Real-Time Testing of Microgrid Control Strategies: A Hybrid Hardware-in-the-Loop (H-HIL) Approach

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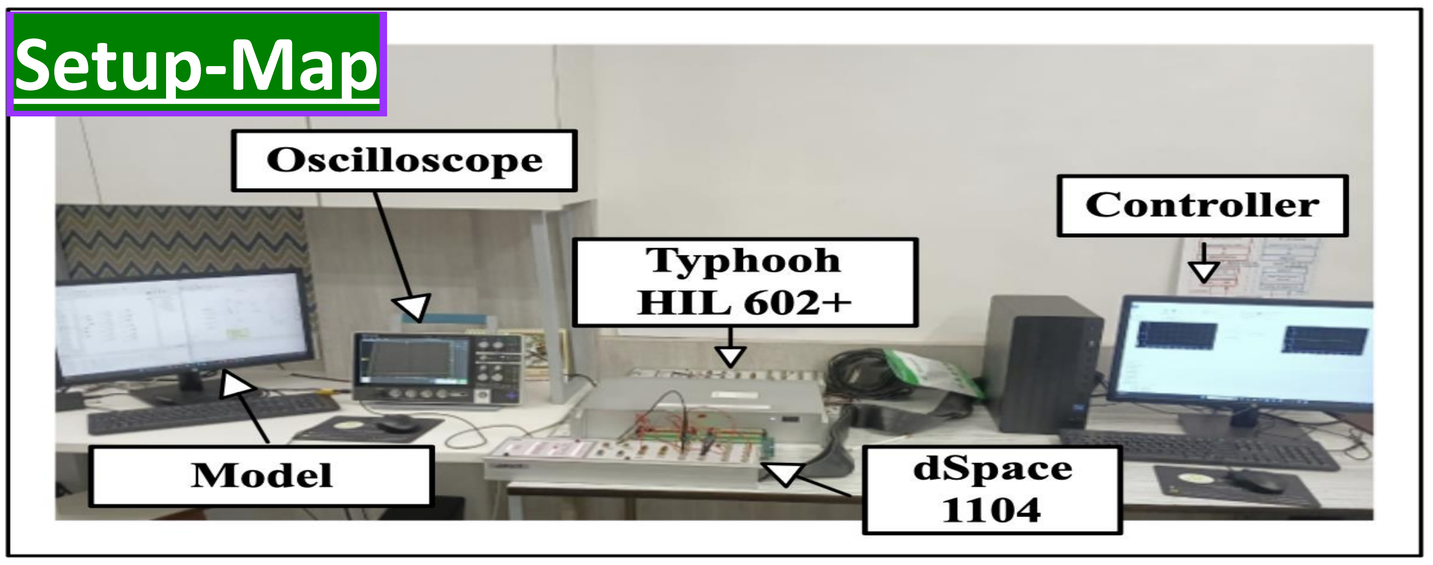
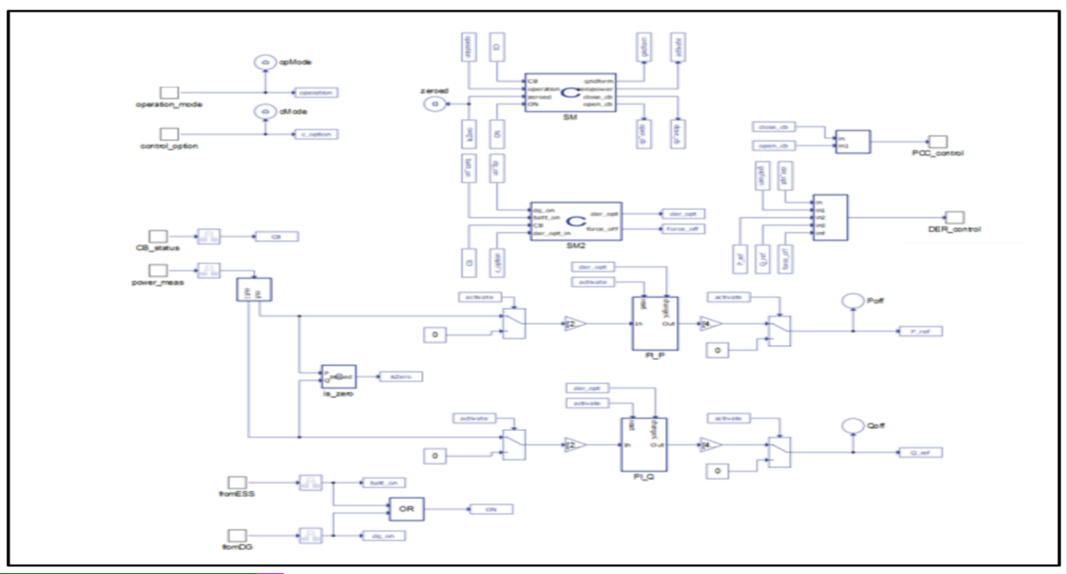
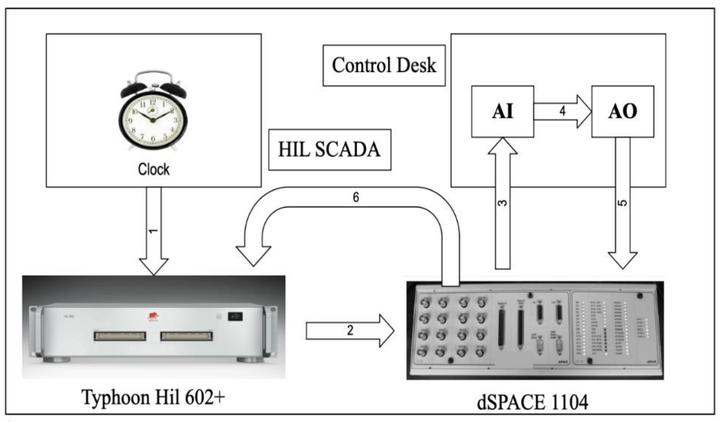
Abstract:

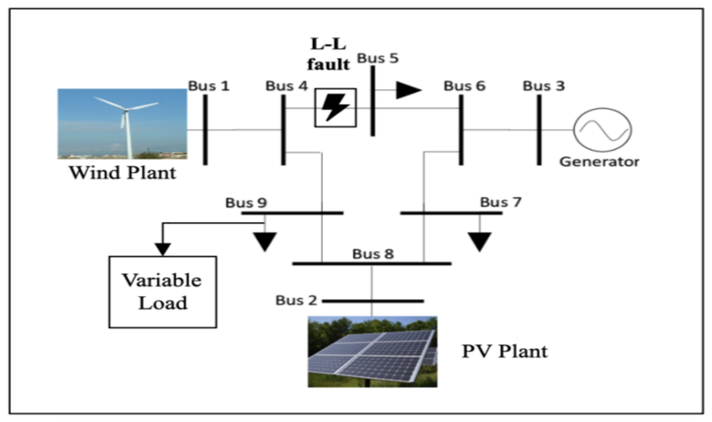
- **Need for Robust Control**: As renewable energy sources increase in power grids, reliable control is vital to maintain grid stability.
- **Testing Limitations**: Conventional Software-in-the-Loop (SIL) simulations don't capture real-world analog delays, affecting realism.
- **Hybrid HIL Testbed**: A **Typhoon HIL 602+** and **dSPACE DS1104** are directly connected via analog channels to emulate real analog delays.
- **Realistic Closed-Loop Control**: The testbed allows precise control strategy evaluation under conditions closer to actual grid dynamics.
- **IEEE-9 Bus Adaptation**: Two renewable sources replace conventional generators in the IEEE-9 system for demonstration.
- **PI Controller Implementation**: Deployed on dSPACE DS1104 to regulate frequency and maintain voltage in the HIL setup.

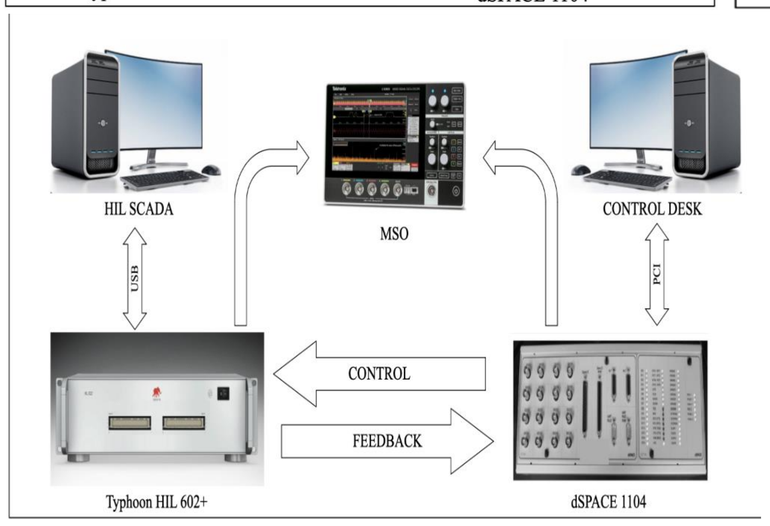
Setup-Map

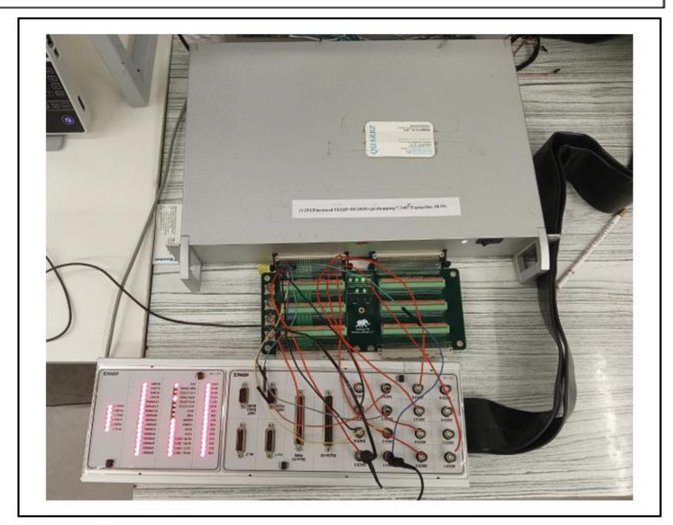












Results:

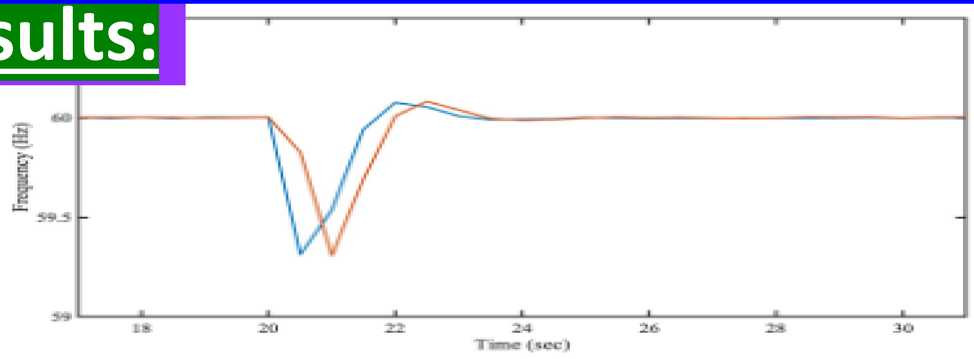


Fig. 7. Frequency response to the injection of active power into the system. Blue - RT-SIL (Typhoon), Red - H-HIL (dSAPCE-Typhoon)

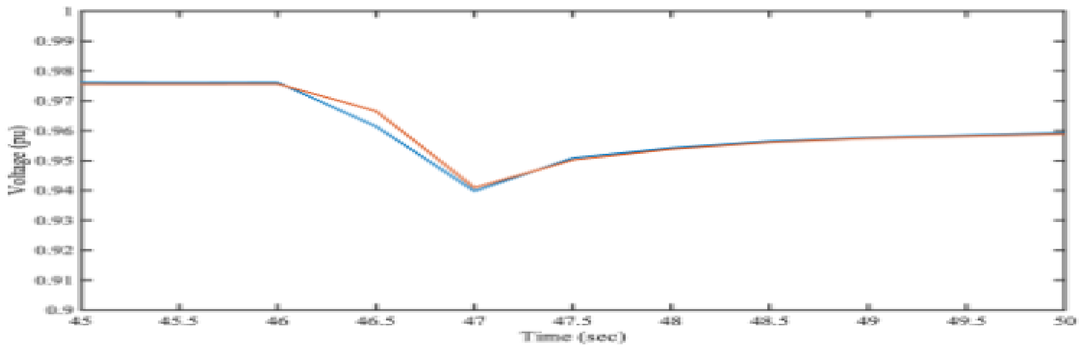


Fig. 8. Voltage response to the injection of reactive power into the system. Blue line - RT-SIL (Typhoon), Red line - HIL (dSAPCE-Typhoon)

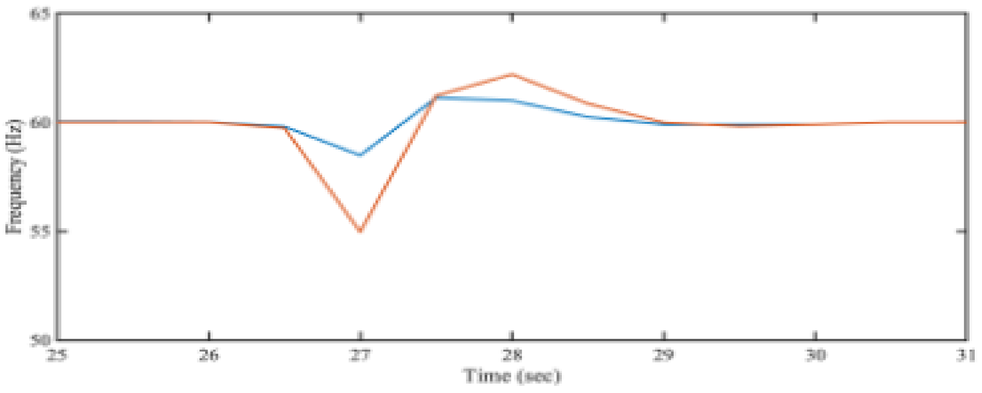


Fig. 9. Frequency response to Line-to-Line fault. Blue - RT-SIL (Typhoon) Red - HIL (dSAPCE-Typhoon)

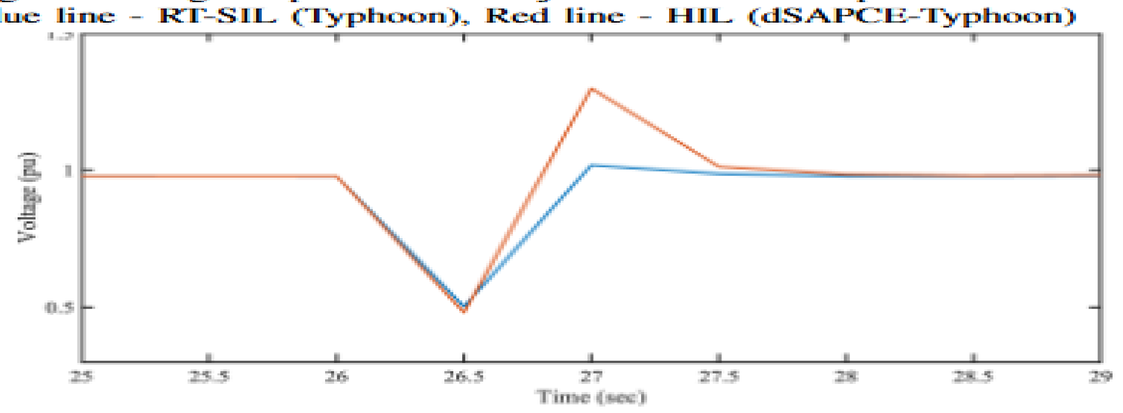


Fig. 10. Voltage response to Line-to-Line fault. Blue - RT-SIL (Typhoon), Red - HIL (dSAPCE-Typhoon)

Conclusions:

- **H-HIL Framework**: Combines Typhoon HIL and dSPACE to create a real-time simulation and control platform for microgrids.
- **9-Bus IEEE Microgrid**: Includes both renewable and conventional sources; HIL simulations assess dynamic performance and stability.
- **Closed-Loop Control**: Real-time feedback between Typhoon HIL simulator and dSPACE controller replicates real-world conditions and enables detailed analysis of system behavior.

Experimental Findings:

- **Normal vs. Fault Conditions**: High renewable penetration tested under both scenarios.
- **RT-SIL vs. HIL**: Minor events (load increases) show similar results, but severe faults (line-to-line) highlight the importance of hardware realism.
- **Key Metrics**: Fault-clearing times, voltage stability, and frequency response confirm the effectiveness of dSPACE-based control strategies, validating the framework's accuracy in real-time environments.

The poster prepared based on the research paper accepted for presentation and publication in PES General Meeting 2025, TEXAS , U. S. A.