CIMAC CONGRESS 25
ZURICH, MAY 19 – 23, 2025

2025 | 228

Advancing Decarbonization of Electrification with IHI Power Management System

Electrification and Fuel Cells Development

Masaki Takiguchi, IHI Power systems

Isao Watanabe, IHI Power systems

ABSTRACT

IHI Power Systems (hereinafter called "IPS") has been supplying many engines and Z-PELLER for tugboats and offshore support vessels as a system integrator for the marine propulsion system. IPS has consistently expanded its product lineup and improved performance to accommodate a wide range of output and bollard pull in response to meet the market demands. IPS has been leading the marine propulsion system for many years.

Recently, with the growing demand to reduce environmental impact, new technologies have been introduced to the market. These include Common Rail engines and Dual Fuel engines in terms of engines, and electric propulsion systems and hybrid propulsion systems using main engines and electric motors in terms of propulsion systems. Electrification is increasing in the marine industry, similar to other fields such as automotive industry.

In response to the trend of electrification and the demand for electric propulsion systems, IPS has developed and commercialized a Z-PELLER equipped with an electric motor.

However, we are not only focusing on propulsion machinery, but also actively working on the development of comprehensive electric propulsion systems.

IPS played a pivotal role as a system integrator in the "TAIGA", Japan's first electric tugboat. We have not only delivered a Z-PELLER equipped with an electric motor, but also oversaw the integration of the electric propulsion system. While we reported on the design of "TAIGA" at the conference in 2023, we will present the operational results including contributions to the environment in this paper.

In addition, in terms of developing an electric propulsion system, it's crucial not only to focus on the propulsion machinery but also to properly control the power of key components such as generators and batteries to improve the overall energy efficiency of the vessel.

IPS has developed a power management system to control the DC grid distribution system, enabling more efficient operation to meet market demands. We will also report on the results of this development.

1 INTRODUCTION

IHI Power Systems Co., Ltd. (hereinafter referred to as “IPS”) has provided diesel engines and azimuth thruster Z-PELLER for tugboats and offshore support vessels as a system integrator of propulsion systems.

By responding to market demands with a wide range of output power and bollard pull (BP), expanding its lineup, and improving performance, IPS has led the marine propulsion system industry for many years.

In recent years, the demand for reducing environmental impact has increased, and new technologies addressing this have been introduced to the market. In the maritime industry, like other sectors such as the automotive industry, there is a growing need for electrification. Hybrid electric propulsion systems that combine engines and batteries, as well as fully battery-powered electric propulsion systems, have been put into practical use.

IPS has commercialized the Z-PELLER equipped with an electric motor to accommodate electrification. In addition, IPS is also developing a DC grid distribution system that connects major equipment such as propulsion motors, generators, and batteries to the DC distribution switchboard. In the DC grid system, it is possible to supply power to the propulsion inverter directly from the battery without going through a converter, as the DC bus of the switchboard and the DC circuit of the propulsion inverter can be connected.

IPS played a role as the system integrator for the electric propulsion system in Japan's first electric tugboat, "Taiga." This paper reports on the achievements of "Taiga" and its contributions to the environment.

Furthermore, the DC grid distribution system can improve energy efficiency by appropriately controlling the power from generators and batteries. IPS is developing a power management system (PMS) to control the DC grid distribution system. In this paper, IPS presents out development of PMS.

2 Z-PELLER® AZIMUTH THRUSTER

One of the main products of IPS azimuth thruster “Z-PELLER”, that is fully rotational propulsion unit, primarily for tugboats. The Z-PELLER boasts a high market share in the tugboat sector both domestically and internationally.

To meet the fluctuating market demands, IPS has continued to expand and improve its product range each year. As shown in Table 1, a wide range of fixed pitch propeller (FPP) models is available, and many customers have adopted these products.

3 IPS’S EFFORTS IN ELECTRIC PROPULSION SYSTEMS

3.1 Evolution of Development at IPS

At IPS, we collect and analyze operational data from tugboats and provide feedback to the development of propulsion systems. Tugboats, which support the berthing and unberthing of large vessels, are equipped with high-power main engines.

However, a significant portion of their actual operation consists of low-load tasks or idling periods, such as moving to work locations and waiting in standby mode. Due to the characteristic reduction in efficiency of diesel engines under low-load conditions, it is challenging to improve efficiency in systems where the propulsion is driven directly by the main engine. Therefore, we have proposed electrification or hybrid systems combining downsized main engines with electric motors.

IPS has a track record of delivering hybrid propulsion systems to two tugboats so far. Additionally, in recent years, we have supplied the electric propulsion system for Japan's first electric tugboat, "Taiga." This vessel began actual operation in 2023.

Table 1. Lineup of Z-PELLER

model		ZP-09	ZP-10	ZP-21	ZP-31	ZP-41A	ZP-41	ZP-41B	
Max. cont. rating	kW	735	956	1323	1680	1939	2461	2574	3000
Input speed	min^{-1}	1000 1650	1000	750 1200 1800	750 1200 1800	750 1200 1800	750 800 1800	750	800 1200 1800
Propeller Dia.	m	1.4/1.5/1.6	1.75	2.0	2.2/2.3	2.3/2.4	2.5/2.7/2.8	2.7/2.8	3.0/3.1
Bollard 100%	ton	26	33	45	60	68	85	90	100

3.2 Electric Propulsion tugboat “Taiga”

"Taiga" is Japan's first electric propulsion tugboat, utilizing electric motors exclusively for propeller drive. IPS developed the L-drive model electric propulsion system, which vertically mounts the electric motors on the Z-PELLER and supplied this system to "Taiga" (Figures 1 and 2).

Figure 1. L-drive Z-PELLER

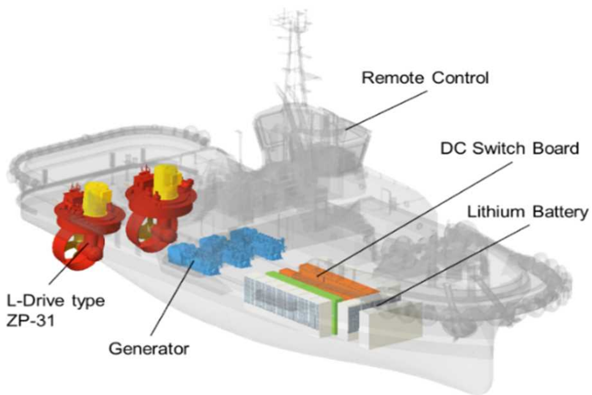

Figure 2. Electric propulsion tugboat “Taiga”

"Taiga" is equipped with permanent magnet (PM) motors, which were chosen for their high efficiency even under low-load conditions, making them well-suited to the operational profile of tugboats. Compared to traditional induction motors, PM motors are also more compact, fitting well within the limited installation space of a tugboat.

For the electric propulsion system, we adopted ABB's DC grid technology, utilizing high-capacity lithium-ion batteries and generators as power sources. The high-capacity batteries enable zero-emission operation during low-load conditions, contributing to the reduction of CO_2 emissions.

"Taiga" began operation in January 2023. Over the course of its first year, we collected and analyzed data on its energy consumption. On average, over the one-year period, we confirmed a 25% reduction in energy consumption and a 29% reduction in CO_2 emissions.

4 DEVELOPMENT OF POWER MANAGEMENT SYSTEM

4.1 Control Methods of PMS in vessels

IPS has previously developed the aforementioned L-drive Z-PELLER and served as the system integrator for the electric propulsion systems installed in “Taiga”. However, the software system for electric propulsion was sourced from another company. IPS has been developing a PMS for electric propulsion systems. In this paper, we will explain the concepts and approach behind the development of our PMS.

Figure 3 shows a conceptual diagram of the power system in an electric vessel. Note that the types of power sources (AC or DC) and converters are omitted for simplicity. In this system, the main consumer of power is the propulsion motor, and the onboard power supply also consumes power. However, the output of the propulsion motor is determined by the handle input from operators, and the load of the onboard power supply operates independently of the PMS. Therefore, these elements cannot be controlled by the PMS.

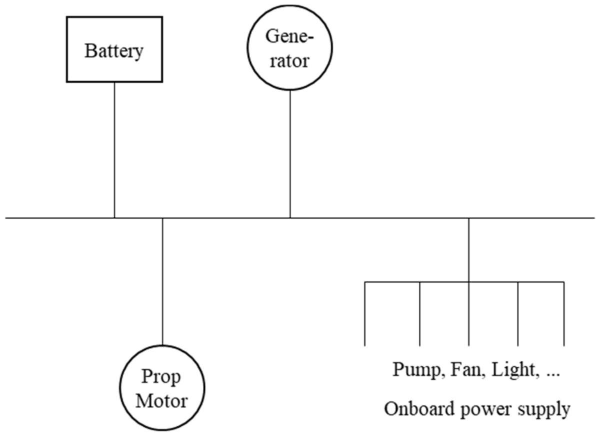

Figure 3. Conceptual diagram of the power system in an electric vessel

The remaining elements in this system are the battery and the generator. In the absence of battery, this system operates similarly to conventional diesel-electric system, where the total power consumption of the propulsion motor and onboard power loads is balanced by the output of the generator. Specifically, voltage regulation by the generators is generally employed (AVR). For AC generators, AVR is achieved through excitation current control, whereas when connected to a DC grid via inverters, the inverters maintain a constant DC voltage.

When battery is present, it absorbs any imbalance between the total power consumption and the generator output. The PMS manages the charge and discharge of the batteries by appropriately control the generator output. Conversely, it is necessary to adjust the generator output based on the battery's State of Charge (SOC) and the operational conditions.

In the case of electric and hybrid vehicles, it is possible to recover energy during braking by regenerating power through the motors. However, in the case of vessels, regenerative power is minimal. To reduce fuel consumption and CO_2 emissions, the use of shore power (green power derived from renewable energy sources) and the efficient operation of generators are crucial. This means that it is important to efficiently use the power charged into the batteries while the vessel is berthed. For ferries and cargo ships, where it is easy to fix or predict the operational patterns, routes, and distances, prioritizing the use of battery power becomes the optimal solution.

In the case of tugboats, their operations are not fixed, and additional tasks may be added during their operations. Therefore, if the battery's SOC is allowed to drop too low, there is a risk that the tugboat may not be able to deliver or sustain the necessary power for unexpected additional tasks. This requires careful attention. The key difference between tugboats and ferries or cargo ships is that, for tugboats, it is not always optimal to prioritize battery usage to maximize shore power usage. This is a crucial consideration when developing the PMS for tugboats.

Additionally, in tugboats, the output of the propulsion system can change rapidly, so it is necessary to design the equipment and control systems to ensure that the discharge power does not exceed the battery's allowable limits.

4.2 Energy Efficiency of Electrifying Tugboats

For the reduction of fuel consumption and CO_2 emissions through the electrification of vessels, it is crucial to maximize battery usage and increase the proportion of shore power usage. However, in the case of tugboats, it is often difficult to fully deplete the batteries. On the other hand, due to the operational characteristics and engine output characteristics of tugboats, electrification can improve energy efficiency through power storage in batteries and smoothing of engine output.

Tugboats require high output when pushing or pulling large vessels, while their output is low during transit, and they spend a significant amount of time waiting for tasks. An example of the propulsion output pattern of a tugboat is shown in Figure 4.

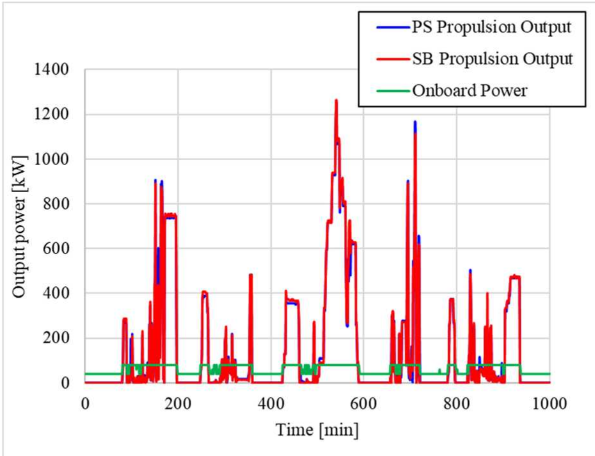

Figure 4. Example pattern of the propulsion output and onboard power of tugboat

Diesel engines operate most efficiently near their rated output, and efficiency decreases at low loads. In the case of electrifying vessel, by using batteries and operating the generator engines close to their rated load, fuel consumption can be reduced. Additionally, by stopping the engines when power generation is not needed, fuel consumption during idling can also be minimized.

Figures 5 and 6 show examples of generator operation, battery charging power, and battery SOC in a hybrid electric vessel. In this example, there are two generators, each generating 1000kW when power generation is needed.

It should be noted that, for the purpose of later fuel consumption analysis, the generators are used to charge the batteries in such a way that the SOC eventually returns to the same 80% level as at the start.

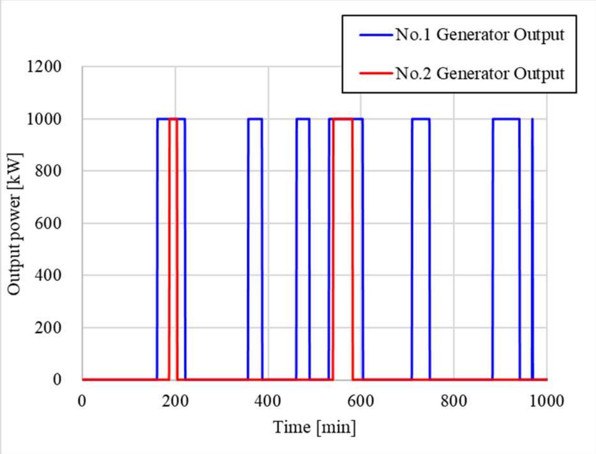

Figure 5. Example pattern of generator output (2 generators)

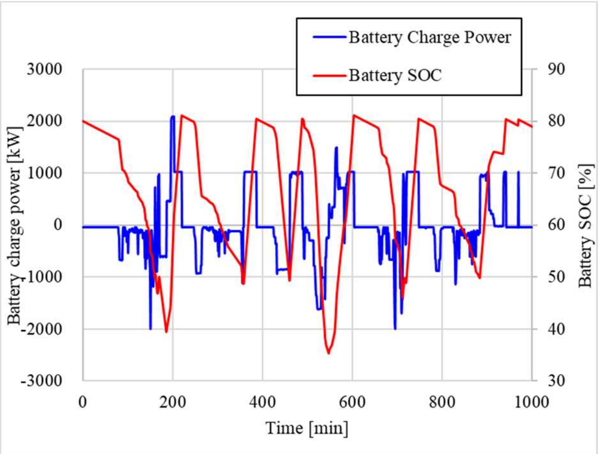

Figure 6. Example pattern of battery charging power and battery SOC

Under the aforementioned operational pattern, we calculate the fuel consumption for both engine-driven vessels and hybrid electric vessels. Figure 7 shows an example of the fuel consumption rate depending on the load state of the generator. Note that the fuel consumption rate means the amount of fuel used per unit kWh, and it is normalized with the load at 100% as 1. In practice, the characteristics of the fuel consumption rate vary depending on the engine, so it is necessary to select an engine suitable for the operating characteristics. Table 2 shows the results of calculating the fuel consumption in the patterns of Figures 4 to 6. The hybrid electric vessel demonstrates a 12% reduction in fuel consumption compared to the engine-driven vessel. In practice, the reduction in SOC can be compensated by charging from shore power when the vessel returns to the port base, leading to even greater potential for fuel savings and CO_2 reduction.

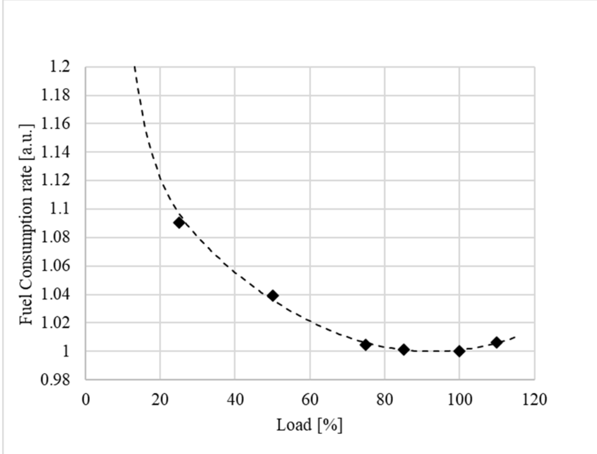

Figure 7. Example of the fuel consumption rate of generator

Table 2. Comparison of calculated fuel consumption values between engine-driven vessel and hybrid electric vessel

Engine-driven vessel		Hybrid electric vessel	
Item	Fuel Consumption [kg]	Item	Fuel Consumption [kg]
Main Engine	1080.4	Generator Engine	1167.5
Auxiliary Engine (Onboard Power Supply)	229.7		
Total	1310.1	Total	1167.5

Additionally, vessels are equipped with numerous auxiliary motors. In particular, hydraulic pumps often operate their motors at rated speeds even when hydraulic equipment is not in use. By implementing inverters and controlling the hydraulic generation as needed, energy savings can be achieved.

4.3 Comparison of Electric System Configurations

In recent years, DC grid power configurations have been increasingly used for marine applications. This section discusses the configurations of DC grid system in electric vessels.

The DC grid configuration has several advantages, such as the ability to perform power conversion for propulsion motors from DC to AC in a single step, and the ease of connecting batteries. Regarding the inverter implementation for auxiliary motors mentioned in the previous section, the DC grid is particularly compatible with this approach, as auxiliary inverters can be connected to the DC system.

Additionally, auxiliary motors experience high inrush currents when directly connected to AC power. However, in DC grid electric vessels, where onboard AC power is generated by inverters, the overload tolerance tends to be lower due to the characteristics of inverters. When driving large-capacity auxiliary equipment, soft starters are typically used. By replacing these soft starters with inverters and connecting them to the DC system, the integration of inverter for auxiliary equipment can be achieved. The reduction of inrush currents by inverters is also a factor that makes DC grids suitable.

Next, as an element of the DC grid power configuration, we will discuss the onboard power supply configuration. The onboard power supply configuration in a DC grid can be broadly classified into two types:

(Case A) A system configuration where the generator is separated from the AC power system, and the AC power is entirely supplied by inverters (As shown in Figure 8).

(Case B) A system configuration where the generator is integrated with the AC power system, supplying AC power from the generator when it is running, and from the inverter when the generator is stopped (As shown in Figure 9).

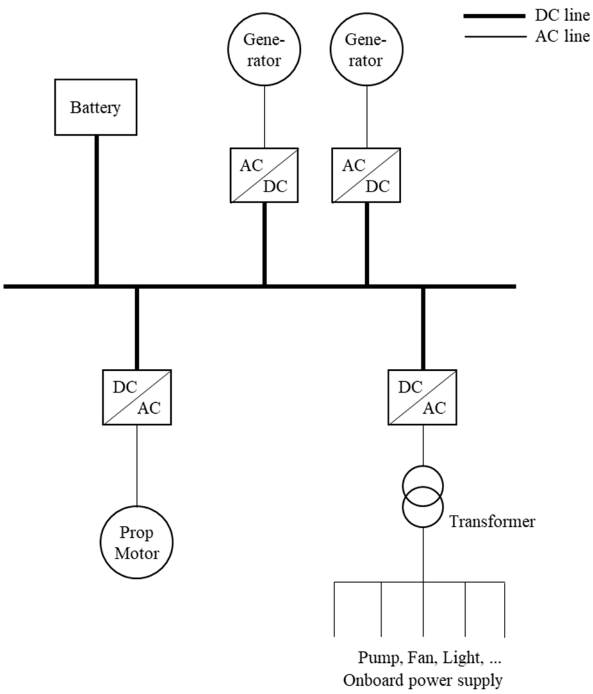

Figure 8. Case A: A system configuration where the generator is separated from the AC power system

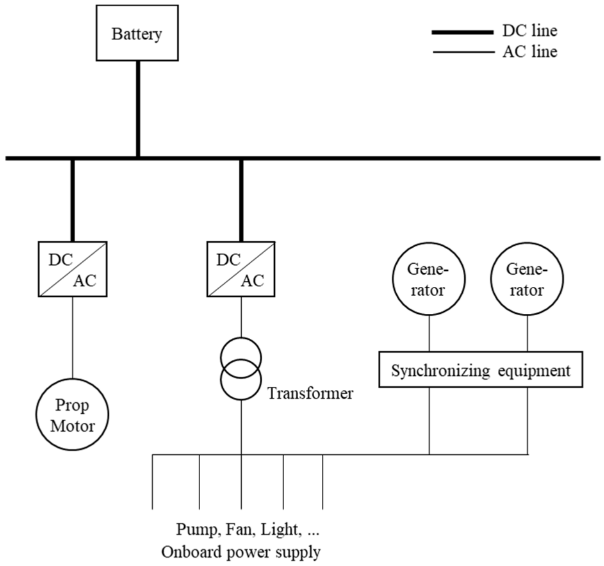

Figure 9. Case B: A system configuration where the generator is integrated with the AC power system

Each of these two power configurations has its advantages and disadvantages, and it is necessary to design them appropriately based on factors such as the capacity of the propulsion system, generators, batteries, and the operational methods of the onboard power loads. The advantages and disadvantages of the power configurations are summarized in Table 3.

5 SUMMARY

This paper discusses the energy consumption and CO_2 emission reduction performance data over the first year of operation for Japan's first electric propulsion tugboat, "Taiga," which was equipped with an electric propulsion system supplied by IPS. Additionally, IPS emphasized the characteristics of the power management system necessary for the electrification of ships, particularly focusing on the power management system in tugboats. Furthermore, IPS introduced examples of energy-saving measures and power system configurations for electric ships, explaining the advantages and disadvantages of each.

As a global leading company in tugboat propulsion systems, IPS has been enhancing product performance and expanding its lineup to meet market demands. Electrification is one of the effective means for decarbonizing ships such as tugboats, and IPS will continue its development efforts to lead the world in electrification as well.

Table 3. The advantages and disadvantages of the power configurations

Case A	Advantages	➢ Flexibility in the types of generators that can be selected (Synchronous machines, induction machines, low speed, variable speed) ➢ Synchronization is not required even when multiple generators are operating ➢ Control of the inverter for AC power is independent of the generators state (Using generators and batteries equivalently) ➢ The inverter for AC power only needs to have sufficient capacity to supply the onboard power
	Disadvantages	➢ In case of a failure of the inverter for AC power, the onboard power becomes unusable (redundancy or interconnection to other power source are necessary) ➢ Each generator requires an AC to DC converter, necessitating large-capacity inverters
Case B	Advantages	➢ Existing AC distribution technology can be utilized, making the implementation hurdle relatively low (AC distribution, synchronization, generator control) ➢ Converters for generators are not necessary ➢ Even in case of a failure of the inverter for AC power, the onboard power can be supplied by the generators ➢ For applications with high onboard power loads, direct supply from the generators is more efficient
	Disadvantages	➢ The control of the inverter for AC power depends on the start-stop state of the generators (AC to DC, DC to AC) ➢ A large-capacity inverter is required because the power for battery charging and propulsion also passes through the inverter for AC power

6 ACKNOWLEDGMENTS

We would like to express our gratitude to Tokyo Kisen, Kanagawa Dockyard, and e5 Lab. for their contributions to this paper and its development. We are particularly grateful to Tokyo Kisen for providing operating data for the electric propulsion tugboat “Taiga” and for their cooperation in data analysis.

7 REFERENCES

[1] Shiraishi, K. et al. 2013. Development of the hybrid tugboat system. CIMAC congress 2013 paper No.138.

[2] Harada, Y et al. 2023. Z-PELLER electrification and optimization for decarbonization. CIMAC congress 2023 paper No.090.

8 CONTACT

Masaki Takiguchi
Senior Assistant Manager
IHI Power Systems Co., Ltd., Japan
TEL: +81-276-31-8115
E-mail: takiguchi0270@ihi-g.com

Isao Watanabe
Group Manager
IHI Power Systems Co., Ltd., Japan
TEL: +81-276-31-8115
E-mail: watanabe1412@ihi-g.com