Column Electric Propulsion System Used on Icebreaker “Shirase” in Extreme Cold of Southern Ocean

The new Shirase icebreaker was commissioned in May 2009. The Shirase is intended to transport personnel and goods to research expeditions stationed in Antarctica, and to support their research work. The vessel boasts excellent icebreaking performance and a large cargo capacity by world standards, and is scheduled to enter service from the 51st Antarctica Research Expedition. The electric propulsion system was developed based on Hitachi’s extensive technology for the control of rotating machinery in steel rolling mills, railway systems, and elsewhere.

INTRODUCTION

THE new Shirase icebreaker is a multi-purpose vessel intended for transport and research work carrying personnel and goods on Antarctic research expeditions. It took over from the old Shirase in May 2009. As indicated by their name, icebreakers move through the sea ice by breaking the ice as they go and therefore require a very powerful propulsion system. The Showa Station visited by Japanese research personnel is reached by sailing across Lützow-Holm Bay, one of the major regions of drift ice in the Southern Ocean, and the Shirase makes its way through this region by a process of repeated ramming whereby the vessel first reverses to get a run up and then breaks the ice by ramming into it. To make progress using this icebreaking technique, the Shirase, which has a displacement of more than 10,000 t, requires a propulsion system capable of rapid acceleration and deceleration and able to deliver high torque to break any chunks of ice that come into contact with the propeller. To satisfy these requirements, the Shirase uses an electric propulsion system consisting of generators, electric propulsion unit, and propeller. Hitachi developed the electric propulsion unit that represents the core of this system.

ELECTRIC PROPULSION SYSTEM ON NEW SHIRASE

Fig. 1 shows an overall structure of the electric propulsion system. The system consists of the propulsion motors that drive the propellers,

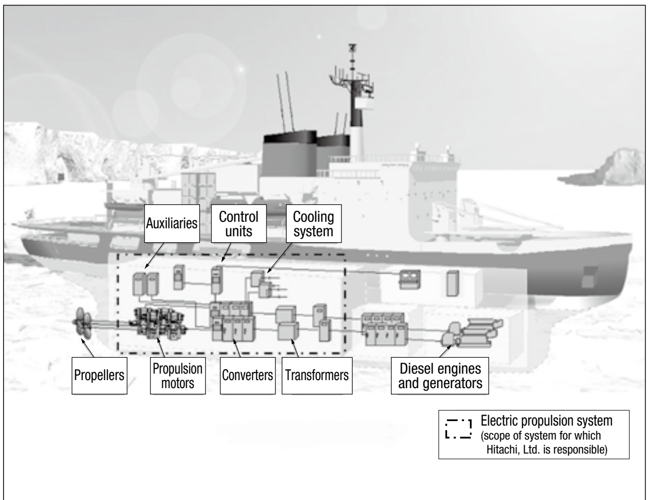

Fig. 1—Overall Structure of New Shirase.

Specification	New Shirase	Old Shirase
Conventional displacement (standard displacement)	18,500 t (12,500 t)	17,230 t (11,600 t)
Propulsion method (maximum output)	Electric propulsion (30,000 PS)	Electric propulsion (30,000 PS)
No. of shafts	2	3
Electric motor	Induction motor	DC motor
No. of electric motors	5,516 kW × 4 (2 motors × 2 shafts)	3,680 kW × 6 (2 motors × 3 shafts)
Converter control method	Diode converter + IGBT inverter with PWM control	AC-R-DC
Power supply type	Integrated power supply	Split power supply
Bus bar voltage	6.6 kV	715 V
No. of generators	7,400 kW × 4 (also 2 × 1,200-kW auxiliary generators)	4,050 kW × 6 (also 4 × 900-kW main generators)

PS: metric horsepower PWM: pulse width modulation IGBT: insulted gate bipolar transistor
AC: alternating current R: rectifier DC: direct current

TABLE 1. Comparison of Old and New Shirase Vessels

converters that control the propulsion motors, transformers, cooling systems, auxiliary equipment including pumps and fans, and a control unit that integrates the different units of equipment. Table 1 lists a comparison of the new and old Shirase vessels and the following sections describe the features of each sub-system.

Integrated Power Supply

Fig. 2 shows the power supply system on the new Shirase. Whereas the old Shirase used a split power supply whereby the propulsion system and general load (ship systems other than propulsion) were supplied from separate generators, the new Shirase has an integrated power supply that supplies the entire load from the same generators. However, to prevent any adverse effects on the general load if the generators were to completely shutdown, the integrated power supply limits the output of the propulsion motor to avoid sudden overloads or changes in load that might cause a generator to stop.

Propeller Shaft

The new Shirase has only two propeller shafts compared to three on its predecessor. This change was adopted to make the engine compartment smaller and reduce weight. Each shaft is connected directly to two electric motors so that, even if one motor fails, the vessel can continue to move using the other motor. Switching between motors can be performed smoothly using the control system.

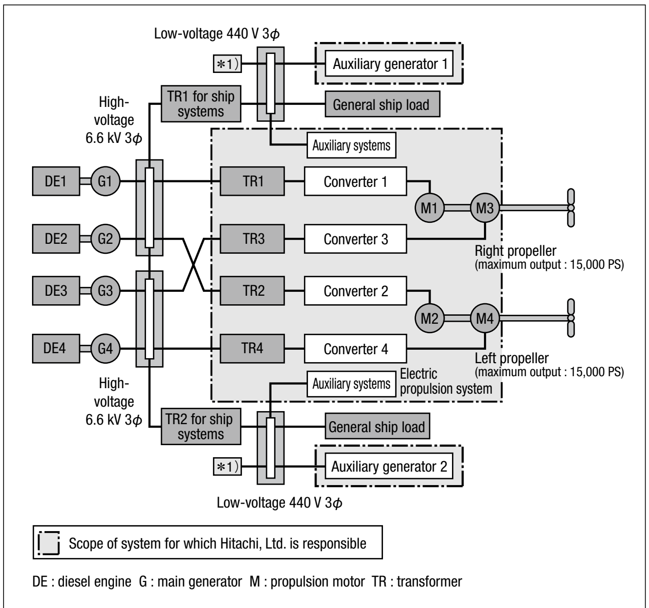

Fig. 2—Overview of Power Supply System on New Shirase.

Propulsion Motors

The propulsion motors selected for the new Shirase are robust induction motors that have better maintenance performance because they do not require the brush or commutator maintenance associated with DC (direct current) motors. The vessel has four of these motors in total (two per propeller shaft), each of which has a rated output of 5,516 kW, giving a total maximum output of approximately 30,000 PS (metric horsepower). This is sufficient to power the vessel at up to 20 knots in the open sea. In ice, the vessel can achieve 3 knots through ice 1.5 m in thickness.

Converters

The converters consist of inverters used for motor acceleration and deceleration control, rectifiers that supply the inverters with DC power, and a control unit that controls these. The IGBT (insulated gate bipolar transistor) inverters use PWM (pulse width modulation) control and are capable of rapid control of motor acceleration and deceleration using the vector control method. The rectifiers use multi-phase diode rectification which can keep harmonics in the power supply system to 2% or less (single component).

Control Unit

The control unit receives commands from higher level systems such as from the ship bridge and performs supervisory control over the other equipment. It also reports the status of the other equipment back to the higher level systems. The system has a very reliable design able to cope with emergencies including backup control equipment to improve redundancy in the event of one of the CPUs (central processing units) failing and a battery-powered DC power supply to maintain power during outages.

VERIFICATION OF ICEBREAKING USING MINI-MODEL

As the Shirase is designed mainly for use in Antarctic waters, it is nearly impossible for it to receive supplies or assistance from other vessels. As the vessel would be unable to maneuver and would become stuck in the icy waters if the electric propulsion system were to shutdown, verification of the motor control associated with icebreaking is extremely important in the context of system reliability.

As it is not practical to test icebreaking in Japan, a computational analysis of the load placed on the motor during icebreaking was conducted based on the propeller shape and hull data and the data obtained was used as a basis for operational simulations of a wide range of icebreaking patterns to check the operation of the electric propulsion system during icebreaking. A mini-model (approximately a 1:500 scale model in terms of output) of the electric propulsion system was also constructed using an electric motor to act as the propeller load to confirm the soundness of the operational simulations. Performing these tests minimized the potential risks when traveling through icy waters.

CONCLUSIONS

The newly developed system had to deal with numerous requirements that were specific to an icebreaker. Hitachi intends to continue developing electric propulsion systems for other naval and merchant ship based on the technology it has accumulated.

ABOUT THE AUTHOR

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Joined Hitachi, Ltd. in 2006, and now works at the Electrical Systems Planning Department, Defense Systems Company. He is currently engaged in the design and development of electric propulsion systems.