Mission Innovation, Green Powered Future Mission Workshop
Policy and Technology for Grid Flexibility and Stability

Day2 March 13(Wed) 14:40-15:05
Technology Session 3: Grid Stability
(Inertia Management, Smart Inverters, Grid forming converters)

Grid Forming Converters: Advanced capabilities for grid stability with high penetration of Renewable Energy

NEDO STREAM Project

March 2024

National Institute of Advanced Industrial Science and Technology （AIST）
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Outline

1. Background

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

2. Global Trends in GFM Inverters

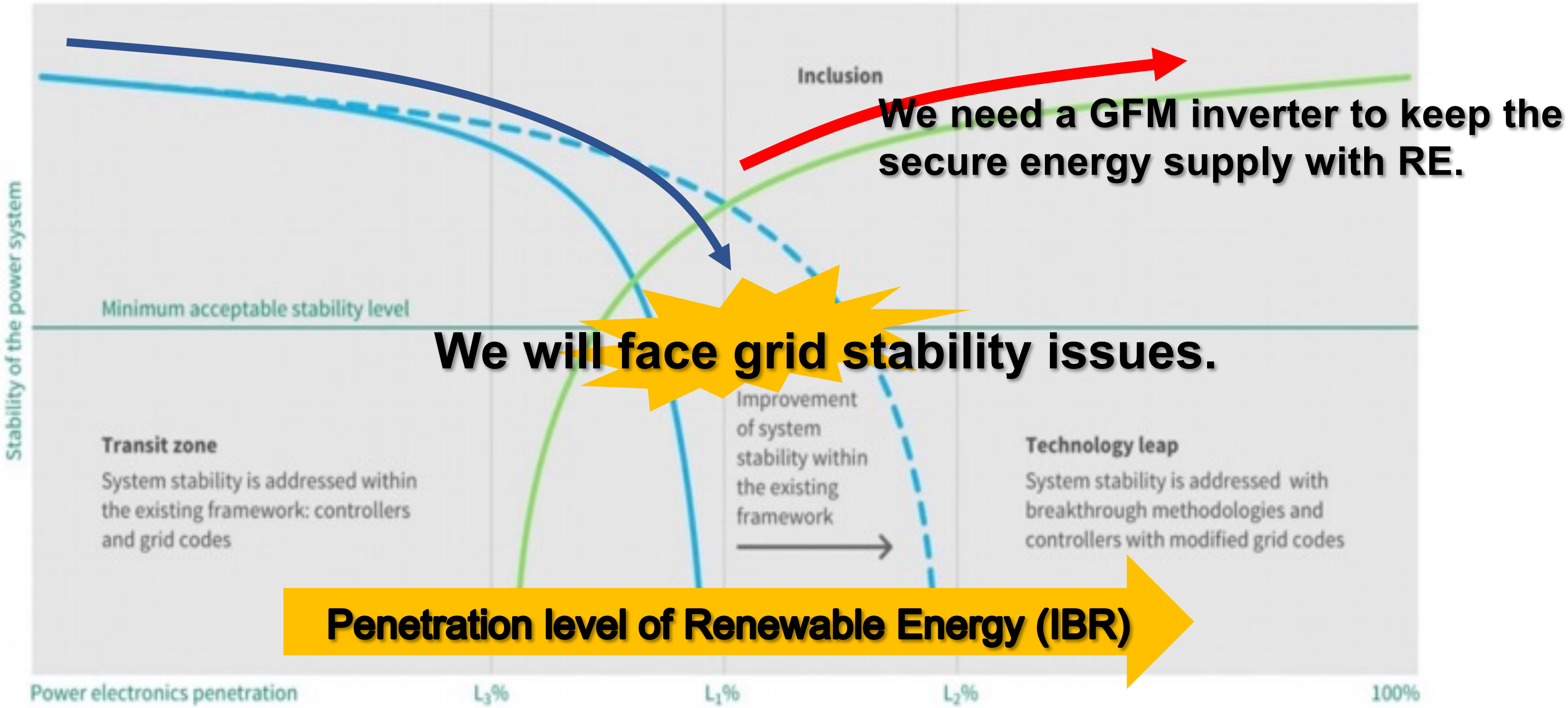
- Global Trend of GFM Inverter Demonstration

3. NEDO STREAM Project

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

Grid stability issues with high penetration of Renewable Energy

- Further expansion of renewable energy will increase the number of inverter-based resources (IBR), including storage batteries.
- With the increase in the IBR ratio, the number of synchronous generators is expected to decrease, leading to grid instability.
- Therefore, grid-forming (GFM) inverters with functions equivalent to synchronous generators are needed for high penetration of renewable energy (RE).



Cf. EU funded project, “MIGRATE Roadshow”

IBR ratio ≒ Renewable Energy Ratio

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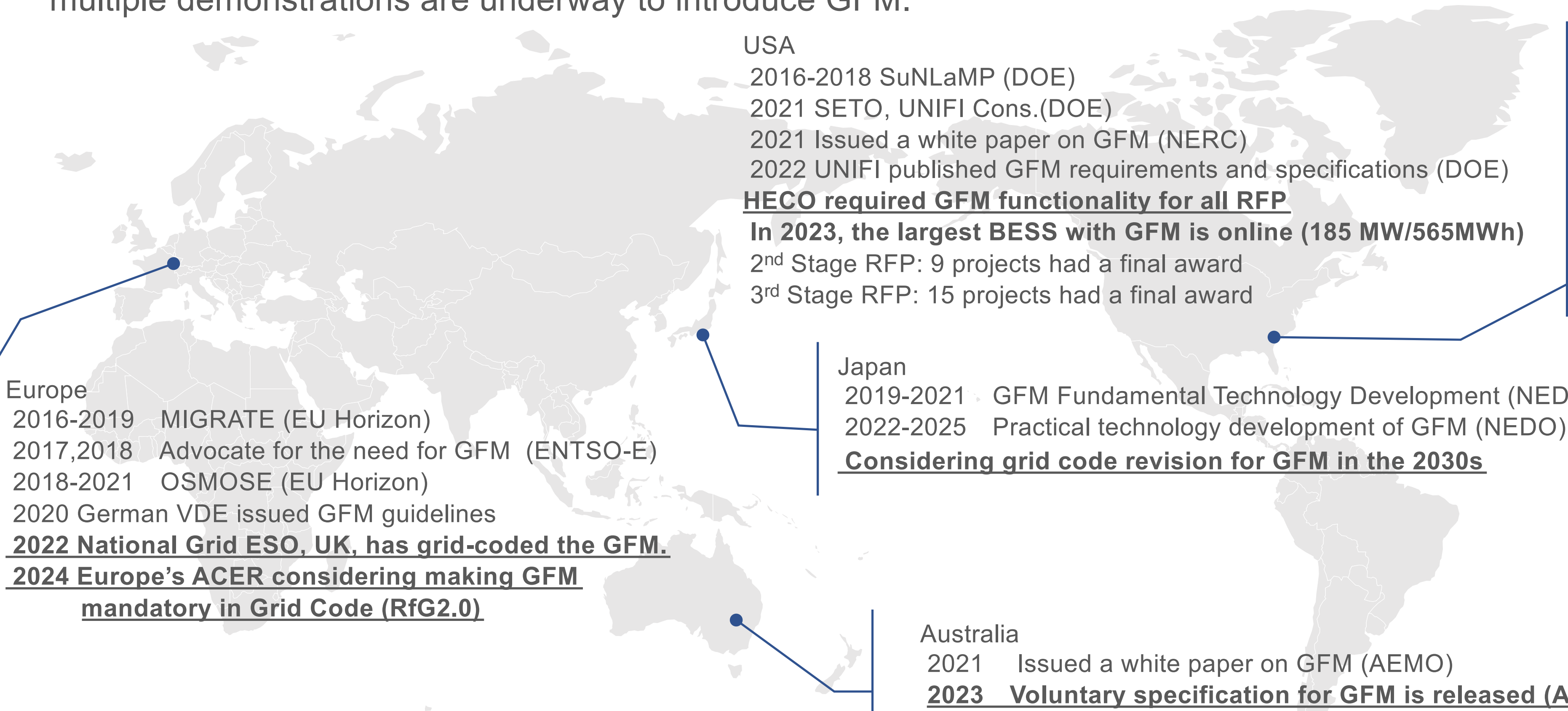
Grid-code and Demonstration Trends Related to GFM Inverters

- Discussions on rules, requirements, and specifications are underway (in Europe, U.S., Australia, etc.). Implementation is progressing from demonstration to operation.
- In Europe, ACER is considering making GFM mandatory through the Grid Code, intending to issue the Code in 2024.
- The U.S. and Australia have compiled 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)
2022 UNIFI published GFM requirements and specifications (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

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)

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

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

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.
- Secure grid stability with inertia, etc., through the revised grid code and open a market in the 2030s.

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 applying GFM inverters

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

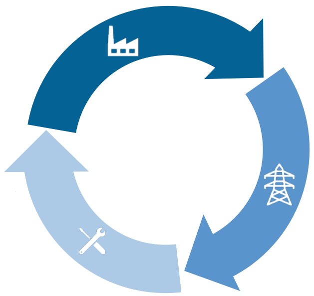
Project Overview

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 grid forming inverter.



Laboratory testing

- Development of test procedure achieving certification.
- Impact assessment of GFM with 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
- Revision of inverter requirements

Lab testing: Smart System Research Facility, AIST

Demo field testing: Akagi testing Center, CRIEPI

WP3 Power System Stability Analysis

- Simulation-based impact assessment study for system stability

Output

- Proposal and proof data for the standard.
- Provide a evidence and report for revision of Grid Code.

Requirement and Specification for GFM (WP1)

- Requirements and specifications for the Japanese version of GFM inverter are summarized with reference to overseas examples.
- The project is unique in that it is also study GFM for distribution systems.

Working Draft of Requirement and Specification

Outline
1. General
2. Frequency maintenance/ Inertial response
3. Voltage magnitude/phase retention capability
4. Power Quality
5. Protection Coordination
6. Inverter-driven instability prevention
7. Low SCR operation
8. Other

The schedule to be planned

- **Mar. 2024**: Compilation of requirements and specifications for the Japanese version 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 with the following revised 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 marginal performance of the GFM inverter.
- Conversely, the PHIL test examines the grid's interaction and identifies any potential issues.
- The laboratory test was conducted in a test environment similar to a typical grid interconnection test for the domestic market.
- The control parameters were standardized as much as possible to clarify the differences in the characteristics of each inverter vendor.

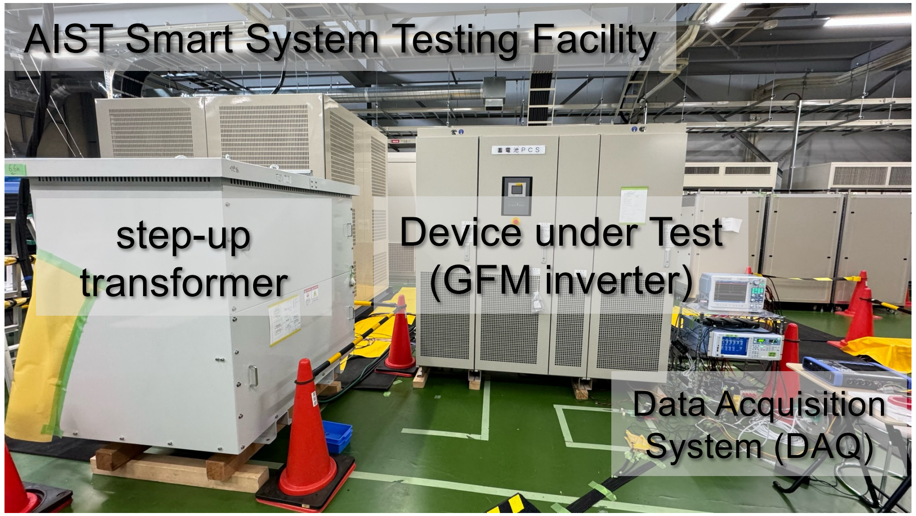


Fig. Laboratory testing of "vender A"

- Different setting parameter testing. E.g., Inertia constant, governor gain, damping coefficient, etc.
- Various test conditions.
  - Frequency ramp up/down testing from 0.1 to 5 Hz/sec
  - FRT testing with different 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 variety of controls, confirming that differently behaved GFMs may be introduced if the specifications are not clear.
- There is a need to organize requirements from the perspective of system operation while determining the performance that can be achieved by the vendor.

3LG, voltage drop to 20%, 0° phase angle, 0.3 s fault clear time (basic setting)

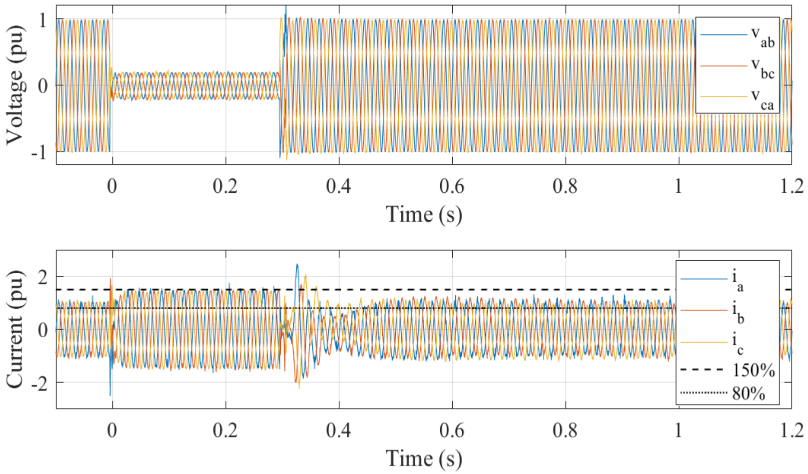


Fig FRT(3LG) sample testing result

- Confirmed ride through the 3LG event.
- 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 accident.
- The DuT switches to the FRT mode, dualling voltage drop. We need to define the required performance behavior after the fault removal.

Status of development and study of models and test methods for PHIL testing

- A model that can test various use cases is being built for the PHIL test.
- Thermal power generation, IBR, etc., are bulk power sources on the left side. The IBR consists of three types: conventional GFL, GFL with fast frequency response, and GFM.
- It is envisioned to reproduce various accident events under different RE ratio conditions by changing this power supply capacity.

Test No.	Supply and demand conditions (e.g., distribution and substation tidal currents)
1	Forward power flow; mean distribution for both generation and load
2	Reverse power flow; mean distribution for both generation and load
3	Reverse power flow: generation is concentrated in the center of the feeder
4	Zero power flow: generation is concentrated close to sub-station and center of feeder

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

Status of development and study of models and test methods for PHIL testing

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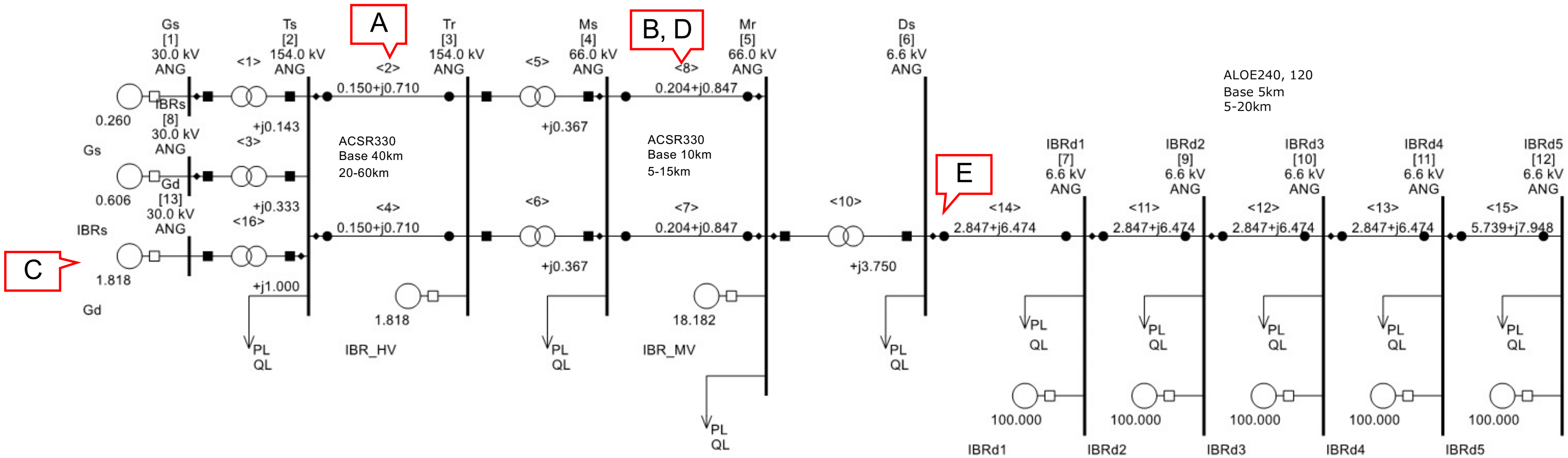
From A to E are contingency event locations.



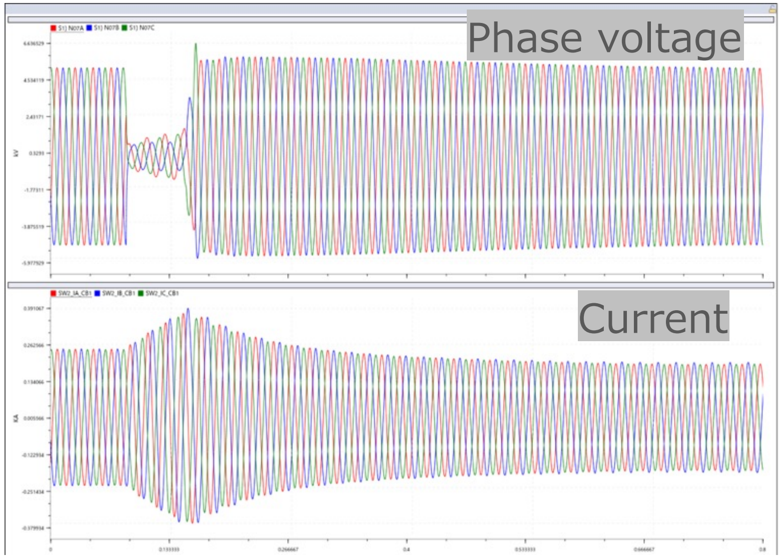
Main power sources: Grid capacity approx. 1300 MVA/ Output approx. 800 MVA
Gs: Thermal power generation (LAT=1, LPT=1)
IBRs: 3 inverter power sources: GFL, S-GFL, GFM
Gd: Thermal power generation (LAT=1, LPT=1) Within 1~4% of grid capacity

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 study to understand the behavior of the prototype machine under test during a system disturbance.
- Three-phase ground fault (3LG) testing with a PHIL on a GFM inverter.

Test No. 1-B-1-3LG
Transmission line <8> ground-fault accident
→ one line open after 70 ms (accident type: 3LG)



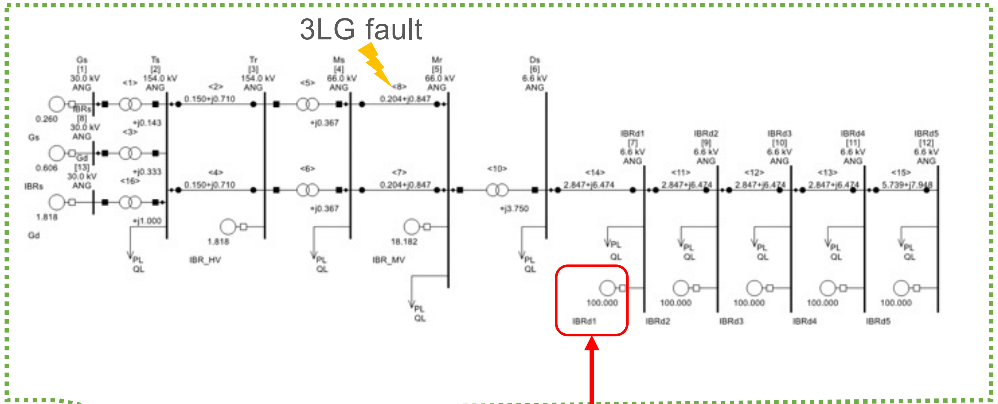
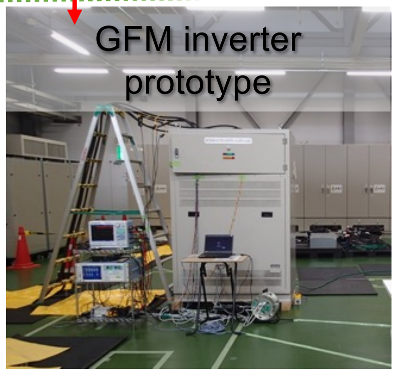


Figure: PHIL test of GFM behavior during a system disturbance with one line open after a 3LG accident.

The interconnection point is 1 km long from the distribution substation of the distribution feeder (IBRd1)

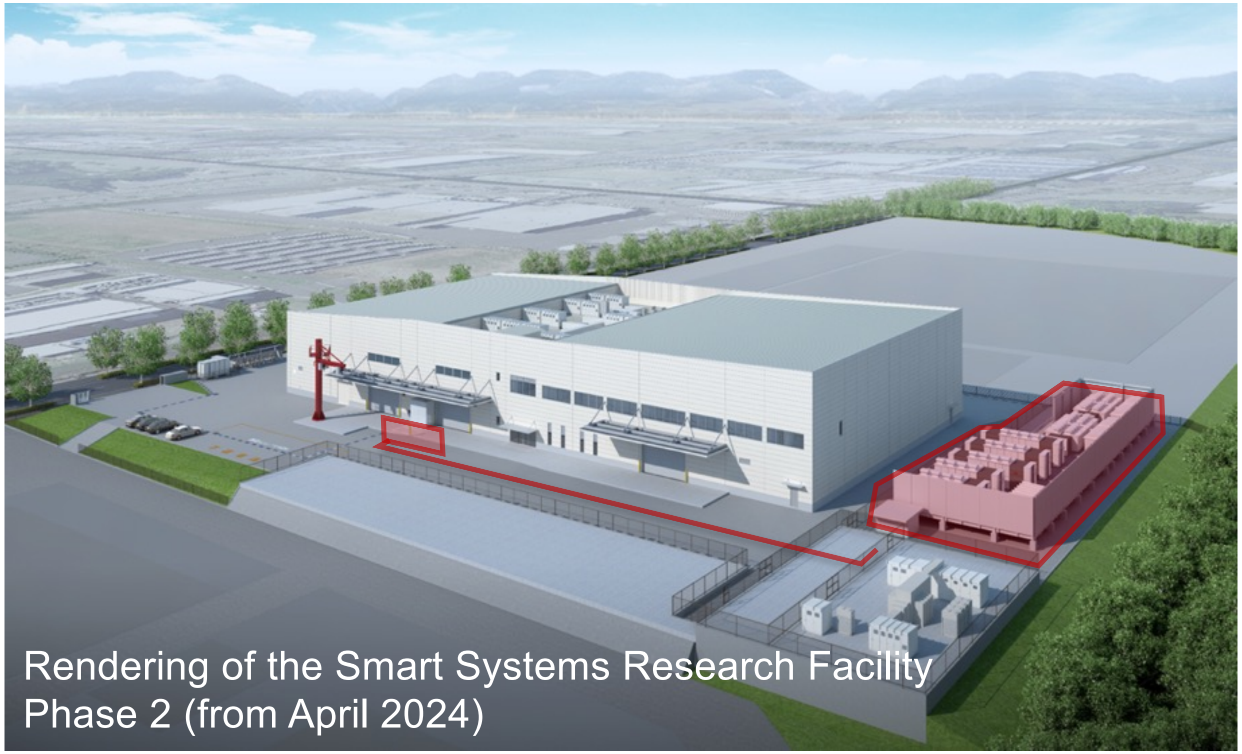
Virtual sector
DRTS（NovaCor)



Physical (Hard) Sector
GFM inverter（50kVA)

FREA Smart Systems Research Facility Enhancement

- Opened at FREA in FY2016 under the "Global Certification Infrastructure Development Project of METI" of the FY2013 supplementary budget.
- The expansion work will be completed in FY2023 under the "International Standard and Certification Center Development Project for Promoting Carbon Neutrality of METI," a supplementary budget for FY2021, and the facility will be available for use from FY2024.



Rendering of the Smart Systems Research Facility Phase 2 (from April 2024)

Interconnection Test M Room

7.5 MVA Grid simulator and 5 MW load bank

Conclusion

- Concerns about grid stability due to the growing use of Inverter-based resources (IBR) have become a global issue, and many countries are now studying the formation of rules and requirement specifications such as grid codes for GFM inverters.

- Japan also aims to revise the grid code in the 2030s as a mid-to-long-term goal and is conducting the necessary research under the NEDO STREAM project.

- As part of this project, we reported on the status of organizing requirements, specifications, and test methods for the Japanese version of the GFM inverter.

- The Grid-forming (GFM) inverter is a key solution for expanding the use of renewable energy. We look forward to working with various initiatives in each country to promote better technology.

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
Please visit our facility.

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