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Original Paper

Test plan for ecofriendly alternative fuel system using K-GTB (Korea-Greenship Testbed)

Bonggi Choi[1] · Hyungwon Shim[2] · Hee Jin Kang[3] · Donghee Hwang[4] · Jang-Pyo Hong[†]

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Abstract: With the strengthening of international regulations concerning marine environmental standards, there has been a rapid acceleration in the technological advancement of ecofriendly alternative fuels tailored for ships. In contrast, despite Korea's keen interest in developing environmentally sustainable ships, breaking into the global market for ecofriendly ship propulsion systems poses challenges owing to existing technological disparities and difficulties in ensuring the performance of alternative fuel and propulsion systems. To address these challenges, we are currently constructing a test ship capable of concurrently accommodating various alternative fuel systems. The primary goal is to validate the stability and reliability of these alternative fuel systems through comprehensive sea trials while also establishing a track record for the associated equipment. This paper presents a maritime demonstration methodology for an alternative fuel system utilizing the aforementioned test ship. It details the sea vessel specifications, preparation for sea trials, and procedures for installation, operation, and disembarkation. It is anticipated that the procedures detailed herein, by employing a test ship, will significantly contribute to the assessment of the performance of alternative fuel systems and the advancement of technology within the sustainable marine industry.

Keywords: Alternative fuel, Ecofriendly ship, Sea trial, Test plan, Test procedure

1. Introduction

The acceleration of international marine environment regulations has spurred a rapid surge in the technological advancement of environmentally friendly alternative fuels for ships. To comply with ship emission regulations, fuels that satisfy the sulfur emission standards for ship fuel oil can be utilized. Alternatively, existing ships can replace their fuel oil with low-carbon options, such as liquefied natural gas (LNG) and compressed natural gas. Furthermore, various engine systems utilizing ammonia, methanol, etc. and methods employing carbon-free power sources, such as batteries **[1][2]** and hydrogen fuel cells, are being explored. Consequently, numerous countries have constructed advanced electric propulsion **[3]** and ecofriendly fuel propulsion ships **[4]** with diverse specifications and charging and discharging methods to develop various ecofriendly vessels **[5][6]**. However, despite Korea's significant interest in developing ecofriendly ships, it faces challenges in entering the global market owing to technological gaps and difficulties in ensuring the performance of alternative fuel and propulsion systems. To address these challenges, we are currently constructing a test ship capable of simultaneously accommodating various alternative fuel systems. This approach aims to ensure the stability and reliability of alternative fuel systems through sea trials and to establish a track record for related equipment.

Finding ships capable of simultaneously installing and testing various alternative fuel systems at sea, both domestically and

† Corresponding Author (ORCID: http://orcid.org/0000-0002-5054-2110): Senior Researcher, Alternative Fuels and Power System Research Center, Korea Research Institute of Ships & Ocean Engineering, 32, Yuseong-daero 1312beon-gil, Yuseong-gu, Daejeon 34103, Korea, E-mail: jphong@kriso.re.kr, Tel: +82-42-866-3943

1 Researcher, Alternative Fuels and Power System Research Center, Korea Research Institute of Ships & Ocean Engineering, E-mail: bgchoi@kriso.re.kr, Tel: +82-42-866-3916

2 Principal Researcher, Alternative Fuels and Power System Research Center, Korea Research Institute of Ships & Ocean Engineering, E-mail: hwshim@kriso.re.kr, Tel: +82-42-866-3824

3 Principal Researcher, Alternative Fuels and Power System Research Center, Korea Research Institute of Ships & Ocean Engineering, E-mail: hjkang@kriso.re.kr, Tel: +82-42-866-3417

4 Director, Technology and Research Institute, KTE Co., Ltd, E-mail: dhhwang@kte.co.kr, Tel: +82-51-265-3551

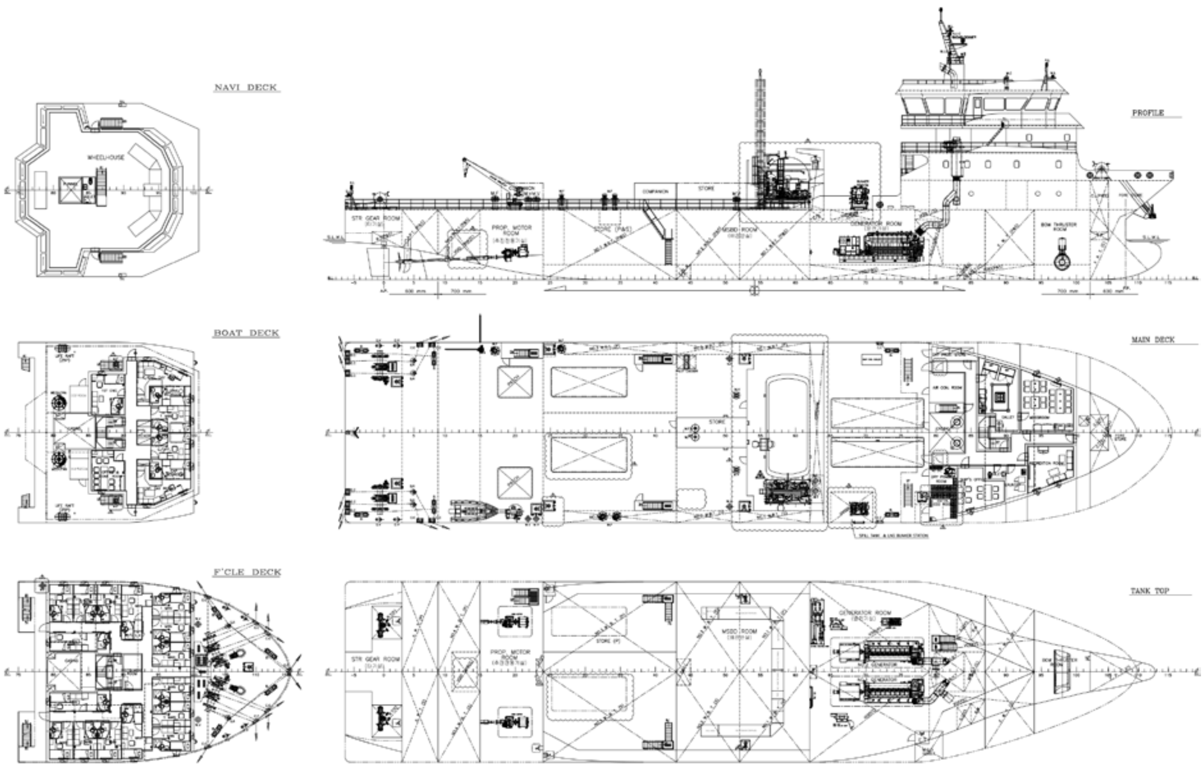

Figure 1: General arrangement of K-GTB **[7]**

internationally, is challenging, as exemplified by this ship. In addition, the development of this ship is intended to mitigate the substantial costs and extended demonstration periods associated with building and operating separate test ships for each new eco-friendly alternative fuel technology. Consequently, this paper aims to not only present a standardized testing procedure that establishes comprehensive guidelines for ensuring the safety and reliability of tested alternative fuel systems but also introduce the detailed methodology and process of maritime demonstration using a test ship. This will emphasize the practical aspects of system installation, operation, and evaluation in a maritime environment.

2. Overview and Technical Specifications of the Test Ship

The Korea-Greenship Testbed (K-GTB) serves as a platform for demonstrating the application of a 1 MW-class ecofriendly alternative fuel propulsion system at sea. The power system was designed to facilitate the concurrent operation of a 1 MWh-class battery system, 1 MW-class fuel cell system, and 2 MW-class engine system within the power infrastructure of the vessel. The overall configuration of the ship is shown in **Figure 1**. An eco-friendly alternative fuel system was strategically positioned beneath the main deck, allowing for the seamless replacement of the fuel system through a dedicated hatch. The external appearance of the K-GTB is depicted in **Figure 2**, and **Table 1** provides a comprehensive overview of the specifications of the ship.

Figure 2: 3D rendered image of K-GTB **[7]**

Table 1: Specifications of K-GTB

Classification	Specification
Length Over All (LOA)	82.6
Length Between Perpendicular (LBP)	74.0
Breadth(MLD)	18.0
Depth(MLD)	7.0
Draft(scant)	4.0
Draft	3.6
Gross Tonnage	2,600 TON
Service Speed	12.5knots
Propulsion Motor	1,100kW x

	1,200RPM(2EA)
Gear Box	3:1(PROP. 400RPM)

The expected roles of this ship are as follows:

(1) Development of marine verification and certification techniques for three or more types of ecofriendly alternative fuels **[8]** (carbon-free fuel co-fired engines, batteries, and fuel cells)

(2) Development of marine verification and certification techniques for ecofriendly ship core technologies **[9]** (power converters, control systems, seawater battery technology)

(3) Other tests, verification, etc. required for research by the ordering agency.

3. Sea Trial Procedures

3.1 Preparing for an Ecofriendly Alternative Fuel System

It is crucial to clarify the purpose of the test and establish its direction. To achieve this, detailed records of the alternative fuel system type, capacity and, if possible, class certification must be maintained. This ensures the reliability of the test and compliance with regulatory agency requirements. Furthermore, a thorough review of the Hazard and Operability (HAZOP) report is imperative for proactively identifying and managing potential risks that may arise during the maritime verification process.

To guarantee the secure execution of test operations and facilitate coordination with regulatory agencies, it is imperative to confirm the test date and operational route beforehand. Restricting onboard presence exclusively to essential personnel mitigates risks and enables streamlined and efficient test operations. Finally, personnel embarking on the test can fortify the baseline safety level and alleviate operational risks by procuring suitable insurance coverage.

3.2 Installing the Ecofriendly Alternative Fuel System

3.2.1 Preparing to install the Ecofriendly Alternative Fuel System

The installation of an alternative fuel system entails the utilization of a crane, wherein the weight and precise positioning of the alternative fuel system emerge as pivotal considerations influencing the selection of the installation methodology. In cases where the deployment of an onboard crane is infeasible, using a substantial crane becomes imperative during the docking of the ship at the shipyard. Moreover, bottom cleaning is deemed a requisite to ensure the fundamental propulsion functionality of the vessel, which can be preemptively executed at the shipyard before commencing the installation process. All aspects of the operation, including ship docking, alternative fuel system installation, and bottom cleaning, require meticulous oversight and guidance from shipyards and pertinent regulatory bodies. Finally, a comprehensive evaluation must be conducted to ascertain the influence of the weight of the alternative fuel system on the stability and operational performance of the ship.

3.2.2 Placement and Fixation of the Alternative Fuel System

Before installing an alternative fuel system on a ship, a thorough examination of the location and condition of all equipment intended to secure the system is imperative. This is crucial to ensure secure and reliable installation of the system. Subsequently, the hatch is opened using a crane, and the space is carefully prepared for the placement of the system. The determination and implementation of the installation location and dimensions must adhere precisely to the installation drawings and technical specifications of the equipment. Throughout this process, emphasis should be placed on verifying the explosion-proof performance of the surrounding facilities in the presence of an explosive fuel. It is imperative to exercise caution to prevent damage to the surrounding equipment during the mounting of an alternative fuel system. Additionally, a comprehensive check of the fixation state is essential after completing the mounting and fixing processes.

3.3 Ecofriendly Alternative Fuel Charging and Connecting

3.3.1 Battery System Charging Procedure

The initial step involves selecting an appropriate charging mode by assessing the battery status. Adjustments to the charging system parameters are made to ensure safety and optimize the efficiency of the charging process. Specifically, the battery voltage, current, and temperature are continuously monitored. Data are logged systematically to identify the overvoltage, overcurrent, and overheating conditions swiftly, safeguarding the entire test system. After charging, the battery conditions are reevaluated, and the charging data are analyzed to identify any issues that may have arisen during the process.

3.3.2 Cryogenic Liquid Fuel Charging Procedure

Special emphasis should be placed on the cryogenic liquefied fuel charging stage, particularly during refueling with fuels, such as LNG and liquefied hydrogen (LH_2). Before charging, it is imperative to monitor the temperature and insulation of the liquid fuel storage tank and charging system to ensure a conducive charging environment under cryogenic conditions. Throughout the charging process, fuel leaks must be monitored using a leak detection system, and continuous checks on the safety valves and pressure control systems are essential for normal operation. After charging, a thorough examination of the temperature and pressure of the storage tank and charging system is necessary to confirm that all the parameters fall within safe ranges.

3.3.3 Fuel System Connection

The primary purpose of a ship is the safe transportation of cargo and people. For ships involved in transporting large quantities of cargo and passengers, it is crucial to establish a system that ensures the minimum operational capacity of the ship, even in the event of an emergency or a breakdown. The K-GTB, which is designed to evaluate the performance of various alternative fuel systems, is equipped with a load-sharing technology based on a direct-current distribution. This technology ensures that the ship maintains its operational performance, even when potential issues with the test system arise during performance evaluations. Upon installation of the aforementioned alternative fuel system and charging each energy source, the system must be connected to the load-sharing distribution system. Subsequently, it is imperative to verify communication, power transmission, reception, and other relevant parameters to ensure proper functionality.

3.4 Control and Monitoring of Eco-friendly Alternative Fuel Systems

This ship is equipped with alternative fuel systems developed by various manufacturers. The connection of an alternative fuel system to the power system of the ship is crucial, emphasizing the importance of connectivity between the power connection and communication access systems. Considering the varied nature of alternative fuel systems serving as power generation sources for ships, a control system is imperative for monitoring the status of diverse power generation sources and utilizing them for propulsion. Our researchers developed an open integrated control and monitoring system (OPEN ICMS) that facilitates the interface and propulsion control of various power generation sources. To achieve this, a careful review of the data on the key linkage facilities and the characteristics of each alternative fuel system is necessary. The real-time monitoring of all abnormal situations that may arise during the power and communication connection process of the alternative fuel system is conducted using OPEN ICMS. If abnormal signs are detected, they must be reported promptly to an inspection supervisor.

3.5 K-GTB Operation Equipped with an Alternative Fuel System

The K-GTB, equipped and interconnected with an ecofriendly alternative fuel system, operates on a designated test route following the final inspection upon departure from the port. The primary objective is to assess the functionality of the alternative fuel system and establish a dependable performance record.

3.5.1 Test Route Plan

The demonstration route for the K-GTB necessitates meticulous planning involving an analysis of the testing criteria of the equipment. The route is then categorized into short-, medium-, and long-distance segments through collaboration with the inspection supervisor and test requester, who define the testing requirements. Furthermore, a weather forecast system can be utilized to anticipate and address potential operational issues along the K-GTB's route.

3.5.2 Departure Procedures

The departure procedures for the test ship must be executed with utmost attention to safety and accuracy. Initially, the verification of the boarding completion of crew members and researchers is imperative to ensure the presence of all essential personnel on board, aligning with safety regulations. Subsequently, the fuel status of the K-GTB’s main generators and the supply of fuel to alternative fuel systems must be confirmed to guarantee sufficient energy for the planned route. In addition, the operating status of the main switchboard, alternative fuel system, and OPEN ICMS must be scrutinized to ascertain the normal functioning of the propulsion control system.

3.5.3 K-GTB Operation Procedures

The power grid configuration on this ship can consist of either a combination of the main generator and a standalone ecofriendly alternative fuel power source or the main generator and a parallel ecofriendly alternative fuel power source. In the case of parallel operation, which includes all three types of ecofriendly alternative fuel power sources, it is necessary to determine whether this configuration can be applied by considering the possibility of testing on a test ship. In addition, initiating an alternative fuel system during the parallel operation of the main generator is deemed significantly less effective in terms of operation and load addition; therefore, it is not performed unless there is a special request.

To ensure safe and seamless interconnection among various power systems, the power operation of an ecofriendly alternative fuel system using an integrated energy management system (IEMS) is categorized into three modes, as illustrated in **Figure 3**.

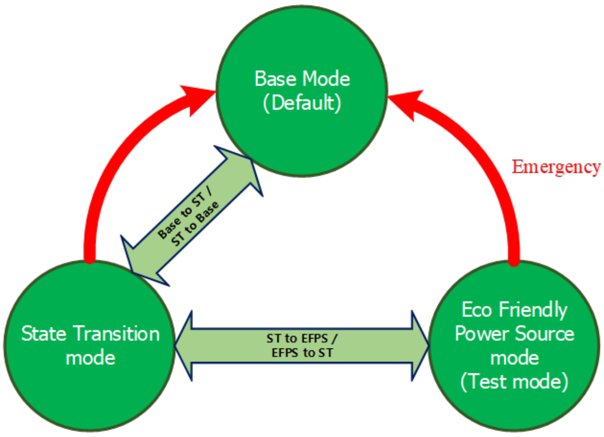

Figure 3: IEMS operational mode transition

① Base mode

As shown in **Figure 4**, during the normal operating mode, the two primary generators operate either independently or in parallel to provide power to the ship. Generators 1 and 2 must remain connected to the busbar at all times, regardless of the operating mode. Between Generators 1 and 2, the generator that is not currently connected to the bus is designated as the standby.

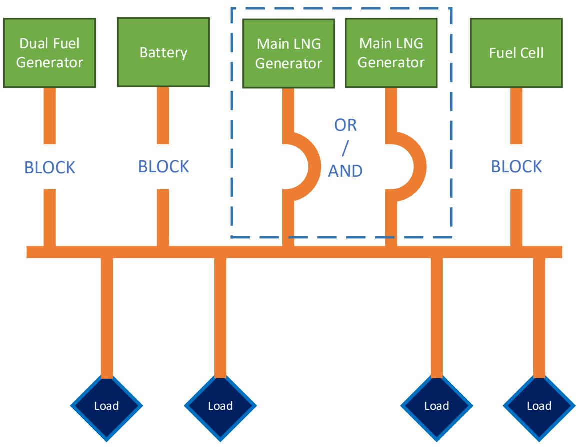

Figure 4: IEMS operational classification: base mode

② Status transition (ST) mode

- Case 1: Mode change from base mode

It is essential to input operation-related information for an ecofriendly power source (EFPS) and verify the connection to alternative fuel systems. The main generator is set to the minimum load state, it is then transitioned to the standalone operation state, and load reduction is executed. When preparing for maneuvering the EFPS, it is ensured that no alarms or warning elements are triggered and appropriate action is taken if needed, such as switching to the base mode. Test personnel should be ready to address the field conditions while maintaining the current configuration status screen display.

- Case 2: Mode change from EFPS mode

The connected load must be disconnected to ensure that the load applied to the EFPS during testing reaches the minimum required load. The EFPS is shut down, and the main generator is allowed to handle the remaining load. When preparing to switch to the base mode, it is ensured that no alarms or warning indicators are triggered, and appropriate action is taken if needed, such as transitioning to the EFPS mode. Similar to Case 1, the test personnel must be ready to address the field conditions while maintaining the current configuration status screen display. The operational classification of the IEMS in the ST mode is shown in **Figure 5**.

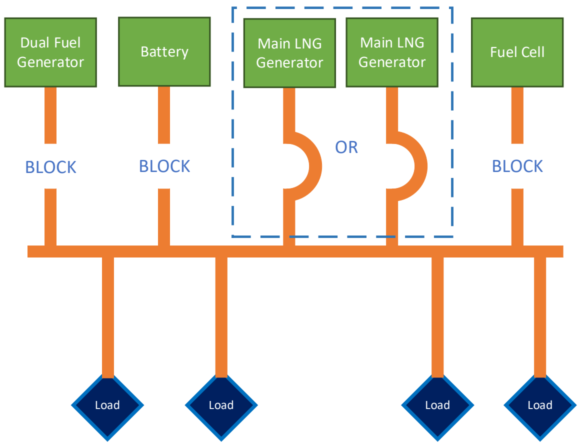

Figure 5: IEMS operational classification: status transition mode

③ EFPS mode

The EFPS mode is designed to conduct performance tests on ecofriendly alternative power sources (such as test generators, batteries, and fuel cells). The control system is configured to activate the EFPS mode only upon confirmation by an operator. The generator for the ship operations maintains a minimum fixed load, and an additional load is applied to the EFPS for performance testing. All loads beyond the essential minimum required for ship operation are allocated to alternative ecofriendly power sources. The operational classification status of the IEMS in this mode is illustrated in **Figure 6**.

- EFPS mode entry procedure

In the ST mode, the mode change must be initiated by entering a confirmation command from the operator. The operator approval for the mode change should be configured to allow approval only after the configuration and operating conditions of the EFPS have been entered in the preceding mode (base mode/ST mode) and the operator confirmation has been successfully completed. Similar to the procedure for entering the ST mode, if an emergency occurs during the mode transition, automatic reversion to the base mode occurs. However, in the case of an alarm, operators can wait at the current progress level, depending on the conditions.

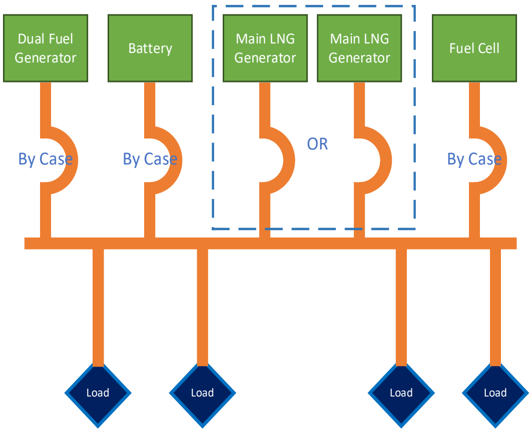

Figure 6: IEMS operational classification: EFPS mode

Figure 7 illustrates an operational example of an ecofriendly alternative fuel system (EFPS) and the generators in an IEMS. L_1 represents the minimum required load level for the EFPS, and L_2 indicates the minimum load level for the generator. At t_1, a load reduction is performed to enter the ST mode. At t_2, the test operator confirms entry into the ST mode and waits for a connection with the EFPS. Once the connection with the EFPS is ready, at t_3, the test operator executes a mode change to the EFPS. During this phase, load sharing between the EFPS and the generator occurs, and balanced control by the converter is implemented for stable load control. Starting at t_5, planned testing of the EFPS commences once the generator reaches its minimum load level. At t_8, if the output of the EFPS decreases to zero, the IEMS reverts to the ST mode.

3.6 Disconnection and disembarkation of alternative fuel system

3.6.1 Disconnection of power and communication in the alternative fuel system

The disconnection of power and communication devices within the alternative fuel system is executed in accordance with the procedures specified in the manual provided by the system development organization. Initially, the communication device should be disconnected after the power source is disconnected, and throughout this process, the connection status of both power and communication must be continuously monitored. Prior to disconnecting the communication link of the alternative fuel system, it is imperative to verify the proper storage of the communication log data. When disconnecting the power supply, meticulous attention is required to prevent potential damage to the device and mitigate the risk of personal injury. Upon completion of

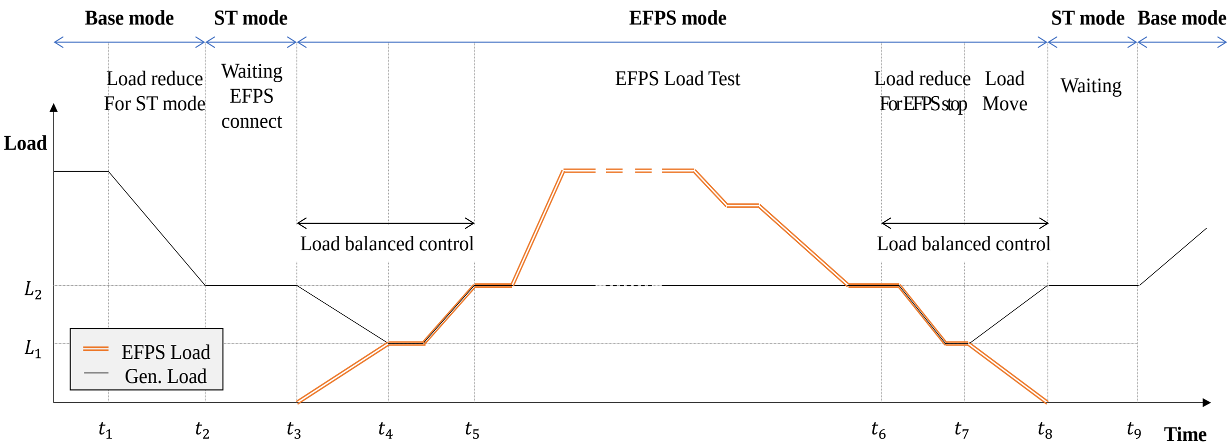

Figure 7: Operational example of an ecofriendly alternative fuel power generator using IEMS **[7]**

the disconnection, it is crucial to close the terminal block securely to ensure the integrity of the power supply. Finally, the individual responsible for the disconnection procedure promptly reports the task completion to the verification manager.

3.6.2 Unfastening and disembarkation of alternative fuel systems

After opening the hatch of the ship using a crane, the alternative fuel system is removed and disembarked. A procedure is executed to ensure the complete removal of residual gas from the interior of the system and piping. The removal process commences with the main equipment. If the removal of other equipment becomes necessary, depending on the situation, it is determined in consultation with the person in charge of verification. Care must be exercised during the removal process to prevent damage to the equipment or power connection devices. Following the successful removal and disembarkation of the system, all fasteners used must undergo thorough cleaning and inspection to ensure their readiness for subsequent use. Appropriate transportation measures must be taken considering the weight of the removed system, and the cargo must be securely fastened to prevent damage during transportation. Finally, the personnel responsible for removal and disembarkation must inspect the quantity and condition of the surrounding equipment upon completion of the work.

Table 2: Alternative fuel system test operation procedures using K-GTB

Step	Category	Contents
1	Preparing	Determining demonstration feasibility on a sea testbed and identifying a shipping route
2	Installation	Installing an alternative fuel system on the sea test bed under test
3	Charging	Charging alternative fuel for alternative fuel system
4	Connecting	Verification of communication and power access and powering up of critical equipment on board
5	Pre-Operation	Preliminary operation check of core equipment that can be operated while at anchor
6	Operation	Demonstration voyage operation (draft/acceleration/steady-state) and operation of test equipment during the voyage according to operating procedures
7	Disconnecting and Disembarkation	De-energization and disconnection of onboard test equipment and disembarkation of test equipment by crane

The test procedures introduced in Section 3 are summarized in **Table 2**.

4. Conclusion

In this paper, detailed operational procedures for the maritime verification of alternative fuel systems were presented. Elaborate designs for the requisite procedures at each stage were outlined, including preparation before the departure of the test ship, monitoring during operation, and removal and disembarkation procedures. Given that ships are equipped with various types of alternative fuel systems, open-signal propulsion-control systems capable of handling diverse interfaces have been developed.

Furthermore, to facilitate the flexible operation of various power generation sources, such as parallel operation, the IEMS operation mode was subdivided to ensure the stability and reliability of the power system of the ship. This study established the groundwork for the stable maritime demonstration of alternative fuel systems aboard a test ship, with the anticipation of making a significant contribution to forthcoming advancements in the sustainable maritime industry.

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Author Contributions

Conceptualization, B. Choi, H. Shim, J. Hong, D. Hwang and H. Kang; Methodology, B. Choi, H. Shim, J. Hong, D. Hwang and H. Kang; Validation, B. Choi; Formal Analysis, H. Shim, J. Hong and H. Kang; Investigation, B. Choi; Resources, H. Shim, J. Hong, D. Hwang and H. Kang; Data Curation, B. Choi; Writing—Original Draft Preparation, B. Choi; Writing—Review & Editing, H. Shim and H. Kang; Visualization, B. Choi and D. Hwang; Supervision, H. Kang; Project Administration, H. Kang; Funding Acquisition, H. Kang.

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