, OPAL-RT provides a seamless path to integrate and simulate the controller in accelerated offline simulation or real time. The process is standardized and supports secure blackbox deployment.

SUPPORTED CODE INPUTS

- Simulink-generated code
- Handwritten C/C++ or Fortran code
- Precompiled libraries (.dll, .lib, .so, .a)
- FMUs and IEEE/CIGRE standardized interfaces
- Custom legacy or vendor-specific binaries

INTEGRATION OUTCOMES

- The controller code becomes readily available for simulation with the plant model—offline or real time.

Why it's different.

No step delays
Execute your controller code in direct feedthrough with the electrical model

Multi-rate execution
Support for mutiple rates, including high-speed control loops even below 5 µs, within one or multiple blackboxes

Smooth workflow
Seamlessly move from offline to real time, on desktop or OPAL-RT simulators

Full controller fidelity
Make no compromise on feature fidelity of your controller, running everything on standard x86 Intel/AMD CPUs

Scalability built in
Simulate hundreds of black-boxes simultaneously on the same platform

No external boxes or cables
Controller, plant and grid models run on the same hardware, each using dedicated cores

An Interview with Entergy's Thomas Field Inverter-based Resource Integration and Modelling Challenges

Thomas Field is Senior Engineer – Transmission at Entergy Mississippi, where he has worked for 15 years. He currently serves in the Design Basis group, managing the use of the OPAL-RT real-time simulator and working closely with the utility's transmission protection standards team. He also oversees the utility's collaboration on university research initiatives.

Where does your interest in IBRs come from?

I was involved early on when we started integrating IBRs into the system and modifying our generator interconnection standard to accommodate them. Quickly, some issues became apparent with regards to power quality due to the new types of generation. Then, we became aware of additional issues with protection.

As time went on, more stakeholders started publishing on protection issues. For example, Schweitzer or the IEEE PSRC published on the oscillating apparent impedance that can be seen by protective relays, which will fool the dynamic mode characteristics on traditional impedance-based relays. We were aware of the insufficient negative sequence current for polarization on directional elements and for ground fault detection.

The IEEE 2800 standard came out and gave some guidance on negative sequence requirements for IBRs. Of course, there are issues with overcurrent elements, meaning that when you have an IBR on and a contingency where the stronger part of the system is removed, you don't have much fault current for tripping overcurrent elements. Now, in addition to the relay functions, there are also issues with the models for setting the traditional elements in our short circuit program.

What issues do you generally see with IBR models?

A lot of parameters in the model are kept hidden through blackboxes, and the only interface that a system operator has with the manufacturer is the initial interconnection request. Meanwhile, the need for updated models and settings within those models arises, with users needing additional model data, both steady state, such as the voltage-controlled current source (VCCS) table, and transient models.

With traditional generators, it was easy to obtain mechanical and electrical model parameters, including governors, power system stabilizers, and voltage regulators. It was also easy to get updates from the owners when those parameters changed. IBRs, on the other hand, are new, with a wide range of models that are not easily understood. We want models that help us better understand the system and improve its reliability.

> ***"Since blackbox models are typically provided in PSCAD format, we need the collaboration of manufacturers to facilitate their conversion into real-time simulation models."***
>
> Thomas Field, Senior Engineer Transmission at Entergy Mississippi

What types of system behaviors have been most challenging to study due to current IBR modeling limitations?

Performing protection studies! Another type of study that we're starting to look at is interactions with other devices such as FACTS devices, other IBRs, other power electronic devices, or control devices, where the output of one affects the system in one way, and then other devices respond.

We have seen this in simulations with DERs, where we found that the solar DERs could have a ratcheting interaction with our load tap changers on the transformers at the substation, causing the DER and LTC to change each other's output in cascades.

Those tests have not been run yet for IBRs due to the lack of sufficient IBR models to run in real time. We are currently working with OPAL-RT to obtain real manufacturer models from specific vendors. For SVCs, for instance, we use manufacturer replicas with the actual control boards in them to determine their performance on the system under various conditions. Now that we're adding IBRs, we should be running studies to look at interactions between those SVCs and the IBRs in the vicinity, to see if we can have similar interactions.

What challenges do manufacturer blackboxing practices pose to your current study timelines?

Since blackbox models are typically provided in PSCAD format, and with the information that our interconnection customers currently provide us with, we need the collaboration of manufacturers to facilitate their conversion into real-time simulation models. These are critical studies, it is essential that we find a reliable method to obtain usable models. Our real-time simulations are conducted with OPAL-RT's HYPERSIM, and PSCAD blackbox models cannot be converted without additional information that manufacturers have not yet provided.

"I WOULD LIKE TO SEE REGULATIONS THAT REQUIRE IBR OWNERS TO WORK MORE CLOSELY WITH UTILITIES TO UPDATE MODELS AND RESPOND TO THE UTILITY'S RELIABILITY IMPROVEMENT REQUESTS, EVEN AFTER THE INTERCONNECTION PROCESS."

As you've taken an interest in IBRs for many years, have you seen positive changes that make you hopeful for the future?

In the early stages, devices were being connected to the grid without standards or formal requirements in place to address the issues they could introduce. NERC has contributed through its working groups, and IEEE has been advancing this work through efforts like IEEE 2800, though there is still a need for more improvements. Revisions are expected in upcoming documents. NERC has continued to strengthen its requirements, and we're seeing ongoing updates from groups like CIGRE as well.

We're also seeing progress through research efforts, particularly from EPRI, which has collaborated with short-circuit program developers, specifically Aspen and CAPE, as noted in their published work. Those programs continue to evolve, with new models being added and reliability improving.

Are there technical innovations that you think will make IBR integration easier in the long run?

One innovation I'm hopeful for is traveling wave relays for line protection. These relays don't rely on the output of a short circuit program but only depend on the line impedance. I'm optimistic that we will see more traveling wave relays deployed, which should improve protection reliability by eliminating the need to wait for short circuit programs and manufacturer models.

What regulatory changes do you expect will bring down barriers to accessing IBR model information?

We need a better mechanism for obtaining models and model support from interconnections, whether from the OEM or the interconnection owner. We also need a process that ensures information is communicated as modeling needs emerge and as manufacturer models, firmware, and hardware are updated. Currently, there is a lack of communication mechanisms between manufacturers, owners, and utilities.

I would like to see regulations that require IBR owners to work more closely with utilities, particularly to update models and respond to the utility's reliability improvement requests, even after the interconnection process has been completed.

IBR owners would also benefit from collaborating with utilities, as it would improve the reliability of the systems they are connected to. I hope the ongoing IEEE CIGRE standardization efforts will prompt NERC to require manufacturers to provide models in formats that are adaptable across EMT simulation platforms. ■

Leveraging Advanced Grid Support Capability from Inverter–Based Resources

By: Deepak Ramasubramanian, Electric Power Research Institute (EPRI)

The power grid is at the cusp of transition with increasing amounts of inverter-based resources (IBRs) in the interconnection queue. These resources have a performance characteristic that is significantly different from the conventional synchronous machines that have supplied power to the power system as of now. As IBRs become more prevalent in the power network, they bring in new, previously unseen challenges. To overcome these challenges, it is pertinent that we leverage the full capability of the IBRs.

An IBR, unlike synchronous machines, does not have any natural characteristic. Rather, its entire performance is governed by lines of computer code. Therefore, an IBR's behavior or characteristic is based upon the performance requirements that are present in the interconnecting region. As a result, it's important for transmission planners to clearly define performance expectations for these resources, while avoiding the risk of overprescribing requirements.

Until recently, an IBR was not expected to provide much service or capability to the power network, as the understanding was that the synchronous machine fleet would take care of providing these capabilities and services. However, with the increased retirement of the synchronous machine fleet comes the need to leverage services and capability from IBRs. Such a paradigm brings the two different bookends of IBR control objectives to the forefront. At one end is a legacy control objective that can be termed as grid following (GFL). Here, an IBR operates in a constant power injection mode. When operating in this mode, the IBR provides no reactive power support to the network and additionally, provides no form of frequency dependent variation of output power. If one draws a comparison of this operating mode from a dynamic time domain paradigm to a steady state power flow paradigm, then such an operating mode would be modeled as a PQ bus in a power flow solution with Q limits set as 0. As one is aware, in a power flow solution, an increase in the number of such PQ buses for representing generators can quickly lead to a non-convergent scenario. A similar situation can arise even in a dynamic scenario, wherein for a grid disturbance event, if all the inverters continue to inject the pre-disturbance amount of active power and inject no reactive power at all, it can lead to an unstable situation.

At the other bookend, there's a control objective that can be termed as grid forming (GFM). This control objective has been applied in islanded and standalone networks for many years and essentially portrays an IBR as close as possible to an ideal voltage source. If we map a dynamic

"If we keep the focus on advanced grid support capabilities, then terminology such as grid following or grid forming could be safely ignored"

Deepak Ramasubramanian,
Electric Power Research Institute

paradigm again to a steady state power flow paradigm, then such an operating mode would be modeled as a slack bus in a power flow solution. We also know that it is not possible to obtain a converged power flow solution with numerous independent slack buses. A similar situation can arise even in a dynamic scenario wherein for a grid disturbance, if all the inverters operate as an ideal voltage source, it could lead to an unstable solution.

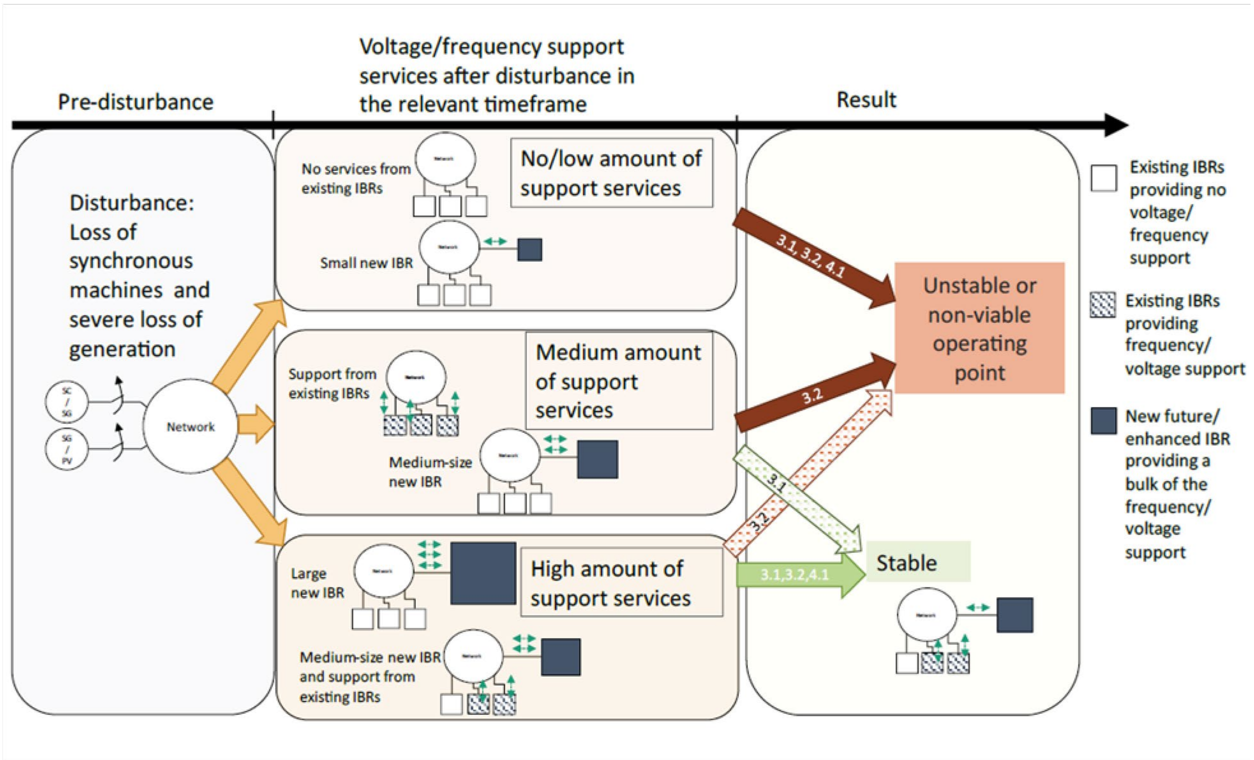
Between these two bookends of the control objectives lies a continuum of control that can be achieved by IBRs and is important for the stable and reliable operation of the future power grid. The concept of advanced grid support capabilities arises from this continuum. It is to be noted that if one keeps the focus on the notion of advanced grid support capabilities, then bookend terminology such as grid following or grid forming could be safely ignored, or at best left to sales and marketing personnel.

The safe and reliable operation of the power grid depends upon the existence of sufficient voltage control and frequency control. From a steady state power flow perspective, this implies the requirement of sufficient PV buses and distributed slack buses. From a dynamic perspective, the speed of frequency and voltage control is important to maintain a stable response for a power system disturbance. In an IBR, there usually exists two levels of control hierarchy. The slower level of control hierarchy acts as a plant level control which takes care of coordinating the outputs of the individual inverters or turbines within an IBR plant. This slower level control, if enabled with the capability to provide voltage and frequency response, can bring about a first level of improvement in advanced grid support capabilities. The faster level of control hierarchy is at the inverter or turbine level within an IBR plant. This faster level of control, if also enabled with the capability to provide voltage and frequency response, can drastically increase the advanced grid support capabilities that can be delivered by IBRs.

It is important to note that a variety of control methods or mechanisms can achieve these objectives. Therefore, leveraging advanced grid support capability should be approached from the perspective of performance requirements rather than control architecture. Enabling capability in existing IBRs can also help improve the leverage of advanced grid support capabilities. Today, many IBRs operate with higher level plant control delivering functionality of voltage and frequency response, while the inverter or turbine level controls usually operate to meet an objective of following the power commands from the plant level control. Moving some of these control objectives down to the inverter level, either through existing control architecture or via new forms of control architecture, can help with leveraging advanced grid support capability.

“IBRs CAN BE EVALUATED IN MULTIPLE SIMULATION DOMAINS IF THE NECESSARY CAUTIONS ARE TAKEN TO BRING ABOUT MODEL INTEROPERABILITY AND PARAMETERIZATION”

Recent work through the Services Task Force of the Energy Systems Integration Group (ESIG) highlights the advantages of using the control objectives at inverter level to leverage advanced grid support capabilities. The evaluations carried out by the task force identify the impact of both bookend IBR control objectives while also showcasing the nature of the continuum of control.



Use of a variety of advanced grid capability to illustrate continuum of control from IBRs (Source: Energy System Integration Group AutoShape 8, Shape [Reliability Services Project Team - ESIG](#))

Further, the evaluations also showcase the importance of appropriate parameterization of models when comparing IBR operation across simulation domains. The figure above showcases how many different aspects of leveraging advanced grid support capability from IBRs can be evaluated in multiple simulation domains, if the necessary cautions are taken to bring about model interoperability and parameterization. A recent [IEEE CIGRE effort](#) on this topic could bring about interoperability across simulation domains in a more efficient manner.

IBRs can be controlled to provide any form of dynamic behavior as desired, ranging from constant power operation, all the way to being a first resource on a black start energization sequence. Their impact on the network is however based on definitions of expected performance, capability, and subsequent utilization of this capability. As more such resources interconnect to the power system, leveraging this vast available capability would be crucial to securing a reliable and resilient operation of the bulk power system. Let's not be weighed down by bookend terminology and notions, but rather utilize this opportunity to recognize the myriads of grid support capabilities that exist and can be leveraged such that order can emerge from chaos. ■

Fast and Real-Time EMT Simulations for HIL Controller Performance Testing

By: S. Li, J. Bélanger, M. Cervantes, M. Kazemtabrizi, J.N. Paquin, V. Lapointe, W. Li, J. Paez-Alvarez

The increase in Inverter-Based Renewables (IBRs), Flexible AC Transmission System (FACTS), and High Voltage Direct Current (HVDC) systems, coupled with the retirement of synchronous generating plants, is significantly reducing inertia in large-scale power systems. Fast controllers of IBRs should stabilize these systems, but they are highly sensitive to fast transients, harmonics, and system imbalances. Research findings indicate that relying managing a significant amount of data and interfacing HVDC, FACTS, and IBR plant controller models, which are often delivered as black box codes without any interoperability standard, with grid simulation tools. This paper describes solutions to achieve real-time or near-real-time EMT simulation of large-scale power systems with high IBR penetration. The proposed techniques implement fast parallel simulation either based on

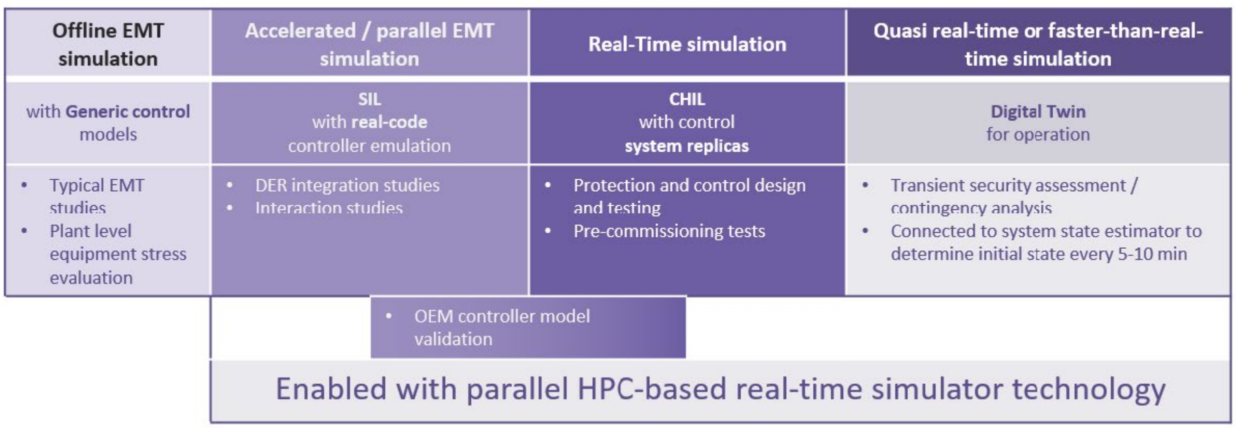


Figure 1. Study-simulation matrix with real-time simulator technology

solely on simplified positive-sequence simulations is inadequate for evaluating the transient stability of extensive power grids equipped with a substantial number of IBR controllers. In this context, detailed Electromagnetic Transient (EMT) simulations are becoming essential for the seamless integration of renewable energy sources such as wind and solar. The capability to perform fast simulations in Software-In-The-Loop (SIL) mode with generic or real-code controllers is indeed useful to determine the worst contingencies in the shortest time to develop the equivalent circuit required for real-time Hardware-In-The-Loop (HIL) simulation to test and optimize control performance. Naturally, fast EMT simulation of large-scale power systems will also become essential for online transient stability assessment to aid system operators, planning, and IBR integration analysis. However, EMT simulation of large-scale power systems with complex power electronic systems is computationally intensive. Moreover, it involves in-house clusters of high-performance computers or cloud servers.

The proposed solution further simplifies the design and testing of Wide Area Monitoring, Protection and Control Systems (WAMPAC) through near-real-time fully digital Software-In-The-Loop (SIL) tests with virtual wide area controllers or in real-time with the actual hardware controller equipment typically used in the control room. Most importantly, it will aid system owners and operators in performing online transient stability assessments at much higher speeds and with high-fidelity models, including OEM control emulators. ■

Read the full article here: CLICK HERE

OPAL-RT Unveils the PHIL Prime Test Bench: The Only Fully-Integrated Test Bench on the Market

With over 20 years of experience serving the Hardware-in-the-Loop (HIL) simulation market, OPAL-RT is proud to announce the release of its PHIL Prime Test Bench. As close to a hundred PHIL setups have been delivered to utilities and research laboratories worldwide, OPAL-RT continues to demonstrate its commitment to the HIL experience.

The PHIL Prime Test Bench: An All-in-One Solution

The PHIL Prime Test Bench stands out as the only fully-integrated PHIL test bench on the market. This versatile power testing platform merges the OP1400 and OP1420 Test Benches into one, offering an improved user experience with easy plug-in & plug-out capabilities. The seamless integration of simulation models with the power amplifier and the ability to easily switch between 120V RMS and 240V RMS emulation with simple wiring adjustments make this test bench particularly user-friendly.

Unique Attributes for Advanced Testing

The PHIL Prime introduces remarkable new features, including the simultaneous integration of multiple Devices Under Test (DUTs) and the parallelization of amplification units within the same test bench. Its improved power output capability now reaches 30 kW. Additionally, extra packages are available, such as the Hybrid AC-DC uGRID and the motor emulator.

Adding Power to Your Simulations

PHIL (Power Hardware-in-the-Loop) takes HIL testing to the next level by enabling real-time power exchange and precise interaction with electrical transients. A power amplifier, directly controlled by the simulation, interfaces the DUT with the virtual environment. PHIL Prime Test Benches are engineered for high-fidelity power-level HIL simulations and are accurate across diverse applications.

A Versatile Platform for Numerous Applications

The PHIL Prime Test Bench is suited for a wide range of applications, including:

- Power Systems & Smart Grids: Microgrid and distributed energy resource (DER) testing, renewable energy integration (solar, wind, battery storage), smart inverter testing with distributed energy resource management systems (DERMS).
- Electric Drives & Transportation: Motor

"PHIL has allowed us to reduce the gap between simulations and real-world performance. We have validated DER models, studied resonance phenomena, and tested advanced grid-forming controls with synthetic inertia, all without relying on a fixed grid."

Research Centre for Greenhouse Gas Innovation

Dr. Renato Machado Monaro
The Research Centre for Greenhouse Gas Innovation

emulation and drives, EV charging station integration to the grid, aircraft and marine power systems, more electrical aircraft systems.

- Academic & Research Applications: Development of advanced control algorithms, hardware validation of new converter topologies, hybrid virtual and analog laboratory environment testing DERs.

Dr. Renato Machado Monaro from The Research Centre for Greenhouse Gas Innovation:

“PHIL has allowed us to reduce the gap between simulations and real-world performance. We have validated DER models, studied resonance phenomena and tested advanced grid-forming controls with synthetic inertia, all without relying on a fixed grid”.

Prof. Arun Rahul from IIT Palakkad:

“With PHIL simulation, we significantly reduced the cost and time associated with prototyping electrical machines, as we didn’t have to rely on a physical machine prototype. This accelerated our development process and allowed for deeper and more flexible lab validation”.

Electric Motor Emulation for E-mobility

The PHIL Prime Test Bench addresses e-mobility applications with high fidelity motor models for accurate representation of motor dynamics and load behavior. It is equipped with the necessary I/O interfaces to implement application-specific resolvers or encoders. This expands test case coverage while testing traction inverter performance for multiple real-world conditions and allows full power testing without using a real vehicle or real vehicle components.

Versatile Connectivity with the Smart Bus Bar

The Smart Bus Bar, available in two variants (LP with 3 x 30 A DUT connections and HP with 2 x 100 A DUT connections), allows extending real-time simulated microgrids into the lab for advanced power emulation. It offers scalability from 5 kW to 30 kW, up to 6 emulated nodes, and real-time control of bus bar contactors from the simulator or a control unit integrated into the HIL environment via digital I/O or Modbus via Ethernet. Real-time voltage & current measurements of all DUTs are available at the simulator for control and manipulation.

“With PHIL simulation, we significantly reduced the cost and time associated with prototyping electrical machines, as we didn’t have to rely on a physical machine prototype. This accelerated our development process and allowed for deeper and more flexible lab validation.”

IIT PALAKKAD

Prof. Arun Rahul
Indian Institute of Technology Palakkad

The bench also includes a rack-mountable Power Distribution Unit (PDU) for safe connection to the three-phase AC Mains input to the DC power supplies and fast installation. A safety panel with an emergency stop function is also integrated.

Packages for Specific Solutions

The PHIL Prime offers optional packages such as the Hybrid AC-DC uGRID, realized using either LP or HP Smart Bus Bars and offering local controller options (HIL2GO or OP8666) and a master controller (OP5707 or another simulator)3 .... ETS' Hybrid AC-DC Test Bench, for example, utilizes OPAL-RT's PHIL test bench for its work on microgrid cybersecurity, grid-tied EVs, V2G, and DER energy management. Prof. Kamal Al-Haddad from ETS emphasizes that "OPAL-RT's PHIL test bench is invaluable to us. It supports our work on microgrid cybersecurity, grid-tied EVs, V2G, and DER energy management. Its remote controllability allows researchers located here and beyond to access it".

Advanced Validation and Testing

Imperial College London uses PHIL to identify on-line admittance in IBR-dominated power systems, while Rensselaer Polytechnic Institute uses a PHIL test bed for grid-connected photovoltaic inverters, demonstrating improved accuracy and reliability compared to purely simulated testing.

The PHIL Prime Test Bench from OPAL-RT positions itself as an essential tool for researchers, developers, and industry professionals seeking to perform accurate, reliable, and versatile power HIL testing for a wide range of energy and transportation applications. ■

Missed the PHIL Testbench Suite webinar? CLICK HERE to watch the full recording:

75 YEARS OF VISION: JEAN BÉLANGER'S LIFE IN MILESTONES

From rooftop childhoods to real-time simulators:
A timeline of curiosity, courage, and creation.

1954
At 4, Jean secretly watched hockey from the stairs, on one of the first black-and-white TVs.

1976
At 26, Jean built a house with his father. Cost? Just $30K, land included!

1993
Jean starts his commercialization endeavors with real-time analogue simulators, backed by Hydro-Quebec and Mitsubishi.

1997
With a renewed vision, Jean and Lise launch OPAL-RT with the goal of democratizing real-time digital simulation.

2009
OPAL-RT's first non-American subsidiary is incorporated in Paris. Many more will follow with a sustained growth.

2025
Still innovating after five decades. 1000+ customers worldwide, and he's not done yet!

"More than birthdays, I celebrate 54 years of design, simulation, and adventure—with 25 more to go."

- Jean Bélanger, CTO, President & Founder, OPAL-RT TECHNOLOGIES

HAPPY 75TH JEAN!

Case Study: The 5000-Bus New York State Transmission System

By: Sagnik Basumallik, Mohammad Ali Dashtaki, Reza Pourramezan, Luigi Vanfretti, Ziang Zhang, Hossein Hooshyar

New York State Clean Energy Goals

The New York Climate Act requires the state to reduce economy-wide greenhouse gas emissions by 40% by 2030. To this end, the New York Power Authority (NYPA), the largest state power organization in the U.S., plays an important role in accelerating renewable energy projects to support the New York State's energy goals. To enable this, NYPA's Advanced Grid Innovation Laboratory for Energy (AGILe) provides a testing environment where real-time simulation is extensively used to analyze the impacts of new technologies on the grid.

New Control Capabilities with Grid-Forming Inverter Technology

The renewable technology of choice is the Grid-Forming (GFM) inverter, which can facilitate the integration of various inverter-based resources, such as renewable, storage, FACTS devices, HVDC, and large loads. GFM offers new control capabilities including the ability to respond to system disturbances, providing active and reactive power support, and enabling stable operation when connecting to weak grids.

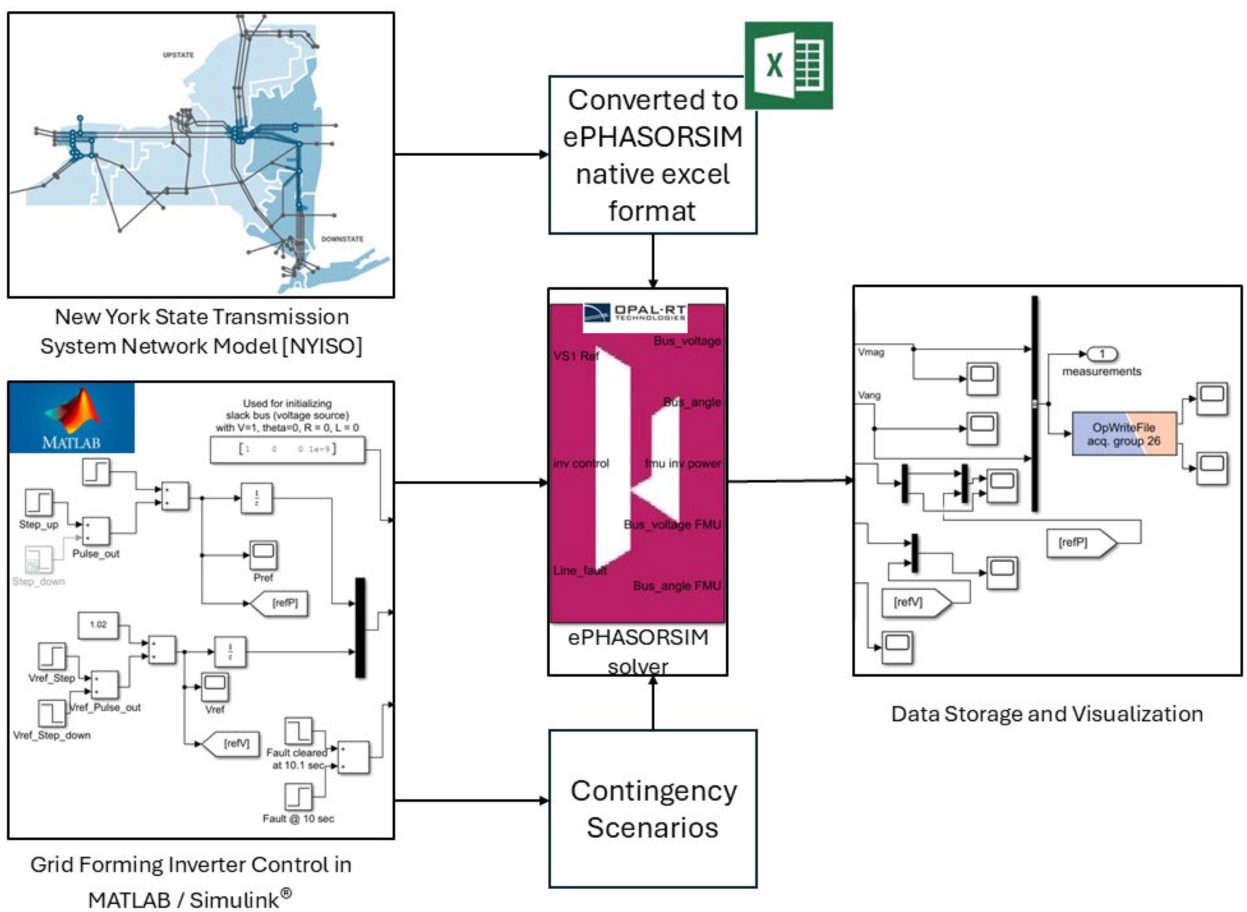


Figure 1: Integration of a single FMU with ePHASORSIM

Future deployment of GFMs requires comprehensive testing and simulation to ensure their reliability and stability under various operating conditions, especially when integrated into large-scale power systems like the New York State grid. However, scaling up the deployment of GFM inverters introduces substantial challenges in terms of modeling and integration efforts.

NYPA's Use of OPAL-RT's Real-Time Software with Functional Mockup Units

To address this challenge, NYPA AGILe successfully developed GFM using Functional Mockup Units (FMU) and deployed inverters in large-scale with OPAL-RT's ePHASORSIM software.

The GFM models were created in Modelica and implemented as FMUs. These FMUs are pre-packaged, standardized containers of user-defined models adhering to the FMI standard. The key advantage is that FMUs allow models to be re-utilized with full control over parameters, thereby making deployment highly scalable and efficient. Two GFM inverter models - (a) droop-based and (b) Virtual Synchronous Machine (VSM)-based were developed for this study. The droop-based control has two primary control loops, the P-f loop and the Q-V loop, along with an overload mitigation loop. The VSM-based GFM has the same Q-V loop control structure, however, the P-f loop has the swing equation modeled to emulate virtual inertia.

In addition to the GFM components, models of traditional machines and controls were interfaced with ePHASORSIM as FMUs. An automated tool, independent of PSS/e and RT-LAB versions, was further developed to import network data that is fully compatible with the ePHASORSIM native library.

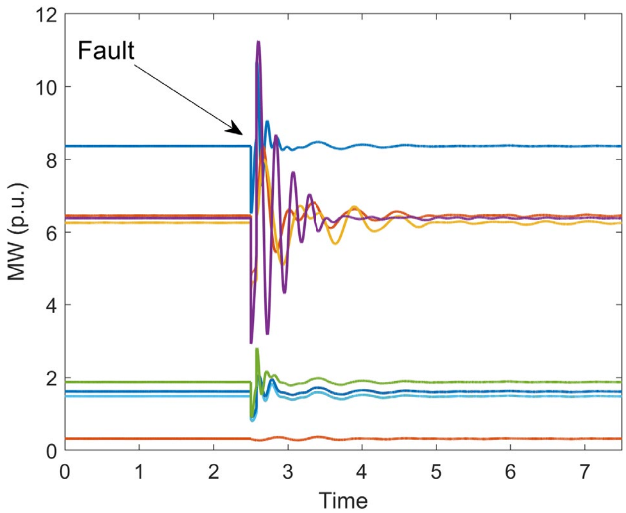


Figure 2: Transient stability analysis under fault with large-scale GFM deployment using FMU inside ePHASORSIM

An example of FMU integrated with ePHASORSIM is shown in Figure 1. The core advantage of using FMUs is that for large-scale deployment, each GFM can be added to the system using a single line in the Excel file containing the network data.

Results and Outlook

The impact on the transient stability was analyzed on the 5000-bus, 800-machine New York State power system under different operating conditions and renewable penetration levels. A total of 6000+ MVA of renewables is integrated into the system. An example of transient stability analysis under fault is shown in Figure 2.

The implementation of GFM inverters as FMUs simplifies simulation studies involving high renewable penetration. In the future, the penetration level will be further increased to assess system stability. We also aim to develop FMU models for grid following inverters and explore FMU interoperability with other tools. ■

POWER IN MIND MAGAZINE

SUBSCRIBE HERE

Our Worldwide Locations

WWW.OPAL-RT.COM