Demonstration Testing of Triple-Hybrid Power Generation System toward Era of Distributed Power Sources - Development of “EBLOX” and “COORDY” -

MASAYUKI TANAKA*1 YOSHIYUKI HANASAWA*2
EIJI TAKAHASHI*3 YUSUKE ISOBE*4
MASATO MITSUHASHI*5 HAZUMU ABE*6

Advancing toward a Low-carbon society, as represented by the increasing use of renewable energy, a global shift of introducing electric vehicles (EVs) and conversion from centralized to distributed power sources, the environment surrounding the engine-based power generation business is facing a paradigm shift. Mitsubishi Heavy Industries Engine & Turbocharger, Ltd. (MHIET) has constructed a demonstration facility of a hybrid power generation system called “EBLOX” on the premises of the Sagamihara Machinery Works. EBLOX is a combined power generation system of an engine generator plus a renewable energy source such as solar power generation and an energy storage system (ESS). With EBLOX, MHIET is proceeding with demonstrations with a view to acquiring technologies crucial to develop a triple-hybrid stand-alone power supply system to be used in off-grid areas for which demand is expected to arise, as well as developing a system in which a gas engine generator operates in combination with energy storage batteries to serve as the primary balancing power for the domestic electricity balancing market that is expected to gather momentum. This report presents the outcomes that MHIET has obtained from the demonstration testing to date.

1. Introduction

Against a backdrop of a global shift toward a carbon-free society in recent years, changes such as the increasing use of renewable energy and conversion from centralized to distributed power sources have been rapidly taking place and the business environment surrounding engine-based power generation systems has reached a major turning point. Global environmental programs such as Sustainable Development Goals (SDGs) have presented eco-friendly and sustainable development goals, in which stand-alone power supply systems in off-grid areas are included. There is also increasing need for power sources that can independently operate in times of natural disasters. Under these circumstances, MHIET constructed at the Sagamihara Machinery Works a triple-hybrid power generation facility called “EBLOX” in which the engine-based power generation system operates in combination with a renewable power generation system such as solar energy and energy storage batteries. Demonstration testing has been underway since November 2018.

In addition to the validation of the stand-alone power supply system with three power supply sources, MHIET is planning to perform further demonstration testing of the combined gas engine generator and energy storage battery system with a view to serving as the primary balancer of frequency containment reserve or FCR for the electricity supply-demand balancing market that is

*1 Chief Staff Manager, Engine Engineering Department, Engine & Energy Division, Mitsubishi Heavy Industries Engine & Turbocharger, Ltd,
*2 Executive Vice President Chief Regional Officer, Asia Pacific and India, Mitsubishi Heavy Industries, Ltd. President Mitsubishi Heavy Industries Asia Pacific Pte.Ltd., ex-President Mitsubishi Heavy Industries Engine & Turbocharger, Ltd.
*3 Senior Manager, Engine & Energy Division, Mitsubishi Heavy Industries Engine & Turbocharger, Ltd.
*4 Manager, Engine Sales Department, Engine & Energy Division, Mitsubishi Heavy Industries Engine & Turbocharger, Ltd,
*5 Chief Staff Manager, Electricity & Applied physics Research Department, Research & Innovation Center, Mitsubishi Heavy Industries, Ltd.
*6 Engine Engineering Department, Engine & Energy Division, Mitsubishi Heavy Industries Engine & Turbocharger, Ltd,

scheduled to be introduced in Japan.

For EBLOX, MHIET has developed a proprietary control system called “COORDY,” that controls these power sources in a coordinated way, determines the optimal power output assignment and controls the facility in response to frequency fluctuations. The validation is ongoing.

2. Features of EBLOX and COORDY

2.1 Features of EBLOX

The name “EBLOX” was coined as a hybrid between energy (E) and building blocks (BLOX). The name has been chosen in expectation that, with EBLOX, multiple combinations of various energy sources such as engine generators, renewable energy and energy storage batteries can be made as if handling toy building blocks of energy sources to best suit the situation and ultimately supply the optimal power solution to each customer.

Table 1 lists the specifications of each piece of equipment that configures the EBLOX demonstration facility constructed at the Sagamihara Machinery Works and **Figure 1** gives the facility layout. MHIET’s 500kW gas engine generator set with a GS6R2 engine is selected as the engine generator. For solar power generation, 1152 photovoltaic (PV) panels with a total output of 300 kW are installed on the rooftop of Factory Building No. 3. A battery-based ESS with an output of 500 kW and an energy storage capacity of 331kWh is included in the system.

For the purpose of the validation of this three-source stand-alone power supply facility, MHIET introduced a 500kW dummy load and two units of 125kW air compressors as an inductive load on the premises. Arrangements were made so that the air compressed by the compressors is used by the production facilities in the factory. Each piece of equipment can also be connected to the electrical grid by switching the disconnector. Moreover, the gas engine generator and battery-based ESS have been arranged to have an option to enable connection to the grid for future FCR testing. The facility has been designed in such a way that it can also be used as a private power plant for the factory when no testing is carried out.

Table 1 List of the installed equipment

Equipment	Specifications	
1. Gas engine generator	GS6R2-PTK Output: 500kW	
2. Solar power generation system	Panel YGE 60 CELL 270 W × 1152 units Total output: 311.04 kW	
	PCS RPI M50A 50 kW × 6 units Total output: 300 kW	
3. Energy storage system	PCS DES10JB125K01 125 kW × 4 units Total output: 500kW	
	Lithium battery Capacity: 331 kWh × 1 unit	

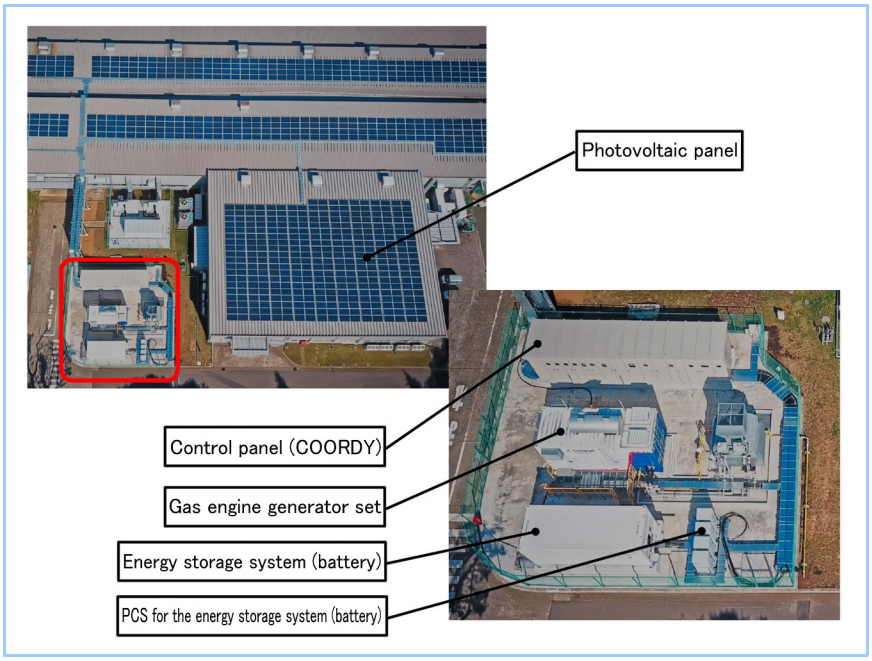

Figure 1 Facility layout

2.2 Features of COORDY

It is essential for the EBLOX demonstration facility to properly control the three power sources. MHIET named its control system "COORDY," which was coined from the term "coordinate" in expectation of appropriately and efficiently regulating and combining the three power sources. A diagram of the EBLOX and COORDY system configuration is depicted in **Figure 2**.

The control system, COORDY, is characterized by the following two features.

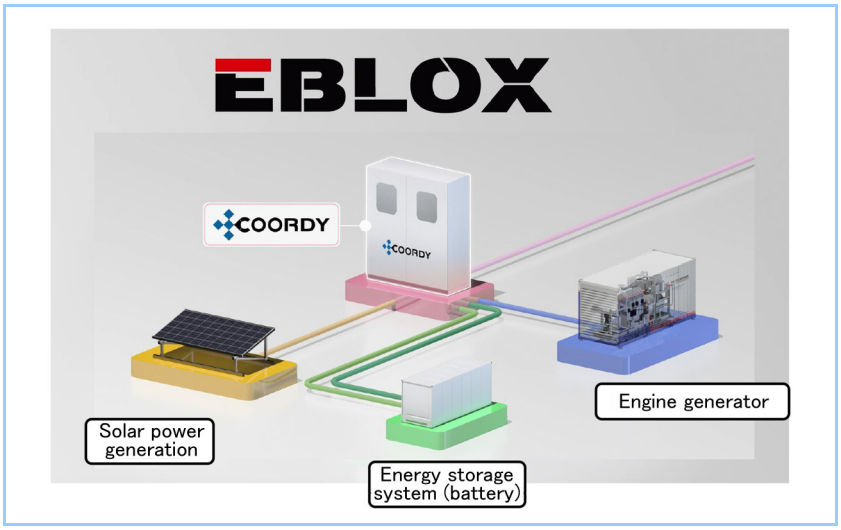

Figure 2 EBLOX and COORDY

Feature 1: Optimal control of multiple power sources

When using multiple power sources, it is indispensable for the system to have the function of determining how much output should come from which power source and optimally assigning each of the power sources the amount of power to generate for the stable supply of power. COORDY is therefore equipped with the following functions.

(1) Optimal power output assignment for stand-alone power supply

Stand-alone power supply denotes providing electricity to areas with no electrical grid (i.e., off-grid areas) for loads that consume electricity. With this power output assignment function, the following become possible; generate power via solar as much as possible on sunny days and shut down the engine generator, and when the PV output starts dropping in the evening, start the engine generator and gradually increase its output; if clouds appear and

cause the PV output to fall, supply power from the energy storage battery to compensates for the drop and start the engine generator.

(2) Optimal control of battery state of charge (SOC)

COORDY constantly monitors the SOC of the energy storage battery. With this function, when SOC is low, the output from the solar power generation and the engine generator will be controlled accordingly to allow the battery to be charged to a sufficient level.

(3) FCR control by gas engine generator and energy storage battery (future function)

FCR refers to using operating reserves to provide balancing capacity (ΔkW) to the electrical grid by increasing or decreasing the output within 10 seconds after detecting a deviation in the frequency. In the case of MHIET's gas engine generator, it takes about 7 minutes until it reaches the rated output from shut-down state. During this period of time, therefore, COORDY selects the energy storage battery as the primary power source and later controls the output in connection with the output from the engine generator.

Feature 2: Stabilization of the local grid during stand-alone operation

The local grid frequency and voltage depend on the grid system if it is connected to a commercial grid, hence even if there is a large load fluctuation, it can be absorbed by the grid. In the case of a stand-alone power supply system, however, such fluctuation in the loads affects the local grid frequency or voltage, involving the working power supply unit paralleling off from the local grid (i.e., open the circuit to stop the supply) and leading to a power failure in the worst-case scenario. Apart from sudden load fluctuations, output from renewable energy sources (e.g., solar or wind power) is susceptible to sudden fluctuations because of sudden changes in the weather, which is considered to be a factor that causes sudden frequency and voltage fluctuations in the local grid.

COORDY is therefore equipped with a function to stabilize the local grid by immediately commanding the battery to charge or discharge when the local grid frequency or voltage fluctuates. This new control was made possible by combining the virtual synchronous generator technology of the MHI Research & Innovation Center with MHIET's droop control technologies and technology for coordinating the different types of motors that MHIET acquired through many years of engine generator development.

Using the analogy of the human body, COORDY's feature 1 corresponds to the activities of the human brain; just like when we move our bodies while taking in the surroundings through the eyes, ears, etc., this function monitors various information and the condition of each piece of equipment to provide proper instructions. Feature 2 works like our reflexes; when you touch a heated object by accident, you involuntarily and nearly instantaneously snatch your hand away without even thinking. Likewise, this function controls the energy storage battery by making an instant response to changes in the local grid conditions. With these two features, COORDY can realize the stable supply of power from a system with multiple power sources.

When using renewable energy in a stand-alone power supply system, it is necessary to consider fluctuations in the power supply caused by the weather or time of day. Especially in the case of combining solar power generation with an engine generator, the fluctuations from the solar power generation have to be absorbed by the engine generator, which generally limits the maximum acceptable capacity of the solar power generation to 20% of the rated capacity of the engine generator. However, with the EBLOX system and COORDY control, a solar power generation system with capacity equivalent to the engine generator can be introduced, which enables the stand-alone power supply system to make full use of the advantages of renewable energy.

3. Demonstration testing outcomes

The demonstration of EBLOX currently focuses on the following tasks. Presented here are the outcomes that we have obtained so far.

(1) Control of stand-alone power supply system incorporating an engine generator and energy storage battery against fluctuations in loads

When a load fluctuates while power is being supplied from a stand-alone engine

generator, the fluctuation is normally absorbed by governing the engine speed. However, when a large, instantaneous load fluctuation occurs, such governing control fails to avoid the effect, causing considerable reduction of the local grid frequency and worsening the quality of the power supplied. In the worst case, such instantaneous and excessive fluctuation can cause the engine to stall, which can then lead to a power outage (**Figure 3**).

COORDY, if used in this situation, can instantly detect the change in the frequency caused by the load fluctuation through the aforementioned feature. By demanding the energy storage battery to provide the optimal output, COORDY can minimize the amplitude of frequency fluctuations affecting the engine generator, as shown in **Figure 4**.

With regard to the initial load acceptance performance, COORDY has made it possible to accept as much as 50% of the rated output of the gas engine generator though it is generally around 30% (**Figure 5**).

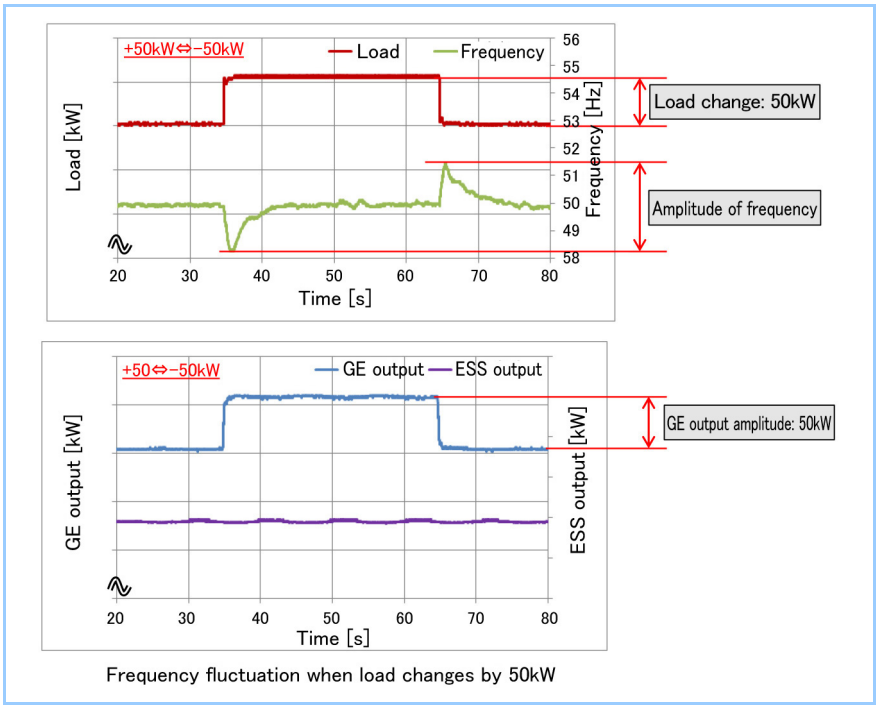

Figure 3 Frequency amplitude in relation to load change (with engine generator only)

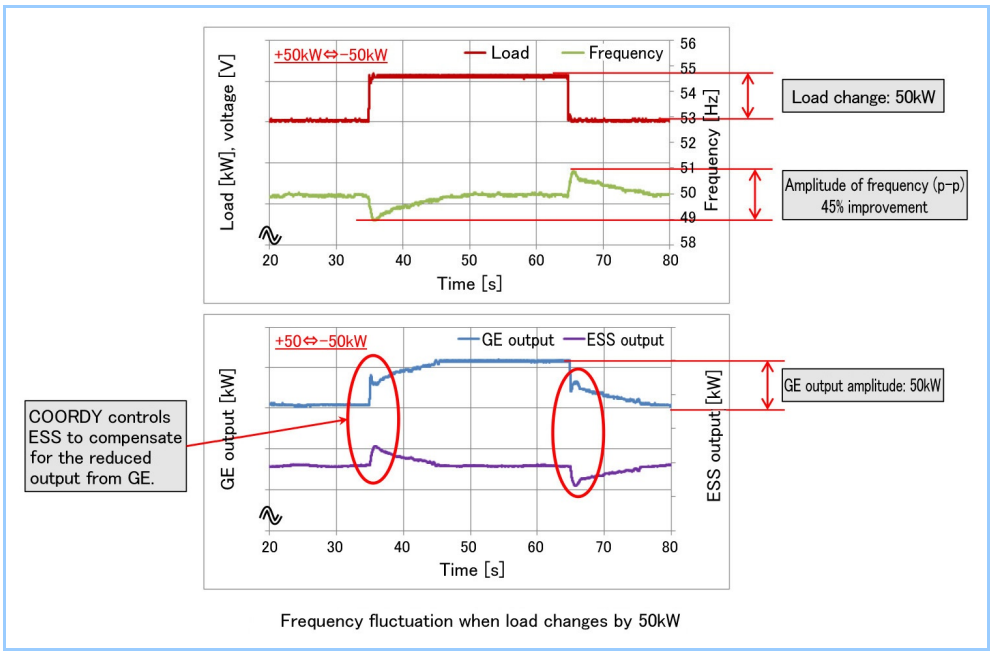

Figure 4 Frequency amplitude in relation to load change (with engine generator + COORDY)

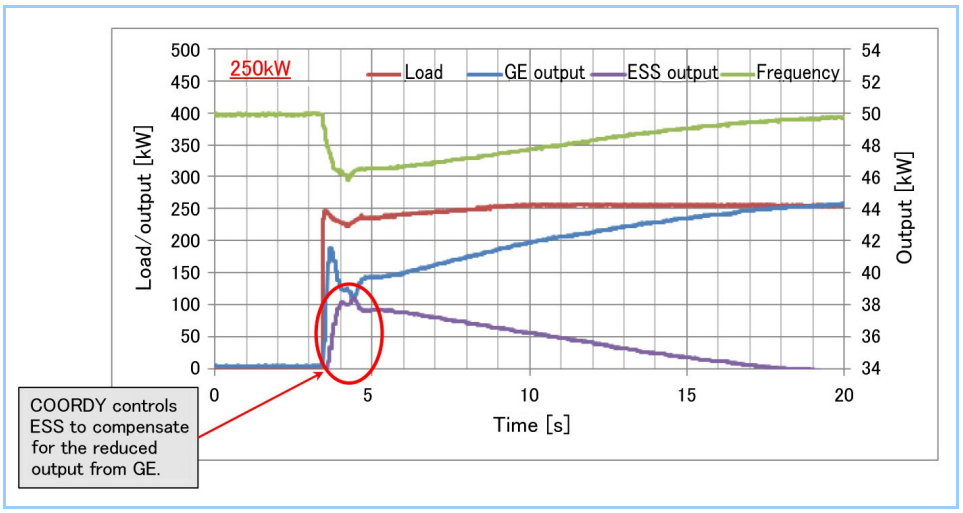

Figure 5 EBLOX output behavior with 50% initial loading

(2) Stabilization of PV power output during stand-alone operation with three power sources

Even when the electricity is supplied by the combination of three power sources and PV output is negatively affected by clouds (**Figure 6**), COORDY' can stabilize the local grid frequency by immediately supplying electricity from the energy storage battery via its feature 2, as depicted in **Figure 7**. When the evening hours bring a gradual decline in the PV power output, COORDY's feature 1 increases the output of the gas engine generator, thus achieving the optimal power output assignment (**Figure 8**).

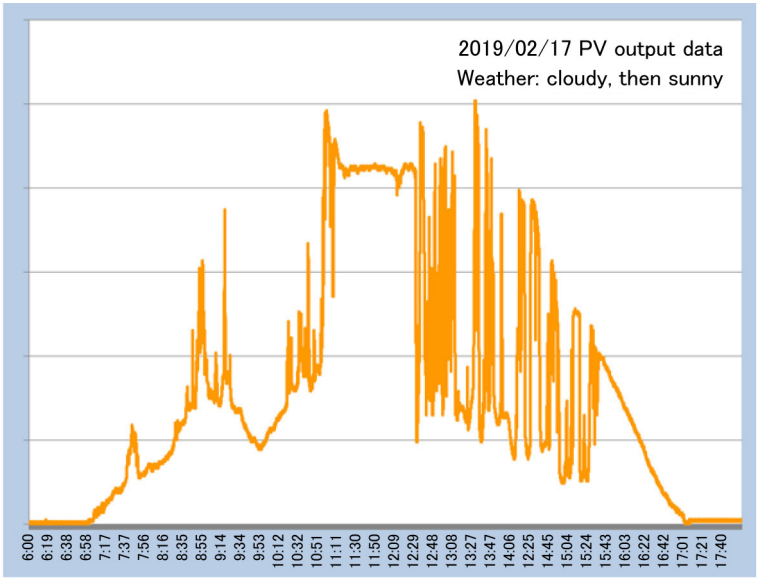

Figure 6 Output fluctuations of solar power generation

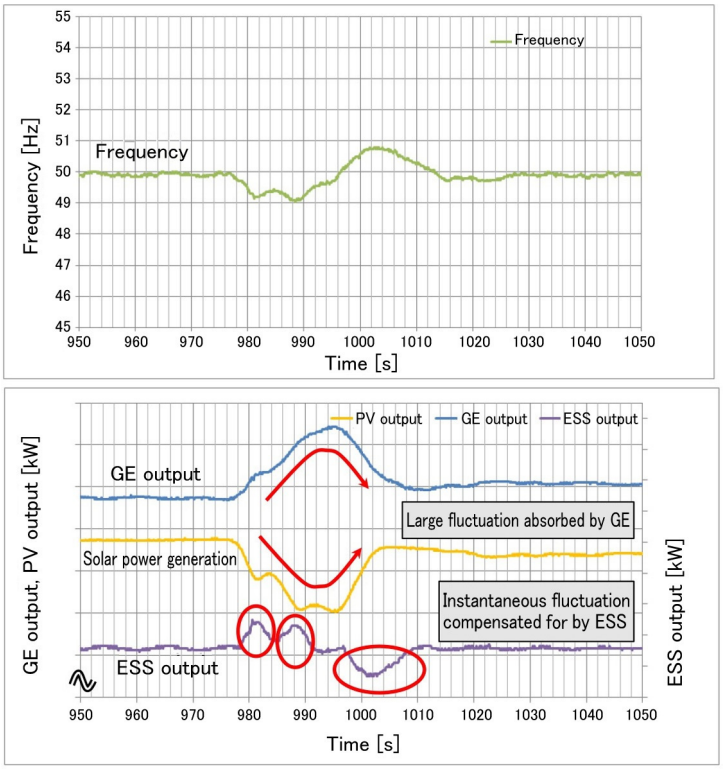

Figure 7 EBLOX output from three sources (absorb PV output fluctuations)

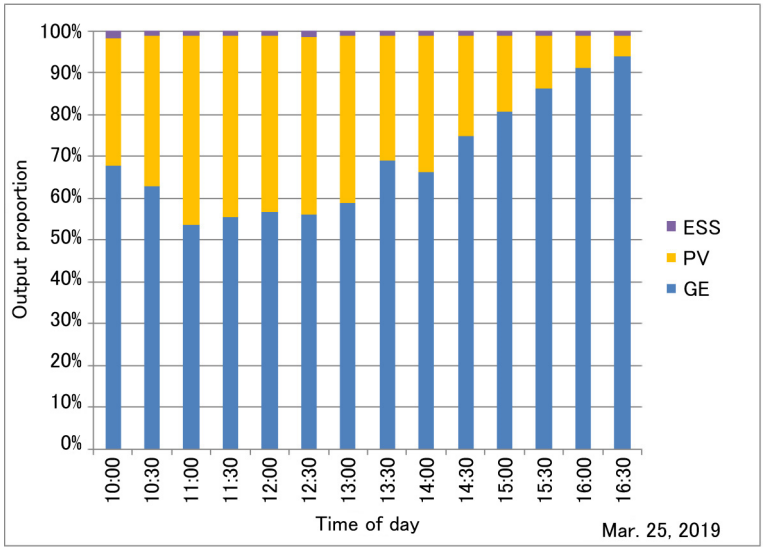

Figure 8 Power generation proportion during stand-alone operation

4. Conclusion

Starting construction in April 2018 and testing from November, MHIET has so far obtained the outcomes described in section 3. To realize a control that can fully respond to much larger fluctuations in loads, MHIET will continue the optimization of each of the control parameters of COORDY to offer MHIET's stand-alone power supply systems to off-grid areas where a commercial grid is not available.

For FCR as well, the detailed requirements of which are undetermined at this point in time, MHIET will continue to make efforts to add value to our product and create additional value for customers by identifying feasible functions through the utilization of COORDY's feature 1 in anticipation of the expansion of the electricity supply-demand balancing market.