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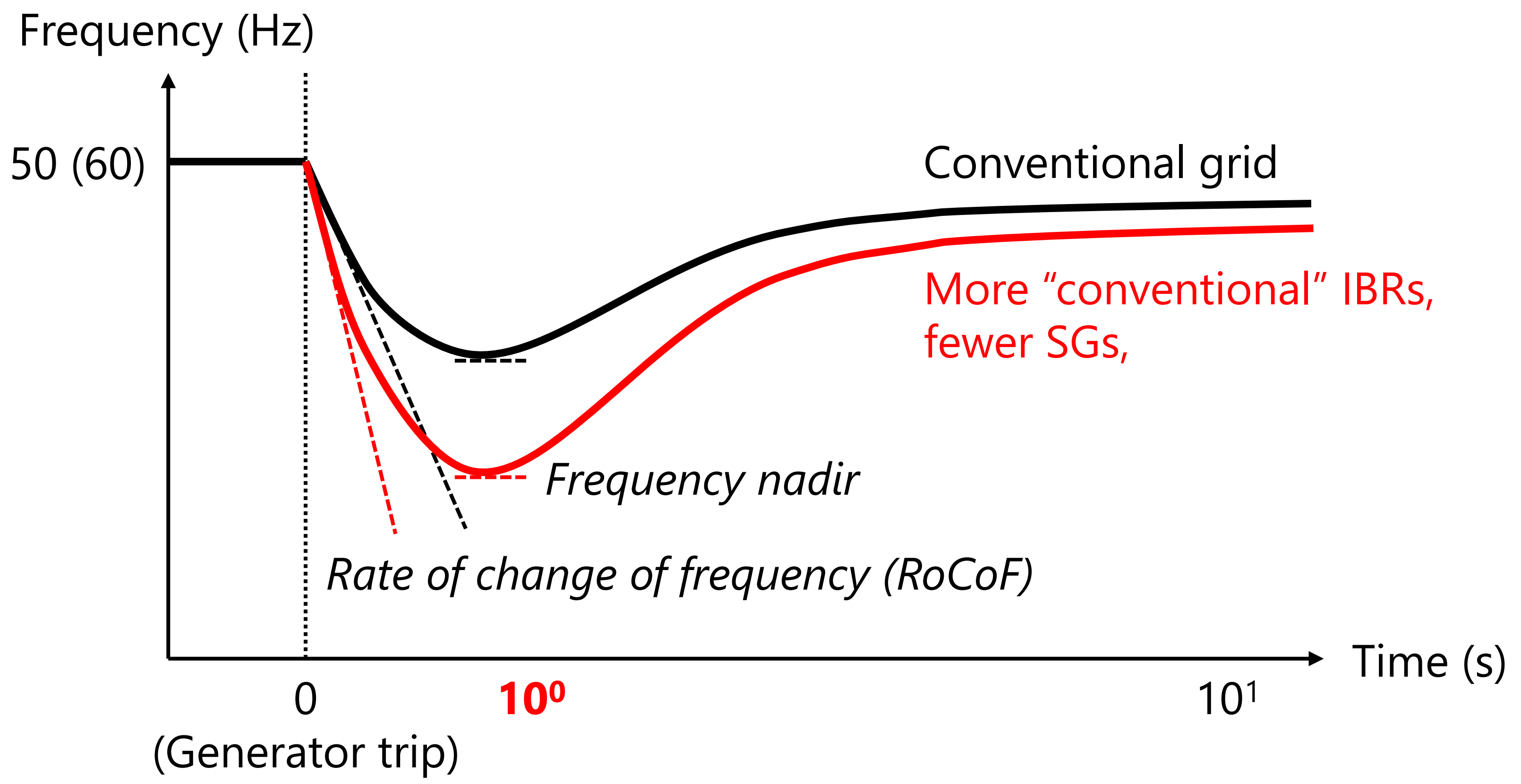
Verification of Power Hardware-in-the-Loop Environment for Testing Grid-Forming Inverter

Hiroshi Kikusato, Dai Orihara, Jun Hashimoto, Takahiro Takamatsu, Takashi Oozeki
(Fukushima Renewable Energy Institute, AIST)

Takahiro Matsuura, Satoshi Miyazaki, Hiromu Hamada, Teru Miyazaki
(TEPCO HD)

GFMI is Expected to Replace Some of Services provided by SG

- Reducing the number of synchronous generators (SGs) decline grid frequency stability
- Frequency control including **inertial response** is required for inverter based-resources (IBRs)
- **Grid-forming inverter's (GFMI's)** performance in hardware has not been discussed well

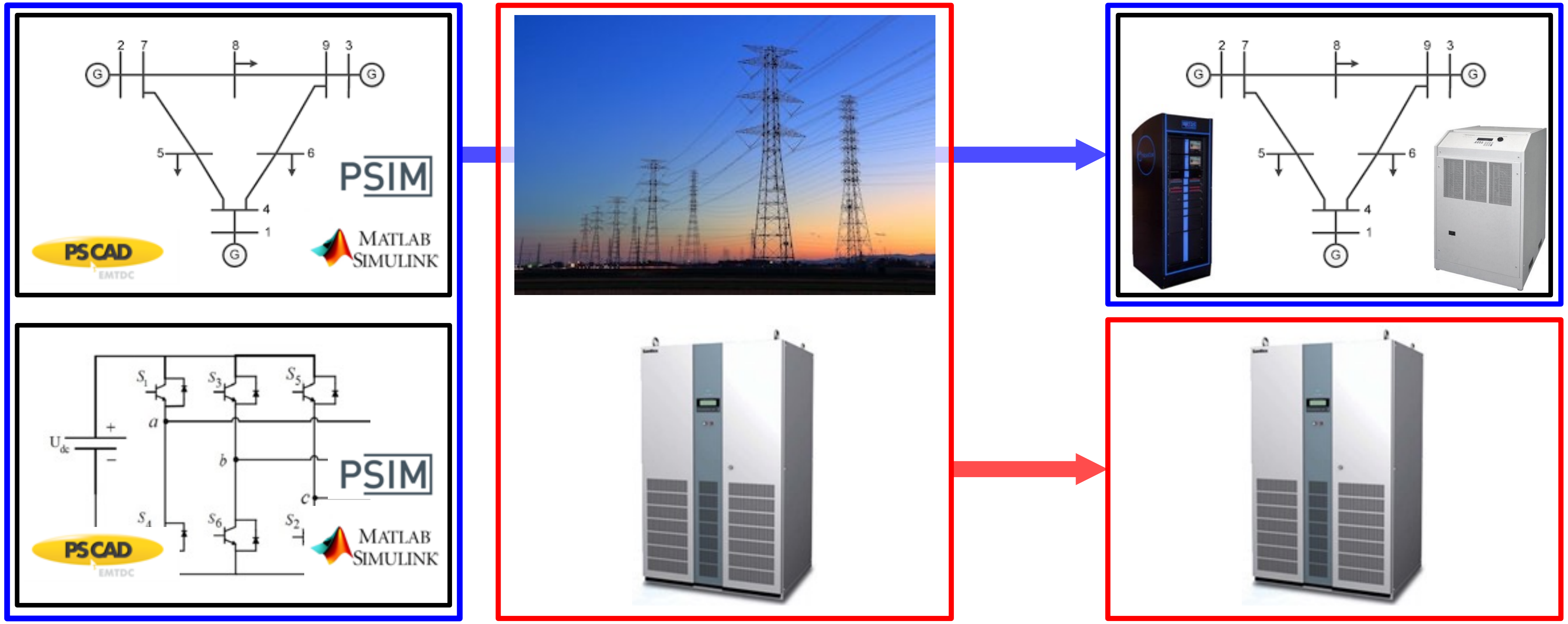


PHIL Simulation is a Flexible and Reliable Testing Method

	Simulation	Demonstration	**Power hardware-in-the-loop (PHIL) simulation**

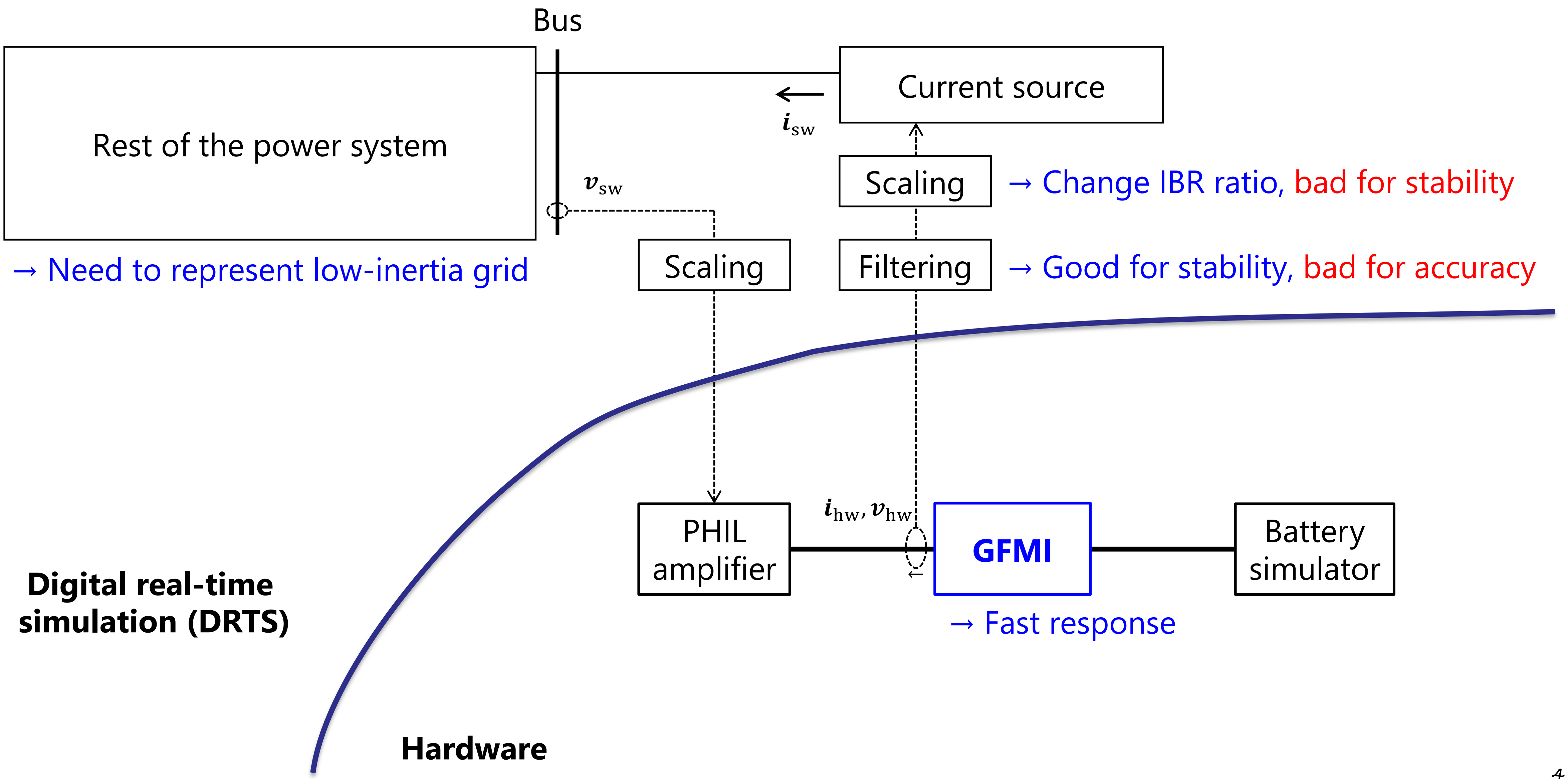
Grid

GFMI

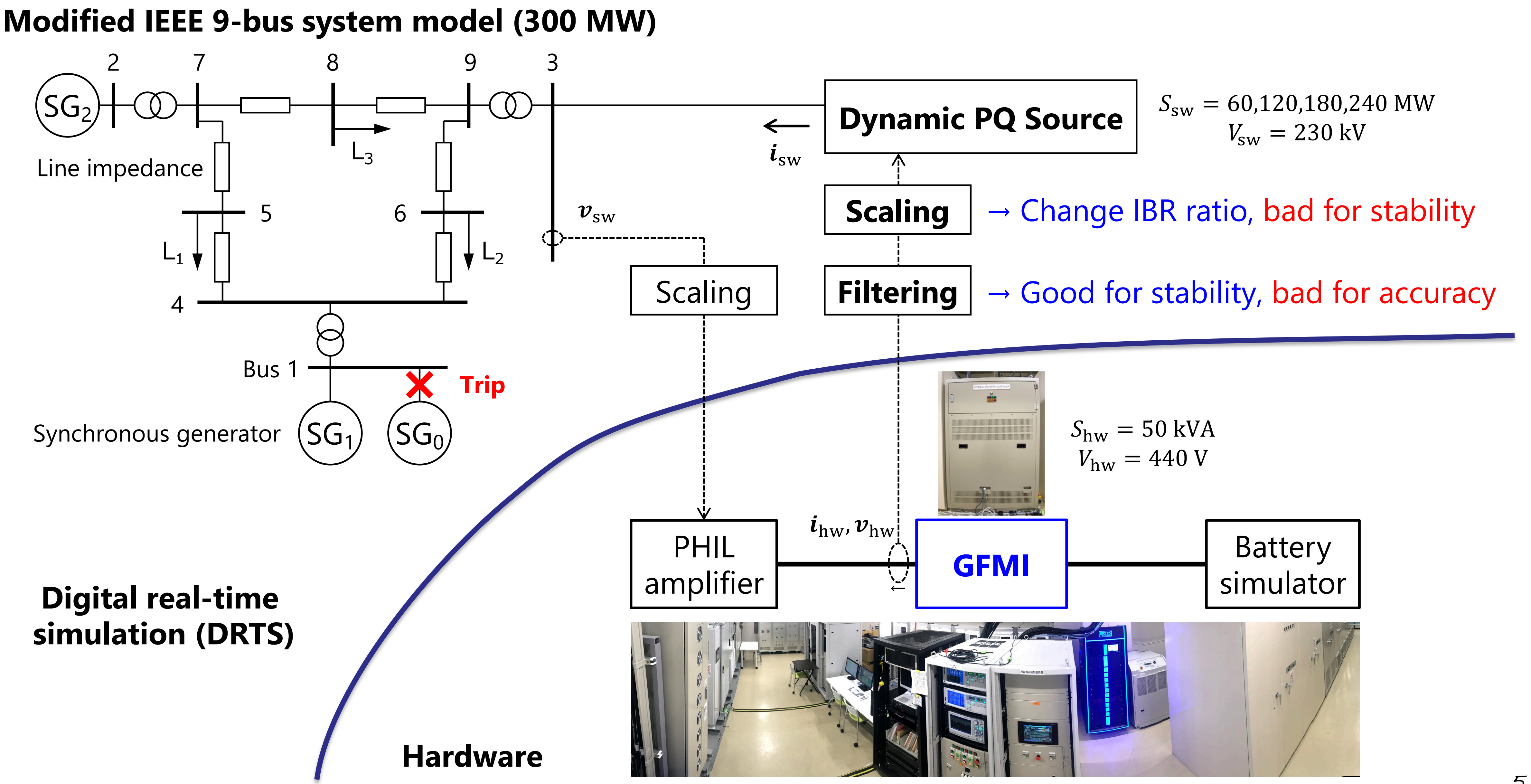


Flexibility (Grid)	**High**	Low	High
Fidelity (GFMI)	Low	**High**	High

Challenges in PHIL Testing for GFMI



PHIL Configuration for GFMI Testing Using Modified IEEE 9-Bus System Model



AIST FREA

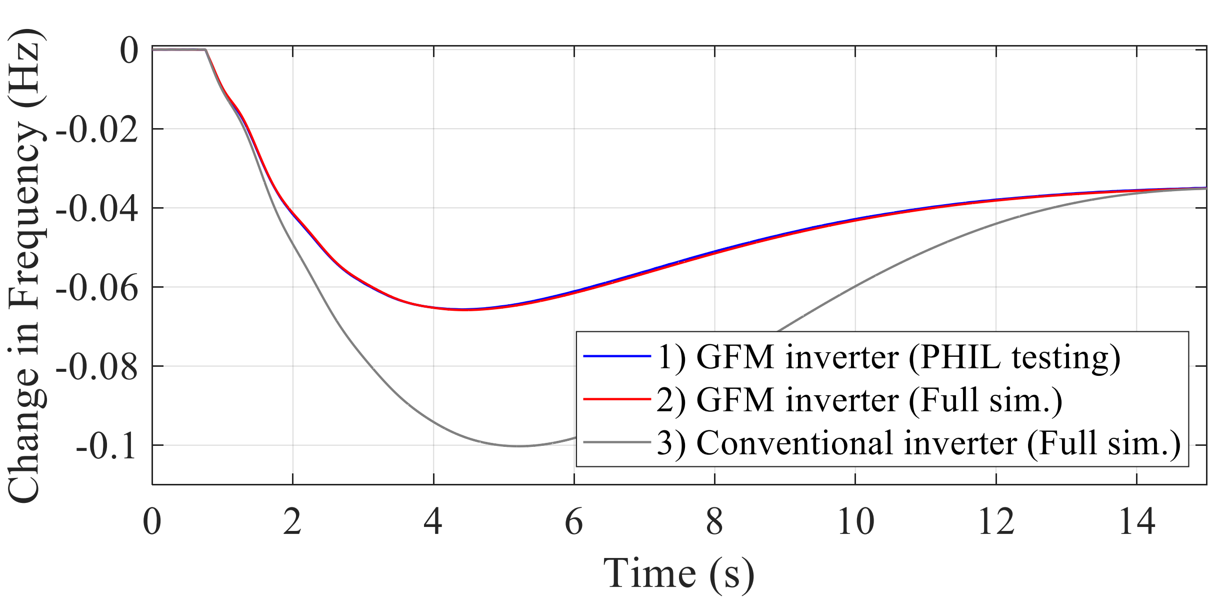
Stability Assessment

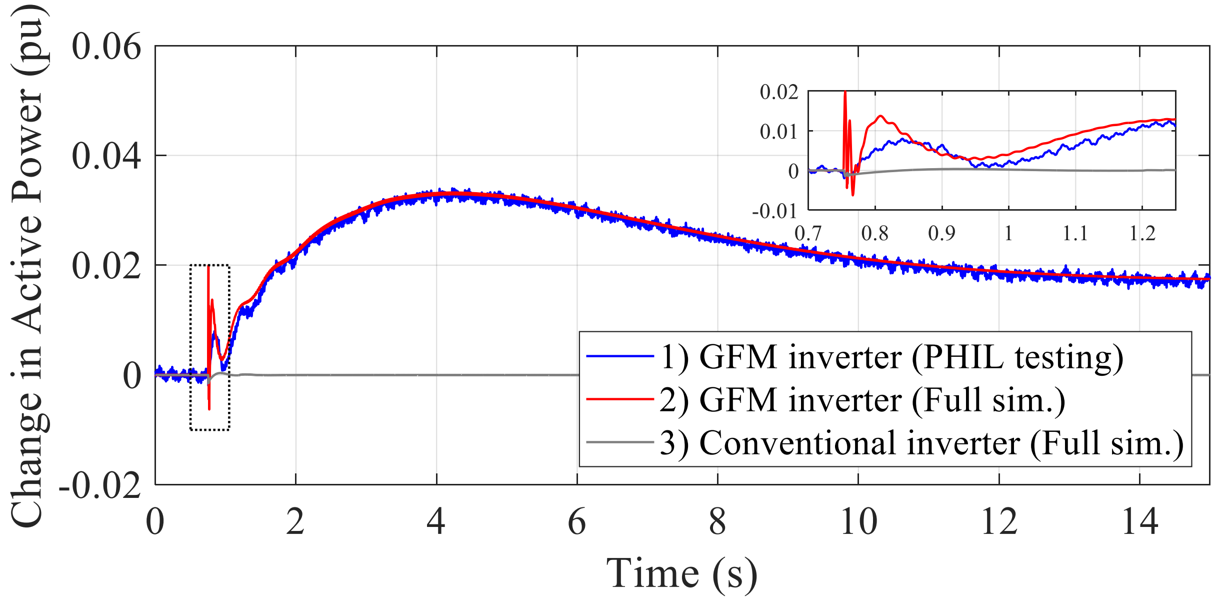
- PHIL testing needs to be initialized in the proper sequence
  - In most cases, initialization was appropriately completed (*Stable*)
  - Conditions under 80% load factor and 80% IBR ratio were *Unstable*
    - Smaller HW impedance and reduction of synchronization power (increase in phase-angle difference)

	IBR ratio	Basic settings $H = 2.35, G = 25$	H+ setting $H = 7.05, G = 25$	G+ setting $H = 2.35, G = 75$
Light load (load factor 40%)	20%	*Stable*	*Stable*	*Stable*
	40%	*Stable*	*Stable*	*Stable*
	60%	*Stable*	*Stable*	*Stable*
	80%	*Stable*	*Stable*	*Stable*
Heavy load (load factor 80%)	20%	*Stable*	*Stable*	*Stable*
	40%	*Stable*	*Stable*	*Stable*
	60%	*Stable*	*Stable*	*Stable*
	80%	*Unstable*	*Unstable*	*Unstable*

Accuracy Assessment

- Frequency and active power changes for PHIL testing were nearly identical to full simulation
- Clearly observe the effect of introducing GFM capability

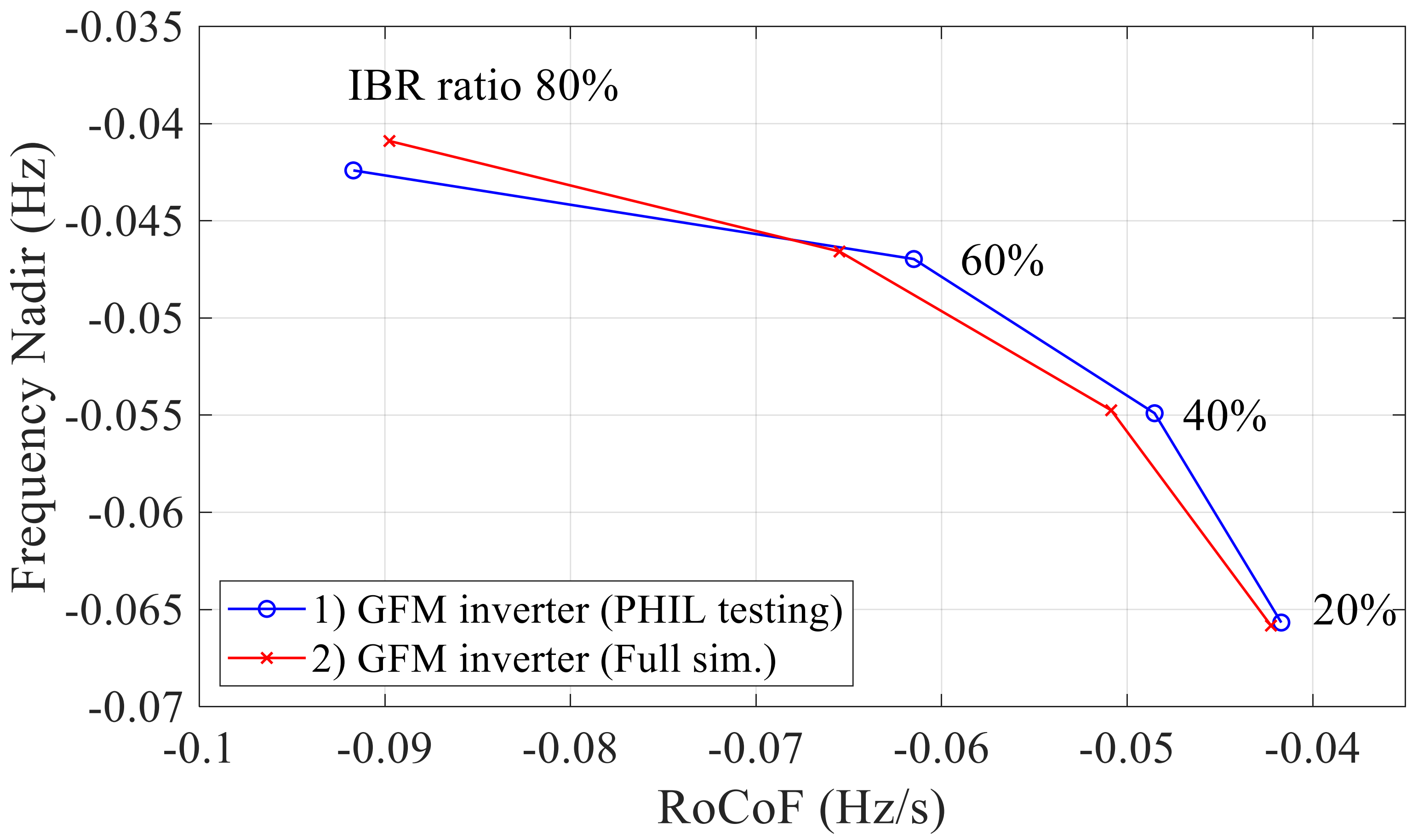




IBR ratio 20%, basic settings

Accuracy Assessment

- Can adequately observe the effect of the IBR ratios
- The same can be said when the control parameter setting changed



Summary

- PHIL simulation for testing GFMIs has not been discussed well
  - GFMIs are promising technologies in future power systems
  - PHIL simulation is an attractive verification method for inverter hardware

- Built PHIL configuration for testing GFMIs
  - “Dynamic PQ Source” component
  - Appropriate filtering and scaling

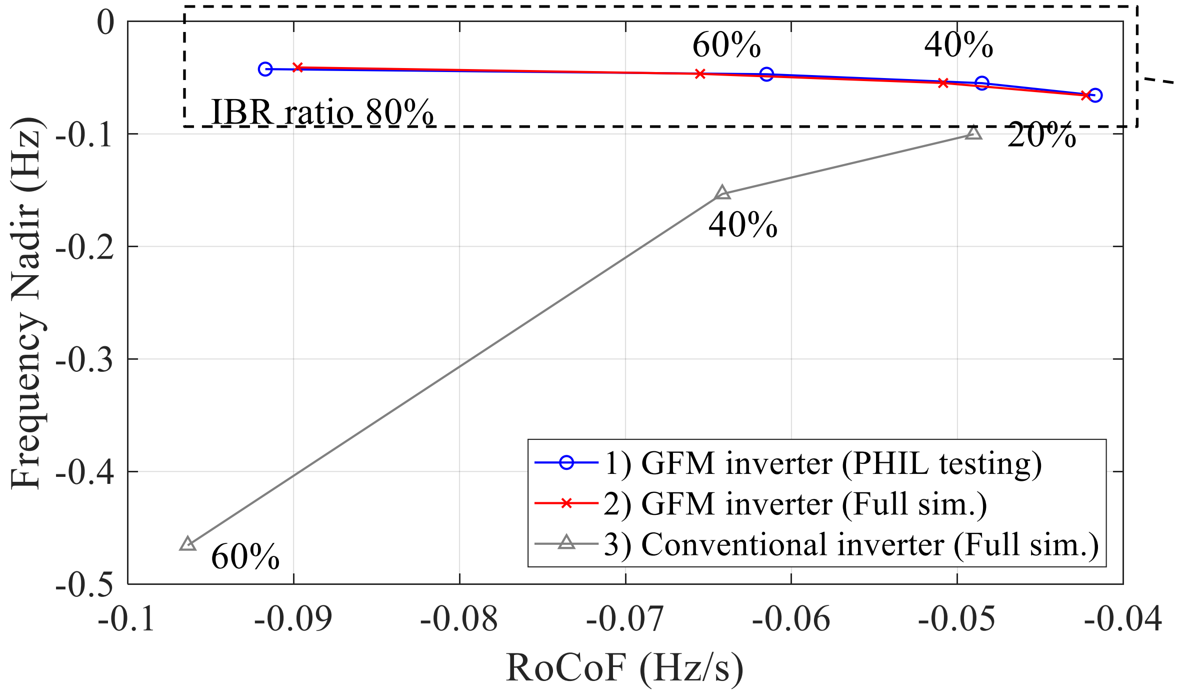
- Confirmed that the PHIL configuration was adequately stable and accurate to test GFM inverters
  - Can identify the effect of the introduction of GFM inverters, changing IBR ratios, and changing control parameter settings

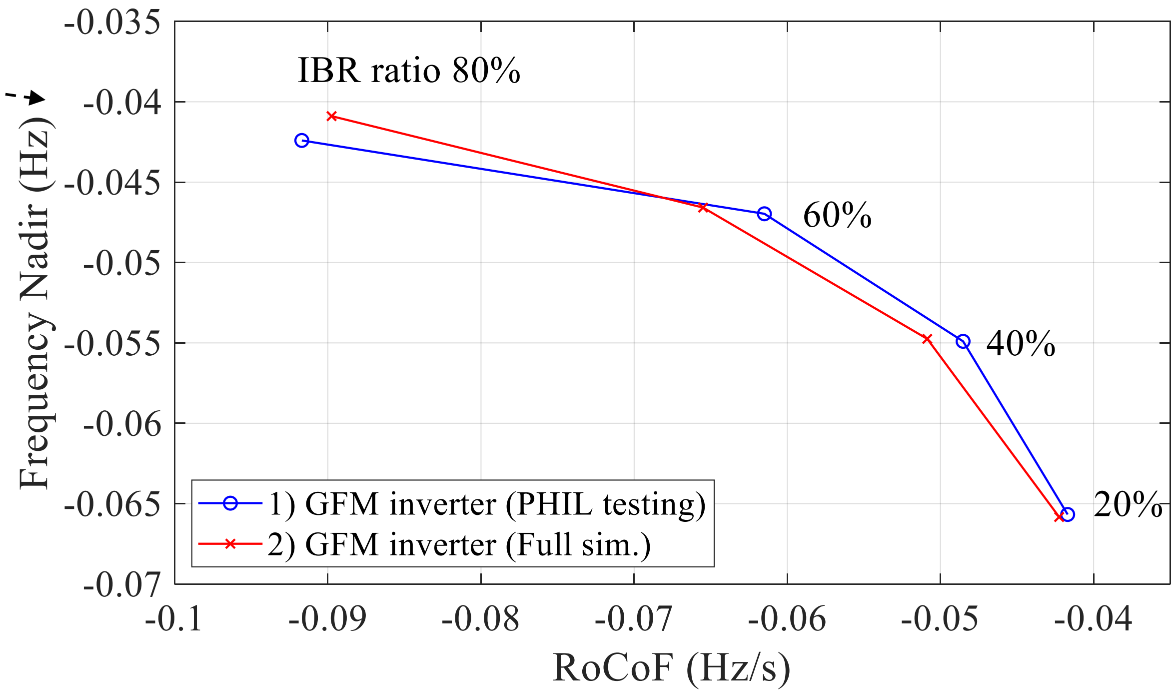
Appendix

AIST FREA

Accuracy Assessment

- Can adequately observe the effect of the IBR ratios
- The same can be said when the control parameter setting changed





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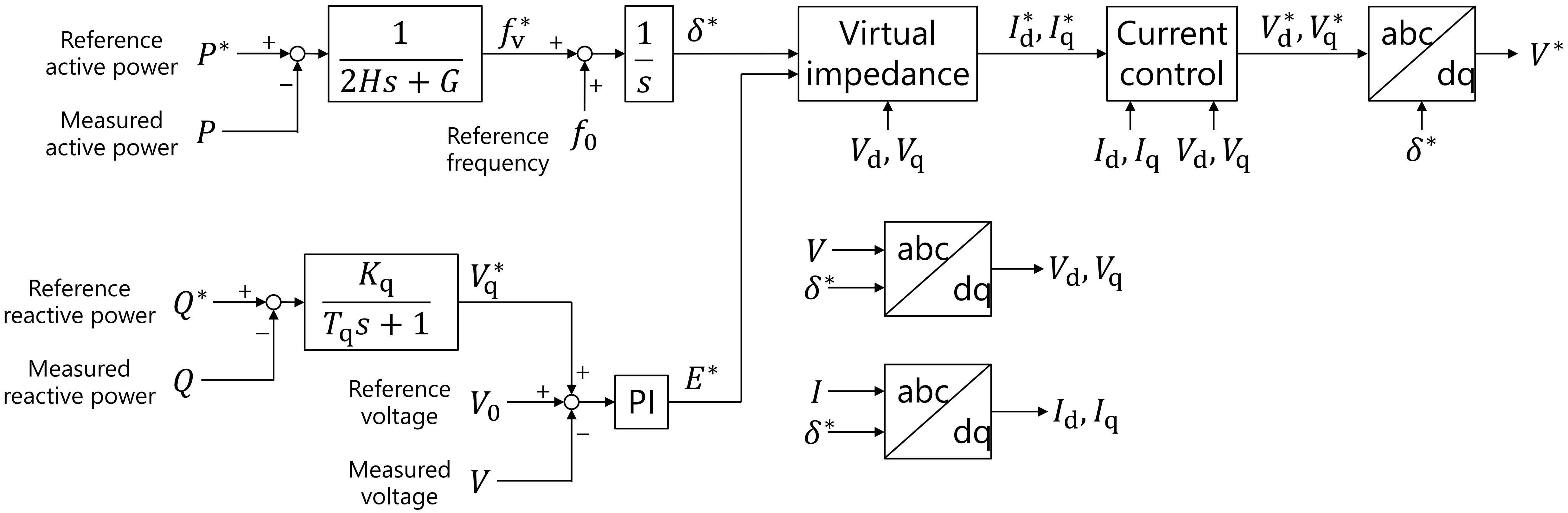
Block Diagram of Virtual Synchronous Generator Control



PHIL Configuration for GFMI Testing Using Modified IEEE 9-Bus System Model