The development of the flywheel energy storage system applying the high temperature superconducting magnetic bearing — The examination of a demonstration machine by having it charged/discharged with solar photovoltaic power —

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Abstract

The flywheel energy storage systems (FESS) that can stabilize the fluctuation of the output of the solar photovoltaic power generation system have been developed as a joint project of five enterprises. In this project, a FESS demonstration machine was developed and the examination of the machine was conducted in such a way as to alternate charge and discharge with solar photovoltaic power using this machine. This project was implemented for 4 years. The main devices were assembled so as to be completed as the FESS demonstration machine in an assembly plant. After the completion of the FESS demonstration machine, the machine was reinstalled in the examination plant that is located in Kofu City, Yamanashi Prefecture. The charging/discharging examination with solar photovoltaic power was conducted after the reinstallation. And it was confirmed that the FESS demonstration machine has the ability necessary for stabilizing the solar photovoltaic power generation.The occurrence of the blackout was assumed as the abnormality that would occur when the FESS demonstration machine is really operated, and the simulated blackout examination was conducted and it was confirmed that the FESS demonstration machine was able to stop safely even in cases where a blackout in operation occurred. With the completion of all the examinations in February 2016, the development project of the FESS demonstration machine was completed. The FESS demonstration machine can stabilize the photovoltaic power generation, and it can stop safely when a blackout in operation occurs. The above mentioned performances of the FESS demonstration machine were confirmed by the results of the performance evaluation examinations.

Keywords : Flywheel energy storage systems, High temperature superconducting magnetic bearing, Stabilization, Solar photovoltaic power, Charge/discharge, Blackout protection, Development project, Demonstration machine

1. Introduction

The flywheel energy storage systems (FESS) that can stabilize the fluctuation of the output of the solar photovoltaic power generation system have been developed as a joint project of five enterprises subsidized by the New Energy and Industrial Technology Development Organization (NEDO).

The FESS converts electricity into the kinetic energy of rotation and stores it. Therefore, the storage capacity and the output can be designed independently, and there is a lot of flexibility in the design. In comparison with battery, the energy storage system of the FESS does not have the electrochemic problems such as the chemical deterioration and the harmful influence of toxic substances.

In contrast with these good points, there is a problem in that the storage capacity per volume is smaller than rechargeable batteries. Because the high temperature superconducting magnetic bearing (SMB) can support the rotor in a non-contact state, it is possible to increase the mass of the rotor and improve the rotating speed of FESS. To increase the storage capacity of the FESS, the development of a FESS by means of the SMB has been promoted. [(1) ~(3)]

Based on the result of past studies, the FESS development project in which five companies participated was conducted. In this project, a FESS demonstration machine was developed. [(4)] And the examination of the machine was conducted in such a way as to alternate charge and discharge with solar photovoltaic power using this machine.

In this report, the design and the performance of the FESS demonstration machine that was developed by this project and the result of the proof examination of its performance is reported.

2. Development framework of the FESS demonstration machine

2.1 Development framework

The purpose of this project was the development of the FESS demonstration machine for the stabilization of the photovoltaic power and the evaluation of its performance. Regarding the framework of the implementation of this project, Railway Technical Research Institute took charge of the total management of the project, and project members took charge of the production of each device and the construction of the facilities under the management of Railway Technical Research Institute.

2.2 Development process in the project

This project was implemented for 4 years from 2012. In 2012, the specifications of the FESS demonstration machine were devised based on the predetermined life, cost, capacity, and output. In 2013, the prototypes of the important parts of the main devices were produced and performance examinations of these prototypes were conducted. In 2014, main devices were produced, and these devices were assembled so as to be completed as the FESS demonstration machine in an assembly plant.

In 2015 as the last year of this project, the evaluation examinations of the various kinds of performance of the FESS demonstration machine were conducted.

3. Summary of the FESS demonstration machine

3.1 Specifications of the FESS demonstration machine

At First, the electrical specifications such as the capacity and the output that are necessary for the stabilization of the 1MW class photovoltaic power were designed. Based on the electrical specifications, the mechanical specifications necessary for the devices such as the speed of rotation and the mass were designed. Finally, the specifications of the FESS demonstration machine were determined after confirming whether the devices could be produced in such a manner as to meet the specifications.

As the result of these design examinations, the FESS demonstration machine was designed as follows; the mass of the rotor is about 4,000 kg, the speed of rotation is 100 Hz, the storage capacity of electricity is a grade of 100kWh. Table 1 shows the specifications of the FESS demonstration machine.

The examination plant in which the examination of the FESS demonstration machine regarding charge/discharge with solar photovoltaic power is conducted was designed by the same process. Figure 1 shows the flow of the power in the examination plant of the FESS demonstration machine.

Table 1 The specifications of the FESS demonstration machine

the storage capacity	100kWh class
the rated power output	300 kW
the mass of the rotor	about 4,000kg
the speed of rotation	50～100 Hz

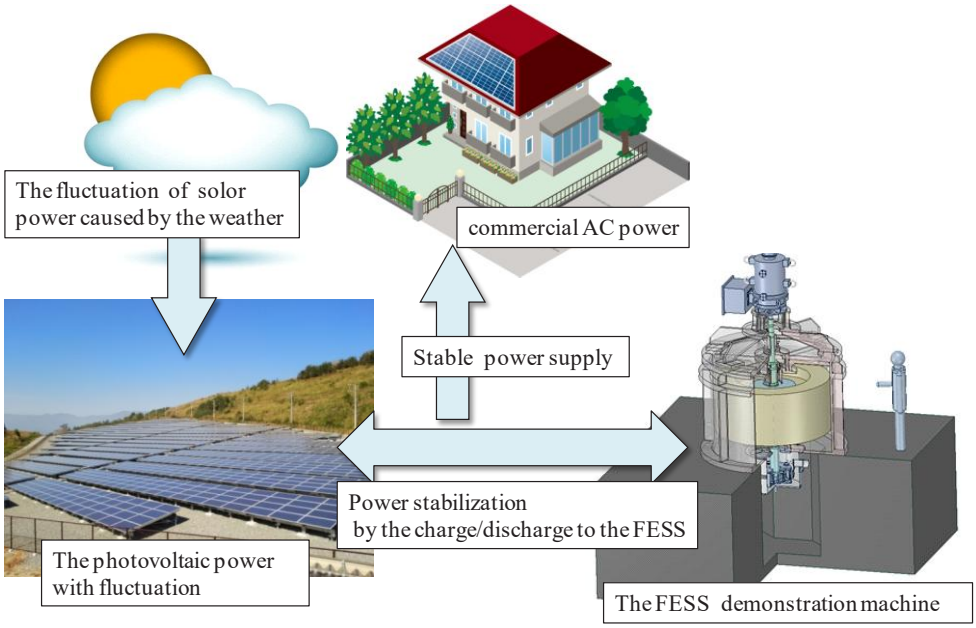


Fig.1 The flow of power in the examination plant of the FESS demonstration machine

3.2 The whole constitution of the FESS demonstration machine

After the specifications of the FESS demonstration machine were decided, each device of the machine was designed and the whole constitution of the machine was decided.

As shown in Fig.2, the machine is composed of the following; the rotating shaft, the generator motor in the atmosphere, the sealing that connect the rotor in the vacuum container and the generator motor in the atmosphere, the rotor with a large mass that was made of carbon-fiber-reinforced plastic, the superconducting magnetic bearing that is composed of a superconducting coil made of REBCO conductors and a superconducting rotor made from GdBCO bulks, and the vacuum vessel that stores these parts.

At the design stage, the rotating shaft of the FESS demonstration machine was divided into three parts to make it easy to assemble; the shaft in the vacuum seal section, the shaft at the center of the rotor, the shaft that was set on the superconducting magnetic bearing.

Each axis was designed and produced individually. And in the course of assemblage, these shafts were connected so as to be completed as a rotating shaft.

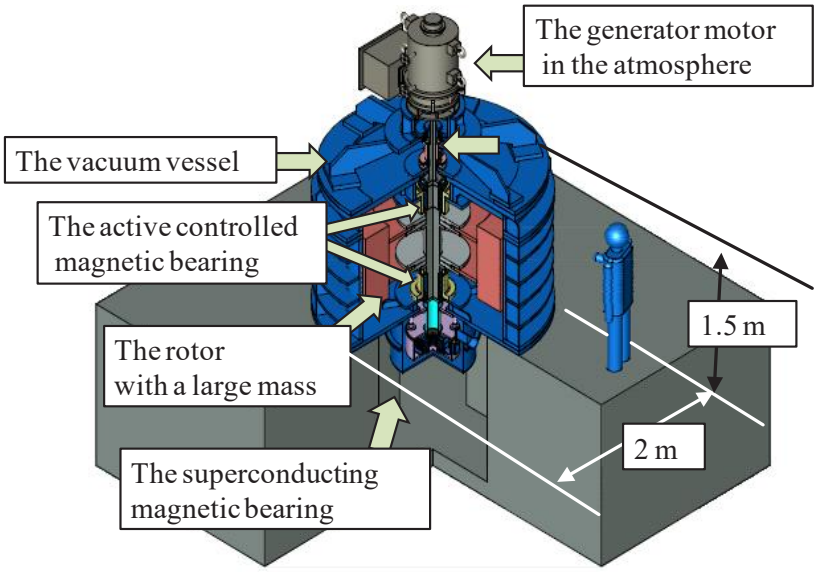


Fig.2 Cross section of the FESS demonstration

By installing the generator motor in the atmosphere, the possibility of the trouble such as the insulation breakdown and the excessive heat generation can be reduced. By installing the rotor in low pressure gas helium, the air resistance that was caused by the high speed rotation can be decreased. By these reasons, the atmospheric pressure constitution of the FESS demonstration machine was decided as shown in Fig.3. As measures for the release of the rotary energy that will occur when abnormality occurs, the pressure resistance strength of the vacuum vessel was so designed as to be capable of withstanding the release of the rotary energy.

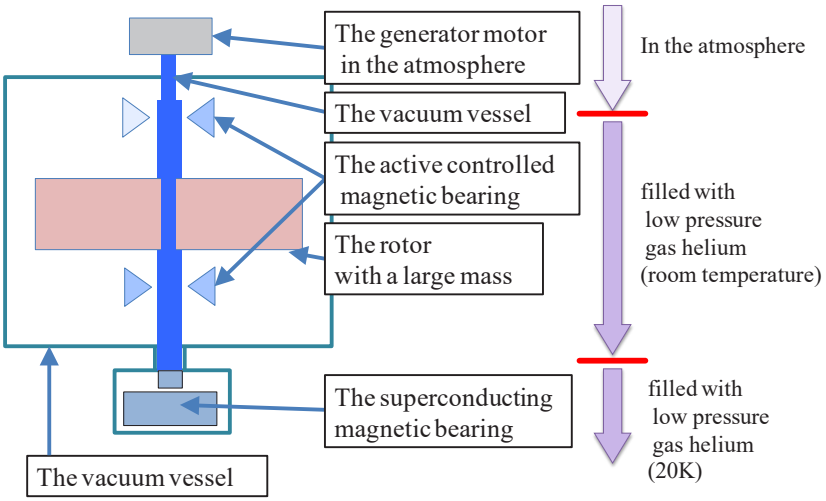


Fig.3 Atmospheric pressure constitution of the FESS demonstration machine

3.3 Summary of the examination plant

A solar power plant with a grade of 1MW was completed at Mt. Komekurayama that is located in Kofu City, Yamanashi Prefecture, and it is now operating. The location of the examination plant is shown in Fig. 5. The examination plant of the FESS demonstration machine was constructed in the solar power plant.

The photovoltaic power generation panel of the 1MW class which was built for the examinations, and it was interlinked systemwise with 6.6kV commercial AC power.

The performance evaluation examination of the FESS demonstration machine was conducted at the examination plant. The location of the examination plant of the FESS demonstration machine was shown in Fig.5. In addition, the FESS demonstration machine was installed in underground storage space and covered with an iron protective cap as measures for the release of the rotary energy. By this installation method and the high pressure resistance strength of the vacuum vessel, double measures for the release of the rotary energy were taken.

(a) Location of the examination plant (b) The appearance of Komekurayama solar photovoltaic power plant

Fig. 4 Location of the examination plant of the FESS demonstration machine

3.4 Main circuit constitution of the examination plant

The main circuit constitution of the examination plant and the FESS demonstration machine was shown in Fig.5. In the examination plant, solar photovoltaic power is converted into direct current with a converter. And the direct current is converted into three-phase alternating current with the inverter. The generator motor is driven by the three-phase alternating current and the FESS demonstration machine stores kinetic energy of rotation. In the discharge process, the FESS demonstration machine supplies the electric power to the electric power systems through the reverse process.

The control unit of the FESS demonstration machine monitored the power generation of the solar photovoltaic power. The control unit calculates necessary charge/discharge energy for stabilizing the power generation and outputs an charge/discharge orders to the inverter.

When a blackout or equipment failure occurs, it could be assumed that the FESS demonstration machine is damage by the counter electromotive force or that the rotation cannot be stopped could occur. To prevent these kinds of failure, a protection resistor to reduce kinetic energy of rotation by converting it into thermal energy is installed between the converter and the inverter.

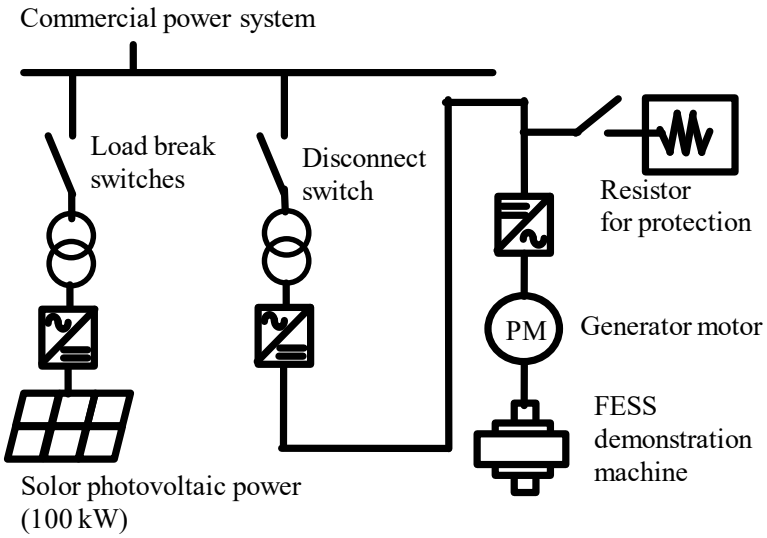


Fig.5 The main circuit constitution of the examination plant of the FESS demonstration machine

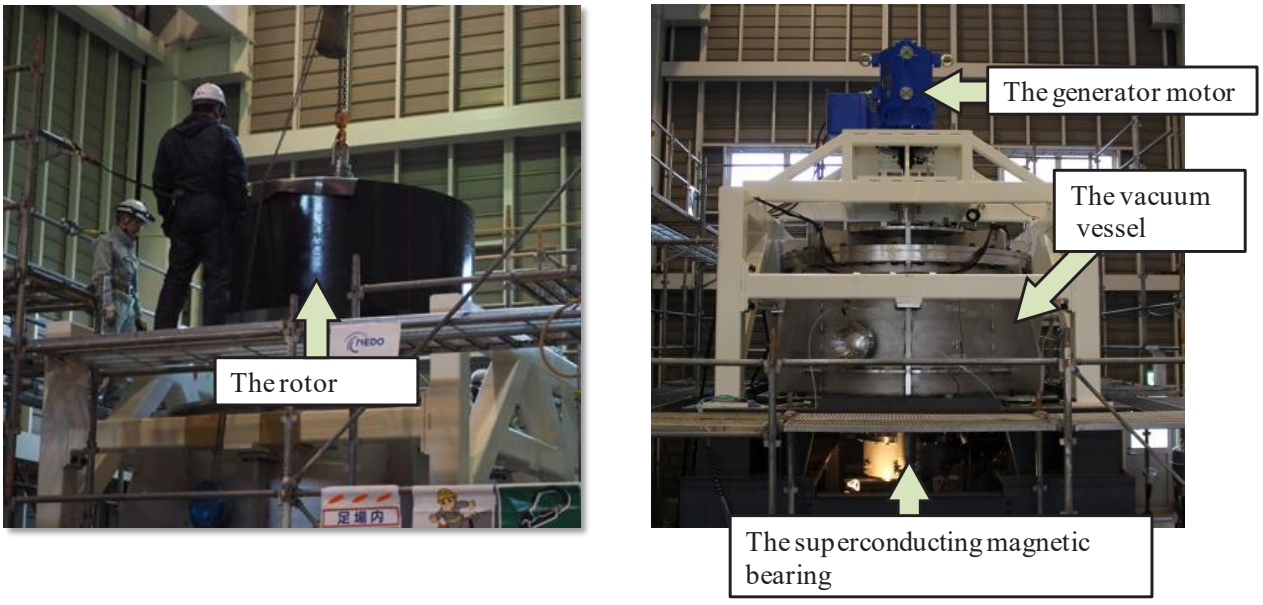
4. Production process of the FESS demonstration machine

4.1 Production of the FESS demonstration machine

After specifications were decided in 2013, the prototypes of the important parts of the main devices were produced and the performance evaluation examinations of these prototypes were conducted. Based on the specifications, the manufacturing and the adjusting method of each device of the FESS demonstration machine were decided.

In 2014, the main devices were produced, and these devices were assembled so as to be completed as the FESS demonstration machine in an assembly plant. The assembling situation of the FESS demonstration machine was shown in Fig.6.

After the completion, the adjustment of each device and the examination of the rotation at low speeds were conducted. The speed of rotation was increased up to 4.2 Hz, and it was confirmed that the machine was operated in a stable state.

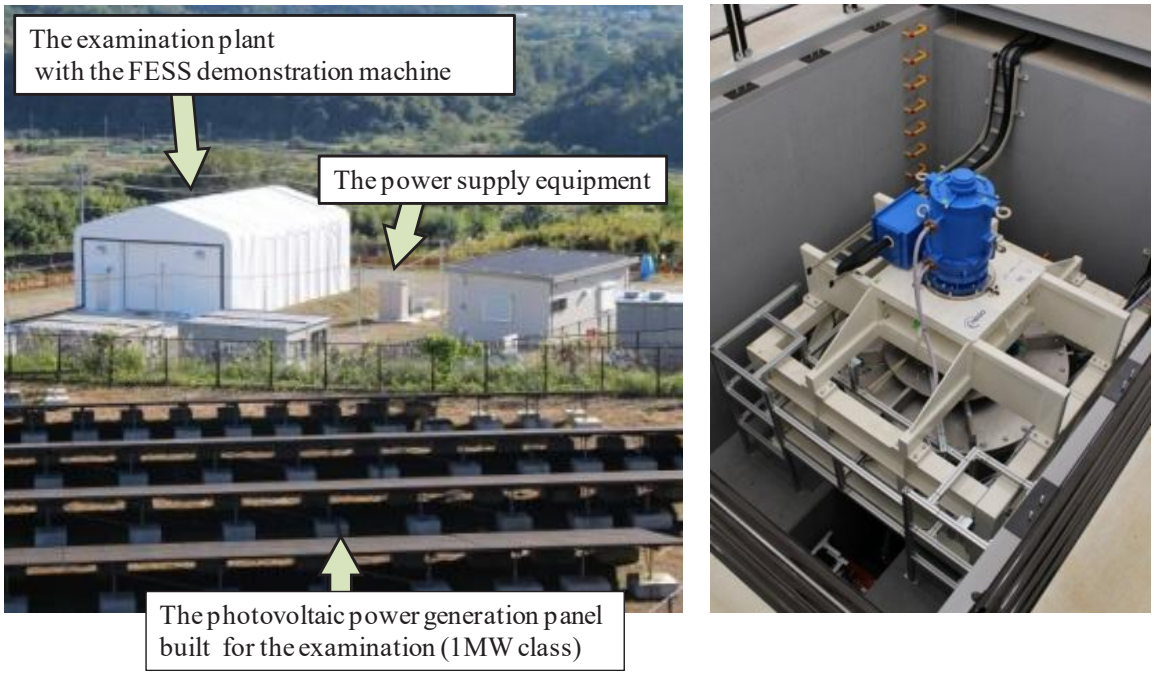


(a) Assembling state (b) Assembled state

Fig.6 The situation in production of the FESS demonstration machine

4.2 Reinstalling of the FESS proof machine in the examination plant

After the completion of the FESS demonstration machine in 2014, the machine was reinstalled in the power plant in July 2015. The machine was connected to 6.6kV alternating current electric power systems and the examination plant of the FESS demonstration machine was completed in September. The appearance of the examination plant was shown in Fig.7.



(a) The examination plant (b) The FESS demonstration machine installed in underground storage space

Fig.7 The appearance of the examination plant

5. Examination of the demonstration machine regarding charge/discharge with solar photovoltaic power

5.1 Charging/discharging examination with solar photovoltaic power

After the reinstallation and the readjustment of the FESS demonstration machine, the charging/discharging examination with solar photovoltaic power was conducted in December, 2015. The control of the FESS demonstration machine regarding charge/discharge with solar photovoltaic power was started after the speed of rotation was increased up to 25 Hz, and the charging/discharging examination was conducted.

The result of the examination was shown in Fig.7. The speed of rotation was fluctuated by the inverter in response to the order of the control unit, and the storage energy of the FESS demonstration machine was also fluctuated in the opposite to the fluctuation of the solar photovoltaic power generation. By the test result, it was confirmed that the FESS demonstration machine has the ability necessary for stabilizing the solar photovoltaic power generation.

The power conversion efficiency of the charging/discharging was confirmed as follows; the efficiency of the charge is 95%, the efficiency of the discharge is 91%, the efficiency of one cycle of the charge/discharge is 87%.

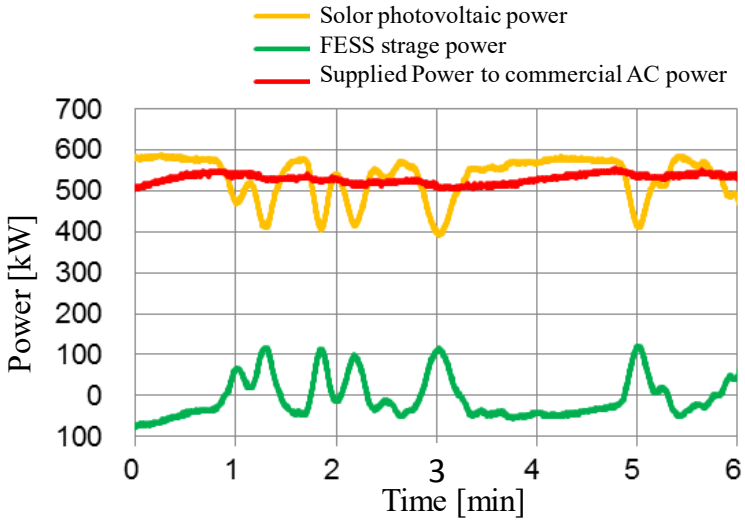


Fig.7 The charging/discharging examination with solar photovoltaic power

5.2 Simulated blackout examination

The occurrence of the blackout was assumed as the abnormality that would occur when the FESS demonstration machine is really operated, and the simulated blackout examination was conducted in January, 2016.

In order to make the simulated blackout occur, after the speed of rotation was increased up to 17.5 Hz, the main circuit was separated from commercial AC power forcibly by opening of the main circuit breaker that was shown in Fig.6. It was confirmed that the machine had enough capability to stop safely when a blackout in operation occurs. Independent power supply was prepared for measurement devices.

The result of the examination was shown in Fig.8. At the same time when the simulated blackout occurred, the inverter connected to the protection resistor, and the reduction of the speed of rotation by means of the conversion of the rotation energy into thermal energy was started. By auxiliary power supplies, the SMB maintained a levitating state for 40 minutes that is the set time for reducing of the speed of rotation, and AMB also maintained the control of the rotation. 40 minutes later, the speed of rotation was reduced to 5 Hz which was the speed at which a safe landing was possible, and the SMB was demagnetized automatically and the rotor made a landing at the safe speed.

As a result of this examination, it was confirmed that the FESS demonstration machine was able to stop safely even in cases where a blackout in operation occurred.

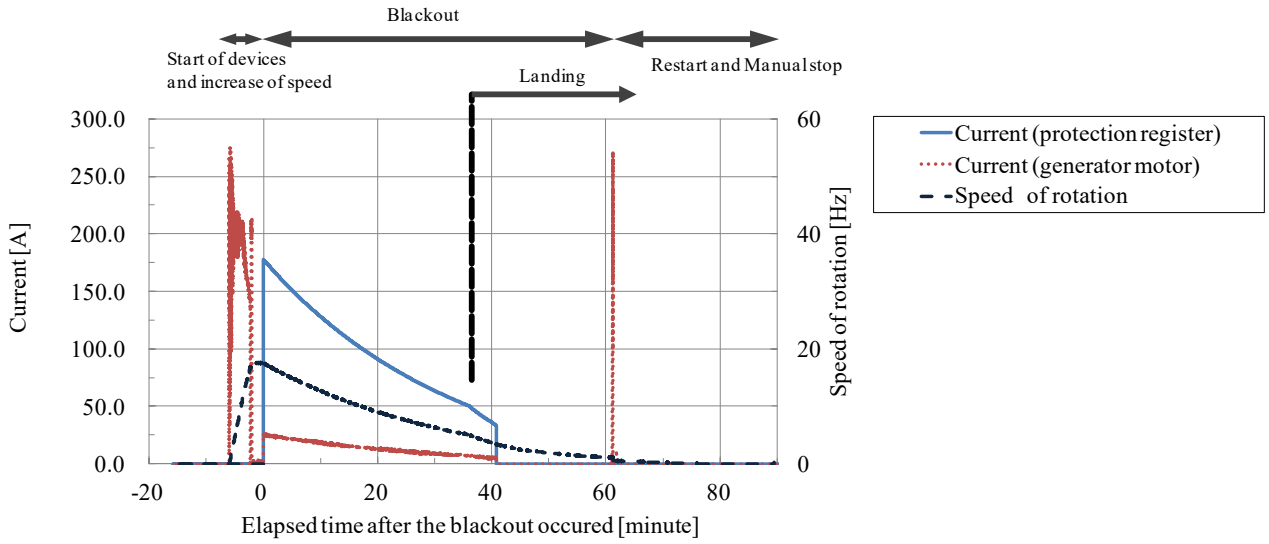


Fig.8 The result of the simulated blackout examination

6. Conclusions

With the completion of all the examinations in February 2016, the development project of the FESS demonstration machine was completed.

Through the development period of 4 years, the FESS demonstration machine was developed. The FESS demonstration machine can stabilize the photovoltaic power generation, and it can stop safely when a blackout in operation occurs. The above mentioned performances of the FESS demonstration machine were confirmed by the results of the performance evaluation examinations.

After this, we will utilize much technical knowledge acquired through this development, and will push forward studies with a focus on the higher performance of the FESS and the improvement of the constitution of the FESS.

Acknowledgement

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