MIST Capability Statement

Hardware-in-the-Loop Testing

ERGON ENERGY
NETWORK
Part of Energy Queensland

Overview of Testing Approaches

Performance testing for medium to high voltage devices is commonly conducted using two main approaches: physical hardware testing and simulation-based analysis. Physical hardware testing offers the most precise representation of system behaviour. However, it is frequently constrained by the availability of suitable test equipment, leading to increased costs, extended timelines, and practical limitations. Moreover, defining the full performance characteristics of a system often demands unique testing scenarios, which can be challenging to implement with actual hardware.

In contrast, simulation-based testing provides a more cost-effective solution that enables the replication of intricate scenarios, as well as straightforward modifications to device configurations without the need for physical redesigns. Nevertheless, the creation of an accurate model that faithfully emulates the behaviour of a physical device remains a complex undertaking. The recent advancements in computational capabilities have paved the way for real-time computers that can simulate power electronics with microsecond-level timesteps. This advancement allows simulated systems to interact with dynamic physical devices, thereby merging the strengths of hardware and simulation-based testing while compensating for the limitations inherent to each method.

Hardware-in-the-loop (HIL) testing is a methodology that leverages digital and analogue signals to translate simulated outputs from a real-time computer into physical signals compatible with the device under test. Sensors are then employed to feed the physical responses of the device back into the simulation environment, thus establishing a closed-loop feedback system. This integration effectively immerses the physical device within the simulation, bridging the gap between exclusively hardware and exclusively simulation-based testing. By doing so, HIL testing optimally harnesses the benefits of both approaches.

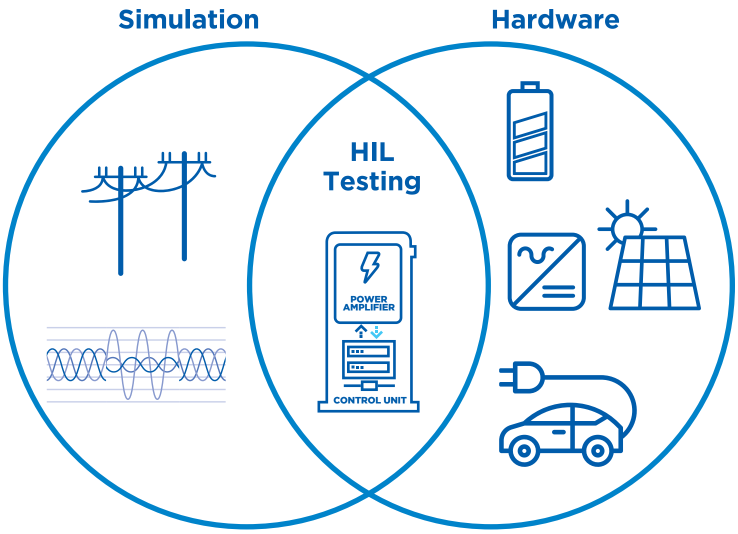


Figure 1: HIL testing Venn diagram

Control Hardware-in-the-Loop (CHIL) Testing

Control hardware-in-the-loop (CHIL) testing is a technique in which a physical controller is connected to a real-time simulator using small-scale digital and analogue signals, establishing a closed-loop feedback system. Through this configuration, the control hardware receives inputs and outputs from the simulated system in such a manner that it perceives itself to be interacting with actual physical devices.

This approach enables the assessment of controller performance without the need to set up the physical devices. As a result, CHIL testing offers a cost-effective solution, eliminating the financial and logistical challenges associated with physical device testing. Furthermore, it allows the controller's behaviour to be evaluated under complex system conditions that would otherwise be difficult or impractical to replicate with real hardware, but which can be easily modelled in a simulation environment.

For instance, the control algorithms of a microgrid controller can be thoroughly tested without the need for physical batteries, solar inverters, or diesel generators. This avoids the associated expenses, safety risks, and practical constraints that come with handling such equipment. By leveraging a simulated system, developers can rigorously examine the controller's response to a wide range of scenarios.

CHIL testing is especially valuable during the early stages of controller development, as it provides an efficient means to validate functionality and quickly address any bugs or issues that arise. This accelerates the development process and ensures a robust controller design prior to deployment with physical devices.

Power Hardware-in-the-Loop (PHIL) Testing

Power hardware-in-the-loop (PHIL) testing represents an advancement over CHIL testing by enabling the evaluation of physical devices that are capable of both absorbing and generating power. Unlike CHIL, where the interactions are limited to small-scale digital and analogue signals exchanged between a real-time simulator and a controller, PHIL testing employs devices such as power amplifiers to bridge the gap between simulation and actual power equipment.

In PHIL testing, the real-time simulator sends a reference signal to a power amplifier, which then converts this signal into a form suitable for the device under test. For example, the amplifier might generate a three-phase voltage signal that a physical power device would normally interact with in a real-world scenario. This allows the physical device to operate as if it were connected to an actual power system.

The system is completed by using sensors that capture the physical responses of the device under test. These responses are then converted back into reference signals by the power amplifier, which the real-time simulator can process. This closed-loop feedback arrangement effectively integrates the physical device within the simulated environment, allowing for comprehensive testing and validation of its performance under realistic and dynamic conditions.

Test Equipment Used for CHIL and PHIL Testing

The MIST facility employs advanced equipment designed to support rigorous simulation and testing requirements. Central to this setup is the real-time digital simulator (RTDS) supplied by RTDS Technologies, complemented by a linear power amplifier from Spitzenberger & Spies GmbH & Co.

The RTDS serves as the core of the simulation environment, capable of performing high-fidelity electromagnetic transient (EMT) simulation. Where the simulation timestep is not as critical, the RTDS can also handle larger network models to validate wide-area control schemes.

RTDS offers a range of communication options to interface with external controllers. These include protocols such as Modbus, DNP3, and IEC 61850, as well as ±10 V analogue and digital channel connections. These interfaces allow for comprehensive testing of controller responses within a simulated environment.

For PHIL testing, the MIST utilises a 30 kVA linear power amplifier, which connects to the RTDS via a fibre optic link. This amplifier is designed with four quadrant voltage and current amplification capabilities, enabling it to convert voltage and current reference signals from the RTDS simulation into actual power signals suitable for the device under test.

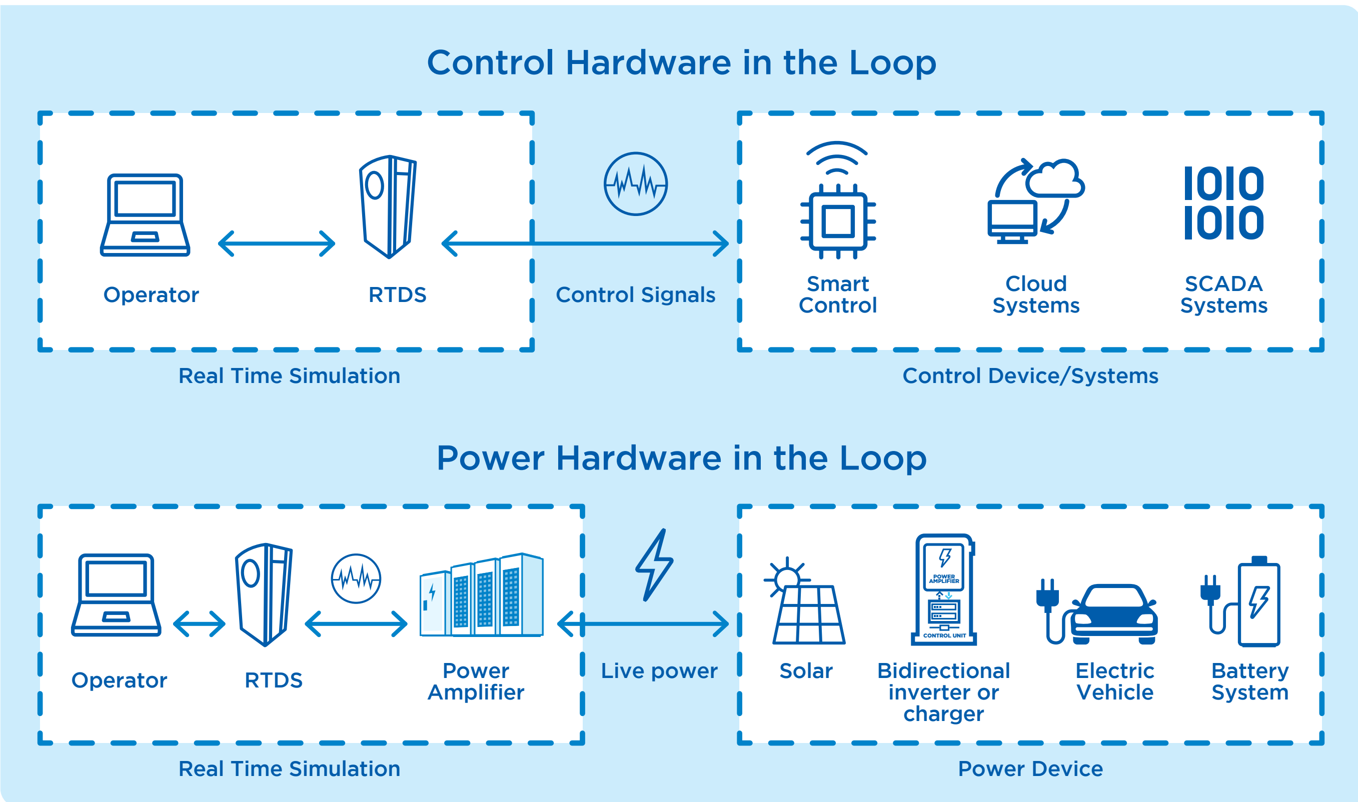


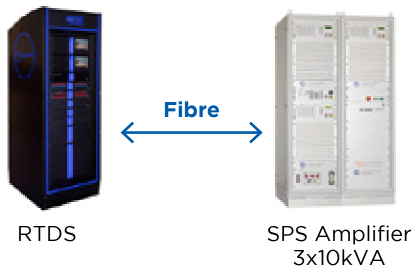
Figure 2: High level comparison of CHIL and PHIL test architectures, (MathWorks, 2019)

The linear power amplifier is distinguished by its extremely low harmonic distortion and rapid rise time of less than 5 µs. It operates across a wide frequency range, from DC up to 10 kHz, and is capable of reaching 50 kHz for small signal applications. This performance ensures precise and reliable delivery of power signals during testing, making it well suited to the demands of PHIL methodologies.

Control Device Testing

- Protection Relays
- Cloud-based Control Systems (e.g. DERMs)
- IEC61850 Devices
- Local Control Systems (PLC/RTU)
- SCADA (DNP3)

Real Time Simulator (RTS) Platform



Power Device Testing

- Inverter/Battery Systems
- Residential/ Commercial Devices
- Standalone Power Systems
- Diesel Genset

Figure 3: Example applications of the RTDS and power amplifier

Case Studies

CHIL (Controller Hardware-in-the-Loop) and PHIL (Power Hardware-in-the-Loop) testing methodologies have been applied across multiple projects conducted at the MIST facility. These advanced testing approaches have supported rigorous evaluation and validation of devices and systems within simulated and real power environments. To explore specific examples of how CHIL and PHIL testing have contributed to project outcomes, please refer to the MIST case studies available on our website.

Contact the MIST Team

The MIST team is composed of highly skilled engineering and electrical service professionals, each bringing a wealth of expertise to support your project requirements. Our team members are experienced in a variety of specialist areas, ensuring comprehensive support throughout your engagement with the MIST facility.

To engage the MIST team please reach out via the Expression of Interest form located on our website.

Areas of Expertise:

- **Power System Modelling and Simulation:** Our professionals are adept at using leading industry software such as Powerfactory, PSCAD, and RSCAD to model and simulate power systems with high accuracy and reliability.
- **Product Testing and Deployment:** The team has considerable experience in testing products and deploying new technologies, particularly in remote and fringe-of-grid locations, ensuring effective integration and operation in challenging environments.
- **Functional Testing and Inspection:** We conduct rigorous functional tests and inspections of small and medium-scale inverter battery systems to guarantee their performance and compliance with industry standards.
- **Control and Operation of Power Generation Systems:** Our expertise includes the control and operation of diesel generators and power stations, supporting the management and optimisation of various power generation assets.
- **Design and Implementation of Standalone Power Systems (SAPS):** The MIST team is skilled in designing and implementing standalone power systems, providing reliable off-grid solutions tailored to specific needs.
- **Power System and Control System Simulations:** We offer detailed simulations of power and control systems, supporting the analysis, validation, and optimisation of new technologies and control strategies.
- **Project Management:** Our professionals provide end-to-end project management, ensuring that all phases from initial concept to final delivery are executed efficiently and effectively.

1. MathWorks. (2019). Hardware-in-the-Loop Testing for Power Electronics Control Design (White Paper).