An Overview and Preliminary Results of the NEDO STREAM Project ~ Grid Forming Inverters Development ~

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Outline

1. Background

- Why do we need a grid-forming (GFM) inverter/converter?

2. Global Trends in GFM Inverters

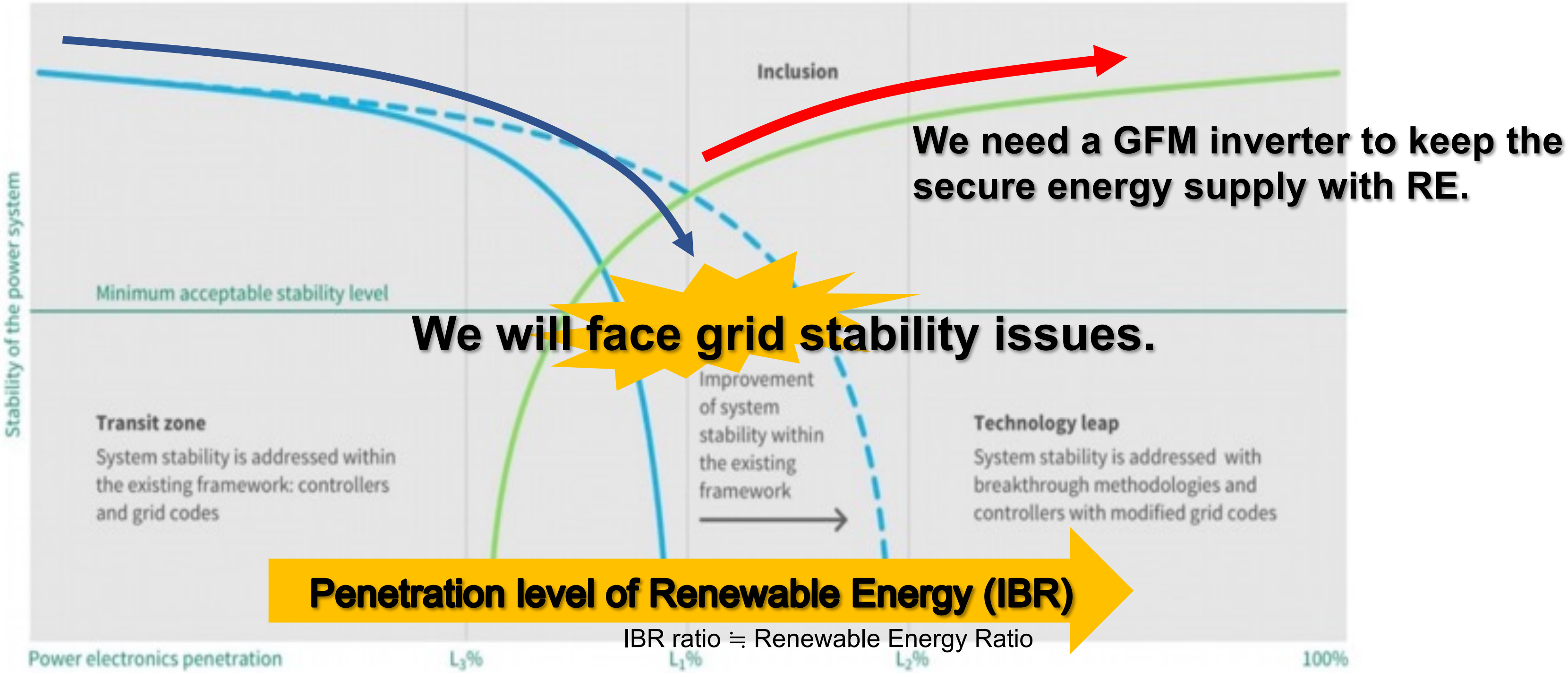
- Global Trend of GFM Inverter Demonstration

3. NEDO STREAM Project

- Japan’s Policy
- Japan National Project (NEDO STREAM)

Grid Stability Issues with High Penetration of Renewable Energy Source

- Further expansion of renewable energy sources will increase inverter-based resources (IBR), including batteries.
- As the IBR ratio rises, the number of synchronous generators will likely decrease, leading to grid instability.
- Developing grid-forming (GFM) inverters with functions equivalent to synchronous generators becomes imperative for accommodating high penetration of renewable energy sources (RES).



Cf. The EU-funded project, "MIGRATE Roadshow."

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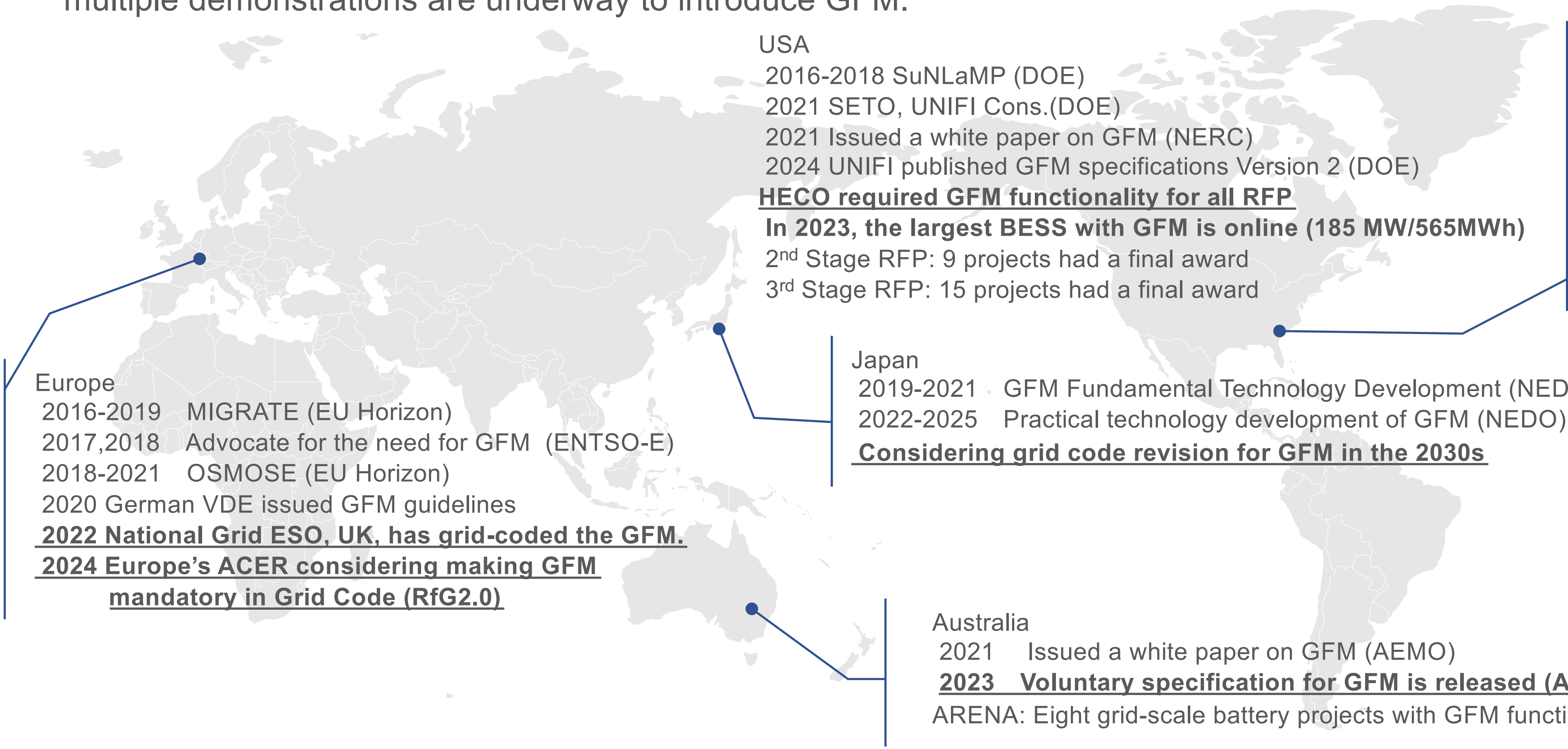
Grid-code and Demonstration Trends Related to GFM Inverters

- Discussions on rules, requirements, and specifications are underway in Europe, the U.S., Australia, etc. Implementation is progressing from demonstration to operation.
- In Europe, ACER is considering mandating GFM through the Grid Code, with the intention to issue the Code in 2024.
- The U.S. and Australia have developed and published their GFM requirements and specifications, and multiple demonstrations are underway to introduce GFM.



USA
2016-2018 SuNLaMP (DOE)
2021 SETO, UNIFI Cons.(DOE)
2021 Issued a white paper on GFM (NERC)
2024 UNIFI published GFM specifications Version 2 (DOE)
HECO required GFM functionality for all RFP
In 2023, the largest BESS with GFM is online (185 MW/565MWh)
2nd Stage RFP: 9 projects had a final award
3rd Stage RFP: 15 projects had a final award

Japan
2019-2021 GFM Fundamental Technology Development (NEDO)
2022-2025 Practical technology development of GFM (NEDO)
Considering grid code revision for GFM in the 2030s

Europe
2016-2019 MIGRATE (EU Horizon)
2017,2018 Advocate for the need for GFM (ENTSO-E)
2018-2021 OSMOSE (EU Horizon)
2020 German VDE issued GFM guidelines
2022 National Grid ESO, UK, has grid-coded the GFM.
2024 Europe's ACER considering making GFM mandatory in Grid Code (RfG2.0)

Australia
2021 Issued a white paper on GFM (AEMO)
2023 Voluntary specification for GFM is released (AEMO)
ARENA: Eight grid-scale battery projects with GFM function

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National Project Related to GFM Inverters

Japanese Government Policy

Jul. 2018
5th Strategic Energy Plan

Oct. 2021
6th Strategic Energy Plan

- Promote technological development and institutional considerations for introducing inverters with synthetic inertia functions, etc.
- Update grid codes and integrate corresponding services into an electricity market in the 2030s to secure grid stability with inertia, etc.

NEDO project

Next-Generation Power Network Stabilization Technology Development for Large-Scale Integration of Renewable Energies

- Development of basic technology to cope with decreases in inertia

Phase A: primary study for synthetic inertia
(FY2019～FY2021)

Future-generation power network Stabilization Technology development for utilization of Renewable Energy As the Major power source (STREAM)

- R&D for practical use of GFM inverters

Phase B: implementation of GFM inverter
(FY2022～FY2026)

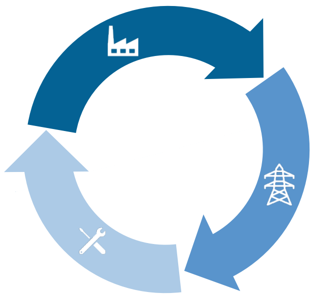
Project Overview

WP1 Development of Inverter-based Countermeasures for Low System Inertia

- Requirement and specification study.
- Design & development of Prototype.
- 3+α GFM inverter for battery storage and one GFM inverter for PV

WP2 Validation and testing

- Equipment-based study, e.g., Lab/Field testing and conformance of GFM inverter.



Laboratory testing

- Development of test procedure achieving certification.
- Impact assessment of GFM using PHIL testing technologies

Demo field testing

- Testing on full-scale distribution systems
- Remaining test that lab testing does not cover

Prototype improvement

- Grid interconnection testing and conformance to requirements
- Proposal for inverter requirement revisions

Lab testing: Smart System Research Facility, AIST

Demo field testing: Akagi testing Center, CRIEPI

WP3 Power System Stability Analysis

- Simulation-based impact analysis study for system stability

Output

- Accumulation of new findings and lessons learned to inform grid code updates
- Recommendation for updating the grid code

Requirement and Specification for GFM (WP1)

- Requirements and specifications of GFM specifically designed for Japanese grids have been sorted out by referencing overseas examples.
- The unique feature of this project is proactive examination for integration of GFM into distribution grids.

Ongoing Working Draft of Requirement and Specification

Contents
1. General Information
2. Frequency Containment/ Inertial response
3. Constant Voltage Source Capability
4. Power Quality
5. Protection Coordination
6. Inverter-driven Instability Prevention
7. Low SCR Operation
8. Other

Technical Report Timeline

- **Mar. 2024**: Compiling requirements and specifications tailored to the unique characteristics of the Japanese power grid for the exploration of GFM
- **From Apr. to Jul. 2024**: Exchange views with relevant stakeholders, e.g., TDGC, JEMA, vendor, TEPCO PG, related project members, etc.
- **Sep. 2024**: Publish the draft
- **Aug. 2025**: Second round testing that follows initial testing with updated requirements and specifications

Transmission & Distribution Grid Council (TDGC)
The Japan Electrical Manufactures Association (JEMA)

Validation and Testing of GFM Inverter (WP2)

- The laboratory testing comprises two main components: basic testing and PHIL testing.
- The basic test aims to assess the fundamental and maximum performance of the GFM inverter.
- Conversely, the PHIL test examines external grid interactions and identifies potential issues.
- The laboratory test has been conducted in an environment similar to a typical grid interconnection test for the domestic market.
- The control parameters have been generalized as much as possible to highlight the differences in each inverter vendor's characteristics.

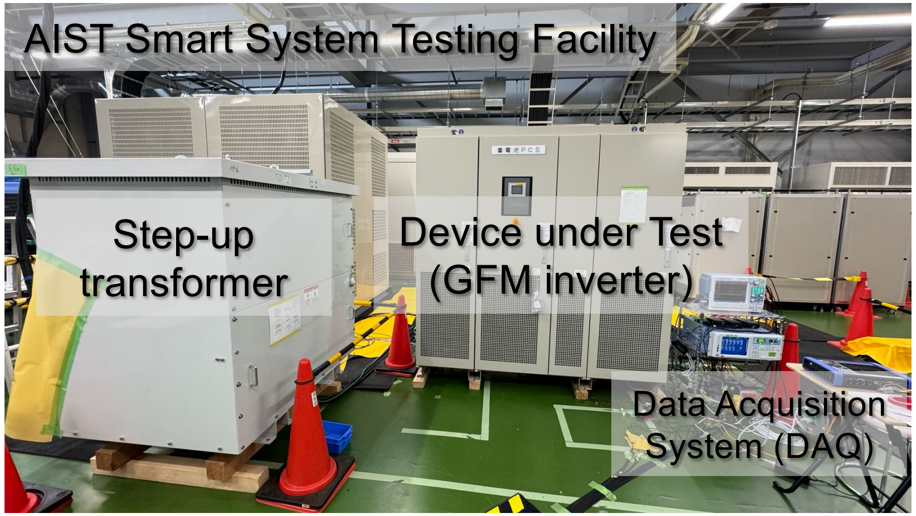


Fig. Laboratory testing of "vender A"

- Different setting parameter testing. E.g., Inertia constant, governor gain, damping coefficient, etc.
- Various test conditions.
  - Frequency ramp tests with ±0.1~ ± 5 Hz/sec
  - FRT tests with varying voltage levels, phase angles of fault, fault clear time, etc.

GFM Inverter General Testing Result

- Performance tests are conducted to determine the detailed required specifications.
- The priority issues of GFM are "Appropriate overcurrent control," "Fault rides through," and "anti-islanding detection."
- Each vendor uses a unique set of controls, which requires confirming that differently behaved GFMs may be introduced if the specifications are unclear.
- We perceived the necessity of more tailored requirements from the grid operation's perspective, considering each vendor's maximum inverter performance through our observations and comparisons.

3LG, residual voltage of 20%, 0° phase angle, Fault duration of 0.3 s (baseline setting)

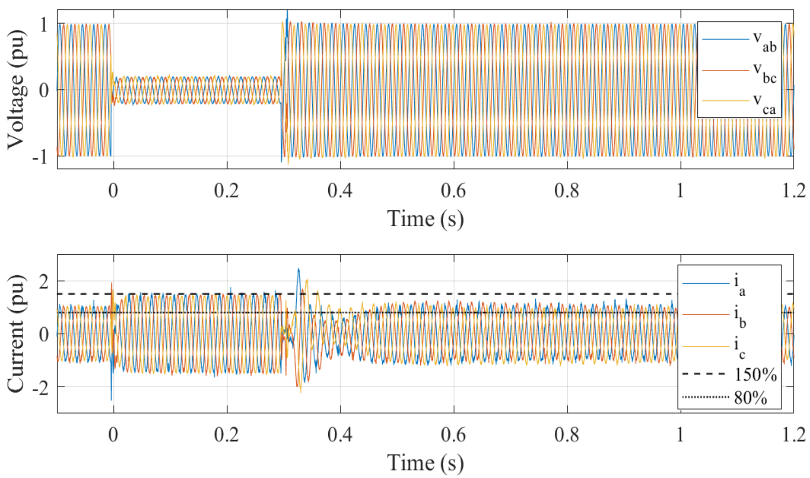


Fig FRT(3LG) sample testing result

- Confirmed ride through 3LG faults.
- Fault current is supplied up to the overcurrent limit as expected during instantaneous voltage drop. (Appropriate overcurrent control)
- Above 150% of the current is supplied immediately after the voltage is restored.
- It is essential to define the behavior after removing the fault.
- The DuT switches to the FRT mode, during the voltage sag. We need to define the required performance behavior after the fault clearance.

Status of Development and Study of Models and Testing Methods for PHIL Testing

- A model capable of testing various use cases is being constructed for the PHIL test.
- Thermal power generation, IBR, etc., are primary power sources. The IBR consists of three types: conventional GFL, GFL with fast frequency response, and GFM.
- The model reproduces various system faults under different RES penetration levels by adjusting this supply capacity.

Test No.	Supply and demand conditions (load feeder power flow)
1	Forward power flow across the distribution transformer banks with load feeders where both IBRs and loads are equally deployed
2	Reverse power flow across the distribution transformer banks with load feeders where both IBRs and loads are equally deployed
3	Reverse power flow across the distribution transformer banks with load feeders where loads are equally deployed, while IBRs are concentrated to the center of feeders
4	Zero power flow across the distribution transformer banks with load feeders where both IBRs and loads are equally deployed between the sending end and the center

Contingency type		test sequence
A	Interaction with generators	Open transmission line <2> for 10 ms
B	Ground fault/short-circuit	Transmission line <8> short-circuit fault (30% from MV side) → fault duration of 70 ms. Fault type: 3LG, 2LG, 1LG, 3LS, 2LS
C	Generator trip	Generator Gd (about 1% of the system) is disconnected.
D	Transmission route switch	Open transmission lines <8>.
E	Anti-/islanding operation	Open the CB on high voltage side of the transmission line <14>

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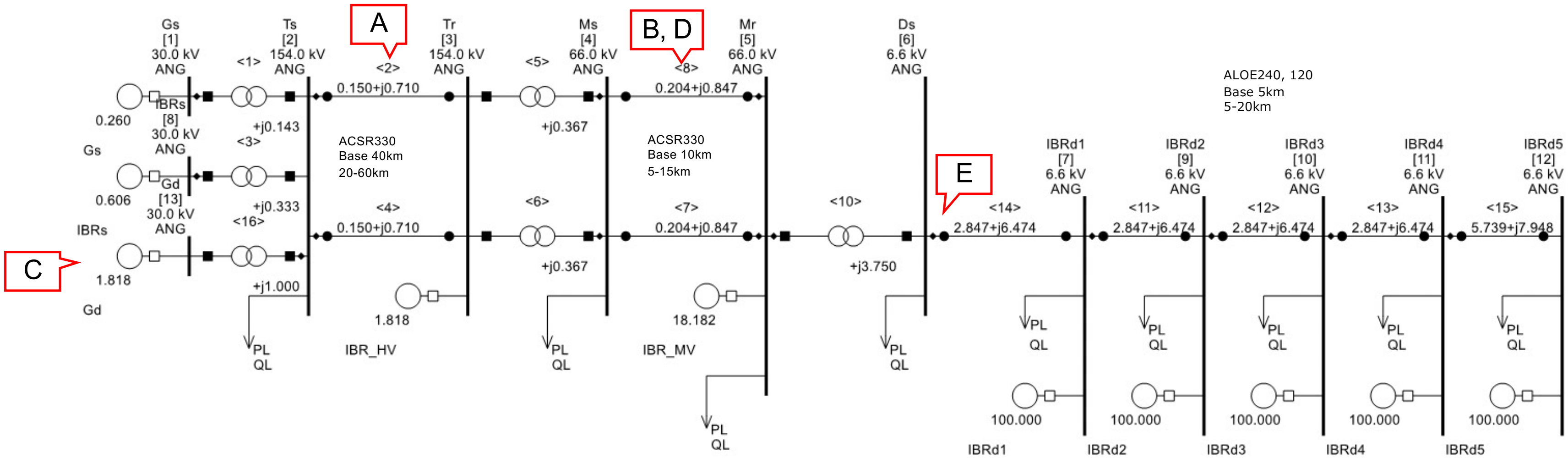
From A to E are contingency event locations.



Main power sources: Grid capacity approx. 1300 MVA/ Output approx. 800 MVA
Gs: Thermal power generation (LAT=1, LPT=1)
IBRs: 3 inverter power sources: GFL, S-GFL, GFM
Gd: Thermal power generation (LAT=1, LPT=1) Within 1~4% of grid capacity

Common system conditions (line type)
Transmission lines <154, 66kV> ACSR330 (1 conductor)
Distribution lines <6.6kV> ALOE240, ALOE120

PHIL test confirmation results

- The PHIL test reproduced various system disturbances and completed the initial scrutiny regarding the dynamic behavior of the prototype machine under test following a system disturbance.
- Three-phase ground fault (3LG) testing was performed with a PHIL on a GFM inverter.

Test No. 1-B-1-3LG
Transmission line <8> ground-fault
→ fault duration of 70 ms (fault type: 3LG)

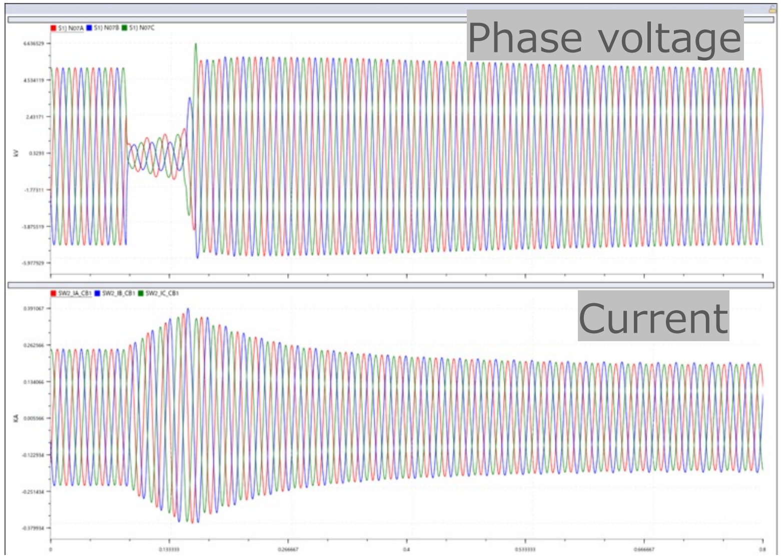
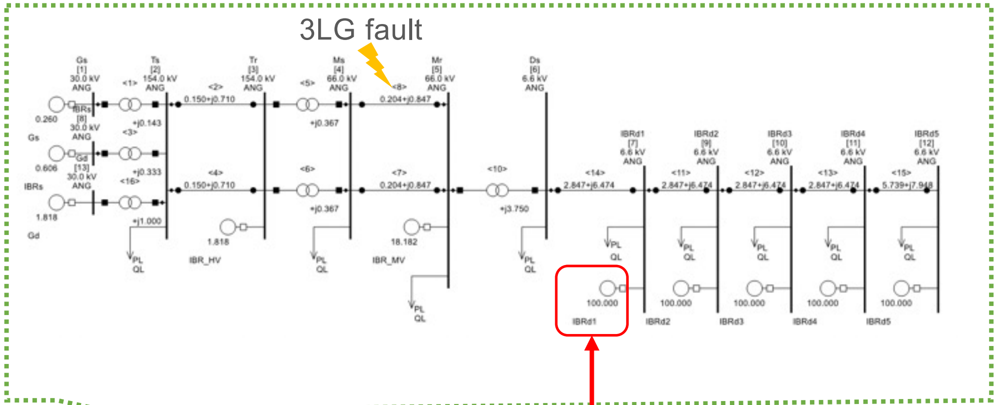
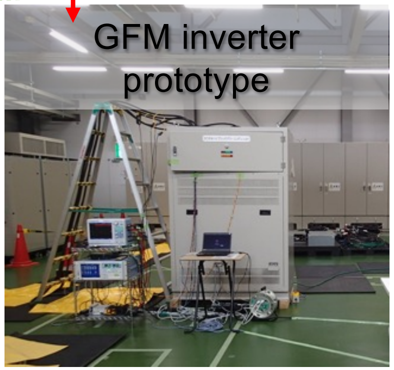


Figure: PHIL test of GFM dynamic behavior following a system disturbance with one line open after a 3LG fault.

The interconnection point is electrically 1 km away from the distribution substation serving the load feeder (IBRd1)



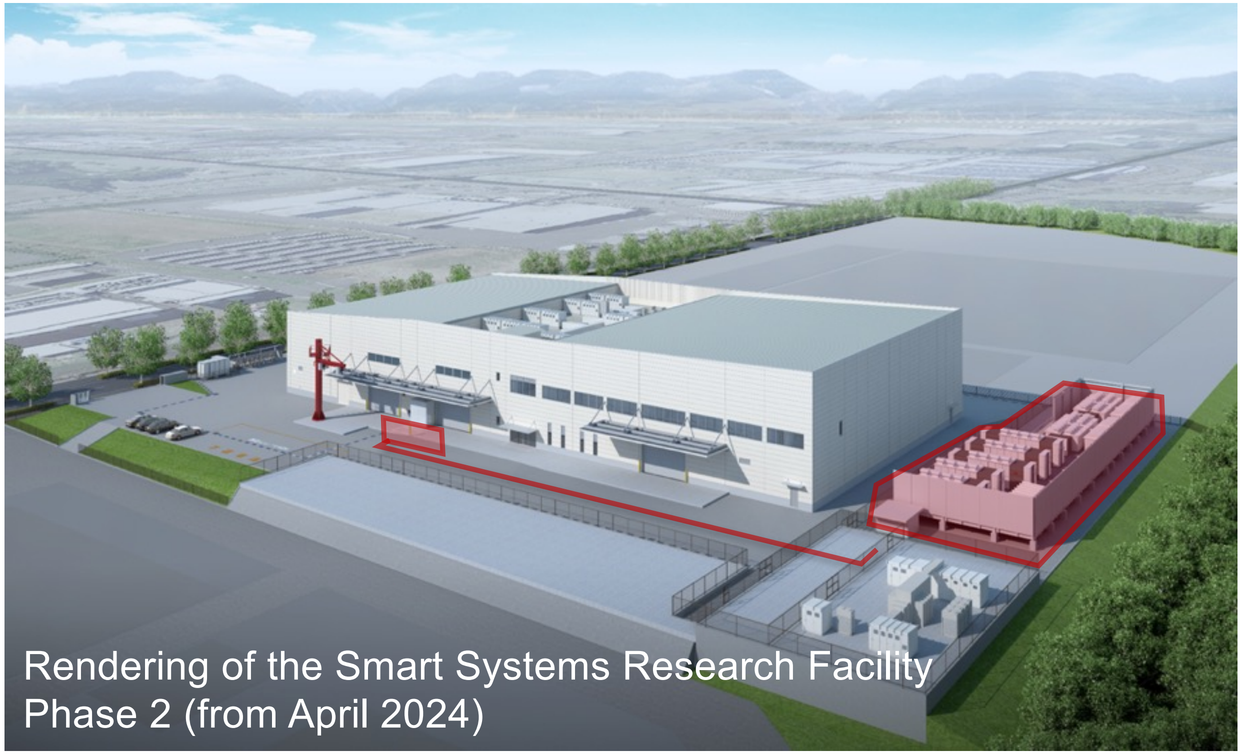
Virtual sector
DRTS（NovaCor)



Physical (Hard) Sector
GFM inverter（50kVA)

FREA Smart Systems Research Facility Enhancement

- Opened at FREA in FY2016 as part of the 'Global Certification Infrastructure Development Project of METI' from the FY2013 supplementary budget.
- Expansion work is scheduled to be completed in FY2023 under the 'International Standard and Certification Center Development Project for Promoting Carbon Neutrality of METI,' funded by the supplementary budget for FY2021. The facility will be available for use starting last April.



Conclusion

- A concern regarding grid stability has arisen due to the increasing presence of Inverter-based Resources (IBR), becoming a worldwide issue. Many countries are now working on refining the rules, requirements, and specifications in their grid codes, with a specific focus on GFM inverters.
- Japan also aims to refine its grid code in the 2030s as a mid-to-long-term goal, pursuiting necessary research under the NEDO STREAM project.
- As part of this project, we have reported on the progress of organizing Japanese-oriented requirements, specifications, and test methods for GFM inverters.

The Contents include results obtained from a project, JPNP22003, commissioned by the New Energy and Industrial Technology Development Organization (NEDO)

Thank you for your attention
You are more than welcome to visit our facility in Fukushima.

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