Energy Storage System

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Abstract

To realize a low-carbon society, wide introductions of renewable energy resources like solar and wind power are advancing worldwide. In Japan, there are concerns regarding negative influences, such as disturbance in the balance of power demand and supply and output fluctuations and frequency changes in power grids caused by the extensive introduction of renewable energy resources. Because of the aforementioned, in some areas in Japan, the inter-connection of renewable energy to power grids is restricted. In addition, because of deregulation of the power retail market and successive legislation for the unbundling of power generation, the transmission and distribution from a power utility firm became effective in April 2016. There is expected to be a change in relationship between energy demand and supply. The increase of renewable energy resources is an important target for the national energy policy in Japan and the stabilization of grid systems is a pressing technical challenge of our time. As an effective tool in order to solve this issue, energy storage systems are getting increased attention.

1 Preface

In an effort to reduce unusual climatic change occurring worldwide, various actions have been taken at home and abroad to reduce CO_2 emissions. In the field of power generation, a large volume of CO_2 is generated from fossil fuels and the rate of thermal power generation must be suppressed. For this reason, wider introductions of renewable energy resources like solar and wind power are observed worldwide.

In Japan, the Feed-in-Tariff (FIT) Law was put into effect force in July 2012. Supported by this law, the total amount of renewable energy resources has remarkably increased.

Since the Great East Japan Earthquake caused a large-scale disaster in March 2011, most nuclear power plants in Japan ceased operation despite providing stable power before the earthquake. This caused Japanese Government to review its energy policy. Securing energy resources in the event of a disaster became a particularly important issue for households and communities.

Solar and wind power have been widely introduced in Japan as renewable energy resources. They have generated power which is changed greatly by variations in sunlight or wind velocity, thus causing voltage rise, frequency deviation, and an imbalance in demand and supply. These factors are the source of concern because they can cause adverse influences upon stable operation of power systems. Thus, verification research programs for stable management of power grids had been carried out in various places. As a solution to this technical challenge, the use of energy storage systems is getting increased attention and is nearing the phase of practical implementation.

This paper introduces some examples of application of the Power Conversion System (PCS), a key component of the energy storage system. In addition, the paper also introduces the energy storage systems delivered to overseas countries for power system stabilization.

2 PCS for Energy Storage

2.1 Features

(1) A single PCS unit 250kVA can offer a combination of total capacity (a maximum of eight units: 2MVA in total) and parallel generation. According to

the scale of each facility, an optimal capacity can be determined.

(2) In addition to the conventional function of load leveling, this model offers new functions such as a fluctuation relaxing function for renewable energy, system voltage regulation, and a frequency fluctuation relaxing function.

(3) A function of an islanding operation is provided. In place of emergency generators, this model can be applied to the Business Continuity Plan (BCP).

(4) A bidirectional chopper is installed on the PCS battery side so that equipment can operate in a wide voltage range. Various types of storage batteries such as a lithium-ion battery, lead battery, lithium-ion capacitor, redox flow battery, and Durathon battery (zebra battery) can be used as DC power sources. The most effective batteries can be selected per the required application.

(5) This model conforms to the recent EU Directive such as Low Voltage Directive (EN50178) and EMC Directive (EN61000-6-2, EN61000-6-4). In addition, it can also conform to Japanese standards.

Table 1 Specifications of PCS Equipment

The PCS products are manufactured in accordance with both Japanese and overseas standards.

	Item			Rating and performance
Major factors	Rated capacity of equipment			250kVA～2MVA
	Type of rating			A0: 100% continuous
	Inverter control system			Self-cooled voltage type current controlled PWM inverter
	Insulation type			Power frequency insulation transformer type
	Conversion efficiency			95% or above
	Environment	Cooling system		Forced-air cooled
		Ambient temperature		0～40℃
		Relative humidity		15～85%
		Quake durability		Horizontal: 1.0G, Vertical: 0.5G
	Dimensions			W1600 × H1950 × D700mm
	Mass			2000kg
	Applicable standard			JEC2440, JEC2433 EN50178, EN61000-6-2, -4 EN50160, IEC60146-1-1
Specifications for grid-connected operation	AC	No. of phases		3-phase 3-wire
		Rated voltage		400V class
		Permissible voltage regulation range		Rated voltage −12～10%
		Rated frequency		50Hz or 60Hz
		Permissible frequency deviation range		Rated frequency ±6%
		Effective power control range		−100% (charge)～0～+100% (discharge)
		Reactive power control range		−100% (lagging)～0～+100% (leading)
		Power control accuracy		±1%
		Current harmonics content rate		Total 5% Max., each order 3% or less
	DC	Voltage range		240～600V
Specifications for islanding operation	AC	No. of phases		3-phase 3-wire
		Rated voltage		400V class
		Rated frequency		50Hz or 60Hz
		Rated load power factor		0.9～1.0 lagging
		Voltage control accuracy		Within ±3%
		Frequency control accuracy		Within ±0.1%
		Voltage harmonics content rate		3% or below
	DC	Voltage range		240～600V

2.2 Equipment Specifications and Circuit Configuration

Table 1 shows specifications of the PCS equipment and **Fig. 1** shows the circuit configuration of the PCS (including main control unit). The PCS is

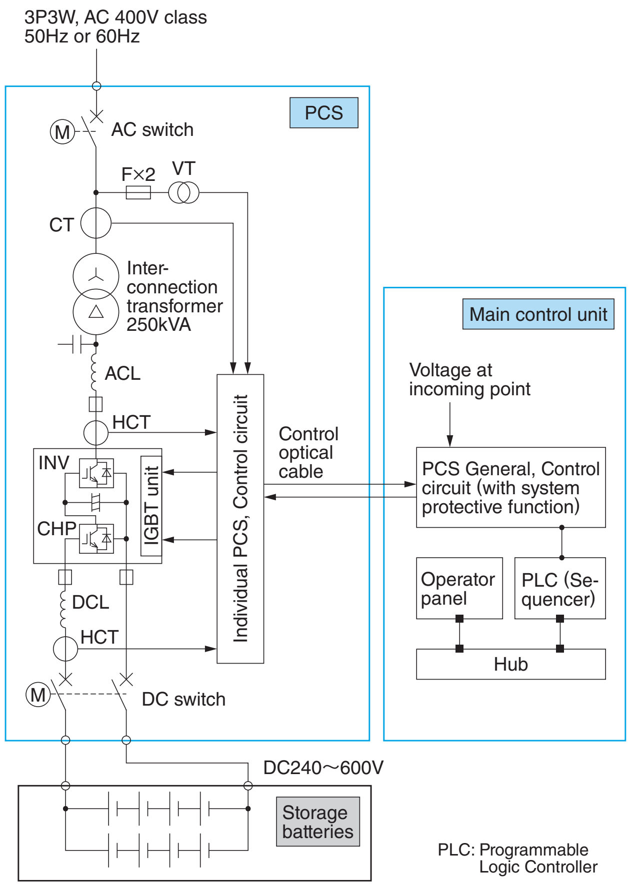

Fig. 1 Circuit Configuration of PCS (Including Main Controller)

A single unit of the main controller can accommodate a maximum of eight PCS units connected in parallel.

composed mainly of AC and DC switches, a filter, an Insulated Gas Bipolar Transistor (IGBT) Unit of the inverter and chopper type, and the main control unit (for PCS control, monitoring sequencer, operator panel, and auxiliary devices.)

2.3 Major Functions

The basic operation mode of the PCS is introduced below. Table 2 shows control functions and functional outlines to be covered by the PCS.

2.3.1 System Interconnection Charge-Discharge Operation

This is an operation mode intended to make charges and discharge in interconnection with the utility system. When the right of control is “local,” an arbitrary charge or discharge action can be taken per the power setup value indicated on the operator panel. When the right of control is “remote,” an arbitrary charge or discharge action may be taken according to the power dispatch value given from a host system. If the power dispatch value is not given, the standby mode is assumed by taking an action of a gate block for inverters so that switching loss is eliminated.

2.3.2 Islanding Operation

This is an operation mode to feed power to the load at the constant voltage and frequency by using storage batteries if the power source of the utility system is lost due to a power outage or system error. When a maximum of eight PCS units, 250kW per unit, are used for a parallel operation, an islanding operation is possible at the maximum of 2MVA. These PCS units can be used as an alternative power source like an emergency generator. They can start up in a matter of a few seconds. This feature is superior to that of an emergency generator.

Table 2 Control Functions and Functional Outlines

The PCS has a variety of functions such as system protection function, grid stabilization function, and battery control function.

Control function	Functional outlines
System interconnection protection	This function is used to make a gate block for inverters in the case of a system error and the AC switch is tripped for their parallel off from the system. Available factors for protection are AC overvoltage, AC undervoltage, frequency rise, frequency drop, and isolated operation detection (passive and active). Signals of external relay contacts are also dealt with.
Fault Ride Through (FRT)	In order to avoid simultaneous and unnecessary PCS parallel off in the case of system voltage error, this function is used to continue operation at the specified voltage drop rate and within the specified time range.
Interconnection inrush current prevention	In order to prevent device deterioration and system disturbance due to inrush current of an interconnected transformer during system interconnection, the PCS output voltage is synchronized with the system in advance and system interconnection is then accomplished.
Renewable energy tidal flow deviation relief	This function is used to smooth the generated power from renewable energy by solar or wind power generation. Output current from renewable energy is detected, charge-discharge control of storage batteries is carried out, and changes in tidal flow are smoothed.
Load deviation relief	In order to smooth the load side tidal flow deviation, the load side current is detected and charge-discharge control is performed for storage batteries.
Battery refresh operation	This operation mode accompanies CV (constant voltage) charging in order to adjust the State Of Charge (SOC) of storage batteries. This function is also expressed as a battery refresh operation or reset charge and discharge.
Power distribution control according to SOC	In order to relieve the differential component of battery SOC in the parallel system, charge-discharge command values are controlled to accomplish adequate power dispersion to each PCS.

3 Utilization of Energy Storage System and Practical Application

The purposes of using the energy storage system are classified into three categories: peak shaving, countermeasures against renewable energy output deviation and excess power, and system stabilization.

At overseas markets, the demands for storage batteries are visibly increasing. Some Independent System Operators (ISO) and such grid system management companies in foreign countries are beginning to take measures for securing conditions for using storage batteries based on their wider renewable energy sources in the future. Japan has a government policy to increase the capacity of inter-connecting renewable energy resources by installing energy storage systems with renewable energy resources.

A considerable difference of the energy storage system (from other distributed energy resources) is that it can offer negative power generation (so-called charging). Since excess power can be absorbed in the energy storage system, the Load Frequency Control (LFC) for conventional power generation (thermal and hydraulic) can be replaced by an energy storage system. As described above, the capability of demand and supply adjustment can be deemed as the greatest advantage of the energy storage system.

Active use of this system as a backup power resource can be utilized for the application of the BCP. Other cases are for the support of community activities, etc.

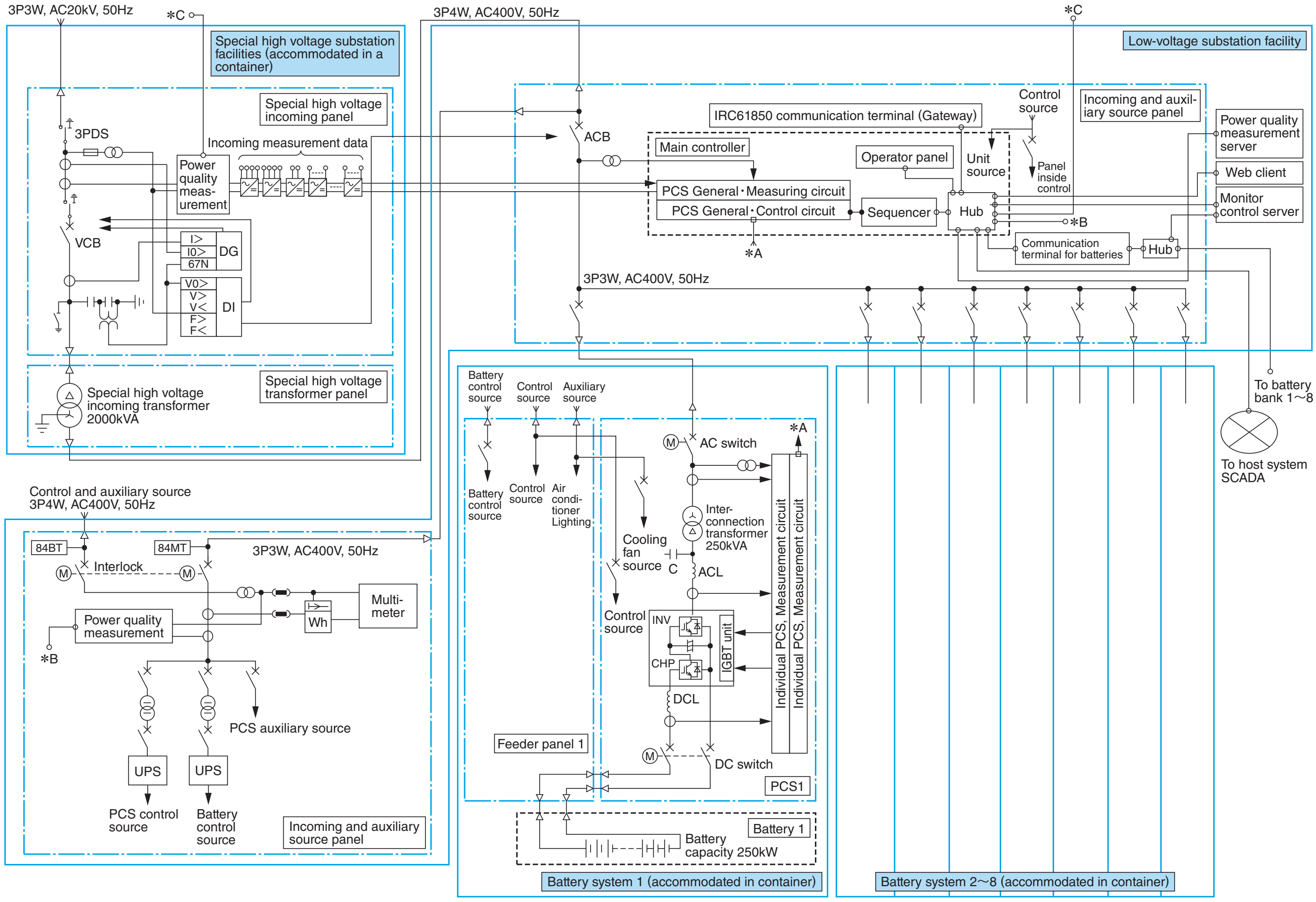

Fig. 2 Example of System Configuration

This system is composed of substation facilities, a PCS, an incoming and auxiliary source panel, control and monitoring equipment, and subsidiary components. Operation and control command signals are sent from the host SCADA.

4 Case Study of an Energy Storage System Application

We built an energy storage system in the European market for grid stabilization.

4.1 System Configuration

Fig. 2 shows an example of a system configuration. This system is composed mainly of special-high voltage (over 20kV substation facilities, eight 250kVA PCS units connected in parallel, incoming and auxiliary source panel, control and monitoring circuits, and an outdoor container. Since this system is intended for shipment for the European market, the respective components and module units are CE marking-compliant.

Since this system is to be managed by power receiving and distribution service providers, it is designed for connection with the Supervisory Control and Data Acquisition (SCADA) equipment from which this system is controlled and monitored.

A specific communication protocol is adopted based on IEC61850 that is an international standard. This system can assure a high-speed response of about 300ms to meet the SCADA control command.

This system also offers a variety of functions such as emergency operation and islanding operation in the event of a power outage in the utility grid and automatic system shutdown.

4.2 Grid Stabilization Function

This system is generally connected with the terminals of unstable power systems where many renewable energy resources like solar and wind power are connected. In this situation, it is expected that this system will stabilize the grid by suppressing voltage and frequency fluctuations. Table 3 shows the grid system stabilization functions of this system.

4.3 Remote Control and Monitoring Function

This system has a remote control and monitoring function in its remote control server. It, there-

Table 3 Grid Stabilization Functions

This system is provided with a variety of functions for grid stabilization. According to system conditions, a system manager makes arbitrary ON/OFF setting in regard to system functions.

Function	Application
Voltage imbalance compensation	In order to relieve voltage imbalance at the power incoming point, negative-phase sequence voltage is extracted from the detected voltage and the intensity of negative-phase sequence current is determined. When this function is made effective, autonomous control is carried out on the system side.
Momentary voltage dip compensation	When a voltage dip occurs in the FRT domain, the system discharges effective power at a maximum value of possible power. When this function is made effective, autonomous control is carried out on the system side.
Harmonics compensation	In order to relieve voltage harmonics at the power incoming point, harmonic component is extracted from the detected voltage and the intensity of the 5th and 7th harmonic current is determined. When this function is made effective, autonomous control is carried out on the system side.
Voltage regulation	When the detected voltage value at the power incoming point deviates from the dead band, reactive power output is autonomously generated so that the voltage settles within the band. This function of regulation conforms to the computed formula set up in advance for the system.
Frequency regulation	When the detected frequency value at the power incoming point deviates from the dead band, effective power output is autonomously generated so that the frequency settles within the band. This function of regulation conforms to the computed formula set up in advance for the system.
Load leveling Demand and supply adjustment Power factor compensation	These functions are controlled by the P and Q control commands from the SCADA. According to these commands, the system performs a charge and discharge so that the system is stabilized.
Control of preference for each function	When two or more functions are made effective, the control logic incorporated in the system determines the order of preference for each function in order to avoid functional interference and inadequate system operation.

fore, works as a control server playing the role of a machine standing by for the SCADA. It also has a user interface (Web GUI) to cope with control command equivalent to the SCADA and system supervision toward the remote control clients (Web client). Fig. 3 shows an example of the Web client screen.

These remote control and monitoring functions are used at the time of failure in the SCADA system, communication stacking, or maintenance. Since the system has various functions equivalent to the SCADA, it offers equivalent advantages and system redundancy.

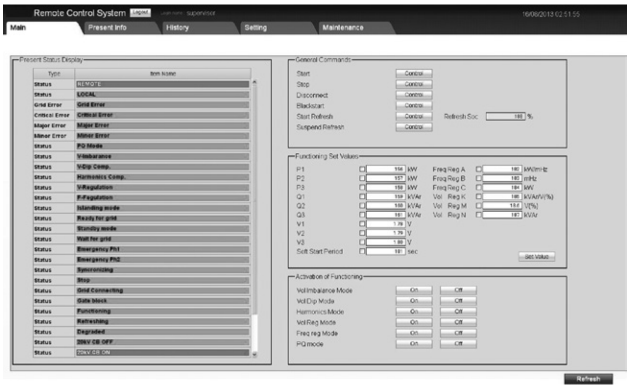

Fig. 3 Example of Web Client Screen

The Web client is provided with functions of the system's real-time data display and performing monitor and control equivalent to the SCADA.

Various logging data and trend graphs saved in the server can be picked up from remote places via the web clients. By analyzing the logging data, the cause of system problems can be grasped at an early opportunity. Thus, system's maintainability is exponentially improved during system management.

5 Postscript

For the purposes of system stabilization and BCP, the energy storage system is now in the phase of commercialization. It is expected to be widely introduced soon. There are still some issues regarding wider acceptance such as further improvement of system management efficiency and cost reduction.

Japan's energy-related policy is now in a time of great change in the deregulation of power retailing and the separation of power generation and transmission. Consequently, the market of energy storage systems is anticipated to grow in an accelerated manner. Drawing on our engineering resources and expertise cultivated through these experiences, we will positively promote product development of PCSs that are key components of energy storage systems. We will continue to offer high-value added systems.