Applying OPAL-RT System to Microgrid Applications

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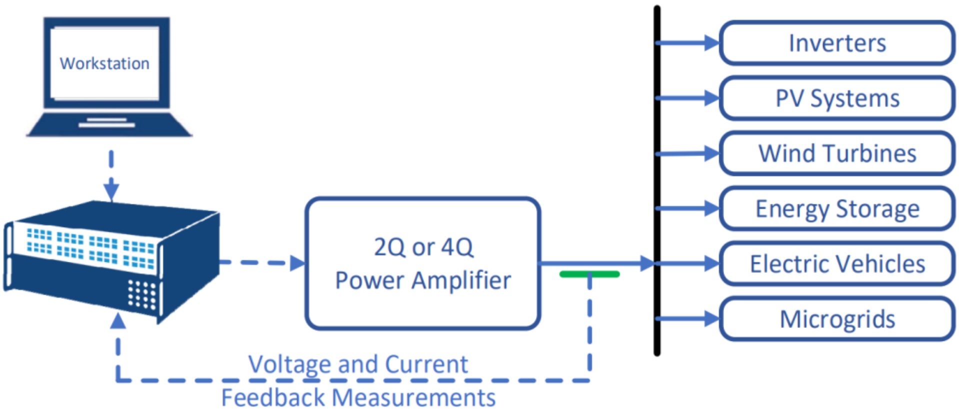
1. Research Background and Objectives

As the penetration rate of renewable energy increases, the applications of microgrids become more and more popular. A typical microgrid includes a microgrid controller, dispatchable generator sets, solar power generation, energy storage systems, and loads. Therefore, the future power grid will have more and more inverter-based resources (IBRs). The inverter control methods include grid-following and grid-forming types. As the proportion of renewable energy gradually increases, the number of traditional synchronous generator units will decrease, which will cause power system stability problems. According to the literature [1], at least 25% to 30% of grid-forming inverters are required in a 100% IBR power system. However, grid-forming inverter control methods include many types, such as droop control, virtual synchronous generator/machine control, virtual oscillator control, etc. Even with the same control method, each commercial grid-forming inverter's control parameters may differ. Therefore, through power hardware-in-the-loop testing, the actual grid-forming inverter can be connected to the power grid imported into the host machine, and the dynamic characteristics of the grid-forming inverter in the power grid can be verified. This research uses the OPAL-RT system to conduct real-time closed-loop simulation of power-level hardware.

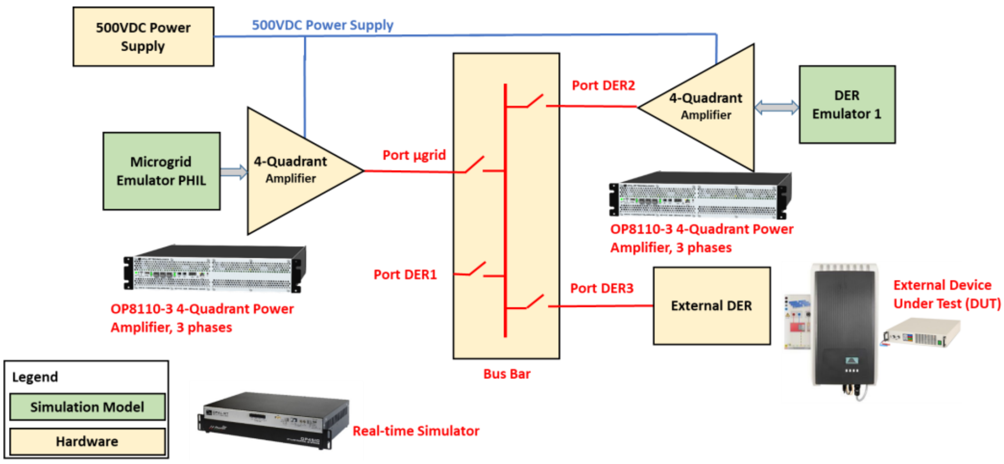
2. Research content

Fig.1 shows the power hardware-in-the-loop framework. From Fig. 1, it can be seen that this research includes a computer controller, OPAL-RT host, amplifier, feedback control, and physical connection equipment, such as inverters, solar systems, wind power systems, energy storage systems, electric vehicles, microgrids, etc. The computer controller simulation software used in this research is Hypersim. This software is suitable for the simulation of large power systems, and the PSS/E, PowerFactory, and PSCAD files can be imported into Hypersim files. Through OPAL-RT host and amplifier, externally connected hardware equipment can be connected to the power grid, thereby verifying the performance of the physical equipment on the power grid. Fig. 2 shows the power hardware closed-loop real-time simulation framework based on OPAL-RT. Microgrid Emulator PHIL and DER Emulator 1 are virtual devices; external DER is an actual device. The virtual device is connected to the actual device through an amplifier. Through this power grid research platform, the performance of physical equipment can be verified, such as the characteristics of the commercial grid-forming inverters in the Kinmen power grid. In order to verify the feasibility of OPAL-RT to achieve real-time simulation of closed-loop power hardware, this research constructed a simple model, as shown in Fig. 3. Fig. 3 (a) shows two virtual synchronous generators connected in parallel, with their output terminals connected to the same resistive load. The two virtual synchronous generators are simulated in Hypersim and connected to the physical output load through amplifiers. Fig. 3 (b) shows the output waveforms by using PHIL, and Fig. 3 (c) shows the experimental equipment.



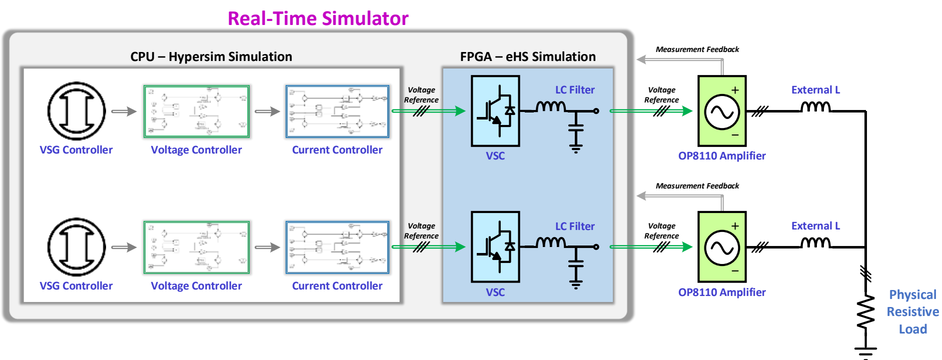
Source: von Jouanne, A.; Agamloh, E.; Yokochi, A. Power Hardware-in-the-Loop (PHIL): A Review to Advance Smart Inverter-Based Grid-Edge Solutions. *Energies* 2023, *16*, 916.

Figure. 1　Power hardware closed-loop real-time simulation framework

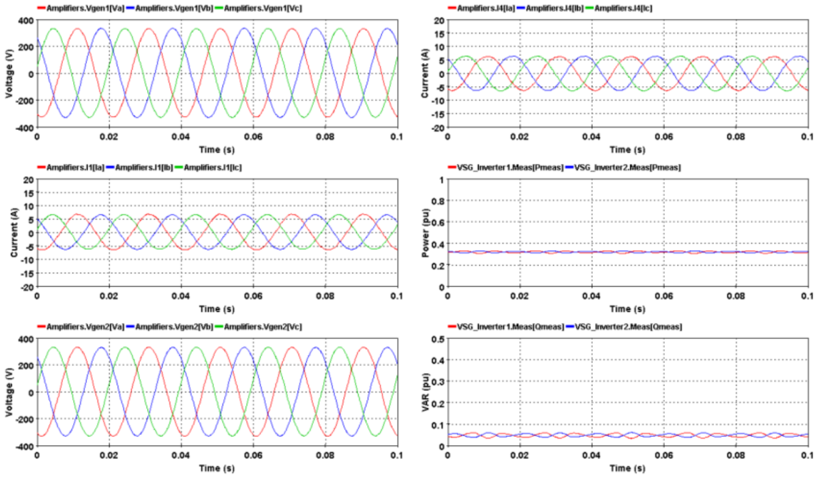


Source: Made by authors

Figure. 2　Framework for realizing closed-loop real-time simulation of power hardware based on OPAL-RT system



(a)



(b)

(c)

Source: Made by authors

Figure. 3 Two virtual synchronous generators operating in parallel: (a)framework, (b)output voltage, current, and power waveforms, (c)physical OPAL-RT system

3. Conclusion

As the proportion of renewable energy gradually increases, there will be more and more IBRs. Most of the inverter control modes are grid-following. When the proportion of grid-following inverters gradually increases, it will have a negative impact on the power system. Therefore, grid-forming inverters are required to improve the stability of the power grid. However, commercial grid-forming inverters' control modes and parameter settings are different. To verify the characteristics of commercial grid-forming inverters in actual power grids, this research first used a simple system to verify the feasibility of real-time closed-loop simulation of power hardware. In the future, this OPAL-RT system can be used to analyze the transient characteristics of grid-forming inverters, fault ride-through, and coordinated operation among grid-forming inverters from different brands.

4. References

[1] Ben Kroposki, "Introduction to Grid Forming Inverters-a Key to Transforming out Power Grid," NREL, June 2024.