POWER IN MIND

News.
Innovation.
Breakthroughs.

OPAL-RT TECHNOLOGIES

VOLUME 8
AUTUMN 2024

A Word from the Editor

Welcome, readers, to this exciting edition of Power in Mind, where we continue to explore the technologies shaping the future of energy systems. In our last edition, we delved into the world of power grid digitalization—a critical pillar for the evolution of modern grids. Today, we shift our focus to another transformative force: inverter-based resources (IBRs), a key enabler in the future of power systems and industrial energy solutions.

As industries worldwide seek to integrate renewable energy and optimize grid performance, IBRs are proving to be essential in maintaining stability, reliability, and efficiency in the energy landscape. These intelligent resources offer unprecedented control and flexibility, enabling smooth transitions between various energy sources, whether they be solar, wind, or battery storage systems. The integration of IBRs not only facilitates renewable energy adoption but also ensures that grids remain resilient under increasing demands for sustainability.

At OPAL-RT, we have witnessed firsthand how global leaders are utilizing IBRs to unlock new opportunities. In China, our toolchain has become the go-to solution for OEMs delivering models to utilities, ensuring robust and reliable energy solutions. Siemens Energy, a pioneer in power technology, has embraced our tools in their continuous integration process, streamlining their operations and accelerating innovation. The EPEC Group, a forward-thinking project developer, has revolutionized its pre-commissioning phase with OPAL-RT solutions, minimizing risks and saving critical time before final commissioning.

One of the most significant advancements we feature in this edition is the role of Power Hardware-in-the-Loop (PHIL) testing. PHIL enables precise testing of grid-forming inverters and motor emulation, ensuring that systems are resilient, efficient, and ready for the complex demands of modern energy infrastructure.

As you dive into this edition's stories and innovations, we invite you to explore how inverter-based resources and advanced testing methods are shaping the future of energy for industries around the globe. Together, let's envision a more sustainable, reliable, and resilient energy future—one powered by innovation and driven by progress.

Happy reading!

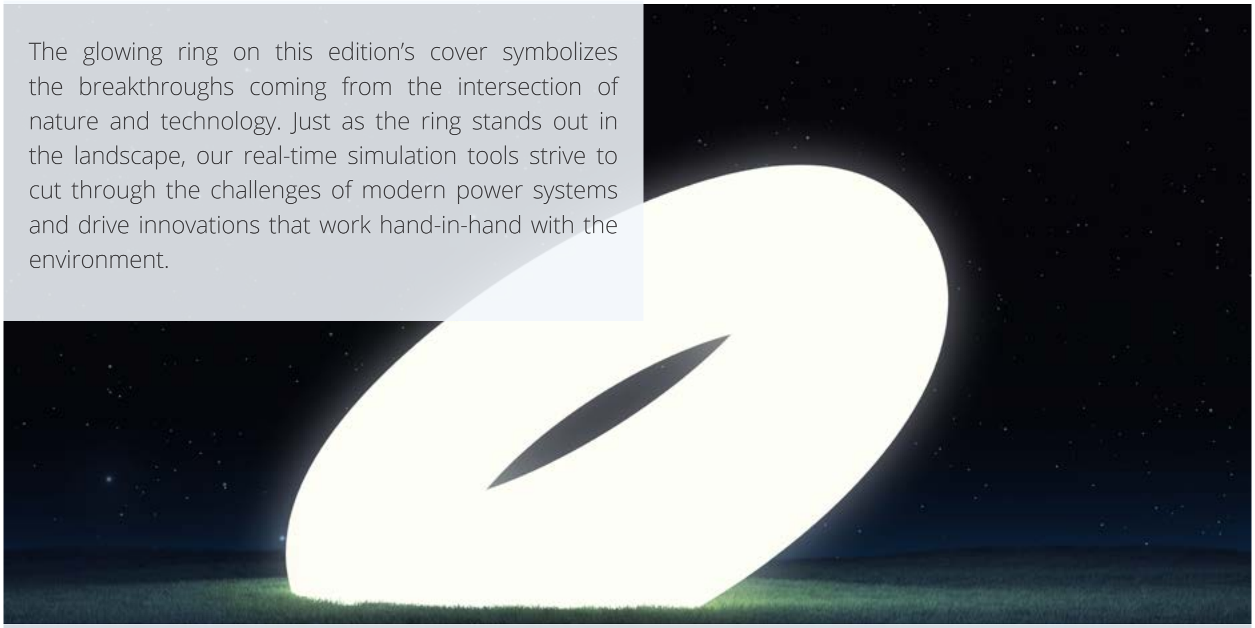
Etienne Leduc,
Director of Product Strategy

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

The glowing ring on this edition's cover symbolizes the breakthroughs coming from the intersection of nature and technology. Just as the ring stands out in the landscape, our real-time simulation tools strive to cut through the challenges of modern power systems and drive innovations that work hand-in-hand with the environment.



Editors: Etienne Leduc, Geneviève Deschamps, and Sofía Escalera Eguíluz
Design and layout: Sofía Escalera Eguíluz, Maija Baroni and Tania Gray

Using Hardware-in-the-Loop (HIL) to validate designs and de-risk renewable project delivery

EPEC Group is an Australian engineering contractor involved in the entire connections process, from modelling and design to substation construction, testing, commissioning and compliance testing to full commercial output for projects ranging from tens of megawatts to gigawatts in scale. Integrating these systems into the grid requires a detailed process, including developing and negotiating generator performance standards, control system design and modelling, and system commissioning and testing. Our experience in delivering these projects has highlighted key issues that cause delays, such as discrepancies between the performance of hardware on site and modelled behaviour, which can extend delays from months to years before achieving full commercial output.

Asset owners are experiencing revenue loss for large plants, that can exceed AUD$100,000 per day, also construction companies are experiencing financial loss due to liquidated damages and prolongation costs, which has led to market exit or administration. Hardware in the Loop testing is of critical importance to mitigate and minimise these issues.

In collaboration with the University of Queensland, EPEC Group has identified several common issues causing project delays:

- **Design Architecture –** Where procured equipment is inadequate for the intended purpose, or unnecessary.
- **Communication Delay –** Inaccurate matching in models or missing data on communication delays and controller cycle times can lead to overshoots and instability.
- **Modelling Differences –** Provided models often differ from actual hardware, with missing or additional functionality and unrealistic simplifications.
- **Human Error –** Mistakes in converting model parameters to hardware settings, including incorrect conversion factors, frequently cause delays.
- **Integration Risks –** Multi-vendor projects often face delays due to challenges in integrating systems.
- **Hardware/Firmware Issues –** Controllers can underperform or have firmware problems, leading to poor system control.

"In a recent 50MW solar project, EPEC Group has utilised the HIL pre-commissioning methodology and has resolved 15+ issues related to the integration, modelling and hardware design of the control system. The time saved from HIL validation is estimated to be approximately 5 months. Additionally, the testing has significantly reduced the risk of liquidated damages for the EPC contractor."

Marty Johnson, EPEC Group

Webinar

epec

HIL (Hardware-in-the-loop) testing has traditionally been used by OEMs and researchers for designing and testing equipment. However, EPEC Group has repurposed HIL testing as a project delivery method to reduce risks in the connections process. This approach includes a pre-commissioning stage where aggregated plant level controls (such as Plant Controller, PQ Meter, SCADA) are integrated with the hardware, and high-power components (like inverters, reticulation systems and transformers) are incorporated in the model. An example of the test setup is pictured in Fig. 1.

The system is then tested according to the typical commissioning plan and validated against the model to ensure that hardware meets the designed specifications and regulatory standards. The advantages of HIL testing include rapid design and validation, identifying issues before project deadlines, and avoiding the use of the electrical network as a test bed.

EPEC Group's application of HIL testing is crucial for de-risking project delivery by validating control systems and simulating real-world conditions with actual hardware before on-site deployment. This proactive method improves project efficiency, ensures regulatory compliance, and mitigates risks associated with hardware and model discrepancies.

For more details or to access our research paper, please contact us at newbusiness@epecgroup.com.au. Also, check out our upcoming OPAL-RT webinar for a detailed overview and live demonstration. ■

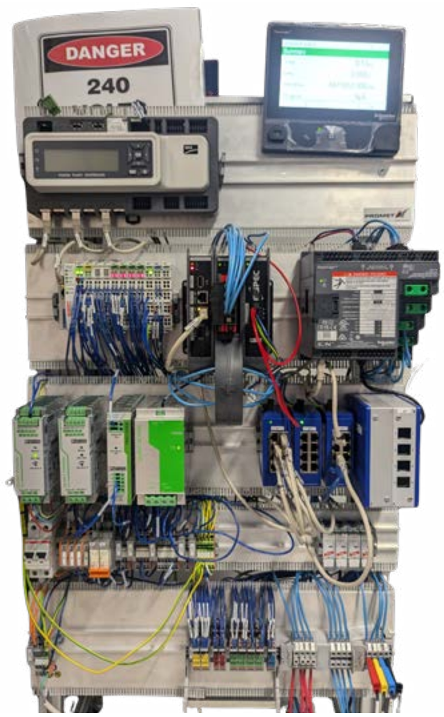
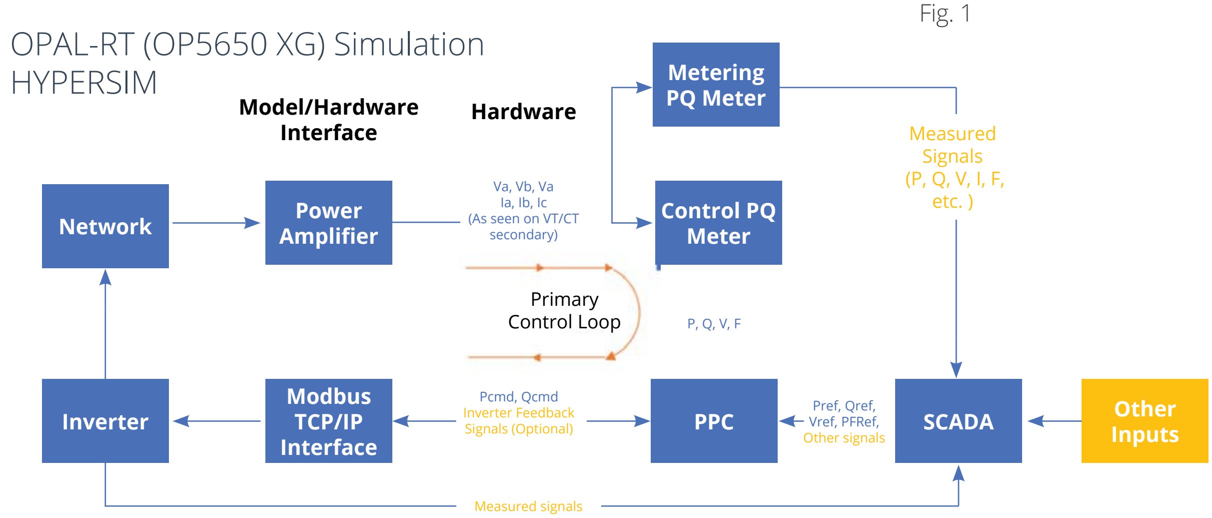


Fig. 1



Exploring China's Renewable Energy Shift: Insights on Real-Time Simulation and Grid Stability

Weihua, thank you for joining us today. Could you start by telling us a bit about your role and background?

I'm the General Manager of OPAL-RT China, a subsidiary that I started in 2014, which at the time was mostly tasked with providing technical support for distributors in the Asia-Pacific region and our exclusive distributor in China, KeLiang. We collaborated with research centers, Chinese utilities, universities, and manufacturers to develop new applications, particularly to simulate inverter-based resources (IBRs) integrated into the power grid. Over the past decade, our focus has been on enhancing these simulations for complex AC and DC power grids with large-scale renewable-energy integration. Our team has grown significantly with the market. Since 2021, we have expanded our scope to include automotive applications, vehicle-to-grid (V2G) applications, medium or low-voltage drive applications via direct sales, and exercised local integration. Our daily operations are diverse, but supporting our customers remains central to our mission.

The energy sector is undergoing a significant shift with the rise of alternative energy sources and IBRs. What does the energy landscape look like in China right now?

The Chinese government has set ambitious goals to reduce carbon emissions—peaking by 2030 and reaching zero emissions by 2060, known as the 30/60 carbon peaking and carbon neutrality goals. This has led to significant infrastructure changes on both the user and utility sides, with a strong push toward integrating renewable energy at various levels. In China, energy load centers and source centers are geographically distant - similarly to what you see in Quebec! The west has abundant hydro energy, solar potential, and strong wind, while the eastern coast is rich in offshore wind energy. The challenge has been to convert this renewable energy into electricity and transmit it over long distances to load centers using high-voltage direct current (HVDC) technologies. This is where real-time simulation plays a crucial role in testing, implementing, and maintaining these systems - OPAL-RT plays a very important role here.

Speaking of utilities, how many utility companies are there in China?

The electric power transmission system in China is primarily operated by two major players: the State Grid Corporation of China, which covers 26 provinces, and the China Southern Power Grid, which covers 5 provinces Each province also has its own subsidiary of the state grid, managing their research centers, transmission systems, and distribution systems at city and town levels. The electric power market is structured around this, with five large and four small generation groups that produce electric energy, including renewable energy farms.

What are the specific challenges that IBRs present to utility companies in China?

One major challenge is the distance between the energy source and the load center, which requires long transmission lines. The TSOs (Transmission System Operators) are generally responsible for ensuring grid stability, but there's a very interesting growing trend where generation groups, particularly when it comes to offshore wind energy, are also becoming responsible for delivering electricity to land. They own the cables for transmission from offshore wind farms to the coast. Unlike before, where TSOs handled most of the stability concerns, generation groups now have to manage shorter, yet still significant, distances of up to 100km for HVDC cables, requiring them to maintain stability as well.

That sounds like a complex situation, especially with different manufacturers involved. How does the multi-vendor system affect grid stability?

The multi-vendor system, especially for renewable energy, requires inverter-based control provided by different manufacturers. Each vendor might use their own algorithms, which can lead to interoperability issues even when they meet standardized tests. These risks and instabilities are becoming more of a shared responsibility between utility companies and original equipment manufacturers (OEMs), as they must now manage their lines and systems more closely.

How does real-time simulation and Hardware-in-the-Loop (HIL) systems help address these challenges?

Real-time simulation is crucial for testing multi-vendor systems like IBRs, FACTS, and HVDC technologies. It allows various control tests, such as low-voltage-ride-through (LVRT), impedance scans, and islanding tests, on a Hardware-in-the-Loop (HIL) system. Twenty years ago, HIL wasn't widely recognized in this field. It wasn't like in Automotive, where HIL was standard. Renewable energy was like throwing a stone into the ocean! With the rise in renewable energy and complex grid dynamics, the need for precise testing has grown. Today, HIL is standard, and RT-LAB is widely used because it integrates different modeling environments and supports comprehensive testing.

What does the process look like for testing and integrating new systems between utility companies and IBR groups?

Utility companies require vendors to submit detailed reports based on standardized tests. While they don't mandate a specific brand of HIL, RT-LAB is commonly used. Initially, manufacturers would bring their controllers to the utilities for testing, but with increasing vendors and long wait times, many have started investing in their own testing systems to pre-validate their models before approval. In recent years, it's also become mandatory for vendors to provide protected control code compatible with RT-LAB for multi-vendor systems. This two-way process ensures that the control code behaves consistently and aligns with the utility companies' requirements.

It sounds like OPAL-RT and RT-LAB have become pretty integral to the testing ecosystem in China.

Absolutely! RT-LAB provides a unique capability to run both Software-in-the-Loop (SIL) and HIL simulations simultaneously, making it easy to validate control codes. This dual capability ensures that the code behaves as intended in various scenarios, which is crucial for maintaining grid stability. As renewable integration grows more complex, such integrated and versatile platforms are essential.

Finally, what do you see as the future of energy management in China?

The future will focus on more sophisticated testing techniques, tighter integration of multi-vendor systems, and collaboration between utilities, manufacturers, and technology providers. As China continues to push toward its carbon reduction goals, the ability to simulate, test, and validate these complex interactions in real-time will be key to ensuring a stable and sustainable power grid. ■

Weihua Wang
OPAL-RT CHINA - Technical Director

How Sungrow Leveraged OPAL-RT Technologies to Revolutionize Real-Time Simulation and HIL Testing

Sungrow, a global leader in the renewable energy sector, has long been at the forefront of innovation, with significant achievements in PV inverters and energy storage systems. A critical component of their success is the integration of innovative real-time simulation and hardware-in-the-loop (HIL) testing, powered by OPAL-RT TECHNOLOGIES.

The Growing Need for HIL Simulation at Sungrow

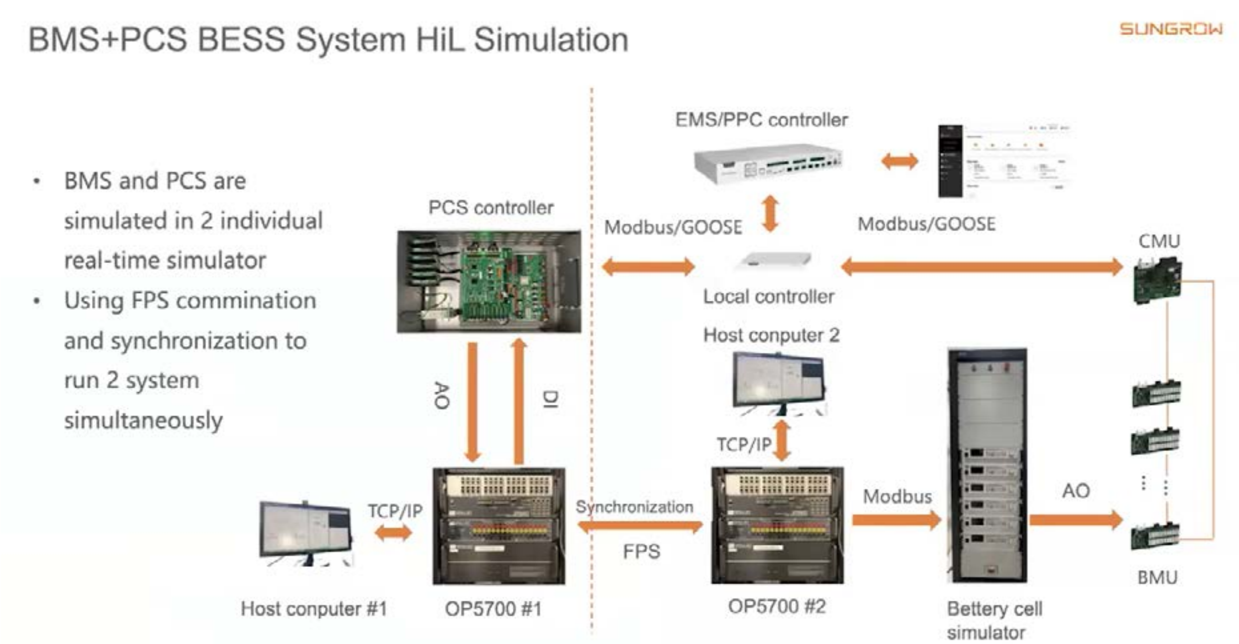
Founded in 1997, Sungrow began its journey as a PV inverter manufacturer. Over the years, the company has expanded into energy storage and other renewable energy sectors, including electric vehicle chargers and hydrogen equipment manufacturing. With a vast global presence spanning six R&D centers, three manufacturing bases, and operations in over 170 countries, Sungrow has seen rapid growth, achieving a remarkable $10 billion in revenue last year alone.

Given the complexity and scale of its operations, Sungrow recognized the need for advanced simulation tools to ensure the efficiency, safety, and reliability of its products. HIL simulation emerged as a pivotal technology, providing a bridge between digital simulations and real-world hardware testing. But why is HIL simulation so critical for a company like Sungrow?

Unlocking the Potential of HIL Simulation

Yuanze Zhang, Manager of the Power Electronics Research Center at Sungrow, a key figure at Sungrow, explains HIL simulation with an analogy: just as virtual reality enhances video gaming by adding immersive physical experiences, HIL simulation enriches digital power system simulations by integrating them with real hardware. This synergy enables Sungrow to conduct tests that are both comprehensive and safe, reducing the risks associated with testing on actual power systems.

OPAL-RT's technology allows Sungrow to create highly accurate models of PV modules, batteries, converters, grids, and loads within a simulated environment, connecting them with real hardware controllers (power converter



SUNGROW

View the webinar:
opal-rt.com/resource-center/

systems, BMS, EMS, PCC, etc.) The result is a highly realistic testing environment that mimics real-world conditions.

Real-World Applications of OPAL-RT's HIL Technology at Sungrow

Sungrow's HIL simulation lab, equipped with over 20 OPAL-RT simulators (primarily OP4510 and OP5700 models), plays a crucial role in their operations. These simulators are capable of testing high-speed switching converter devices, crucial for both converter controller tests and power plant controller HIL simulations.

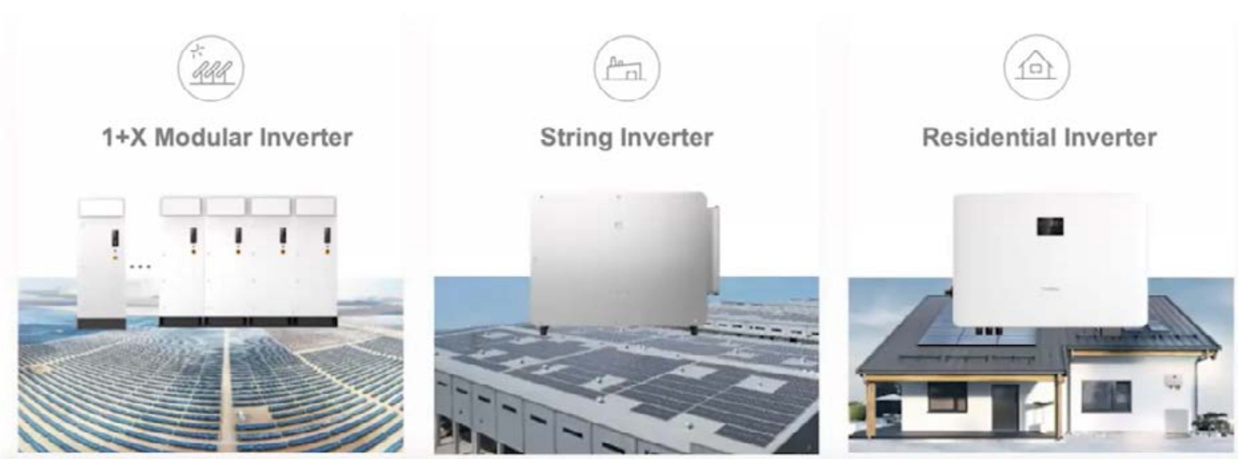
1. Enhanced Testing and Validation: HIL simulation provides a realistic environment that helps Sungrow detect and resolve software issues early in the development process. Test automation through scripting enables running volumes of test overnight and get detailed reports the next day. This has significantly accelerated software development timelines, allowing the company to maintain its competitive edge.

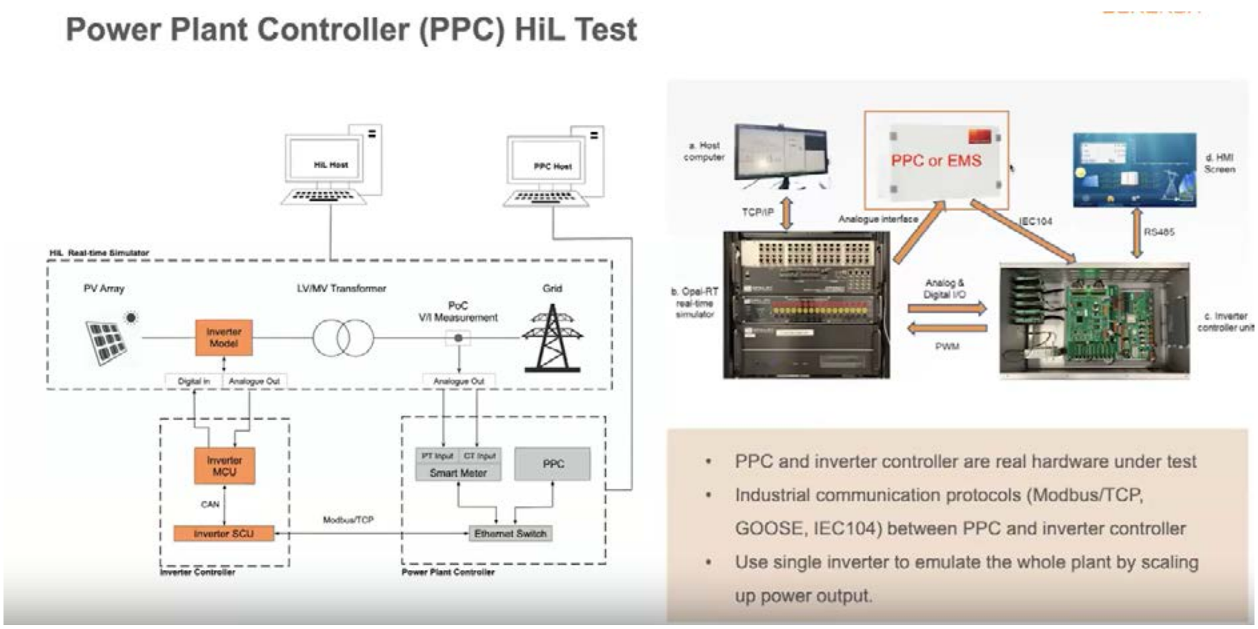
2. Safe Testing of Edge Cases: HIL simulation enables Sungrow to safely test extreme scenarios, such as grid contingencies, without risking network safety or facing penalties. This capability is particularly important for regions with stringent grid integration standards, like Australia and the Middle East, where HIL testing is now a mandatory requirement.

3. Time and Cost Efficiency: By simulating real-world conditions before physical prototypes are available, Sungrow can complete up to 90% of software testing in advance. This approach has not only shortened development cycles but also reduced costs, contributing to Sungrow's operational efficiency.

Case Studies: HIL Simulation in Action

One of the simplest yet most effective applications of HIL at Sungrow is grid connection testing for inverter controllers. By connecting these controllers to real-time simulators, Sungrow can test various grid-forming and grid-following control strategies





under different conditions such as low voltage ride through or extremely low short circuit ratio, ensuring optimal performance.

In a more complex scenario, Sungrow utilized HIL simulation for a power plant controller test, incorporating battery cell performance, local controllers, and power plant controllers into a unified testing environment. By connecting multiple simulators via fiber optics, the team was able to run comprehensive tests that validated their control algorithms.

One of Sungrow's standout projects involved a black start in the US, where HIL simulation proved invaluable. Before deploying the system on-site, Sungrow used HIL to identify and fix potential control algorithm issues. This preparation allowed the team to smoothly commission the system on-site in just a few days, demonstrating the effectiveness of HIL in real-world applications.

Conclusion: A Strategic Partnership for Innovation

Sungrow's partnership with OPAL-RT TECHNOLOGIES has been instrumental in advancing their testing and validation processes. By leveraging OPAL-RT's HIL technology, Sungrow has achieved significant improvements in efficiency, safety, and cost management, reinforcing its position as a global leader in renewable energy solutions.

As Sungrow continues to push the boundaries of innovation, HIL simulation will remain a cornerstone of its strategy, ensuring that it meets the evolving demands of the global energy market with confidence and precision. ■

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horoscopes

It's written in the code!

ARIES

Prepare for an electrifying month! Your bold ideas will light up team meetings like a high-voltage spark. However, be cautious around actual high-voltage equipment—overconfidence and electrical currents do not mix well. Balance your bravery with a touch of common sense.

TAURUS

Your stubbornness finally pays off as your project hits a major breakthrough. Celebrate with a well-earned break, but don't be surprised if you start dreaming in code. Your dedication is admirable, but remember to unplug occasionally—your circuits (and sanity) will thank you.

GEMINI

Your dual nature is in full swing this month. One moment, you're solving complex equations with ease, the next, you're daydreaming about turning your office chair into a motorized go-kart. Make sure your boss catches you in 'genius engineer' mode though.

CANCER

You'll feel a strong connection to your colleagues this month, almost as if you share a neural network. Use this to collaborate on challenging projects, but beware of emotional overloading. When the simulations get tough, remember: even engineers need a good cry sometimes.

LEO

Your leadership skills will shine brighter than an LED. People will look to you for guidance, so be ready to steer your team towards success. Just don't let your ego short-circuit the process. Stay grounded, even if your simulations take you to new heights.

VIRGO

Your attention to detail is legendary, and this month, it'll be your superpower. You'll catch errors that no one else can see, earning you the title of "Debugging Deity." Just remember, it's okay to let a few small glitches slide; perfection is a myth, even in real-time simulation.

LIBRA

Balance is key for you, especially when it comes to work and play. You'll find harmony in the most unexpected places, like between lines of code or during a team brainstorm. Keep an eye out for new software updates—they might just bring the equilibrium you've been seeking.

SCORPIO

Your passion for power engineering will ignite new interests this month. Dive deep into the latest tech trends, but don't get lost in the rabbit hole of research. Remember to resurface and share your findings with the team—they'll appreciate your intensity and insights.

SAGITTARIUS

Adventure awaits! This month, you'll tackle new challenges with the zeal of a pioneering engineer. Your optimism will be your guiding star, but watch out for overconfidence. It's one thing to aim high, another to forget to check the power supply.

CAPRICORN

Your meticulous nature makes you the master of simulations. This month, the stars align in your favor—literally. Expect an unprecedented drop in debugging errors and a mysterious surplus of coffee in the office kitchen. Don't question it.

AQUARIUS

Innovation is your middle name! This month, you'll dream up ideas so advanced, even your AI simulations can't keep up. Just be sure to write them down before your next coffee break, or they might vanish like a fleeting algorithm.

PISCES

A wave of inspiration will wash over you, making you think you can write the perfect simulation code in one go. Spoiler: You can't. But your optimism will be contagious, and your colleagues will appreciate your boundless enthusiasm.

*Intended for fun and entertainment purposes only


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Success, delivered faster than ever.

Siemens Energy's Grid Solutions: Leading the Way in Power Transmission and Distribution

Grid Solutions, a business unit of Siemens Energy, stands at the forefront of power transmission and distribution, offering innovative solutions that enhance the efficiency, reliability, and sustainability of power grids across the globe. With a wide-ranging portfolio of products, systems, and services, Grid Solutions is dedicated to addressing the evolving needs of the energy industry and facilitating the transition to renewable energy sources.

FACTS and HVDC systems, powered by the advanced Modular Multilevel Converter (MMC), are pivotal to controlling the power flow in high-voltage transmission. With such critical functions, very high demands are placed on the quality and reliability of the MMC's control. Additionally, the control software must be flexible and adaptable for different projects and transmission lines.

Therefore, testing the software on real hardware across diverse projects is crucial for early fault detection in the software development of the converter controls. For this purpose, it's essential to develop an easily usable HIL test bench capable of automated test execution to enhance efficiency.

Leveraging OPAL-RT's FPGA-Based Power Electronics Toolbox

First, it was crucial to adapt the existing plant model, constructed with Simulink and the electrical circuit with Simscape Specialized Power Systems, to run seamlessly on the simulator. Through close collaboration with OPAL-RT's local team in Germany, necessary modifications were swiftly identified and implemented, enabling rapid integration of the plant model onto the OPAL-RT simulator.

- The eHS solver enables the execution of the electrical circuit on the FPGA with an impressive execution time of less than 1us, eliminating the need for time-consuming synthesis.
- A Simulink-based control algorithm is executed on the simulator's CPU, achieving an execution time step of 10 us.

"One of the advantages of OPAL-RT is the seamless interaction with MATLAB/Simulink, which enabled us to work in our usual development environment to setup the simulator software. Thanks to the competent support of the OPAL-RT team, we were able to familiarize ourselves quickly with the simulator and could develop together solutions for our use case."

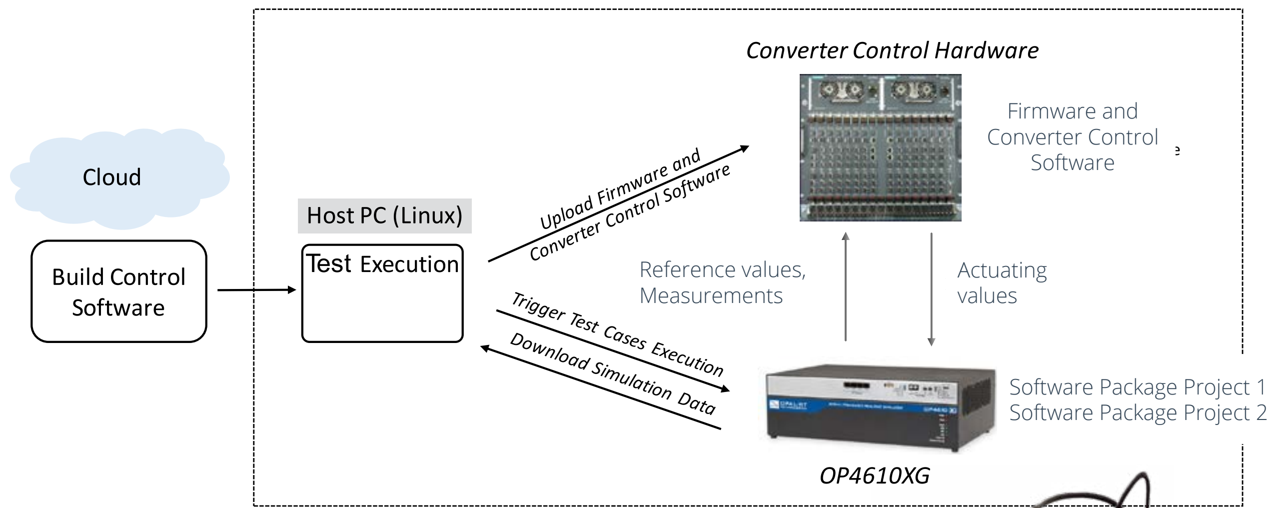
Frank Schuhmann, Senior Development Engineer at Siemens Energy AG

Read the full success story here

SIEMENS

Automation with RT-LAB's Python API

To support various configurations and parameterizations of the plant model, multiple software packages are created with the corresponding plant model and transferred to the simulator. Thanks to RT-LAB's Python API, the creation of the software packages for the simulator can be fully automated.



Integration with GitLab CI/CD Pipeline

Triggered by a Linux host PC, which is integrated into a GitLab CI/CD pipeline, the firmware and control software is loaded on the control hardware and the appropriate software package with the test cases is then executed directly on the simulator. Finally, the recorded data is downloaded from the host PC to check the test criteria in MATLAB/Simulink.

Thus, it is possible to execute the test cases defined for the control of MMC's for FACTS and HVDC systems with each GIT commit before a merge is executed or with a manual trigger, depending on the requirements of the development process.

Advancing MMC Control Software Testing with OPAL-RT Simulation Technology

Thanks to a successful collaboration with OPAL-RT, the integration of the Simulink plant model into the simulator was swift. Additionally, leveraging the FPGA-based Power Electronics Toolbox of OPAL-RT, Siemens Energy easily harnessed the performance benefits of FPGA technology for the modeling of plants in HIL environment." ■

Focus on Grid Stability: Testing Grid-Forming Converters with PHIL

The energy transition is rapidly accelerating. As the world moves away from fossil fuels and embraces renewable energy, the structure of our energy supply is undergoing significant changes. Large, centralized power plants, which have provided a stable energy supply for decades, are being gradually replaced by smaller, decentralized generation units. This change is having a fundamental impact on the electricity grid. One of the critical challenges arising from the phase-out of large conventional power plants is the loss of grid inertia. Traditionally, the rotating masses of generators in these plants provided a stabilizing effect on the grid.

Without this inertia, the grid becomes more vulnerable to fluctuations and potentially unstable, necessitating new approaches to maintain stability. This circumstance has already been recognized and efforts such as the German roadmap for system stability are demonstrating this.

To address this challenge, decentralized generation units and loads, such as wind and solar plants, electric vehicle charger and many more, must contribute to grid stability. This is where grid-forming control concepts for inverters come into play. These concepts have been extensively researched in recent years to ensure that power grids remain stable even without traditional inertia. Different inverter-based grid forming control approaches were invented, on promising control is based on droops, which are proofed in many island grids projects since decades. For the synchronization with other inverter-based resource and loads suitable current limiting methods are mandatory. One solution for that control challenge is SelfSync+ and SelfLim from Fraunhofer IEE - whether in microgrids, in the interconnected grid, or in islanded mode. To validate grid-forming control concepts, it is essential to test a wide range of grid scenarios, from small microgrids with few participants to more complex grid structures. Fraunhofer IEE utilizes advanced testing techniques

"To validate grid-forming control concepts, it is essential to test a wide range of grid scenarios, from small microgrids with few participants to more complex grid structures."

Jonas Steffen, Fraunhofer Institute for Energy Economics and Energy System Technology

such as Power-Hardware-in-the-Loop (PHIL), combined with powerful real-time computers and Rapid Control Prototyping (RCP) systems. Discussed in many committees worldwide, like CIGRE, FNN and CENCLEC, for further adoption in the standards.

An example testbench can be seen in the figure which involves a grid-forming inverter, configured in RCP mode, connected to a load and a PHIL system. The RCP inverter executes the desired control model, which, in this case, is a grid-forming control with current limitation. The PHIL system, consisting of an OPAL-RT OP4512 real-time system and a RICOSO as a PHIL amplifier, simulates a small grid with a load and another grid-forming method. This simulated grid is connected to the real grid via the amplifier, allowing the real grid section to be expanded with a scalable emulated grid. This configuration allows for comprehensive closed-loop testing of the real inverter behavior within the grid and enables the validation of grid stability under various conditions, ensures that the connected RICOSO RCP with grid-forming control meet the requirements of the modern energy system. RCP and PHIL are therefore essential tools for validating control strategies and are a key component in expanding test networks into complex, realistic grid structures. The use of these techniques opens up nearly limitless possibilities for researchers to assess the performance of grid-forming inverters. ■

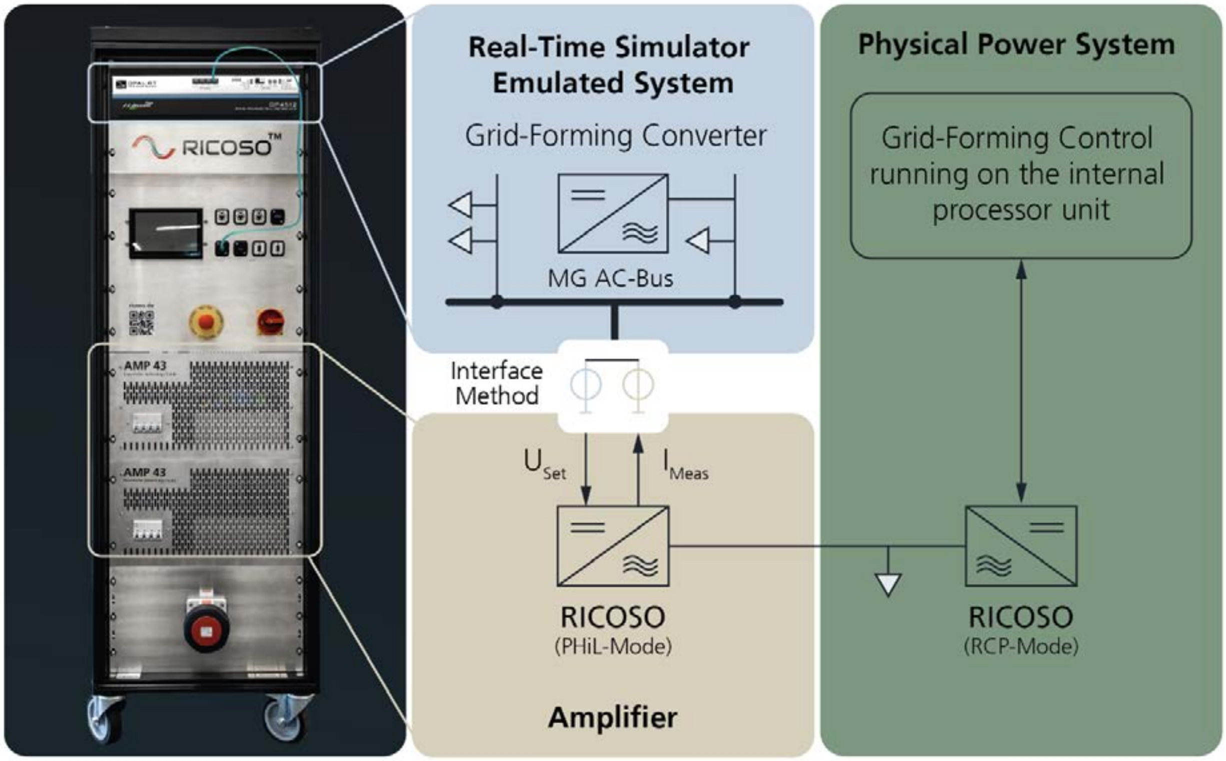


Figure 1: Testbench for grid-forming control showing an emulated microgrid on RTS with PHIL system and RCP inverter as the device under test.

Power Hardware-in-the-Loop Smart Inverter Testing

By: Hao Chang Electrical and Luigi Vanfretti, Computer and Systems Engineering - Rensselaer Polytechnic Institute Troy, NY

This article summarizes the results of a project that we - Rensselaer Polytechnic Institute (RPI) - conducted in collaboration with Smarter Grid Solutions to test smart inverter functionalities, which is supported by the New York State Energy and Research Development Authority (NYSERDA). The project established a Power Hardware-in-the-Loop (PHIL) experimental facility for smart inverter testing, with the goal of verifying its compliance with the IEEE 1547.1-2020 standard, for interconnecting distributed energy resources (DER) with electrical power systems (EPSs).

This setup was successfully used to test the functionality of the SMA inverter in different operating conditions and control modes. The six experiments documented in the original paper include the testing of the inverter operating in control modes: constant power factor, constant reactive power, voltage-var, voltage watt, voltage ride through and return to service. In this article we will detail only the “Constant Power Factor Mode” experiment.

OPAL-RT OP1400 Power Amplifier

The OP1400 power amplifier labeled 4 in Figure 1 is an essential component of the experimental platform, as it emulates the power grid to which the inverter is connected.

To control and monitor the amplifier, a user interface (UI) has been implemented; see Fig. 2. The UI serves as the control panel of the OP1400 power amplifier is executed using a real-time simulator. This interface is critical in ensuring the successful operation of the experimental platform during the testing experiments, as it allows the user to adjust parameters and observe the system’s behavior in real-time. In Figure 2, enclosed in red squares and numbered, are the different experiment control and monitoring functions used to carry out the tests:

1. **Automated RMS Voltage Set-point Adjustment**
2. **Voltage Set-point Adjustment**
3. **Voltage Slew-rate Limiter**
4. **Voltage Set-point Display**
5. **RMS Voltage and Current for Each Phase (Monitoring)**

PHIL LABORATORY EXPERIMENTAL FACILITY

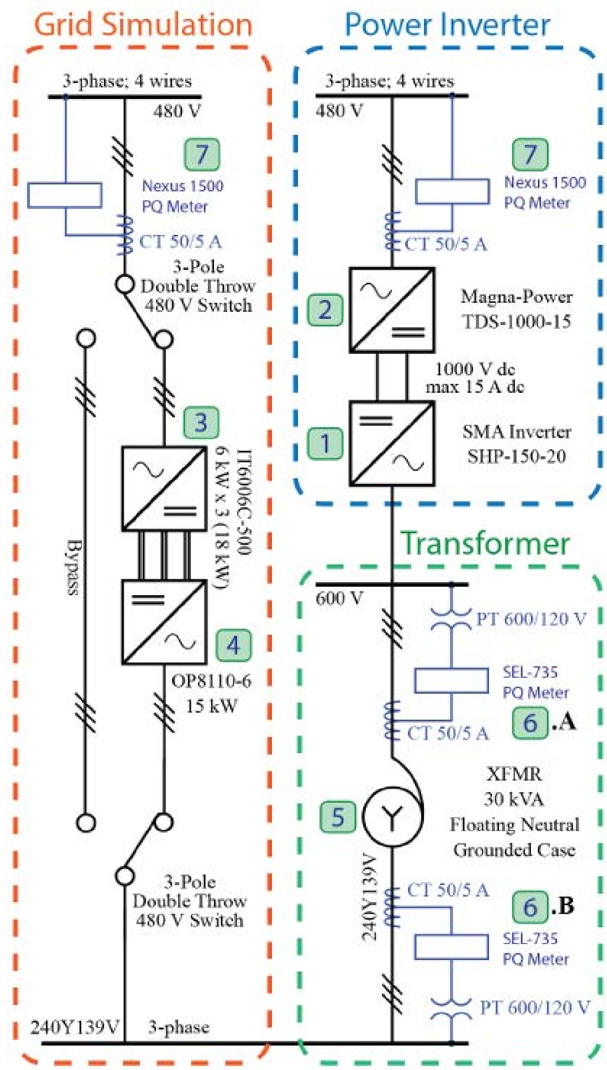


Fig. 1 PHIL Lab One Line Diagram

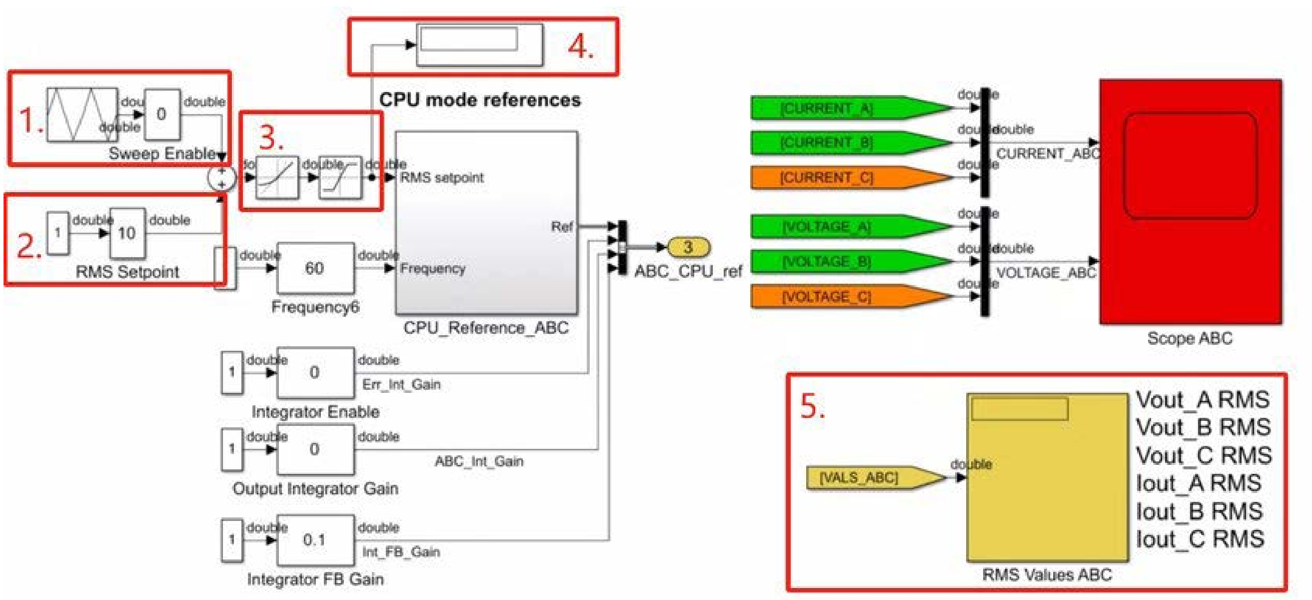


Fig. 2 OP1400 Power Amplifier UI

In the following experiments, the 3-Phase RMS Voltage Set-Point is used to control the input voltage for the inverter to conduct High/Low voltage ride-through tests. The Automated RMS Voltage Set-Point Adjustment is used to automatically change the input voltage for the inverter to obtain the characteristic graphs of Volt-Watt and Volt-Var control mode operation. The Slew-Rate limiter is used to limit the impact of the autotransformer inrush current. This was necessary since during the coupling of the experimental platform it was observed that in experiments when the voltage was changed too quickly, the power amplifier's protections would trip because of the autotransformer's inrush current. The Saturation Limiter avoids user input errors that exceed the amplifier and inverter voltage limits. The voltage saturates at 160 Vrms L-N. Therefore, the voltage can reach 692 VLL on the high side of the autotransformer, which is sufficient for all testing procedures within the scope of the experimental facility.

DC Power Supply

The DC power supply labeled as number 2 shown in Fig. 1 is used to emulate a Photovoltaic (PV) cell working under different conditions. The Photovoltaic Power Profile Emulation (PPPE) software automatically calculates the solar array voltage and current profiles based on user-defined parameters.

Since the experiments do not require a change on the DC side and the maximum active power output of the inverter is set to 3 kW. Meanwhile, the profile in box 1 is sent to the DC power supply to have a maximum of 7.2 kW, which allows the DC supply to operate following the characteristic of the emulated PV panel. This power profile is used in all experiments.

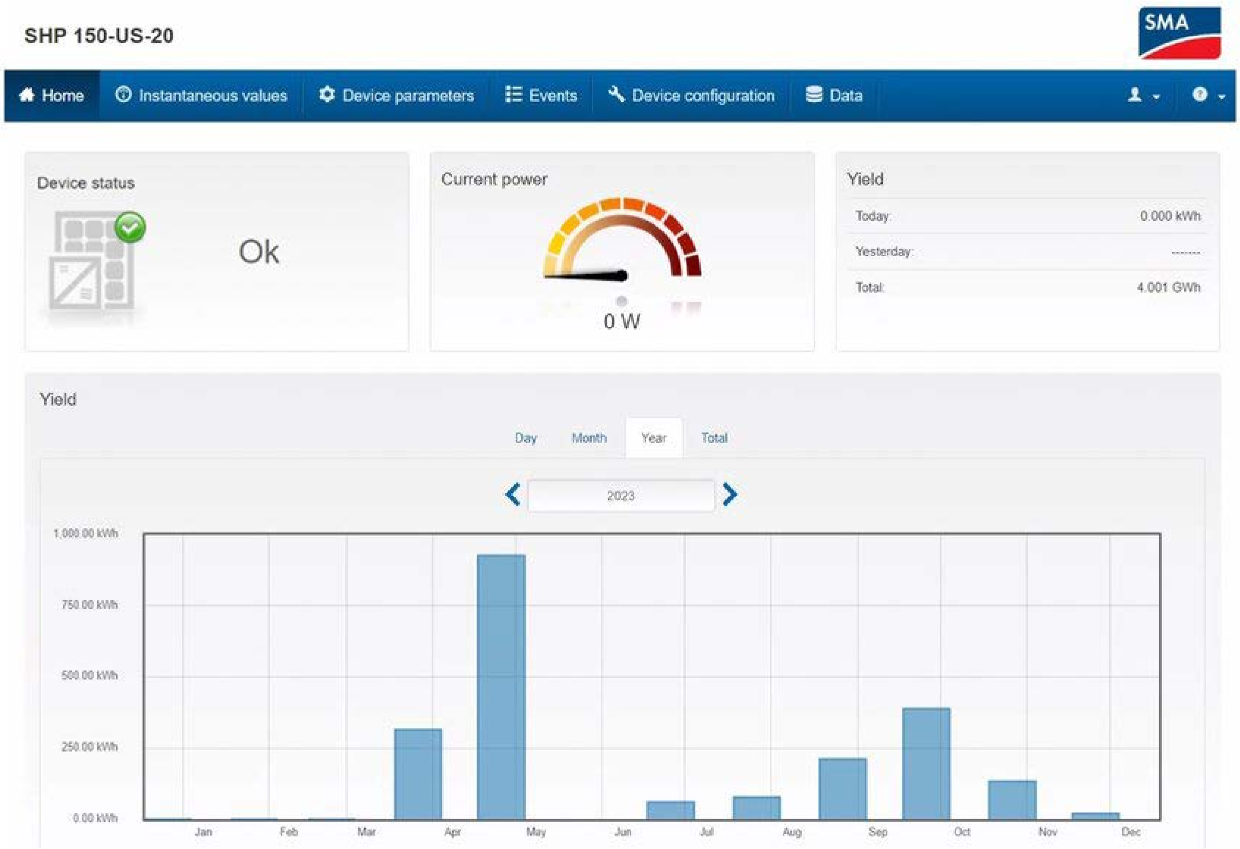


Fig. 3 SMA Inverter UI

SMA Inverter

The SMA inverter is the EUT (equipment under test) for all tests carried out and documented next. The inverter is configured through its embedded server user interface, shown in Figure 3. In the UI's main screen (i.e., the Web Server's home page), the current output power and device status are displayed. The "Device Parameters" tab is where the configuration and settings for the inverter are displayed and can be modified. In the following experiments, the detailed settings are all displayed and configured through this tab.

Experiment - Constant Power Factor Mode

Understanding how an inverter interacts with the grid under constant power factor conditions is crucial for the integration of renewable energy sources, as it affects the stability and efficiency of the grid. In the following test, the constant power factor (pf) mode of the inverter will be tested with a 0.95 lagging power factor. From the UI, the power factor is set to be constant at 0.95. Measurement data were recorded after the inverter finished adjusting the output power (i.e., when it reached a "steady state"). These recordings are used to verify whether the inverter is outputting and maintaining the desired active and reactive power.

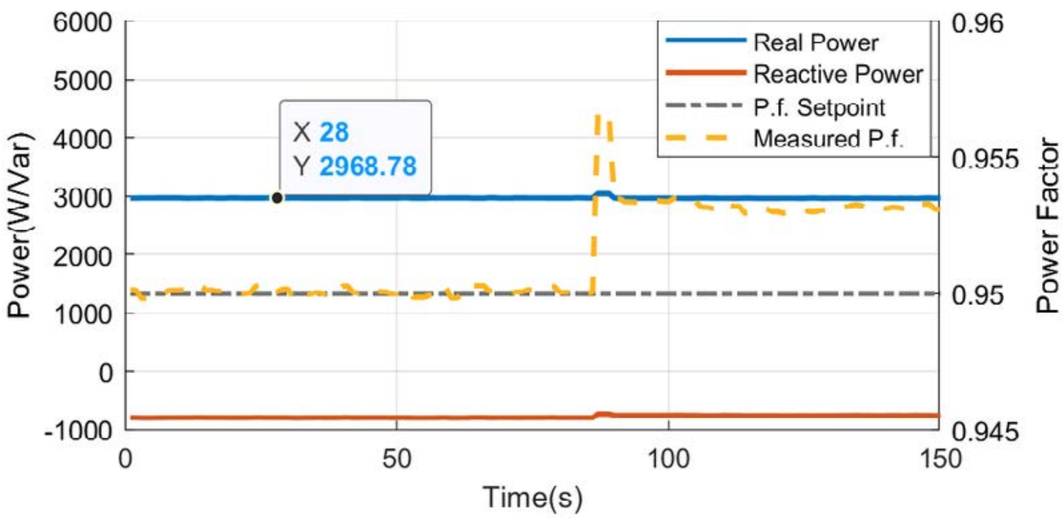


Fig. 4 SEL-735 Meter Measurements under 0.95 Lagging Power Factor

Figure 4 shows the inverter generating 3 kW and the power factor is 0.95, as expected. Since the SMA inverter is capable of generating 150 kW, 30.67 W of error is within tolerance. The oscilloscope is used to verify the lag angle. From the measurement, the time lag is 827 microseconds. In terms of angle, this corresponds to Φ = 17.8º. The desired angle is Φ = 18.2º. The measured lag angle is close to the desired angle. Noting that the waveforms are slightly distorted, the angle error can be attributed to instrumentation issues. However, the error is low and within tolerance. The experiment is repeated for an Overexcited (Leading) power factor of 0.95, and the results are shown in Table I, with similar results as in the previous test. ■

Table 1 - 0.95 Leading Constant Power Factor Test Results

Power	Desired	Measured	Error
Real	3000W	2747W	8.4%
Apparent	3162VA	2916VA	7.8%
Reactive	986Var	977Var	0.9%
P.f.	0.95	0.94	1%

Read the full article here:

Motor Emulator Testbed (OP1600) for teaching, research and testing

Power-hardware-in-the-loop (PHIL) systems have become increasingly popular in multiple application areas including electric drive systems. In motor PHIL, also known as motor emulation, motor behavior is mimicked using a high-performance, high-dynamic power amplifier. Because of this fidelity, PHIL-based motor emulation allows the possibility of studying different motor topologies and their control, due to its large test coverage combined with flexibility and relatively low investment costs, making it an invaluable tool for testing, as well as for education and research.

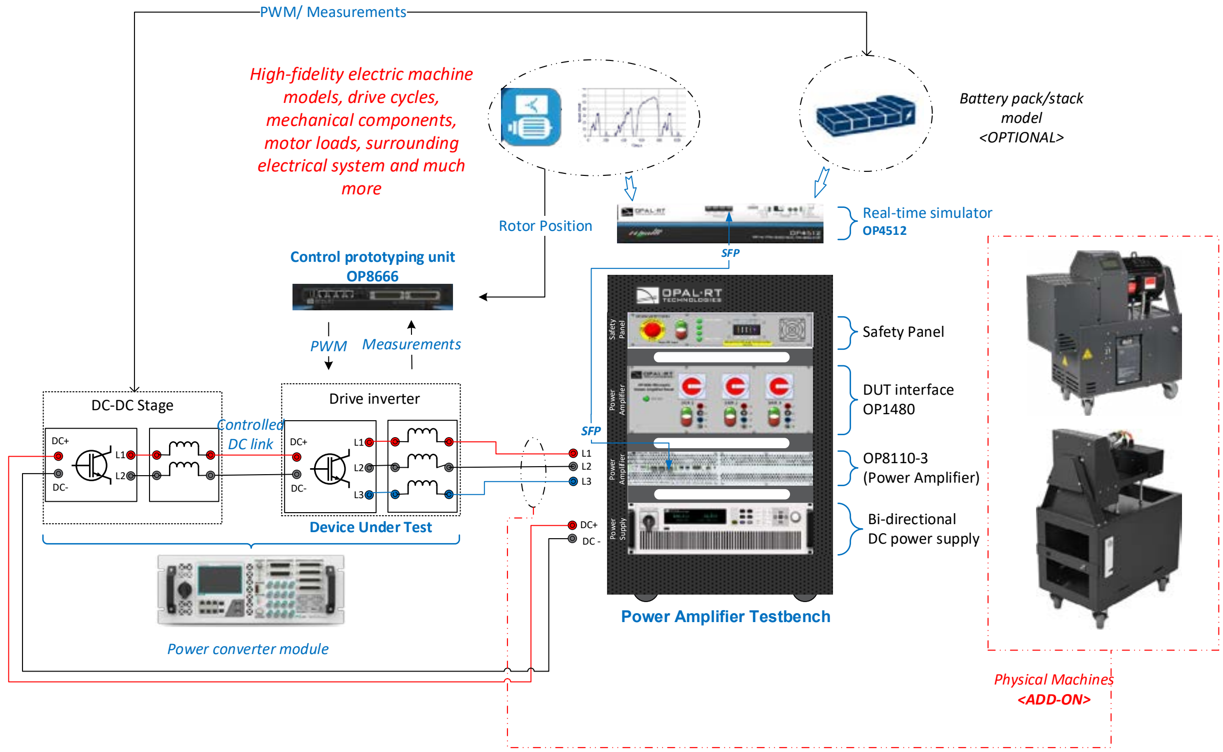


Figure 1: Schematic overview of OPAL-RT's Motor Emulator Testbench (OP1600)

A schematic overview of OPAL-RT's Motor Emulator Test Bench (OP1600) is shown in Figure 1. The heart of the OP1600 is OPAL-RT's high-performance amplifier OP8110-6 which achieves a bandwidth of 10 kHz. The OP1600 also consists of a power converter module, which operates as a drive inverter and as a DC-DC stage. The brain of the OP1600 is its HIL simulator, which contains several processor cores and a powerful FPGA capable of simulating complex systems in real-time. The OP4512, as well as all the other of our strong FPGA-oriented hardware platforms, supports modeling of several types of electric machine models including various topologies of permanent magnet synchronous machines and induction machines. OPAL-RT's FPGA-based electrical solver eHS allows implementing complex drive inverter topologies on its FPGA as well. The versatility of the system is further augmented by the flexible control prototyping unit, OP8666 , used to implement innovative drive control strategies.

Motor Emulator	CHIL	RCP
✓ Test various drive inverter control strategies on an emulated motor at power level	✓ Test various drive inverter control strategies on a simulated motor and drive inverter	✓ Test various drive inverter control strategies on a physical motor and dynamometer
✓ Emulate various motor models (PM, IM, BLDC) using the OP8110-6	✓ Simulate various motor models (PM, IM, BLDC) and drive inverters on the HIL Simulator	✓ Compare emulated and real motor behavior for observation and education of motor control engineers
✓ Configurable motor parameters during run-time	✓ Configurable motor and drive inverter parameters during run-time	
✓ Understand the complex functionality of motor emulation as a means of innovative motor controls testing at power level		

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FLEXIBLE
Change the motor type by just loading another model

OP1600 High-Level Specifications	
EMULATOR OUTPUT	208Vrms (3-Æ) 5 kVA
PHYSICAL MOTOR	208Vrms (3-Æ) 2 kW
DRIVE DC LINK	Up to 350 VDC
EMULATOR BANDWIDTH	2.5 kHz
DRIVE BANDWIDTH	Up to 500 Hz
MOTOR TYPE	PMSM, IM, BLDC
ENCODER TYPE	Resolver, Encoder, Hall
MOTOR SPEED	Up to 15000 rpm (2 pole)
MOTOR PROGRAMMABLE PARAMETERS (EMULATOR)	Inductances, poles, resistance, flux, mechanical inertia and friction, etc.

Table 2: Motor Emulator Testbed High-Level Specs

The OP1600 Motor Emulator Test Bench can be used to study various phases of the development cycle of a motor drive system. Modules addressing specific phases, which can be implemented with the OP1600, are indicated in Table 1. Along with the base module offering of PHIL-based Motor Emulation, OP1600 can help realize modules of controller-hardware-in-the-loop (cHIL) and rapid-control-prototyping (RCP). High-level specifications of the OP1600 Motor Emulator Testbed are indicated in Table 2. ■

IEEE Power & Energy Society General Meeting: Spotlight on Real-Time Simulation and a Night of 90s Fun

At the 2024 IEEE Power & Energy Society General Meeting in July, OPAL-RT TECHNOLOGIES showcased its innovation and expertise in the power systems sector. A highlight was **Jean Bélanger**, OPAL-RT's President and CTO, who delivered an insightful presentation on *"Design & Testing of WAMPAC for Stabilizing Very Large Grids."* His talk emphasized the importance of full EMT real-time HIL simulations on HPC and cloud platforms for addressing transient stability and cybersecurity.

Jean-Nicolas Paquin, Vice President of Electrical Engineering and Expertise, also contributed to the panel session on **EMT Simulations: Solvers & Applications** with his presentation titled *"Leveraging Real-Time Simulation Technology for Large-Scale, Multi-Fidelity Simulation Studies."* He illustrated how real-time simulation is redefining solutions for complex power system challenges.

Wei Li, OPAL-RT's Power Electronics Team Lead, further enriched the discussions with his presentation on *"Real-Time HIL Simulation of Modular Multilevel Matrix Converter Using Switching Function Model,"* highlighting the intricacies of simulating advanced power electronics.

These presentations, alongside insights from other distinguished speakers, sparked engaging discussions on the evolving role of real-time simulations in engineering.

Beyond the technical sessions, OPAL-RT hosted the **Retro Games & Demos** event on July 24th at the VIP Hospitality Suite in SPIN Seattle. This evening offered attendees a nostalgic experience with classic games, cocktails, appetizers, and live demos of OPAL-RT's latest real-time simulation technologies.

The event fostered a unique environment for networking and interaction, blending entertainment with innovation. We extend our gratitude to everyone who contributed to making the event a success and look forward to hosting more exciting events in the future!

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