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Power Hardware-in-the-Loop Testing for Multiple Inverters with Virtual Inertia Controls

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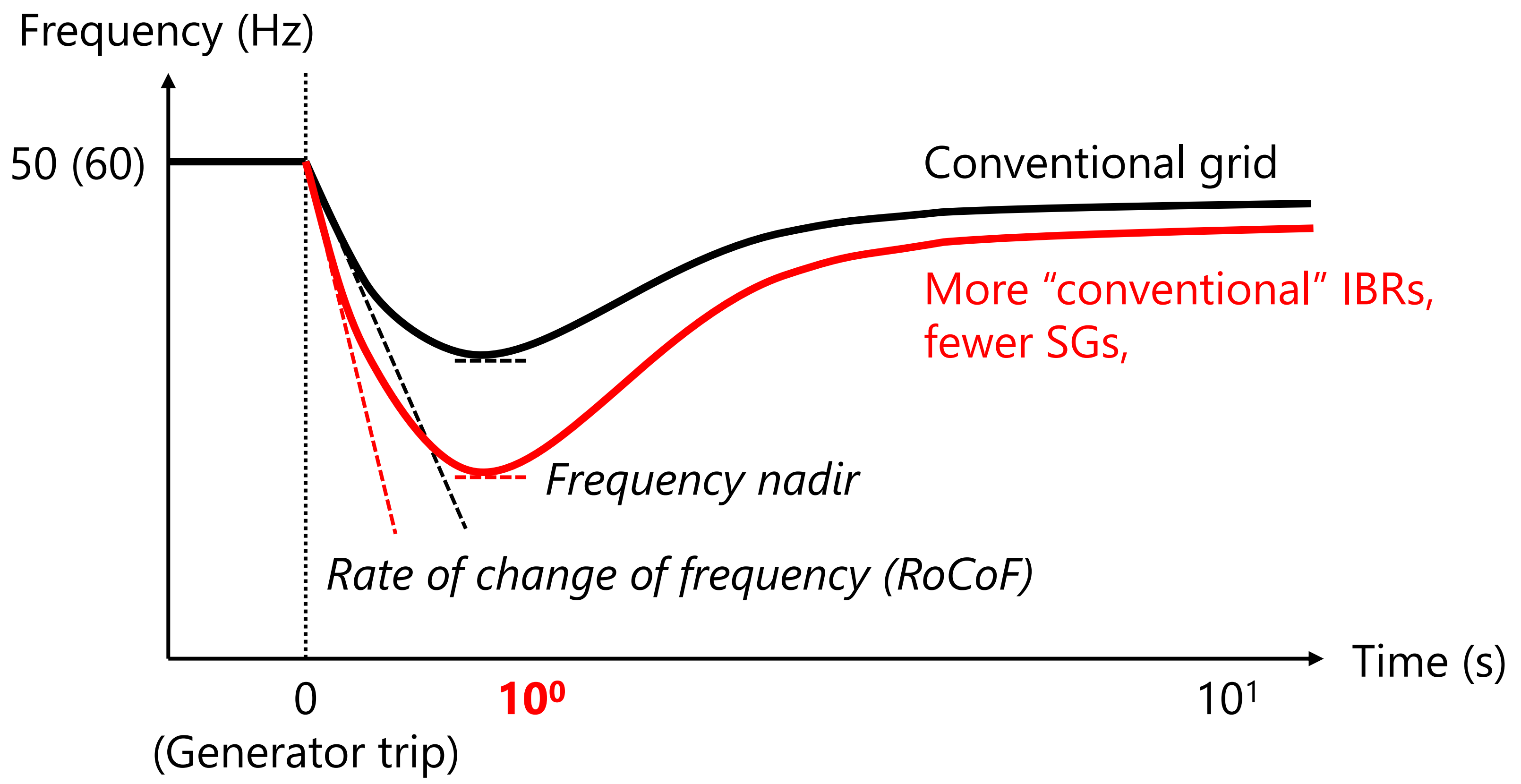
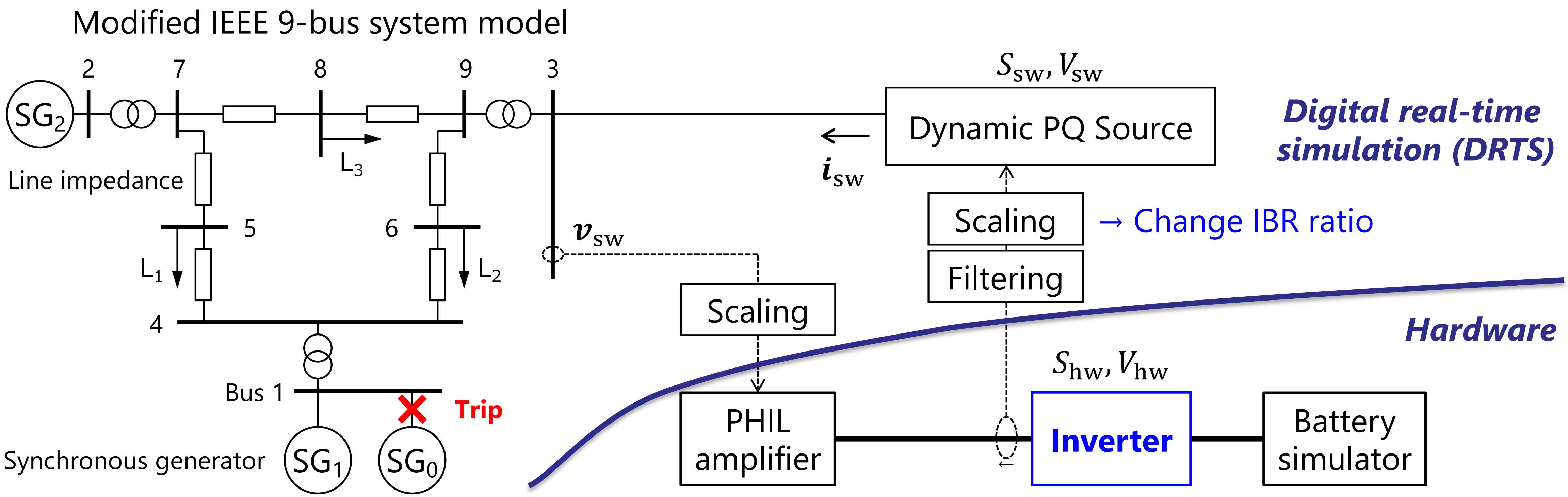
IBR is Expected to Replace Some of Services Provided by SG

- Reducing the number of synchronous generators (SGs) decline grid frequency stability
- Frequency control including **inertial response** is required for inverter based-resources (IBRs)
- Performance of **IBRs with virtual inertial controls** in hardware has not been discussed well



Power Hardware-in-the-Loop (PHIL) Testing is an Attractive Option for Testing Inverters with Virtual Inertia Controls



- Developed a PHIL setup to test inverters with virtual inertia controls (Kikusato et al., 2022)
- Tested several inverters alone (Kikusato et al., 2022)
- Not tested the multiple inverters connected in parallel

Tested Inverter Prototypes with Virtual Inertia Controls

	Grid-following inverter		**Grid-forming inverter**	
	GFL 1	**GFL 2**	**GFM 1**	**GFM 2**
Control function	df/dt-P droop f-P droop	df/dt-P droop f-P droop	P-f droop Q-V droop	VSM Q-V droop
Rated capacity (kVA)	20	49.9	20	50
Rated AC voltage (V)	200	200	200	440

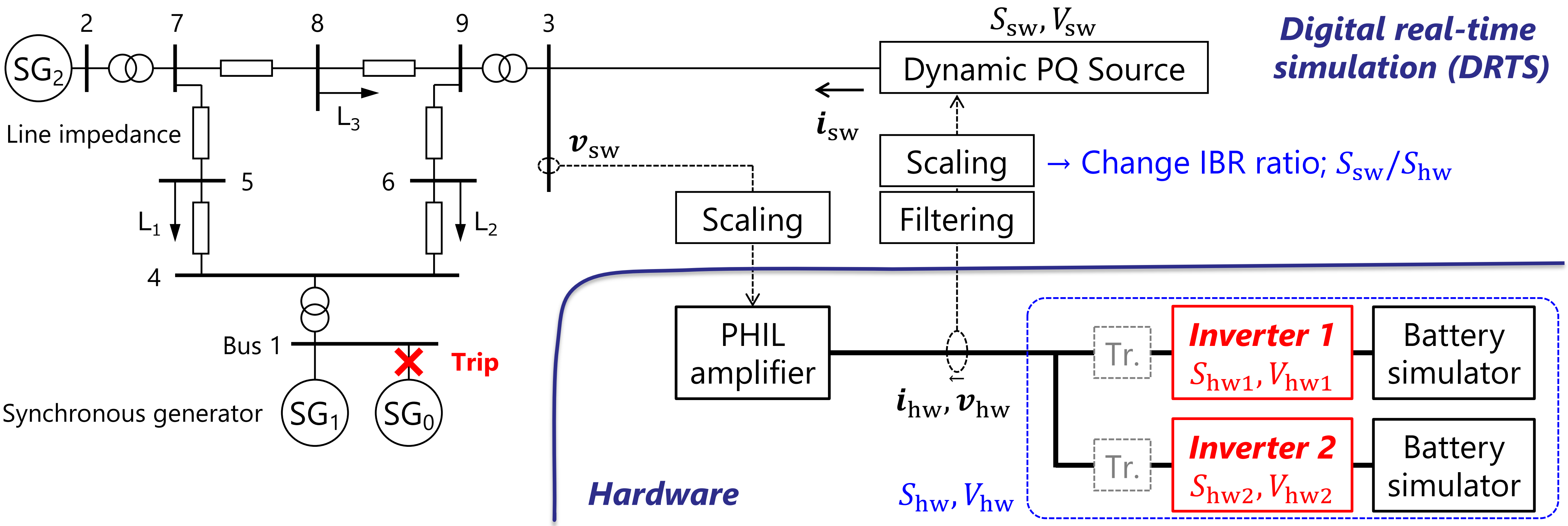
Prototype 1

Prototype 2

Prototype 1

Prototype 3

Configuration of PHIL Testing for Multiple Inverters

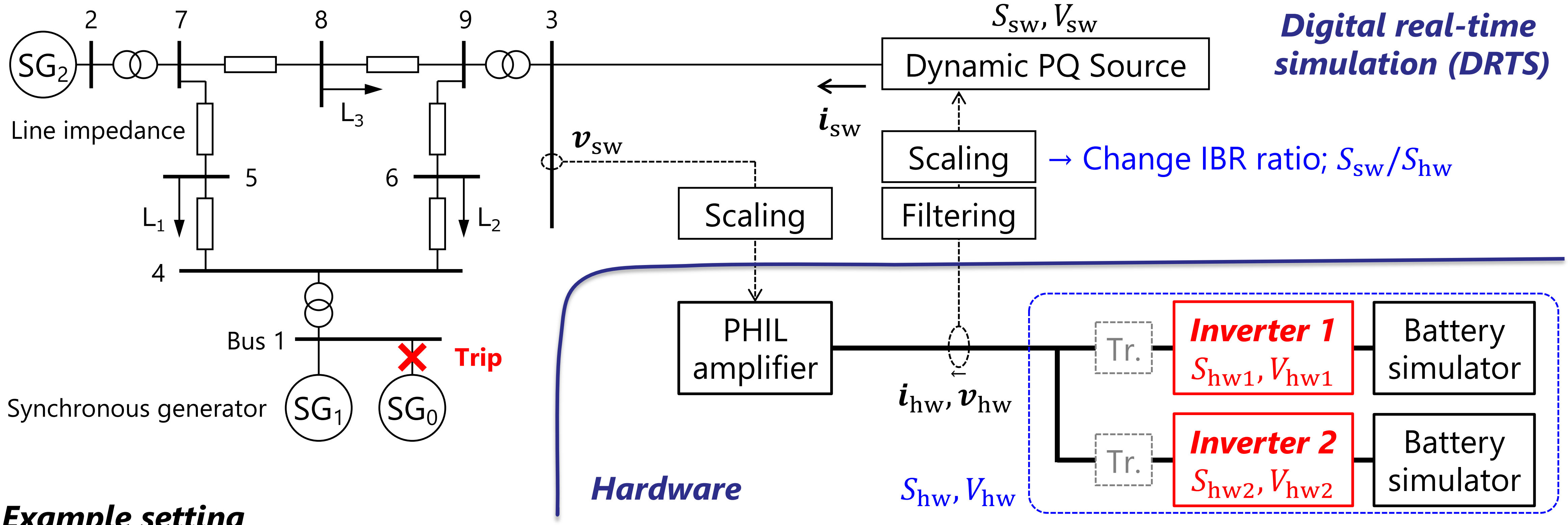


How do we test multiple inverters with different ratings?

▼

Equalize rated capacities, voltages, and control parameters

Configuration of PHIL Testing for Multiple Inverters



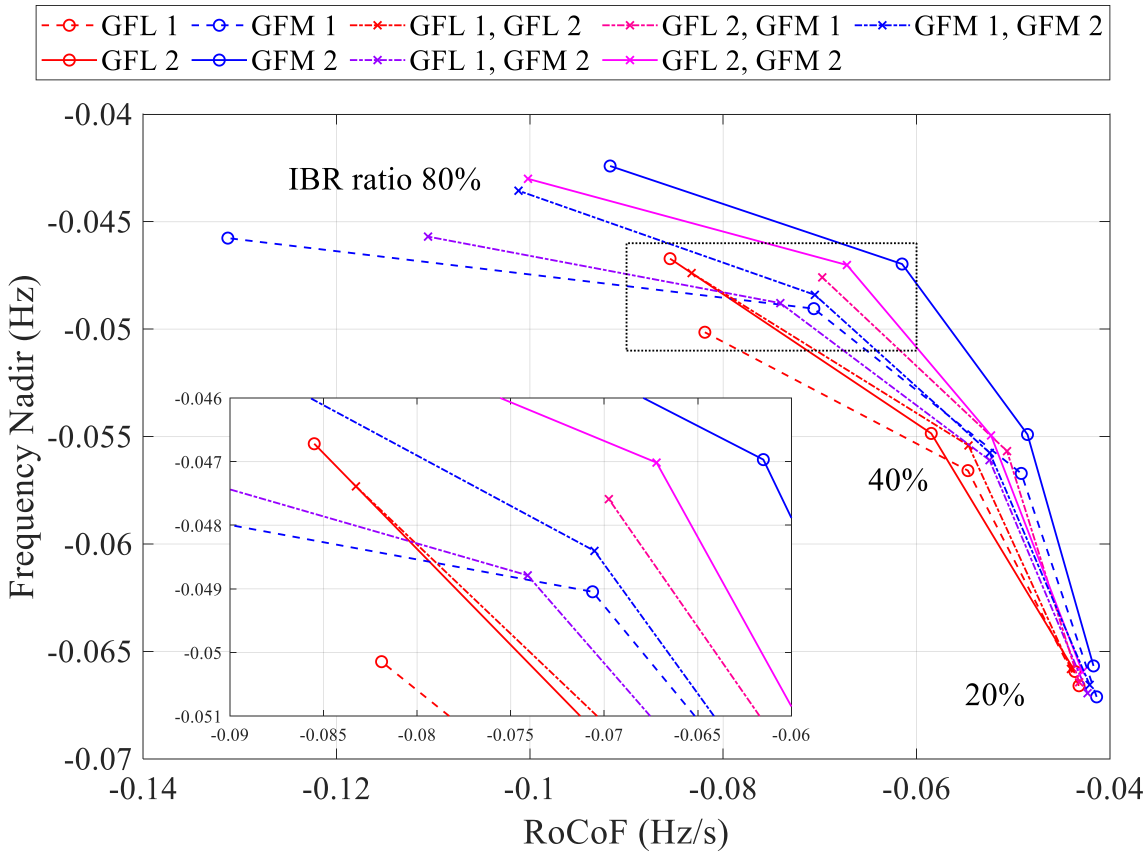
Example setting

Inverter 1	$S_{hw1} = 20\ \mathrm{kVA} \Rightarrow S'_{hw1} = 20\ \mathrm{kVA}$	$V_{hw1} = 200\ \mathrm{V} \Rightarrow$ use Tr.	$H'_1 = \frac{S'_{hw1}}{S_{hw1}} \times H_1, G'_1 = \frac{S'_{hw1}}{S_{hw1}} \times G_1$
Inverter 2	$S_{hw2} = 50\ \mathrm{kVA} \Rightarrow S'_{hw2} = 20\ \mathrm{kVA}$	$V_{hw2} = 440\ \mathrm{V}$	$H'_2 = \frac{S'_{hw2}}{S_{hw2}} \times H_2, G'_2 = \frac{S'_{hw2}}{S_{hw2}} \times G_2$
Total setting	$S_{hw} = S'_{hw1} + S'_{hw2} = 40\ \mathrm{kVA}$	$V_{hw} = 440\ \mathrm{V}$	-

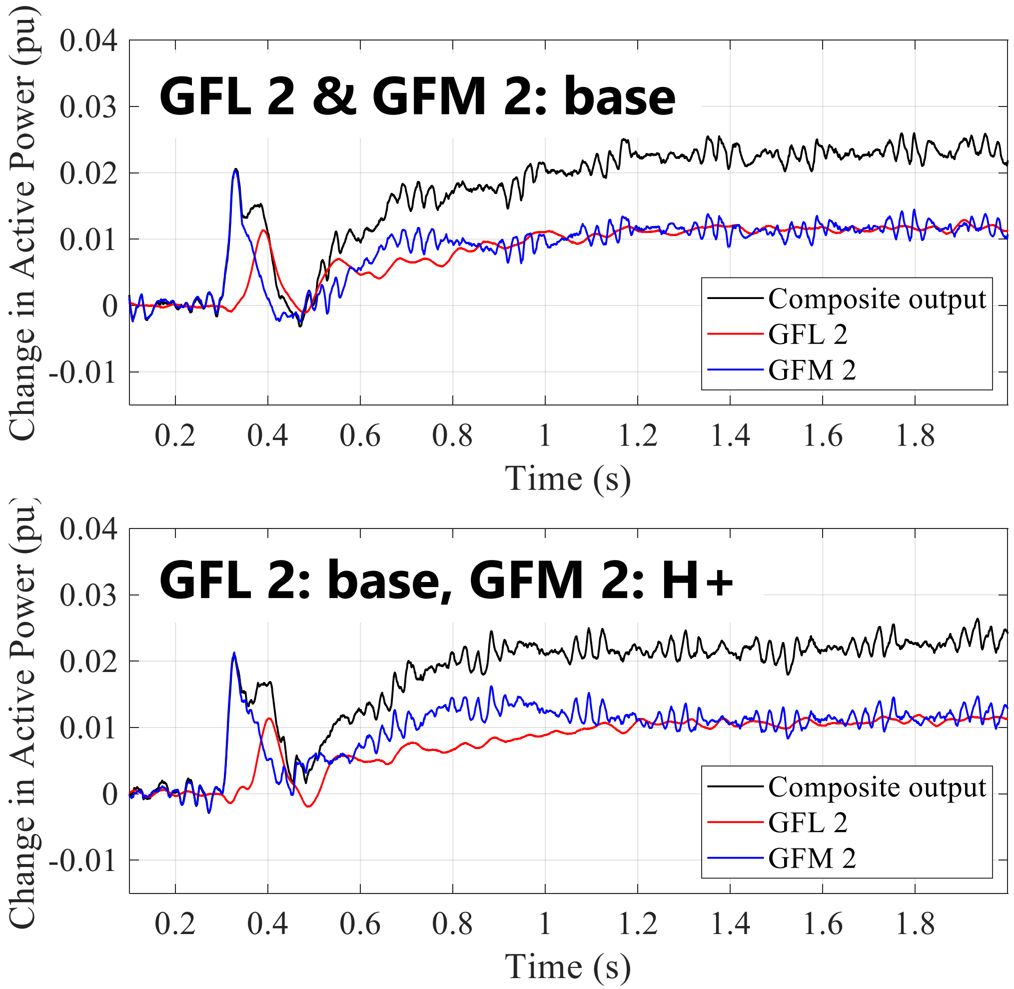
Parameter Settings

	Inertia constant H_1, H_2 (s)	Governor gain G_1, G_2(puMW/puHz)
Base setting	2.35	25
H+ setting	7.05	25
G+ setting	2.35	75
H0 setting	0.05	25

No inverter combination caused interference that significantly worsened the grid frequency stability. Combined inverters' performance was intermediate between the performance of each inverter alone.



RoCoF and frequency nadir



Active power

Summary

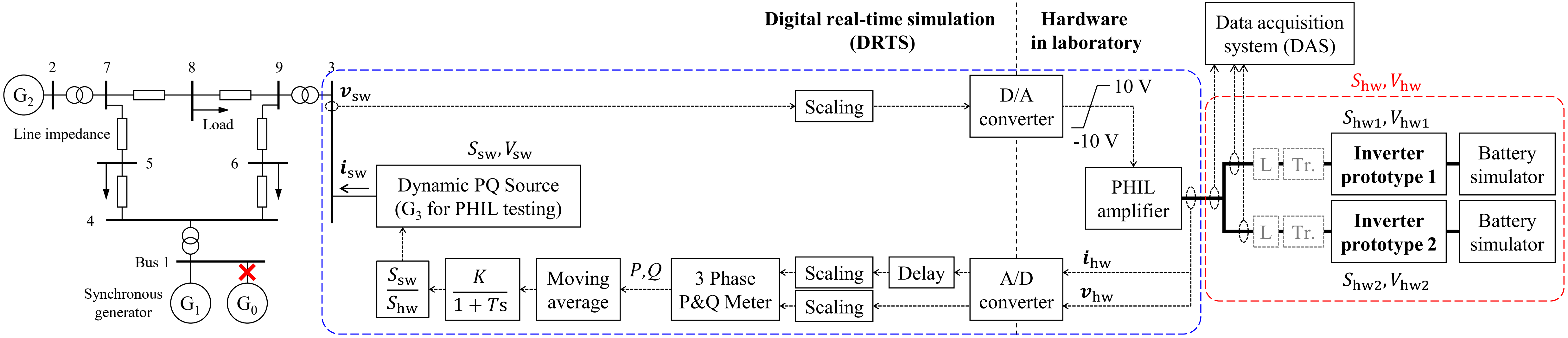
- GFL/GFM inverters are expected to replace the inertial response of synchronous generators
- PHIL testing is an attractive option to test GFL/GFM inverters with virtual inertia controls
  - Built PHIL configuration and tested the performance of each inverter alone
  - Not tested multiple inverters connected in parallel

- Proposed PHIL setup to test multiple GFL/GFM inverters with different rated capacities and control mechanisms as if they had equivalent capacities and control parameters
- Test results showed
  - No Inverter combination caused interference that significantly worsened the grid frequency stability
  - Combined inverters' performance was intermediate between the performance of each inverter alone

- Future work
  - Propose PHIL setup to test multiple inverters to be connected to different buses

Appendix

PHIL Testing for Multiple Inverter Combinations



Modified IEEE 9 bus system model

PHIL interface

Advanced Control of GFL and GFM inverters

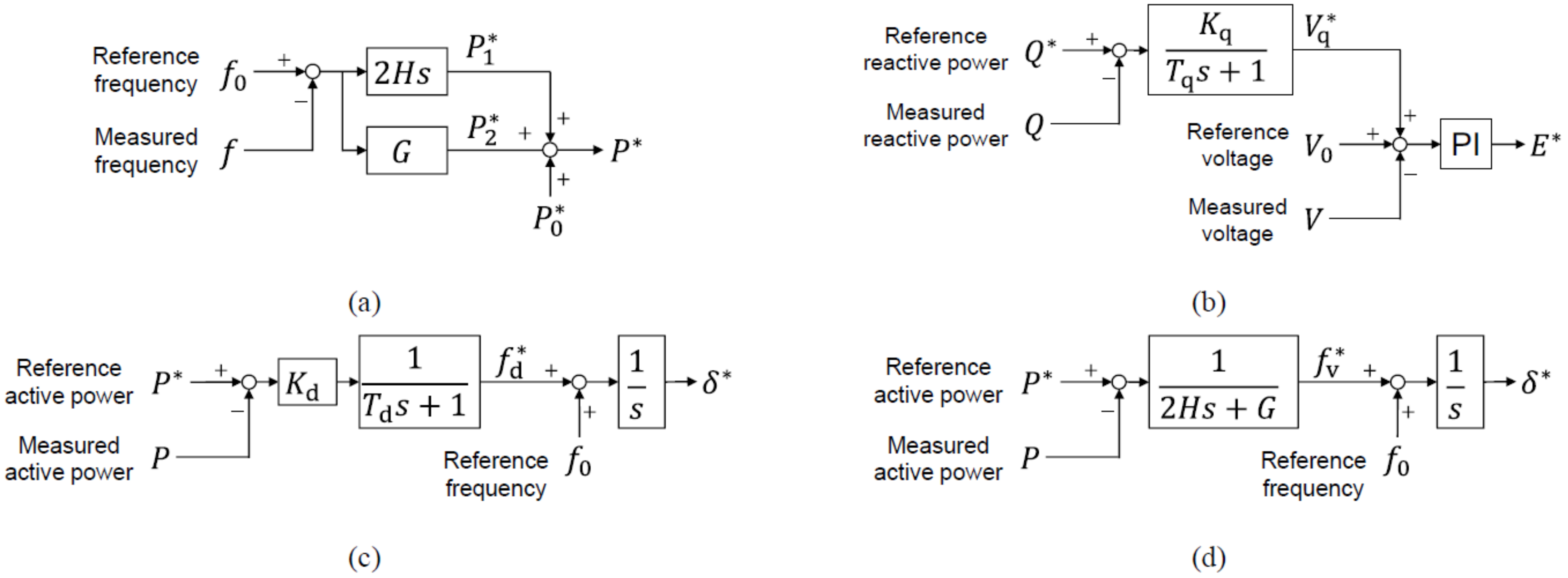


Fig. 1. Generalized control block diagrams of (a) the frequency control implemented in GFL 1 and GFL 2; (b) the voltage magnitude control implemented in GFM 1 and GFM 2; the voltage phase angle control implemented in (c) GFM 1; and (d) GFM 2.

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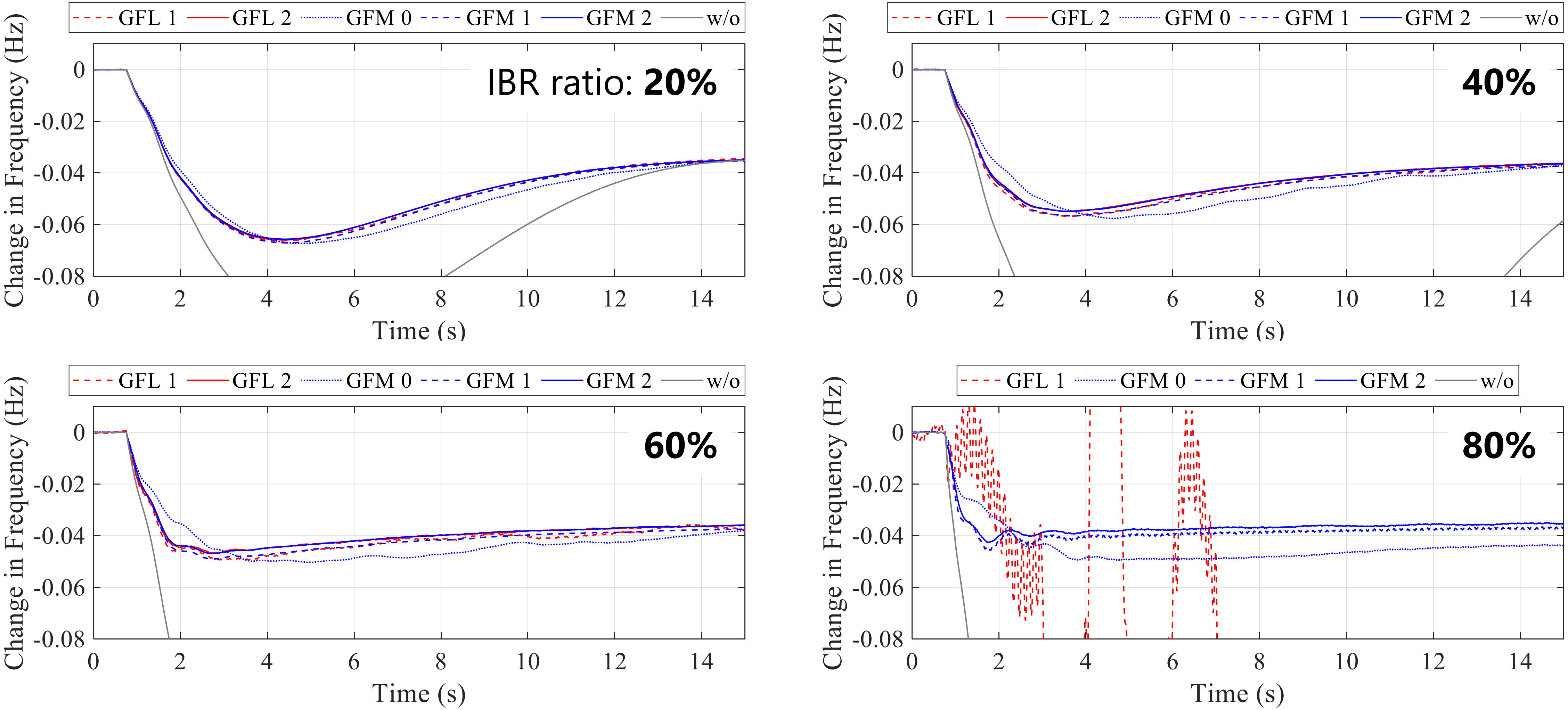
As IBR Ratio Increased, Frequency Change Increased for Conv. IBR, Decreased for GFL and GFM Inverters. GFM Inverters were Stable at 80%.



Source: H. Kikusato, et al., "Performance Evaluation of Grid-Following and Grid-Forming Inverters on Frequency Stability in Low-Inertia Power Systems by Power Hardware-in-the-Loop Testing," Energy Reports 2023, 9 (supplement 1), 381–392.