"PVI1000": Outdoor High-Efficiency Power Conditioners for Mega Solar Projects

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ABSTRACT

The solar power market ranges from home power generators to large-scale installations for Mega Solar projects. Fuji Electric developed an 1 MW power conditioner (PCS) that is optimal for these Mega Solar projects. This PCS achieves world-class efficiency through use of an AT-NPC 3-level IGBT module. In addition, setup costs are reduced as the high-voltage transformers and the PCS are integrated on the same stage into a sub-station. Furthermore, it achieves highly reliable solar power generation through Fault-ride-through capability and unit parallel redundancy when connecting to a power system.

1. Introduction

The global demand for energy continues to grow and global warming caused by CO_2 is becoming a major problem. With this as a background, there are increasing expectations for electricity generation using renewable energy sources such as solar cells. The size of the global market for solar cells exceeded 10 GW in fiscal 2010 and is predicted to exceed 35 GW in 2015. Furthermore, the demand is not just for residential applications. In various locations around the world, there are rapidly increasing actual records and plans for installations exceeding 1 MW, what we call mega solar power plants. The market for solar cells is also expanding rapidly, not only in Europe, but also in places such as China, the U.S.A., Southeast Asia and India.

Meanwhile, there are multiple mega solar power plants being planned around Japan, on consideration of the start of "Feed-in Tariff System for Renewable Energy" from July 2012. Fuji Electric developed a highly efficient power conditioner (PCS) for outdoor installation which is optimal for mega solar applications. This PCS uses a new circuit system using advanced t-type neutral-point-clamped (AT-NPC) 3-level IGBT module[(1)] employing the latest, Fuji Electric proprietary switching device, reverse-blocking insulated gate bipolar transistor (RB-IGBT)[(2)]. It realizes an operating efficiency at the highest level in the world. This paper explains the characteristics, functions and performance of high-efficiency, outdoor installation PCS "PVI1000" for mega solar applications.

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2. Characteristics

In mega solar systems, there are demands not only for reduction of the unit price per watt for solar cells, but also for the simultaneous achievement of both reductions of the electricity generation unit price and improvements of reliability concerning the PCS, which is a major element of the systems. This means that the following three points are necessary:

(a) The power generating efficiency must be high
(b) The total cost must be low
(c) The reliability must be high, because they are connected to the grid

Fuji Electric developed the PVI1000 that achieves all these. Figure 1 shows its external appearance.

2.1 High Efficiency

(1) Use of RB-IGBT and new circuit system

This is the first practical application in the world of the AT-NPC 3-level IGBT module (see Fig. 2), which

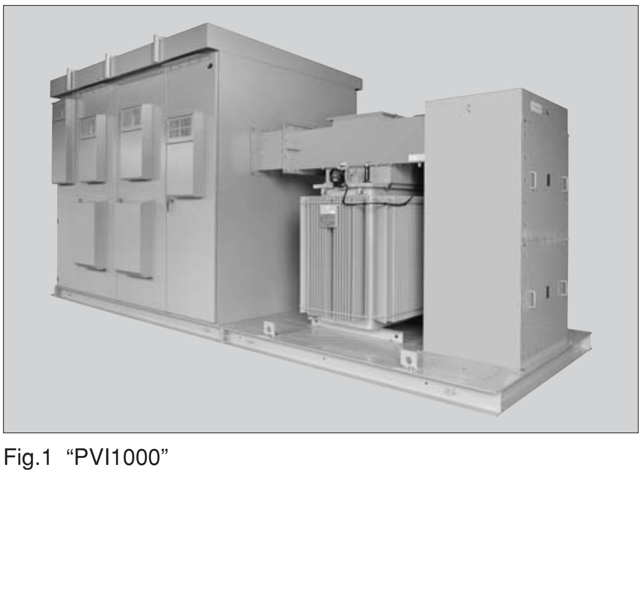

Fig.1 "PVI1000"

Fig.2 AT-NPC 3-level IGBT module

is equipped with the RB-IGBT and conventional IGBT in one package. By using this module for a 3-level conversion circuit, it is possible to simultaneously achieve a great reduction in both power losses and the number of components.

(2) Achievement of world-leading 98.5% efficiency

By applying the 3-level IGBT module to the new power conversion technology (AT-NPC 3-level conversion circuit), the switching loss in the IGBT device is greatly reduced. Furthermore, the filter loss is reduced because the harmonic content included in the PWM waveform output voltage from the inverter is reduced to half of the conventional devices. This results in the achievement of a world-leading high efficiency of 98.5% (IEC 61683 efficiency tolerance, not including internal power supply). It also achieves 98.2% for Euro efficiency, which considers the partial load efficiency and is in a situation close to the actual efficiency of PCS used for solar power generation.

2.2 Reduction in Total Costs

(1) Single unit capacity of 1 MW

A large capacity of 1 MW per single unit is realized. For use in large-scale mega solar systems, increasing the capacity per single unit means that fewer PCS are necessary, which leads to the reduction of the space required for installation.

(2) Outdoor substation type

The PCS panel is suitable for installation outdoors, and there is no need for a container to cover the PCS panel and air conditioning. Furthermore, fuses for a direct current branch can be built-in inside the PCS panel as an option, and the output of the solar cells collected at the connection box can be connected directly to the PCS.

A substation type has been adopted for the structure of the PCS, where switchgear necessary between PCS and the grid, and a high voltage transformer (corresponding to outdoor use) are built together on a common base. It can be delivered as it is from the factory to the customer's site, and installation costs can be reduced.

2.3 High Reliability

(1) FRT function

A fault ride through (FRT) function, which is becoming essential on PCS for mega solar, is included as standard in the PVI1000. With the FRT function, even when there occurred a three-phase short-circuit or a two-phase short-circuit accident in the grid, the inverter outputs a three-phase current within the regulated range (the momentary power dip time and the extent of the voltage drop required in each country), working to suppress the fluctuation in the grid.

(2) Units in parallel

The single unit of 1 MW capacity inverter is constructed from four 250 kW inverter units. Even if one of the component units fails, the electricity generation can be continued with the remaining units. Even if one of the inverter units can not operate during the daytime, the electric power generated by 1 MW of solar cells (maximum 750 kW) can be output until its maintenance at night. The availability factor can therefore be better than the systems using separate PCS for each 250 kW.

2.4 Global Standard

The product supports the connection of grid voltages from 4.15 to 34.5 kV, and the direct current input voltage is possible up to the global standard of a maximum 1,000 V DC. Furthermore, the IEC 62109 is supported as the electrical safety standard (with the acquisition of 3rd party authentication planned), and, as an option, the IEC 61000-6-2 and CISPR11 EMC specifications can also be supported.

3. Specifications

Table 1 shows the PVI1000 specifications. The direct current voltage range supports the 1,000 V DC

Table 1 "PVI1000" specifications

Item	Specifications
Capacity	1 MW
DC voltage range	450 to 1,000 V
MPPT range	460 to 850 V
Maximum input current	2,440 A
AC voltage	270 V (−12 to +10%)
Frequency	50/60 Hz
Power factor	0.99
Total harmonic distortion in current	5%
Maximum efficiency*	98.5%
Euro efficiency*	98.2%
Internal power supply capacity	2,000 W or less
Stand-by loss	200 W or less

*IEC-61683 efficiency tolerance indication, excluding internal power supply

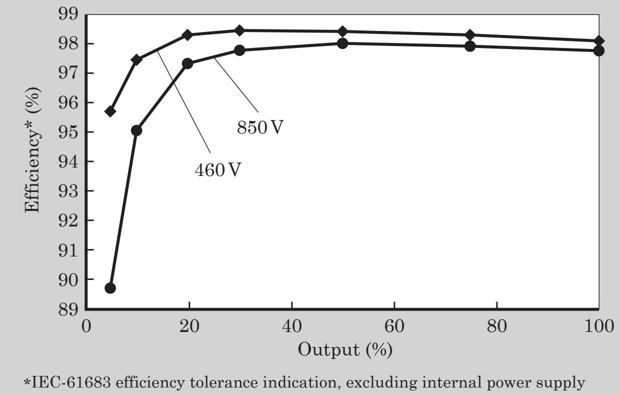

Fig.3 Efficiency curves

which is becoming standard in Europe and the U.S.A. The maximum power point tracking (MPPT*1) range for the rated output is 460 to 850 V. The alternating current voltage is 270 V and the voltage is transformed to the grid voltage at each site with the transformer connected. The maximum efficiency and the Euro efficiency which is partial load efficiency are the figures at the time when the DC open circuit voltage is 460 V.

Figure 3 shows the efficiency curves when the solar cell voltage is 850 V and 460 V. The efficiency will vary depending on the value of the solar cell voltage, and the efficiency curves for the upper limit values and lower limit values are shown.

4. PCS Structure and Operation

4.1 Circuit Configuration

As shown in Fig. 4, the circuit configuration of the PVI1000 is composed of four 250 kW units. The DC input is drawn as four inputs in the figure, but these can be increased to a maximum of 24 inputs. Two inputs are connected to a single breaker and the outputs from 2 breakers are connected to one DC link. This makes the four inverters operate on the same DC voltage and no circulating current is generated among

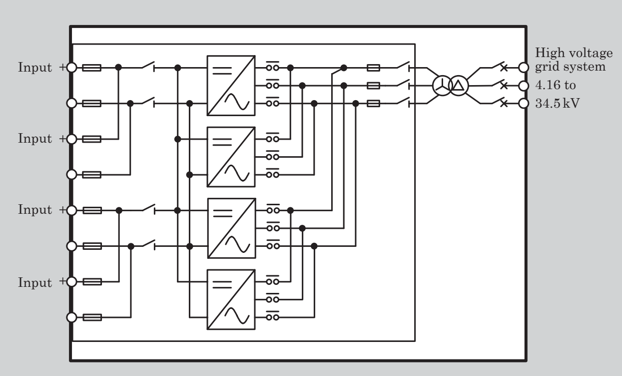

Fig.4 Circuit Configuration

*1: MPPT: See “Explanation 4” on page 218

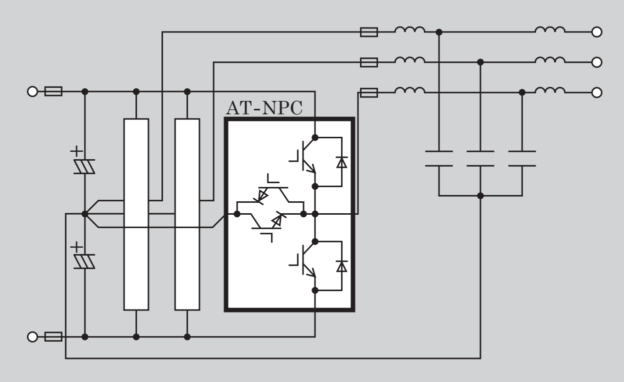

Fig.5 Power unit and filter circuits

units because each unit is switched on the same carrier. Moreover, when starting up, as the connection to the grid is performed so that the contactor switched on in the state each inverter outputting voltage synchronized with the grid, the start-up can be completed without any generation of a rush current to the grid.

Each unit which realizes the inverter is composed of a 3-level inverter, fuses and LCL filters (see Fig. 5). This kind of 3-level circuit had already been proposed in the 1980s(3), but inability to lower the withstand voltage of the IGBT device prevented widespread of its use. However, in an inverter, where the connection of devices in series is not necessary, as it is possible to reduce the number of devices that the output current passes, there is the merit that the conduction losses can be reduced. Fuji Electric therefore has developed the practical application of a 3-level IGBT module using an RB-IGBT as the switch for connecting the AC output and DC midpoint where a reverse withstand voltage is necessary. Using this, it is possible to realize 3-level inverters with the same number of modules as conventional 2-level inverters. The practical application of highly efficient inverters is therefore achieved without any increase in circuit cost.

4.2 Outdoor Panel Structure

Up until now, when power electronics equipment with forced air cooling was placed outside, it was often the case that an indoor panel was stored inside a container for outdoor use and cooling was done using an air conditioner. However, with this method, as the air conditioner accounts for roughly 1/2 to 1/3 of the generated loss, it is disadvantageous for PCS, for which operating efficiency is considered an important factor. Furthermore, when the storage in a container is not done and a filter for outdoor use is placed on an ordinary indoor panel, as the replacement cycle for the filter becomes extremely short, there is the problem that the maintenance cost would increase.

We therefore used the double structure shown in Fig. 6. The power unit (PWU), which is made up of the dust intolerant printed circuit board and IGBT module, is placed in an airtight area and isolated from

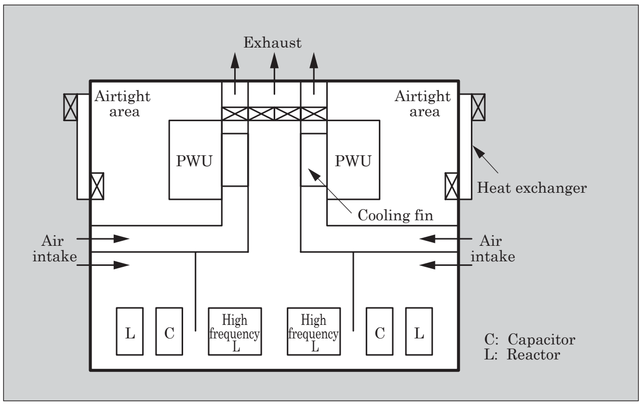

Fig.6 Outdoor panel structure

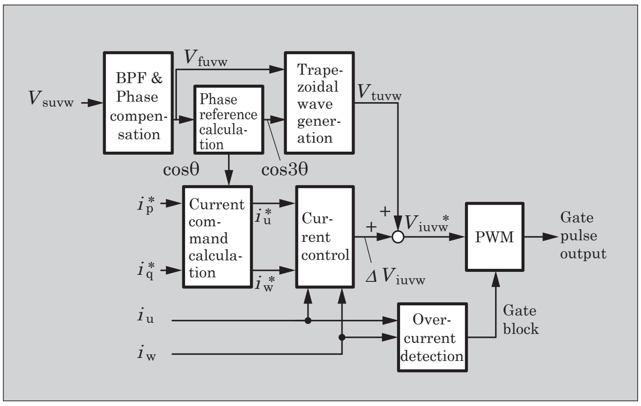

Fig.7 Block diagram for control logic of inverter

the outside air. The cooling fins and filter circuits are cooled using outside air. With this method, as the filter on the part taking in the outside air can just be wire netting sufficient to prevent garbage and small animals from entering, maintenance becomes unnecessary. Furthermore, by using a filter like this, it is possible to increase the air flow for the forced air cooling, and the miniaturization of the equipment as a whole becomes possible.

Also, the structure is designed so that the heat generated by the PWU in the airtight area is exhausted to the outside with a heat exchanger using a heat pipe. This makes the dust in the outside air completely blocked from the airtight area, and the PCS can be protected from malfunctions caused by dust.

4.3 FRT Function and Inverter Control method

An FRT function is demanded of PCS in preparation for large-scale introductions to the grid. This FRT function is already mandatory in Europe and the U.S.A., and will become mandatory in Japan for equipment introduced from fiscal 2013. Furthermore, the levels demanded for the FRT function (residual voltage and duration) vary from one country to another. We balanced the costs with the required specifications by making continued operation possible with 0% residual voltage and offering an option for a backup method of the control power supply for improving the duration. The system was designed so that the control power supply can be selected from either an external grid supply or from self-supply within the system. If a supply from the grid is selected, a power dip of 1 s or shorter is backed up with an internal capacitor. If a backup is required for a long period of time, it is decided to install an external UPS.

Furthermore, as shown in Fig. 7, to support the FRT function, the current phase reference cosθ and the voltage base (equivalent to the grid voltage at the connection point), which were previously generated in the phase-locked loop (PLL), are changed to be referenced from the grid voltage[(4)]. Ordinarily, if the grid voltage is referenced directly, then system resonance and output current distortion can sometimes occur. A band-pass filter (BPF) is therefore used to remove the high frequency component from the grid voltage detected, to realize a high-speed response to grid abnormalities and a countermeasure to grid resonance. From this BPF output, the compensated value of the output filter phase delay is taken as V_{iuvw} and we determine the current phase reference cosθ and trapezoidal wave voltage base V_{tuvw} which are necessary for converting the dq axis current command i_p*, i_q* into three-phase current commands from this value. Furthermore, in order to prevent any overcurrent caused by rapid changes in the voltage, a mechanism is adopted to perform a gate block as soon as any overcurrent is detected.

The operation resulting from these improvements to the control was verified using control verification equipment (20 kW). With a residual voltage of 0%, it becomes a continuous gate lock state, and the output current becomes 0 A. However, as shown in Fig. 8, it was confirmed that when the residual voltage is 20%, an intermittent gate lock stops occurring 6 ms after the power dip occurs, and after roughly 2 cycles, the rated current can be output. In this way, it was confirmed that even when power dips occur, the PCS can continue operating.

Furthermore, there is also an option for a grid compensation dynamic voltage support (DVS) function. The DVS is a function to stabilize the grid voltage when a power dip occurs and when the power returns. Reactive current decided by the user is output according to the grid voltage level. Even if the grid phase be-

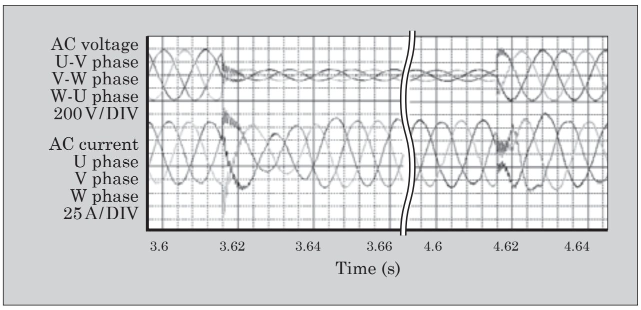

Fig.8 FRT verification waveforms

comes into an unbalanced state such as with a two-line short circuit, by putting the V_{tuvw} shown in Fig. 7 to an unbalanced state in accordance with the grid, it is possible to output a balanced three-phase current.

When the FRT function operates, it is sometimes the case that the rapid change in the grid voltage causes mistaken detection of islanding mode operation*2. As for the PVI1000, a method of actively detecting islanding mode operation with reactive current fluctuations and a method of passively detecting islanding mode operation with frequency deviations were applied. This makes it possible to both continue operation when there occurs a short-circuit in the grid and to stop quickly when the grid is open.

4.4 Units in Parallel

As shown in Fig. 5, the reason why fuses are installed in the DC and AC parts of the power unit is to cut off short circuit current from other units if the IGBT or the electrolyte capacitor inside the unit fails. If temperature abnormalities, contactor abnormalities or a continuation of overcurrent protection occur in a unit, the operation is stopped and then a start-up is done automatically with the other, problem-free units. However, when there are abnormalities which involve destruction, such as fuses blowing or component device abnormalities, this is judged to be a major failure and the operation is stopped to prevent a spreading of the abnormality.

By using this structure of units with fuses in parallel, even if one of the component units fails, as long as the solar cells are generating 750 kW or less of electricity, it is possible to output the amount of maximum power determined in the MPPT to the grid, and this leads to improved reliability for the equipment.

*2: Islanding mode operation: a state in a system isolated from commercial power supply where electricity flows the power line using only power from the distributed power supply

5. Postscript

The "PVI1000" high-efficiency PCS for installation outdoors is an optimal PCS for mega solar power plants. This is because of its characteristics such as reduction in system cost due to the large capacity of a single unit, reduction in installation cost due to substation type, and increase of generated electricity output due to its high efficiency.

We will continue to make a contribution to the realization of a low-carbon society by promoting even further increases in capacity and efficiency.

References

(1) YATSU, M. et al. "A Study of High Efficiency UPS Using Advanced Three-level Topology." PCIM Europe Conference, 2010.

(2) NAKAZAWA, H. et al. "Hybrid Isolation Process with Deep Diffusion and V-groove for Reverse Blocking IGBTs." ISPSD, 2011.

(3) NABAE, A. et al. "A New Neutral-Point-Clamped PWM Inverter." IEEE Trans. on industrial applications, 1981,vol.1 A-17, no.5, p.518-523.

(4) FUJII, K. et al. "Fault Ride Through Capability for Solar Inverters." EPE Conference, 2011.

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