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Method to Interface Grid-Forming Inverters into Power Hardware in the Loop Setups

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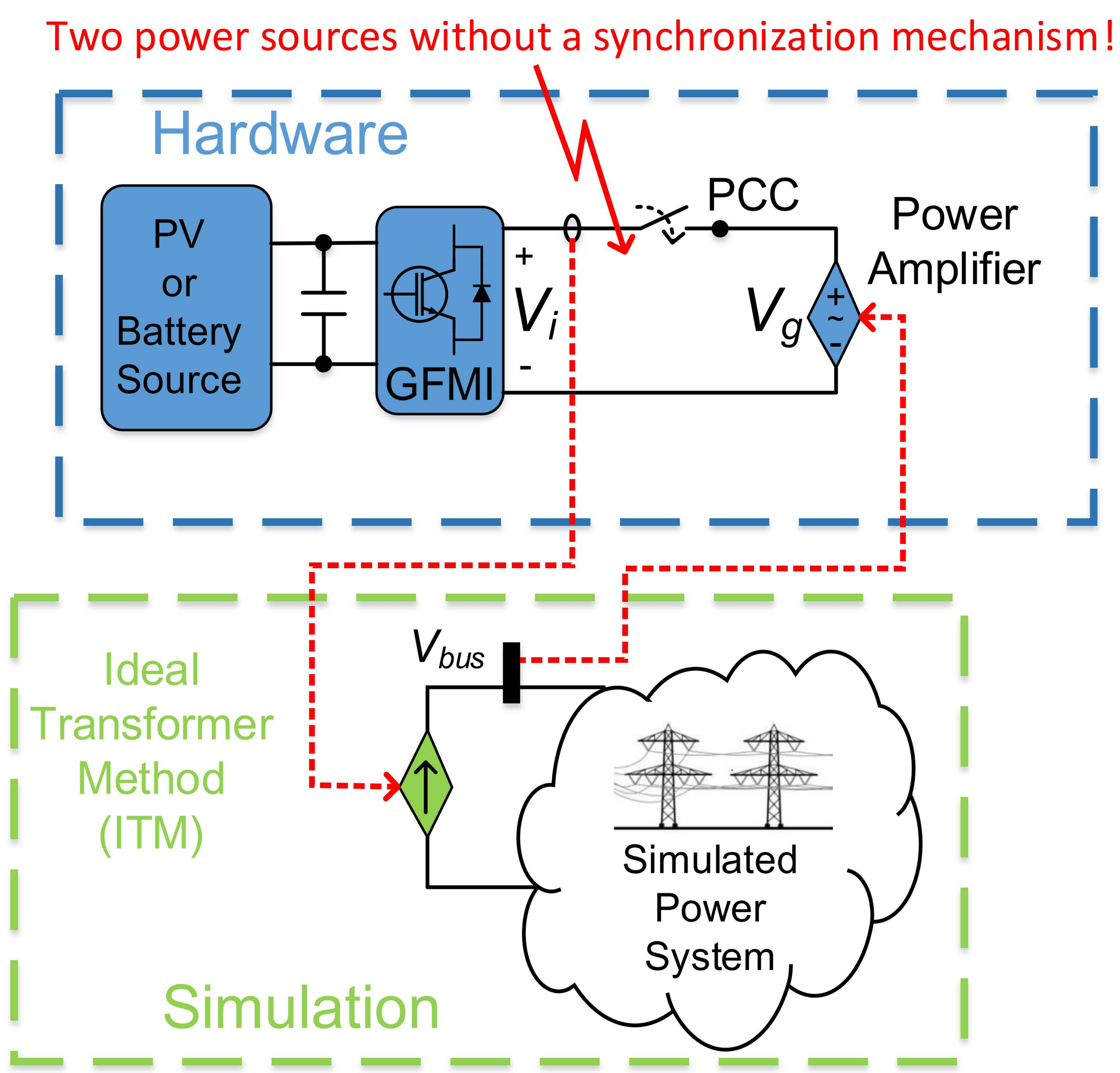
1. Introduction

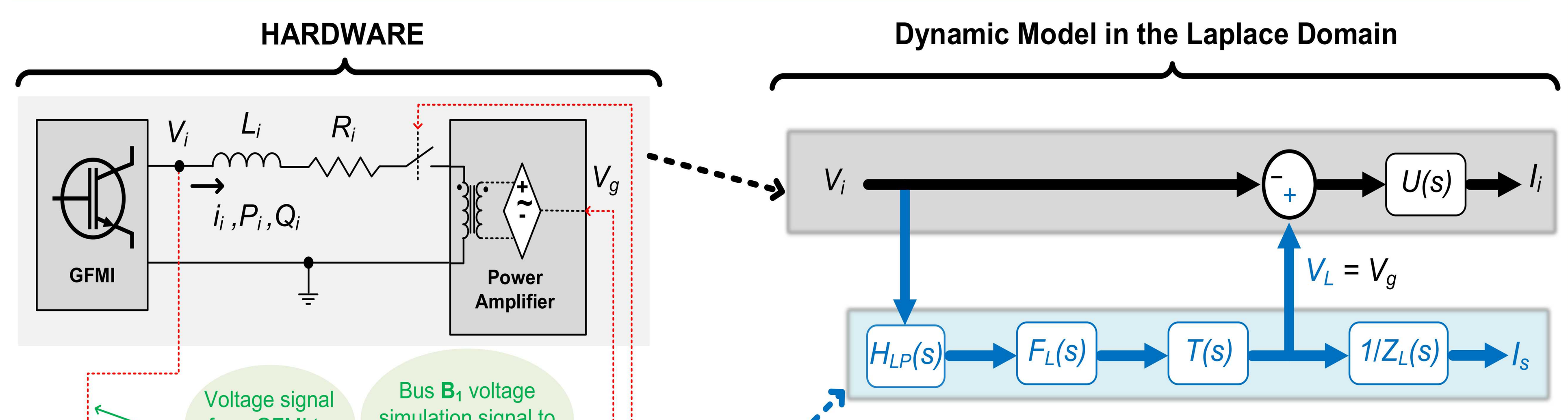
- Power converters with grid-forming capabilities have attracted interest from researchers and utilities as keystone devices enabling modern microgrid architectures.
- Grid-Forming Inverters (GFMIs) are becoming more popular due to the benefits they provide to the grid and their off-grid capabilities.
- Testing GFMIs using Power Hardware-in-the-Loop (PHIL) simulations is important to understand their dynamics

2. Potential problems and risks of interfacing GFMIs into PHIL setups.

- Large scale GFMIs come with a synchronization mechanism that helps them to initiate interconnection with main grids or microgrids.
- Lower to medium scale commercially available GFMIs are difficult to interface into PHIL simulations because of their lack of a synchronization mechanism.
- The Ideal Transformer Method (ITM) can pose catastrophic damages to GFMI's.
- It is dangerous to connect two voltage sources without a synchronization mechanism.



3. Proposed Method and Dynamic Model.



$$H_{LP}(s) = \frac{\omega_c}{s+\omega_c}$$; LOW PASS FILTER

$$F_L(s) = \frac{s+(p_1/\alpha)}{s+p_1}$$; PHASE LEAD COMPENSATOR

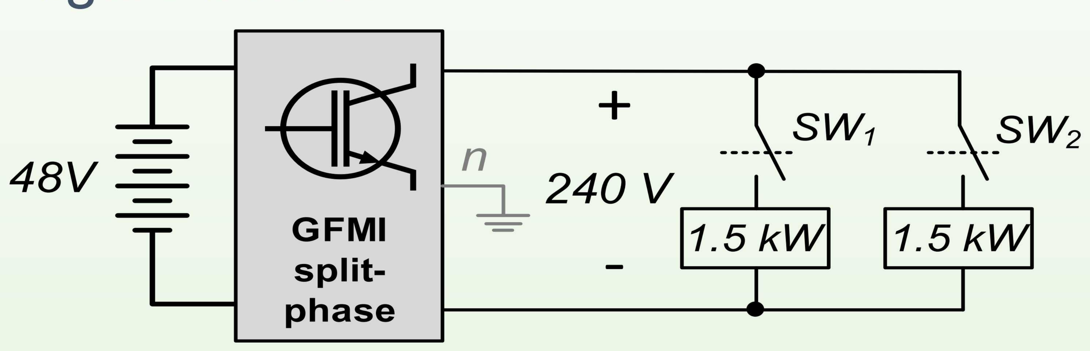
$$T(s) = \frac{Z_L(s)}{sL_s+R_s+Z_L(s)}$$; TRANSFER FUNCTION OF SIMULATION CIRCUIT

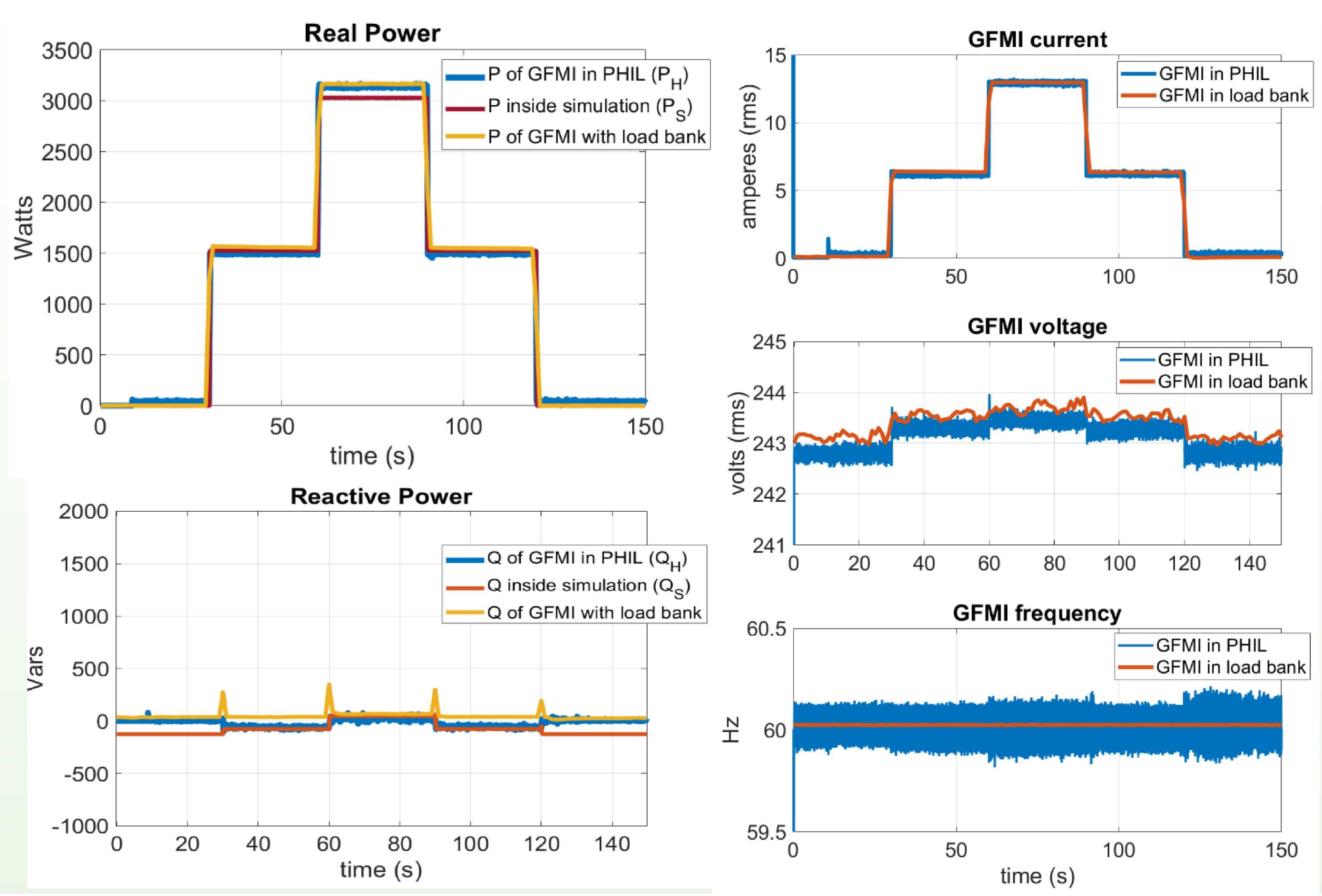
$$U(s) = \frac{1}{sL_i+R_i}$$; TRANSFER FUNCTION OF HARDWARE CIRCUIT

- An external inductor (L_i) is placed between the GFMI and the power amplifier.
- The voltage at the terminals of the GFMI is sensed and injected into simulation model, this marks a fundamental difference with the ITM.
- A digital twin of the hardware circuit is created at simulation level.
- If L_i=L_s , R_i=R_s, and if V_L drives the power amplifier, then the power amplifier acts as a voltage-programmable load whose P and Q are equivalent to simulated loads at **B1**.
- Stability is highly dependent on load impedance Z_L. For series RLC loads the system is exponentially stable (see proof in manuscript)

4. Experimental Results.

- A commercial GFMI was interfaced using the proposed PHIL method.
- Two 1.5 kW virtual loads were placed in the real-time simulation. They were configured to switch in a staircase sequence.
- PHIL results were validated against results from the GFMI connected directly to a load bank as shown in figure below:





5. Discussion of Results.

- From real and reactive power traces, the method is stable and accurate (< 5%) under step load demands.
- Traces in voltage and frequency corroborate the grid-forming nature of the inverter as the voltage and frequency are regulated despite load changes

6. Conclusions.

- The proposed method overcomes the issue of connecting two voltage sources without a synchronization mechanism.
- It can be used for GFMI's operating with droop or isochronous.
- Experimental results demonstrate the ability of the power amplifier and real-time HIL simulation to act as a controllable load

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