“FRENIC4800VM5,” a Water-Cooled High Capacity, High Voltage Inverter

MOKUTANI Masafumi † HANAZAWA Masahiko † ADACHI Akio †

ABSTRACT

High-voltage inverters used to drive main rolling mills for steel and non-ferrous metal materials, large blowers and compressors are seeing increased demands for higher capacities and reduced size of board dimensions as facilities increase in scale. Fuji Electric is conducting researches in the water cooling and miniaturization technologies needed to meet these requests. Through repeated analysis and testing, we aimed to improve cooling performance and reliability through water cooling technology and as a result released the “FRENIC4800VM5,” a water-cooled, high-capacity, and high-voltage inverter, which has 2.4 times more output capacity and 1/3 smaller panel dimension compared to our previous models.

1. Introduction

High-voltage inverters used to drive main rolling mills for steel and non-ferrous metal materials, large blowers and compressors are showing increased demands for higher capacities and reduced size of panel dimensions as facilities increase in scale and installation area becomes narrowed down.

In this paper, we will present the “FRENIC4800 VM5,” a water-cooled, high-capacity, and high-voltage inverter as a product that is able to meet these increasing demands. In addition, we will also provide an application example of the FRENIC4800 VM5.

2. Water-cooled, High-capacity, and High-Voltage Inverter

The development of high-voltage inverters that have both higher capacity and reduced panel dimension requires to suppress temperature increases due to converter heat loss that occurs at the time of controlling large electric currents by using heat dissipation,

In recent years, insulated gate bipolar transistor (IGBT) modules have advanced toward higher-voltage and higher capacity, and inverters in a high-voltage range, which conventionally used flat components, can be configured with modules that have low power loss.

The panel of the FRENIC4800VM5 is shown in Fig. 1 and its electrical specifications are indicated in Table 1.

In producing the FRENIC4800VM5 for commercial use, Fuji Electric decided to adopt water cooled method for the high-voltage IGBT module so that it could suppress temperature rise caused by heat loss generated from conversion circuits. The adoption of the water cooled method has the effect of greatly increasing cooling efficiency compared to previous air cooled method. The FRENIC4800VM5, in addition to the high capacity and reduced panel dimension, is equipped with the high degree of functionality needed for main rolling mills for steel and non-ferrous metal materials.

Fig.1 Control panel comprising “FRENIC4800 VM5”

Table 1 Electrical specifications of the “FRENIC4800VM5”

Item	Specification			
Configuration (Multiplexing)	Single unit	Double-multiplex	Triple-multiplex	Quadruple-multiplex
Converter capacity (MW)	5.2	10.4	15.6	20.8
Inverter capacity (MVA)	6.2	12.4	18.6	24.8
Voltage	Input 3 kV 3ϕ 50/60 Hz, Output 3.1 kV			
Overload capability	150% for 1 minute			
Driving motor	Induction machine, synchronous machine			

† Fuji Electric Co., Ltd.

The features of the inverter are as follows:

(1) Large capacity output 2.4 times larger than that of our previous products[1]

Capable to configure a single unit capacity of 6.2 MVA and a maximum capacity of 24.8 MVA utilizing quadruple multiplexing (Overload capability: 150% for 1 minute)

(2) Compact panel dimensions 3 times smaller than that of our previous models[1]
  (a) Single unit 6.2MVA
  (b) W 2,800×D 1,650×H 2,400 (mm) (Excluding water cooling equipment)

(3) Employing 3-level PWM control both in the converter and inverter
  ○ Capable of full regeneration 4 quadrant operation
  ○ Power supply power factor ≈ 1

(4) Supporting various transmission methods PROFIBUS-DP, SX Bus, T-link, etc.

(5) Equipped with high-speed pulse tracing function
  ○ Acquires and saves gate output command signals of the inverter as well as on-off state signals of the IGBT with time resolution of μs orders
  ○ Capable of quickly performing cause analysis at the time of faults

3. Water Cooled Technology

High-capacity power electronics equipment including high-voltage inverter requires strong demand for small, light-weight, and low-cost. In order to meet this demand, we have constructed a high-performance and highly reliable water cooled technology and have been progressing in the development of our product design.

Through repeated analyses and experiments, we have strived to improve cooling performance and reliability. The main points of our water cooled technology are as follows:

(a) Highly-efficient heat sink
(b) Piping for cooling with a good split flow balance
(c) Simple cooling structure in panel inside
(d) Water cooled heat sink that is very durable and corrosion resistant

3.1 Heat sink design

At rated output, water-cooled high capacity, high-voltage inverters suffer about a 100 kW loss, and as a result, heat generation occurs. From the power devices in a power unit, heat is generated at a level of 100 W in semi-conductor chips of approximately 1 cm square size. Highly-efficient water cooled heat sink that can cool the high-density generated heat, regardless the small difference in temperature between the power devices and the cooling water, is required. As a result, we have carried out the following design:

(a) In order to expand the liquid contact area, an internal fin structure that arranged narrow ducts in parallel has been adopted.

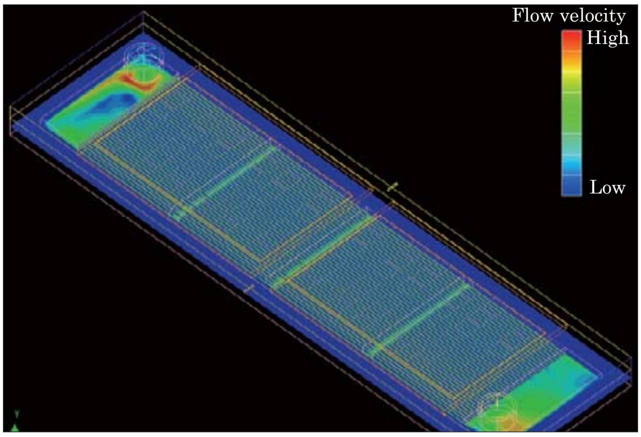

Fig.2 Internal flow velocity distribution in water cooling heat sink

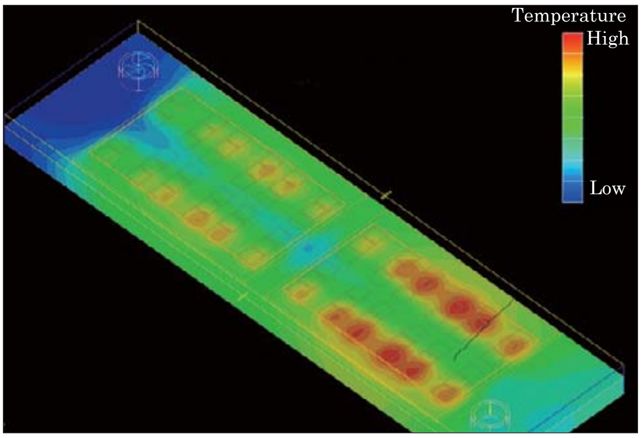

Fig.3 Surface temperature distribution of water cooling heat sink

(b) In order to accelerate the heat transfer due to turbulent flow, an internal fin structure that divided to the flow direction has been adopted.

(c) In order to equalize the flow balance between the parallel ducts, a vertical inflow header structure has been adopted.

Figure 2 shows the internal flow velocity distribution of the water cooled heat sink, and Fig. 3 shows the surface temperature distribution. From these figures, it is apparent that a good cooling capability has been obtained.

3.2 Cooling pipe design

Figure 4 shows a typical structure of the cooling pipes for water-cooled high capacity, high-voltage inverters. Configuration is made by combining two components; one is a heat exchanging water cooling devices composed of pumps, tanks, flow adjustment valves, ionic exchange devices and outside water cooling equipment, and the other is a parallel piping system that connects numerous water cooled heat sinks installed in numerous quantity to the multiple power stacks configuring the inverter and converter panels.

Even if a total of 30 water cooled heat sinks are

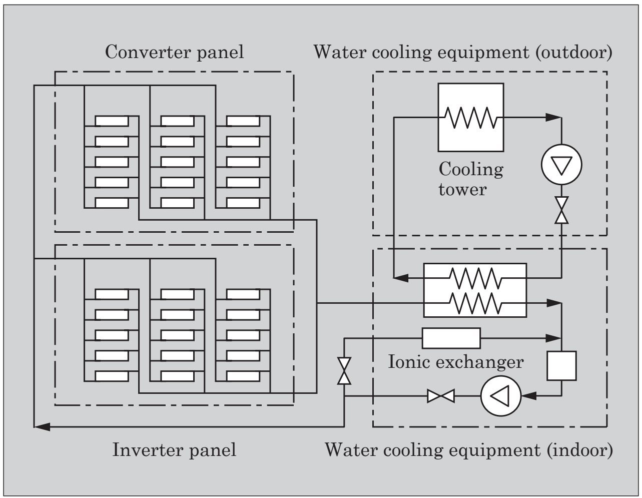

Fig.4 Configuration of cooling pipe system

connected in parallel to water-cooled high capacity, high-voltage inverters, great skill is needed to make appropriate combination of the piping configuration, which includes the main pipe, diverging pipes and branch pipes, so as to obtain flow balance of the cooling water.

Therefore, in order to accurately design the flow and pressure loss of each cooling pipe, which is a combination of numerous components and various pipes, we performed a highly precise design utilizing a pipeline resistance network method.

Figure 5 shows an analysis model example of the pipeline resistance network when the water cooling heat sinks are configured in 6 parallel pipelines. By properly matching the internal diameters of the main pipes and diverging pipes, it is possible to suppress flow unbalance within approximately 5%, and as a result, valve adjustment for each heat sink duct becomes not required. In addition, since calculation results can be obtained in several seconds even when actual system pipes amount to hundreds of nodes, comparative calculations can be made very quickly for diameter and length of pipes, and shape of heat sinks and joints to be used in the system, and theoretical studies regarding how to minimize pressure loss, etc. can be carried out with very accurate precision.

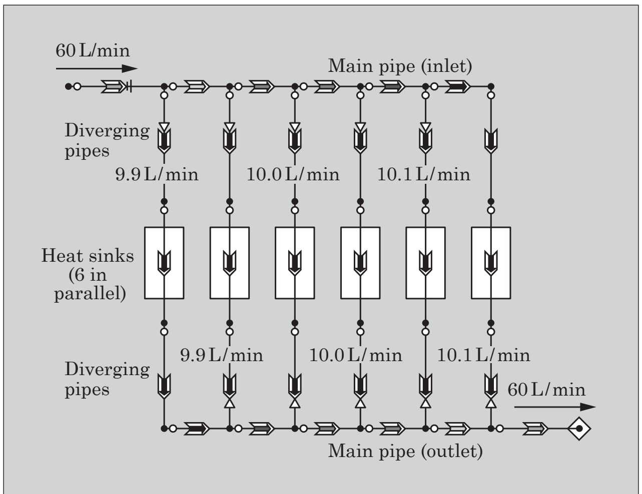

Fig.5 Analysis model example of the pipeline resistance network

3.3 Cooling structure design in panel inside

Since the heating components such as reactors, capacitors, contactors, and control devices, etc. are incorporated with high density in high-capacity power electronics equipment besides the power devices, efficient cooling within the panel is required. Although there are differences depending on part shape and heat density, cooling is carried out through water cooling or air-cooling.

Figure 6 shows the cooling situation of the capacitors, reactor and control devices in a power stack. An air-cooling system is adopted a method that carries out cooling of panel inside by circulating cooled air which is cooled by water cooled heat exchanger. Air flow in the panel inside can be carried out with good balance by adopting a simple structured fan ventilation path that optimizes parts arrangement, partition plate installation, etc.

3.4 Corrosion-resistance evaluation and durable design

A corrosion-resistance evaluation was implemented for copper, aluminum, and two types of water, and examination was carried on a life durable design.

In the corrosion-resistance evaluation, a running water circulation test was implemented for 5,000 hours that combined copper with deionized water, aluminum with deionized water, and aluminum with an antifreeze solution. The following results were obtained through observation of the surface (see Fig. 7) and cross-sections of the sample and by measuring the amount of thinning.

(a) A passive film formed on the wetted surface.
(b) The early stages of the test resulted in some mass reductions (corrosive progression), but al-

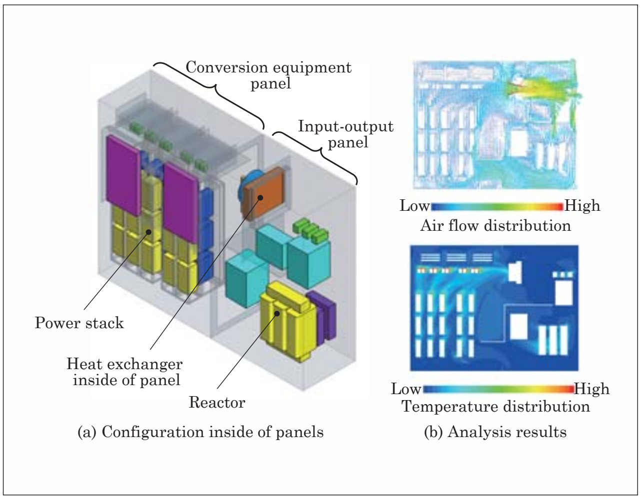

Fig.6 Cooling structure design in panel inside

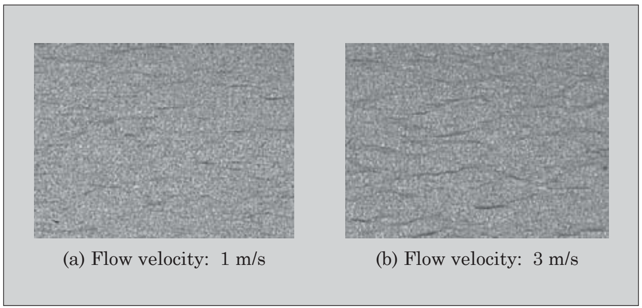

Fig.7 Surface condition after the corrosion-resistance evaluation for aluminum with deionized water

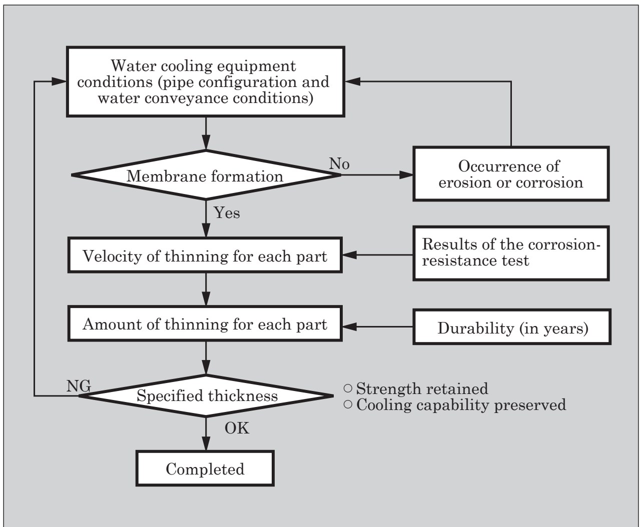

Fig.8 Outline of corrosion-resistance evaluation and life durable design method

most no further corrosion occurred after about 500 hours elapsed.

(c) No local corrosion occurred at a flow velocity of 1 to 3 m/s.

Based on these results, a life durable design method was put together. The outline of the method is shown in Fig. 8. In addition, material and water quality control standards have been separately provided.

4. Voltage & Capacity Enhancement, and Miniaturization Technology

4.1 Voltage & capacity enhancement technology

Water-cooled, high-capacity, and high-voltage inverters make use of the circuit configuration of neutral point clamped (NPC) 3-level conversion circuits shown in Fig. 9, aiming to increase output voltage and suppress harmonics. Power unit components adopt high-voltage module type IGBT components that facilitate high-voltage and large currents, aiming to streamline the structure and simplify the assembly. Furthermore, we have achieved a higher voltage and larger capacity of 6.2 MVA (3.1 kV) for single unit, which is 2.4 times greater than our previous products. These gains have been realized through connecting IGBT modules in

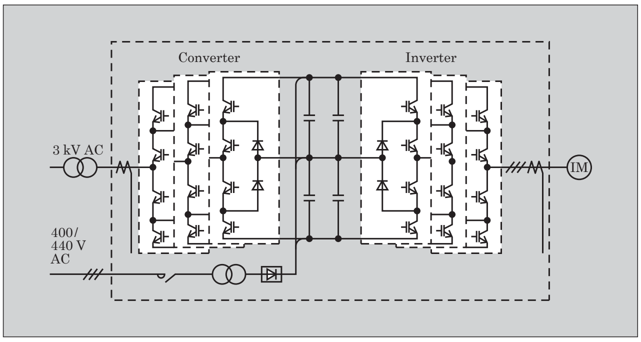

Fig.9 Configuration of NPC 3-level conversion circuit

parallel as well as by adopting the water cooling technology introduced in Chapter 3.

4.2 Miniaturization technology

Snubber circuit that controls the transient high-voltage generated at the time of current cutoff tends to increase the equipment size. If inductance can be reduced, IGBT voltage jumps can be controlled at the time of current cutoff without the need of using snubber circuit. In order to reduce inductance, we have carried out the following improvements:

(a) Laminated bus bars were adopted which enable low inductance for the power circuit conductor and insulted boards of the internal parts of the IGBT stack.

(b) By stacking up the conductors of different current flow directions, inductance can be reduced through negating magnetic fluxes.

(c) High-voltage film capacitors that have a small internal inductance were adopted for direct-current intermediate circuits.

(d) A simulation tool was used to compute the inductance in the laminated bus bar design, and an optimal conductor structure was designed to conduce both of reduced inductance and appropriate current sharing between IGBT modules (see Fig. 10).

In order to decrease the panel size of the power unit, the width of the IGBT stack needs to be reduced. Therefore, we have implemented the following improvements:

(a) Low-profile high-voltage film capacitors were

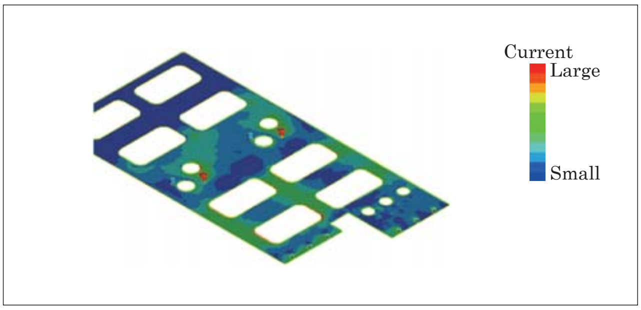

Fig.10 Current distribution simulation results of the laminated bus bars

used in direct-current intermediate circuits.

(b) The configuration of laminated bus bars, IGBT modules, water cooled heat sinks, and water cooling pipes were optimized (currently patent applied for).

(c) Through using the water cooling technology introduced in Chapter 3, good flow rates can be allocated without using adjustment valves in each water cooled heat sink duct.

As the result of these improvements, we attained to store 3 power unit IGBT stacks in panel widths of 1,000 mm.

5. Application Example of Water-cooled, High-capacity, and High-voltage Inverter

We present an application example for a twin-drive reverse rolling mill. In this rolling mill, top and bottom rolls are individually driven using two electric motors as shown in Fig. 11. Synchronous motors (see Fig. 12) are used for the electric motors, and each electric motor is driven by a 6.2 MVA FRENIC4800VM5 double-multiplex configuration (see Fig. 13).

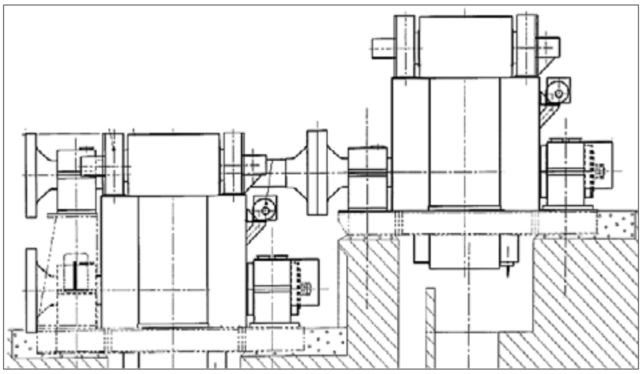

Fig.11 Example of twin-drive electric motor layout

Fig.12 Example of synchronous electric motors for main rolling mill

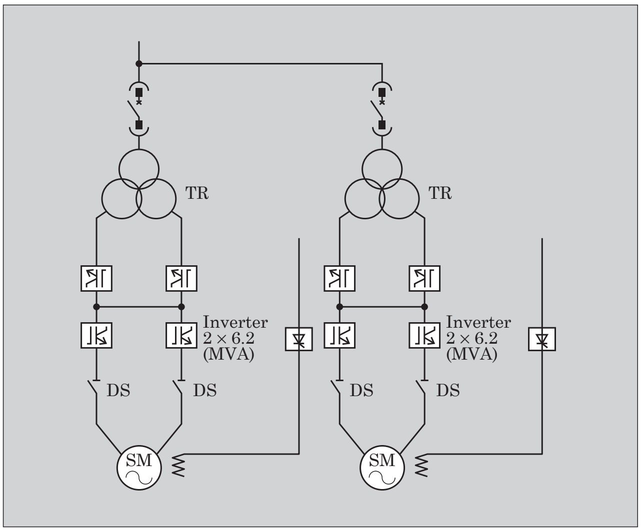

Fig.13 Example of single system diagram for twin-drive reverse rolling mill

By utilizing the FRENIC4800VM5, inverter panels were able to be installed in the existing electric room as a result of greatly decreasing the panel dimensions.

6. Postscript

The “FRENIC4800MV5” water-cooled, high-capacity, and high-voltage inverter enables full regeneration of systems. In addition to rolling mill systems, we are anticipating that it will play an active role in various fields such as wind tunnel test facilities and large-sized conveyors. We look forward to expanding the application of the FRENIC4800MV5 to these fields as well as further developing the water cooling, capacity enlargement, and miniaturization technologies introduced in this paper to other power electronics equipment.

Reference

(1) SAIGOU, K. et al. Drive and Power Supply Technology in the Industrial and Public Sectors. FUJI ELECTRIC REVIEW. 2009, vol.55, no.4, p.133-139.

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