Future-generation Power Network Stabilization Technology Development for Utilization of Renewable Energy As the Major Power Source (STREAM Project)

Utilization of Renewable Energy As the Major Power Source

About the Project Name "STREAM"

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

Background of the Project

- With the large-scale integration of renewable energy (RE), the number of rotating power generation facilities is decreasing. As a result, the power grid may become unable to withstand sudden large fluctuations, potentially leading to major blackouts. Therefore, the importance of technologies that ensure system inertia is increasing.
- The decline in short-circuit capacity has been recognized as a future technical challenge in the utilization of renewable energy as a major power source, as noted in study sessions held by the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) and in the roadmap of the Transmission and Distribution Grid Council (TDGC). However, specific research and development efforts have not yet been undertaken.

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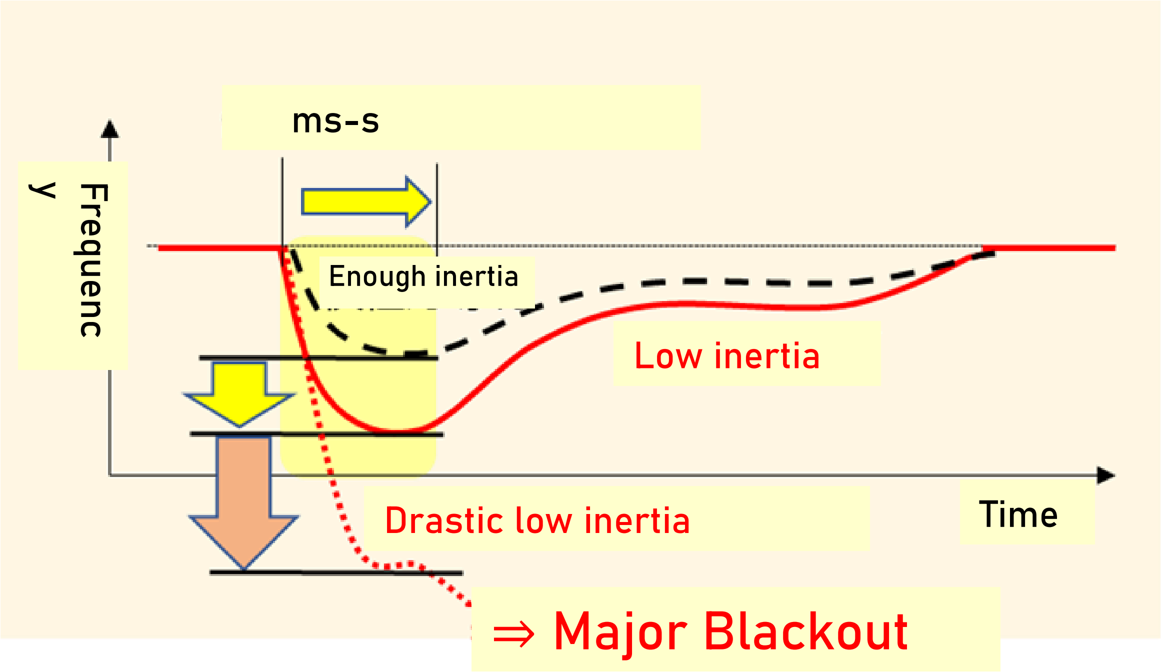
Decline in system inertia / Decline in short-circuit capacity

Project Objectives



The impact on frequency control due to the increasing share of RE

- Based on previous project outcomes, identify the latest technology and policy trends, anticipate future power grid challenges, promote practical application development of countermeasures for low inertia power grid and develop solutions for short-circuit capacity.

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Development of PCS-based Countermeasures for Low-Inertia / M-G Set

Research and development on challenges

Conducting R&D by system category to address grid-related technical challenges in the transition to RE as a main power source.

Grid category	R&D Items	WG
Distribution grid	Ⅰ ：R&D of virtual inertia-based PCSs ①R&D of PCS-based Countermeasures for Low-Inertia Power System	WG1
Regional grid	Ⅰ ：R&D of virtual inertia-based PCSs ②R&D to address challenges for realizing RE-based regional grids	WG2
Bulk grid	Ⅱ ：R&D of a M-G set	WG3

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Project Organization Structure

R&D of virtual inertia-based PCSs / M-G set

【PL】CRIEPI Uemura Associate Vice President
【SPL】Tokyo University Professor Baba

direction ⟷ consultation

NEDO

Commissioning

Ⅰ：R&D of virtual inertia-based PCSs

- TEPCO Holdings — WG1, WG2
- TEPCO Power Grid — WG1, WG2
- CRIEPI — WG1, WG2
  - Recommissioning:
    - Kagawa University — WG2
    - Waseda University — WG1
- AIST — WG1
  - Recommissioning:
    - Japan Electrical Safety & Environment Technology Laboratories — WG1
- Hiroshima University — WG1
  - Recommissioning:
    - National Institute of Technology, Kure College — WG1
- Hokkaido University — WG1
- Tokyo University — WG1
- Environmental Energy Research Institute — WG1
- Mitsubishi Electric — WG2
- Okinawa Electric Power Company — WG2
- Nextems — WG2

Commissioning

Ⅱ：R&D of a M-G set

- CRIEPI — WG3
- Institute of Science Tokyo — WG3

WG1:R&D of PCS-based Countermeasures for Low-Inertia Power System
WG2:R&D to address challenges for realizing RE-based regional grids
WG3:R&D of a M-G set

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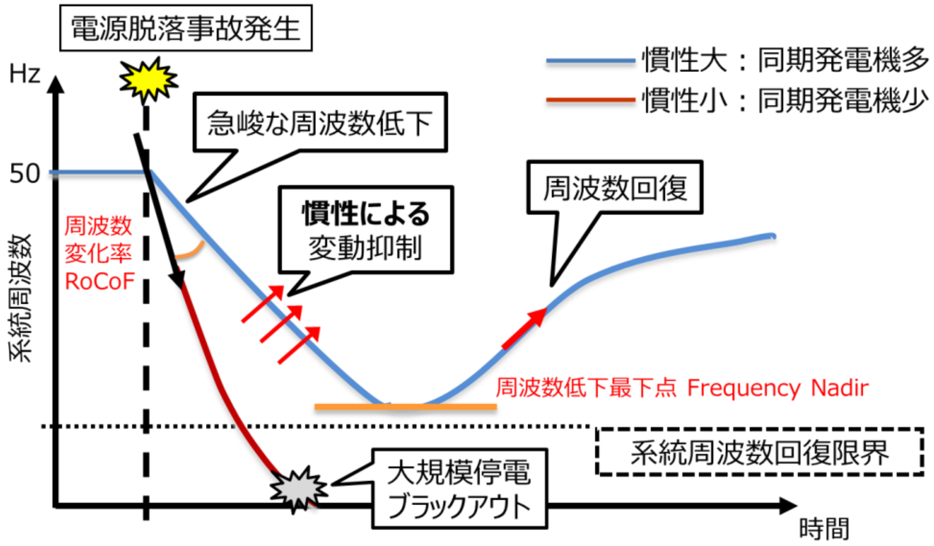
PCS-based Countermeasures for Low-Inertia Power System

I-① R&D of PCS-based Countermeasures for Low-Inertia Power System (WG1)

Challenges of Reduced Inertia in Power Systems (Inertia Reduction ⇒ Risk of System Blackouts)

When grid inertia is low, a major power source failure can cause large frequency fluctuations, triggering under-frequency relays that disconnect other operational power sources and potentially lead to a blackout.



Countermeasures

【Requirement①】 Ensure proper operation against frequency fluctuations!

When the grid frequency fluctuates, power is supplied to suppress the fluctuations.

【Requirement②】 Ensure the PCS does not shut down unnecessarily!

Ensure that the PCS does not shut down due to excessive current exceeding its rated capacity.

【Requirement③】 Ensure public safety!

When the system becomes islanded, the PCS shall detect the islanding condition※ and shut down.

※In the event of a grid fault resulting in an islanded system (i.e., a system separated from the main power grid), distributed energy resources (DERs) are required to cease operation to ensure the safety of maintenance personnel.

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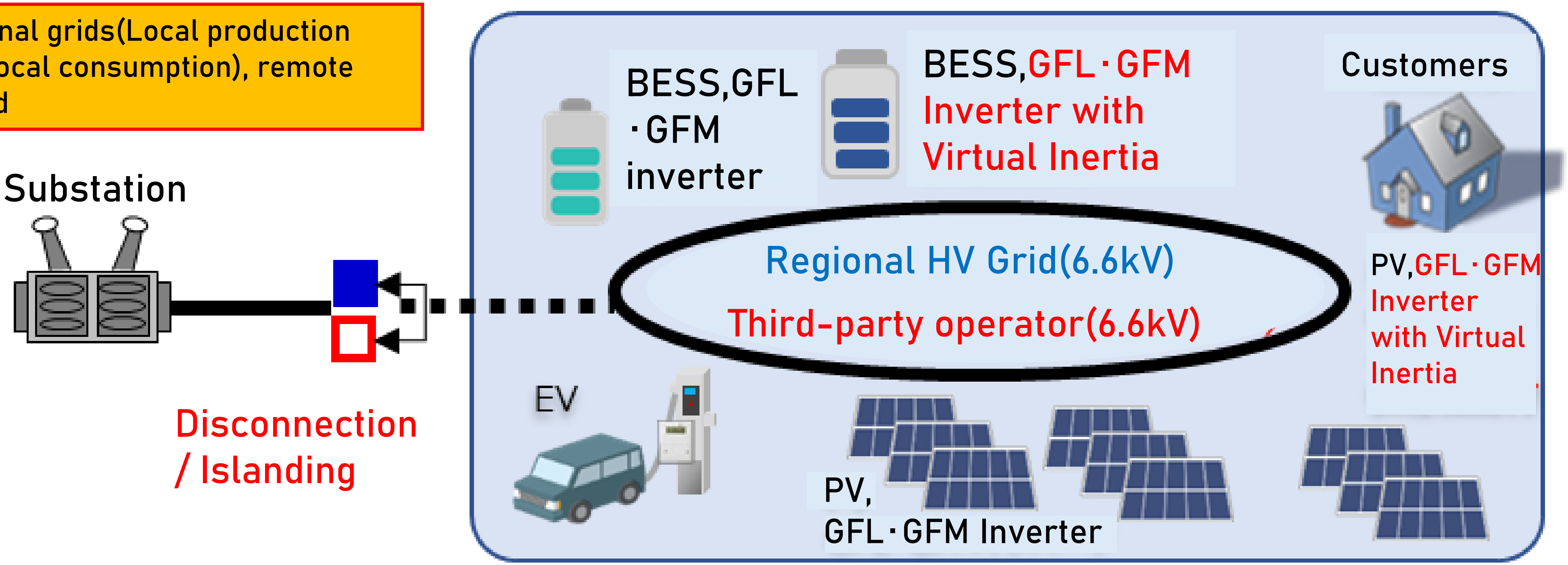
RE-based regional grids

I-②R&D to address challenges for realizing RE-based regional grids (WG2)

Challenges of RE Mainstreaming Due to Changes in Infrastructure Configuration

regional grids(Local production and local consumption), remote island



Technical Challenges (Examples)
- Decrease in short-circuit capacity
- Reduction in system inertia
- Short-term fluctuations
- Long-term fluctuations
- Voltage flicker
- Voltage variations in distribution lines

Future-generation Power Network Stabilization Technology Development for Utilization of Renewable Energy As the Major Power Source (STREAM Project)

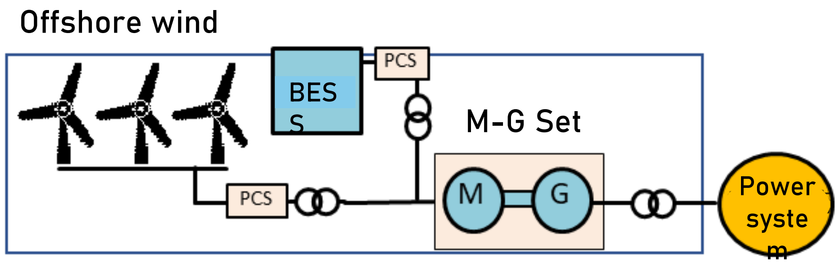
M-G set

Ⅱ R&D of a M-G set (WG3)

Practical Development of M-G Sets

- Verification of the technical feasibility of motor-generator (M-G) sets connected to renewable energy sources and storage batteries, using an analog power system simulator that emulates the main transmission grid
- Verification of the grid stability support functions of various stabilization measures, including M-G sets

【Use Cases of M-G Set】

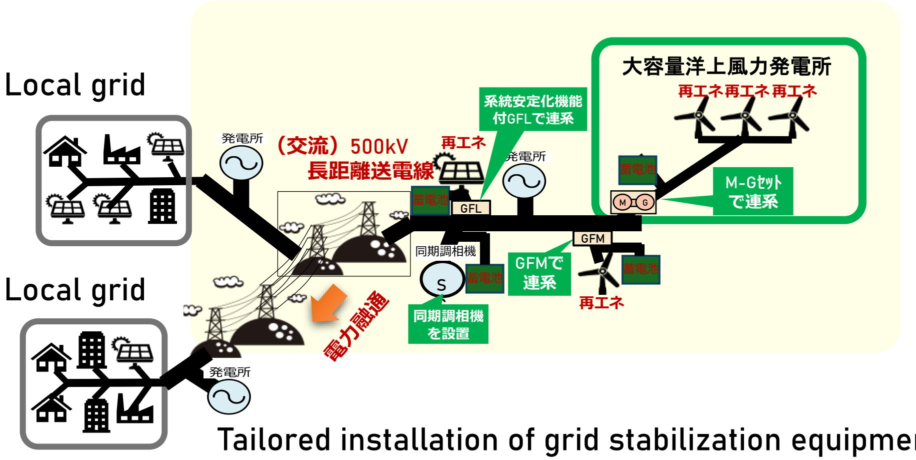


■ From the power system side, only generators are connected in parallel.

➢Therefore, no special consideration is required on the grid side during system faults.

One solution to the challenges of large-scale RE integration

Image of the main power grid with RE as the major power source



Tailored installation of grid stabilization equipment based on power system characteristics.

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PCS-based Countermeasures for Low-Inertia Power System/ RE-based regional grids/M-G Set

R&D Schedule

R&D Items	FY2022	FY2023	FY2024	FY2025	FY2026	FY2027
R&D of virtual inertia-based PCSs ① R&D of PCS-based Countermeasures for Low-Inertia Power System (WG1)	Design & Prototyping →	Testing & Validation →	Interim Goal	Improvement → Testing & Validation →	Final Goal	
R&D of virtual inertia-based PCSs ② R&D to address challenges for realizing RE-based regional grids (WG2)	Identifying issues →	Countermeasure Analysis & Testing →	Interim Goal	→	Final Goal	
Practical Development of M-G Sets (WG3)	(Inverter) Test Preparation → (M-G Set) Testing →		Interim Goal	(Inverter) Testing →	Combined Testing → Final Goal	
Time of Evaluation			Interim Evaluation			Final Evaluation

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Ⅰ-① R&D of PCS-based Countermeasures for Low-Inertia Power System (WG1)

PCS-based Countermeasures for Low-Inertia Power System

Achievement status of output goals

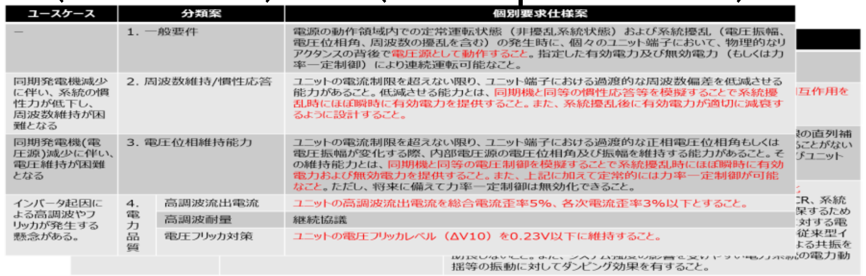
Use cases were developed and a draft requirement specification was compiled for PCS for BESS.

【PCS for BESS】

GFM）Use cases and draft requirement specifications for GFM were organized based on international case studies and expert input from the committee.

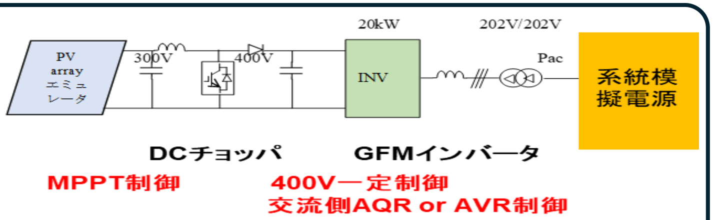
S-GFL）Grid interconnection tests were largely passed under the previous NEDO project, and FFR requirements were organized with reference to international requirements.

（Use cases）→（draft specification）



ユースケース	分類案		個別要求仕様案
ー	1．一般要件		電源の動作領域内での定常運転状態（非擾乱系統状態）および系統擾乱（電圧振幅、電圧位相角、周波数の擾乱を含む）の発生時に、個々のユニット端子において、物理的なリアクタンスの背後で電圧源として動作すること。指定した有効電力及び無効電力（もしくは力率一定制御）により連続運転可能なこと。
同期発電機減少に伴い、系統の慣性力が低下し、周波数維持が困難となる	2．周波数維持/慣性応答		ユニットの電流制限を超えない限り、ユニット端子における過渡的な周波数偏差を低減させる能力があること。低減させる能力とは、同期機と同等の慣性応答等を模擬することで系統擾乱時にほぼ瞬時に有効電力を提供すること。また、系統擾乱後に有効電力が適切に減衰するように設計すること。
同期発電機(電圧源)減少に伴い、電圧維持が困難となる	3．電圧位相維持能力		ユニットの電流制限を超えない限り、ユニット端子における過渡的な正相電圧位相角もしくは電圧振幅が変化する際、内部電圧源の電圧位相角及び振幅を維持する能力があること。その維持能力とは、同期機と同等の電圧制御を模擬することで系統擾乱時にほぼ瞬時に有効電力および無効電力を提供すること。また、上記に加えて定常的には力率一定制御が可能なこと。ただし、将来に備えて力率一定制御は無効化できること。
インバータ起因による高調波やフリッカが発生する懸念がある。	4．電力品質	高調波流出電流	ユニットの高調波流出電流を総合電流歪率5%、各次電流歪率3%以下とすること。
		高調波耐量	継続協議
		電圧フリッカ対策	ユニットの電圧フリッカレベル（ΔV10）を0.23V以下に維持すること。

【PCS for PV systems】



A 20 kW prototype was developed with a voltage control design and a requirement to increase active power output during frequency drops. Basic functions such as power factor control and FRT capability were verified.

【Evaluation test】

Laboratory test）Two testing approaches—basic testing and PHIL testing—were considered. Based on the draft requirements for practical implementation of GFM, a set of laboratory test items was developed, and the first manufacturer's lab testing has started.

Grid simulation test）Referring to demonstration tests from past NEDO projects, test items were narrowed down based on use case studies, equipment specifications, and laboratory test items, and their details were further refined.

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RE-based regional grids

I-②R&D to address challenges for realizing RE-based regional grids (WG2)

Achievement status of output goals

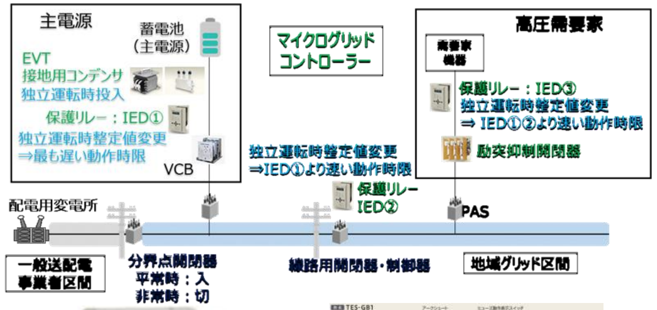
Countermeasure methods and tools were examined through desk studies, verification tests, and analysis of actual measurement data.

【Identification of challenges in RE-based regional grids.】

Initiated measurement and analysis of actual operational data from the Miyakojima regional grid. (in operation)
Aligned with issues discussed by the TDGC.
Verified several challenges through confirmation tests and simulations.

【Consideration of countermeasures for challenges in RE-based regional grids.】

Studied grid and system configurations in Kurimajima and other domestic regional grids. Summarized international countermeasures, explored solutions to challenges, and conducted validation tests including short-circuit and ground fault simulations.



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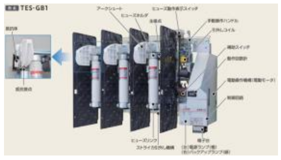
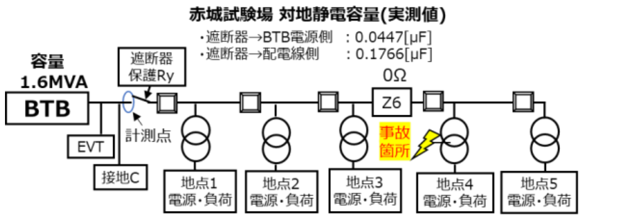


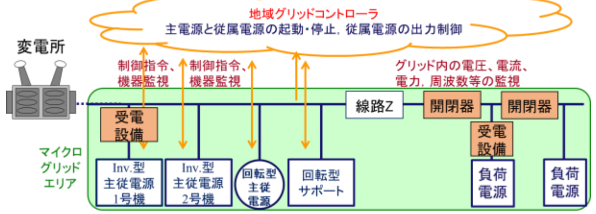
Surge Suppression Switch

【Verification and evaluation of countermeasures for challenges in RE-based regional grids.】

Conducted issue-identification tests at CRIEPI Akagi and implemented trials for selected countermeasure methods. Designed countermeasure devices and systems, and carried out various performance tests.



Verification test of ground fault current (I_0) and zero-sequence voltage (V_0) during ground fault events



Actual-scale distribution system at CRIEPI Akagi

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M-G Set

Ⅱ R&D of a M-G set (WG3)

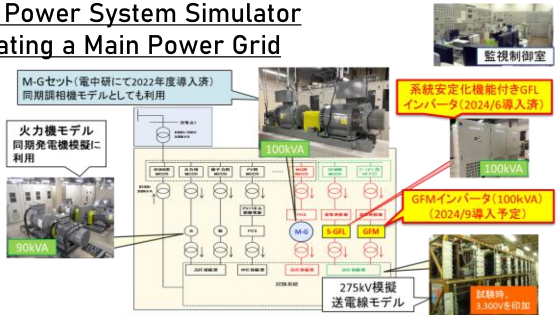
Achievement status of output goals

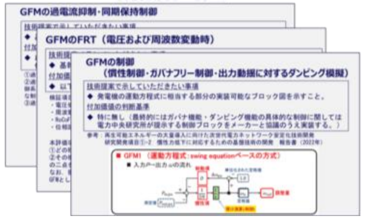
In parallel with the Establishment of the experimental environment, the fundamental characteristics of each device were identified through standalone testing.

【Establishment of an Experimental Environment for Various Grid Stabilization Measures】

The specifications and control logic of the S-GFL/GFM inverters were determined based on manufacturers' technical proposals, taking into account testing and peripheral equipment. The S-GFL inverter was installed in June 2024. (The M-G set was previously installed at CRIEPI in 2022.)"

Analog Power System Simulator Emulating a Main Power Grid

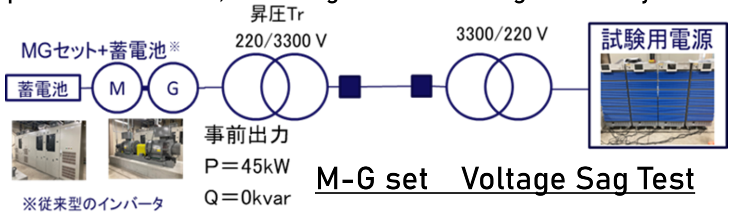




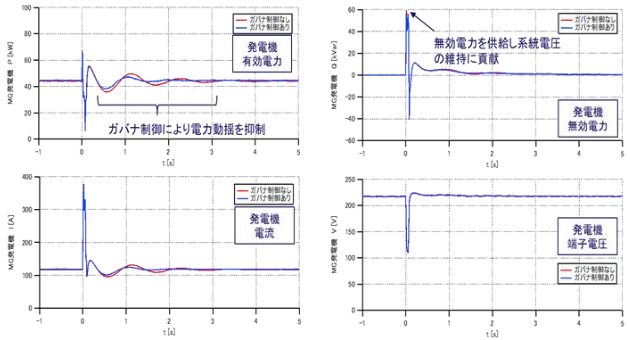
Example of Requirements Specification and Evaluation Criteria

【Experimental Evaluation of Various Grid Stabilization Measures】

Using the power system simulator facility, individual voltage sag and frequency drop tests were conducted to evaluate the fundamental characteristics of each device, including the M-G set, synchronous condenser, and BESS. In addition, the technical feasibility of the M-G set was verified through operational checks, including those involving control systems.



M-G set Voltage Sag Test

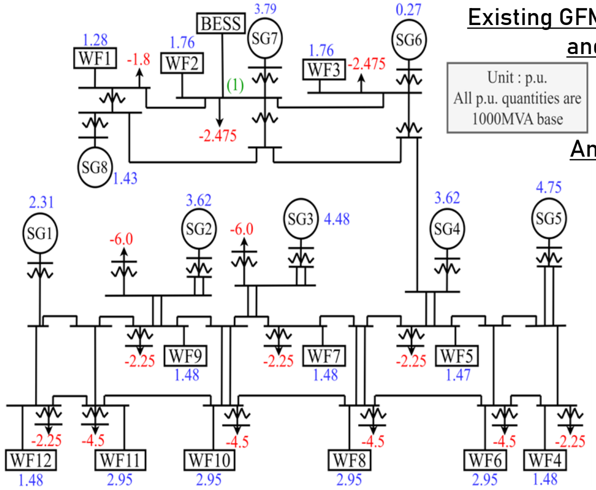


Generator output waveform (G side)

【Analytical Study on the Implementation of Various Grid Stabilization Measures into Power Systems】

A fundamental control theory for GFM applied to RE without BESS was developed, and its effectiveness in frequency stabilization was confirmed through simulations. In addition, a comparison of S-GFL and existing GFM methods (Droop control and VSG) applied to BESS was conducted, clarifying the advantages and disadvantages of GFM for RE applications.

Comparison of S-GFL, Existing GFM (VSG, Droop), and VGC



Simulation Analysis Example