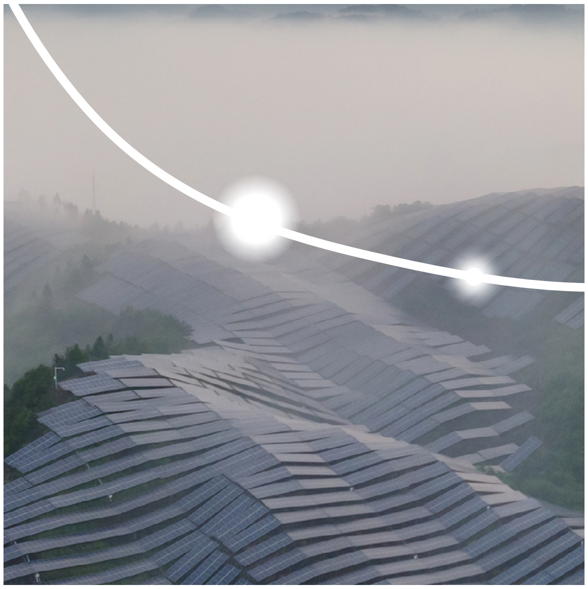
VOLUME 6
WINTER 2024

POWER IN MIND



NEWS, INNOVATION,

& BREAK THROUGHS

A Word from the Editor

Hello again, and welcome to another great edition of OPAL-RT's Power in Mind Magazine. Before you dive into this edition, let's talk a little bit about FPGAs.

To provide some background, a field-programmable gate array (FPGA) is a type of integrated circuit that can be programmed or reprogrammed after manufacturing. It consists of an array of programmable logic blocks and interconnects that can be configured to perform various digital functions.

The first commercially available FPGA was released to the world in 1985 by Xilinx. Soon after this introduction, the 1990s were a period of rapid growth for FPGAs, both in circuit sophistication and the volume of production. In the early 1990s, FPGAs were primarily used in telecommunications and networking. By the end of the decade, FPGAs found their way into consumer, automotive, and industrial applications.

Real-time simulation of power electronics remains one of the greatest challenges to HIL simulation. The I/O capability for capturing PWM frequency, the overall latency of the closed-loop simulation, and the mathematical solving of coupled switches and fault injection on all stages of complex power electronics schematics are just some of the complexities of this evolving industry.

After two decades of real-time simulation research and development, together with hands-on experience with power electronics, OPAL-RT has delivered eFPGASIM, the industry's most powerful and intuitive FPGA-based real-time solution. eFPGASIM combines the performance of high-fidelity digital simulators with very low communication latency to provide power electronics engineers with a state-of-the-art HIL platform for the development and testing of control and protection systems.

And now, we have introduced the most powerful simulator on the market powered by the AMD Versal™ FPGA Technology which will truly allow you to unleash power electronics simulation potential.

With the power of FPGAs, you can embrace complex power electronic circuits, such as power converters, without the constraints of yesterday's decoupling techniques. Double your simulation capacity for agile development and innovative control strategies with unparalleled precision and near-zero latency.

In this edition of Power in Mind, we will take a closer look at the need for FPGA processing and computing power in the simulation across multiple industries.

Etienne Leduc,
Head of Energy Market

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.

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Behind the Cover

This photograph capturing a solar power station atop a mountain, overlaid with a line of progress and glowing dots of possibility, illustrates the ascent to sustainable power. It displays the profound potential and promise when human innovation intertwines with nature's strength.

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Battery Management System Testing: HIL Simulation Innovations

By: Nadine Hariri, Go-to-Market Manager, MARKETING & COMMUNICATIONS

In the fast-evolving landscape of battery technologies, the spotlight on Battery Management System (BMS) testing has never been more critical. As batteries become increasingly integral to our daily lives, from powering electric vehicles to supporting renewable energy infrastructure, ensuring the reliability and safety of these energy storage systems is paramount. The cost of ownership is still a limiting factor in EV adoption, and given the high cost of batteries, governments are investing heavily into this application and various trends are on the rise to maximize the lifespan and minimize cost of batteries.

The Importance of BMS Testing Today

As battery technologies advance, the role of the BMS becomes more complex and vital. The BMS is the brain and guardian of the battery, monitoring and controlling its various parameters to optimize performance, enhance safety, and prolong lifespan. Given the increasing integration of batteries across diverse applications, from electric vehicles (EVs) to grid storage, the need for robust BMS testing has become a critical factor in ensuring the seamless and reliable operation of these systems.

Trends in Battery Technologies Impacting Testing

Higher Energy Density: Advancements in battery technologies are leading to batteries with higher energy density. While this is a boon for extending the range of electric vehicles and increasing the efficiency of energy storage systems, it also presents challenges in managing thermal issues and ensuring the safety of these high-density batteries.

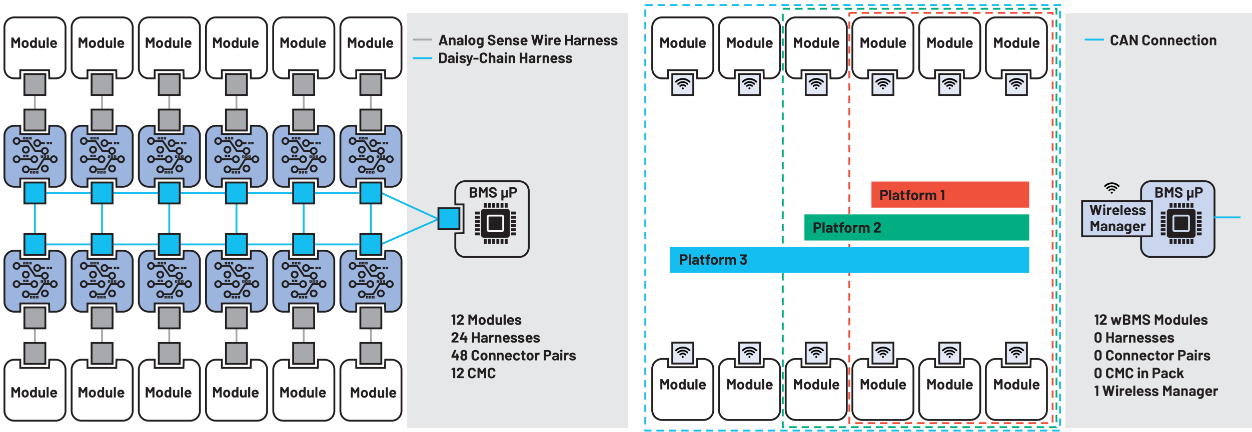


Figure 1. A typical complex, multicomponent wired BMS network (left), and the simpler arrangement made possible by Analog Devices' wBMS technology (right).
Image: Courtesy of wBMS Technology: The New Competitive Edge for EV Manufacturers

Fast-Charging Capabilities: The demand for faster-charging batteries is on the rise, especially in the automotive sector. This trend requires BMS testing to ensure that the batteries can handle rapid charging without compromising safety or long-term reliability. Battery swapping is also a popular subject of interest, being heavily used in China and India. This also poses design challenges in the configuration of the BMS system.

Integration of Solid-State Batteries: The development and integration of solid-state batteries pose both opportunities and challenges. BMS testing needs to adapt to the unique characteristics of solid-state batteries, such as their improved safety and potential for higher energy density.

Sustainability and Recycling: With a growing emphasis on sustainability, the choice of materials in battery production is evolving. BMS testing now needs to consider the impact of these changes on the overall performance and longevity of batteries, as well as the potential challenges in recycling. This has resulted in various battery chemistries and applications being explored.

For example, an EV battery is considered end-of-life when it has lost around 20% of its power capacity. However, although it cannot be used for this purpose, it may be able to satisfy the needs of another application, such as grid storage.

These trends are heavily impacting the design of battery management systems, requiring them to be more modular, to be easily disassembled and reassembled, to be wireless, and to enable faster and cheaper repairs. However, this introduces a whole new set of concerns, including threat analysis, rigor in fault and simulation testing, managing vulnerabilities.

Hardware in the Loop (HIL) Simulation: A Game-Changer in BMS Testing

HIL simulation has emerged as a revolutionary tool in BMS testing, allowing engineers to create a realistic and controlled testing environment. By integrating real hardware components into a simulated environment, HIL simulation enables comprehensive testing scenarios that mimic real-world conditions. This is particularly crucial in BMS testing, where the system's response to various operational scenarios can be accurately assessed .

The advantages of HIL simulation include:

1. **Realistic Environment:** HIL simulation replicates the dynamic conditions that a BMS would face in actual operation, allowing engineers to evaluate its performance under a wide range of scenarios.
2. **Cost-Effective:** Traditional testing methods can be expensive, especially when considering the vast array of conditions batteries may encounter. HIL simulation allows for cost-effective and efficient testing without the need for physical prototypes.
3. **Accelerated Testing Timelines:** HIL simulation enables rapid testing cycles, significantly reducing the time it takes to identify and rectify issues in the BMS.

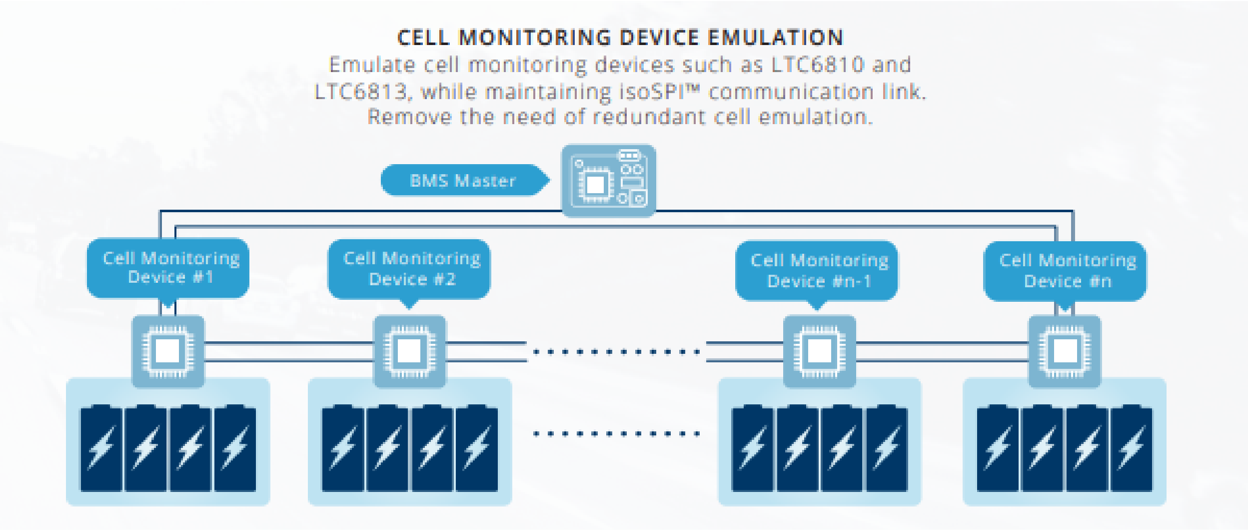
FPGA Technology Transforming Testing

In tandem with HIL simulation, the integration of FPGA-based software technology is transforming the landscape of BMS testing. Customers are increasingly adopting software-based approaches to further virtualize and simulate testing processes, and FPGA technology allows for targeting the performance and emulation needs required for this type of testing. This shift provides additional advantages and test coverage.

OPAL-RT has developed the Cell Monitoring Device Emulation (CMDE) add-on for NI VeriStand, a virtualization technology for BMS cell monitoring devices from major brands such as Analog Devices, Inc. (ADI).

Key benefits

- Expanded test coverage and faulting capabilities on the virtualized cell monitoring devices, like temperature faults, open wires, broken communication links, or CRC errors without compromising security by providing intuitive user access to the chip registers.
- Reduced time, cost, and complexity of setting up hundreds of redundant physical cell emulators by virtualizing commercial integrated circuits designed for cell monitoring, while still maintaining isoSPI™ communication link.
- Maintained integrity of the SPI daisy-chain communication, allowing for connection to real Cell Monitoring Devices as well as physical Comemso cell emulators.



Applications Across Industries

Automotive: BMS testing in the automotive sector ensures the safety and reliability of electric vehicles. HIL simulation allows engineers to assess the BMS's response to varying driving conditions, optimizing performance and extending battery life.

Transportation: BMS testing is crucial in electric buses, trains, and other electrified transportation modes. HIL simulation helps validate BMS performance under diverse operational scenarios.

Aerospace: Batteries are integral to aerospace applications, and BMS testing is essential for ensuring the safety and reliability of these systems. HIL simulation aids in assessing the BMS's response to the unique challenges of aerospace environments.

Power Systems: BMS testing is vital for energy storage systems deployed in power grids. HIL simulation facilitates the evaluation of BMS performance under fluctuating demand and renewable energy source variability.

As battery technologies continue to advance, the importance of robust BMS testing cannot be overstated. The integration of HIL simulation and software technology is revolutionizing the testing landscape, providing engineers with powerful tools to ensure the safety, reliability, and efficiency of BMS across diverse applications. Whether in the automotive sector, transportation, aerospace, or power systems, the evolution of BMS testing methodologies aligns with the broader goals of advancing sustainable and efficient energy storage solutions for the future.

Incorporating OPAL-RT's Simulation Technology into Drive System Design's - Motor Control Development Method

With a proliferation of companies investing in electrification, Drive System Design (DSD) has successfully deployed its Motor Control Development Method to best help partners identify, design, and develop efficient and effective electric motor and inverter control systems.

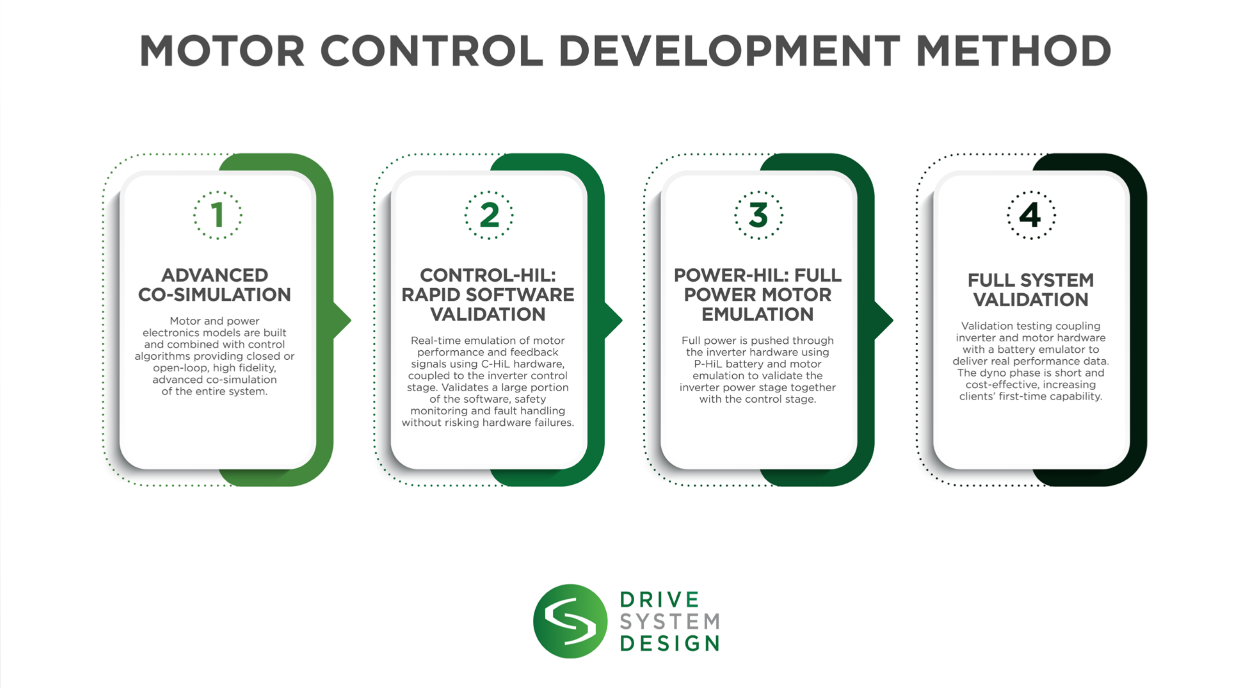
Introduced in late 2022, DSD's approach capitalizes on its electrified propulsion system expertise and ability to span simulation lead design, virtual validation and physical validation, bringing together a unique four-step process. Too often, the company found that industry players were jumping from design release to hardware testing, only to end up with complex hardware issues to overcome and stopping critical programs in their tracks.

With the help of OPAL-RT's Control Hardware-in-the-Loop (C-HIL) and Power Hardware-in-the-Loop (P-HIL) technology, DSD's method ensures more robust, reliable control architecture and algorithms before ever touching a dynamometer (dyno) test cell. This minimizes risk while saving potentially months of time and tens of thousands of dollars for its customers.

DSD's approach encompasses the following:

Phase 1: Concept evaluation and design with advanced co-simulation

Control algorithms, finite element analysis (FEA) motor models and the power electronics model are designed and developed during this phase. A closed-loop, advanced co-simulation



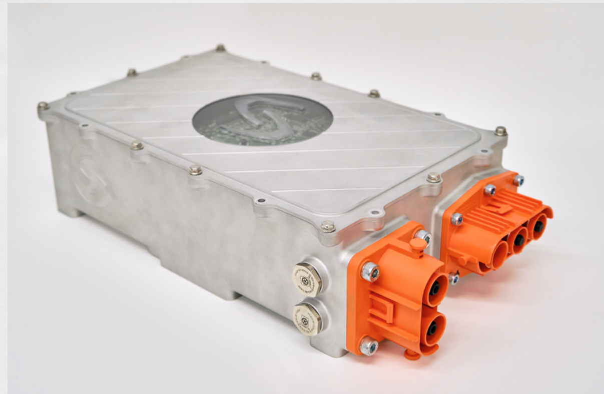
of the entire system is then performed, which helps identify any early-stage electromagnetic and control interaction challenges, as well as providing key data for higher level system analysis activities.

Phase 2: Detailed design and validation with C-HIL

During this phase, DSD leverages OPAL-RT's C-HIL equipment, which was customized for DSD's specific use cases, to emulate motor behavior and sensor feedback so that a large proportion of the software and low voltage hardware validation can be performed. DSD utilizes inverter control board hardware with deployed software and the real-time simulation of the motor model to enable development and validation of safety monitoring and fault handling.

Phase 3: Component level testing with P-HIL

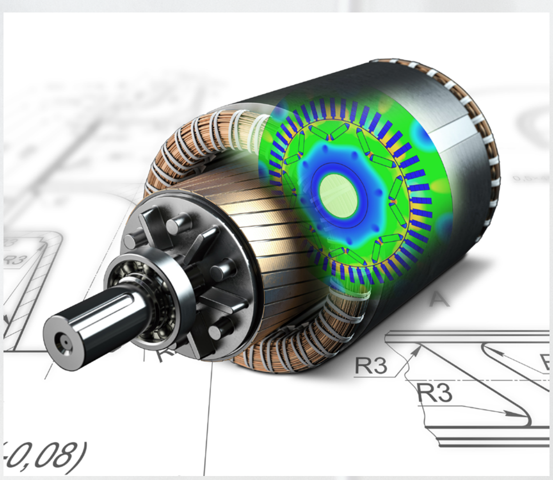
At this stage, DSD utilizes OPAL-RT's P-HIL equipment, which is capable of emulating motor behavior at full power. Full power is run through the inverter with deployed software, along with a battery and high voltage motor emulator. Whilst the motor is emulated, real current and power is being pushed through real inverter hardware to validate its power stage and control. As needed, DSD can leverage its open platform inverter to develop, calibrate, and validate the motor controls quickly and efficiently in this phase of testing.



Phase 4: System level testing and validation on a dyno test cell

After completing phases 1-3, the motor enters the dyno test cell for system validation utilizing inverter and motor hardware together with a battery emulator.

Through this comprehensive approach, DSD's customers have been successfully developing complex new motor control architectures and pairing inverters and motors far more effectively, ahead of shorter, more efficient physical validation programs. Applicable to an array of motor technologies, DSD is confident that this robust method and advanced equipment will take the company – and their partners – far into the future.



Learn more

DSD and OPAL-RT are partnering on a series of webinars taking place in March onwards, to explore each phase of this unique process. Watch out for LinkedIn announcements and register at mobex.io/webinars to tune in.

DECIPHER THE ANAGRAM AND FIND THE SECRET MESSAGE

Unlocking the Potential of FPGAs in Real-Time Simulation

Real-time simulation in power electronics presents formidable go-to *Hardware-in-the-Loop (HIL) systems. Addressing intricacies like capturing PWM frequency and minimizing simulation latency demands innovative solutions. Over two decades, OPAL-RT has led in real-time simulation, culminating in eFPGASIM, an FPGA-based solution.*

Testing *combines high-fidelity digital simulation with minimal latency, empowering engineers with a potent HIL platform. By seamlessly integrating within the* Ecosystem*, engineers can go* beyond *boundaries in their endeavors.*

Engineers may leverage comprehensive integration for holistic efforts, interacting with *complementary products such as ePHASORSIM. Supported by diverse communication protocols and a robust API, they can explore new horizons.*

The Power Electronics Toolbox streamlines workflows. Engineers can utilize tools like the Electric Machine Library and Real-Time XSG editor for efficient development. Notably, FPGA Modular Multilevel Converter (MMC) Models provide high-fidelity simulations.

eFPGASIM *accelerates development in electrical drives, offering sub-microsecond time steps for control and protection system performance.*

OPAL-RT's collaboration with National Instruments brings NI hardware, ensuring compatibility with LabVIEW and VeriStand environments. This partnership enhances integration, empowering engineers with a unified simulation platform.

In a precision-driven world, eFPGASIM catalyzes transformative advancements. With unparalleled performance, seamless integration, and boundless potential, it empowers engineers to transcend limitations in electronic system development.

Some industry leaders that use eFPGASIM for innovation and validation are Valeo, Ford Motor Company, and ABB. Doing this, they achieve success in powertrain solutions, hybrid driveline designs, and medium voltage power converters.

As technology advances, the demand for robust simulation solutions grows. OPAL-RT sets a new standard, empowering engineers to innovate confidently.

Secret message: ___ ________ ____ ___________ ___________ ________

LOOK FOR THE ANSWER ON THE LAST PAGE.

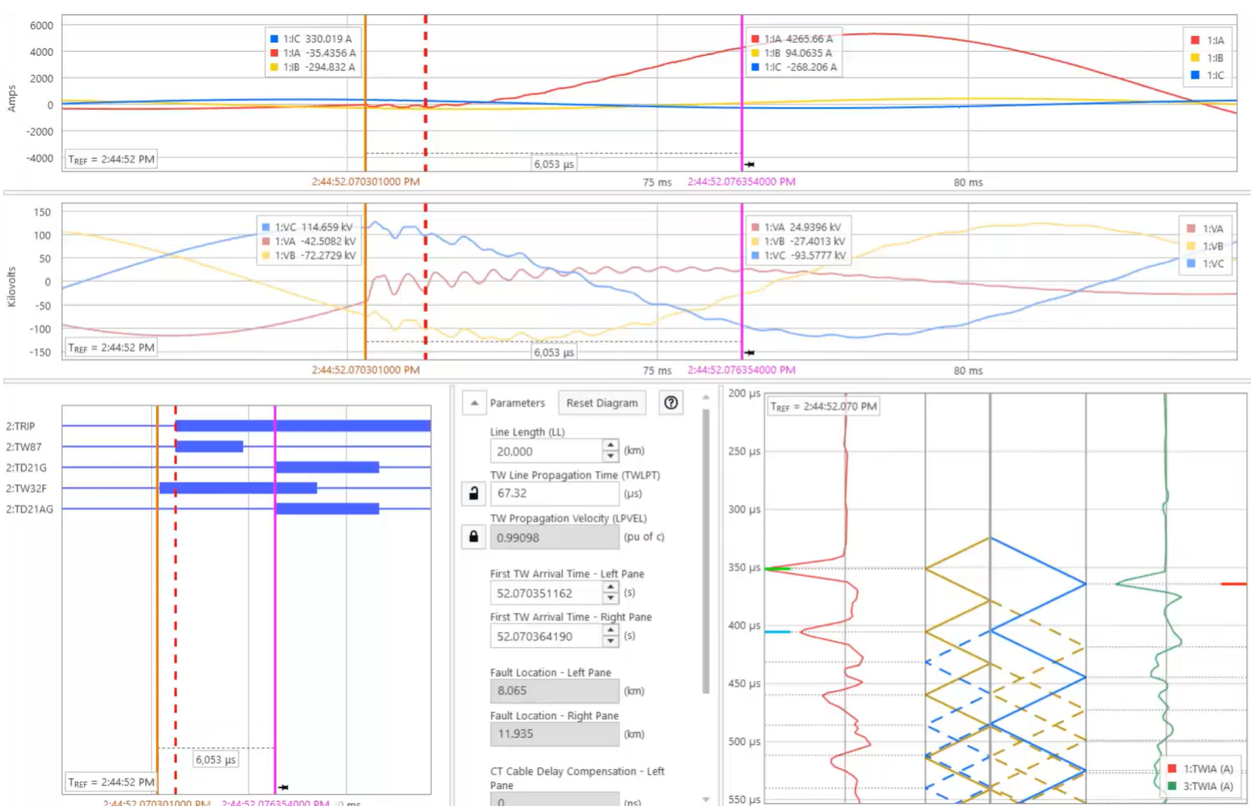
Innovations in Traveling Wave Relay Testing for a Sustainable Energy Future

The evolving landscape of power systems, marked by the rapid proliferation of Inverter-based Resources (IBRs), is swiftly reducing the overall grid inertia. This paradigm shift necessitates a reevaluation of protection strategies, driving the growth of the traveling wave protection market. Moreover, this technology holds promise for mitigating arc flashes and preempting wildfires.

Testing traveling wave (TW) relays poses formidable challenges, compounded by the complexities of high-frequency phenomena and increasingly complex network topologies. The stringent demands of TW fault location algorithms, requiring data acquisition rates up to 5 MHz for precise capture of transient events, underscore the need for precision in the testing process.

In collaboration with industrial partners, OPAL-RT is at the forefront of addressing these challenges. Through advancements in its FPGA-based power system and power electronics simulation toolbox, the eHS solver offers the capability to simulate highly precise frequency-dependent (FD) lines at timesteps as low as 500 ns across diverse network topologies. With the ability to simulate up to 15 FD line segments together with CP and PI lines on a single FPGA, and the scalability to combine multiple FPGAs for virtually any network size, OPAL-RT provides a comprehensive solution.

Our approach integrates cutting-edge simulation techniques with HIL testing methodologies to navigate the complexities of TW relay testing. By ensuring the fidelity and efficacy of TW relay systems in safeguarding power transmission networks against transient disturbances and emergent threats, we contribute to forging a robust and sustainable energy future through innovation and collaboration.



GE Vernova's Power Conversion Keeps German Trains on Time

Introduction | Heading Bravely Forward into the Green Revolution

The 21st century demands of green power generation (stretching over various and multiple shareholders) unquestionably require a cooperative approach. Intriguingly, and perhaps as a demonstration of how larger companies can address both the multi-faceted and inter-related concerns of de-carbonization and forward-looking sustainability, **GE Vernova's 12 lines of business (shown below)—** and operating in 140 countries—have chiefly in common that they research, manage, set up and run renewable digitally hosted energy and carbon reduction businesses and R&D labs of various types.

GE Vernova has taken the 'boutique' approach, or what might alternately be called 'one-stop shop', by consolidating efforts and business lines (in some cases through acquisition) in order that their complete service offering includes not only the DER generation aspects, but also the financing, storage and think tank/R&D development and consulting efforts under one umbrella. This in-house expertise streamlines and speeds up projects and minimizes outsourcing and reliance on non-core partners.

GE VERNOVA'S 12 LINES OF BUSINESS

ONSHORE WIND

- 7GW of ONW reduces our carbon intensity 1 g/kWh
- Repowering extends life and improves capacity factor of aging wind farms

OFFSHORE WIND

- 5GW of OFW reduces carbon intensity 1 g/kWh
- Higher capacity factors get more TWh per unit of capacity

LM WIND

- Blade technology vital to higher capacity factors
- Two-piece blades reduce transport logistics (and associated indirect emissions)

HYDRO POWER

- Efficiency upgrades increase TWh of zero-carbon hydro
- Pumped storage projects enable greater variable renewables

GAS POWER

- 8 MTPA of CCUS reduces our carbon intensity 1 g/kWh
- 8GW of peakers upgraded to 100% H_2 reduces carbon intensity 1 g/kWh

NUCLEAR POWER

- 3GW of SMR reduces carbon intensity 1 g/kWh
- Refueling and life extensions enable more TWh of carbon-free power

POWER CONVERSION

- Enables decarbonization of mission-critical industrial applications
- Off-grid microgrids enable low-carbon solutions in remote locations (Ports, FPSO, Mines)

GRID SOLUTIONS

- Enables necessary grid expansion, stability and flexibility to renewables growth in the power system
- Grid-tied microgrids enable resilient, decentralized low-carbon power islands

STEAM POWER

- Upgrades/extends life of nuclear plants and maintains a largely renewable industrial fleet in the Americas
- Supporting global customers with best-in-class services including end of life as they transition away from coal

DIGITAL

Software that:

- Orchestrates a secure, cleaner energy grid
- Accelerates the transition to zero- and low-carbon energy resources
- Reduces emissions & waste today through efficiency insights

SOLAR & STORAGE SOLUTIONS

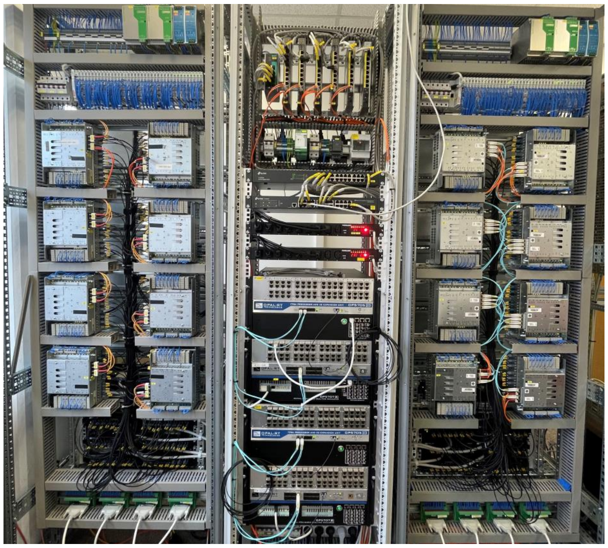
- Batteries and hybrids extend dispatch of renewables enabling reduction of fossil generation for short-durations
- Refueling and life extensions enable more TWh of carbon-free power

FINANCIAL SERVICES

- Financing and securing tax equity are key enablers for zero-carbon projects
- Project development and carbon monetization schemes vital to early carbon capture demonstration pilots

"You can run whichever tests you want; you can do hundreds or thousands, and it's never enough. Issues will absolutely occur and what you must do is to replicate them in a HiL simulator. If you don't have one, you're lost—that's for sure."

Dominik Hofmeyer, GE Vernova



In an encouraging nod to the wide variety of energy forms to come, GE Vernova is responsible for helping in one way or another with a staggering 30% of the world's electricity generation:

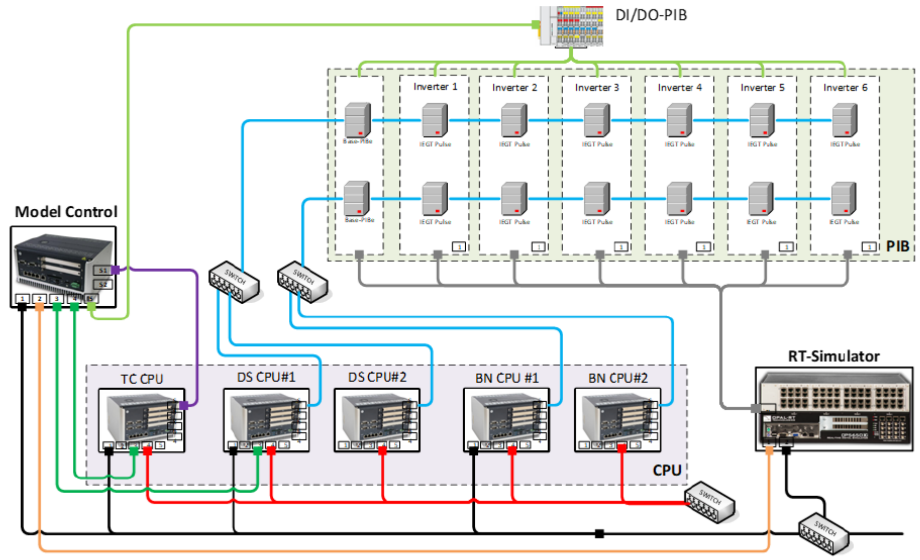
"***We have experienced a transition not only in the energy market, but also in our company. (...) And it's a bit overwhelming,***" says RT23 GE Vernova presenter Dominik Hofmeyer.

With over 54,000 wind turbines installed in over 50 countries, providing over 2,200GWs of installed power, this massive 1 billion Euros advanced research and applied engineering effort really gives us some sense of reach on what the green energy transition might actually mean.

> *"You want to do a controller revamping, and you have a hard-earned certification; you don't want to lose this same certification, so you must guarantee in some sense that before and after it behaves the same. This is what we typically do."*
>
> *Dominik Hofmeyer,*
> *GE Vernova*

Testing the Catenary Supply Medium Voltage SFC

When German trains run on time, it does not happen by accident; a plethora of engineers toil in the background to keep things running smoothly as much as possible, and GE Vernova Power Conversion engineers are themselves no exception. Their MV7308 stacked converter consisting of 6 converters of 19 MVA each, switching at 150 Hz, is controlled by no less than 5 embedded CPU controllers and 14 FPGA controllers, having a total of 116 analog inputs and 126 IGBT firing signals. This highly complex controller architecture necessitates extensive hardware and electronic testing capabilities that are fortunately found in OPAL-RT's robust, scalable, and field-proven simulation systems.



Read the full Success Story at our Resource Center:
opal-rt.com/resource-center/

Collaborative Research: École de Technologie Supérieure

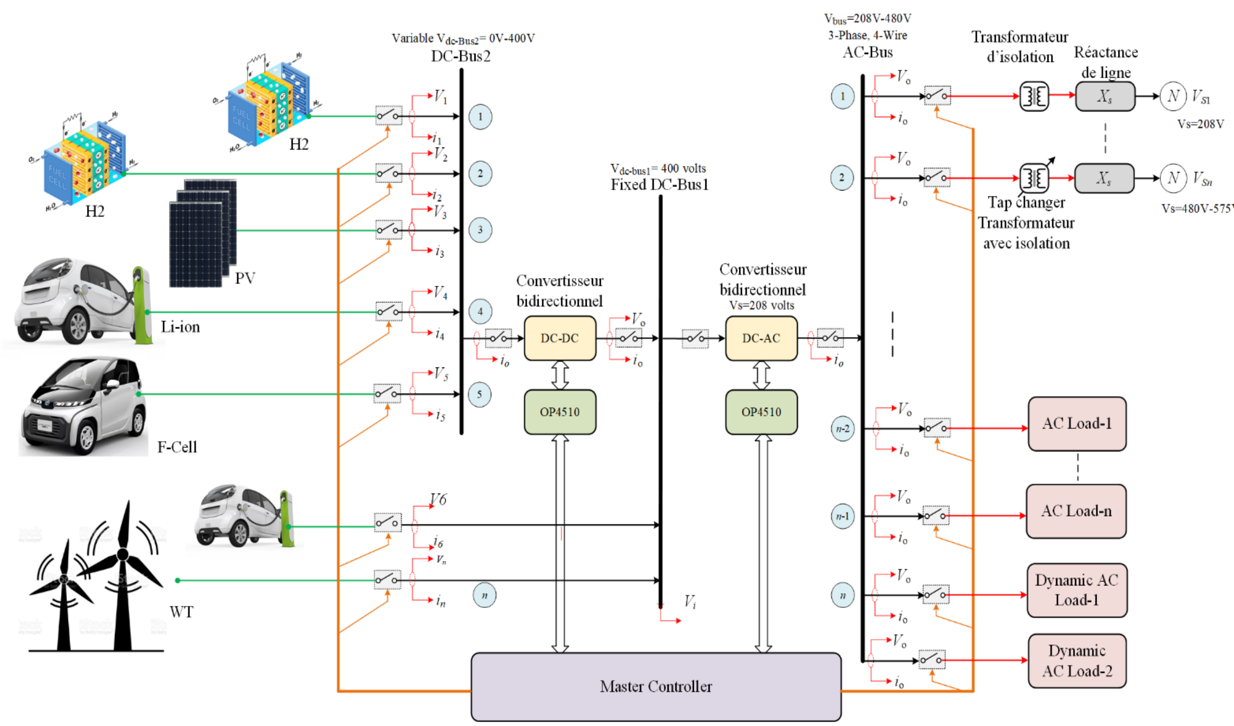
A Laboratory without Walls

The collaborative research infrastructure, spearheaded by the Power Electronics and Industrial Control Research Laboratory at École de technologie supérieure in Quebec, focuses on microgrid and smart grid applications to advance renewable energy integration and transportation electrification. Operating as a "laboratory without walls," it facilitates remote access and seamless collaboration, with a key emphasis on real-world data validation provided by partners.

The primary project objective is the creation of an AC and DC microgrid as well as an open-architecture smart grid, designed to integrate renewable energy sources like hydrogen, solar, and wind. Notably, the infrastructure's uniqueness, equipped with Power-Hardware-In-The-Loop (PHIL), lies in its ability to operate at variable and adjustable voltages for alternating current buses (up to 480 volts three-phase, 4 wires) and direct current (up to 400 volts).

With the capacity to connect up to 10 loads per AC and DC bus, it offers a comprehensive testing environment for energy technology manufacturers in Quebec. This feature allows comprehensive testing of various industrial systems or prototypes, accommodating cumulative power levels.

The hybrid intelligent network, featuring cascading converters, supports bidirectional energy flow and programmability, enabling it to operate in connected or isolated modes. Additionally, the infrastructure incorporates an intelligent Internet of Things (IoT) sensor network for real-time measurements and Deep Learning Energy Balancing, ensuring precise control over energy exchange while regulating bus voltages. This platform also offers the possibility to develop techniques for preventing cybersecurity concerns, enhancing the overall robustness of the network.



Collaborative Research: University of British Columbia

Accelerated Development of Hybrid Multilevel Converters

The development and integration of renewable energy sources have become paramount in meeting growing energy demands while curbing carbon emissions. Voltage-source-converter-based high voltage direct current (VSC-HVDC) transmission is crucial for integrating large-scale renewables into power grids, with modular multilevel converters (MMC) emerging as a leading technology due to their modularity, reduced harmonics, and enhanced efficiency. Dr. Liwei Wang's research team at the University of British Columbia, Okanagan, focuses on advancing hybrid multilevel converters, combining the benefits of conventional VSCs with those of MMCs. Utilizing OPAL-RT technologies, they employ advanced real-time simulation tools and hardware testbenches to develop and validate new converter topologies and control strategies swiftly. An example includes the creation of a scaled-down prototype of a hybrid three-level converter with AC-side cascaded full-bridge submodules (SM), featuring complex circuitry, control loops and SM capacitor voltage balancing method. OPAL-RT's simulation tools and FPGA-based platforms accelerate development by enabling switching modulation implementation and control algorithm execution. The integration of Xilinx FPGA and RT-LAB/RT-XSG models allows for precise control and monitoring of SM operations, streamlining gating control through optical fiber interfaces between the OP45/0 and OP1200. Integrated measurement capabilities in OP1200 modules facilitate data logging for analysis. In summary, OPAL-RT's hardware testbenches and real-time control/simulation hardware expedite converter control prototyping, significantly advancing the development of new multilevel converters for efficient renewable energy integration.

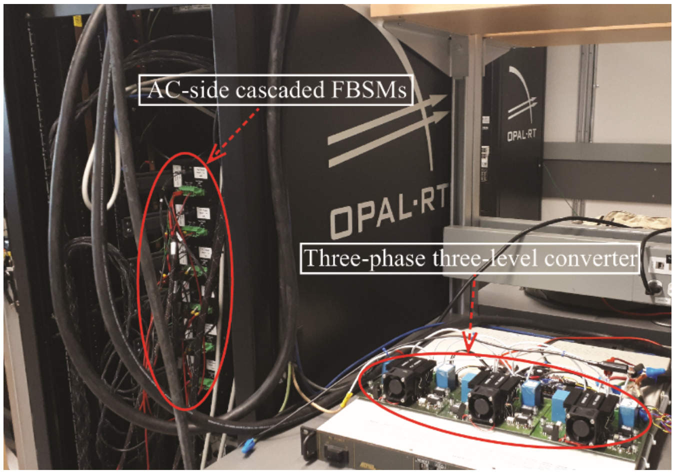


Figure 1. Hybrid three-level converter scaled-down prototype, implemented using MMC testbench and OP1200

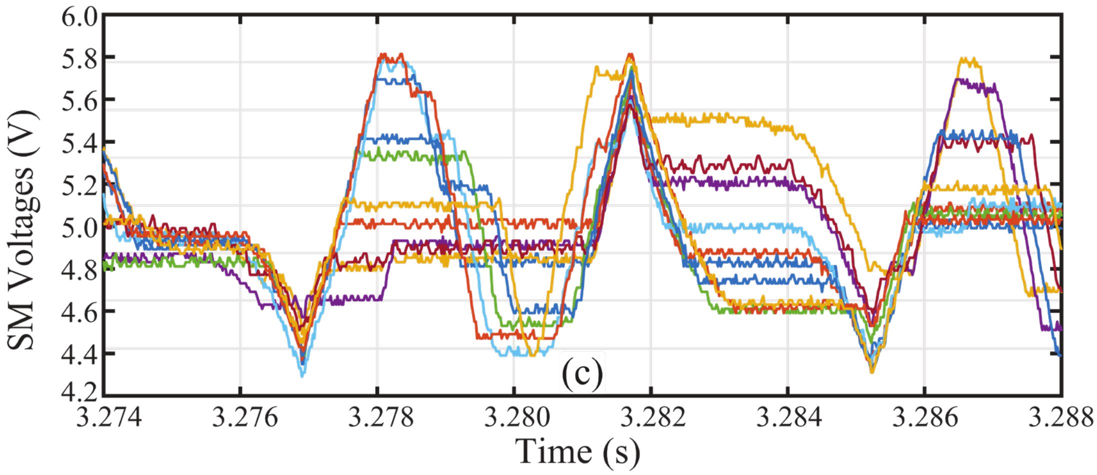


Figure 2. Hardware results logged from Simulink through MMC testbench voltage and current measurements

Empowering customers and industry professionals with OPAL-RT University

OPAL-RT University is a holistic initiative aimed at cultivating internal synergy and customer-centric mastery. With your benefits at the forefront, the program:

- **implements specialized training and content**
- **focuses on elevating your team's skills**
- **shares valuable knowledge with you**

Our active external engagements and strategic partnerships further our commitment to building a strong corporate alliance, ultimately aimed at delivering excellence and ensuring your satisfaction.

For more information and resources, visit https://www.opal-rt.com/courseware/

OPAL-RT
UNIVERSITY

UPCOMING EVENTS

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RT24

ELECTRIFYING THE WORLD BEYOND REAL TIME

MORE INFORMATION COMING SOON

USA
SOUTH AMERICA
UK
INDIA
KOREA
JAPAN

WORKSHOPS & CONFERENCE
POWER SYSTEM
ENERGY CONVERSION
EMOBILITY

ABOUT US

Founded in 1997, OPAL-RT TECHNOLOGIES is the leading developer of open real-time digital simulators and Hardware-In-the-Loop testing equipment for electrical, electro-mechanical and power electronic systems.

OPAL-RT simulators are used by engineers and researchers at leading universities, manufacturers, utilities, and research centres around the world.

OPAL-RT's unique technological approach integrates parallel, distributed computing with commercial off-the-shelf technologies.

The company's core software, RT-LAB and HYPERSIM, enables users to rapidly develop models suitable for real-time simulation, while minimizing initial investment and their cost of ownership. OPAL-RT also develops mathematical solvers and models specialized for accurate simulation of power electronic systems and electrical grids. RT-LAB, HYPERSIM and OPAL-RT solvers and models are integrated with advanced field programmable gate array (FPGA) I/O and processing boards to create complete solutions for RCP and HIL testing.

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SECRET MESSAGE: Go Beyond with eFPGASIM Ecosystem Testing