JFE TECHNICAL REPORT
No. 19 (Mar. 2014)

Development of Power Supply System with Hybrid Turbocharger for Marine Application†

SUTO Naonori[*1]   MINAMI Hiroki[*2]

Abstract:

Hybrid turbocharger is a turbocharger with a small, high-speed generator and is installed on marine diesel engines. A power supply system with Hybrid turbocharger for marine application was developed jointly by Japan Marine United Corp. (hereafter, JMU) and other companies. Use of the power supply system while a main propulsion engine is under normal load condition enables to produce enough electric power even without running ship's diesel generator engine, and, therefore, reduces fuel usage and cost. Outline and feature of this system are discussed, and JMU's focusing points which make the generator possible to operate stand-alone as a marine generator are also described. In addition, the safety of the power supply system on this development has been also confirmed at the first vessel which the system was installed on, built at JMU.

1. Introduction

In response to recent calls for countermeasures against global warming, reduction of greenhouse gases (hereinafter, GHG) emitted from the engine plants of ships has been discussed, regulated, and made compulsory by the International Maritime Organization (IMO) [1]. Greenhouse gases emitted from ships are caused mainly by CO_2 generated by combustion of the fuels used by the ship's propulsion engine (main engine) and diesel generators. Accordingly, in order to reduce GHG from ships, it is necessary to construct a high efficiency engine plant, in other words, an engine plant with low fuel consumption.

The fuels which are mainly used by ships are liquid petroleum fuels, as represented by heavy fuel oil. The prices of these fuels are linked to that of crude oil and are continuing to rise year after year. The sharp rise in the price of fuel, which accounts for the larger part of ship operating costs, is putting pressure on operating profitability and has become a serious issue in the shipping industry, and as a result, the commercial value of low fuel consumption ships has risen dramatically.

As technologies for improving the efficiency of ship engine plants, among waste heat recovery technologies utilizing the energy of exhaust gas from the main engine, steam turbine power generation is the general practice. However, this approach had not been applied in comparatively small ships because an adequate amount of waste heat cannot be obtained, there are large restrictions on the layout in the engine room due to space limitations, etc.

Where this point is concerned, the hybrid turbocharger, which was developed by Mitsubishi Heavy Industries, Ltd., is a device in which a compact generator is built into the turbocharger installed on propulsion engine, and is attractive from the viewpoint that no major changes in the engine room layout are required[2]. However, no ship power supply system which supplies electric power by using this generator in stand-alone operation was available. Generally, shipboard electric power is covered by operation of a diesel generators. However, if shipboard electric power requirements can be satisfied by stand-alone operation of a waste heat recovery-type generator, it is not necessary to operate the diesel generator, thereby contributing to reduced fuel consumption.

This paper discusses the outline and features of a system which was developed and applied practically to a bulk carrier built by Japan Marine United Corp. (JMU). Development of the system was carried out jointly with the ship owner, shipyard, engine manufacturer, turbo-

† Originally published in *JFE GIHO* No. 32 (Aug. 2013), p. 91–94

[*1] Assistant Manager,
Machinery Design Gr.,
Initial Design Dept.,
Ship & Offshore Div.,
Japan Marine United Corp.

[*2] Manager,
Electrical Design Gr.,
Initial Design Dept.,
Ship & Offshore Div.,
Japan Marine United Corp.

charger manufacturer, and electrical machinery manufacturer. Among these, this paper describes the measures that enabled stand-alone operation of the hybrid turbocharger, which were a particular focus of efforts by JMU in this development, and also reports the results of verification when the system was installed in an actual ship.

2. Outline of Power Supply System

2.1 Principle of System

Figure 1 shows a sectional view of the hybrid turbocharger. In the hybrid turbocharger, a compact, high speed generator is built into part of the structure of the turbocharger installed on the ship's main engine (the location of the generator is shown by the broken-line box in Fig. 1). As a distinctive feature, in addition to the essential work of the turbocharger, that is, supplying air to the main engine using the exhaust gas from the engine as a drive power, electricity can also be generated by the generator, which is coupled directly to the rotor shaft of the turbocharger.

In recent years, the efficiency of turbochargers has been improved, and particularly in the high engine load operating region, there have been cases in which the energy of the exhaust gas from the main engine was in surplus relative to the work of supplying air to the engine. If the energy of this exhaust gas cannot be utilized for some other purpose after it passes through the turbocharger, it becomes discarded energy, i.e., waste energy. From this viewpoint, the hybrid turbocharger, which effectively utilizes this exhaust gas energy to generate electricity, can be called an exhaust heat recovery technology.

2.2 Configuration of Main Equipment

Figure 2 shows the configuration of the ship power supply system using the hybrid turbocharger. The power supply system comprises mainly a permanent magnetic generator (hereinafter, PMG), converter, inverter, and main switchboard. The following describes the flow to use as a ship power supply, together with the distinctive features of each device.

2.2.1 PMG

As mentioned above, the power source of the PMG is the turbocharger to which it is directly coupled on the same shaft. Its rotational speed (rpm) depends on the main engine load, and thus varies from 0 to approximately 10 000 min^{-1}. The electric power generated by the PMG accompanied by the rotation of the turbocharger is 3-phase alternating current (AC) in the range of 0–400 V and 0–670 Hz, which is not suitable for use as a power supply for the ship.

2.2.2 Converter

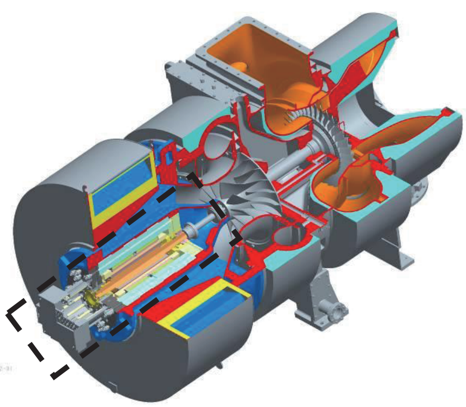
The converter is a device which rectifies the AC power generated by the PMG to direct current (DC) power with a constant voltage. As a switching device, the converter adopted an IGBT (insulated gate bipolar transistor) device with good response to be capable of responding to a high frequency power source.

2.2.3 Inverter

The inverter performs inverse transformation (inversion) of the DC power rectified by the converter to AC 450 V and 60 Hz, which can be used as a ship power supply. An IGBT is also used for switching in this device.

The system makes it possible to obtain a stable power supply by passing the fluctuating power generated by the PMG through the converter and inverter.

On the other hand, seen from the power-receiving side, the inverter is the final power supply source. This system, in which this type of stationary power supply circuit is used as the main power source and provides a stand-alone power supply without parallel running with another diesel generator, etc., is unprecedented as a



Source: Mitsubishi Heavy Industries, Ltd.

Fig. 1 Section of hybrid turbocharger

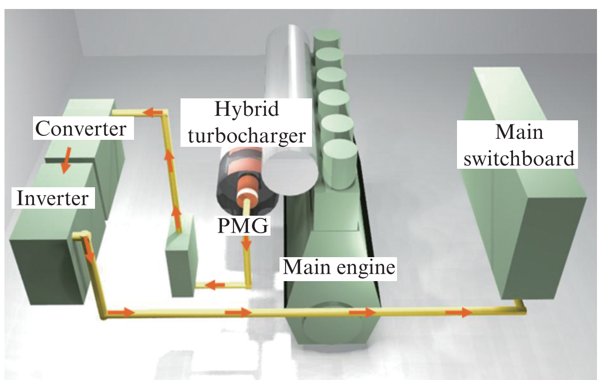


Fig. 2 System configuration of power supply system

shipboard power supply system.

In realizing a stand-alone power supply by the hybrid turbocharger, it was necessary to overcome the following three major issues:

(1) Autonomous Control of Voltage and Frequency

When parallel running with another generator is a condition, an alternating current sine wave can be output so as to be synchronized with the other generator. However, because there is no other reference waveform in stand-alone operation, voltage and frequency must be determined autonomously. Therefore, stable operation was realized by calculating and outputting the same voltage characteristics and frequency characteristics as those of the conventional diesel generator. And momentary voltage and frequency variations during large motor starting are not to exceed specified values required by classification society. Together with this, higher harmonics measures were implemented so that total harmonic distortion (THD) in the distribution system is within 5%, as required by the classification society.

(2) Supply of Reactive Power

Reactive power is power which does not consume electrical energy in a circuit, but is power by a current component that has a phase difference of 90° from the voltage that passes when connected to inductive loads such as motors, transformers, etc. or capacitive loads such as condensers, etc. The larger part of the electric load on a ship is electric motors in drive applications for propulsion auxiliary machineries, and supply of reactive power is necessary to run inductive loads such as motors. When an inductive load is in service, a phase difference is generated between the voltage and current. In cases where a sine wave is output from a switching circuit like an inverter, it is necessary to pass a current of the opposite polarity from that of the voltage. As a measure for this, supply of reactive power was made possible by reverse connection of the feedback diode with the switching device.

(3) Supply of Sustained Short-Circuit Current

As an over current protection function, conventional inverters perform current breaking by activating a protective function in case of an over current of 150% to 200% of the rated current. However, in ship power supply systems, the classification society requires that the generator supply a sustained short-circuit current of 3 times the rated current for 2 seconds. This is required because the protective device (breaker) that is located at higher-level than the fault point will be activated by the flow of the large current during a short-circuit accident, thereby isolating the faulty circuit. As measures for this, the inverter was given a capacity which makes it possible to supply a short-circuit current, and a control function which passes a short-circuit current of 300% or rated current for at least 2 seconds during power supply accidents was added.

2.2.4 Main switchboard

A general type structure is used in the main switchboard. However, as a control function of the panel, total power management in the ship is performed, including the hybrid turbocharger.

The amount of power which can be generated by the hybrid turbocharger varies depending on the main engine load, and power generation is inadequate for shipboard power load particularly in the low engine load region. Moreover, if an excessive amount of power is taken out from the hybrid turbocharger, this will reduce the air intake to the main engine, which is the essential work of the turbocharger, and may damage the long-term reliability of the main engine. Therefore, a system was adopted in which the appropriate amount of power generation for the main engine load was calculated based on various parameters and controlled in the main switchboard.

Furthermore, cases in which power generating capacity suddenly stops due to crash stopping of the ship, main engine emergency stop, or the like are also conceivable. A protection sequence was constructed including, for example, automatic starting of the standby generator, etc., so that power can be supplied continuously even in such cases.

3. Results of Verification of Actual System

The developed ship power supply system was installed on an actual ship for the first time in the world on a bulk carrier constructed by JMU. This ship has a propulsion plant in which one fixed-pitch propeller is directly coupled to one main engine.

Photo 1 shows the main components of the power supply system installed on the first vessel. These components are installed in the engine room compartment of the ship.

This power supply system was installed in the actual ship after a single running test of the turbocharger and performance verification when it was equipped in the propulsion engine[3]. The following presents examples of verification of the performance and function of the system which enables stand-alone supply of electric power, as described in the preceding chapters.

3.1 Hybrid Turbocharger Single Running Test

Figure 3 shows the time-series transition of the supplied electric power, main engine revolution, and turbocharger revolution when supplying power in the ship by

(a) Hybrid turbocharger (b) Converter and inverter (c) Main switchboard

Photo1 Main component of power supply system on the first vessel

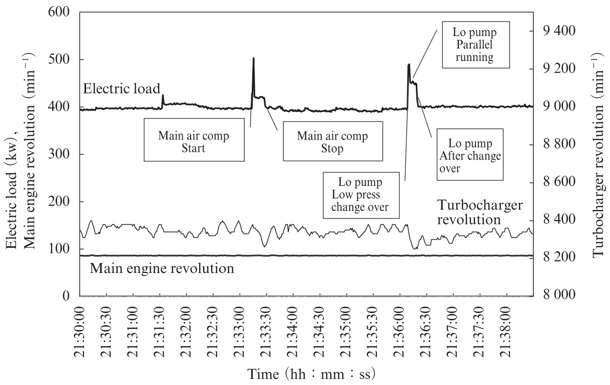


Fig. 3 Result of load variation test with hybrid turbocharger single running

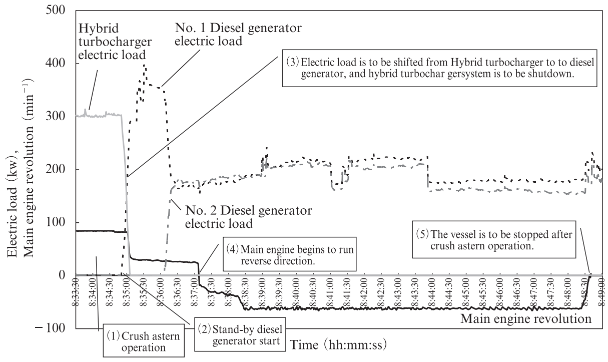


Fig. 4 Result of crush astern test

stand-alone operation of the power supply system. The cases of starting and stopping of large capacity load are shown as variations in the power load in the ship. It was confirmed that the system can follow these variations in the power load and supply power stably. It was also found that power supply is possible at these times with no influence on the main engine speed.

3.2 Crash Astern Test

Figure 4 shows the time-series transition of the supplied power of the shipboard generator and the main engine revolution in a crash astern test.

In order to ensure safety in emergencies, it is necessary to satisfy a certain braking distance in ships. For this, it is important to perform a sequence of operations without delay during the crash astern maneuver. These operations are stopping the fuel supply to the main engine, instantly reducing the engine load, and then charging braking air and reversing the main engine. Therefore, the function of the safety devices constructed in the main switchboard was verified.

As shown in Fig. 4, (1) when the crash astern operation was initiated during stand-alone operation of the hybrid turbocharger, (2) after establishing independent starting of the standby generator and (3) shutting down the hybrid turbocharger, (4) the fuel supply to the main engine was stopped and the main engine was reversed, and (5) the vessel was stopped, thereby demonstrating that control is possible with no problems. This test confirmed that braking and stopping are possible within the braking distance provided in the applicable regulations.

4. Conclusion

Japan Marine United Corp., in joint work with other companies, developed and practically applied a ship power supply system using a hybrid turbocharger. The features of the system are as follows.

(1) The hybrid turbocharger is exhaust heat recovery technology which does not require major modifications of the engine room layout and can be applied to comparatively small ships, as the equipment comprises a compact generator built into the turbocharger equipped on the main engine.

(2) This power supply system makes it possible to supply electric power by stand-alone operation of the hybrid turbocharger, and as such, it is without precedent as a shipboard power system. The main issues which were overcome in the development of this technology were autonomous control of voltage and frequency, supply of reactive power, supply of sustained short-circuit current, and implementation of power management coupled with the main engine.

(3) The developed ship power supply system was

installed for the first time in the world on a bulk carrier constructed by JMU. Through actual ship verification tests, the fact that stand-alone operation is possible using this power supply system and also the performance and function of the system were confirmed.

This paper has described the features of the system and the issues up to development and practical application and their solutions. Although not discussed in this paper, an energy saving effect of approximately 2% has also been confirmed with this system.

Finally, the authors wish to express their heartfelt gratitude to all those concerned at Monohakobi Technology Institute, Nippon Yusen Kabushiki Kaisha (NYK LINE), Mitsubishi Heavy Industries, Ltd., Taiyo Electric Co., Ltd., and Hitachi Zosen Corp. for their invaluable opinions and support as joint developers in the development of this ship power supply system.

The in-service demonstration test of this power generating system has been carried out with the support of the Japanese government, which invested in the technology as part of its program to reduce maritime emissions, and Nippon Kaiji Kyokai, which supported the development as part of its joint R&D industry program.

References

1) Amendments to the annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships, 1973, as modified by the protocol of 1978 relating therto, Resolution MEPC. 203(62), 2011-07-15.
2) Shiraishi, Keiichi et al. Development of Large Marine Hybrid Turbocharger for Generating Electric Power with Exhaust Gas from the Main Engine. Mitsubishi Heavy Industries Technical Review. 2010-09, vol. 47, no. 3, p. 81.
3) Ono, Yoshihisa et al. Application of a Large Hybrid Turbocharger for Marine Electric-power Generation. Mitsubishi Heavy Industries Technical Review. 2012-03, vol. 49, no. 1, p. 35.