Development of Containerized Energy Storage System with Lithium-ion batteries

NAOKI SONODA*[1] HIROSHI MATSUNAGA*[2]

TADASHI GENGO*[3] MASAAKI MINAMI*[4]

MASAZUMI OISHI*[5] TSUTOMU HASHIMOTO*[5]

The lithium-ion battery has the characteristics of low internal resistance, as well as little voltage decrease or temperature increase in a high-current charge/discharge state. The battery is expected to be used not only in a transportation uses such as electric vehicles (EV), but also for stationary energy storage such as in the stabilization of renewable energy, the adjustment of power grid frequency and power peak-shaving in factories. Mitsubishi Heavy Industries, Ltd. (MHI) has been developing a large-scale energy storage system (ESS) using 50Ah-class P140 lithium-ion batteries that we developed. This report will describe the development status and application examples.

1. Introduction

The old status quo was that electric power could not be stored, and power should be generated in accordance with need. In other words, the electric company operated and kept the demand/supply balance in the electric system, which momentarily fluctuated. Some energy storage systems such as pumped hydro storage have existed, but, their large size of such facilities limited potential installation sites, and the energy/utilization efficiency has been low. However, recent energy storage systems, especially the lithium-ion battery technology used in electric vehicles, have shown remarkable innovation. The wide feasibility of the battery allows any installation location, from a supplier's power plant to ordinary houses and factories. In addition, a wide variety of output, ranging from several kW to MW-class, as well as capacities (time endurance) ranging from several minutes to several hours, are easily realized.

An electric energy storage system utilizing a battery can be charged during times of power surplus or low prices, and discharged when power demand or prices are high. The technology of this electric energy storage system and its expansion using batteries can be a tipping point in the history of electricity, in the sense that electric power can be handled as a general consumer good. As any retailer knows, buy low and sell high; and from the perspective of the consumer, stock up when commodities are cheap for later use.

2. Functions required in the electric storage system

Various applications of the energy storage system are planned. Many functions from the perspectives of power generation, transmission and distribution companies, consumers and renewable energy companies are shown in **Table 1**.

Load leveling or peak shaving is known as "time shifting," and energy stored in during a power surplus can be used during peak consumption. The power generating company has the

*1 Electrical Department, Plant Engineering Division, Engineering Headquarters
*2 Senior Manager, Power Systems Project Management Division, Engineering Headquarters
*3 Lithium Battery Department, Power Systems
*4 Electrical Department, Plant Engineering Division, Engineering Headquarters
*5 Chief Staff Manager, Lithium Battery Department, Power Systems

advantages of the lower capability margin, cost reduction by substituting the electric storage system for an adjusting thermal power generation and other benefits, while consumers have the advantages of lower electricity prices with the day time consumption of stored power generated at night, etc. The renewable energy company has the advantage of the capability to sell electricity in a high-price time period.

Table 1 Functions required in energy storage system (ESS)

	Function	Required capacity (hours)
Power generating company	Time shifting	2 to 8 hours
	Electricity quality maintenance	15 to 30 minutes
Power distributing company	Electricity quality maintenance	15 to 60 minutes
	Grid congestion relief	3 to 6 hours
	Extension of facility life	3 to 6 hours
Consumer	Time shifting	4 to 6 hours
	Emergency power source	5 minutes to 1 hour
	Parallel operation with photovoltaic panels and EV	3 to 5 hours
Renewable energy company	Time shifting	3 to 5 hours
	Output stabilization	10 seconds to 15 minutes

The “electricity quality” to maintain the grid frequency and voltage, which was handled by the increase/decrease of generator output power, and the voltage change with a tap changer in transformer, is now attained by charging/discharging lithium-ion batteries utilizing ESS.

In addition, with the installation of ESS in an appropriate transformer station, a sudden increase of demand can be responded to in a short time, and congestion relief and the extension of facility life can also be realized.

Moreover, a more stable power supply will be available with the rapid charging/discharging of ESS in rapidly fluctuating wind power and photovoltaic power generation through the installation of ESS by renewable energy companies. This further contributes to the easing of the load on the grid, as well as a reduction in greenhouse effect gases such as carbon dioxide. The installation of ESS may also be a solution to grid connection problems through the capacity limitation of mega-solar power plants, which are rapidly increasing in number.

3. Development of containerized energy storage system

Our company has been developing a containerized energy storage system by installing a varyingly utilizable energy storage system in a container from 2010. The module consists of eight of our lithium-ion battery cells and the Cell Monitoring Unit (CMU) as shown in **Figure 1**. The battery rack consists of the required number of modules, the Battery Management Unit (BMU), a breaker and other components. The container consists of the required number of the battery racks, as well as air conditioning and fire extinguishing equipment. As for the Power Conditioning System (PCS), which is indispensable to the energy storage system, various structures of (a) installed in the same container with the battery racks, (b) installed in a PCS dedicated container, and (c) installed outside the container are prepared in consideration of system size.

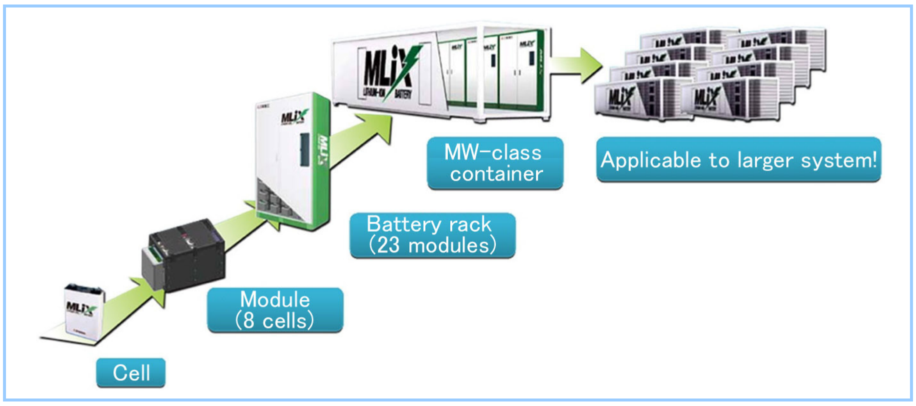

Figure 1 ESS structure

The advantages of supplying the energy storage system in a container are as noted below:

- The dedicated air conditioning equipment controls the temperature in the container.

  The temperature control of the cells, which produce heat in charging/discharging, is one of the important problems for cell life and the potential continuous operating hours of the system. The installation of air conditioning equipment in the container allows the most appropriate air conditioning design.

- The installation of fire extinguishing equipment ensures a high level of safety.

  A gas extinguishing equipment is installed in the container in consideration of the potential for a fire to occur, as many electric parts including the cells are installed in the container. The installation of fire extinguishing equipment in the container minimizes and optimizes the amount of extinguishing gas, and reduces the extinguishing time. Moreover, the fire is limited to the container itself.

- The system can be easily transported by trailer.

  The container complies with the ISO standard. The system is installed in 20 ft, 40 ft and containers of other sizes according to the system size, and the containers can be combined together. In this configuration, the system can be transported by trailer on land and by container carrier over water (**Figure 2**).

- No switchgear room is required, and the installation work is easy.

  A building to install the system is not needed as the required devices are already installed in the container. A minimum of on-site work is required as the wiring in the container has been completed.

A MW-class energy storage system using our 500kW PCS is shown in **Table 2**. The discharge characteristics are shown in **Figure 3**. An implementation example and its operational procedures are described in the next chapter.

Figure 2 ESS during transport by trailer

Table 2 Specifications of MW class energy storage systems

		500kW system	1MW system	2MW system
				
Rated output		0.5MW	1MW	2MW
Storage capacity		204kWh	408kWh	816kWh
Rated voltage		AC 300V		
Frequency		50Hz or 60Hz		
Phase-, Wire-No.		Three-phase, Three-wire system		
Ambient temperature		-5℃ to 40℃		
Size	40ft container	W:12,192×D:2,438×H:2,896mm	W:12,192×D:2,438×H:2,896 mm	W:12,192×D:2,438×H:2,896 mm
	20ft container		W:6,096×D:2,438×H:2,896 mm	
Configuration		40ft container×1	40ft container×1 20ft container×1	40ft container×3

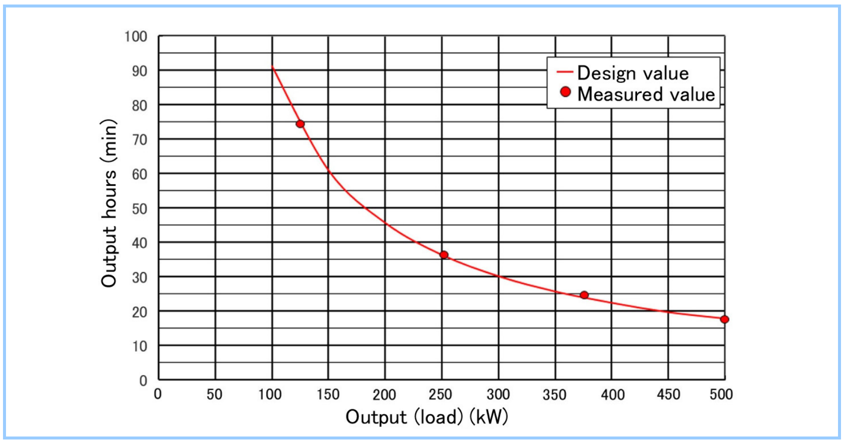

Figure 3 Discharge characteristic of 0.5MW class ESS

4. Example of containerized ESS and its operation

Examples of already delivered systems and their operational procedures including the containerized ESS currently being tested are described below:

4.1 1MW system at our Nagasaki Shipyard & Machinery Works

Currently, the scheduled power discharge of 500kW and 1MW in the plant is conducted during a time band requested by the electric company. Peak shaving operations of 500kW and 1MW discharges in accordance with the demand take priority over the scheduled power discharge, when the receiving electricity demand in the plant is high, in order to not exceed the contracted electricity. **Figure 4** shows the operation of the system one day in September. The fluctuating blue line shows the load in the plant and the pink line shows the integral power consumption at 30 minute intervals. The contracted electricity with the electric company is this integral power consumption every 30 minutes. ESS starts discharging when the contracted electricity is expected to be surpassed, in order to not exceed the contracted electricity (**Figure 5**).

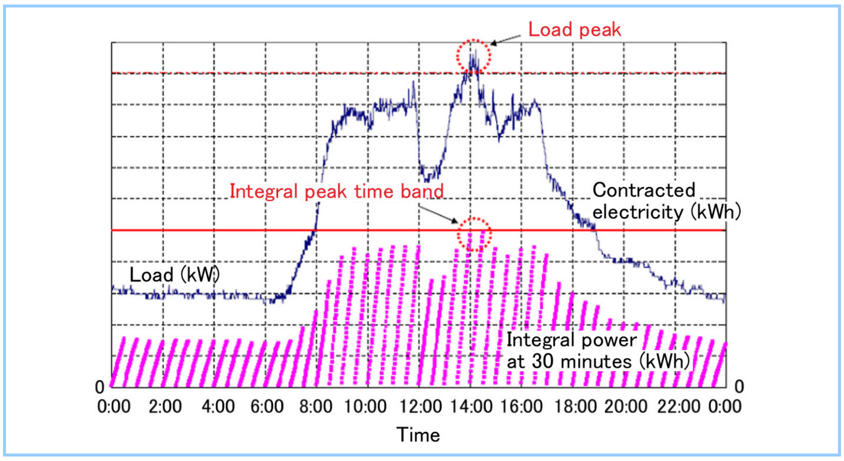

Figure 4 Electricity demand at MHI Nagasaki Ship yard

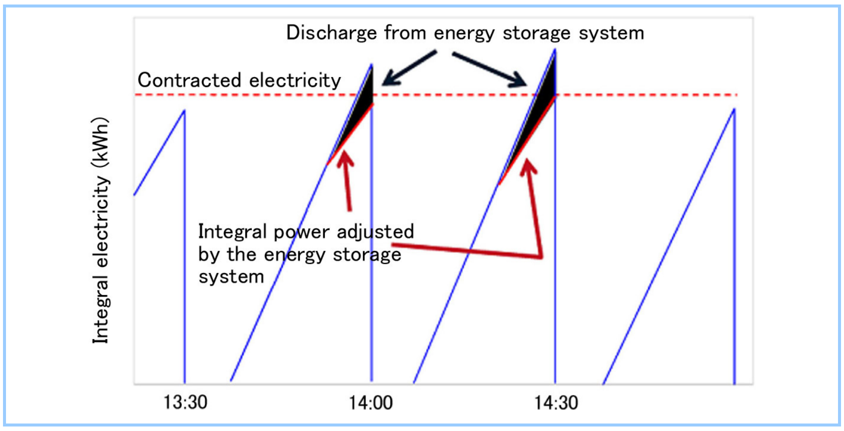

Figure 5 Transition of electricity (enlarged view)

4.2 2MW system for congestion prevention in Europe

A 2MW energy storage system is currently in the process of being commissioned on the Orkney Islands, where wind power, wave power and tidal power plants are part of the energy supply mix and power is exported to or imported from the British mainland through 33kV submarine cables.

As shown in **Figure 6**, the number of submarine distribution lines between the islands is limited, and wind power output would have to be stopped or lowered due to congestion in the lines.

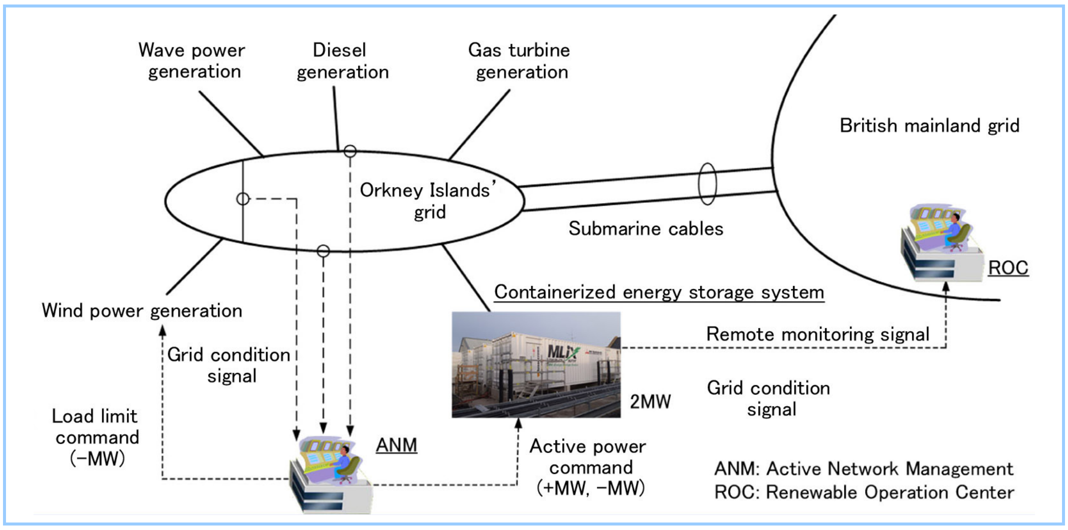

Figure 6 Conceptional diagram of ESS for Europe

Specifically, the Orkney Islands' grid has an overall monitoring and control system (Active Network Management System, ANM) which will control the operation of ESS within a specified availability period within its operational range, and ESS will be free to operate as needed by the ESS system outside the availability periods, alternating 4 times a day. The availability period will allow ESS to be dispatched by the ANM system to reduce constraint levels experienced by some of the other renewable energy generators on the islands. The condition of ESS will be monitored remotely by the SSE Generation Control room at the Renewable Operations Centre (ROC).

A high efficiency air conditioning system for stores and buildings has been selected to optimize overall system efficiency, which accounts for the majority of the auxiliary power used. Fire-fighting equipment conforming to the local regulations using IG-541 fire-extinguishing gas is being applied, and carries an extremely low risk of asphyxiation.

We have conducted FMEA (Failure Mode and Effective Analysis) independently, as well as separately with the customer in the UK. In addition, a system review has been completed with the local fire department, the police and the local Council Emergency Service.

Trials for the full-scale operation of the system are scheduled for July 2013.

The demonstration project is conducted with the support of New Energy and Industrial Technology Development Organization (NEDO) of Japan, under the programme of "Development of Technology for Safe, Low-cost, Large-size Battery System."

4.3 100kW system for condominiums

A 100kW system has been shipped for a condominium (**Figure 7**). Photovoltaic power is charged in the day, and used as a power source in the common use spaces. In addition, the power will be supplied to important lighting, elevator and water-supply pump facilities in the building in the event the power is interrupted. The system is not installed in a container, but installed as a battery rack in the electric room in the basement of the building.

4.4 100kW system for technical research center at construction company

The system is used as a dispersed power source in a micro-grid of the technical research center owned by the construction company for performance assessment tests of customer micro-grids (**Figure 8**). A 600kW-class micro-grid connecting dispersed power source that includes photovoltaic power and rechargeable batteries has been constructed at the research center. Our ESS system has been added to this network and performance assessments are currently being conducted.

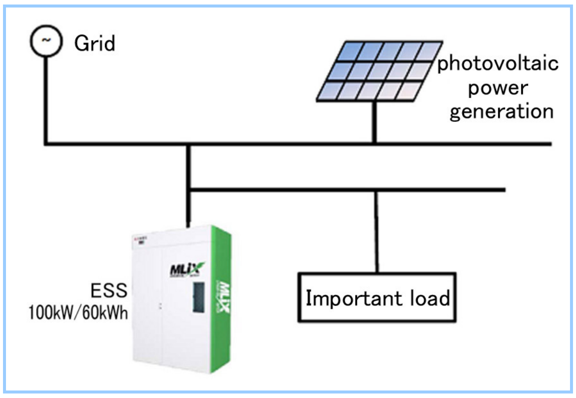

Figure 7 ESS for condominiums

Figure 8 100kW class ESS

4.5 100kW system for micro-grid

ESS has been shipped to a "Zero Energy Building" aiming for self-supporting electric power generation through renewable energy (**Figure 9**). The electric power supply combining biomass generation and photovoltaic panel is conducted in accordance with building power demand, and any overages/shortages are adjusted for by the charging/discharging of the battery.

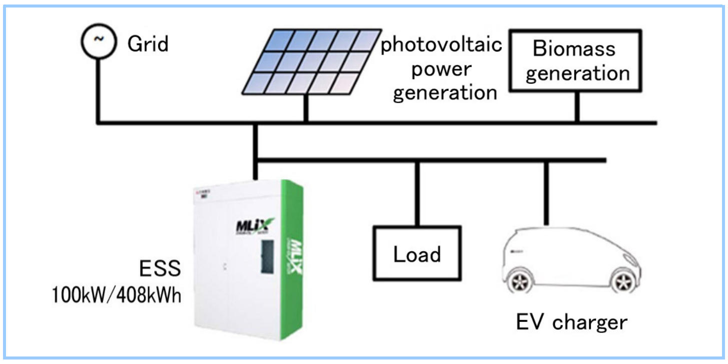

Figure 9 ESS for micro grid

4.6 MW-class system for short frequency fluctuation easing overseas

A 6.5MW system for short frequency fluctuation easing of wind mills and a 500kW system for short frequency fluctuation easing of photovoltaic panels are currently being prepared for assessment overseas.

5. Conclusion

We have developed our Energy Storage System (ESS) using lithium-ion batteries, and we have already conducted verification testing of the system installed in a container, and have started to supply the system to the market. ESS has the potential to be used in many places from the supply side to consumers, and bring about a revolution in the electric power system. We are positioning ESS as one of the products contributing to the social infrastructure, which is our area of specialty, and we suggest total systems in combination with other products such as wind mills, photovoltaic panels and gas engines. We have our sights set on the Energy Management System, which will integrate the all forms of energy generation, and will actively continue market development.

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