Single cell for power storage

Module cell

Development of Lithium Ion Battery and Grid Stabilization Technology for Renewable Energy Using Secondary Battery System

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Renewable energy fluctuates significantly. To supply electricity from renewable energy to a small-scale grid, it thus becomes helpful to stabilize the grid using a large-capacity secondary battery. Mitsubishi Heavy Industries, Ltd. (MHI) and Kyushu Electric Power Co., Inc. are developing a large-scale lithium ion battery with a large capacity and long life. Our group measured the electric power of an actual wind farm and predicted the system specifications required to stabilize this large-capacity lithium ion battery. Though there remain issues, such as cost, to be solved, our measurements and analyses have shown that we configure a system of realistic size in comparison with a comparable system using a lead battery.

1. Introduction

In order to solve problems such as global warming and the rising price of fossil fuel, renewable energies (also called new energies) such as wind power generation, photovoltaic power generation, biomass fuel power generation, and so on have been actively introduced and expanded. In Europe, this trend has been partly driven by an EC-issued directive relating to the promotion of renewable energy power generation (Directive No. 2001/77/EC). All EU member countries have established their own targets for the ratio of electricity consumption by renewable energies. Summing up these target values, 21 % of electricity consumption of each country in 2010 will come from renewable energy. In Japan, meanwhile, the recently enacted "Law on Special Measures Concerning New Energy Use by Electric Utilities (RPS Law)" sets a target power-utilization value of 12.2 billion kWh of renewable energy in FY 2010. This represents only about 0.39 % of the net system energy demand in Japan. To improve the ratio, the Ministry of Economy, Trade and Industry recently set a new target of 16 billion kWh (1.35 %) in FY 2014.

Among renewable energies, power by natural energies such as wind power generation, photovoltaic power generation, etc. fluctuate easily due to weather. Though the latest large-capacity wind turbine reduces the power fluctuation by introducing various technologies, the power unavoidably drops to zero when the wind stops. When the capacity for renewable power generation is big within a grid with a weak power-receiving capacity, a system to suppress the power fluctuation is required. One potential solution to the problem is to develop a stabilization technology using a large secondary battery to accumulate the renewable energy.

This paper describes the performance of a large-capacity lithium ion battery and power storage facility developed through joint research with Kyushu Electric Power Co., Inc., and reviews the results of a project commenced in FY 2006 by the New Energy and Industrial Technology Development Organization (NEDO) and Kyushu Electric Power Co., Inc. to develop a grid stabilization system technology.

2. Development of a lithium ion battery and power storage system

2.1 Principle and feature of lithium ion battery

Fig. 1 shows the reaction principle of the lithium ion battery. Lithium containing metal oxide is used as the positive electrode (cathode) and carbon material is used as the negative electrode (anode). The lithium ion moves from the positive electrode to the negative electrode as the battery is charged, and from the negative electrode to the positive electrode as the battery is discharged.

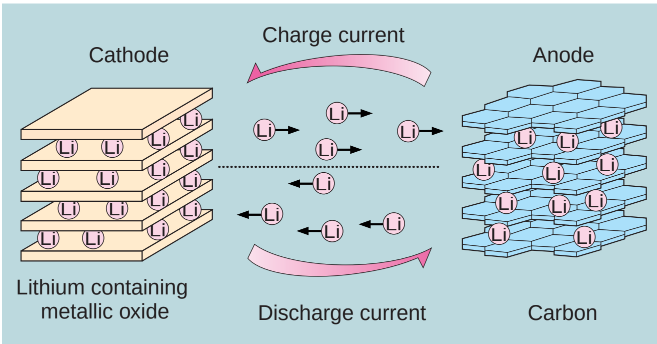

Fig. 1 Reaction principle of lithium ion battery
Showing the chemical reaction occurring between the electrodes of the lithium ion battery

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Since the charge and discharge proceed only by the movement of ion with the co-crystal structures of both electrodes maintained, the lithium battery deteriorates only slightly and offers good energy efficiency in comparison with the conventional secondary batteries in which the structures of electrodes change due to the charge and discharge, such as lead batteries and nickel hydrogen batteries.

The following shows the general features of the lithium ion battery:

- High voltage (nominal voltage is 3.6 – 3.8 V)
- High energy density
- No memory effect
- Battery usable even at low temperature
- Long cyclic life
- Quick charge and discharge
- Long shelf life

The conventional lithium ion battery has the drawback of a high cost, however, since it uses cobalt oxide for its positive electrode. The lithium ion battery is now used principally as a high added value battery for mobile devices such as cellular phones, notebook computers, and so forth. If the price can be reduced and the size enlarged, however, the battery has good potential for widespread application to electric vehicles and stationary equipment such as power storage, grid-stabilization systems.

2.2 Development of the large-capacity lithium ion battery

A large-capacity lithium ion battery for power storage has been developed using the oxide of a low-cost, highly safe manganese system for cathodes while adopting the structural safety design of a single cell and module cell. **Fig. 2** shows the construction of the large-capacity lithium ion battery. **Table 1** shows the battery performance.

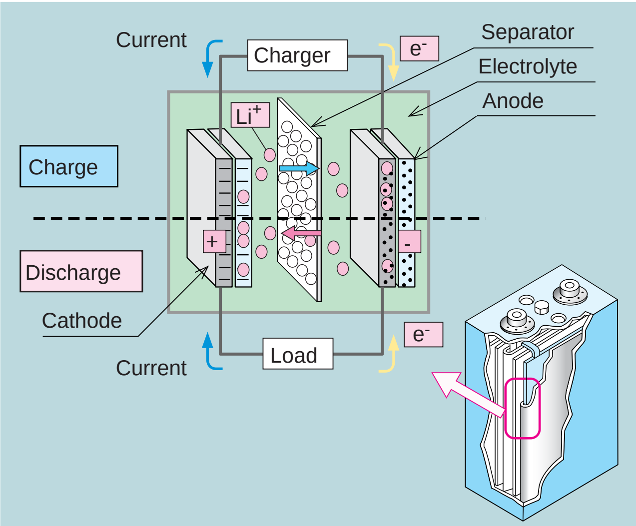

Fig. 2 Construction of single cell
Showing the construction of the square-shaped lithium ion battery developed

This battery is composed of alternately laminated current collectors with films made from a cathode active material of the manganese system and an anode active material of the graphite system. A battery of nominal capacity of 399 Wh (499 Wh at the maximum) is obtained by enlarging the electrode size and using a larger number of laminated sheets.

Evaluations in earlier years showed that the cathode active material of the manganese system had a low energy density and short life. In the cell now under development, however, improvements of the electrodes and electrolytes have led to a higher nominal energy density of 139 Wh/kg. The nominal energy density has reached 130 Wh/kg even for a module cell equipped with a cell balance circuit to correct the dispersion of the charge and discharge of 4 single cells. **Fig. 3** shows the capacity degradation during a charge and discharge cyclic test. When the operation capacity is set as 340 Wh, the expected life until the remaining capacity reaches 340 Wh is 3,500 cycles or more, and a durability of not less than 10 years is expected in the case of 1 cycle/day.

Table 1 Performance of the lithium ion battery newly developed

Specifications			Single cell	Module cell
Weight	(kg)		2.88	12.3
Size	(mm)	W	66.5	160
		L	116	262
		H	175	238
Nominal discharge voltage	(V)		3.8	15.6
Nominal capacity	(Ah)		105	
Nominal energy capacity	(Wh)		399	1 596
Nominal energy density	(Wh/kg)		139	130
Maximum capacity	(Ah)		136	
Maximum energy capacity	(Wh)		499	1 996
Maximum energy density	(Wh/kg)		173	162

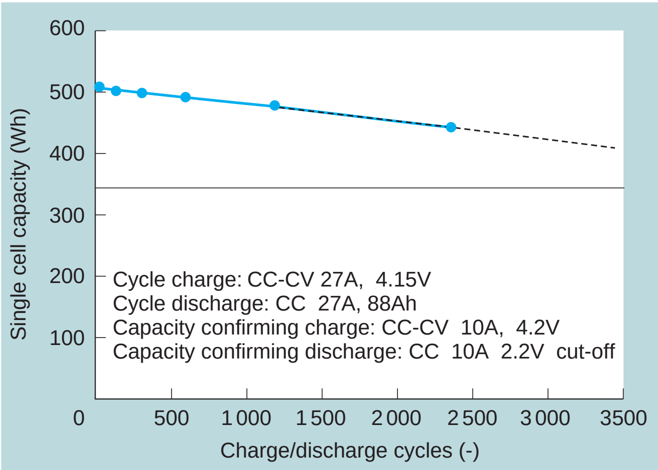

Fig. 3 Cycle characteristics of lithium ion battery
Showing that the developed cell has a life of not less than 3,500 cycles, as a result of the charge/discharge cyclic test

2.3 Development of power storage system

The power storage system copes with the load leveling by storing cheap surplus power from the grid and discharging it during high electricity consumption on the load side, and copes with peak cuts by discharging the power when the load nearly exceeds the contract power. This system can also be used for emergency power supply during blackouts when disasters occur. The power storage system is equipped with the batteries developed in the preceding paragraph. A cell-protection circuit for monitoring anomalies and protecting single cells is installed for each module cell, and the system is interconnected with the electric power grid system via a bi-directional inverter.

Fig. 4 shows the appearances of a 1.5 kW system and 3 kW system. **Table 2** shows the specifications for the systems. The 3 kW system is equipped with lithium ion batteries with a 32 kWh capacity. A charge and discharge energy efficiency of 86 % has been obtained at the AC terminal. The 3 kW system is now undergoing an outdoor field test, and has reached 900 cycles. Similarly, the 1.5 kW system is undergoing a field test in an actual all-electric home.

3. Renewable energy grid stabilization system using the lithium ion battery

3.1 Principle of the grid stabilization system

Fig. 5 shows a block diagram of the grid stabilization system for wind power generation using the secondary batteries (the basic configuration is the same for that of photovoltaic power generation). The mechanism is to use the power generated by natural energy, which fluctuates rapidly due to wind conditions and levels of solar radiation, to stabilize the composite power by charging the surplus power and discharging the deficit power to and from the battery. Accordingly, the secondary battery side must be capable of instantaneously inputting/outputting to the required input/output values of the system without time delays.

The maximum power (MW) and energy capacity (MWh) of the secondary battery, the input/output value of the inverter (MW), etc., all of which are basic specifications of the grid stabilization system, are determined in accordance with the operation mode, the stabilization operation condition, and the existence of nighttime countermeasures. There are two operation modes: 1) a stabilization operation mode to calculate the target value of the composite power using the output value of the wind power generation and to adjust the power with charge and discharge of the secondary battery in order to achieve that target value; 2) a flat operation mode to fix the target value of the composite power for each interval of the specified operation period and to adjust the power with charge and discharge of the secondary battery in order to achieve that target value. As conditions for stabilization, a short-cycle fluctuation countermeasure is used to set relatively short stabilization times (for example, not longer than 20 minutes), and a long-cycle fluctuation countermeasure is used to set relatively long times. The nighttime countermeasure is an operation method to completely charge the wind-generated power to the secondary battery during the night when the electric power demand lowers, and to switch to the short-cycle fluctuation countermeasure operation during the daytime.

Table 2 Specification of the power storage system newly developed

Example of usage	Household use	Business use
Power (kW)	1.5	3
Terminal voltage (h)	1φ3W AC101/202V (50/60Hz)	
Discharge time (h)	8~9	8~10
Charge/discharge efficiency (%)	83	86
Size (mm)	$600^W \times 550^D \times 1625^H$	$980^W \times 550^D \times 1825^H$

Fig. 4 Appearance of the power storage facility (left: 1.5kW class system; right: 3 kW class system)
The 1.5kW class is of a suitable size for household use; the 3kW, for business use.

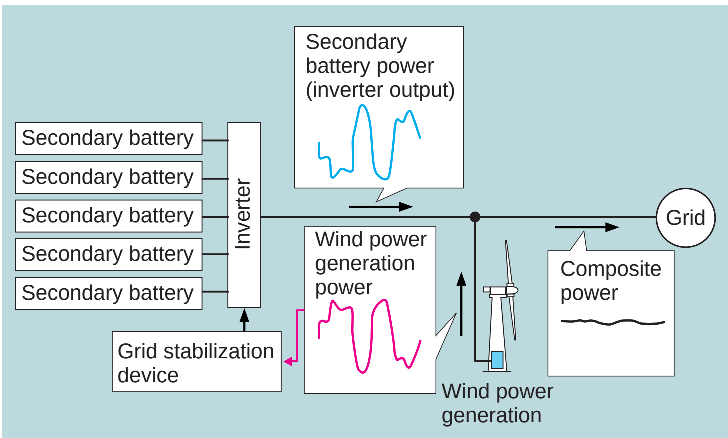

Fig. 5 Block diagram of grid stabilization system for wind power generation
Showing the principle of the grid stabilization system combining wind power generation and a battery

3.2 Stabilization simulation method for wind farm generation power

Using power-generation data from the wind farm in the NEDO project, we performed a simulation of the stabilization operation. **Fig. 6** shows the location, and a photograph, of Seto Wind Hill, where the data were collected. Seto Wind Hill is located in the western part of Ehime Prefecture and possesses 11 wind turbines of the 1000 kW class. **Fig. 7** shows the output power data of Seto Wind Hill and the power wave forms when stabilization time constants of 30 minutes, 60 minutes, and 200 minutes are applied. **Fig. 8** shows the power values from the battery system, with the same stabilization time constants applied. The power data of Seto Wind Hill in Fig. 7 start from power zero, because wind is absent for 30 or more minutes from the beginning of measurement. Thereafter, the power fluctuates largely as the wind power strengthens. A stabilization operation with a long time constant is deemed to be required for the maximum stabilization of the power fluctuation. If the time constant is long as shown in Fig. 8, the required power and required capacity on the battery side climb to high levels. The time constant required for the stabilization cannot be categorically determined, as it depends on the strength of the grid and the power characteristics and operation pattern of the wind farm. Roughly speaking, however, a time constant of 60 minutes is considered sufficient if a power-generation facility capable of following the power fluctuation exists in the vicinity. We can thus assume the case of a 20 MW wind farm stabilized at a time constant of 60 minutes, to review a grid stabilization system with an energy capacity of 20 MWh calculated theoretically.

We also need to consider the losses due to the inverter efficiency and the resistances of the batteries and wiring, to ensure that the grid stabilization system will output the specified power and capacity. Here, we presume that the discharge loss of the batteries and wiring is 9 % when the system outputs the maximum capacity (20 MWh) and the inverter loss is 5 %.

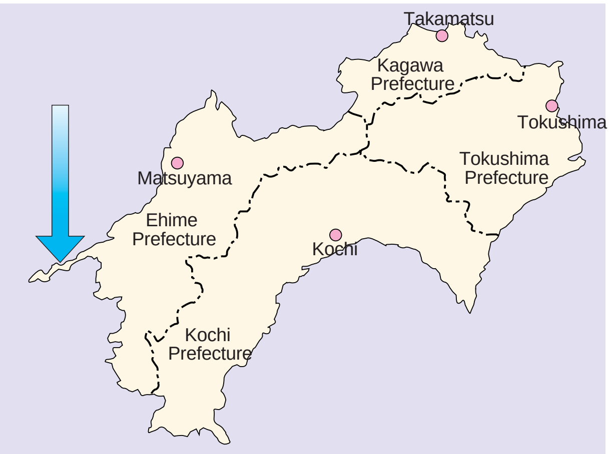

Fig. 6 Seto Wind Hill

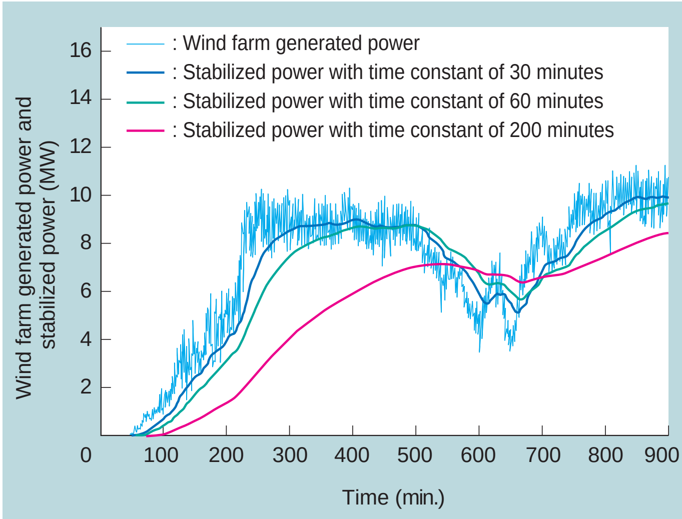

Fig. 7 Power generated by a wind farm (measured value) and power stabilized by a battery (calculated value)
Showing the generated power measured at Seto Wind Hill and stabilized powers with respective time constants

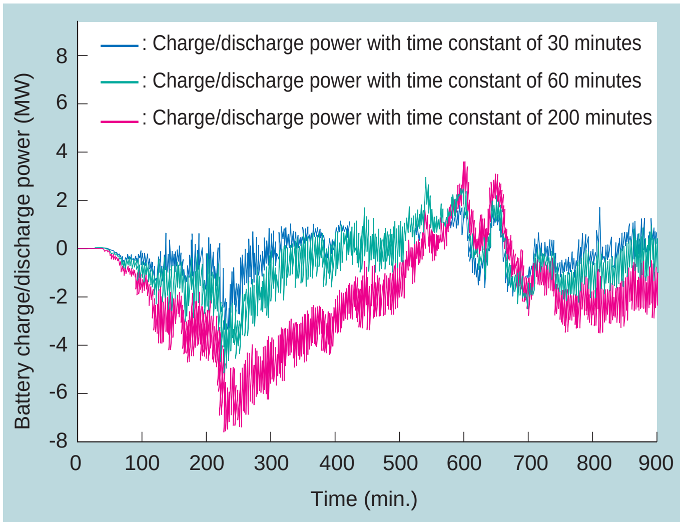

Fig. 8 Charge/discharge power required to stabilize wind power generation power (calculated value)
The larger the stabilization time constant, the higher the power requirement for stabilization

Table 3 Specification (draft) of grid stabilization system of 20MW class wind farm

Item		Design value	Remarks
Specification of system	System input/output (MW)	20	Typical wind farm size
	System capacity (MW)	20	Assuming stabilization with a time constant of 60 minutes
Specification of battery portion	Total power of all cells (MW)	21.1	Presuming that inverter loss is 5%
	Total capacity of all cells (MWh)	23.1	Accounting for the losses of the inverter and cell resistance
	Number of single cells (cells)	34 022	Calculation with a single cell capacity of 340Wh in consideration of lifetime
	Volume of all cells (m^3)	170	Calculation only with cells and module container
	Weight of all cells (t)	209	

3.3 Results of a review of the grid stabilization system with the lithium ion battery, and considerations

(1) Single cell

To conform acceptably with the operational conditions of the above-mentioned system, the single cell within the system must have the maximum possible capacity, as compact a design as possible, and the lightest possible weight. As power characteristics, it requires a charge/discharge of a about 1 C (charge/discharge can be done in 1 hour). The lithium ion battery shown in Table 1, a system already developed, is expected to achieve the target performance without large-scale design changes, if and when a higher power can be realized.

(2) Unit battery

The unit battery is a battery pack unit of the minimum possible size, used to input and output power via a control mechanism equipped by direct connection of single cells in parallel and/or in series. A converter and inverter are installed for each unit battery. Since these electrical components make up a large percentage of the total cost, however, a unit battery with a higher voltage and energy capacity is better suited to realize a low system cost. For the voltage of the unit, meanwhile, it becomes important to consider factors such as the legal voltage classification (low voltage is a voltage not higher than 750 V, DC), the operation voltage of the switches for the inverters, etc. used between the module and the grid (normally about 600 V for switches with a withstanding voltage of 1200 V), and other items.

In this review, we therefore consider a unit of about the 600 V class, realizing 581 V through the connection of 140 single cells with an upper limit of 4.15 V in series. In order to achieve an energy capacity that can flexibly correspond to other usages, we also design a new unit of the 100 kWh class by connecting two of the above-mentioned units in parallel. Thus, we have ascertained that one unit battery equipped with 280 single cells has a total capacity of 95 kWh and weighs about 860 kg.

(3) System

Table 3 shows the results of the review of the system specifications. Considering the system energy loss during output and the system capacity of 20 MWh, the system requires cells with a total capacity 23.1 MWh, and the combined weight of the lithium ion batteries is 209 t (including the module container).

Lead batteries have disadvantages, as their low energy density requires a weight and volume unsuitably large for a grid stabilization system configured with this battery. MHI has also found, through operational results with a grid stabilization system developed and installed for wind power generation using a seal type lead battery, that the life of the battery is short.[1]

If, as an alternative, we apply the lithium ion battery we have developed, the volume and weight can be reduced by about tenfold in comparison with the lead battery. The life of the lithium ion battery must be confirmed in field tests, etc. with the grid stabilization system in the future.

3.4 Actions in the future

Though the lithium ion battery has a high energy density and small footprint and weight in comparison with other secondary batteries, several tasks must be accomplished before the battery can be used within a grid stabilization system:

(1) Energy density

The weight and size of the battery should be further reduced by obtaining higher energy density, to ensure that installation conditions for the wind turbine remain unhindered.

(2) Power characteristics

In the specification above, we assumed a cell that can be charged/discharged within 1 hour. The current cell for power storage is optimized with an 8-hour rate. It will thus be necessary to aim for higher power by improving the electrolyte composition, etc. and reducing the internal resistance.

(3) Life

Generally speaking, the lithium ion battery has a longer life than the lead battery, even with a cycle with a deep charge/discharge depth. The new MHI battery is expected to have a life of not less than 3,500 cycles at the constant current. When repeating inputs and outputs to the battery at high power, the battery temperature may rise and the deterioration of the battery may be accelerated. In the future we plan to reduce the internal resistance of the cell and evaluate the life with the wave form of the actual wind farm.

(4) Cost

As matters now stand, the cost is as high as several hundred thousand yen per kWh because of the small production scale. In the future, however, it will be possible to lower the cost by expanding the production scale and adopting higher-capacity and lower-cost materials. But given that the unit price of power generation is higher in comparison with that of a system comprised of only wind turbines, the production scale cannot be expected based on the market principle as matters stand now. To increase renewable energy in the future, mechanisms to promote the introduction of wind power generation systems equipped with the grid stabilization system are likely be developed. In parallel with the technology development of the grid stabilization system itself, efforts will be made to review the financing facility of facility investment, in order to reinforce the electricity purchasing system using schemes with renewable energy power generation similar to those adopted overseas.

4. Conclusion

If we are to significantly increase the amount of power generation with renewable energy, we must promote this grid stabilization system. Given its higher performance compared to other batteries, the lithium ion battery draws attention as a stationary facility for the grid stabilization of renewable energy, power storage, etc., and as a power source for automobile such as electric vehicle. Though the conventional secondary battery (lead battery) was precluded from practical use by its unacceptably large footprint and other problems, a practical system can be configured if a large-capacity lithium ion battery is used in its place. Lithium ion batteries with higher performance and lower cost are now required. In view of the economic benefit of CO_2 reduction via the increase usage of renewable energy, the practical use and expanded introduction of the grid stabilization system should be hastened.

Reference

1. Goto, M. et al., Development of Hybrid Wind Power Generating System , The Journal of the Institute of Electrical Installation Engineers of Japan Vol. 21 No. 8 (2001) p.647


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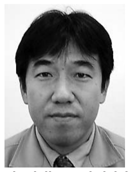
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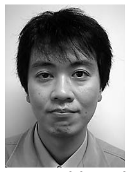
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