The Circuit and Control Technology in the Power Conditioner and Converter for Wind Turbine Systems

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ABSTRACT

Because the generating power of wind turbines fluctuates according to changes in wind speed, this affects system voltage. To enable large-scale implementation of wind turbines, power system supply quality is demanded. Power conditioning subsystems are available for stabilizing power as a means to compensate for fluctuations in power supply. Using an AT-NPC 3-level conversion circuit, we have greatly reduced switching loss in IGBT devices and also, by halving harmonic components, we have reached 98.1% efficiency, the highest in the industry. Moreover, we have achieved power supply quality sufficient for grid connection by incorporating a fault ride through function so that the system continues to operate without disconnecting even if there is a drop in system voltage due to lightning strike or other causes.

1. Introduction

The introduction of renewable energy is about to be accelerated by the "Feed-in Tariff Scheme for renewable energy," which was initiated in July 2012. Although conventional wind power generation was mainly done on land, development of offshore wind power generation has accelerated because it has few restrictions in terms of increasing capacity to improve power generation efficiency and selecting from available installation locations, and because the wind conditions offshore are stable. For large-volume introduction of wind power generation in the future, it is becoming essential to improve power quality. Therefore, this paper describes a power conditioner (PCS) that alleviates changes in the amount of wind power generation and contributes to higher power quality, and it also describes circuit technology and control technology on converters for wind power generation.

2. PCS for Power Stabilization

2.1 Structure of wind power generation system with storage battery

The basic structure of a wind power generation system with a storage battery is indicated in Fig. 1. This system is a method of converting the output of a wind power generator to direct current via an AC/DC converter, which is connected to a synchronous generator, and interconnecting to a system by conversion to alternating current via a DC/AC converter. In wind power generation, the amount of power generated is in proportion to the cube of the wind speed; therefore, only a subtle fluctuation in wind speed causes a large fluctuation in the amount of electric power generated.

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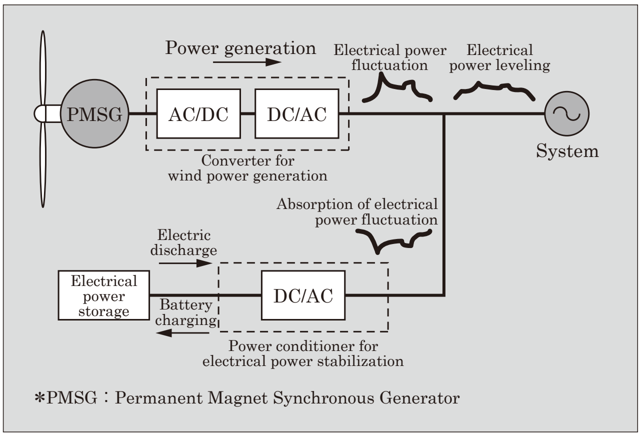

Fig.1 Basic structure of wind power generation system with storage battery

There is a concern about prompting voltage fluctuations or frequency fluctuations in power grids, which would lead to deterioration in electric power quality, when the number of wind power systems increases in the future. A PCS for electrical power stabilization eliminates such concern. For an electrical power storage section, select a lead-acid battery, lithium ion battery, or other type of battery according to the use. Electric power fluctuations in wind power generation are stabilized by means of controlling battery charging and electric discharging of the electrical power storage section by using a DC/AC converter.

2.2 PCS for electrical power stabilization "PVI750-3/500"

Figure 2 indicates the external appearance of PCS for electrical power stabilization, "PVI750-3/500."

(1) System structure

PVI750-3/500 is comprised of two 250 kW inverters (see Fig. 3). In order to replace and maintain storage batteries individually, two secondary-side direct

Fig.2 “PVI750-3/500”

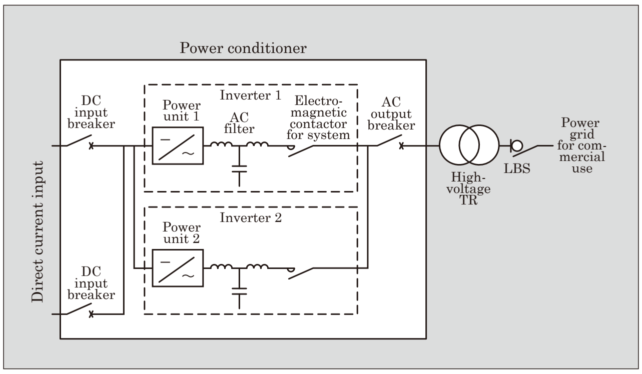

Fig.3 System structure of “PVI750-3/500”

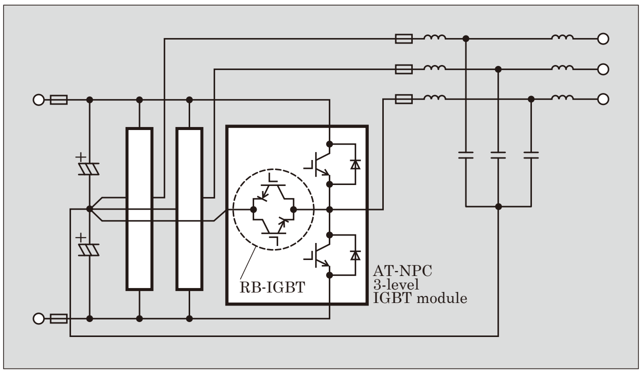

Fig.4 Power unit and filter circuit

current input breakers are connected to one direct current link. During start up, it is possible to complete start-up without generating a rush current in the system by interconnecting to the system by turning the contactor on while each inverter outputs the voltage, which was synchronized with the system.

The power unit of the inverter is comprised of an IGBT module of an advanced T-type neutral-point-clamped (AT-NPC) 3-level, fuse, and LCL filter (see Fig. 4). Although a 3-level converter circuit has already been proposed in the 1980s, it did not become popular because it was not possible to increase the withstand voltage of the insulated gate bipolar transistor (IGBT) element. However, there is a merit that the number of element passages of output current can be reduced and as a result, conductor loss can be reduced in the inverter that does not require elements to be connected in series.

Fuji Electric made practical use of the AT-NPC 3-level IGBT module[1] in which reverse-blocking IGBT (RB-IGBT)[2] is applied to the switch that connects the direct current intermediate and AC output, which requires reverse withstand voltage. As a result, we produced a 3-level inverter comprised of the same number of modules as the existing 2-level inverter and it was possible to achieve a highly efficient inverter without making the circuit complicated.

(2) Specifications

Table 1 shows the specifications of PVI750-3/500. The range of the direct current voltage corresponds to 750 V DC, with which construction at low voltage is possible, and the AC voltage output by the PCS is 200 V. In addition, Fig. 5 indicates the efficiency curve. By using a conversion circuit for which an AT-NPC

Table 1 Specifications of “PVI750-3/500”

Item	Specifications
Capacity	500 kVA
DC voltage range	310 to 750 V
Maximum input current	1,600 A
AC voltage	200 V (–10 to +10%)
Frequency	50/60 Hz
Power-factor	0.99
Harmonic distortion factor	5% or below
Highest efficiency*	98.10%
EU efficiency*	97.80%
Maximum value of internal power capacity	900 W
Stand-by loss	130 W

* Indicate IEC-61683 efficiency tolerance, excluding internal power source

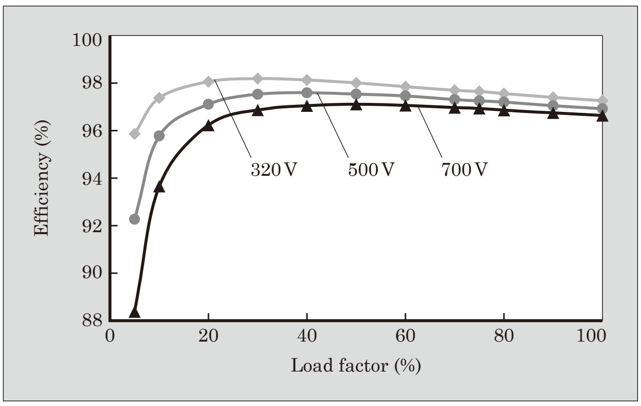

Fig.5 Efficiency curve

3-level IGBT module is applied, the switching loss of the power unit was significantly reduced. Furthermore, by halving the harmonic contained in the pulse width modulation (PWM) waveform that the inverter outputs reduced by one half compared to conventional products, filter loss was reduced and the highest efficiency in the industry of 98.1% (according to IEC-61683 efficiency tolerance, excluding internal power supply) was achieved.

(3) Characteristics (FRT performance and inverter control method)

An fault ride through (FRT) function, which is becoming a prerequisite for new energy sources, is mounted on PVI750-3/500 as standard. The FRT function is used to allow for continuous operation by enabling the inverter to output a three-phase current within the specified range (within the instantaneous voltage drop time and voltage drop required in each country) and suppress electric power fluctuation of the system even if system three-phase short-circuit and two-phase short-circuit occur. This FRT function became mandatory in the EU and USA and it is mandatory for devices that are to be introduced from FY2013 in Japan. In addition, the residual voltage and continuation time required as an FRT function differ depending on the country. As a result, in order to enable continuous operation even with 0% of residual voltage, it became possible for the controlled source to select either external supply or self-supply from the system. Power flickers that last no more than one second are backed up by an internal condenser and there is an option to be able to have continuous time of FRT that exceeds one second. As a result, it has become possible to achieve the requirements from both cost and specification aspects.

The FRT function of operational verification was performed with a control verification machine (10 kW). By putting residual voltage 0% constantly into a gate lock state and by performing 0 A control, operation is continued. As shown in Fig. 6, it was confirmed that at residual voltage 20%, spasmodic gate lock no longer occurs from 6 ms after occurrence of instantaneous voltage drop and it is possible to output a rated current after about 2 cycles. By doing so, it is confirmed that PCS can continue operating when an instantaneous voltage drop occurs.

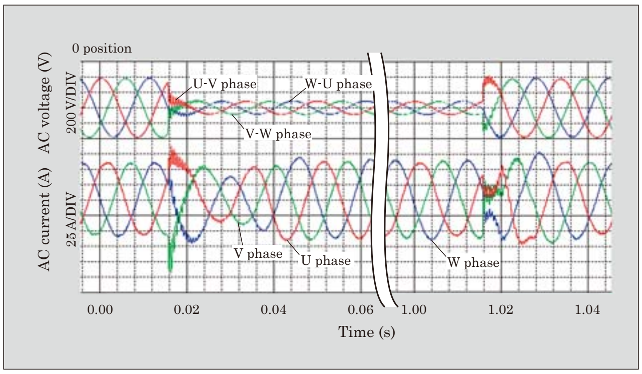

Fig.6 Operation verification wave of FRT function

3. Converter for Wind Power Generation

Figure 7 indicates the structure when a wind power generator is a multi-winding type. Two converter boards of 1,500 kVA are connected in parallel.

A converter board is comprised of 3-parallel DC/AC converters as a water cooling power unit of 500 kVA, chopper, and resistance for energy consumption. This chopper is used to control the DC/AC converter so that the direct current intermediate voltage does not go up at times such as when a system abnormality occurs. A water cooling power unit has a plug-in structure and there are three in parallel, and the converter board consists of two boards in parallel. Therefore, maintainability was improved and when a failure occurs, it is possible to operate with the sound section; as a result, operating ratio was improved. Table 2 indicates the specifications of a converter for wind power generation

3.1 Water cooling power unit

Water cooling power unit that uses IGBT

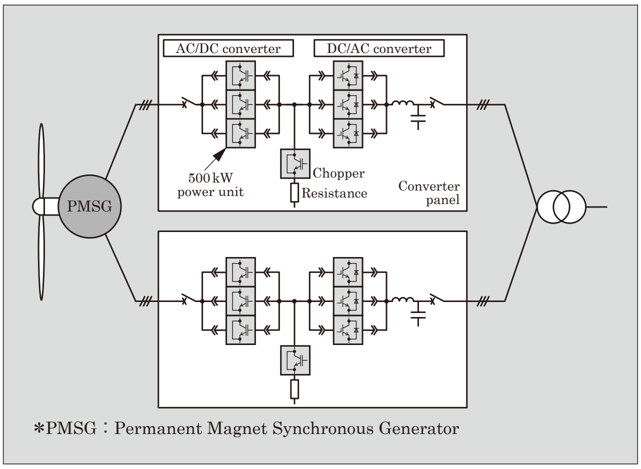

Fig.7 Wind power generation system (synchronous power generator)

Table 2 Specifications of converter for wind power generation

Item	Specifications
Capacity	1,500 kVA×2 (3,000 kVA)
Rated effective power	1,350 kW
Rated reactive power	650 kVar
Rated voltage	690 V
Rated current	1,255 A
Frequency	50/60 Hz
Power-factor	0.99
Harmonic distortion	5% or below
Highest efficiency	97.20%

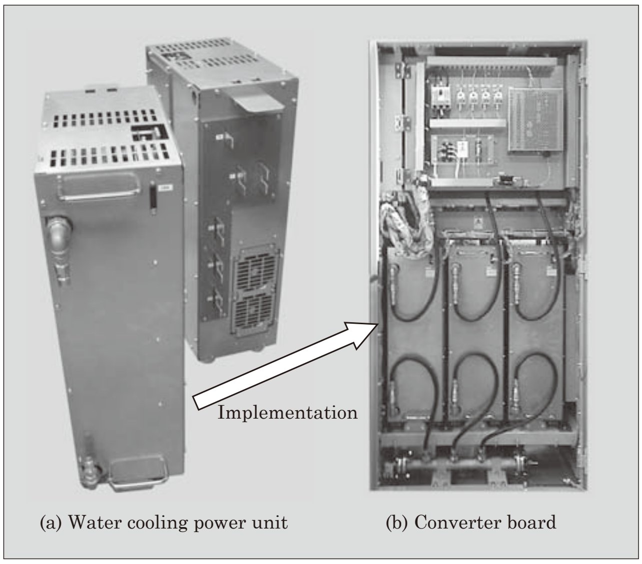

Fig.8 Water cooling power unit (500 kVA)

“6MBI450V-170-50” of Fuji Electric comprises parts such as a water cooling heat sink, film condenser for direct current intermediate, radiator fan, gate drive, and protection monitoring circuit. This power unit is easier to maintain because it has a plug-in structure, and it enables operation by eliminating the failed power unit. In order to achieve this, a laminated bus bar and common mode core are combined so that impedance becomes constant before and after the power unit is plugged in. As a result, the currents between each power unit are in balance with each other and the cross current becomes 5% or lower. For that reason, it has become possible to continue operation even if the power unit on any position is disconnected according to necessity. Figure 8 shows the outside appearance of the cooling power unit and converter board.

An optical fiber connects the control unit and power unit and transmits a gate signal from the control unit and failure information from the power unit. In addition, as a self-monitoring function, arm-short protection, abnormality in element temperature, abnormality in temperature within the unit, and excessive current protection, and abnormality in gate voltage, abnormality in clock are detected and the information is sent to the control unit at the same time as abnormality judgment protection.

3.2 Air current circulation cooling within panel by radiator

The converter board, which is applied to wind power generation, is fit into IP54*1 in order to be able to withstand an environment such as floating on the sea and the structure provides air tightness without taking in the outer air. In order to do so, as shown in Fig. 9, a radiator fan is installed in the power unit and a reactor for filtering is prepared in the vicinity to cool inside the board by means of forced airflow circulation with the fan.

*1: IP54: Protection level pertaining to dust-proofing performance and water-resistant performance defined in IEC 60529

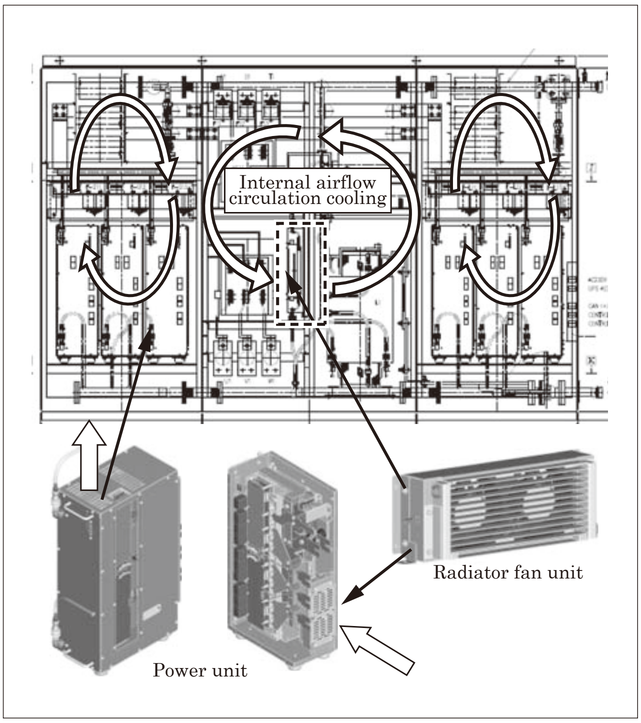

Fig.9 Internal airflow circulation cooling by radiator

3.3 System arrangement

Along with the increase in wind power generation capacity in the future, it will be necessary to restrain any increase in expected power influence and improve the operating ratio. As Fig. 7 shows, by operating two converter boards in parallel with a power generator, a torque reduction request command is sent from the sound converter even if one of the converters fails. As a result, by operating with reduced capacity by means of pitch control of wind power generator blade, it is possible to realize a system that allows continuous operation within the allowance capacity of the healthy converter.

3.4 System voltage safety control

Depending on the fluctuation of power from wind power generation, fluctuation of system voltage occurs. As a countermeasure against this, the following two types of reactive power control functions are equipped to improve the compensation performance.

(a) Reactive power control by power-factor constant command

This is applied in order to restrict any influence on system voltage by supplying reactive power so that the predetermined power factor can be obtained. In particular, a system controller to control the voltage of power grid and power factor is unnecessary.

(b) Control by command from system controller

From a system controller, send a command to each wind power generator. Apply when voltage of grid connection point is surely controlled.

By doing so, it is possible to control system voltage without preparing for facilities such as static var compensator (SVC) within a allowable range.

3.5 FRT function

When the degree of importance increases as a result of an increase in generation capacity of power sources such as photovoltaic power generation and wind power generation in the interconnection system, if parallel off*2 occurs simultaneously due to decrease in system voltage when thunder or a system accident occurs, the risk of causing a power failure due to lack of system power increases. The function to prevent this risk is the FRT function, which is similar to the PCS as described in Section 2.2. It makes it possible to continue operation even during power system disturbance.

There are various phenomena regarding system accidents such as system three-phase short-circuit and two-phase short-circuit. At this time, an imbalance of system three-phase voltage or phase hit occurs. It is important to be able to control a converter without performing overload trip for this phenomenon. There are the following three technologies to continue stable operation by responding at high speed even if any changes in the system occur.

(a) When the system voltage decreases and it becomes impossible to output the generated output to the system, power is consumed by the chopper within the device and resistance.

(b) In order to respond to a rapid change in system voltage, create basic voltage command of converter from sine wave, for which band bus filter and phase were adjusted by a system voltage detection process of converter, and improve the wave form responsiveness.

(c) In order to reduce waveform distortion at start-up from system residual voltage 0% and perform stable control, perform synchronous control of the 3rd harmonic wave form that is generated from system voltage and the 3rd harmonic table data that is synchronized with PWM career within the control device (see Fig. 10).

By doing so, it becomes possible to synchronize PWM carrier and basic wave by about 0.1 second. Figure 11 shows the FRT operation characteristics that are implemented in a test device for control validation (3 kW). Stable operation was achieved for both output current and input current when an abnormality in the system occurred.

*2: Parallel off: Disconnecting power generation equipment and so on from a power grid

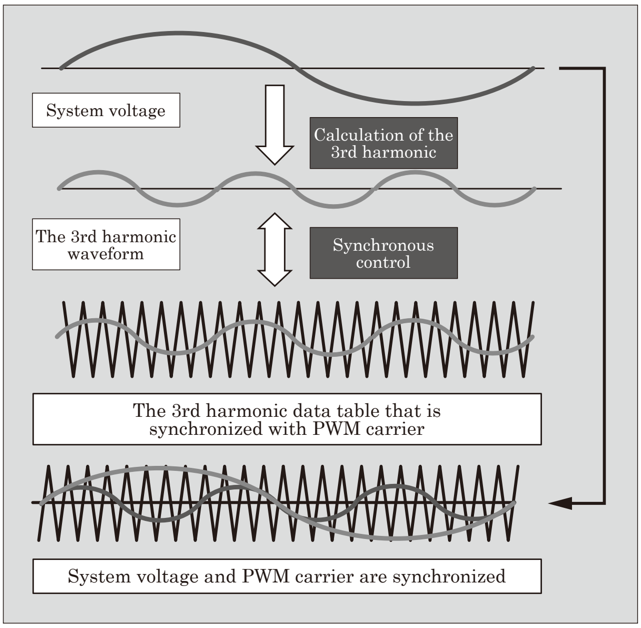

Fig.10 Synchronization of system voltage and PWM carrier

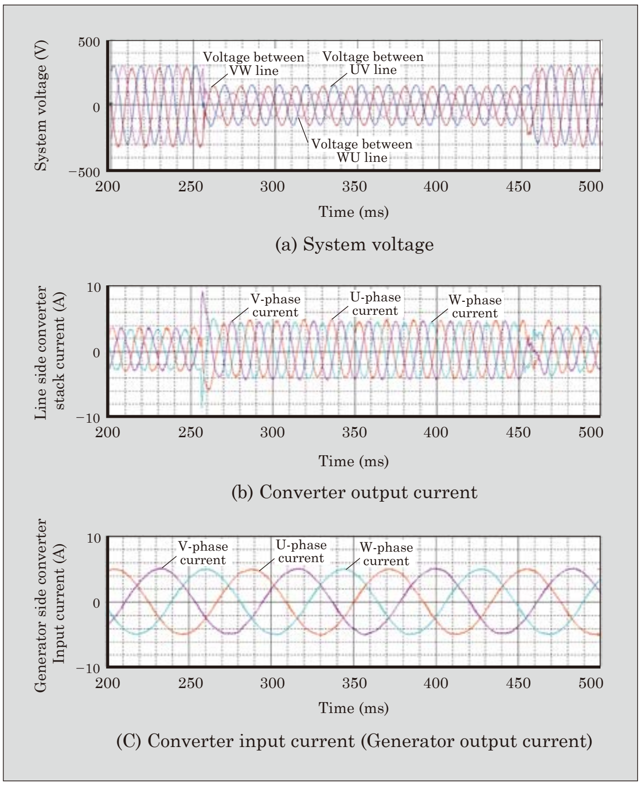

Fig.11 FRT operation characteristics by control verification device

4. Postscript

This paper described circuit and control technology used in a power conditioner and converter for wind power generation. In the future, aiming for mass introduction of wind power systems, we will promote technical development further, and achieve control technology and power conversion circuit technology.

Reference

(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.