“PVI1500CJ-3/2500” 1,500-V DC PCS for Mega Solar Systems

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ABSTRACT

In recent years, it has been anticipated that the market for renewable energy equipment, including solar cells, will increase throughout the world. Fuji Electric has developed a high-voltage high-capacity power conditioning system (PCS) for overseas markets that has an input voltage of 1,500 V DC and an output capacity of 2.5 MW. The PCS comes with an outdoor panel structure that complies with IP55 dustproof and waterproof standards. In addition, it has achieved a smaller installation footprint through its improved cooling performance and optimized layout of the components. In order to meet the expected growth of the Southeast Asian market, the PCS meets grid interconnection codes in Thailand and the Philippines.

1. Introduction

The newly added generating capacity of solar power generation systems has been increasing worldwide. It is expected that the capacity of 94,000 MW in 2017 will increase to 154,000 MW in 2022.(1) Asia accounts for more than 60% of the total capacity. Large growth is expected especially in Southeast Asia and India.

Fuji Electric has been providing 1,000-V direct current (DC), 1-MW power conditioning systems (PCSs) for solar power generation by mainly targeting the Japanese market.(2) In view of the increasing demand outside Japan, we are considering the entry to overseas markets.

This paper describes the features, functions and performance of the “PVI1500CJ-3/2500,” a 1,500-V DC PCS for mega solar systems developed for overseas markets.

2. Features

Figure 1 shows the external appearance of the PVI1500CJ-3/2500.

2.1 PCS with larger capacity

The equipment capacity of this PCS has been increased from 1 MW of the conventional model to 2.5 MW. Increasing the capacity while suppressing the increase in size of each PCS unit as much as possible allows reduction in the number of PCSs and the installation footprint.

Fig.1 “PVI1500CJ-3/2500”

2.2 Supporting of 1,500 V direct current

In general, increasing the number of solar panels connected in series to support high voltage can reduce the number of columns of panels connected in parallel. This reduces the number of junction boxes and direct current cables used for each branch, resulting in the cost reduction of the PCS auxiliary equipment. Consequently, high voltage solar power generation systems with 1,500 V DC are increasing. To respond to the situation, our PCS has also moved to support higher input voltage of 1,500 V DC from 1,000 V DC of the conventional model.

2.3 Outdoor panel structure

Fuji Electric has already adopted dustproof and waterproof outdoor panel structure with a degree of protection of IP55. When a PCS installed outside without using a enclosure is compared with an indoor panel

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structure where a PCS is installed inside a container and the surrounding temperature is controlled with an air conditioner, the outdoor panel structure achieves efficiency of approximately 1.5% higher because it does not entail the power loss caused by the air conditioner while the efficiencies of the PCSs themselves are the same.

2.4 Compliance with global grid interconnection codes

In order to respond to the demand in Southeast Asia, this PCS complies with the grid interconnection codes in Thailand and the Philippines, PEA Interconnection Code and Philippine Grid Code, respectively. The setting of the PCS can be switched to ensure compliance according to the destination country.

3. Equipment Configuration

Figure 2 shows the circuit configuration of the PCS. The capacity of 2.5 MW has been achieved through the parallel run of three 833-kW inverter units. The PCS conducts the maximum power point tracking (MPPT) control so that the output power of the solar cells is kept maximum at all times. We calculated the input voltage range where the MPPT control is possible and set it between 915 and 1,350 V DC. The output voltage is 590 V AC and is boosted with the interconnection transformer located outside the PCS panel before the connection to the grid.

The inverter unit uses the I type, NPC3 level inverter circuit to operate at 1,500 V DC. As shown in Fig. 3, when compared with the T type, A-NPC3 level circuit, this circuit can reduce the voltage applied to each insulated gate bipolar transistor (IGBT) from 88.0% to 62.5% of the device rating. The higher the voltage applied to an IGBT, the more the risk of chance failure caused by cosmic rays increases. We therefore selected the I type, NPC3 level inverter circuit to improve reliability.

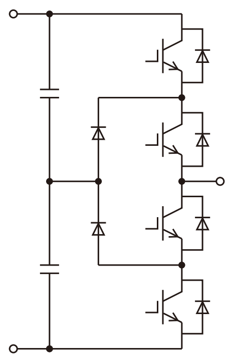
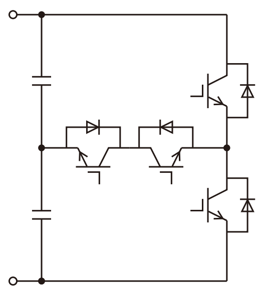
	PVI 1500CJ-3/2500	Conventional model
Type	I type NPC 3 level	T type A-NPC 3 level
Circuit		
Device	1,200 V × 2 in series	Main: 1,700 V Intermediate: 1,200 V
Duty	1,500 V / (1,200 V × 2) = 62.5%	1,500 V / 1,700 V = 88%

Fig.3 Inverter circuit configuration

4. Equipment Specifications

Table 1 shows the equipment specifications of the PCS. As described earlier, input voltage is 1,500 V DC, power capacity is 2.5 MW, and the operating temperature range is −10°C to +57°C (−20°C to +57°C with cold region option). To protect the parts inside, the output is suppressed when the ambient temperature is 40°C or higher. To ensure operation even in hot environment of Southeast Asia, we designed the PCS so that it can output 90% of the rating even at the temperature of 50°C.

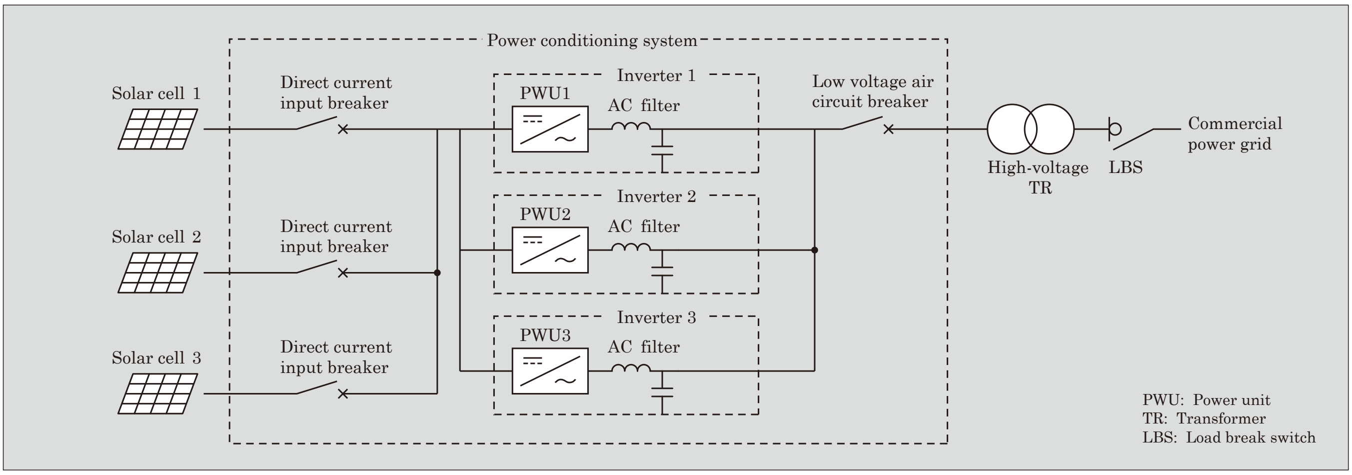


Fig.2 PCS circuit configuration

Table 1 Equipment specifications

Item	Specification
Capacity	2.5 MW
Direct current voltage range	840 to 1,500 V
MPPT*1 range	915 to 1,350 V
Maximum input current	2,788 A
Alternating current voltage	590 V (−12% to +10%)
Frequency	50/60 Hz
Power factor	0.99
Harmonic distortion	5%
Maximum efficiency*2	98.70%
Euro efficiency*3	98.50%
Internal power supply capacity	3,000 W or less
Stand-by loss	350 W or less
Dustproof/waterproof standard	IP55
Operating temperature	−10°C to +57°C

*1 MPPT: Maximum power point tracking
*2 Maximum efficiency: IEC 61683 efficiency tolerance, not including internal power supply
*3 Euro efficiency: 90% output at 50°C in temperature derating at 40°C or higher

5. Equipment Operation

5.1 Improved power generation

The output from solar cells fluctuates and is not always constant depending on solar irradiance, module temperature and other conditions. To increase the amount of power to be generated, it is necessary to improve the accuracy of the MPPT control and the conversion efficiency of the PCS.

The PCS conducts the MPPT control by using the hill-climbing method, which gradually changes the output voltage from the solar cells gradually by the specified voltage change range so that the output power (current × voltage) from the cells becomes larger. In addition, the PCS is provided with the sweep mode function as shown in Fig. 4.

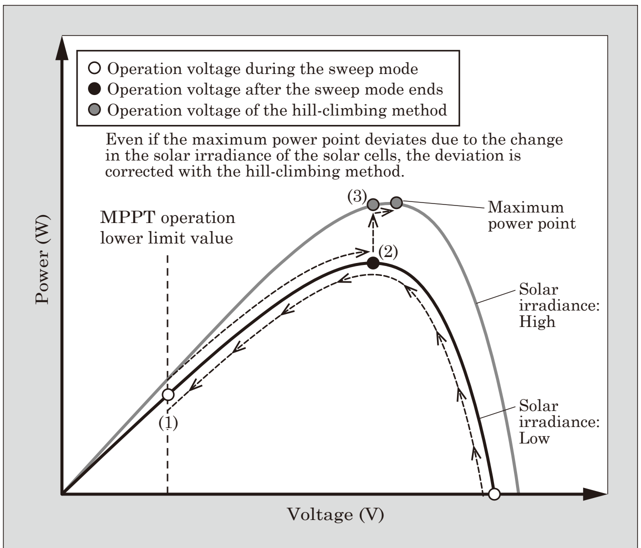


Fig.4 Sweep mode function

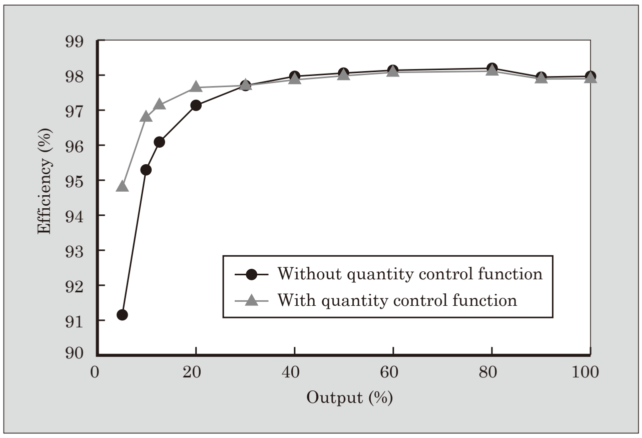


Fig.5 PCS efficiency curve

(1) When the operation starts, the PCS automatically enters the sweep mode to change the output voltage from the solar cells to the MPPT operation lower limit value by the specified voltage change range at the specified speed [see Fig. 4(1)].

(2) When the voltage reaches the MPPT operation lower limit value, it returns to the operation voltage that led to the maximum power during the sweep [see Fig. 4(2)].

(3) After that, the PCS continues operation at the optimal voltage based on the hill-climbing method until it stops [see Fig. 4(3)].

With the sweep mode, the PCS can find the maximum power point even in the solar cell configuration of which the output characteristic of the solar cells has two peaks, resulting in increased amount of power generation.

Furthermore, to improve the conversion efficiency of the equipment, this PCS offers the quantity control function to limit the number of inverter units to be used under low load. Reducing the number of inverter units to be used under low load has reduced the no-load loss and improved the efficiency under low load. Figure 5 shows the difference in the efficiency with and without the quantity control function. The efficiency can be improved by approximately 0.6% when the load factor is 20% and 1.6% when the load factor is 10%.

5.2 Outdoor panel structure and thermal cooling of the components

As for PCSs installed in outdoor environment, it is necessary to protect the precision instruments, such as inverter units and control parts, from outdoor environments. It is also necessary to discharge the heat produced from the PCS. In order to address these issues, we divided the inside of the panel into an airtight area and an outside air area as shown in Fig. 6. The precision instruments are stored in the airtight area and isolated from the outside air environments. The heat from the parts generating low heat, such as control substrates, is dissipated with heat exchangers which cool the airtight area. As for IGBTs and other parts

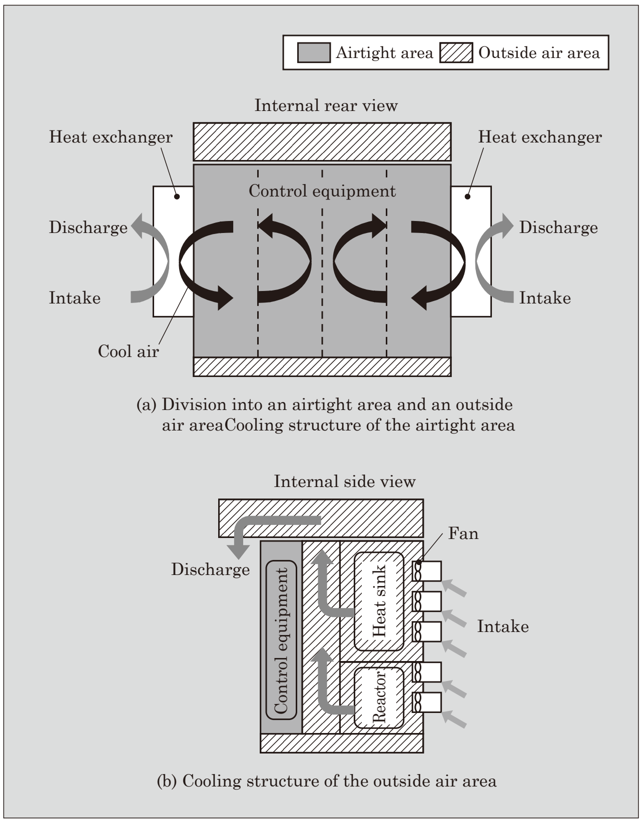


Fig.6 PCS cooling structure

generating high heat, only their heat sinks are exposed to the outside air area and cooled with outside air.

In the Asian markets, low cost is also an essential requirement. While the conventional model used four inverter units, this PCS uses three units with increased capacity per unit. This prevented the increase of the equipment volume and installation footprint. In order to address the increase of the heat produced from the units, we conducted wind velocity simulation as shown in Fig. 7 and addressed the issue by improving the cooling air path and increasing the flow rate of the fans.

This PCS has the smallest class installation footprint in the industry among the PCSs of the same capacity.

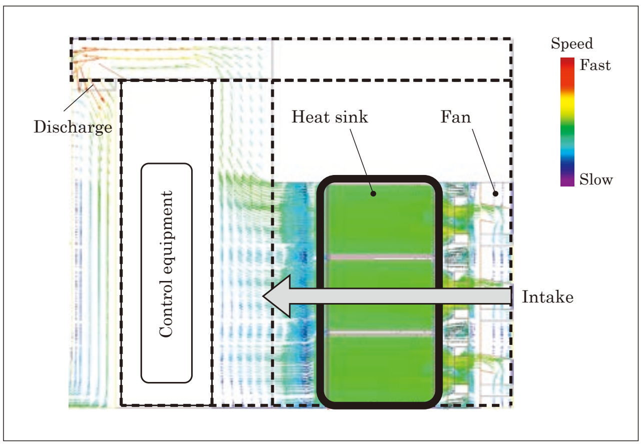


Fig.7 Wind velocity simulation result

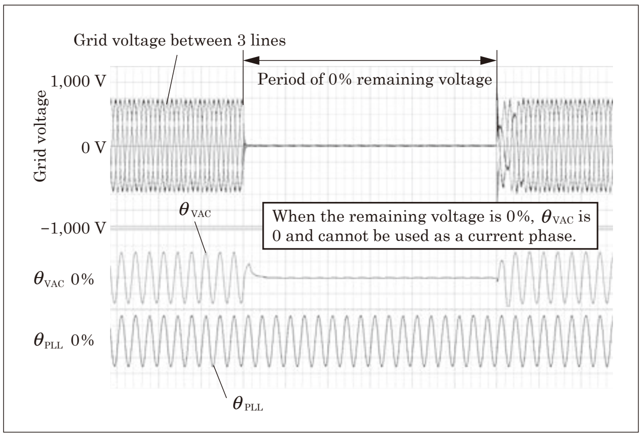


Fig.8 Comparison of current phase θ at voltage drop

5.3 Grid compensation (DVS: dynamic voltage support) function

PCSs are required to continue operation specified in the standards and codes even when an accident occurs in the grid such as three-phase short-circuit or two-phase short-circuit. The Philippine Grid Code, the grid interconnection code in the Philippines, for example, requires the DVS function that will perform grid compensation during three-phase short-circuit. The PCS must output current to the power grid in accordance with the voltage remaining in the grid (remaining voltage).

The current control of the PCS uses θ_{VAC} which is the current phase calculated from the grid voltage. When, however, the grid voltage is 0% as shown in Fig. 8, the PCS cannot output current because it cannot calculate current phase θ_{VAC}. In such a case, the PCS uses a phase-locked loop (PLL) circuit to calculate θ_{PLL}, which is the current phase before the voltage drop, and switches phase θ to be used for the current control to phase θ_{PLL}.

When the operation with 0% remaining voltage was verified with function verification unit (23 kVA), the PCS output current in accordance with the voltage drop and satisfied the requirements of the standard compliance test. Improving the control in this way allows the PCS to output current even when the grid voltage is 0%.

6. Postscript

This paper described the "PVI1500CJ-3/2500," 1,500-V DC PCS for mega solar systems. The energy demand is increasing worldwide and the expectation for solar cells and other renewable energies, in particular, will likely grow further in the future. Fuji Electric is determined to contribute to measures against global warming by promoting this product in the Southeast Asian market where future expansion is expected.

References

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