Performance Evaluation of Grid-Following and Grid-Forming Inverters in Low-Inertia Power Systems

[Japan's national project for FY 2019–2021]

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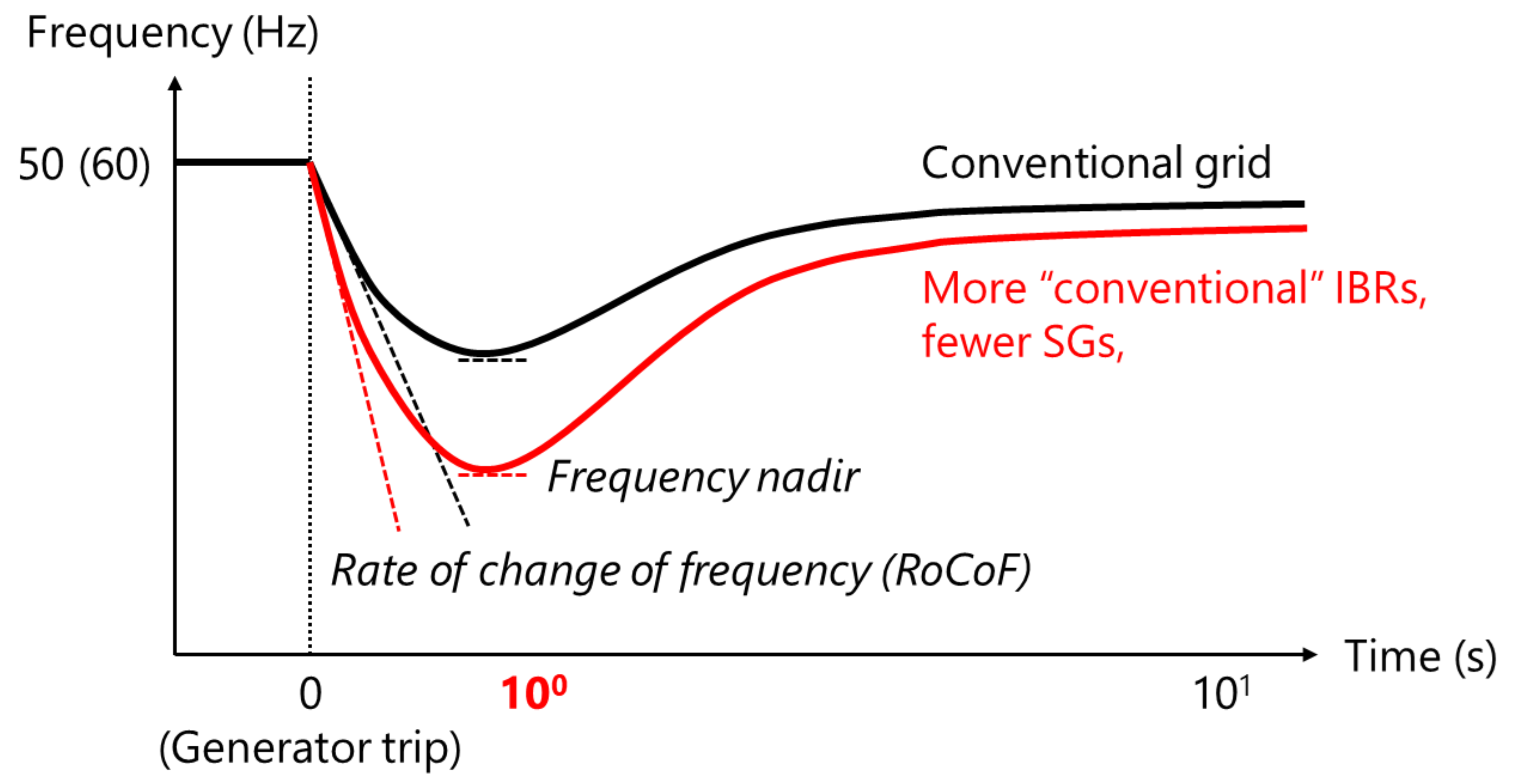
1. Introduction

- **GFL/GFM inverters with virtual inertia controls are expected to replace the inertial response of retiring synchronous generators.**
- **We studied KPIs and evaluation methods and tested GFL/GFM inverters from different manufacturers to verify performance and possible interference with existing protective functions.**

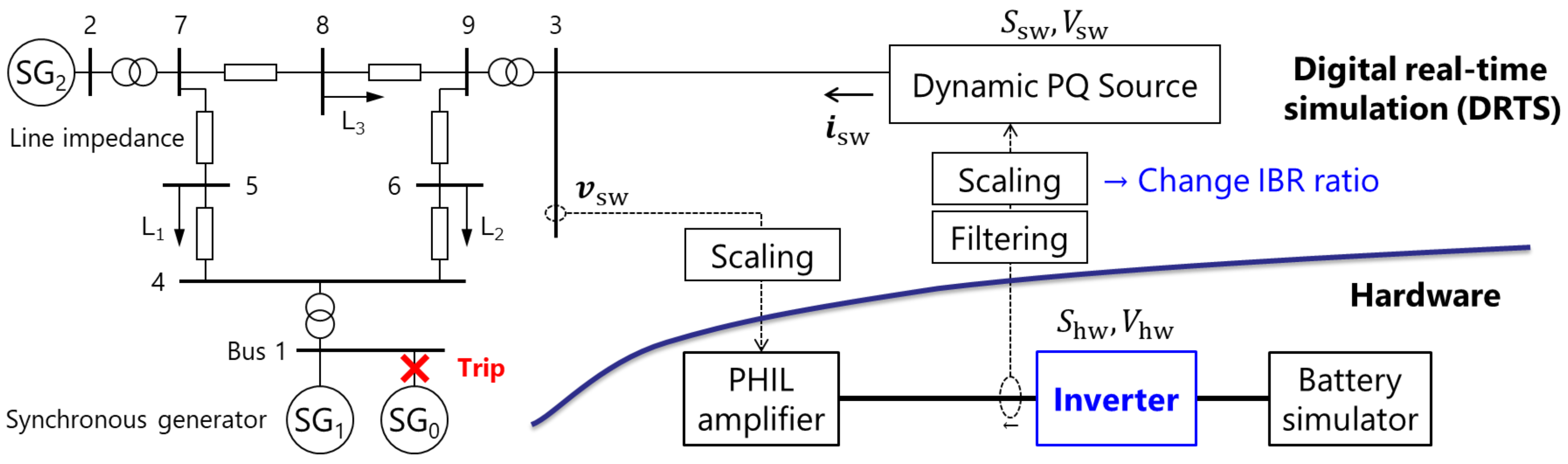


2. Prototype inverters with virtual inertia controls

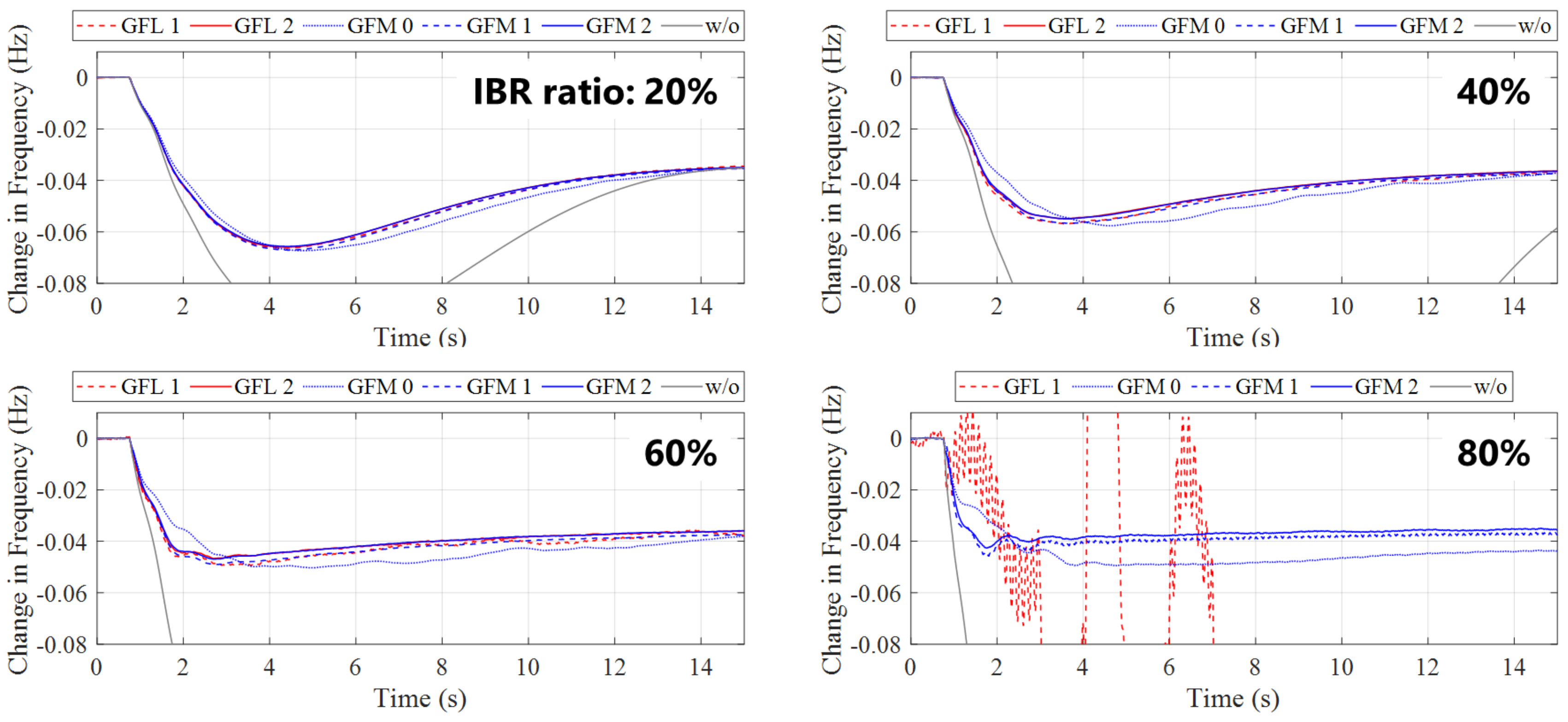
	Grid-following inverter		Grid-forming inverter		
	GFL 1	GFL 2	GFM 0	GFM 1	GFM 2
Control function	df/dt-P droop f-P droop	df/dt-P droop f-P droop	VSM Q-V droop	P-f droop Q-V droop	VSM Q-V droop
Rated capacity (kVA)	20	49.9	12	20	50
Rated AC voltage (V)	200	200	420	200	440

3. Power hardware-in-the-loop (PHIL) testing

PHIL test setup using modified IEEE 9-bus system model.



- **As the inverter-based resource (IBR) ratio increases, frequency change increased for conventional IBR (w/o), decreased for GFL and GFM Inverters.**
- **At IBR 80%, GFL inverters were unstable, but GFM Inverters were stable.**



4. Conventional Japanese conformance testing

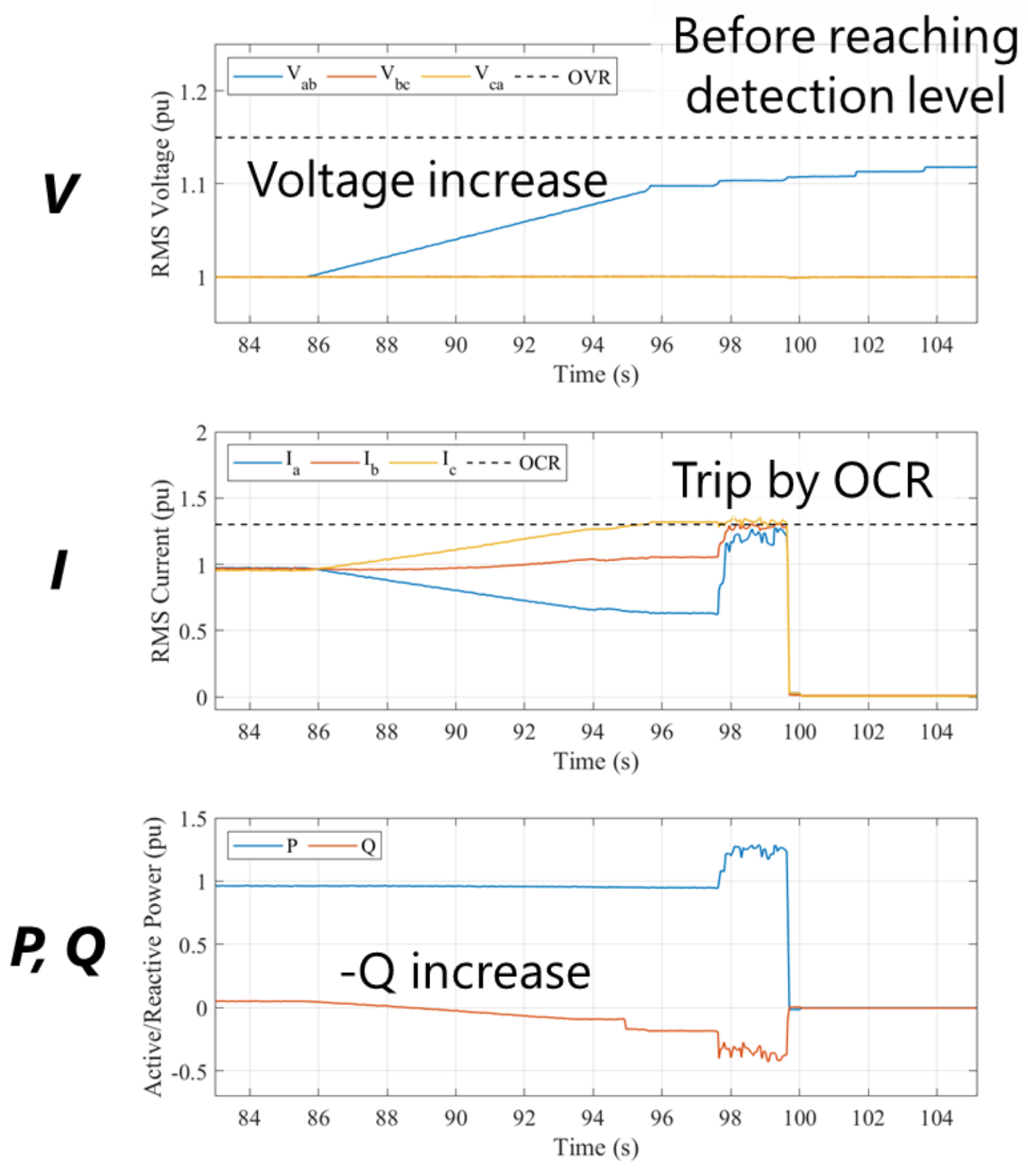
Performed tests with changes in voltage magnitude, frequency, and phase angle.
- GFL inverters: almost conformance in all tests.
- GFM Inverters: non-conformance in most tests, three issues were identified.

#	Test	GFL 1	GFL 2	GFM 0	GFM 1	GFM 2
1	Test for over/under-voltage trip	C*	C	N	N	N
2	Test for over/under-frequency trip	C*	C	N	N	N
3	Unintentional islanding test	C*	C*	-	N	C*
4	Test for voltage magnitude change within continuous operation region	C	C	N	C	C
5	Test for voltage phase angle change	C	C	C	N	N
6	Test for low/high-voltage ride-through	C*	C*	N	N	N
7	Test for low/high-frequency ride-through	C	C	N	N	C

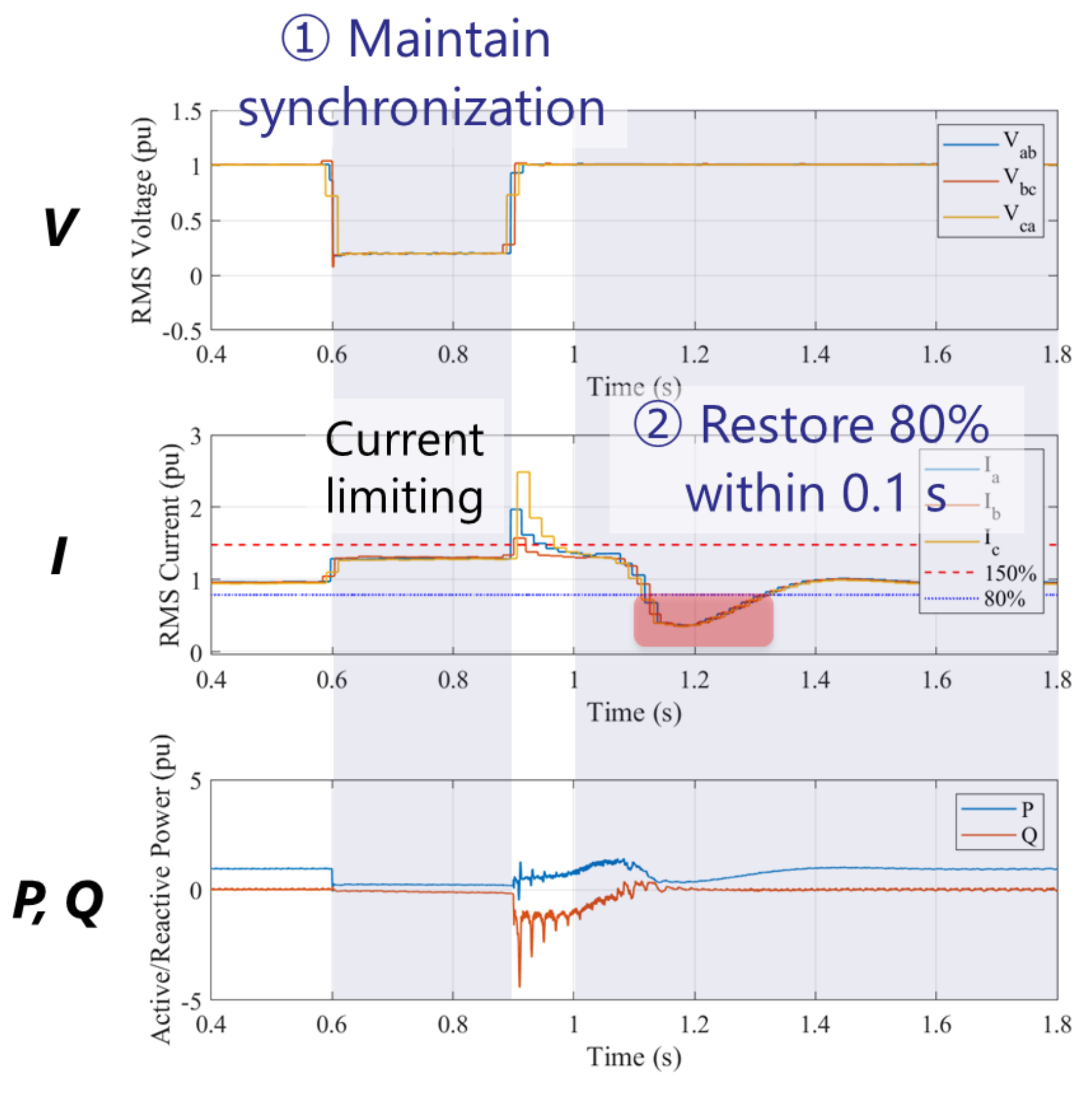
C: Conformance; N: Non-conformance; -: Not conducted
* Conformance can be expected by minor changes to device configuration, control logic, etc.

Three issues on GFM inverters;

- **Issue 1: Unwanted tripping by OCR due to changes in grid voltage.**
- **Issue 2: Active power swing after recovery from voltage sag.**
- **Issue 3: Coexistence of grid stabilization capability and islanding detection.**



Test for over-voltage trip (GFM 0)



Low-voltage ride-through test (GFM 0)

5. Conclusion and future work

- **Identified advantages and issues on GFL/GFM inverters with virtual inertia controls.**
- **Will evaluate other power system stabilities than frequency.**
- **Will develop protective functions for GFM inverters.**
- **Will review the inverter testing procedure and criteria.**

Related works

1. 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 (in press).
2. H. Kikusato, et al., "Performance Analysis of Grid-Forming Inverters in Existing Conformance Testing," Energy Reports (in press).
3. H. Kikusato, et al., "Verification of Power Hardware-in-the-Loop Environment for Testing Grid-Forming Inverter," PEEE 2022 (accepted).
4. H. Kikusato, et al., "Power Hardware-in-the-Loop Testing for Multiple Inverters with Virtual Inertia Controls," ICPEE 2022 (under review).
5. D. Orihara, et al., "Contribution of Voltage Support Function to Virtual Inertia Control Performance of Inverter-Based Resource in Frequency Stability," Energies 2021, 14, 4220.
6. D. Orihara, et al., "Internal Induced Voltage Modification for Current Limitation in Virtual Synchronous Machine," Energies 2022, 15, 901.
7. J. Hashimoto, et al., "Development of df/dt Function in Inverters for Synthetic Inertia," Energy Reports (in press).
8. J. Hashimoto, et al., "Developing a Synthetic Inertia Function for Smart Inverters and Studying its interaction with other functions with CHIL testing," Energy Reports (in press).
9. T. Takamatsu, et al., "Simulation Analysis of Issues with Grid Disturbance for a Photovoltaic Powered Virtual Synchronous Machine," Energies 2022, 15, 5921.
10. H. Hamada, et al., "Challenges for a Reduced Inertia Power System Due to the Large-Scale," Global Energy Interconnection 2022, 5(3), 266–273.

Acknowledgment

This study was based on the results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO), no. JPNP19002. We would like to thank the inverter manufacturers, M. Suzuki, S. Sugahara, and M. Takahashi, for their grateful cooperation in the testing. We are also thankful to the researchers of IEA ISGAN Working Group 5, Smart Grid International Research Facility Network (SIRFN).