Multifunctional On-Shore Power Systems for Harbors and Shipyards

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ABSTRACT

In recent years, even in the maritime and shipbuilding industries, reduction of environmental impact has come to be required. To meet that issue, Fuji Electric has developed a multifunctional on-shore power system equipped with both power supply functions for the on-board power systems and load testing functions for the on-board generator. Since this system is installed outdoors, we examined its placement to make maintenance easy and give it an effective cooling system and decided to install the main facilities in a container of use outdoors. The containers can be connected in parallel so that it is easy to enlarge the capacity. The facility's characteristic control functions include abilities to supply power to on-board power systems at the desired voltage/frequency and to conduct a load test for the on-board generators via load resistor or power regeneration.

1. Introduction

In recent years, even in the maritime and shipbuilding industries, reduction of environmental impact has come to be required. To meet that demand, Fuji Electric has developed a multifunctional on-shore power system equipped with both power supply functions for on-board power systems and load testing functions for on-board generators from commercial (internal) system. Considering that this system is to be installed outdoors in areas subject to salt damage such as ports and shipyards, we decided to use a container to install converter boards incorporating power conversion units and controlboards. This paper describes the structure of the container-housed system and converter board and the control technologies of the power conversion unit.

2. Overview

2.1 System specifications

The specifications of the system in a single container are as follows. Connecting several containers makes it possible to enlarge the capacity. Both the input and output voltages can be changed as desired.

(a) Capacity: 1,667 kVA continuous, overload capability 115%, 1 hour
(b) Input power supply: 6,600 V or 3,300 V, 50 Hz or 60 Hz
(c) Output power supply: 11,000 V or 6,600 V, 50 Hz or 60 Hz
(d) Dimensions of container: W7,400 × D2,600 × H3,200 (mm)
(e) Mass of container: Approx. 21 t

2.2 Characteristic of control functions

(a) Power can be supplied from a commercial (internal) system to the on-board system at the desired voltage and frequency.
(b) A load test for the on-board generators can be conducted via power regeneration or load resistor. The load pattern for the test (effective power, power factor and power change amount) can be set as desired and the repeatability is high.
(c) Even when large excitation inrush current flows due to the on-board transformer being turned on, power supply can be continued without tripping.
(d) When several container-housed systems are used, power supply is not affected by a partial equipment malfunction but can be continued through reduced capacity operation.
(e) It is possible to perform automatic synchronous parallel in and parallel off[*1] to/from a commercial system or on-board system.
(f) Disturbance in a commercial system can be suppressed when a fluctuation occurs in the on-board system due to an accident with the on-board power system.
(g) Remote operation and state monitoring are possible from the ship.

3. Structure of Installing Converter Boards and Other Equipment

3.1 Structure overview

This system will be installed outdoors in ports or

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*1: Parallel off: Disconnecting an electrical facility from a power system shipyards; however, it is not easy to design individual converter boards and controlboards for outdoor use in terms of dimensions and cost. Therefore, we decided to install the entire system in a container suitable for outdoor environments. We designed a structure that makes it possible to enlarge capacity by having a parallel connection of several containers which contain systems having the same configuration. Figure 1 shows the appearance of the container-housed system, Fig. 2 shows its dimensional diagram and Fig. 3 shows the board layout inside the container. Air-cooled load resistors are mounted on the roof of the container. There is an aisle in the center of the container, and the controlboards, converter boards and auxiliary boards are installed so that the master side and slave side are placed opposite each other. Moreover, a water-cooling heat exchanger is placed at the end of the aisle to allow all regular maintenance works to be performed from the aisle. The container is not completely sealed but is pressurized by taking in outside air with ventilation fans equipped with salt-resistant filters. This prevents sea-salt particles and dust from entering through openings.

Fig.1 Container-housed system

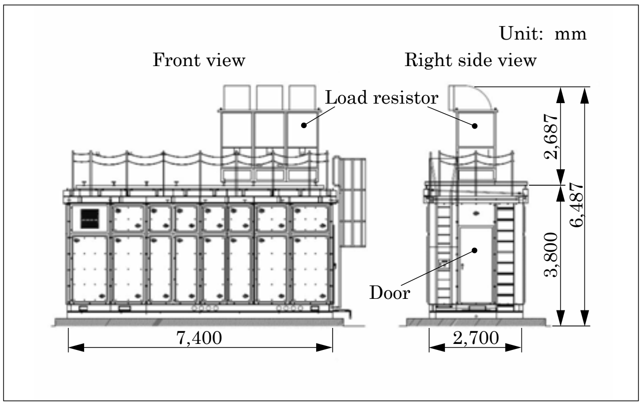

Fig.2 Dimensional diagram of container-housed system

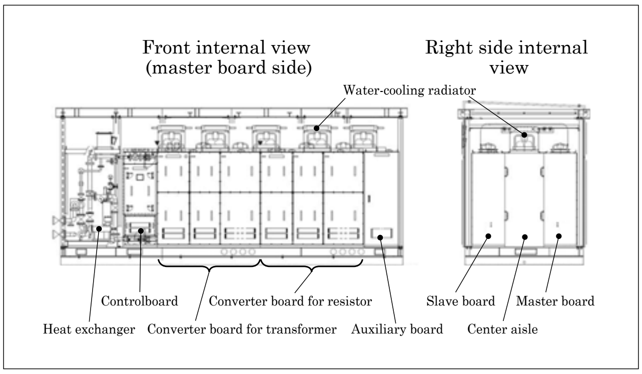

Fig.3 Board layout inside container

This system consists of 2 converter boards, one for the transformer and the other for the resistor, and their basic structures are the same. As a result, the equipment in the converter board such as power stacks, reactors and capacitors are also the same, which makes maintenance easy. These are based on the converter board for wind-power generation to optimize their structure and cooling system.

3.2 Cooling the facilities inside container

Each converter board of the system contains 3 power stacks with insulated gate bipolar transistor (IGBT) elements mounted. To ensure efficient cooling of the elements, we used an aluminum water-cooled heat sink.

The reactor is also a water-cooled type. We adopted a direct water-cooling method that lets refrigerant flow directly inside the copper windings to obtain high cooling capacity. For the refrigerant, we use pure water that transports more heat compared with antifreeze solution. The use of pure water faced the following problems:

(a) The heat sink of the power stack is made of aluminum so it may be corroded by pure water used as refrigerant.

(b) The existence of aluminum and copper in the same water-cooled system might cause bimetallic corrosion in the system.

We therefore conducted a long-term corrosion test and confirmed that a coating formed over the aluminum surface could suppress corrosion and ensure quality.

On the other hand, there are some pieces of air-cooled equipment in the converter board and controlboard. Consequently, it was necessary to cool the air inside the container. We mounted water-cooling radiators in the ceiling of the container to cool the air discharged from the converter boards with these radiators, release the air to the aisle and feed it again to the board. The pure water piping for cooling the radiators is connected in parallel with the piping for cooling the converter boards (see Fig. 4).

There are 3 water-cooled systems: for the converter boards on the master side, converter boards on the slave side and radiators. The power stacks and reactors in the converter boards are directly cooled with pure water while the air-cooled equipment in each board is cooled with the radiators using circulated air. Consequently, it was extremely important to have a

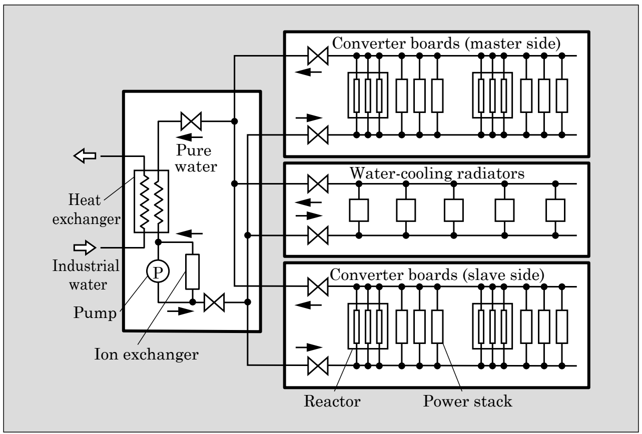

Fig.4 Diagram of water-cooling systems inside container

good thermal cooling balance. We used thermal analysis software and a model shown in Fig. 5 to analyze the thermal cooling of each piece of equipment and the air flow inside the container (see Fig. 6) and determined the required amount of pure water flow and number of radiators. Based on the result, we decided to supply 404 L/min of pure water from the heat exchanger and distribute 127 L/min to the converter boards on both sides respectively and 150 L/min to radiators.

Next, we used piping analysis software to analyze the pressure loss in each area of piping and verified whether the specified flow could be obtained or not. The sections with a potential risk of insufficient flow were improved through the use of a pipe with a larger diameter or by changing over to equipment that loses less pressure.

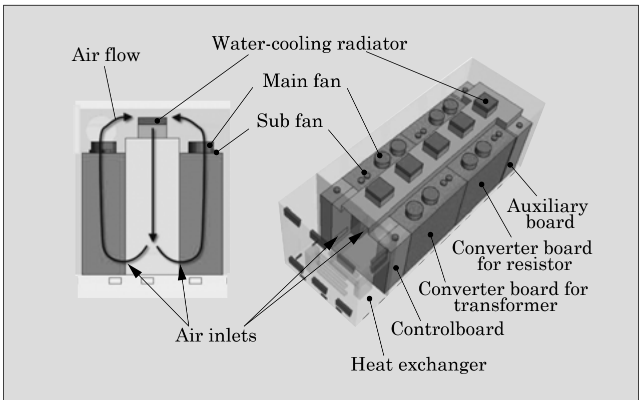

Fig.5 Air flow analysis model of container

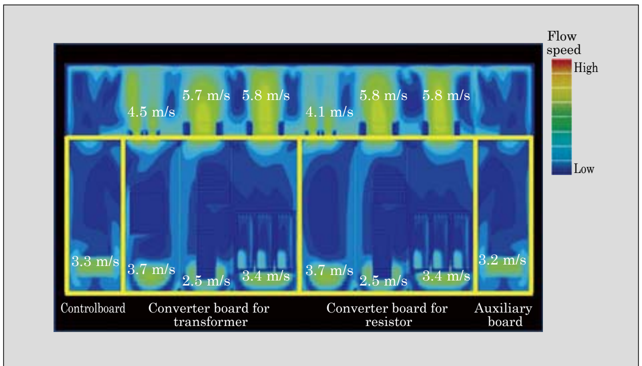

Fig.6 Result of the air flow analysis inside container

The heat exchanger was designed to provide cooling by using industrial water supplied from outside, and the instruments are arranged in positions that make maintenance easy. With these efforts, we have succeeded in building the optimum structure and cooling system.

4. Control Technologies of Power Conversion Unit

This system switches the control mode of the same power conversion unit between power supply mode and load test mode to provide 2 different functions of supplying power to the on-board power systems and conducting a load test for the on-board generators.

The control technologies of the power conversion unit are described below with an example of supplying up to 5,000 kVA power to a ship.

4.1 Control in power supply mode

To supply up to 5,000 kVA power to a ship, 3 power conversion units of 1,667 kVA should be operated in parallel (3 container-housed systems connected in parallel).

As a power supply, this system provides the following functions:

(a) When the on-board electrical facility operates at light load, the parallel operation is changed from using 3 power conversion units to using 2 units to improve efficiency.

(b) If one of the power conversion units breaks down, the broken unit is paralleled off and the operation is continued through the use of the other healthy units.

(c) Power supply is switched without instantaneous interruption from the on-board generator to the system and vice versa.

In order to share the load to ensure stable operation, the 3 parallel power conversion units calculate the effective power component and reactive power component from the load current. The load between the parallel units is balanced through a combination of the droop control that drops the frequency of output power inversely proportional to the effective power component and the droop control that drops the output voltage inversely proportional to the reactive power component.

For parallel in and parallel off between the power conversion units, automatic load shifting control is used to control the load balance gradually so that the load does not change abruptly for the operating unit. Figure 7 shows the power flow in the power supply mode. The converter 1 converts the power of 6.6 kV, 50 Hz or 60 Hz received from a commercial (internal) system to direct current, and controls the input current

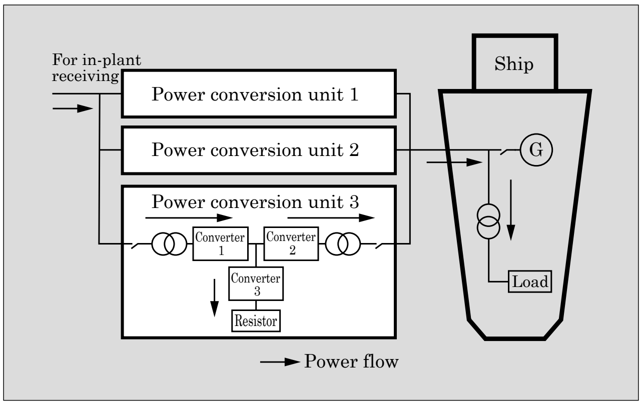

Fig.7 Power flow in power supply mode

so that it has a power factor of 1 and distortion of 5% or less.

The converter 2 converts and outputs it to the ship side according to the frequency and voltage of the on-board system. The operation equalizes the loads between the 3 power conversion units. Figure 8 shows the waveforms at parallel in and parallel off when 2 power conversion units are used. When one unit is operating and the second unit starts operation for parallel in, the second unit preparing for voltage paralleling synchronizes with the first unit by following the voltage and frequency. When a circuit breaker is turned on after the synchronization, the paralleled-in second unit remains in parallel status without current flow. After that, by gradually canceling the voltage following compensation at parallel in, the paralleled-in unit shares the load gradually and the cross current between the parallel units stabilizes within 5%. Figure 9 shows the waveforms when 2 units are operating in parallel and one of them breaks down. When 2 units are operating by sharing the load and one of them breaks down and stops, stable power supply is continued with the remaining active power conversion unit.

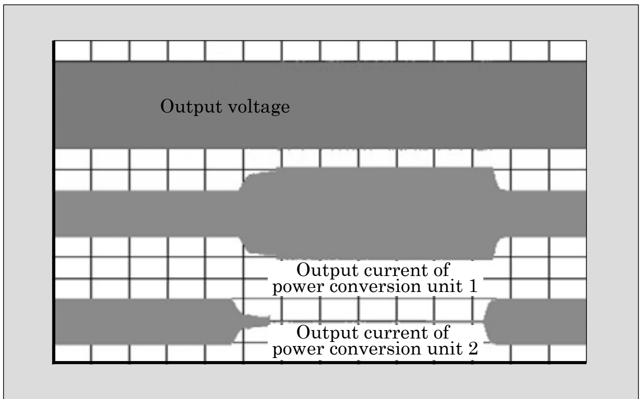

Fig.8 Waveforms at parallel in and parallel off

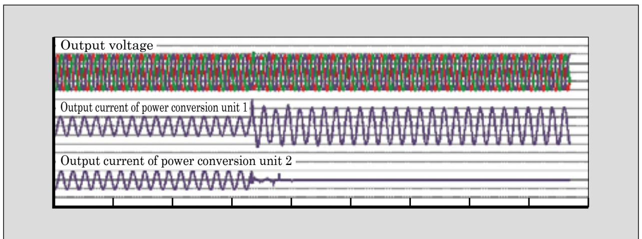

Fig.9 Waveforms when 2 units are operating in parallel and one of them breaks down

4.2 Control in load test mode

The power flow in the load test mode is shown in Fig. 10. To perform the load test of the on-board generators, the control mode is changed from the power supply mode described above to the load test mode in which the converter 2 connects to the generator output voltage for the control by following the power and power factor references.

As shown in Fig. 10, the power from the generator is returned to the commercial (internal) system. This allows the test to be performed without consuming energy in a load resistor as in the case of conventional method. If, however, the power cannot be returned to an electric power company, it must be consumed in the internal electrical facility. In order to continue the load test smoothly, the converter 3 is operated to consume the power in the resistor. If a system error such as instantaneous interruption occurs during the generator test, the converter 1 continues the connection and operation [fault ride through (FRT) function]. Consequently, when the power cannot be returned to the system, the converter 3 is operated to consume it in the resistor.

In the sudden load change test of the generator load test, applying 5,000 kVA with stepwise changes generates an abrupt reverse power flow to the system, causing voltage fluctuation. To prevent this, the system has a function to change the regeneration power gradually to prevent voltage fluctuation. Figure 11 shows the current waveform during the test. Converter 2 operates to address the abrupt increase of the generator load and converter 1 outputs the power to the receiving side at the specified power change ratio. The surplus power is consumed in the resistor connected to converter 3 so that the system can continue operation.

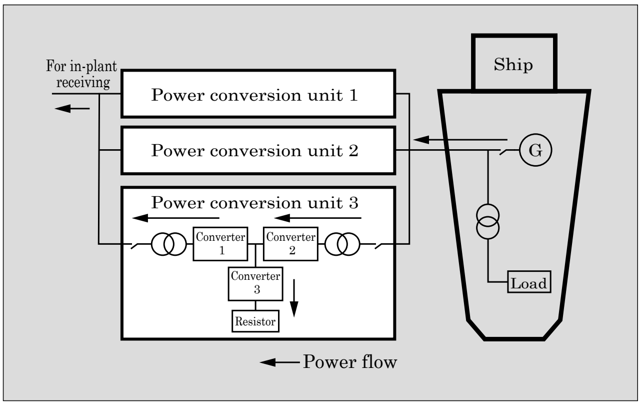

Fig.10 Power flow in load test mode

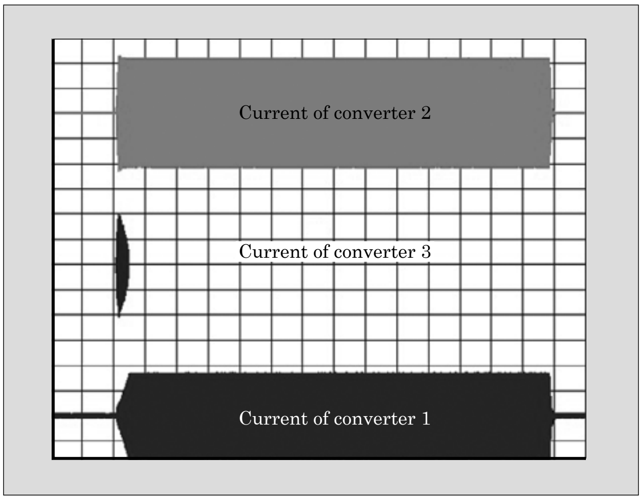

Fig.11 Waveform during sudden load change test

5. Postscript

This paper described the structure and control technologies of a multifunctional on-shore power system equipped with both power supply functions for the on-board power systems and load testing functions for the on-board generators. Fuji Electric is committed to making further efforts to improve the functions of the system in order to expand its applications.

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