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New Proposal of the M-G Set with Renewable Energy and Storage Battery

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SUMMARY

As one measure to maintain power system security with the expansion of renewable energy, in this paper we propose an "M-G set with renewable energy and storage battery" (referred to as the M-G set), which combines a synchronous motor (referred to as motor M) and a synchronous generator (referred to as generator G) with a renewable energy and storage battery.

When viewed from the power system side, the M-G set has a configuration in which only the generator G is connected in parallel, so the synchronous generator capacity (synchronous generator ratio) required for the system can be secured, with no special consideration needed, even in the event of a system fault.

As the renewable power generation increases, thermal power generators may have to be stopped due to the minimum output limit for active power. However, in the M-G set motor M is driven by the active power output from the renewable energy and storage battery, while generator G generates electricity and connects it to the power system. Therefore, renewable energy can be connected to the power system without reducing the ratio of the synchronous generator in the system. In addition, since the storage battery enables high-speed and wide-ranging control of the active power output of generator G of the M-G set, it contributes to the maintenance of the power system security (frequency stabilization, voltage stabilization, and maintenance of system stability). Also, it enables governor-free operation at 0 kW, which is not possible with thermal power generators, and a simulated generator shedding action that rapidly reduces the active power output in the event of a power system fault (for enhancing the power system stability).

Furthermore, the M-G set can let the renewable energy sources, such as large-capacity offshore wind power generators, behave as synchronous generators that can control the active power output at high speed, when viewed from the power system side. This is currently considered to be a feasible measure that can solve various problems caused by short-circuit capacity shortages during grid connection and power system faults. Therefore, it can contribute to the expansion of the amount of renewable energy, already incorporated into the power system.

In this paper, an example of effective value simulation analysis of power supply limit simulation operation by an M-G set is carried out. Moreover, for the development of practical (100 MVA or more) M-G sets, the authors are currently working on the installation of (100 kVA) M-G set demonstration equipment into the power system simulator, which simulates the actual generator, transformer, and transmission line characteristics.

KEYWORDS

renewable energy, motor-generator set (M-G set), storage battery, power system security, power system stability

1. INTRODUCTION

The targets for introducing offshore wind power in Japan are 10 GW by 2030 and 30 - 45 GW by 2040 [1]. In other countries, a system non-synchronous penetration (SNSP) ratio, or an operational limit for power system inertia, is managed to simultaneously increase the introduced renewable energy power sources (referred to as renewable energy) and to maintain power system security [2], [3], and [4].

As one measure to maintain power system security with the expansion renewable energy, in this paper we propose an “M-G set with renewable energy and a storage battery” (referred to as the M-G set), which combines a synchronous motor (referred to as motor M) and a synchronous generator (referred to as generator G) with renewable energy and a storage battery.

As the renewable power generation increases, thermal power generators may have to be stopped due to the minimum output limit for active power. However, in the M-G set motor M is driven by the active power output from the renewable energy and storage battery, while generator G generates electricity and connects it to the power system. Therefore, renewable energy can be connected to the power system without reducing the ratio of the synchronous generator in the system. In addition, since the storage battery enables high-speed and wide-ranging control of the active power output of generator G, it contributes to the maintenance of power system security (frequency stabilization, voltage stabilization, and maintenance of system stability). Also, it enables governor-free operation at 0 kW, which is not possible with thermal power generators, and active power-limited control that rapidly reduces the active power output in the event of a system fault, and enhances the power system’s stability.

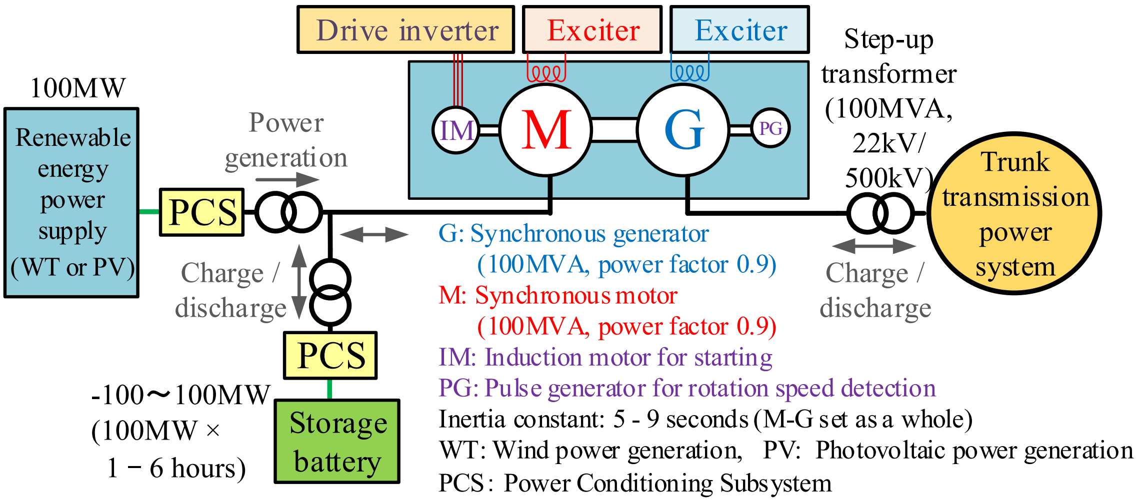
Furthermore, the M-G set can let the renewable energy sources, such as large-capacity offshore wind power generators, behave as synchronous generators that can control the active power output at high speed, when viewed from the power system side. Currently, this is considered to be a feasible measure that can solve various problems caused by short-circuit capacity shortages during grid connection and power system faults. Therefore, it can contribute to the expansion of the amount of renewable energy, already introduced into the power system.

2. M-G SET WITH RENEWABLE ENERGY AND STORAGE BATTERY

2.1 Outline of M-G set

When connecting a renewable energy to the power system, a storage battery may be installed to compensate for output fluctuations and to smooth out the output. In addition to this, motor M and generator G are combined to construct the “M-G set with renewable energy and storage battery.” Fig. 1 shows the conceptual diagram of the M-G set.

When viewed from the power system side, the M-G set has a configuration in which only generator G is connected in parallel, so the synchronous generator capacity (synchronous generator ratio) required for the system can be secured; no special consideration is needed, even in the event of a system fault. A thermal generator can only be operated with an active power output in the range of approximately 30 to 100%, usually due to the minimum output limit. In contrast, it is possible to operate generator G of this M-G set in a wide range, from -100 to +100%. Thus, this would prevent the thermal generator from shutting down due to the mass introduction of renewable energy; therefore, it can become one of the measures to expand renewable energy’s introduction without reducing the ratio of synchronous generators in the power system.



G: Synchronous generator
(100MVA, power factor 0.9)
M: Synchronous motor
(100MVA, power factor 0.9)
IM: Induction motor for starting
PG: Pulse generator for rotation speed detection
Inertia constant: 5 - 9 seconds (M-G set as a whole)
WT: Wind power generation, PV: Photovoltaic power generation
PCS: Power Conditioning Subsystem

Fig. 1 Conceptual diagram of M-G set with renewable energy and storage battery

Here, the capacities of motor M and generator G of the M-G set are assumed to be 100 MVA or more, and it can be connected to the backbone system of about 220 kV or more, making it possible to contribute to the maintenance of frequency stability and voltage stability. Furthermore, since the active power output of the generator G can be changed at high speed by the storage battery, power supply-limited control is also possible. This can also contribute to the improvement of system stability, especially in Japan where large-capacity offshore wind power plants are installed in remote areas far from the demand locations. Table 1 shows the contribution of generator G in the M-G set to the power system security.

Table 1 Contribution to Power System Security by Large-Capacity Generators

Features of large-capacity generators	Contribution to power system security
The active power output can be adjusted according to the frequency	Frequency
	Power System Stability
It has an inertial force (with a constant of about 8 seconds)	Frequency
	Power System Stability
It does not stop due to instantaneous voltage drops (when the voltage drops momentarily) during a power system fault	Voltage
	Power System Stability
The voltage of the trunk transmission power system can be adjusted	Voltage
	Power System Stability

2.2 Features of the M-G set

The features of the M-G set are listed below.

A) Looking from the power system side, since only generator G is connected, the synchronous generator capacity (synchronous generator ratio) required for the system can be secured, and the operation in the event of a system fault does not require special considerations.
B) Since the renewable energy and the storage battery are not directly connected to the power system, and the terminal voltage of the renewable energy and the storage battery is maintained by motor M, a system fault or short-circuit capacity shortage in the power system will not affect the stable operation of the renewable energy and the storage battery.

C) Due to the minimum active power output operation constraint, thermal generators can usually only be operated in the range of about 30 to 100% of the rated active power output. However, generator G in the M-G set can be operated in a wide range, from -100 to +100%, but it is expected that the insufficient output reduction allowance of the thermal generator will be resolved. Therefore, it will be possible to expand the introduction of renewable energy without reducing the synchronous generator ratio of the system.

D) Compared to thermal power generators, it is possible to change the output of generator G at high speed by changing the output of the storage battery; therefore, simulated generator shedding action, without disconnecting the generator from the power system in the event of a system fault and subsequent correction control, is possible. In addition to the ability to supply reactive power that can maintain the voltage of the backbone system, it can be expected to contribute to maintaining system stability in the event of a system fault.

E) It can act as a test transmission generator during power system blackouts.

F) Since the output can be adjusted at high speed when the generator is accelerated due to a system fault, generator G of the M-G set can be treated as a "generator that does not step out."

Fig. 2 shows another example of introducing the M-G set where the rating of M-G set is less than the capacity of the offshore wind power plant. In Fig. 2, since inverter#2 is directly connected to the system, there is a risk that the voltage may decrease due to system fault, which may lead to the trip or output decrease of the inverter#2. However, the risk that inverter#1 and the storage battery trip or output decrease can be reduced by M-G set.

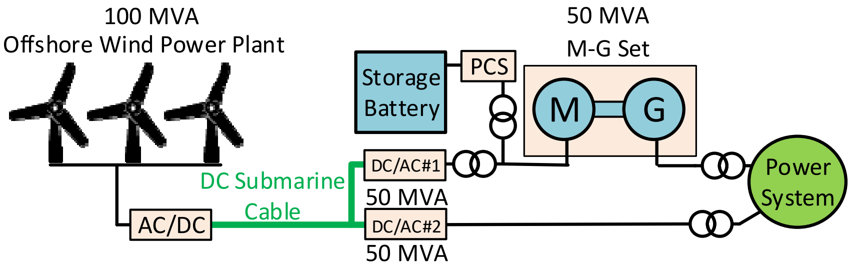


Fig. 2 Introduction example of M-G set with renewable energy and storage battery

Assuming that a storage battery is attached to the synchronous condenser, the cost of installing the motor of the M-G set, and the loss of the original M-G set itself, will be factors that increase the cost of the proposed M-G set. However, using M-G set, the wind power plant and storage can be decoupled from the grid. Therefore, the M-G set solution could reduce the risk that the inverters trip or the active power output decrease due to voltage dip. Therefore, the authors believe that M-G set is more effective solution than synchronous condenser depending on the connecting point and the capacity of offshore wind power plant. The author plans to compare synchronous condenser and M-G set solution through tests using a demonstration equipment described in Section 4.

3. EXAMPLE OF EFFECTIVE VALUE SIMULATION ANALYSIS OF SIMULATED GENERATOR SHEDDING ACTION BY THE M-G SET

3.1 Simulation analysis conditions

An example of effective value simulation analysis of a simulated generator shedding action by an M-G set was carried out. In general, generator shedding is achieved by disconnecting the generator from the power system but, since generator G of the M-G set can reduce the active power output very fast by controlling the active power output of the storage battery, in this paper we call this operation the simulated generator shedding action. Fig. 3 shows the system model and system conditions used in the dynamic characteristic analysis simulation; Fig. 4 shows the control block of the M-G set for determining the active power input *Pm* of the synchronous motor M of the M-G set.

For the simulation analysis, the Power system Analysis Tools (CPAT) [5] was used to compare two cases; that is, with and without the simulated generator shedding action by the M-G set. As for the system disturbance condition, a one-line three-phase ground fault was made to occur at time t = 1.0 s on the two-line transmission line, and the fault was cleared 0.07 seconds later at t = 1.07 s. The simulated generator shedding action limit rapidly reduced the active power output of the battery from 0 MW to 500 MW in 0.1 seconds at 1.1 s. As a result, the output of generator G of the M-G set was reduced from 250 MW to -250 MW. The simulation analysis uses a simple model for the renewable energy storage battery, and the M-G set acts as one synchronous machine model whose machine input changes according to the output of the renewable energy and the storage battery: the loss of the PCS and M-G set are ignored.

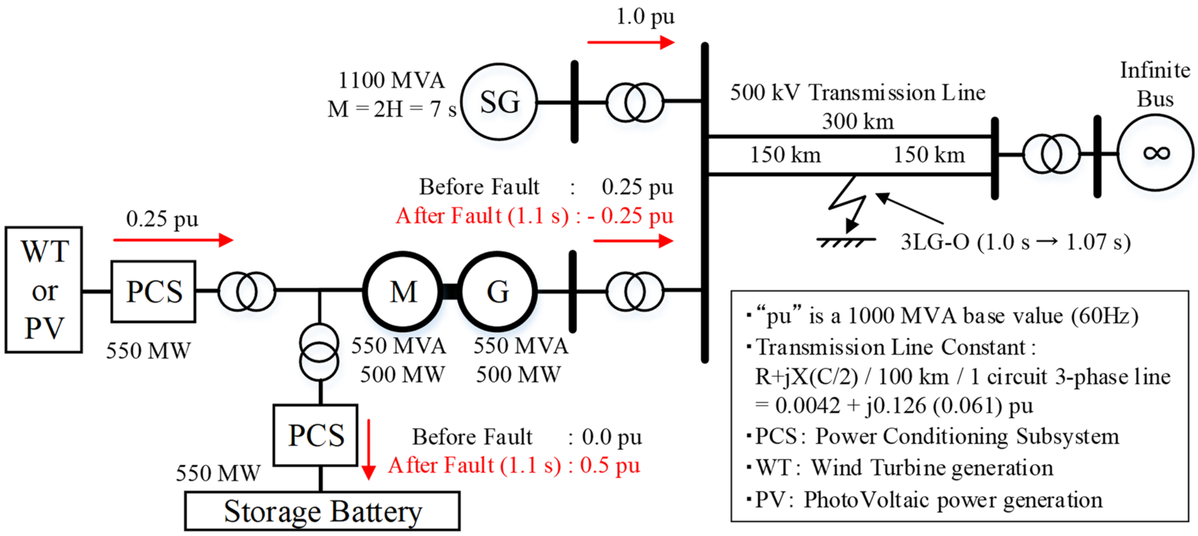


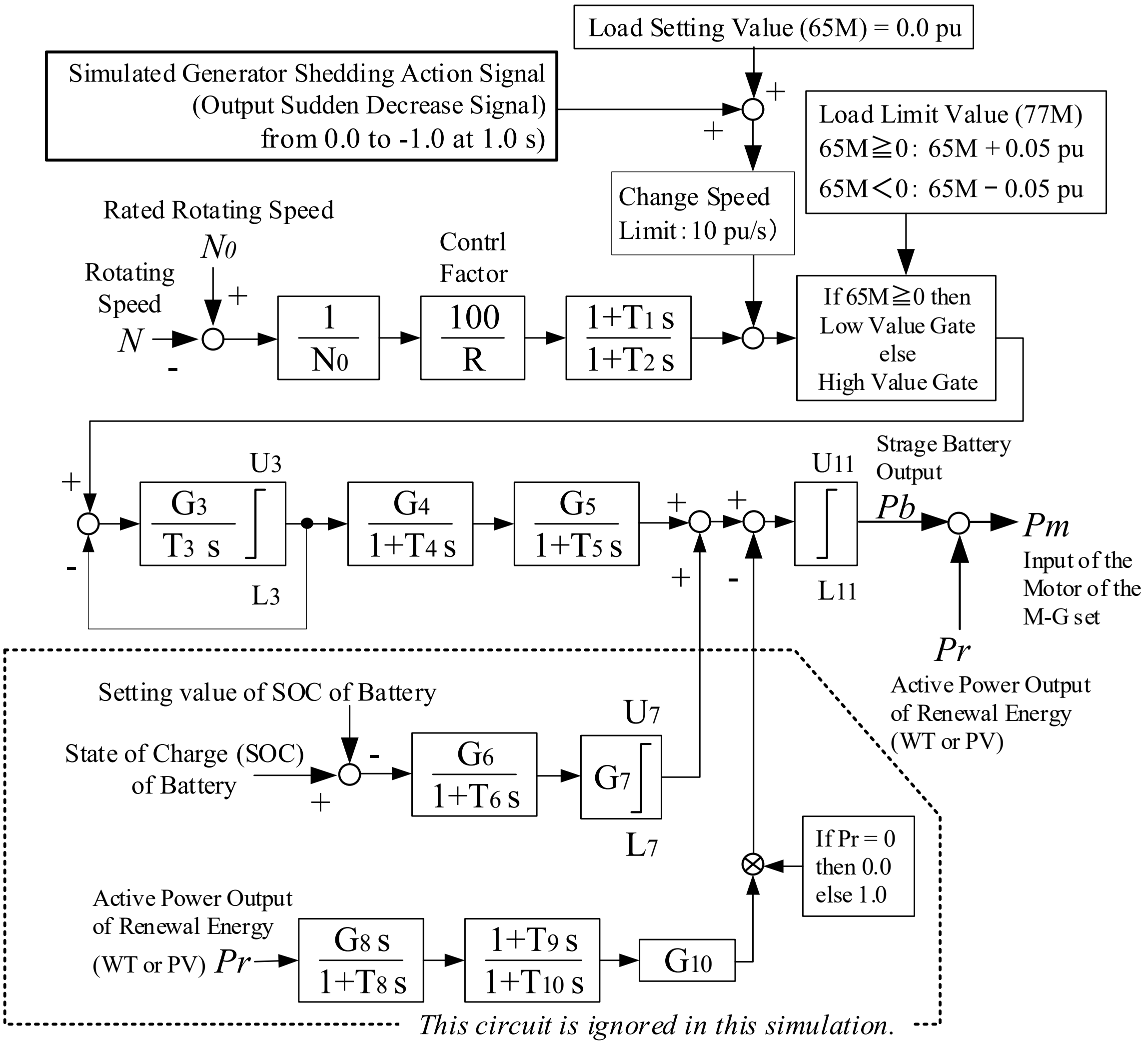
Fig. 3 System model and system conditions used for dynamic characteristic analysis simulation

3.2 *Analysis results*

Fig. 5 shows the simulation analysis results. The active power output of the M-G set decreased from 250 MW to -250 MW due to the simulated generator shedding action, and the M-G set shifted from generator operation to motor operation (Fig. 5 (a)). As a result, it can be confirmed that the first wave of transient fluctuation of the internal phase angle of the synchronous generator SG was reduced, and the transient stability was improved (Fig. 5 (b)). When synchronous generator G is shedding, due to a power system fault such as a lightning strike, synchronous generator G is disconnected from the power system, so it is not possible to supply active and reactive power after the disconnection. It takes a certain amount of time to reconnect to the power system.

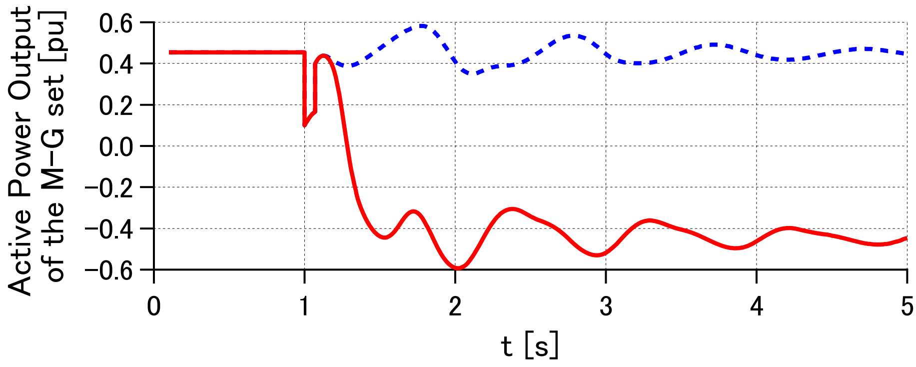
However, since the simulated generator shedding action by generator G of the M-G set is realized by rapidly reducing the active power output of the attached storage battery, it is possible to supply reactive power during a power system fault, and it is possible to control the active and reactive power output immediately after the power system fault is cleared. Similar control is possible when the storage battery is directly connected to the power system without going through the M-G set, but there is a risk that the storage batteries may be temporarily shut down due to the influence of the system fault, and an inability to supply active/reactive power for about 1 second after the system fault is cleared.

By connecting the storage battery to the power system via the M-G set, it is possible to avoid such phenomena. Since the frequency of the power system is expected to drop significantly after a large-capacity generator shedding, we believe that the ability to supply active and reactive power quickly and reliably after a power system fault is important for stabilizing the power system.



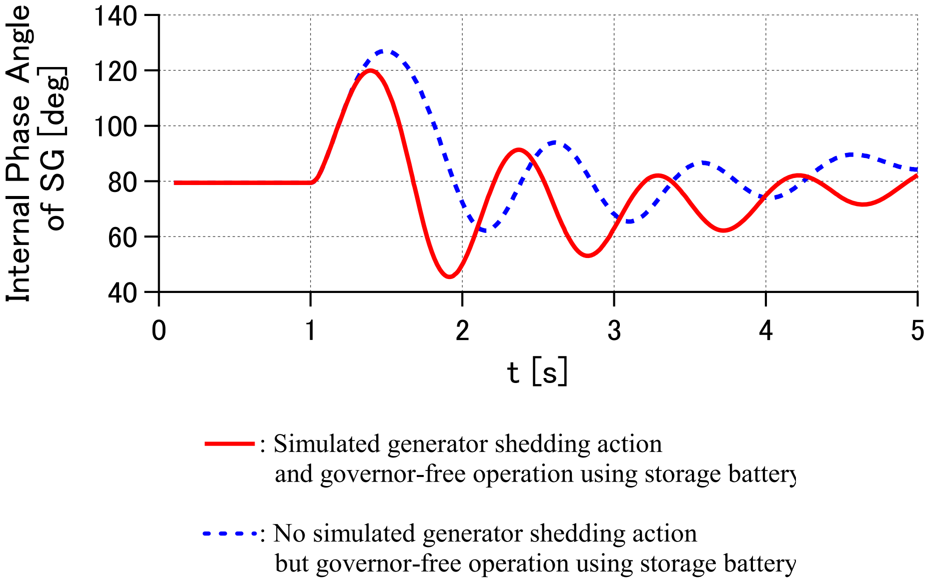
Parameters : $R = 4$, $T_1 = T_2$, $G_3 = 1.0$, $T_3 = 0.01$, $U_3 = 1.0$, $L_3 = -1.0$,
$G_4 = 1.0$, $T_4 = 0.01$, $G_5 = 1.0$, $T_5 = 0.01$, $U_{11} = 1.0$, $L_{11} = -1.0$

Fig. 4 System model and system conditions used for dynamic characteristic analysis simulation



【"pu" is a 550MVA base value.】

(a) Active Power of Generator G of the M-G set



(b) Internal Phase Angle of Synchronous Generator SG

Fig. 5 Dynamic characteristic simulation results

4. M-G SET DEMONSTRATION EQUIPMENT

For the development of practical (100 MVA or more) M-G sets, the authors are currently working on the installation of (100 kVA) M-G set demonstration equipment into the power system simulator, which simulates the actual generator, transformer, and transmission line characteristics [6]. Table 2 shows the outline of the M-G set demonstration equipment.

Table 2 Outline of M-G set demonstration equipment to be installed

Device Name	**Specification Summary**
Synchronous Generator (G)	Rated Capacity = 100 kVA, Power Factor = 0.9, Rated Terminal Voltage = 220 V, Rated Frequency = 50Hz and 60Hz, 4-poles, Xd=1.7 pu, Xd'=0.26 pu, Xd"=0.2 pu, Xq=1.55 pu, Xq"=0.25 pu, Tdo'=2.0 s
Synchronous Motor(M)	same as above
Induction motor (IM)	For starting the M-G set
Pulse generator (PG)	Pulse Generator for rotation speed detection
Inverter for driving	Drive inverter for the above PG
Per-unit Inertia Constant	M = 2H = 9.0 s（for entire M-G set)
Excitation Devices	2 sets of AVR and $\Delta P+\Delta \omega$ input type PSS(Power System Stabilizer)
Step-up Transformer	Rated Capacity = 100 kVA, 220 V / 3300 V, Impedance = 14%、The Number of Taps : 5
Renewable Energy Simulator	0 ～ 100 kW (Inverter)
Storage Battery Simulator	-100 kW ～ 100 kW（Inverter)
Operation monitoring operation panel	For start/stop, synchronization, adjust output

The features of the demonstration equipment are described below:

- The rated capacity of M and G of the M-G set is 100 kVA, but they are designed to be as close as possible to the electrical characteristics (electrical constants) of the practical (100MVA or more) machine.

- The bypass circuit allows the renewable energy simulator and the storage battery simulator to be directly connected to the power system simulator.

- The G of the M-G set can be operated as a synchronous condenser.

- It is equipped with a torque measuring device that measures the shaft torque applied to the shaft between M and G

- The rating of both the power conditioning subsystem (PCS) of the renewable energy simulator and the storage battery simulator is 100 kW, but the rating can be reduced by the software limiter.

Through tests using this demonstration facility, we plan to verify the stability of the behavior of the entire M-G set, especially in the event of a three-phase ground fault closer to the high-voltage side of the step-up transformer of synchronous generator G of the M-G set, and during the simulated generator shedding action.

5. CONCLUSION

By connecting renewable energy and storage batteries to the power system via the M-G set, we have proposed an “M-G set with renewable energy and storage battery” as one of the measures to maintain system stability, even in the event of a system fault, without lowering the system synchronization ratio when a large amount of renewable energy is introduced. In the future, we will create an M-G set prototype with a small capacity of 100 kVA, and aim for practical use by resolving issues and constraints in the hardware, developing their countermeasures, developing and verifying system stabilization control methods, and considering the required specifications of practical implementations and cost reduction methods.

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