Technology for Large-Scale Photovoltaic Power Generation Systems

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ABSTRACT

The market for photovoltaic power generation systems in Japan is expanding to large-scale photovoltaic power generation (mega solar), and the need for high efficiency, high reliability, and compact equipment increases. Fuji Electric supplied a package of mechanical and electronic equipment for Abu mega-solar plant of the Okinawa Electric Power Company, Incorporated including devices for a solar power generation system and a remote surveillance control system, which commenced operation in the end of March 2012. We have applied a highly-efficient, high-capacity power conditioner utilizing the power electronics technology and a large-scale surveillance control system.

We are also developing system-interconnection technologies to resolve issues that would arise in the power grid with large-scale implementation of renewable-energy power production through microgrid verification equipment using stable systems etc. for remote islands.

1. Introduction

The "Kyoto Protocol" was adopted at the 3rd Session of the Conference of the Parties to the U.N. Framework Convention on Climate Change (COP3) in December 1997. It clarified the reduction of greenhouse gases and a low carbon society became the goal. In order to promote the introduction of photovoltaic power generation, the Japanese government provided support for the installation of large-scale photovoltaic power generation facilities with outputs of 1 MW or greater, which are generally described as mega solar facilities. After the Great East Japan Earthquake in March 2011, the government announced a policy of accelerating the development of renewable energy to secure an alternative energy source to nuclear power generation. Furthermore, after the start of the "Feed-in Tariff Scheme for renewable energy" in July 2012, there have been increasing examples of photovoltaic power generation facilities being constructed by parties other than the electric power companies, for example, ordinary companies or local governments, both for the purpose of selling the power and for their own use.

Fuji Electric has been supplying photovoltaic power generation systems both in Japan and overseas since 1980. This article introduces the company's technologies for large-scale photovoltaic power generation systems, which are based on that track record.

2. Fuji Electric's Solutions for Photovoltaic Power Generation System

Fuji Electric has utilized the plant technologies developed in power generation facilities, transforming facilities and factory facilities, and has supplied many photovoltaic power generation systems and verification facilities both within Japan and overseas. The company is also a world leader in the development and delivery of film-type amorphous solar cells, which are "thin, light and flexible."

Figure 1 shows an overview of measures for photovoltaic power generation systems. Fuji Electric performs all processes from the selection of solar cells to the design, installation and maintenance of extra-high voltage and high voltage facilities, power grid inter-

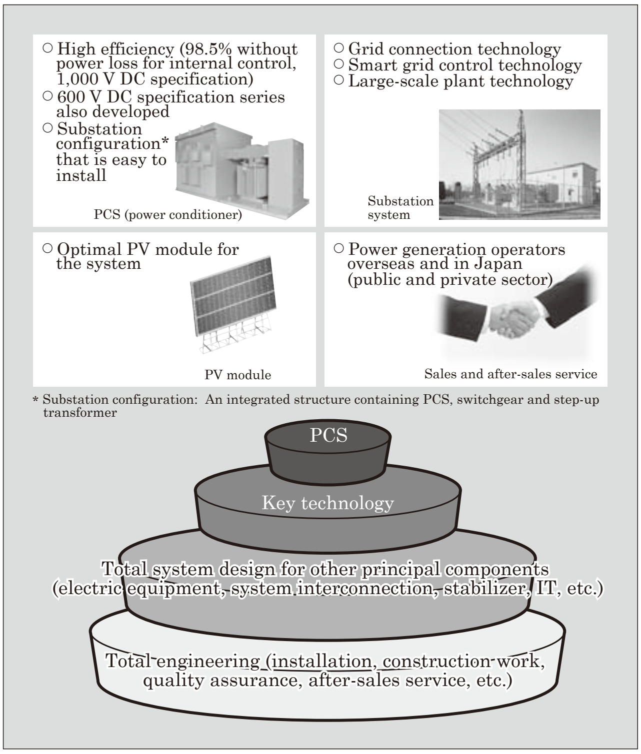

Fig.1 Measures for photovoltaic power generation systems

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connection facilities, and supply and demand control systems. In the installation of mega solar facilities, an elaborate plan is necessary as a great deal of time is required for the various procedures and technical considerations. This includes the acquisition of land, an investigation of the environmental conditions where the facilities will be installed, the investigation of investment and return with consideration of the feed-in tariff system and subsidies, and also conformity with the various laws and regulations related to the security of the facilities.

As shown in Fig. 2, photovoltaic power generation systems such as mega solar are made up of photovoltaic module (PV module), arrays, junction boxes, connection boxes, power conditioner (PCS), interconnection facilities, environmental measurement equipment and monitoring control systems. Figure 3 shows the procedure for their installation. The main points of the system plan are as follows.

(a) There are many different types of solar cell, including single crystal and polycrystalline types, amorphous and multi-junction thin-film types and types that do not use silicon, such as those with CI(G)S compounds and other, organic types. Each of these has their own characteristics and different costs and power generation efficiencies. The optimal solar cell is selected from solar cell manufacturers both in Japan and overseas after considering the requests of the customer and the conditions such as the installation environment and the price.

(b) The angle of inclination, direction for PV module attachment and number of rows and columns on the arrays are planned after consideration of the environment, the setting area and the costs.

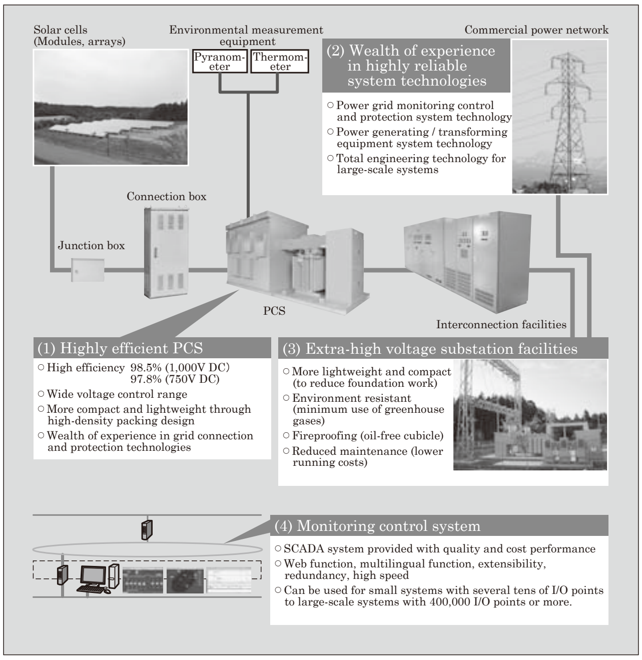


Fig.2 Configuration of photovoltaic power generation systems

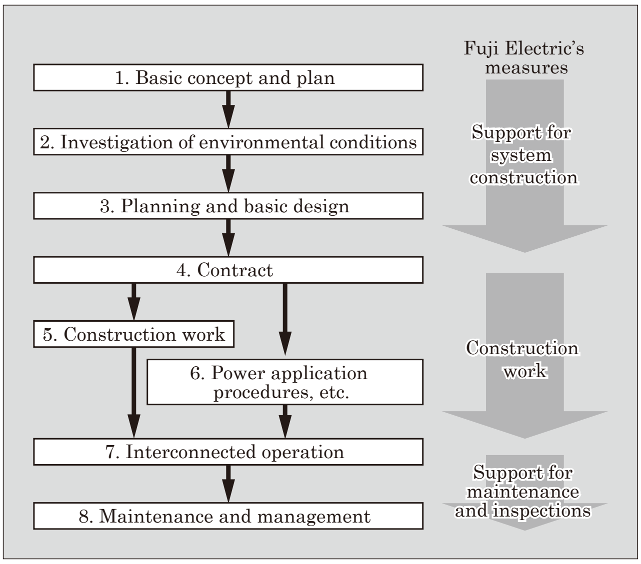


Fig.3 Procedure for the installation of photovoltaic power generation systems

(c) The junction boxes and connection boxes are planned with consideration of the installation environment and by investigating the arrangement with consideration of the optimal number of solar cells in series and the transmission losses, and then designing the number of branches.

(d) Highly efficient large-capacity and transformer-less PCS are used.

(e) For the switchgear for the interconnection facilities, at the 22 to 77 kV class, cubicle type gas-insulated switchgear using SF_6 gas or environmentally friendly dry air is selected. For larger classes, SF_6 gas-insulated switchgear is used.

(f) For the transformer for the interconnection facilities, an oil-immersed transformer using a highly efficient mineral oil or environmentally friendly palm oil is selected.

(g) For the purpose of energy management and environmental enlightenment, the environmental measurement equipment includes pyranometers are installed at the same inclination as the arrays, and external thermometers to measure air temperature are installed at a location not exposed to direct sunlight.

(h) For the monitoring control systems, CitectSCADA*1 systems suitable for processing large numbers of I/O points are used in order to enable to perform monitoring control remotely and measure the current and voltage per individual junction box unit.

(i) For the design of the direct current side, the "Regulations on photovoltaic power generation facilities" were revised based on the "Partial revision of the interpretation of the technical stan-

*1: CitectSCADA: Trademark or registered trademark of Schneider Automation, Inc., France.

dards for electrical equipment" (Nuclear and Industrial Safety Agency, Ministry of Economy, Trade and Industry, June 29, 2012) and PV cables can now be used in the high voltage range (limited to 1,500 V DC and below) (see Fig. 4).

Table 1 shows a comparison of 600 V and 1,000 V DC distribution systems. Compared with the 600 V DC distribution that is currently the most common, with the 1,000 V DC distribution it is theoretically possible to increase the number of PV module in series to 10/6 and reduce the number in parallel to 6/10. This makes it possible to reduce the number of PV cables and junction/connection boxes, and it is possible to reduce the cost of the power generation and to reduce the transmission losses. Fuji Electric is actively including the 1,000 V DC distribution method in system plan.

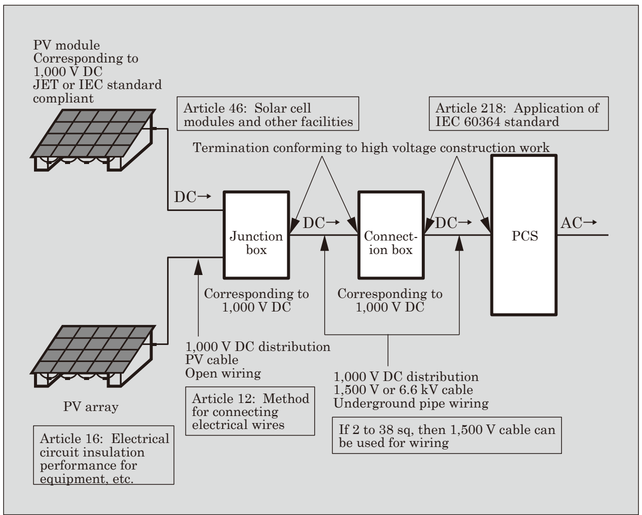


Fig.4 Examples of photovoltaic power generation facilities and related technical standards

Table 1 Comparison of 600 V and 1,000 V DC distribution systems

	1,000 V DC distribution	600 V DC distribution
Circuit division	1,000 V DC ◄ ► AC; PV module → Junction box → Connection box → PCS → Transformer → Distribution board → Electric power company distribution system	600 V DC ◄ ► AC; PV module → Junction box → Connection box → PCS → Transformer → Distribution board → Electric power company distribution system
Circuit image	Less parallel and more series circuits compared with 600 V DC circuit; Number of parallel circuits (60%); Number of series circuits (160%); Circuit voltage 1,000 V DC; Junction box	Number of parallel circuits (100%); Number of series circuits (160%); Circuit voltage 1,000 V DC; Junction box
Number of pieces of DC side equipment and construction costs	○ Junction box: 60% ○ Cables between junction box and PV module: 60% ○ Cables between junction box and connection box: 60% ○ PCS: Number reduced by use of 1,000 V DC large-capacity equipment ○ Construction costs: Reduced because there are fewer wires and units to install	○ Junction box: 100% ○ Cables between junction box and PV module: 100% ○ Cables between junction box and connection box: 60% ○ PCS: 600 V DC unit ○ Construction costs: Proportional to number of wires and units to install
Transmission loss on DC side*	60%	100%

* Transmission losses = Current^2 × cable resistance
Because the solar cell current is the same for both systems, the transmission losses are proportional to the cable resistance (the length of the cables if they have the same diameter).

3. Photovoltaic Power Generation System for the Abu Mega-solar Plant in the Okinawa Electric Power Company, Incorporated

Figure 5 shows an overview of the Abu mega-solar plant. The Okinawa Electric Power Company, Incorporated installed the 1 MW power output Abu mega-solar plant in Nago City, Okinawa prefecture. The objective of this plant was to gain knowledge about the effects on the power grid if photovoltaic power generation is introduced to contribute to reductions in CO_2 emissions and to improve the ratio of zero-emission power supplies. Fuji Electric supplied a package of mechanical and electronic equipment, including devices and a remote monitoring control system. Operations began at the end of March 2012.

For the solar cells, 2 types of thin film solar cell were selected (CIGS type and amorphous silicon + polycrystalline silicon multi-junction type), for an evaluation of the solar cells suitable for the meteorological conditions in Okinawa prefecture.

Figure 6 shows an outline of the Abu mega-solar plant system. The characteristics of this facility are as follows:

(a) There is monitoring control at the 2 locations of

Fig.5 Overview of Abu mega-solar plant (Photograph supplied by the Okinawa Electric Power Company, Incorporated)

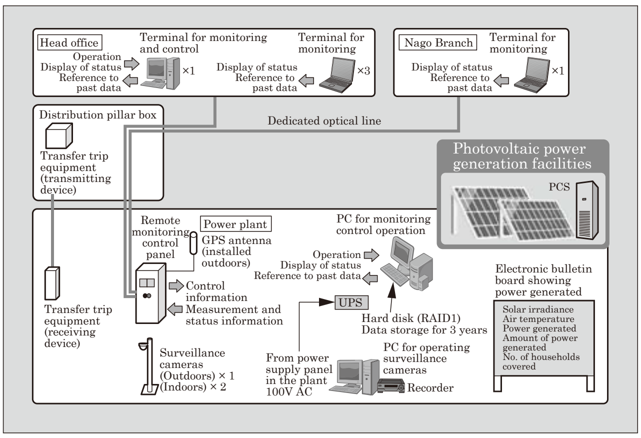


Fig.6 Outline of the Abu mega-solar plant system

the power plant and the head office, and monitoring at a branch.

(b) Generated power output control and reactive power control have been realized.

(c) It is possible to compare the amount of power generated, etc., for different angles of array installation.

(d) Large-capacity 500kW PCS×2 systems are used.

4. Large-Capacity Power Conditioners

The demands placed on mega solar are for a reduction of the unit cost per watt for the solar cells, as well as for high reliability and a reduction of the power generation unit price of the PCS, which is a major component. For this reason, it is necessary for the PCS to realize high efficiency, reduced total costs and the high reliability necessary for connection to the power system.

For these reasons, Fuji Electric commercialized the "PVI1000 Series" and "PVI750 Series," which realize these aims. Figure 7 shows the external appearance of the PVI1000 Series and Fig. 8 shows the external appearance of the PVI750 Series.

Table 2 shows the PCS specifications. The main characteristics are as follows.

(a) An advanced T-type neutral-point-clamped (AT-NPC) 3-level insulated gate bipolar transistor module is used to achieve the global top level efficiency of 98.5%.[1]

(b) Both the 1,000 kW and 750 kW PCS are substation types that integrate the step-up transformer and PCS on a common base and they can be installed outdoors. A standard specification and a salt-tolerant specification have been prepared to suit the installation location. Cooling by air conditioner was made unnecessary to reduce installation costs. Cooling is possible with just the built-in fan, and the power supply capacity for cooling is around 2 kW.

(c) To achieve high reliability, a fault ride through (FRT) function was included as standard.[1]

(d) The AC circuits and DC circuits of the 250 kW unit have been placed in a parallel configuration, and even if one of the units fails, the Fuji

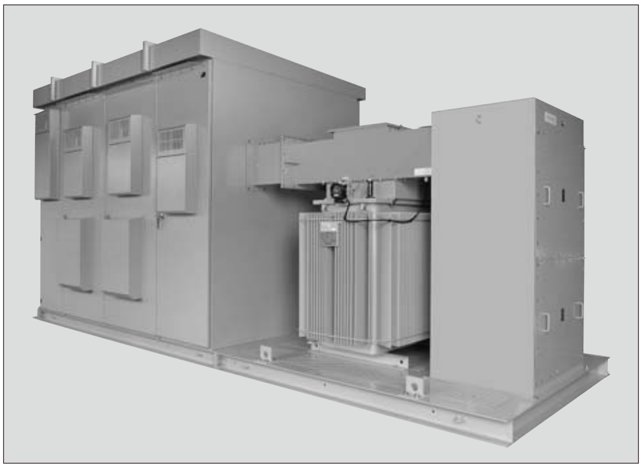


Fig.7 "PVI1000 Series"

Fig.8 "PVI750 Series"

Table 2 PCS specifications

Item	Product		
	PVI1000-3/1000	PVI750-3/750	PVI750-3/500
Rated output	1,000 kW	750 kW	500 kW
Max. DC input voltage	1,000 V	750 V	750 V
DC input voltage (MPPT control range)	460 to 850 V	320 to 700 V	320 to 700 V
No. of DC input branch circuits	4 (Optional: 24)	4 (Optional: 24)	5
PCS output voltage	270 V AC (–12 to +10%)	200 V AC (±10%)	200 V AC (±10%)
Equipment's max. efficiency (without power loss for internal control)	98.5%	97.8%	97.7%
Installation location / method	Outdoor package (built-in PCS + TR + LBS)	Outdoor package (built-in PCS + TR + LBS)	Indoors (PCS and DC input panel) (Separate housing necessary if installed outdoors)
Cooling method	Forced air cooling	Forced air cooling	Forced air cooling (Separate air conditioning equipment is necessary)
Dimensions	W 6,150× D 2,400× H 2,830 (mm)	W 6,150× D 2,400× H 2,830 (mm)	W 2,400× D 900× H 1,950 (mm)
Mass	About 13,000 kg (including step-up TR + LBS panel)	About 12,200 kg (including step-up TR + LBS panel)	About 2,000 kg (PCS and DC input panel)
Acoustic noise	85 dB or below	85 dB or below	75 dB or below

Electric service personnel can remove the failed unit and operations can continue using the sound units remained.

(e) The 1,000 kW PCS has a maximum DC input voltage of 1,000 V, which is the global standard. Furthermore, as a safety standard for the equipment, third-party certification was obtained for IEC 62109 (Safety of power converters for use in photovoltaic power systems).

5. Monitoring Control System for Mega Solar

Monitoring control systems for mega solar play an important role in the power generation status of the power plant, the early detection of failures on equipment such as PV module, connection box and PCS, the understanding of the operating status of the equipment and the long term maintenance and operation.

Specifically, these include the early discovery of equipment failure through the collection of data and the communications network etc., the improvement of the operating ratio of the power plant through preventative maintenance based on equipment trend analysis and also the reduction of maintenance and operation expenses through the reduction of maintenance and inspection work hours at the site. These make a contribution to the maximization of profit for the power generation company.

Fuji Electric's monitoring control system for photovoltaic power generation plants was developed based on CitectSCADA, a general-purpose SCADA package. For this reason, in addition to being able to support power generation facilities from various manufacturers, it also has high reliability and high scalability.

5.1 Monitoring control system configuration

Figure 9 shows the configuration of the monitoring control system. The remote station (RS) panels that perform data collection and the communications network equipment are placed in the area of the mega solar installation. A master data collection device and monitoring server are placed in the "Center." When PCS of Fuji Electric is used, it is possible to integrate the RS panel functions into the PCS.

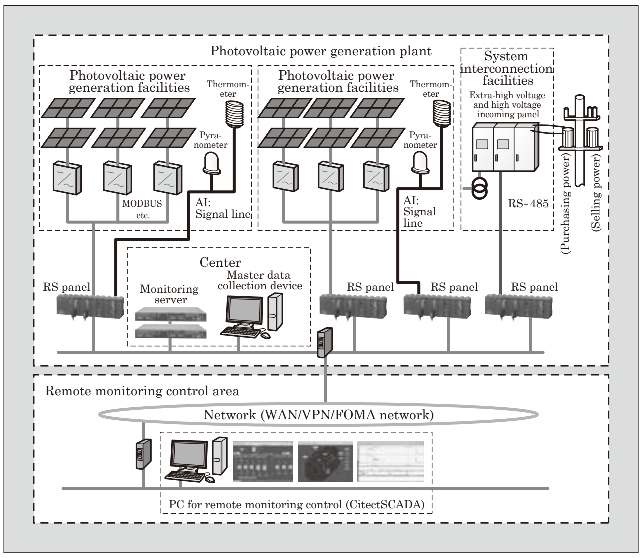


Fig.9 Monitoring control system configuration

In addition, the data communications are compliant with hardware configurations such as Ethernet and RS-485 and open protocols such as TCP/IP and MODBUS. Furthermore, if a wide area network environment is used, it is also possible to perform monitoring control from a remote location.

5.2 Characteristics of monitoring control system

The monitoring control system is built based on the highly functional monitoring control SCADA package (CitectSCADA), and it has the following characteristics.

(a) CitectSCADA has been accepted widely in various fields such as social infrastructure and industry. It already has a track record of over 50,000 licenses supplied around the world and it is highly reliable.

(b) It is designed for web servers and for display servers, and has high speed, extensibility and redundancy.

(1) High speed

Data communications are continually optimized and unnecessary communications are reduced so that, even on large-scale systems, it achieves high-speed data collection and display.

(2) Extensibility

The measurement signals can be increased from 75 points to 400,000 points and various systems from small-scale to large-scale configurations can be supported.

(3) Redundancy

In the construction of communications and servers, completely redundant configurations are possible with just simple settings. This realizes a safe system on which operations will not be damaged even if a problem occurs with the network or a server.

(c) The five functions of I/O, alarms, trends, displays and reports can be split into multiple servers to fit the scale of the system, and various systems up to extremely large-scale system can be realized.

(d) The web function and multilingual function make it possible to obtain information on the photovoltaic power generation system at any time and from any location around the world.

5.3 Functional Structure of Monitoring Control System

The main targets monitored by the monitoring control system are as follows:

(a) System interconnection facilities

(b) PCS

(c) Photovoltaic power generation facilities (Junction boxes and connection boxes)
(d) Meteorological and other environmental data

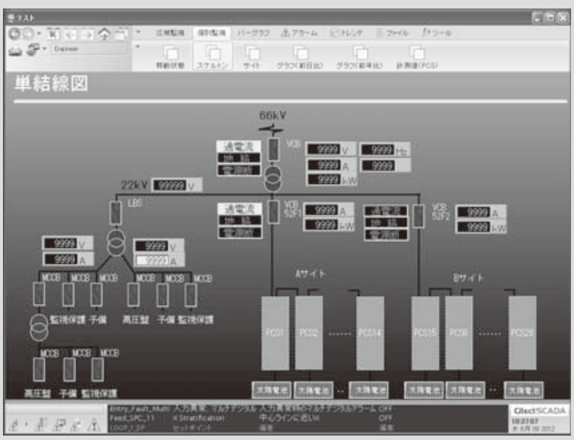
Table 3 shows the standard monitoring screens and the main functions. Figure 10 shows examples of monitoring screens.

Fuji Electric's monitoring control system has the standard monitoring control functions and optional functions to meet the individual requirements of customers. Examples of this include linking with other systems through the automatic generation of CSV files and control of the number of PCS units, which is performed to respond to requests from the electric power companies for a restriction of the generated output. It is possible to flexibly configure these various extension functions.

Table 3 Standard monitoring screens and main functions

Standard monitoring screens	Main functions
Wide area monitoring overview Individual area overview Skeleton monitoring screen Power generation status monitoring screen Meteorological data screen Trend monitoring screen Alarm monitoring screen	Web function Multilingual function Process analyst function Security function Mail sending function Reporting function (Annual, monthly and daily reports) Function for linking to other systems

(a) Wide area monitoring overview



(b) Skeleton monitoring screen

Fig.10 Example of monitoring screens

6. Measures for Microgrids

The output of photovoltaic power generation and other renewable energies is unstable because it is affected by environmental conditions such as the solar radiation and temperature at the place of installation. In the future, when there is large-scale connection of these to the power grid, there is concern that there may be adverse effects on the power grid, for example, from the generation of surplus power, voltage fluctuations and frequency fluctuations. Solutions must be found to these issues.

Fuji Electric has realized the balanced operation of diesel power generation together with renewable energies such as photovoltaic power generation and wind power generation with systems using a stabilizer with storage batteries and capacitors for remote islands power systems in the Kyushu Electric Power Company, Incorporated and The Okinawa Electric Power Company, Incorporated. These systems are verification facilities for microgrids aiming to reduce CO_2 and lower the cost of power generation.(2) The proliferation of the technologies verified is expected as they are systems that absorb the changes in demand and the fluctuations in output from renewable energy sources in the region by having facilities to store the electric power, and as they are also systems that are kind to the network and do not affect the existing electric power. At the same time, these technologies can be utilized as system interconnection technology for mega solar.

7. Postscript

Mega solar is a system of power generation that contributes to the prevention of global warming and the protection of the global environment, and it is expected that its proliferation will continue for the time being through the "Feed-in Tariff Scheme for renewable energy." We will utilize the technologies we have accumulated so far in distribution system control and microgrids, and will work at large-scale photovoltaic power generation that considers the effects on the power network. We will also continue to develop and apply new technologies to offer systems that match the requirements of the market.

Reference

(1) Fujii, K. et al. "PVI1000": Outdoor High-Efficiency Power Conditioners for Mega Solar Projects. FUJI ELECTRIC REVIEW. 2012, vol.58, no.4, p.202-206.
(2) Kojima, T., Fukuya, Y. Microgrid System for Isolated Islands. FUJI ELECTRIC REVIEW. 2011, vol.57, no.4, p.124-129.