PHILS(Power Hardware In Loop Simulation)실험 준비에 대한 고찰

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A Review on the necessary points regarding the preparation of PHILS (Power Hardware In Loop Simulation) experiments

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ABSTRACT

The primary objective of employing a real-time simulator and its capabilities lies in its ability to integrate an external hardware component, convincing it that it is connected to its designated real-world counterpart. The success of the experiment hinges on the real-time simulation's ability to accurately replicate the necessary conditions of the experimental setup, ensuring that the results meet the expected standards of accuracy and reliability. However, the integrity of the experiment is jeopardized if the Device Under Test (DUT) discerns its interaction with a simulated rather than a genuine real-world environment, potentially undermining the experiment’s validity. There are two distinctive approaches to employing real-world surrogates in experimental setups: Controller Hardware in Loop Simulation (CHILS) and Power Hardware in Loop Simulation (PHILS). Although each method imposes stringent requirements and a high degree of precision, PHILS necessitates an additional component—a power amplifier. The power amplifier is crucial, acting as a conduit between the simulated environment and the real world by ensuring power levels are not merely represented at a signal level but are actualized. This work builds upon discussions from a previous presentation in the KIPE lecture series in 2024, augmenting it with a series of cautionary notes on experimental setup considerations regarding PHILS and the amplifier.

Keywords- PHILS; Power amplifier; real time simulation; interface between virtual world and real world

1. INTRODUCTION

Real-time simulators become significantly more effective when they integrate real-world elements, blending virtual and actual interactions. For instance, a simulation might replicate a power electronics system's power stack while the actual system uses a controller on a DSP platform. This is typical in Controller Hardware In Loop Simulation (CHILS)[1], where the interaction between virtual and real components is informational. In contrast, Power Hardware In Loop Simulation (PHILS)[2] incorporates actual power to enhance realism, using a power amplifier to bridge the gap between simulated dynamics and real power levels. This approach addresses the limitations of simulators that cannot exchange real power, emphasizing the importance of a power amplifier in such experimental setups.

This paper elaborates on necessary considerations when incorporating a power amplifier as an integral component of the experimental design, thereby expanding upon the interaction dynamics between virtual simulations and real-world hardware.

2. POWER AMPLIFIER – POINTS TO CONSIDER

2.1 TESTING

Before any testing, it’s crucial to inspect the amplifier system's wiring thoroughly, checking all connections, including those from the AC mains to the power supply and between the amplifier and signal generator. This ensures secure connections vital for managing dynamic interactions and potential vibrations during use. After installation, testing the amplifier is essential to confirm its functionality, as transport damage and discrepancies from the manufacturer’s report can affect performance. Stress tests should push the amplifier to its specified limits and check for any performance deviations, ensuring reliable operation under all conditions.

The process of evaluating the amplifier's performance envelope should encompass not just the output voltage and current, but also other critical metrics like output frequency. An illustrative case of this testing phase might involve observing the distortion patterns in the amplifier's current output waveform as the reference frequency approaches its upper limit, as depicted in Figure 1. This level of scrutiny ensures that any deviations from expected performance parameters are identified and addressed, guaranteeing the amplifier operates reliably under all conditions.

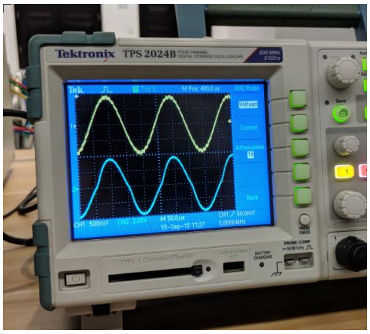

Fig. 1 Distorted current waveform at 5 KHz

The following photo, Figure 2, presents the distorted current waveform which the linear amplifier under testing was asked to produce the output closer to its rated value. The green curve (the distorted sinusoidal waveform) is the output current waveform.

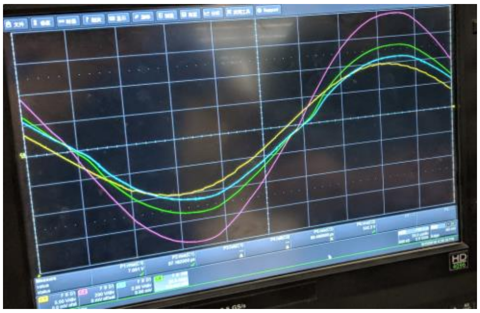

Fig. 2 Distorted current waveform at the rated power output

The next phase in amplifier testing is the step input/output test, designed to evaluate the amplifier's dynamic response. The test starts with a step signal from the signal source, which the amplifier should replicate in its output, either in Controlled Voltage (CV) or Controlled Current (CC) mode. This test checks the amplifier’s ability to handle abrupt signal transitions. Analyzing the time delay between the input and output signals, which can be as brief as 10 microseconds, reveals the amplifier's response speed and output voltage slew rate. This comprehensive testing assesses the amplifier’s capacity for rapid transitions, essential for applications that require precise timing and quick responses, thus ensuring the amplifier's effectiveness and operational efficacy.

An illustrative example of this can be seen Figure 3. The waveforms appearing on the oscilloscope screen depict the latency encountered between the introduction of a voltage reference input and the manifestation of the corresponding voltage output by the amplifier. The delay, which, in the context of the presented results, falls within the range of 10 microseconds (10uS). The second critical metric obtained from the waveform plots is the slew rate of the voltage output, which quantifies the rate at which the amplifier’s output voltage can change in response to the step input signal.

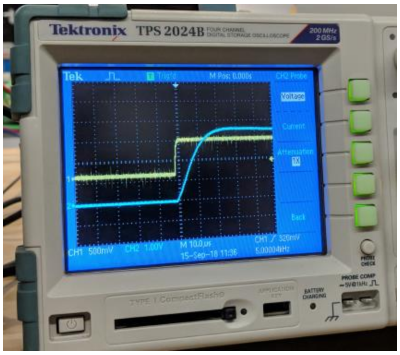

Fig. 3 Delay between the input and output

The step input test is essential for assessing the stability of the amplifier's output, which involves maintaining consistent output without oscillations or deviations during sudden input changes. Instability could distort signals and affect device functionality. The test results, shown in Figure 4, display the amplifier's response to step inputs on an oscilloscope, illustrating its delay, slew rate, and stability under dynamic conditions. This testing phase provides a comprehensive evaluation of the amplifier's performance, highlighting its responsiveness and stability.

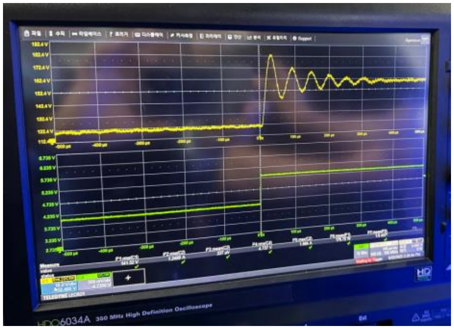

Fig. 4 A long ringing

The initial assessment of the amplifier's response to a step input signal given in Figure 4, as depicted in the lower plot, indicates a rapid activation, with a rise time of less than 50 microseconds (50uS). This quick response is particularly noteworthy given that the amplifier being tested is based on power electronics technology, as opposed to traditional linear technology. Nonetheless, further analysis of the amplifier’s performance reveals that, following the rapid initial response, the transient behavior and subsequent oscillations do not settle after a relatively long time, in the timeframe of 300 microseconds. This prolonged period before reaching a steady state raises potential concerns for applications requiring the amplifier to handle rapid and frequent changes in the input reference signal.

When the testing environment includes two or more amplifier sets, loopback testing becomes a feasible and highly informative method. This testing configuration involves designating one amplifier set as the signal source and another as the load. This arrangement allows for a dynamic interchange between the two sets, encompassing various parameters such as real power, reactive power, voltage, and current, or any pertinent combination thereof.

The loopback setup is particularly advantageous as it facilitates simultaneous assessment and control over both the source and load amplifiers. This approach enables a comprehensive evaluation of each amplifier's performance in real-time, under conditions that closely mimic operational scenarios.

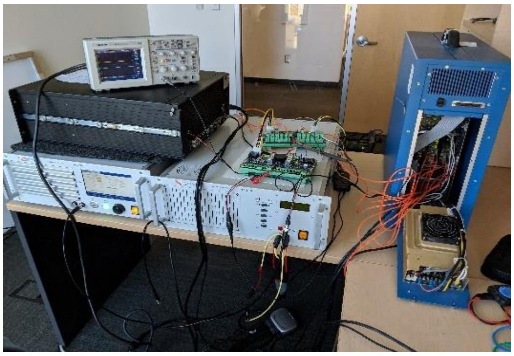

Fig. 5 Loopback testing using two power amplifiers

The loopback methodology enhances testing efficiency, particularly in reducing power consumption. If amplifiers can operate in full regenerative mode, this setup allows for energy recuperation, reducing waste and supporting sustainable practices. This method provides a flexible testing framework, enabling the examination of amplifier behavior under complex conditions and assessing their energy regeneration capabilities. Such insights are crucial for applications requiring energy efficiency and dynamic load management.

2.2 PRACTICAL ISSUES

Careful attention is crucial in planning PHILS experiments to ensure seamless execution and sustainability. Strategic planning for amplifier procurement is complex, often affected by long manufacturing lead times that can extend over a year. This requires advanced planning to incorporate potential delays and specific manufacturer requirements for installation, such as the need for a heat exchanger system to manage heat dissipation. Integrating these details ensures the infrastructure is fully prepared for the operational demands of the amplifiers upon their arrival.

Assurance of After-sales Support and Technical Assistance: High-power PHILS setups are prone to equipment failures that could impact the amplifier. While built-in protections usually shield the amplifier from faults in the Device Under Test (DUT), severe faults may overwhelm these systems, risking damage. Prompt manufacturer support is crucial, providing risk mitigation advice and quick solutions to maintain amplifier functionality. Efficient after-sales service ensures quick recovery, minimizing downtime and costs. It's essential to assess the manufacturer's service policies, technical support, and related costs early in the planning phase to manage risks and maintain experimental continuity.

3. Experiment configuration example

The following figure shows a typical experiment configuration when the DUT (Device Under Test) is a 3-phase PV inverter. The PV (or DC) side of the DUT can be connected to either a DC power supply or a PV emulator, while the AC side can be connected to a 3-phase 4-quadrant power amplifier. The reference of the amplifier is given by a real time simulator. In return, the measurement (either current or voltage, depending upon the interface method) can go back to the real time simulator.

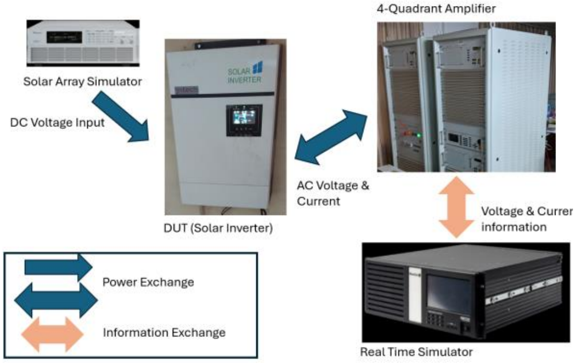

Fig. 6 PHILS experiment setup example

4. CONCLUSION

This paper discusses the setup and execution of Power Hardware in Loop Simulation (PHILS) experiments, focusing on the essential role of power amplifiers in connecting virtual and real-world elements. It emphasizes the need for detailed planning and comprehensive testing protocols to meet accuracy and reliability standards. The paper covers various testing phases, including initial system inspections, dynamic response tests, and loopback testing with multiple amplifiers. It also addresses practical challenges such as long lead times and installation requirements. The discussion extends to the significance of after-sales support in managing potential equipment failures. Effective PHILS experimentation requires understanding technical specifications, strategic planning, and robust support systems to ensure successful and reliable outcomes.

REFERENCE

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