Power Stabilization System with Lead-Acid Batteries and Lithium-Ion Batteries for Galapagos Islands

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ABSTRACT

Fuji Electric has developed a power stabilization system using lead-acid batteries and lithium-ion batteries and delivered it to the Galapagos Islands, a World Natural Heritage site, in March 2016. By combining the outputs from wind turbine generators and two types of batteries with different characteristics, this power stabilization system smooths periodic fluctuations over several tens of seconds to several hours and transmits stable combined output to the electric power system. This achieved a great increase of the maximum output and facility utilization ratio of the existing wind turbine generators and markedly contributed to taking the first step toward zero consumption of fossil fuels.

1. Introduction

The electric power of the Galapagos Islands, a World Natural Heritage site located in the Republic of Ecuador, is mostly supplied by small-scale thermal power plants such as those that use diesel, and there are fears that the exhaust gas will pollute the environment. In order to respond to the growing population and increase in tourists due to the expansion of tourist spots in recent years, the preparation and adoption of an environmental friendly power supply system has become an urgent issue. The government of Ecuador adopted a measure in April 2007 aiming to achieve zero consumption of fossil fuels on Galapagos Islands by 2020, and since then, it has been working to achieve this goal.

As part of “The Project for Introduction of Clean Energy by Solar Electricity Generation System” by the Japanese government to provide grant assistance for environmental programs, Fuji Electric received the go ahead on a full turnkey project to provide equipment consisting of a photovoltaic power generation system and power supply stabilization system. Both systems were delivered in March 2016.

This paper describes the power stabilization system, which is the core component of this project.

2. Project Overview

Figure 1 shows a panoramic view of the project. Figure 2 shows the image of the overall system for the project, and Table 1 shows the specifications of the system and main equipment.

Fig.1 Panoramic view of plant

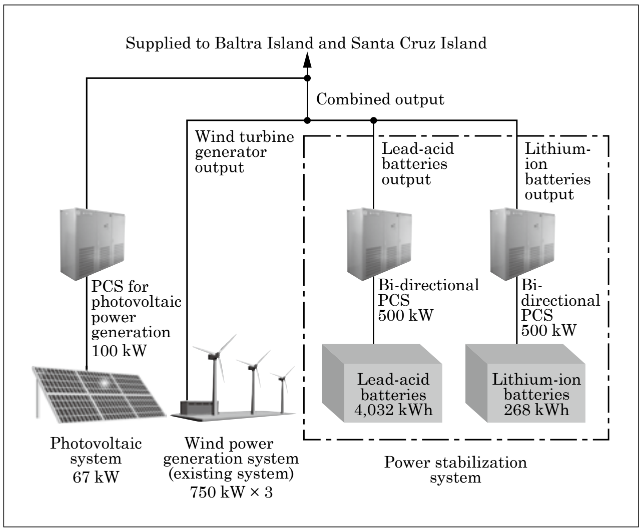

Fig.2 Overall image of system used in this project

Among the various kinds of renewable energies, the power generation output of photovoltaic power generation and wind power generation systems vary

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Table 1 Specifications for system and major equipment used in this project

System and major equipment		Specifications
Photovoltaic power generation system		Output: 67 kW
Power stabilization system	Bi-directional PCS	Model: PVI650-3/500
		Conversion system: 3-level sine-wave PWM
		DC input Operating voltage range: 345 to 600 V Maximum input current: 1,507 A
		AC output Rated capacity: 500 kVA Rated voltage: 210 V Maximum output current: 1,527 A
		Maximum conversion efficiency: 97.3%
	Lead-acid batteries	Capacity: 4,032 kWh
	Lithium-ion batteries	Capacity: 268 kWh
Wind power generation system (existing system)		Output: 750 kW × 3

Table 2 Main functionality of power stabilization system

Function	Lead-acid batteries	Lithium-ion batteries
Wind turbine generator output fluctuation suppression function	Required (Restricts output during peak shifting)	Required
Peak shifting function	Required (Stops use during backup)	—
Output fluctuation suppression backup function	Required	—

greatly depending on weather conditions. Therefore, the integration of these types of power sources into small-scale power systems will impact the power quality (voltage and frequency). The government of Ecuador installed a wind power plant consisting of three 750-kW wind turbine generators ahead of the project. However, power quality issue due to the output fluctuations prevented the plant from operating at its rated output, causing its low utilization despite sufficient amount of wind.

By employing the power stabilization system, the power plant has been able to suppress output fluctuations for the wind turbine generators to increase the equipment utilization and succeeded in raising the amount of renewable energy based power supply. The system controls the high-speed charging and discharging of storage batteries by means of a bi-directional power conditioning sub-system (PCS). It combining lead-acid batteries with lithium-ion batteries to supply high-quality power by taking advantage of the characteristics of those storage batteries.

3. Power Stabilization System

3.1 Overview

The power stabilization system combines the outputs of the wind turbine generators, lead-acid batteries and lithium-ion batteries to smooth periodic fluctuations over several tens of seconds to several hours and transmits a stable combined output to the power system. The lead-acid batteries are suitable for peak shifting control that needs a large battery capacity because of their low cost-to-capacity ratio. On the other hand, lithium-ion batteries are suitable for controlling output fluctuations over short periods of time because they have a high energy density and can highly frequently charge and discharge with high-speed.

Table 2 shows the main functionality of the system is described, and Fig. 3 shows the configuration.

The purpose of the output fluctuation suppression function for wind turbine generators is to compensate periodic fluctuations that occur in the output of the wind turbine generators over several tens of seconds to several hours by using the output of the batteries. With this function, the system calculates output fluctuation suppression command values and allocating them to the lead-acid batteries and lithium-ion batteries.

The peak shifting function aims to smooth loads by charging the batteries during times of low power demand such as night when there is an excess of power and discharging the batteries during times of peak power demand. Target values for peak shifting output and time periods for starting and stopping the function are set in the monitoring control PC, which calculates the peak shifting command values for smoothing the power.

The backup function of the output fluctuation suppression function stops the peak shifting with the lead-acid batteries and performs backup of the output fluctuation suppression when the lithium-ion batteries are stopped due to maintenance or accidents. It aims to increase the output of the lead-acid batteries that can be used for output fluctuation suppression in order to ensure continuous wind power generation.

Each battery supplies high-quality power by providing an output according to each command value.

3.2 Output fluctuation suppression function for wind turbine generators

(1) Design

In order to minimize the impact of wind power generation on an interconnected system, measures to suppress frequency fluctuation are sometimes taken, such as keeping the difference between the maximum and minimum output values within a specified value at any time period.

The output fluctuation suppression function for wind turbine generators of this system adopts variable time constant control that continuously controls the time constant of a fluctuation component removal filter based on the output fluctuations of the wind turbine generators. the filter is equipped with the output

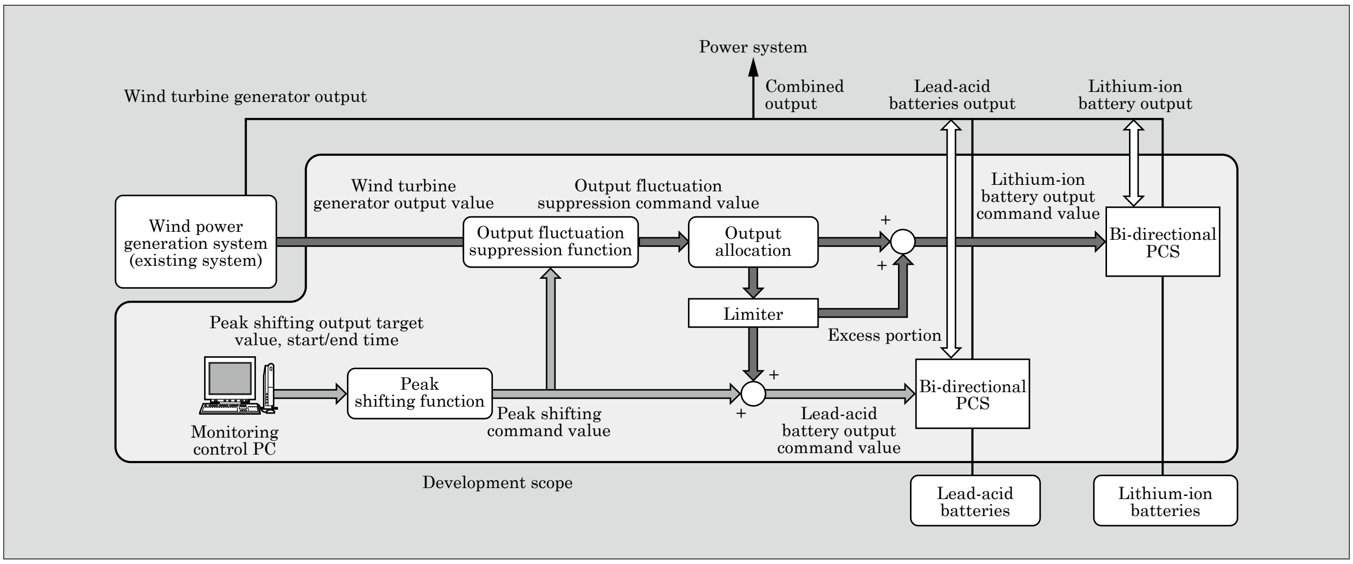

Fig.3 Configuration of power stabilization system

fluctuation suppression function shown in Fig. 3. This control increases the time constant when the output fluctuation is large, and decreases the time constant when the output fluctuation is small, thus ensuring the fluctuation of the combined output to be within a specified rate of change*[1]. Before starting the design, we utilized the measured wind speed data of the Nishime Wind Power Station possessed by Fuji Green Power, a group company of Fuji Electric, to run the simulation of an output fluctuation suppression for the system. From the results, we learned that we could maintain a change rate of 45 kW/min or less for 95% of an entire period. This value is equivalent to 2% of the rated output of the wind turbine generators, meaning that the rate of change is small enough for output fluctuation suppression. Since the site of this project has even less wind speed fluctuation than the Nishime Wind Power Station, we can expect an even better effect.

The output allocation of the output fluctuation suppression command values ensures that the output fluctuation rate is maintained within a specified value by allocating to the lead-acid batteries and lithium-ion batteries so as to maintain the target charging rates for each battery.

Lithium-ion batteries have a smaller capacity than lead-acid batteries; thus, intensive allocation to lithium-ion batteries may cause the shortages of empty-charge capacity needed for charging or charge capacity needed for discharging. If the output of the lithium-ion batteries is restricted because of insufficient empty-charge capacity or charge capacity, it will become difficult to maintain output fluctuation suppression. The lead-acid batteries have a large ratio of charging capacity used for peak shifting to charging capacity used in output fluctuation suppression. For peak shifting operation, charging capacity is, therefore, adjusted to a low target value when in charging, and a high target value when in discharging in advance. For lithium-ion batteries, when the wind turbine generator output is low, the target charging capacity is set low in preparation for a surge in output, but when the wind turbine generator output is high, the target charging capacity is set high in preparation for a sudden drop in output.

After the output fluctuation suppression command value is allocated to the lead-acid batteries, two limiters are established not to inhibit peak shifting. The first is restricting the allocation to the lead-acid batteries during peak shifting from ±500 kW*[2] to ±200 kW in order to ensure that the peak shifting command value, which is another function of lead-acid batteries, is not canceled out. The second is restricting the allocation to the lead-acid batteries when the current charging capacity deviate more than a certain amount from the target charging capacity, thus ensuring the charging capacity needed for peak shifting. Furthermore, the lithium-ion batteries output the portion that exceeds the restriction.

With regard to the wind turbine generator output fluctuation suppression function, we confirmed the operation through a simulation and field test.

(2) Simulation

The simulation generated the simulated wind turbine generator output in a stepwise manner and confirmed the operation of the wind turbine generator output fluctuation suppression function. Figure 4(a) shows the results of the simulation.

At approximately 10:06, we stepped down the simulated wind turbine generator output by 0.5 MW from

*1: Specified rate of change: refers to dividing the output fluctuation (maximum value – minimum value) in the time width specified by the customer by the time width.

*2: ±500 kW: + refers to discharging and – refers to charging.

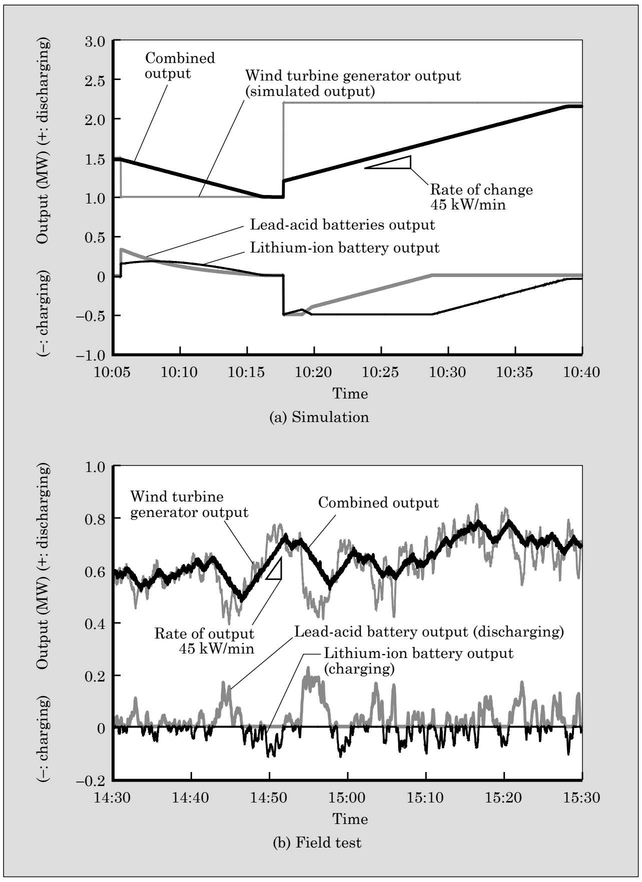

Fig.4 Confirmation of operation of wind turbine generator output fluctuation suppression function

1.5 MW to 1.0 MW. The total output capacity of the lead-acid batteries and lithium-ion batteries was 1.0 MW, which is larger than fluctuation of 0.5 MW, the step fluctuation was canceled out by the variable time constant control so that the rate of change for the combined output would be 45 kW/min.

At approximately 10:18, we stepped up the simulated wind turbine generator output by 1.2 MW from 1 MW to 2.2 MW. The fluctuation was larger than the total output capacity of the lead-acid batteries and lithium-ion batteries. Therefore, by maximizing the output of both batteries, we suppressed fluctuation to 0.2 MW, and thus minimized the impact on the system.

Furthermore, during the time period between approximately 10:06 and 10:15, since the charging capacity of both batteries required in approaching the target charging capacity was about the same, both batteries discharged approximately the same amount of power. During the time period between approximately 10:18 and 10:40, when the wind turbine generator output rose, charging for the lithium-ion batteries, which set the target charging capacity high, was given priority in order to prepare for the subsequent sudden drop in output.

(3) Field tests

Figure 4(b) shows the results of the field tests. We confirmed that we were able to suppress the fluctuation of the wind turbine generator output using the output of the lead-acid batteries and lithium-ion batteries similar to the simulation. Combined output maintained a constant rate of change. At this time, the lead-acid batteries were almost fully charged through a equalizing charge test, which was implemented before the field test. In order to ensure room for charging, the discharge of the lead-acid batteries was prioritized, and thus discharging was implemented in lead-acid batteries and charging in the lithium-ion batteries.

3.3 Peak shifting function

(1) Design

The peak shifting function smooths loads by charging the batteries during times such as night when power demand is low and lower than generation capacity, while discharging the batteries during peak power demand. This operation has made it possible to suppress the sharp fluctuations in output of the conventional diesel generators in the Galapagos Islands, reduce the number of start-up and stop operation, and eliminate low output operation that adversely impacted power generation efficiency.

Furthermore, the operation of discharging the lead-acid batteries according to the evening demand peak reduced the number of diesel power generators in operation, thus making it possible to suppress fuel consumption and the accompanying CO_2 emissions. Specifically, since the fluctuation in demand differed on weekdays and holidays, peak shifting time periods can be set accordingly.

We confirmed the peak shifting function through a factory test and field test.

(2) Factory test

Figure 5(a) shows the results of the factory test. Discharging begins at the peak shifting discharging start time, which was set at 13:40, and discharging ends at the peak shifting end time, which was set at 14:10. In order to reduce the impact on the system, output is implemented at a change rate of 45 kW/min at the peak shifting start and end times. By doing this, we confirmed that peak shifting was implemented according to a target output and start and end times, which were set with the monitoring control PC.

(3) Field test

Figure 5(b) shows the results of the field tests. We confirmed that the lead-acid batteries operated in peak shifting and output fluctuation suppression at the same time. Between approximately 18:00 and 22:00, the lead-acid batteries discharged at 500 kW to shift the demand peak. Between 2:00 and 8:00, they charged at 300 kW for peak shifting due to the low power demand. Since the lead-acid batteries operate in peak shifting and output fluctuation suppression at the same time, their output fluctuates, instead of holding constant at a peak shifting output target value.

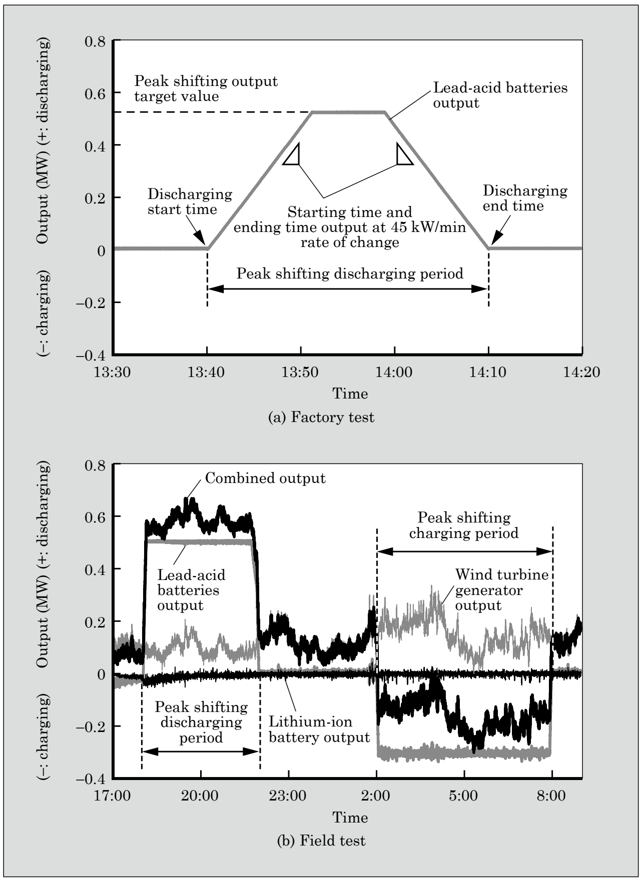

Fig.5 Confirmation of operation of the peak shifting function

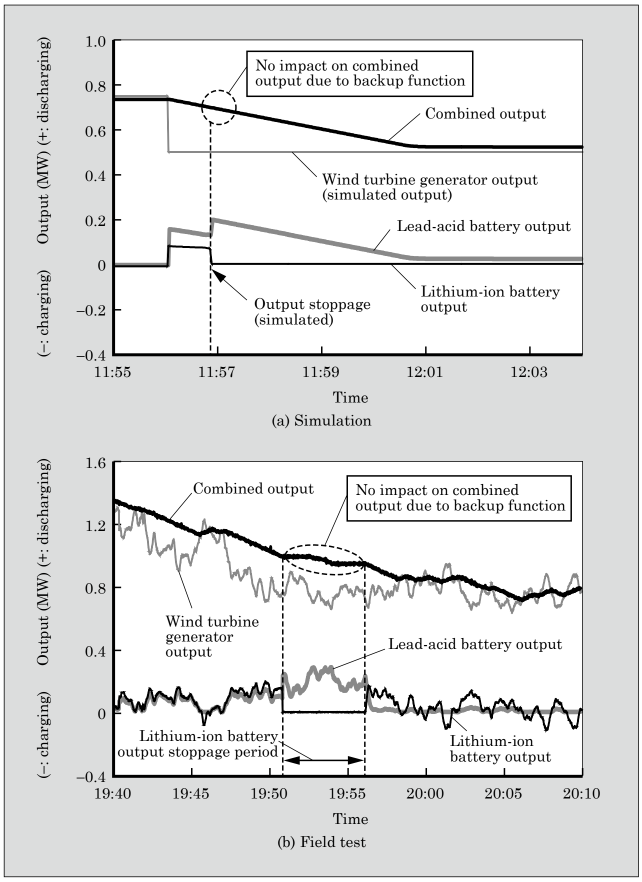

Fig.6 Confirmation of operation of the output fluctuation suppression backup function

3.4 Backup function for output fluctuation suppression

(1) Design

When the lithium-ion batteries are stopped due to maintenance or accidents, the lead-acid batteries stop peak shifting and back up output fluctuation suppression. By doing this, the output of the lead-acid batteries that can be used for output fluctuation suppression is increased, and the wind power generation can continue to operate.

During the lithium-ion batteries are stopped, the lead-acid batteries alone hardly perform both output fluctuation suppression and peak shifting at the same time. When the output fluctuation suppression function cannot be kept, the fluctuation of the wind turbine generator output may adversely impacts the power quality of the interconnected power system. In this case, the output of the wind turbine generator has to be suppressed, or in the worst case, be stopped. However, since this may lead to a loss in power generating opportunities for the wind turbine generators, the lead-acid batteries only implement output fluctuation suppression without implementing peak shifting when the lithium-ion batteries are stopped. This backup function enables continuous operation of the wind turbine generators.

We confirmed the operation of the backup function for suppressing output fluctuation through simulation and field tests.

(2) Simulation

Figure 6(a) shows the results of the simulations. When the lithium-ion batteries are stopped during the operation of output fluctuation suppression, their output drops to zero. We confirmed that, in this case, the lead-acid batteries take over the operation and keep it without any impact on the combined output.

(3) Field test

Figure 6(b) shows the results of the field tests. As one of the test conditions, we stopped the operation of the lithium-ion batteries from approximately 19:51 to 19:56. When the output of the lithium-ion batteries decreased, the output of the lead-acid batteries simultaneously rose to back up the output of the lithium-ion batteries. We confirmed that the operation of output fluctuation suppression continues without any impact on combined output. Furthermore, when the lithium-ion batteries restarted, the operation of output fluctuation suppression by the lithium-ion batteries simultaneously started. We confirmed that the operation continues without any impact on combined output.

4. Postscript

We described the power stabilization system that uses lead-acid batteries and lithium-ion batteries for the Galapagos Islands. The use of this system has achieved a significant increase in the maximum output and facility utilization ratio of the existing wind turbine generators and greatly contributed to taking the first step toward zero consumption of fossil fuels.

Based on our technology cultivated through building this system, we intend to develop a power stabilization system that can suppress both short-cycle and long-cycle output fluctuations to contribute to the expanded use of renewable energies.

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