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Development and real-ship application of intelligent multi-mode switching control device

System Integration & Hybridization

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ABSTRACT

In order to solve the problems of multiple switching processes, complex interlocking conditions and ship power interruption in the switching process of twin-engine twin-propeller hybrid power system, such as the main engine mode, PTO mode, PTI mode and PTH mode, an intelligent multi-mode switching control device is developed, which adopts the methods of independent switching control of port and starboard operating modes, assisted decision of interlocking conditions, dynamic visualization of the whole process, and voice broadcast. The device simplifies the operation process of switching between different working modes, improves the efficiency of mode switching, and ensures the continuous and stable ship power during mode switching. The switching time between different working modes is within 5 seconds, which meets the needs of users.

DEVELOPMENT AND REAL SHIP APPLICATION OF INTELLIGENT MULTI-MODE SWITCHING CONTROL DEVICE

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Abstract: To address the issues in the hybrid power system of twin-engine and twin-propeller ships, such as numerous processes during the switching among the ME Mode, PTO Mode, PTI Mode and PTH Mode, complex interlocking conditions, and power interruption of the ship during the switching process, an intelligent multi-mode switching control device has been developed. This device enables independent switching control of the port-side operating mode and the starboard-side operating mode, independent determination of interlocking conditions, and independent dynamic visual display of the mode switching process.The device simplifies the operation process of switching between various operating modes, improves the efficiency of mode switching, and ensures the continuous and stable power supply of the ship during the mode switching process. Verified by real ship, the switching time between each operating mode is within 5 seconds, meeting the user’s requirements.

Key Words: twin-engine twin-propeller hybrid power system; Multi-mode switching control; real ship application

1 INTRODUCTION

Inland river ships mostly adopt a power system configuration of twin-engine and twin-propeller indirect propulsion matched with fixed-pitch propellers. According to the freight mission profile of the main inland river ship types, due to the complex and changeable hydrological conditions of inland river channels, which are greatly affected by seasons, the main engine(ME) load of ships can even reach 100% under operating conditions such as rapids, beach-rushing, and tides. However, under normal working conditions, the ME load is relatively small. The common load of the ME in the upstream section is 40% - 50%, and in the downstream section, it is 10% - 20%. The phenomenon of "a small horse pulling a big cart" is particularly prominent, resulting in the ME running in the low load range for a long time, which brings problems such as high fuel consumption rate and poor emissions [1].

Based on the above problems, marine hybrid power system is adopted [2-3], and the system modes are flexibly set to meet the power requirements of the propulsion system under various working conditions [4-5]. Due to the complex and changeable hydrological conditions of inland river channels and the relatively low quality of crew members, it is required that the manual operation steps during the mode switching of the marine hybrid power system should be as few as possible, and the mode switching time should be as short as possible. In view of the above situation, this paper optimizes the design of the traditional marine hybrid power system mode switching control device [6]. Methods such as "one-key" independent switching control of the port-side and starboard-side operating modes, independent auxiliary decision-making for interlocking conditions, and independent visual display of the whole switching process are adopted [7 - 9], which effectively solve the defects of the existing technology, such as numerous operation steps, complex interlocking conditions between various devices, and the inability to complete the operation by one person, reduce the difficulty of mode switching, and improve the efficiency of mode switching.

2 MARINE HYBRID POWER SYSTEM

2.1 Systems Configuration

As shown in Figure 1, the hybrid power system of a certain type of ship mainly consists of the following major power equipment: port and starboard MEs, gearboxes(GB), propellers, M/Gs, frequency converters, and the ship's power station. Among them, the GB includes a forward clutch and a reverse clutch.

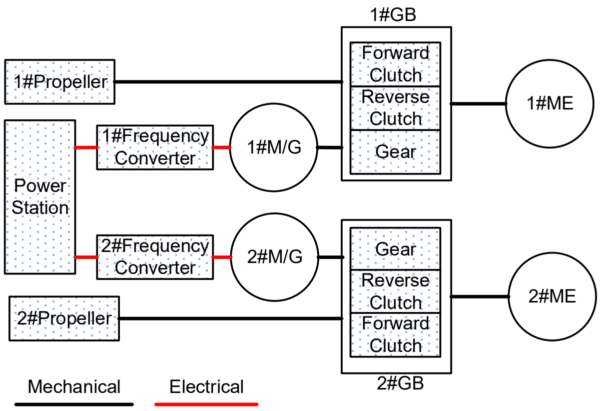

Figure 1. Configuration of the marine hybrid power system

2.2 Marine Hybrid Power System Operating Modes

2.2.1 Operating Mode Definition

The marine hybrid power system operating mode includes ME Mode、PTO Mode、PTI Mode、PTH Mode.The switching control of operating modes is achieved through the intelligent multi-mode switching control device.

2.2.1.1 ME Mode

Main Engine Mode(ME Mode),the ME drives the propeller independently through the GB.When the forward clutch of the GB is engaged, it is called the ME Mode (ahead). When the reverse clutch of the GB is engaged, it is called the ME Mode (astern). When both the forward and reverse clutches of the GB are disengaged, it is called the ME Mode (neutral).The hybrid power system is in ME Mode,the real ship display effect of the HMI of the the intelligent multi-mode switching control device is shown in Figure2 to 4. The red arrows indicate the direction of energy flow.

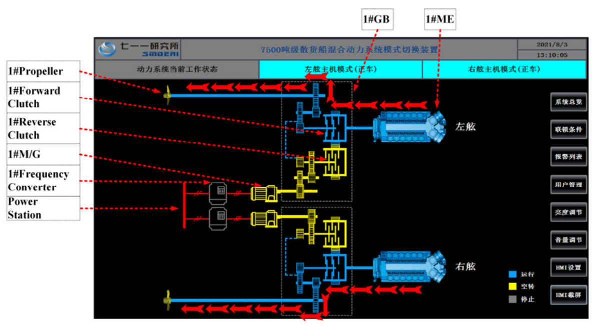

Figure 2. Port ME Mode (forward), starboard ME Mode (forward)

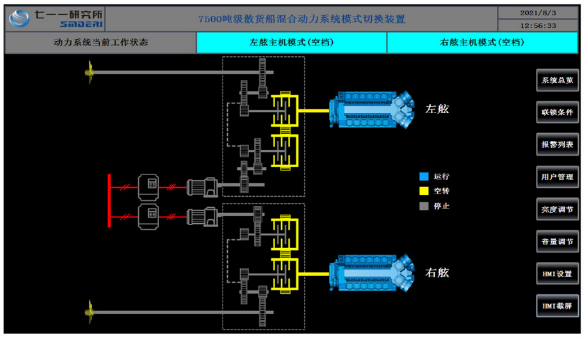

Figure 3. Port ME Mode (neutral), starboard ME Mode (neutral)

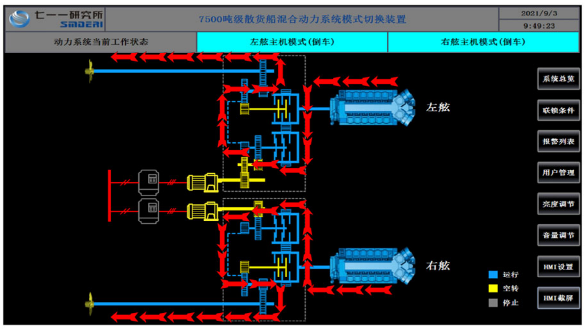

Figure 4. Port ME Mode (reverse), starboard ME Mode (reverse)

2.2.1.2 PTO Mode

Power Take Out Mode (PTO Mode),ME drives the propeller through the GB. In the generating mode of the M/G, the M/G converts the surplus energy of the ME into electrical energy,which is then supplied to the power station.When the forward clutch of the GB is engaged, it is called the PTO Mode (ahead). When the reverse clutch of the GB is engaged, it is called the PTO Mode (astern). When both the forward and reverse clutches of the GB are disengaged, it is called the PTO Mode (neutral).The hybrid power system is in PTO Mode,the real ship display effect of the HMI of the the intelligent multi-mode switching control device is shown in Figure5 to 7. The red arrows indicate the direction of energy flow.

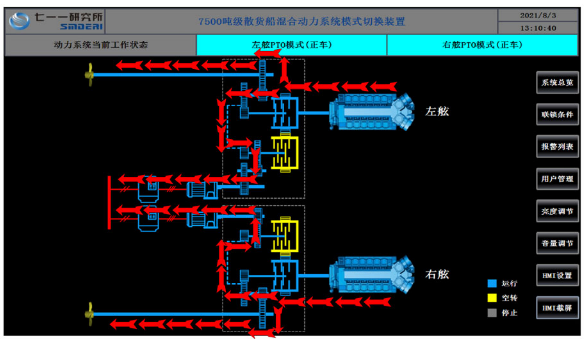

Figure 5. Port PTO Mode (forward), starboard PTO Mode (forward)

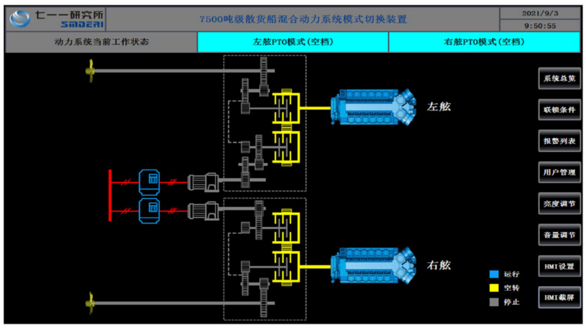

Figure 6. Port PTO Mode (neutral), starboard PTO Mode (neutral)

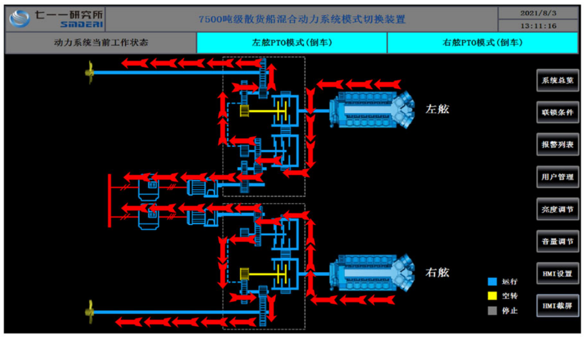

Figure 7. Port PTO Mode (reverse), starboard PTO Mode (reverse)

2.2.1.3 PTI Mode

Power Take In Mode (PTI Mode),ME and M/G drive the propeller together through the GB. In the electric mode of the M/G, the electrical energy required by the M/G is taken from the power station through the frequency converters.When the forward clutch of the GB is engaged, it is called the PTI Mode (ahead). When the reverse clutch of the GB is engaged, it is called the PTI Mode (astern). When both the forward and reverse clutches of the GB are disengaged, it is called the PTI Mode (neutral).The hybrid power system is in PTI Mode,the real ship display effect of the HMI of the the intelligent multi-mode switching control device is shown in Figure8 to 10. The red arrows indicate the direction of energy flow.

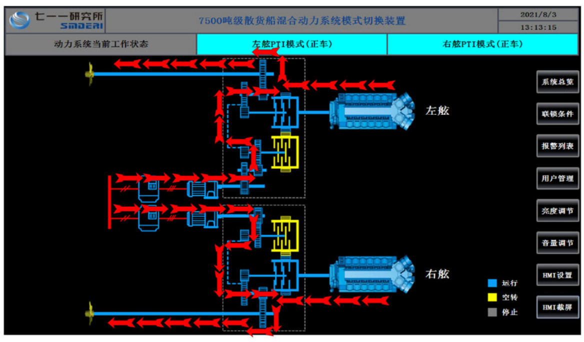

Figure 8. Port PTI Mode (forward), starboard PTI Mode (forward)

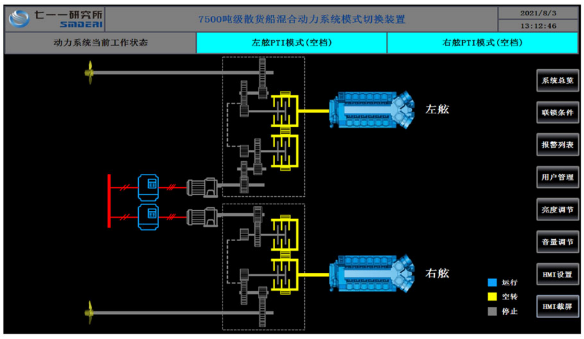

Figure 9. Port PTI Mode (neutral), starboard PTI Mode (neutral)

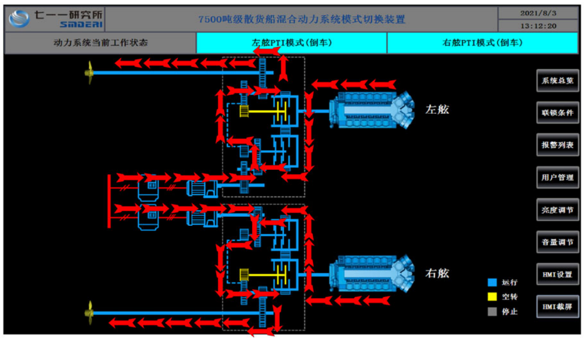

Figure 10. Port PTI Mode (reverse), starboard PTI Mode (reverse)

2.2.1.4 PTH Mode

Take-Home Mode (PTH Mode),the M/G independently drives the propeller. In the electric mode of the M/G, the electrical energy required by the M/G is taken from the power station through the frequency converters.When the rotational speed of the M/G is positive, it is called the PTH Mode (ahead). When the rotational speed of the M/G is negative, it is called the PTH Mode (astern). When the rotational speed of the M/G is zero, it is called the PTH Mode (neutral).The hybrid power system is in PTH Mode,the real ship display effect of the HMI of the the intelligent multi-mode switching control device is shown in Figure11 to 13. The red arrows indicate the direction of energy flow.

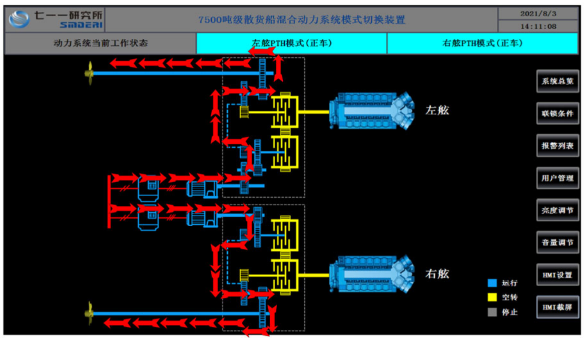

Figure 11. Port PTH Mode (forward), starboard PTH Mode (forward)

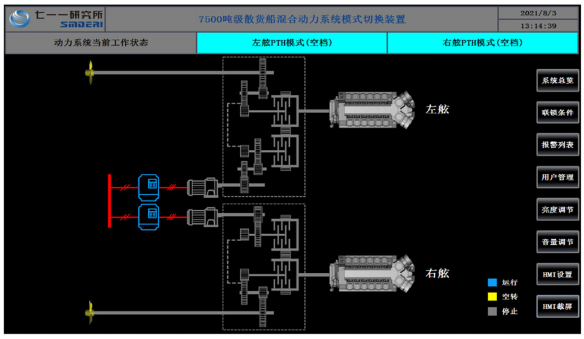

Figure 12. Port PTH Mode (neutral), starboard PTH Mode (neutral)

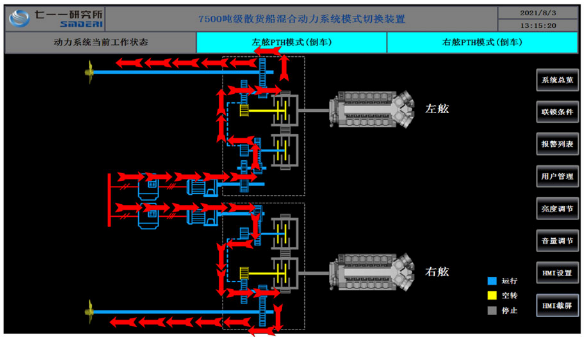

Figure 13. Port PTH Mode (reverse), starboard PTH Mode (reverse)

2.2.2 Operating Mode Switching Rules

The operating mode switching rules of the marine hybrid power system are shown in Figure 14. There are a total of 8 types of mode switching processes.

(1) ME Mode to the PTO Mode
(2) PTO Mode to the ME Mode
(3) ME Mode to the PTI Mode
(4) PTI Mode to the ME Mode
(5) ME Mode to the PTH Mode
(6) PTH Mode to the ME Mode
(7) PTI Mode to the PTH Mode
(8) PTH Mode to the PTI Mode

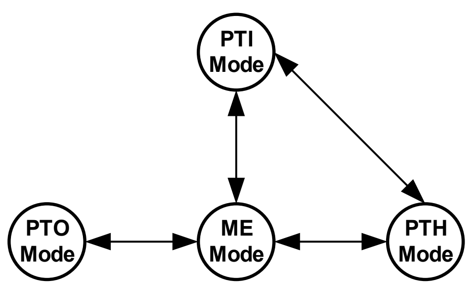

Figure 14. Operating mode switching rules

3 INTELLIGENT MULTI-MODE SWITCHING CONTROL DEVICE

3.1 Function Design

3.1.1 " One-Touch " Independent Switching Control Function

After the intelligent multi-mode switching device detects that the hybrid power system meets the switching interlocking conditions, select the "target mode" and press the "acknowledge" button, then wait for the mode switching to be completed automatically. Moreover, the mode switching on the port side and that on the starboard side are carried out independently. When mode switching is being performed on one side, the other side maintains its propulsion capacity to ensure the continuity of the ship's power.

3.1.2 Interlocking Conditions Independent Judgment Function

The intelligent multi-mode switching device determines whether the states of the port and starboard sides of the ship meet the interlocking conditions before the mode switch based on the state of the hybrid power system.

3.1.3 Dynamic Visualization Display Function

The intelligent multi-mode switching device has designed a multi-state visualization for each device in the hybrid power system, including states such as run,stop and fault. Through the HMI, users can view the real-time status changes of each device during the 4 operating modes and 8 switching processes. Meanwhile, the completion progress of the 8 mode-switching processes is dynamically displayed.

3.2 Hardware Design

The intelligent multi-mode switching device consists of two parts: a control box and a remote control panel. The remote control panel is responsible for sending mode switching commands. After receiving the mode switching commands, the controller in the control box interacts with external devices through signals, thereby realizing the switching among the ME Mode, PTO Mode, PTI Mode, and PTH Mode. Meanwhile, the current parameters of the hybrid power system equipment, the progress of mode switching, and the interlocking conditions are displayed on the HMI.The physical object of the control panel is shown in Figure 15, and its function table is shown in Table 1.

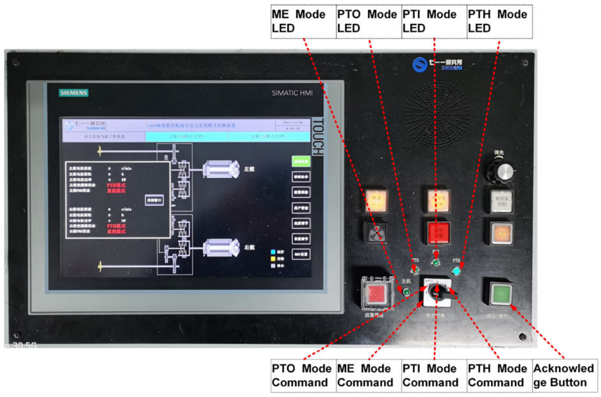

Figure 15. Remote switching control panel

Table 1 Remote switching control panel function

Name	Function
ME Mode LED	Flashing: Switching to the ME Mode Constantly on: In the ME Mode Constantly off: In other modes
PTO Mode LED	Flashing: Switching to the PTO Mode Constantly on: In the PTO Mode Constantly off: In other modes
PTI Mode LED	Flashing: Switching to the PTI Mode Constantly on: In the PTI Mode Constantly off: In other modes
PTH Mode LED	Flashing: Switching to the PTH Mode Constantly on: In the ME PTH Mode Constantly off: In other modes
ME Mode Command	Select to switch to the ME Mode
PTO Mode Command	Select to switch to the PTO Mode
PTI Mode Command	Select to switch to the PTI Mode
PTH Mode Command	Select to switch to the PTH Mode
Acknowledge Button	Acknowledge the selected operating mode

3.3 Control Strategy Design

The control strategy of the intelligent multi-mode switching control device is its control core. The control strategy includes the overall control strategy design and the typical mode switching control strategy design.

3.3.1 Overall Control Strategy Design

The overall control strategy process of the intelligent multi-mode switching device is shown in Figure 16.

① The input module receives control commands, as well as the parameters and status feedback from each associated device of the hybrid power system.

② The operating mode recognition module automatically identifies the current operating states of the port side and starboard side of the hybrid power system.

③ If a port mode switch is detected, the system will enter the port mode switching control module and execute its control strategy. The operating mode will be maintained after the port mode switching is completed, and then the cycle ends.

④ If a starboard mode switch is detected, the system will enter the starboard mode switching control module and execute its control strategy. The operating mode will be maintained after the starboard mode switching is completed, and then the cycle ends.

⑤ If the mode switch is not performed, the system will enter the interlocking condition recognition module.

⑥ If the port interlocking condition is ok and port mode switching command is received,the system will enter the port mode switching control module and execute its control strategy. The operating mode will be maintained after the port mode switching is completed, and then the cycle ends.

⑦ If the starboard interlocking condition is ok and starboard mode switching command is received,the system will enter the starboard mode switching control module and execute its control strategy. The operating mode will be maintained after the starboard mode switching is completed, and then the cycle ends.

⑧ The output module sends control commands to external devices.

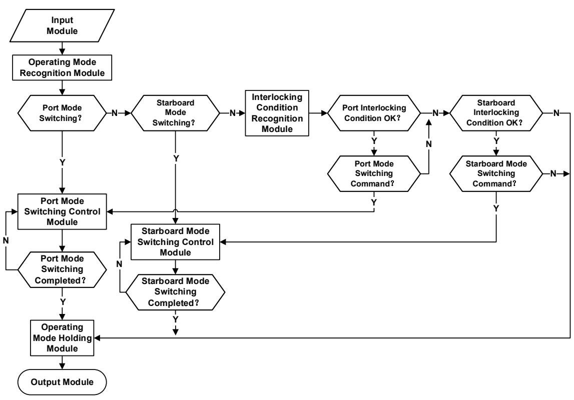

Figure 16. Flowchart of the overall control strategy

3.3.2 Typical Mode Switching Control Strategy Design

The intelligent multi-mode switching device has a total of 8types of mode switching. In this paper, two of the most typical mode switching scenarios are selected for illustration,includes ME Mode to the PTO Mode and ME Mode to the PTI Mode.

3.3.2.1 ME Mode to PTO Mode Switching Control Strategy Design

Step 1: Take over the ME remote control system

The intelligent multi-mode switching device sends a ME take over request signal. If a take over permission feedback is received within N seconds, proceed to Step 2; if no take over permission feedback is received within N seconds, enter the fault handling process and exit the mode switching.

Step 2: Take over the M/G remote control system

The intelligent multi-mode switching device sends a M/G takeover request signal. If a M/G take over permission feedback is received within N seconds, proceed to Step 3; if no M/G take over permission feedback is received within N seconds, enter the fault handling process and exit the mode switching.

Step 3: The frequency converter enters the PTO Mode

The intelligent multi-mode switching device sends a PTO Mode command to the frequency converter. If a feedback indicating the completion of the frequency converter ’ s PTO Mode is received within N seconds, proceed to Step 4; if no such feedback is received within N seconds, enter the fault handling process and exit the mode switching.

Step 4: The energy management system enters the PTO Mode

The intelligent multi-mode switching device sends a PTO Mode command to the energy management system. If a feedback indicating the completion of the PTO Mode is received within N seconds, proceed to Step 5; if no such feedback is received within N seconds, enter the fault handling process and exit the mode switching.

Step 5: Enter the PTO Mode

The intelligent multi-mode switching device enters the PTO Mode, completing the switch from the ME Mode to the PTO Mode. Keep the hybrid power system running continuously in the PTO Mode until the next mode switching is initiated.

3.3.2.2 ME Mode to PTI Mode Switching Control Strategy Design

Step 1: Take over the ME remote control system

The process is the same as that of the mode switch from the ME Mode to the PTO Mode.

Step 2: Take over the M/G remote control system

The process is the same as that of the mode switch from the ME Mode to the PTO Mode.

Step 3: The energy management system enters the heavy-load mode

The intelligent multi-mode switching device sends a heavy-load mode command to the energy management system. If a feedback indicating the completion of the heavy-load mode is received within N seconds, proceed to Step 4; if no such feedback is received within N seconds, enter the fault handling process and exit the mode switching.

Step 4: The frequency converter enters the PTI Mode

The intelligent multi-mode switching device sends a PTI Mode command to the frequency converter. If a feedback indicating the completion of the frequency converter's PTI Mode is received within N seconds, proceed to Step 5; if no such feedback is received within N seconds, enter the fault handling process and exit the mode switching.

Step 5: Enter the PTI Mode

The intelligent multi-mode switching device enters the PTI Mode, completing the switch from the ME Mode to the PTI Mode. Keep the hybrid power system running continuously in the PTI Mode until the next mode switching is initiated.

3.4 Software Design

The software design of the intelligent multi-mode switching device is mainly reflected in the system overview page of the HMI real ship design. According to the current state of the system, it is divided into the operating mode maintenance page and the operating mode switching page. For details of the operating mode maintenance page, please refer to Figures 2 to 13.For details of the operating mode switching page,please refer to Figures 17 to 20,which include the page for switching from the ME Mode to the PTO Mode and the page for switching from the ME Mode to the PTI Mode.

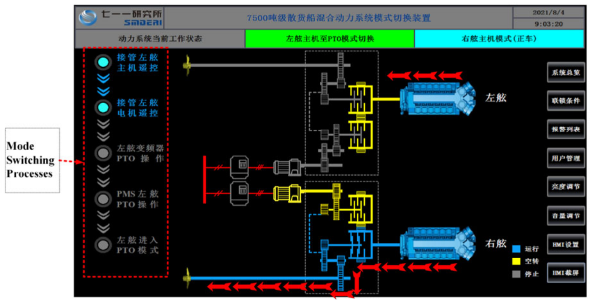

Figure 17. Port ME Mode to PTO Mode Switching Page

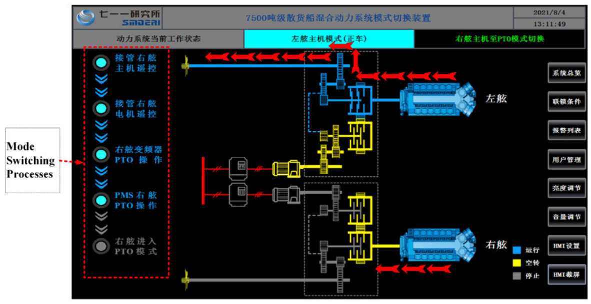

Figure 18. Starboard ME Mode to PTO Mode Switching Page

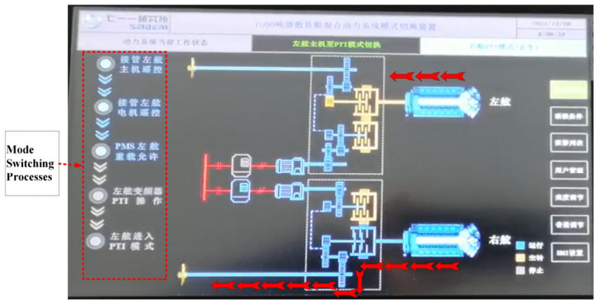

Figure 19. Port ME Mode to PTI Mode Switching Page

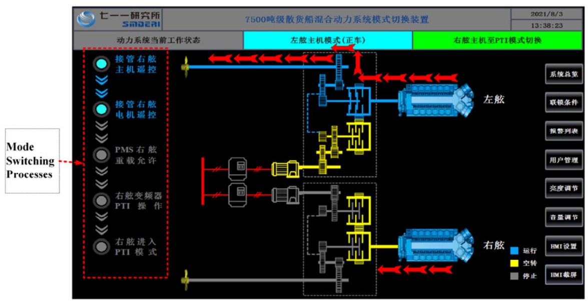

Figure 20. Starboard ME Mode to PTI Mode Switching Page

4 REAL SHIP APPLICATIONS

The intelligent multi-mode switching device has been applied on the ship "Changhang Freight 001"of Changhang Freight Co., Ltd. After the trial voyage and operational navigation on the

Changjiang River, the measured mode switching times are shown in Table 2. During the mode switching process, the ship's power remains stable and continuous, meeting the user's requirements.

Table 2 Mode switching times real ship application

Number	Multi-mode switching process	Time used（s）
1	ME Mode to PTO Mode	2.5
2	PTO Mode to ME Mode	3
3	ME Mode to PTI Mode	3
4	PTI Mode to ME Mode	3.8
5	ME Mode to PTH Mode	4
6	PTH mode to ME Mode	3.5
7	PTI Mode to PTH Mode	4
8	PTH Mode to PTI Mode	3.5

5 CONCLUSIONS

The intelligent multi-mode switching control device, developed using methods such as independent switching control of operating modes, independent judgment of interlocking conditions, and dynamic visualization display of the mode switching process, has successfully passed the real ship verification in trial voyages and operational navigation. When switching among the ME Mode, PTO Mode, PTI Mode, and PTH Mode, the mode switching time is short, and the ship's power remains stable and continuous, meeting the functional requirements of users in different inland waterways. The HMI configuration design has prominent features, providing real-time and comprehensive feedback on the status of each device in the hybrid power system, with good visualization effects.

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