Power System Planning and R&D -Making renewable energy the "major power source"-

Dr. Shoichi Honjo
General Manager, R&D Department,
TEPCO Research Institute,
Tokyo Electric Power Company Holdings, Inc.
2021/9/22

This presentation is based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

TEPCO Research Institute
経営とエネルギー技術の融合

1．Scenarios for Carbon Neutrality Realization by 2050

2．System Planning for Renewable Energy Oriented Grid

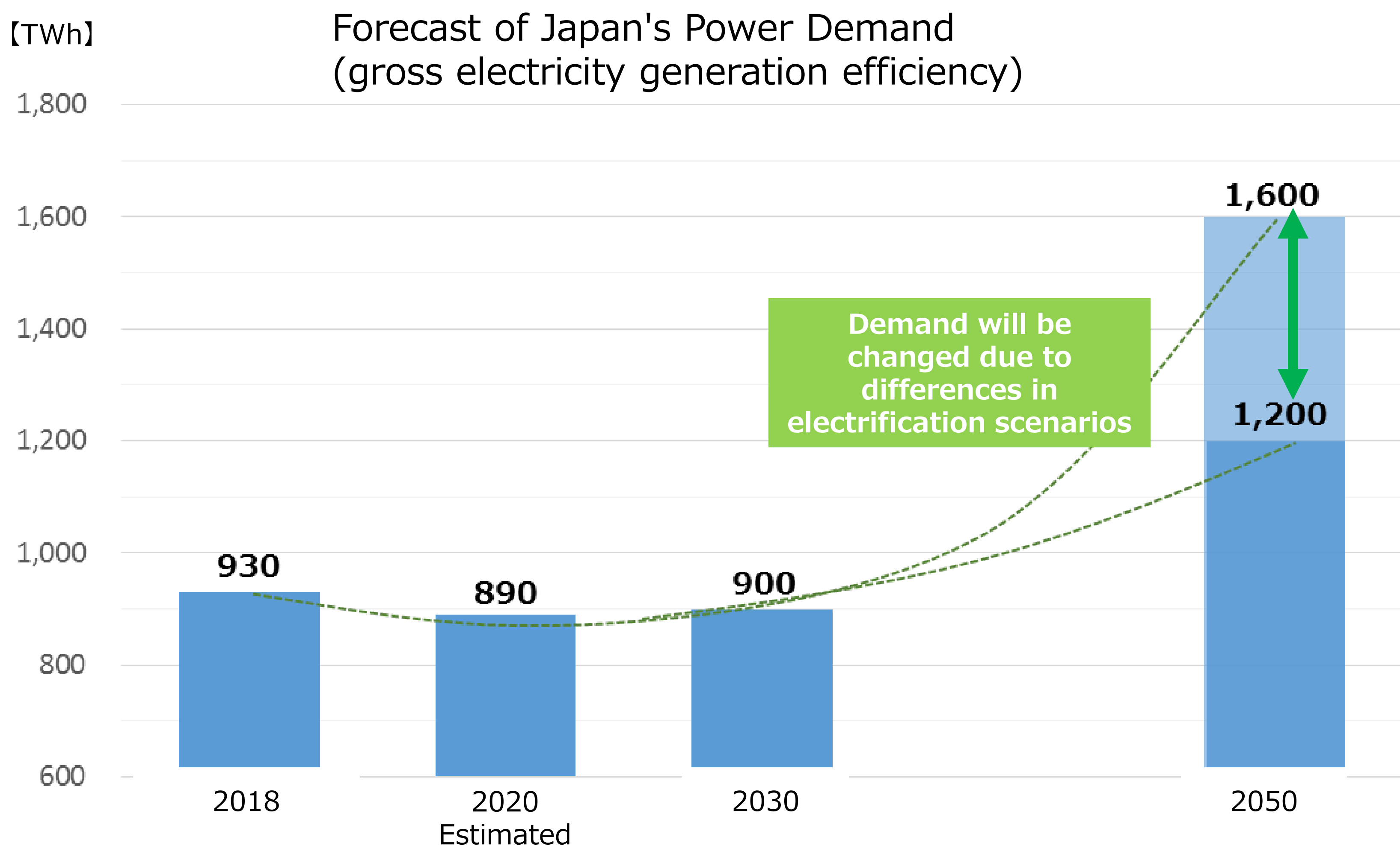
3．Technology Development of Multi-terminal HVDC System for Offshore Wind Farm

4．Future Technical Challenges

1．Scenarios for Carbon Neutrality Realization by 2050

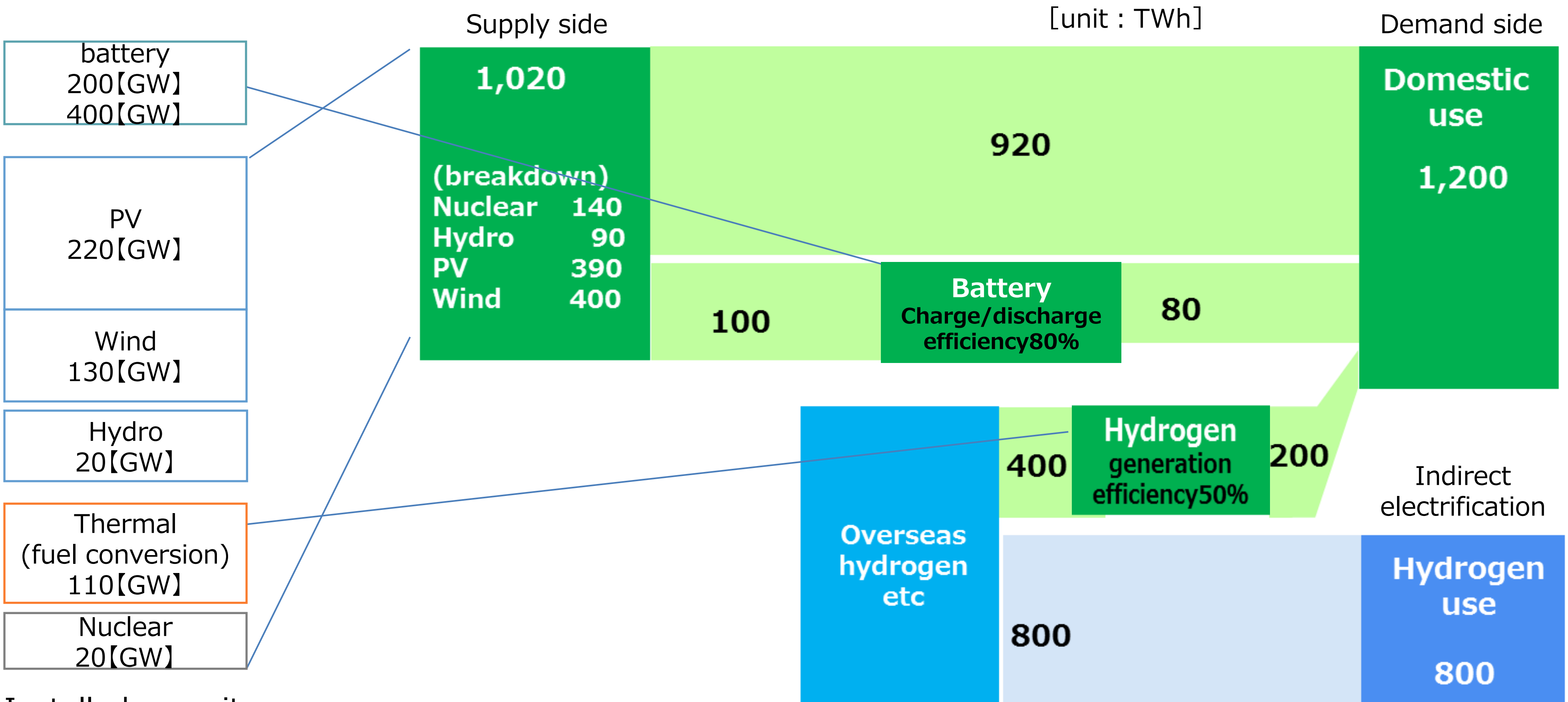
1-1. Forecast of power demand trends

- The silver bullet for achieving carbon neutrality is the progress of supply side decarbonization and demand side electrification.
- Carbon neutrality will increase the power demand to 1,200-1,600 TWh in 2050.



1-2. Energy flow and generation portfolio for 2050

- 790 TWh from Renewable energy (e.g. PV, wind) reaches 77% of total electricity energy.
- In terms of installed capacity, PV and wind power require 220 GW and 130 GW, respectively.
- Thermal power plants using hydrogen as fuel and storage batteries (including pumped water) are used as regulation power sources.



Installed capacity

Energy flow diagram in 2050

1-3. Challenges for high renewable integration to the grid

Renewable energy introduction rate

high

Off-grid

Mainland

low

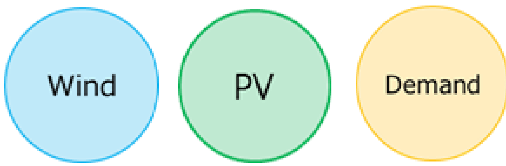
Challenges		Key measures
①Short-circuit capacity drop	decrease in the ratio of synchronous machines	• Review of protection cooperation • Short-circuit current supply function
②Low system inertia		• Establishment of real-time inertia estimation method • Inertia response by IBRs
③Short-term oscillation	supply-demand imbalance	• Improvement of frequency response (Storage battery, FGMO, LFC control)
③Long-term oscillation		• Improvement of downward reserve (PV output control, energy storage) • Renewable energy output and lamp forecast • Supply/demand operation simulation
④Transmission capacity shortage	concentration of interconnected DERs	• Resource aggregation • Connect & Manage • Conductor temperature control by dynamic rating
⑤Voltage flicker	mutual interference of DER's protection functions	• Improvement of anti-islanding function
⑥Voltage fluctuations in distribution line	fluctuations in power generation of DERs	• Smart-inverter development

TEPCO Research Institute
経営とエネルギー技術の融合

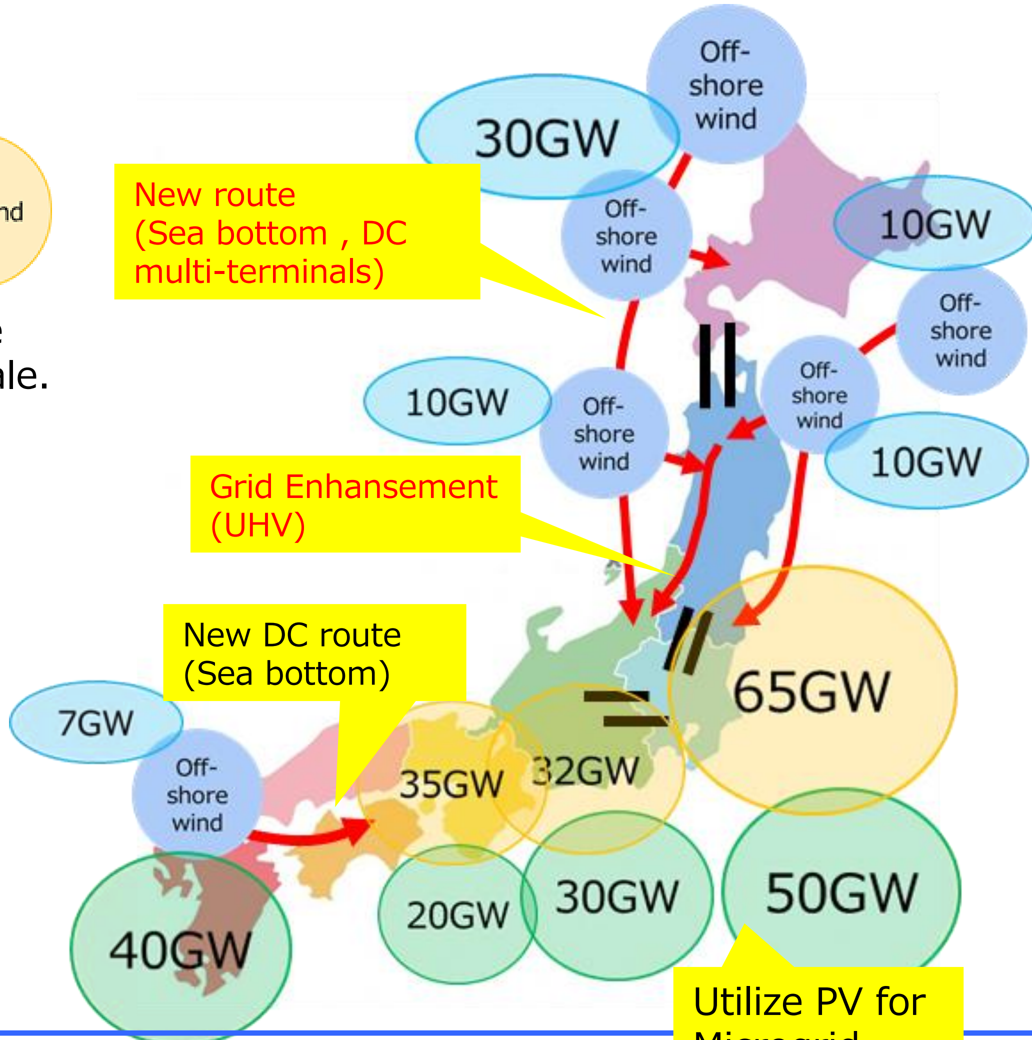
1-4. Suitable sites for renewable energy and system enhancement

- Suitable sites for wind power in Japan are unevenly located in northern and southwest areas away from large demand areas. New long-distance transmission routes be needed.
- Urban areas are suitable for PV. Microgrid with PV will expand as a new distribution system utilization.

(legend)



※The size of the circle indicates the capacity scale.

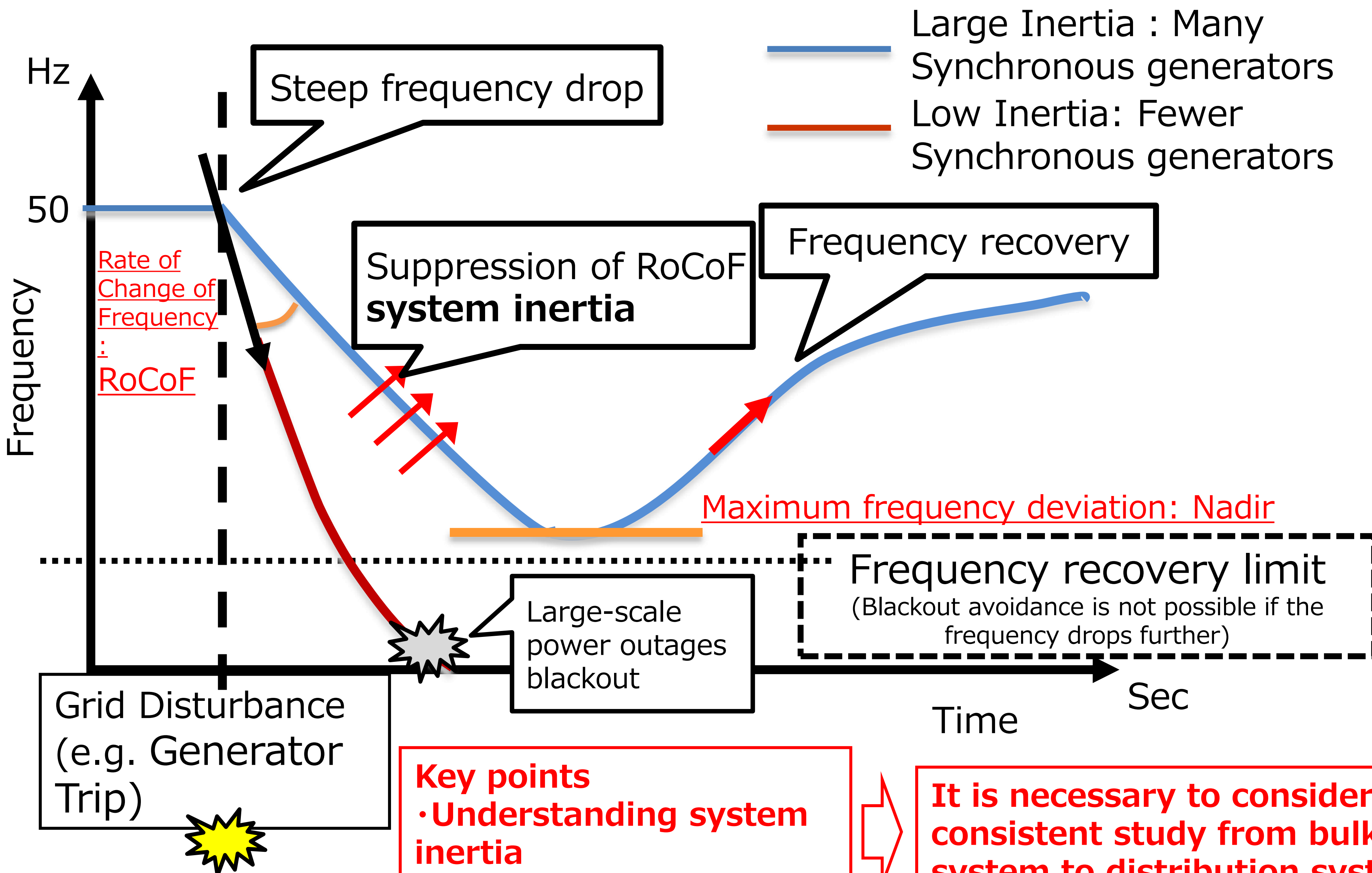


2050 Scenario

2．System Planning for Renewable Energy Oriented Grid

～System inertia～

2-1. Effects of decreased inertia on frequency



Key points
・Understanding system inertia
・Ensuring enough inertia

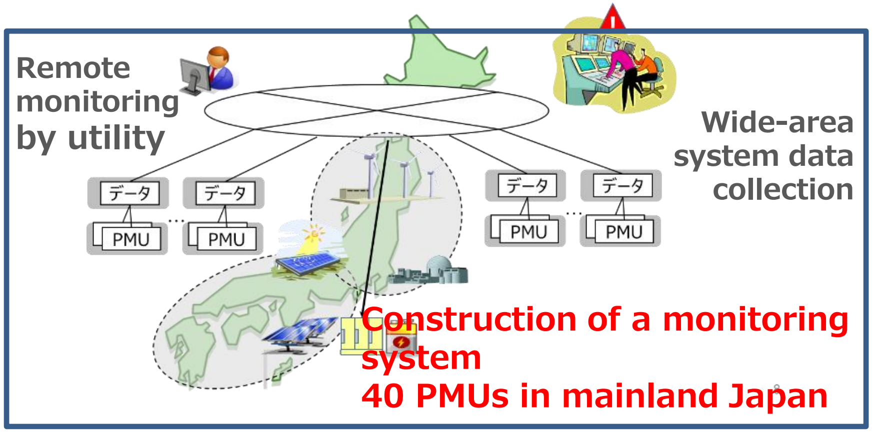
It is necessary to consider the consistent study from bulk system to distribution system.

2-2. Overview of the low system inertia project

〇NEDO project : 2019.7～2022.2(3-year)

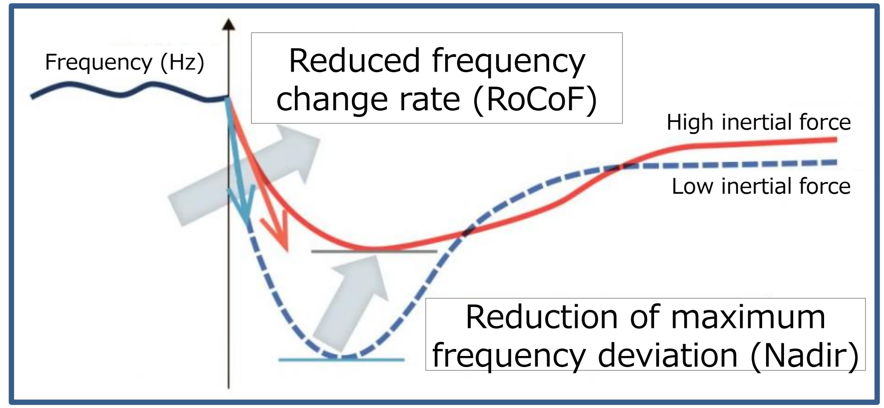
・Responsible Ministry : METI　　・Total budget : 2.3 billion yen

①Establishment of real-time inertia estimation method



Monitoring (Understanding system inertia)

②Development of countermeasure equipment (inveter with inertia function)



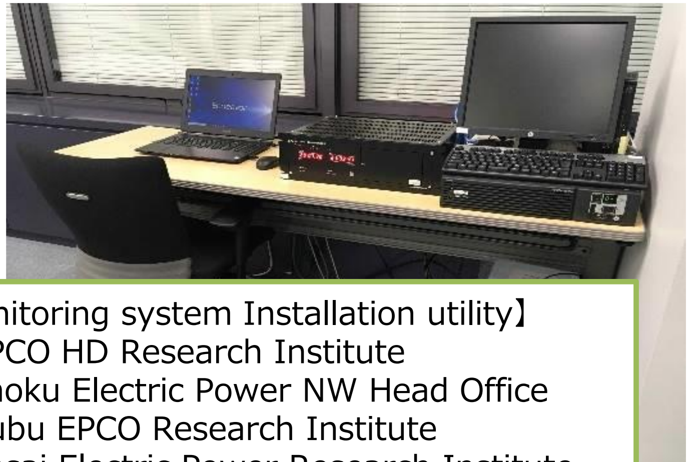
Countermeasures (Various analysis, Equipment development)

・Determining inertia requirements

・Establishment and standardization of countermeasure equipment

2-3. System configuration for inertia estimation

● System inertia monitoring system



【Monitoring system Installation utility】
・TEPCO HD Research Institute
・Tohoku Electric Power NW Head Office
・Chubu EPCO Research Institute
・Kansai Electric Power Research Institute
・Chugoku EPCO NW Head Office
・Kyushu Electric Power Transmission and Distribution Headquarters
・Kyushu EPCO Research Institute

● Phase measurement unit（PMU)

Installed at each substation

● PMU Installation location

50Hz Region : 20
60Hz Region : 20

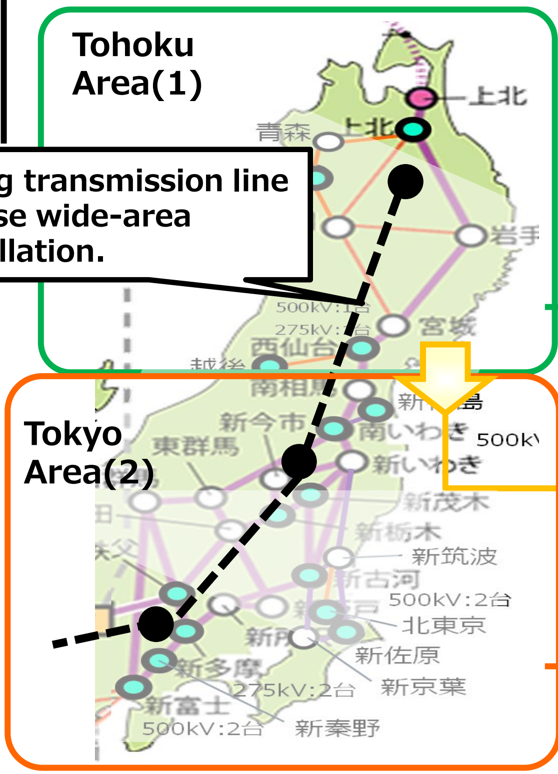
TEPCO Research Institute
経営とエネルギー技術の融合

2-4. Real-time inertia estimation method

Estimation method focusing on wide-area oscillation (※) of power system

(※) the phenomenon in which the phase of a voltage oscillations throughout whole power system

①PMU measurement data ⇒ ②Wide-area oscillation frequency f_0 capturing (by FFT)⇒ ③inertia estimation



Long transmission line cause wide-area oscillation.

Replace with simple system model

PMU Measurement data

Voltage phase

Tohoku-Tokyo Line

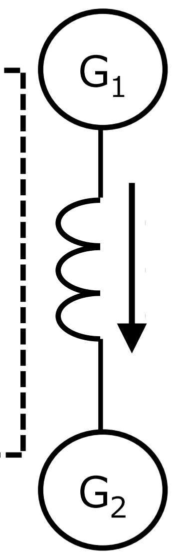
Power flow

Voltage phase

f_0 : Extracted from power flow and phase differences

$$K = \frac{P}{\Delta\delta}$$

Simple system model



A1 : G1 phase amplitude

A2 : G2 phase amplitude

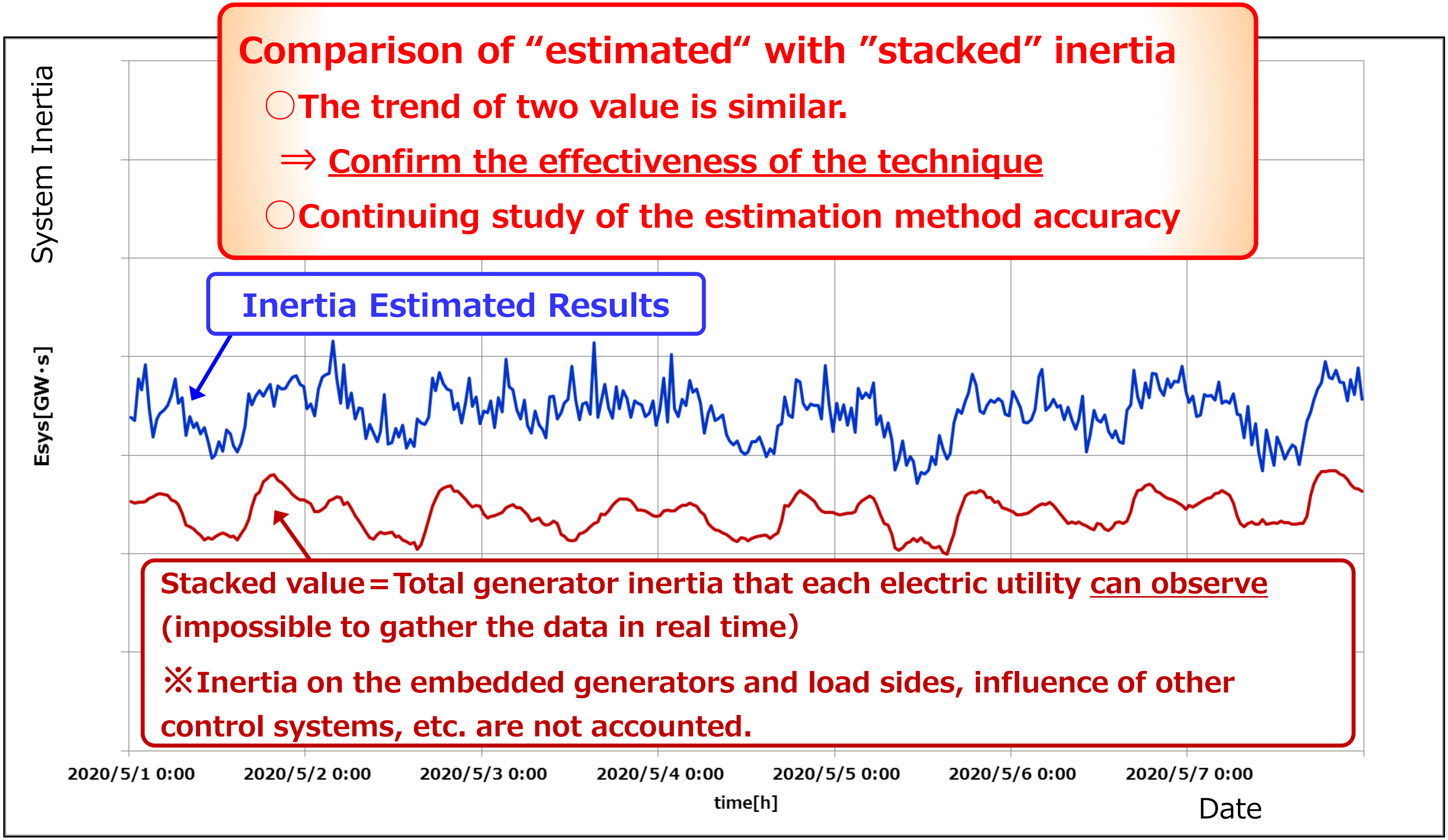
Tohoku Area inertia $H_1 = \dfrac{K(A_1+A_2)}{2A_1\omega_0^2}$

$\omega_0 = 2\pi f_0$

Total inertia of 50Hz system H_1+H_2

Tokyo Area inertia $H_2 = \dfrac{K(A_1+A_2)}{2A_2\omega_0^2}$

2-5. Example of real-time inertia estimation result



2-6. Toward the establishment of a real-time inertia estimation method

Inertia calculated by estimation method (outcome)

difference

Other difference factors

Inertia contribution from load side

Dynamic response (e.g. frequency response)

Stacked value

Generator Inertia
[Can be observed by each EPCO]

①Trend analysis of estimates

②Survey of estimation methods in other countries

③Impact Assessment of Power System Stabilizer (PSS)

PSS:a device installed in a large-capacity generator suppresses the output voltage fluctuation.

Impact investigation, Analysis
⇒ Accuracy improvement

Establishment of real-time inertia estimation method

2-7. Various inertia countermeasures

Countermeasures for low inertia

1. by rotary machine

- Nuclear power plant resume (Decarbonization○)
- Keep thermal power plants online (Decarbonization×)
- keep pumped-strange hydro online (scale small)
- Synchronous condenser, flywheel (High cost)

2. by Inverter (PV·battery·wind power etc)

- Grid following inverters with inertia function
- Grid forming inverters with inertia function

3. Load shut-off

- UFLS operation by utility
- on the consumer side load shut-off

- **Utilizing inverters, which is essential for renewable energy supply, as a system inertia support**
- **Accomplishment of <u>expansion of renewable energy (reduction of thermal power plants) and reduction of countermeasure costs</u>**

2-8. Types of inverters with inertia function and development plan

Renewable energy introduciton rate low → high

	Method① : Grid Following	Method② : Grid Forming
Response time	fast (0.1~1s)	instant (~0.1s)
Effects	Medium	large
Development period	middle : 2 ～ 3 years	long : More than 5 years
Special Features	Add functionality to conventional control methods ⇒ Easy to migrate from traditional inverters	New control scheme ⇒ It is necessary to change Grid Code.
Voltage class	6.6 kV, 66 kV	

Breakthrough required

Method①&② can exist togerther and move seamlessly from ① to ②.

Develop both methods

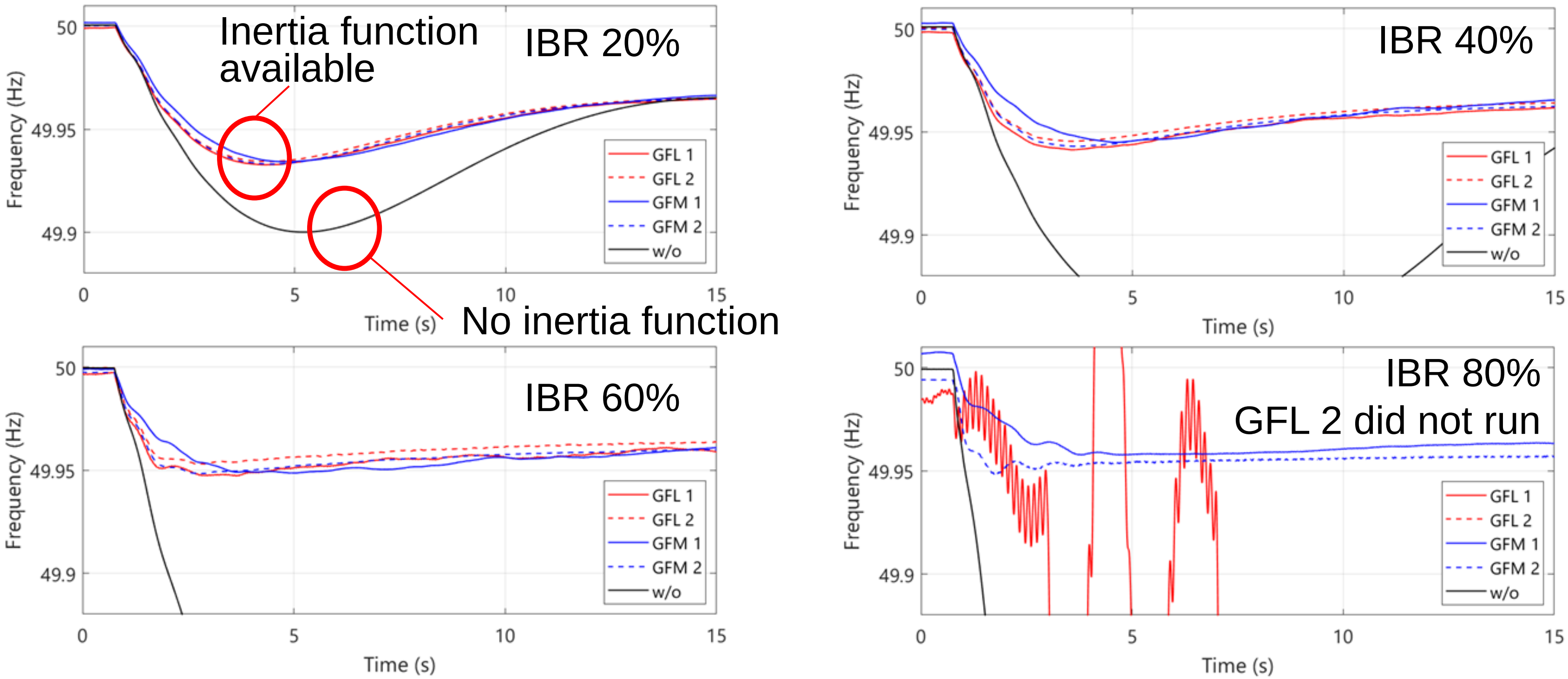
※The problem of method ① introduction only :
Renewable energy : Main power source ⇒ RoCoF : large ⇒ **Simultaneous disconnection due to FRT requirements** (⇒black out) ⇒ **Solution by sequentially introducing method ② inverter according to the renewable energy introduction rate**

2-9. Development status of inertia function

○Development Steps

①Development of control algorithms ⇨	②Simulation evaluation ⇨	③prototype ⇨	present ④Actual machine test ⇨	⑤Establishing a method (Basic specification decision)

○Example of actual test of inertia response (IBR ratio 4 cases)



<u>Both inverters</u> **(GFL, GFM)** <u>**have the effect of inertia function.**</u>
<u>**When the renewable energy ratio is extremely high (80% case), GFL result is instable but GFM is stable.**</u>

2-10. Overseas situation

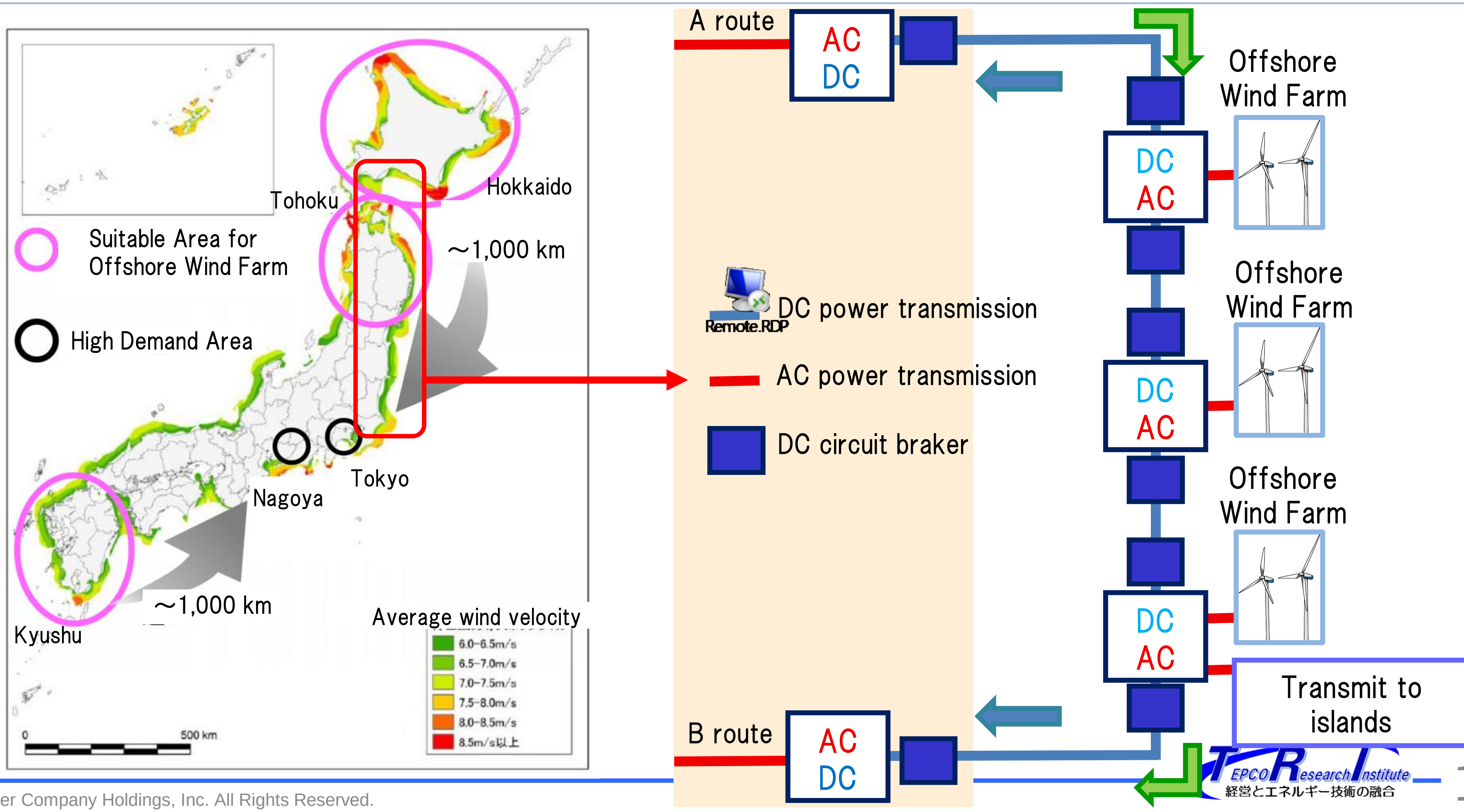
The following four regions are preceded by examinations on inertia.

project	United Kingdom	Ireland	Northern Europe	United States (Texas)
Electric Utility Structure and Renewable Rate	• Unbundling • **Renewable energy ratio 18%**	• Unbundling • **Renewable energy ratio 24%**	• Unbundling • **Renewable energy ratio 10%** • **HVDC linked with continental European grid**	• Unbundling • **Renewable energy ratio 17%**
Main concern by low inertia	• **Generator disconnection due to increased RoCoF**	• **Generator disconnection due to increased RoCoF**	• **UFLS due to lower Nadir**	• **UFLS due to lower Nadir**
The number of frequency reserve menu	• **13** (primary/secondly/ tertiary, reactive power, **inertia** etc)	• **11** (primary/secondly/ tertiary, **inertia** etc)	• primary/secondly/tertiary /FFR • **High-speed frequency response menu including inertia** (under consideration)	• 3 (primary/secondly /tertiary) • ·Subdividing menus • **Inertia** (under consideration)
Recovery of countermeasure costs	**Collected at the general expense of the user**	**Wheeling charges**	**Wheeling charges**	**Collected at the general expense of the user**

3．Technology Development of Multi-terminal HVDC System for Offshore Wind Farm

3-1. Needs of multi-terminal(MT) HVDC system

- Because of the sea depth of Japan, suitable area for offshore wind farm is near from coast and well distributed.
- Suitable area of off-shore wind (Hokkaido, Tohoku, Kyushu) is far from demand area and new transmission lines are needed due to the capacity limitation of conventional AC lines.
- Multi-terminal HVDC transmission system is one of the key solutions to transmit the power of wind farms to the metropolitan area.



3-2. Approach to MT-HVDC system development

〇NEDO Project : 2020.7～2024.2(4 years)

- **Project name : R&D of a multi-purpose and multi-terminal HVDC transmission system**
- **The budget in fiscal year 2020 : 1 Billion yen**

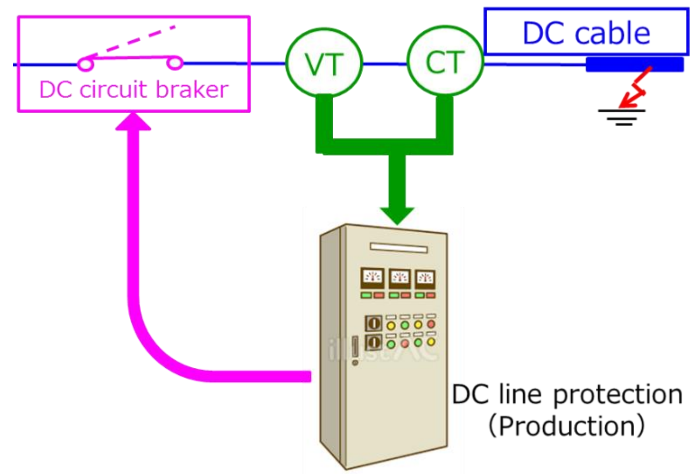
Ⅰ Development of the MT-HVDC control system

Development of the system on Real Time Digital Simulator (RTDS), and functional verification test of power flow control technique on the system.

Picture of RTDS*
(Simulator of the electric power system to verify the function)

Ⅱ Development of DC line fault detector and protector for MT-HVDC

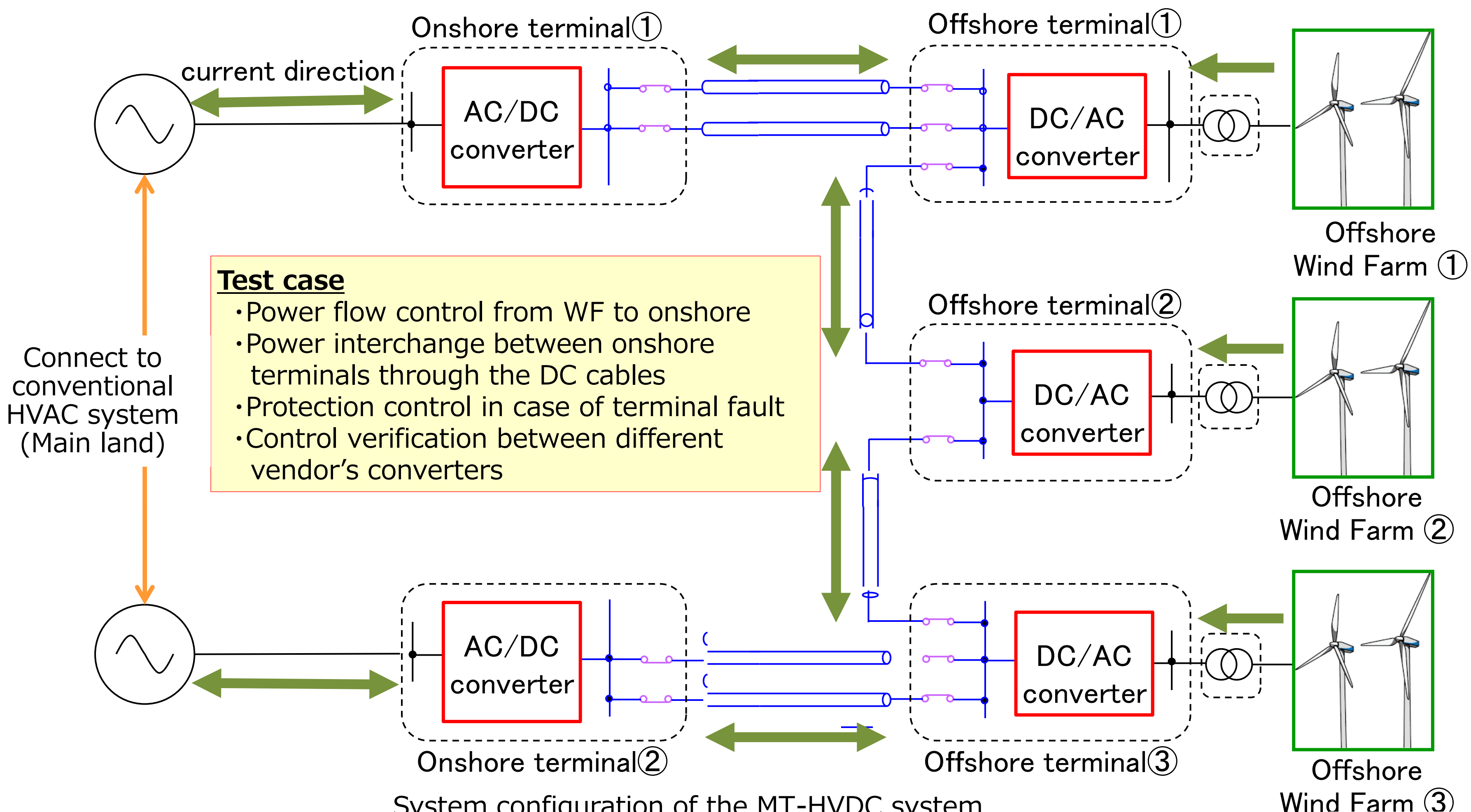
Hardware production of DC line protector, and functional verification test of the control system.



- **Establishment of a power-flow control and protection technique**
- **The technological standardization for different vendor's product interconnection.**

3-3. System configuration of MT-HVDC system

- HVDC system consists of two onshore terminals, three offshore terminals and DC cables.
- The system is capable of both the generated power transmission of offshore wind farms and the power interchange between onshore terminals through the HVDC link.

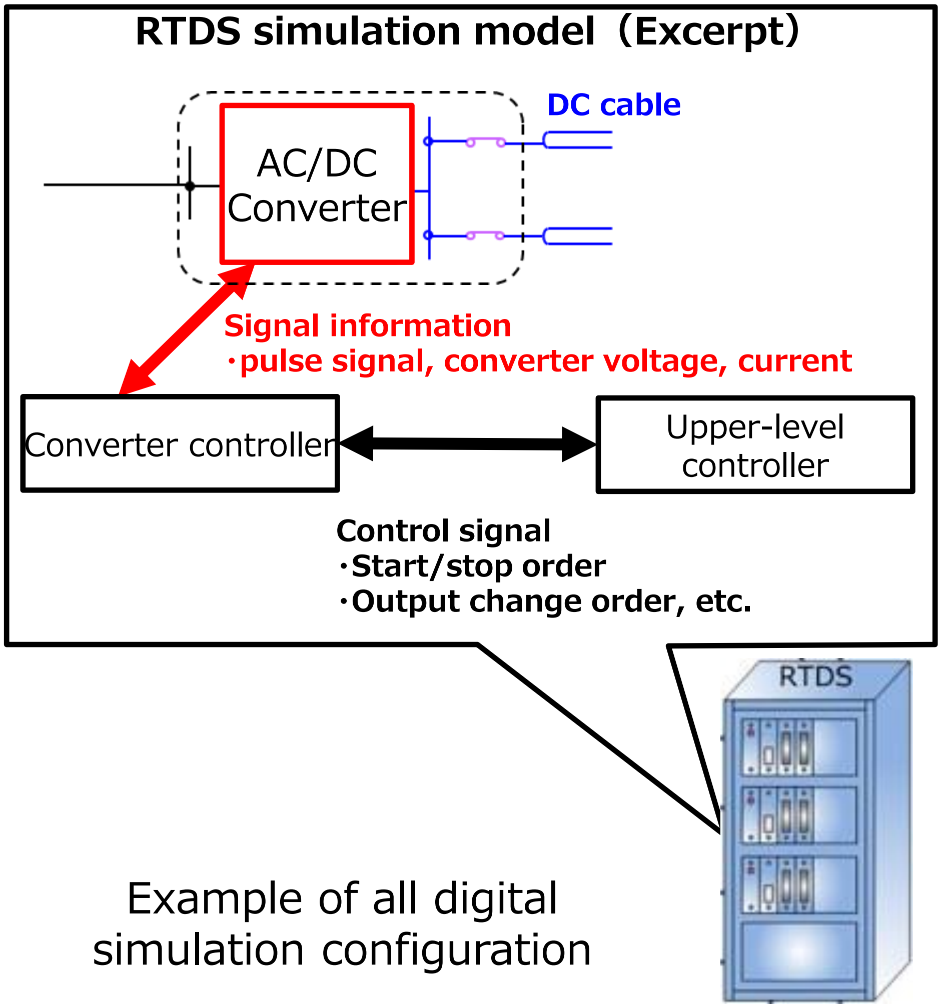


System configuration of the MT-HVDC system
which consists of different vendor's AC/DC converters

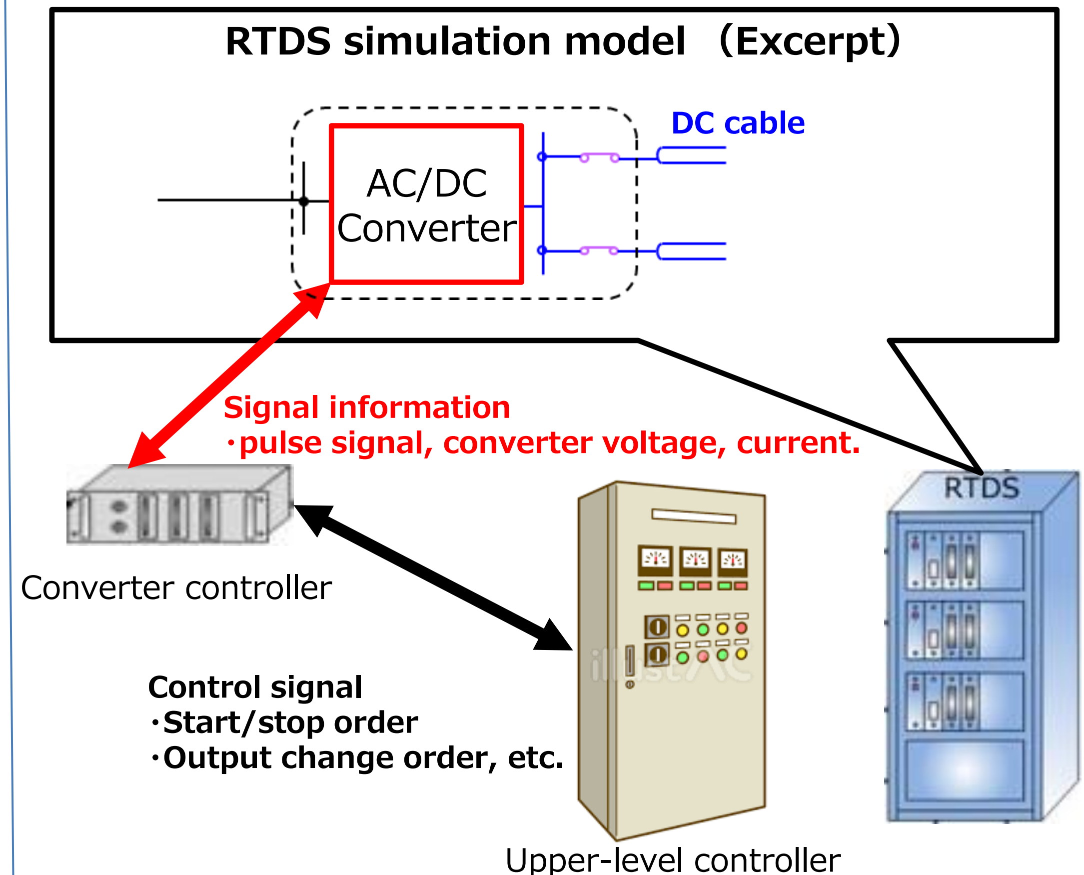
3-4. Function verification of the MT-HVDC system

1. <u>ALL digital simulation</u>
   (built a model of the whole equipment on RTDS)

2. <u>HIL(Hardware In the Loop) simulation</u>
   (made hardware of control units and conducted integration test with RTDS)



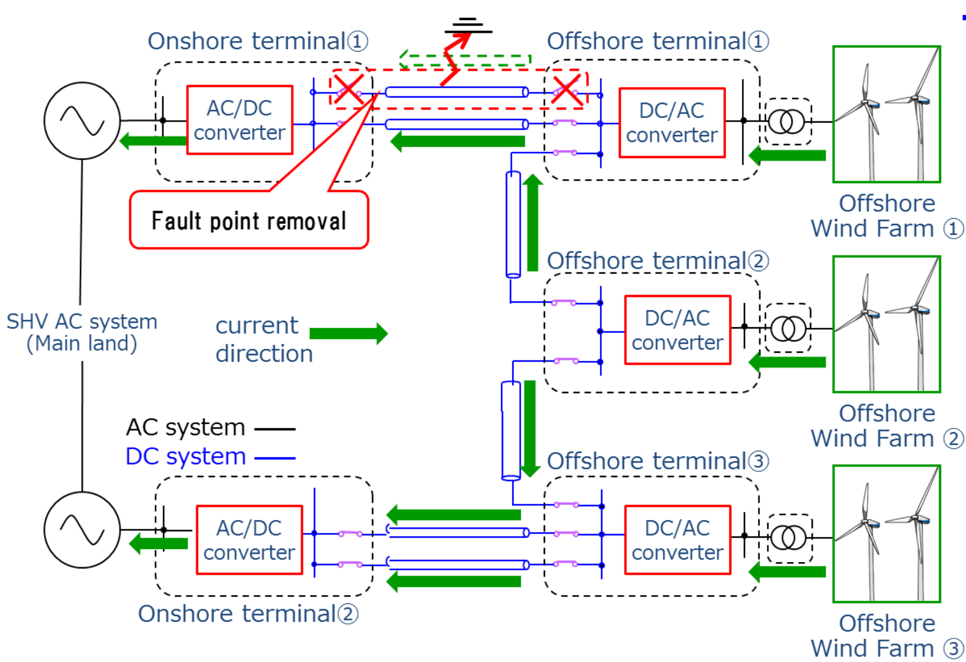
Example of all digital simulation configuration



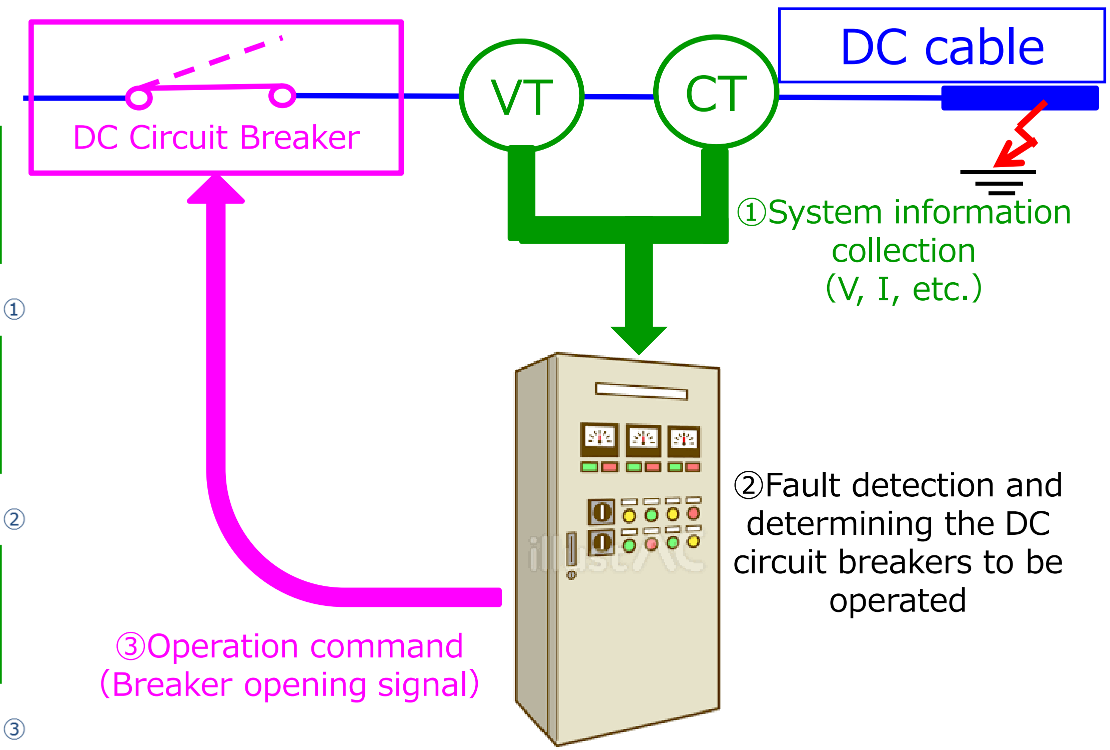
Example of the HIL simulation by RTDS and hardware units

3-5. Development and verification of a DC line protection

○Purpose : Development of a DC cable protection system and verification by HIL simulation
○Function : ①Data collection of DC system (V, I, Relay state, etc.)
②Fault and fault location detection, Circuit Breaker (CB) control
③CB opening signal transmission
○Target : Realization of fast response to fault-removal (required time: several milliseconds)



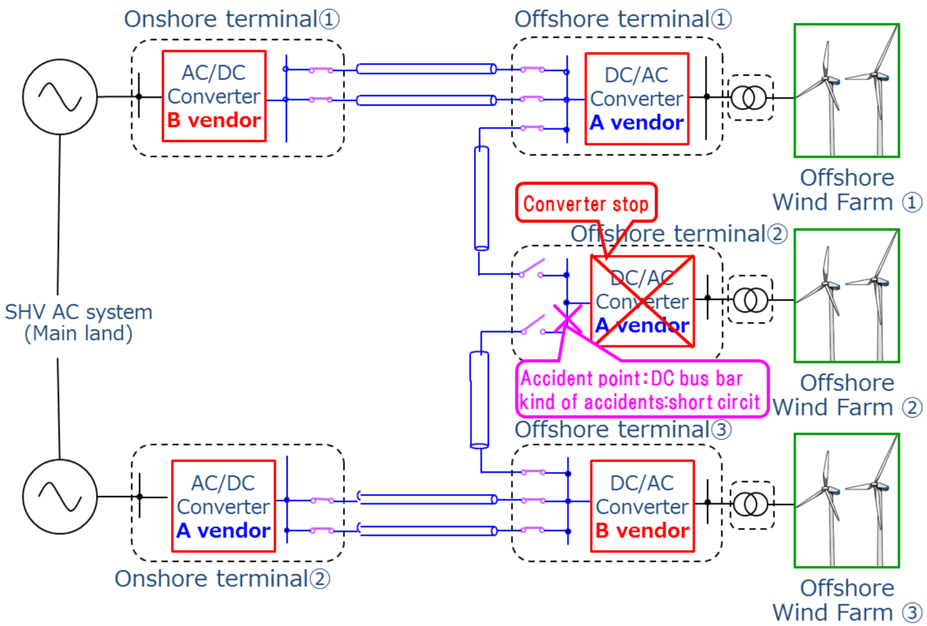
Fault detection and removal scheme in the multi-terminal HVDC system



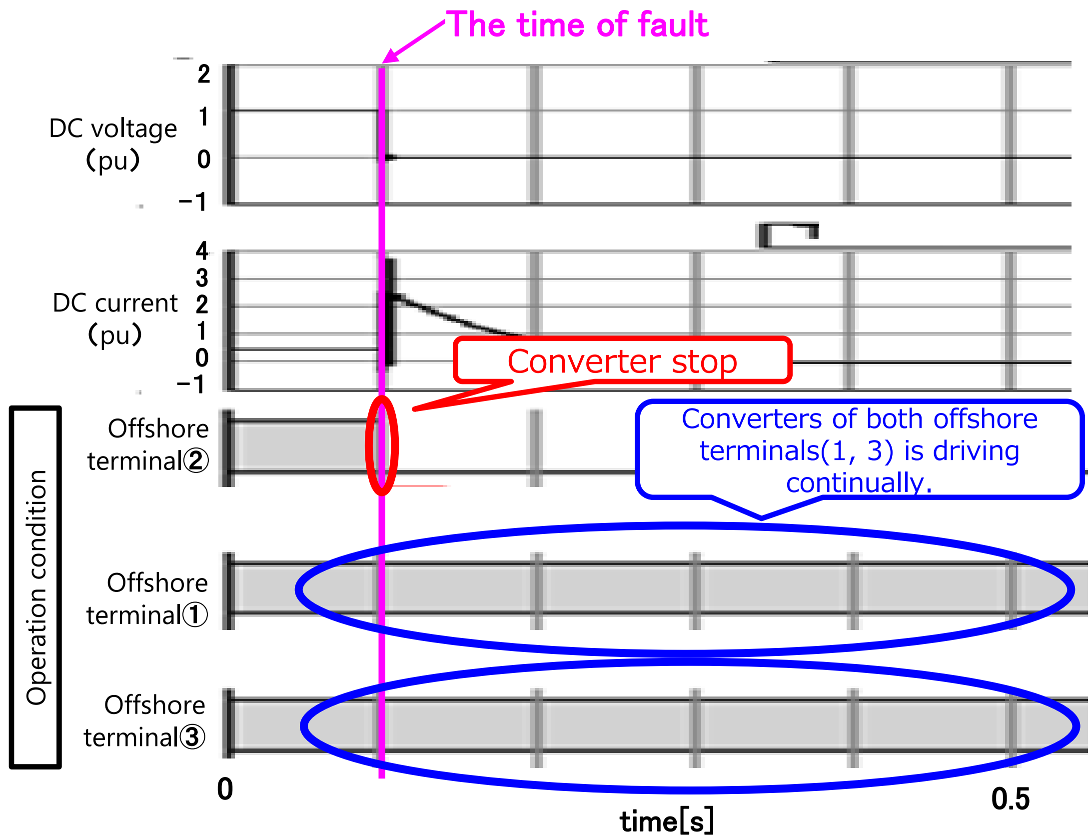
DC line protection Unit

3-6. Simulation result of a MT-HVDC system operation

- The test system including 2 different vendor's converter models is simulated for power flow control and protection scheme verification.
- The goal of this project is to standardize the operating specification through these simulation tests.



Test system configuration of different vendors converter connection



Simulation result (Bus bar short-circuit fault of terminal 2)

4. Future Technical Challenges

4-1. Expected innovations for carbon neutrality

◇**Innovation** **(Basic policy subcommittee)**	2020	2021	2022 ～ 5 years
①Decarbonization of frequency reserve (Hydrogen and storage batteries)			**・H_2/NH_3 utilization** **・Use of storage batteries**
②Regional microgrid support (including promotion of distribution business)			**Technology development for renewable energy oriented grid** **・Practical application of system inertia** **・Addressing regional and local issues**
③System stability (system inertia support)	NEDO Inertia project	NEDO Inertia project	
④Off-shore Wind (Establishment of low-cost technology)	NEDO DC transmission project	NEDO DC transmission project	NEDO DC transmission project **・Low cost of offshore wind** **・Establishment of floating technology**

4-2. Technical challenges for more renewable energy integration

Challenges and solutions for introducing large amounts of renewable energy

- When introducing large amounts of renewable energy, challenges arise in both wide and local areas.
- Local area challenge ought to be examined and verified using test field that can simulate a real network and devices (imitate microgrid)

Challenges when introducing large amounts of renewable energy		Wide area	Local area ～Microgrids
System stability	Frequency, Inertia	○	○
	Voltage, Reactive power	○	ー
	Transient/Small signal stability	○	ー
protection・control	Short circuit, Ground fault	○	○
	Protection coordination, Control	○	○
Anti-islanding		ー	○
Power quality (flicker and harmonics)		△	○
Distribution system voltage		ー	○
Resilience		△	○
DER stability (including black start)		ー	○