CANAL

WHEELHOUSE MANUAL

Hybrid Power & Propulsion System

8073-Manual-Wheelhouse-R1

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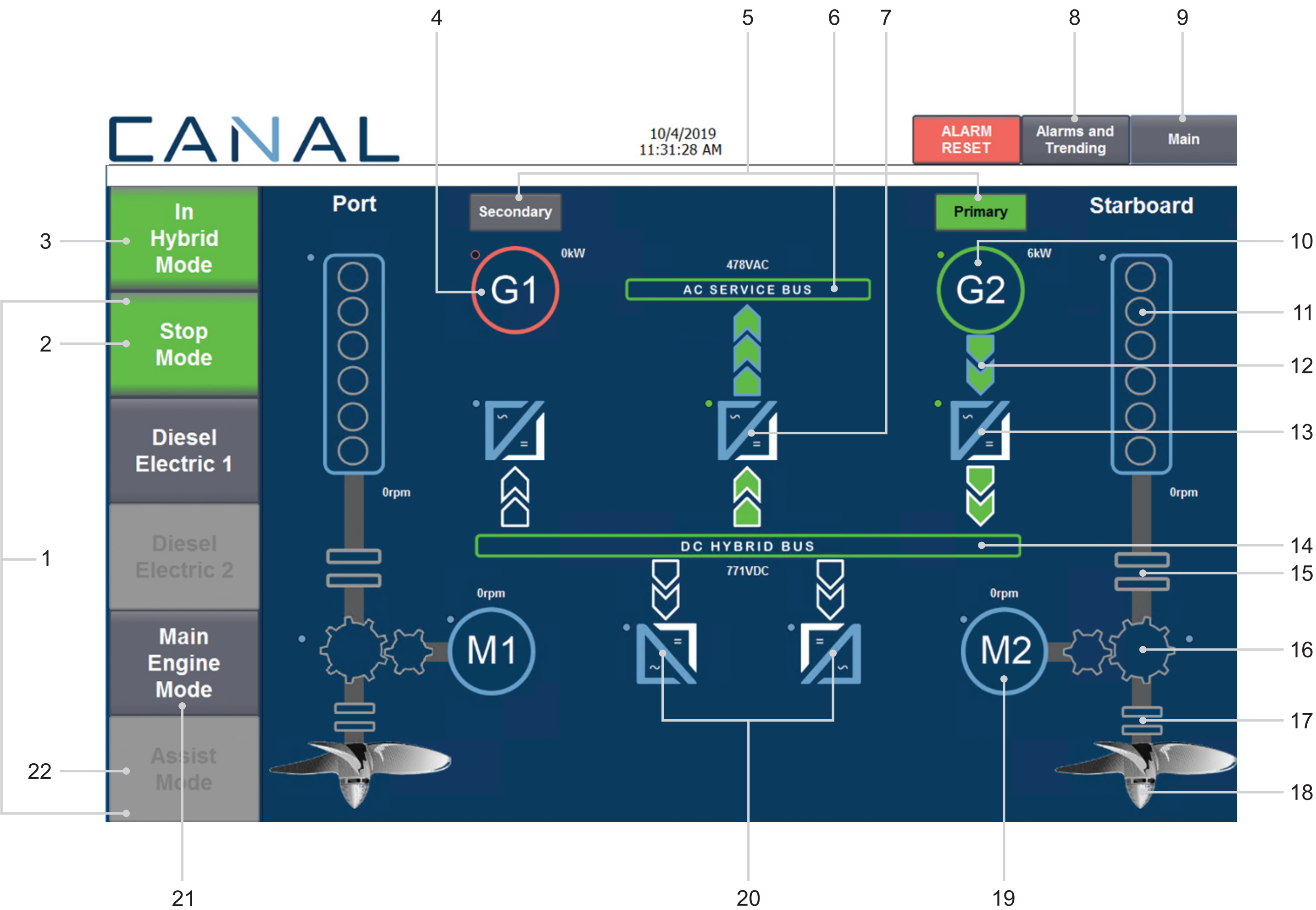
For half a century Canal has provided electrical design, engineering and service around the clock to the merchant marine, naval and coastguard fleets in Canada, primarily in the Great Lakes Basin. From the heaviest Ice Breaker, the largest Bulker, Warships, Tugs and Research Vessels, Fish Boats, Cruise Vessels and Ferries and from the oldest to the newest, we have been there and kept them moving.

HYBRID SYSTEM LEGEND



HMI Interface Components

1. Hybrid Mode Selection/Indication Buttons
2. Current Hybrid Mode
3. Hybrid/Non-Hybrid Mode Indication
4. Faulted Generator
5. Primary/Secondary Generator Selection/Indication
6. AC Service Bus
7. AC Bus Grid Converter
8. Access To Alarms/Trending Screens
9. Return To Main Screen (Current View)
10. Auxiliary Generator
11. Main Engine
12. Direction Of Power Flow Indications Arrows
13. Active Front End
14. DC Bus
15. Master Clutch
16. 2:1 Gear Ratio For Hybrid System Electric Motors
17. Primary/Secondary Clutches
18. Propeller
19. Hybrid System Electric Motor
20. Hybrid System Variable Frequency Drives
21. Available Mode For Selection
22. Unavailable Mode (G1 Currently Faulted)

1. HYBRID SYSTEM BENEFITS

Canal defines a hybrid power and propulsion system as having more than one type of power source for supporting propulsion and, usually, more than one type of power source for supporting the vessel's electrical services.

The benefits of hybrid systems are reduced fuel consumption and emissions, as engines are more optimally loaded when they run or shut down completely in operational modes where they are not required. Maintenance costs are reduced, and equipment life is extended because engines, both mains and diesel generators, run for fewer hours.

1.1 Vessel's Hybrid Features:

The main engines can be clutched out and shut down, allowing low-level propulsion to be achieved using relatively small motors

- The motor drives obtain power from a common DC bus which in turn is supported by one or both diesel gensets
- The vessel's AC bus may be supported from the common DC bus via a 'grid converter'
- The main engines may be clutched in, allowing them to provide propulsive power
- When the main engines are running and clutched in, the motors can be used as generators and can support the common DC bus via their drives. This allows the diesel gensets to be disconnected and shut down
- If necessary, the vessel can be operated as a conventional/traditional vessel. Diesel gensets may be connected directly to the AC bus, and the master clutches may be manually closed using control panels provided. In this scenario the vessel is configured like a conventional tug of the same fleet.

2. HYBRID MODES

The vessel has five hybrid modes of operation that are selectable by the captain using the control touchscreen in the wheelhouse. This touchscreen is also referred to as a human-machine interface (or HMI). Note that the hybrid system is automated; capable of automatically reconfiguring the vessel systems in response to the captain's mode selection. It is not normally necessary for crew intervention below decks during transitions between modes. The hybrid system manages the five modes by controlling:

- Main Engines (starting and stopping them)
- Generators (starting/stopping them and connecting/disconnecting them to the power plant)

- The master clutches between the main engines and motors/gearboxes
- The electrical 'power converters'. These control the flow of power between the various sources and loads within the vessel's hybrid power plant.
- Switchgear within the Hybrid System enclosure

2.1 Stop Mode

Stop Mode is used when the vessel is secured. When the captain selects Stop Mode, the hybrid control system will shut down the main engines (after a cool down period) and ensure that the master clutches are open. The motor drives will be stopped. The hybrid system DC bus will remain up and a diesel generator will continue running to support the system.

Stop is considered a 'hybrid' mode of operation. In Stop Mode the DC bus is maintained and the vessel is in a state of readiness for a propulsion mode to be selected. So, Stop Mode is not the same as Non-Hybrid (or 'conventional') Mode, where the hybrid system can be completely shut down.

In the event that the vessel will not be underway for a few hours, the hybrid system may be shut down (into Non-Hybrid Mode) using the key-switch and 'non-Hybrid' switch in the wheelhouse. Shore power may then be manually connected, avoiding the need to run a diesel genset at the dock. Note that in stop mode the propulsion controls ("sticks") are disabled.

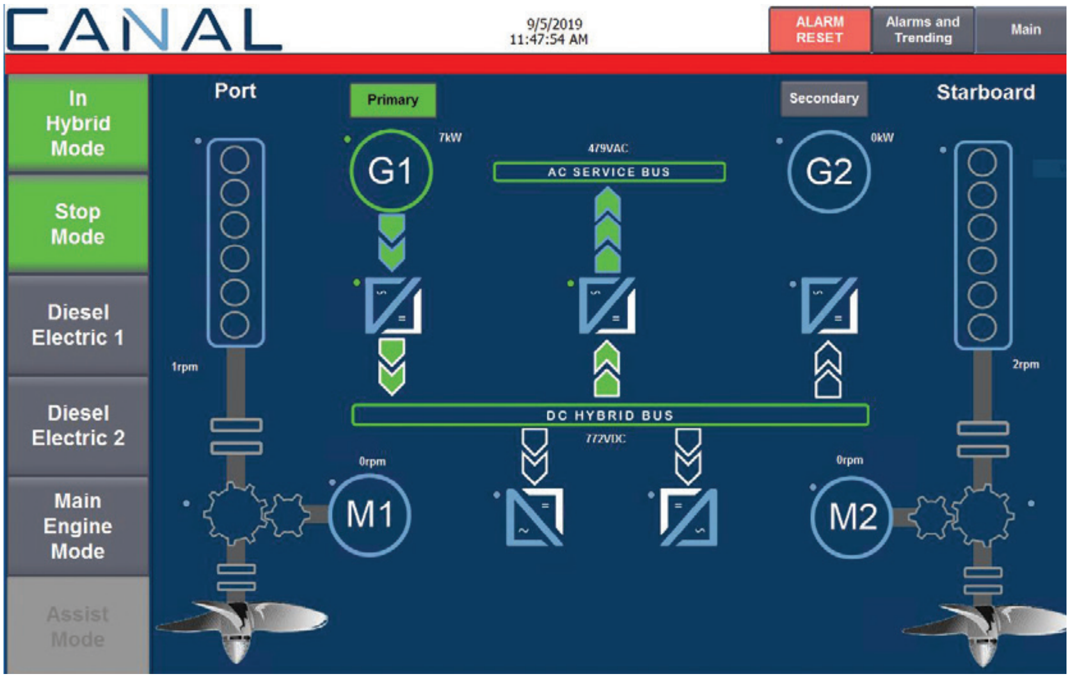
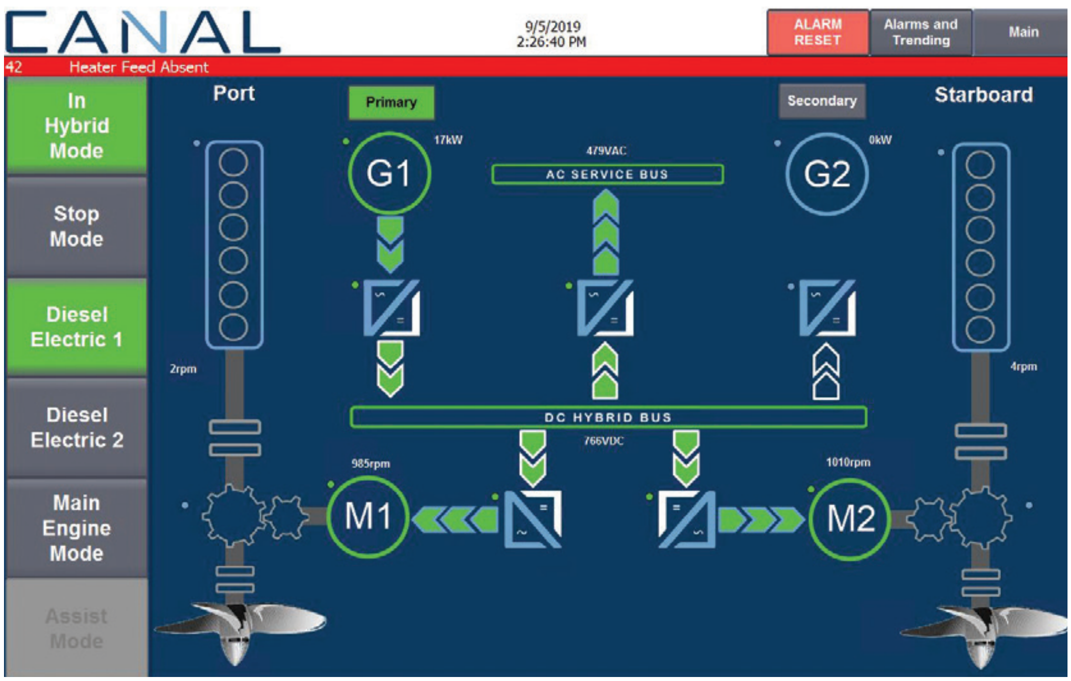


Figure 2-1
Stop Mode

2.2 Diesel Electric 1 Mode

Diesel Electric 1 is used for displacement speed transits. In this mode the hybrid control system will start and connect one auxiliary generator to the common DC Bus via its corresponding active front end (AFE). The genset used will be the one designated by the crew as the ‘primary’. There is a contingency within the automated control system to use the secondary genset should the primary be faulted or unavailable. The main engines are shut down after their master clutches are opened (and after a cool down period). The motor-generators (MGs) are controlled by their corresponding variable frequency drives (VFDs) to drive the main shaft. Propulsion, and the vessel electrical plant loads, will be supported by the primary auxiliary generator only. The grid converter will support the AC distribution bus. The propulsion demand will be balanced with vessel service demand to ensure no overloading of the genset occurs (regardless of stick positions).

Figure 2-2
Diesel Electric 1 Mode



Note that single points of propulsion failure exist within Diesel Electric 1 mode (most obviously the primary genset itself). However, an automated recovery process will start and connect the secondary genset in the event that the primary fails (a process taking just a few seconds).

2.3 Diesel Electric 2 Mode

This mode is identical to Diesel Electric 1 Mode with the exception that the second genset is brought online to assist in supporting the DC bus. The main advantage is a higher level of system redundancy. The system is tolerant of the failure of a single gen with no loss of propulsion (not even for a short duration).

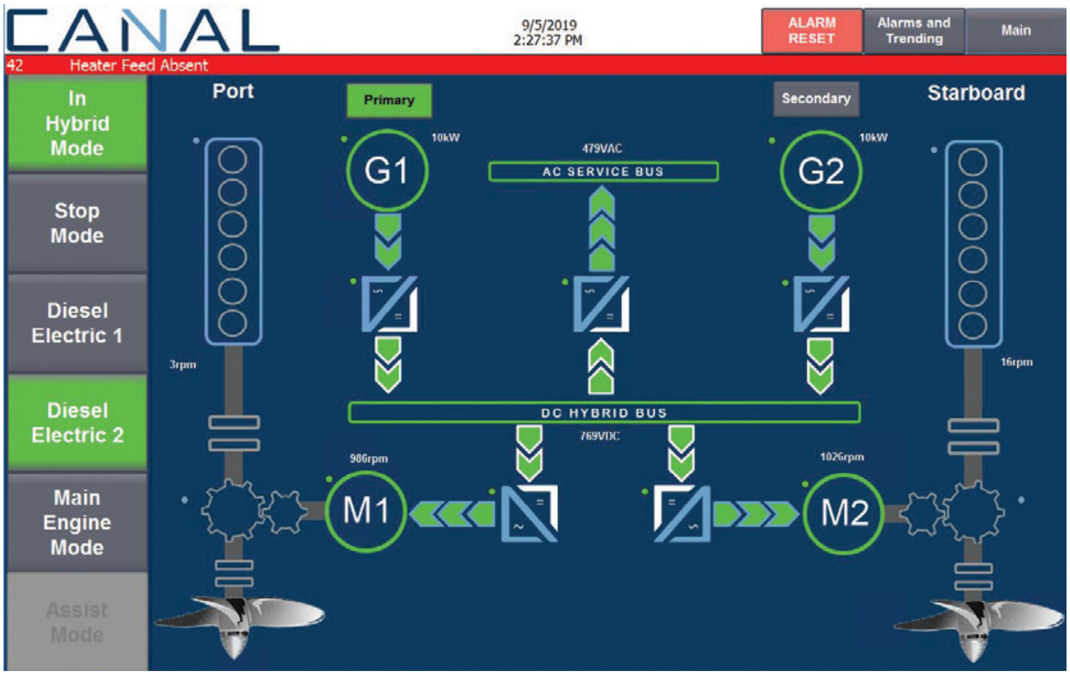


Figure 2-3
Diesel Electric 2 Mode

2.4 Main Engine Mode

Main Engine Mode is used for higher transit speeds, ship assist work and barge moves. In this mode the Hybrid Control System will start both main engines, close the master clutches, and place the MGs in generator mode to support the common DC bus. The system will then disconnect and stop the auxiliary generators. In this mode the main engines provide all the power for propulsion and for vessel service loads. The AC distribution bus is supported by the Grid Converter.

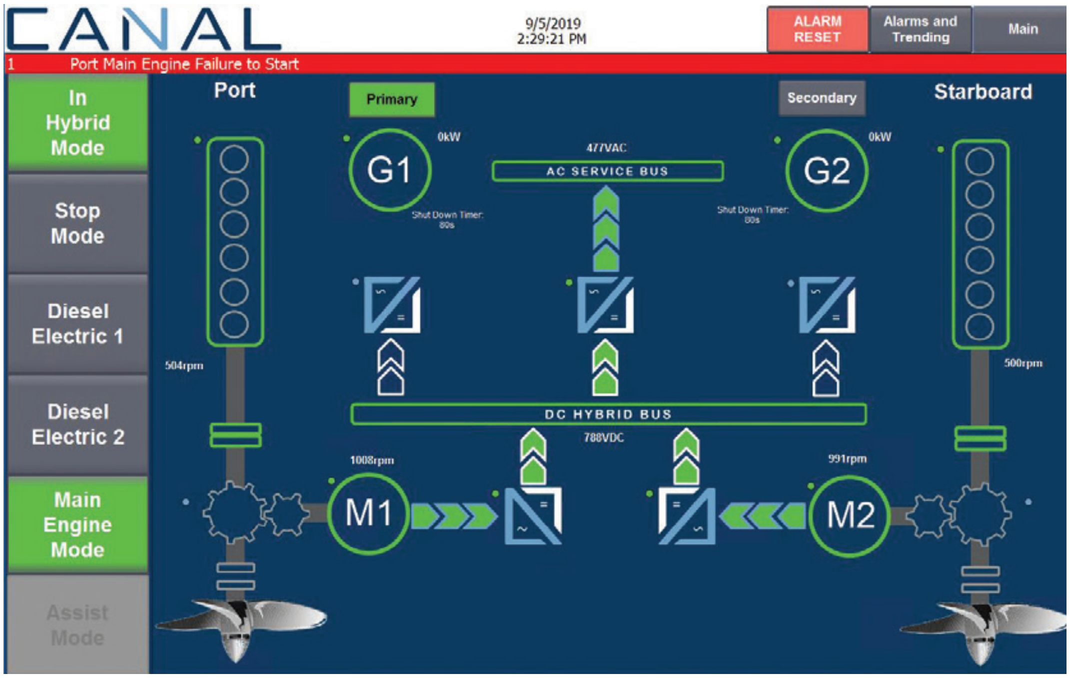


Figure 2-4
Main Engine Mode

2.5 Assist Mode

This mode is similar to Main Engine Mode in that the main engines provide propulsion power. However, in this mode the two auxiliary gensets also remain running and connected to the DC Bus via the AFEs. These provide power for vessel service loads and will also provide a contribution to propulsion in support of the main engines. This support will be managed by the Hybrid Control System to assist engine response under rapidly changing speed reference or load demands (e.g. when engine speed lags the speed reference from the control lever). It will also provide an additional torque contribution to the shaft under maximum throttle conditions.

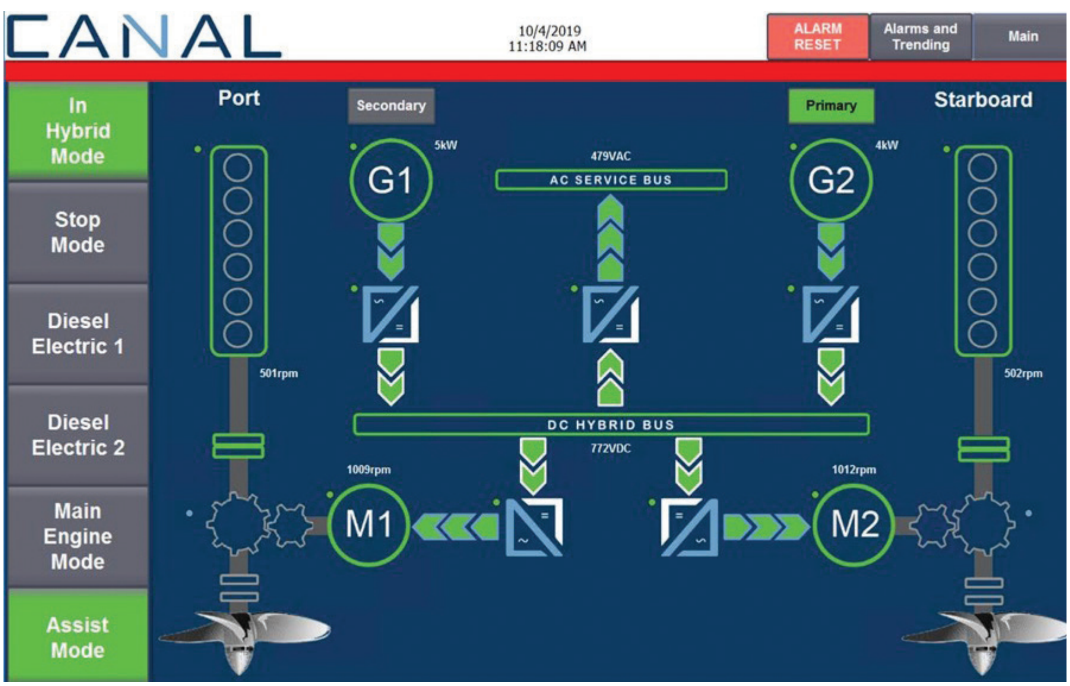


Figure 2-5
Assist Mode

3. NON-HYBRID (CONVENTIONAL) OPERATION

In some cases, you may decide to operate the vessel without the automated control of the hybrid system. Each sub-system (for example a genset, main engine or master clutch) will be placed in local control and manually started/actuated. This is a perfectly valid method of operating the vessel (although the efficiency benefits of the hybrid system are lost).

Non-hybrid (conventional) operation of the vessel is most likely to be used in one of the following two scenarios:

1. *A fault in the hybrid system prevents it's use (or prevents a full range of hybrid modes from being available)*
2. *The vessel is to be temporarily operated by a crew untrained or unfamiliar with the hybrid system*

When you wish to operate the vessel in this manner, the hybrid system should be placed in 'non-hybrid' mode using the wheelhouse control panel. The keyswitch on the main enclosure door must also be turned to the 'off' position. The hybrid control system will no longer attempt to control any machinery (for example genset, engine or clutch). The process of manually placing machinery into local control will, anyhow, make control by the hybrid system impossible. The power converters (AFEs, VFDs or the Grid converter) will also be stopped and the switchgear that connects the gensets to the DC Bus will open. The DC Bus will be down.

Figure 3-1
Wheelhouse Control Panel

When in non-hybrid operation, the vessel becomes very similar to a conventional vessel of the same general type.

Gensets will need to be manually connected to the AC vessel service bus once manually started (using the 'bypass' switches provided).

When in non-hybrid operation, the vessel becomes very similar to a conventional vessel of the same general type.

In non-hybrid mode the hybrid control system will continue to update the HMI with available information (such as switchgear status, sub-system status, metered values etc). The HMI is no longer strictly necessary for operation of the vessel in conventional, non-hybrid mode, but it will continue to show equipment statuses.

In order to return to hybrid operation, the crew must follow procedures listed in the main documentation package. These procedures are intended to be carried out at the dock (never underway). Once configured to operate as a non-hybrid (conventional) vessel, no attempt to return to hybrid operation should be made unless at the dock.

4. USING THE TOUCHSCREEN HMI

4.1 Understanding the Graphical Representations

From the example screenshots included in this wheelhouse manual, you can see that sub-systems (main engines, clutches, gensets and power converters) are represented graphically. The outline colour of the sub system indicates its status:

- **Green** for running
- **Blue** for not running but available
- **Grey** for not available
- **Red** for faulted

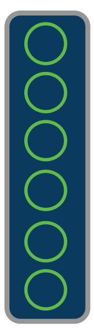
A sub-system may be unavailable for hybrid control if it has been left in local/ manual control. If it is faulted, then clearly further intervention will be needed to make it available.

The statuses of the five power converters are shown using the same colour code scheme. However, these are shown using smaller dots rather than outlines.

Direction of power flow is indicated using green arrow symbols.

Examples:

Figure 4-1
Example HMI Graphics



A main engine running.

A power converter; not running but available.

Using the DC Bus as the source, the drive is controlling the motor. Power is being transferred to the prop.

The drive is running and creating negative torque on the propulsion shaft. The motor is therefore generating and supporting the DC Bus.

4.2 Making Mode Selections

Only the wheelhouse HMI may be used for making hybrid mode selections. This functionality is not available on the HMI below deck.

Hybrid modes of operation are selectable using the touch buttons down the left side of the screen. The current mode is shown in bright green and available modes are shown with white text on a grey background. If a mode is unavailable it is shown with the text greyed out. You should be able to see why the mode is unavailable by looking at the equipment status colours as described in 4.1 on the previous page. If a subsystem is faulted, then the alarm & monitoring functionality may be able to provide more detailed information relating to the cause.

In the example to the right, the vessel is in hybrid operation and the active hybrid mode is: Main Engine Mode. Assist Mode is currently not available for selection but Stop Mode, Diesel Electric 1 and Diesel Electric 2 are.

Note that the "In Hybrid Mode" indicator is not a touch button and cannot be used to take the vessel in and out of hybrid operation. A physical switch is provided on the wheelhouse control panel for that purpose (along with the keyswitch on the main enclosure panel below deck).

Figure 4-2
Mode Selection

4.3 Hybrid Mode Transitions

Transitions between modes are automated. The hybrid system controller will start/stop machinery and open/close clutches and switchgear. It will start and stop power converters and control the direction of power flow through them. A transition can take several seconds to complete. Progress can be monitored on the HMI as the statuses of the sub-systems change. During a transition, the destination mode button on the left of the HMI touchscreen flashes. When the transition is complete it ceases flashing and becomes solid bright green.

Transitions between diesel electric modes and modes that use the main engines should only be carried out with the sticks pulled back to the null position. This ensures that the master clutch is never operated at speeds above idle. If you forget to put the sticks in the null position and attempt such a mode transition, a flashing message will appear on the HMI reminding you to do so.

If a transition fails – for example; if a resource fails to come online in response to a request from the hybrid system – then the process will time out and the vessel will be returned to its original mode of operation.

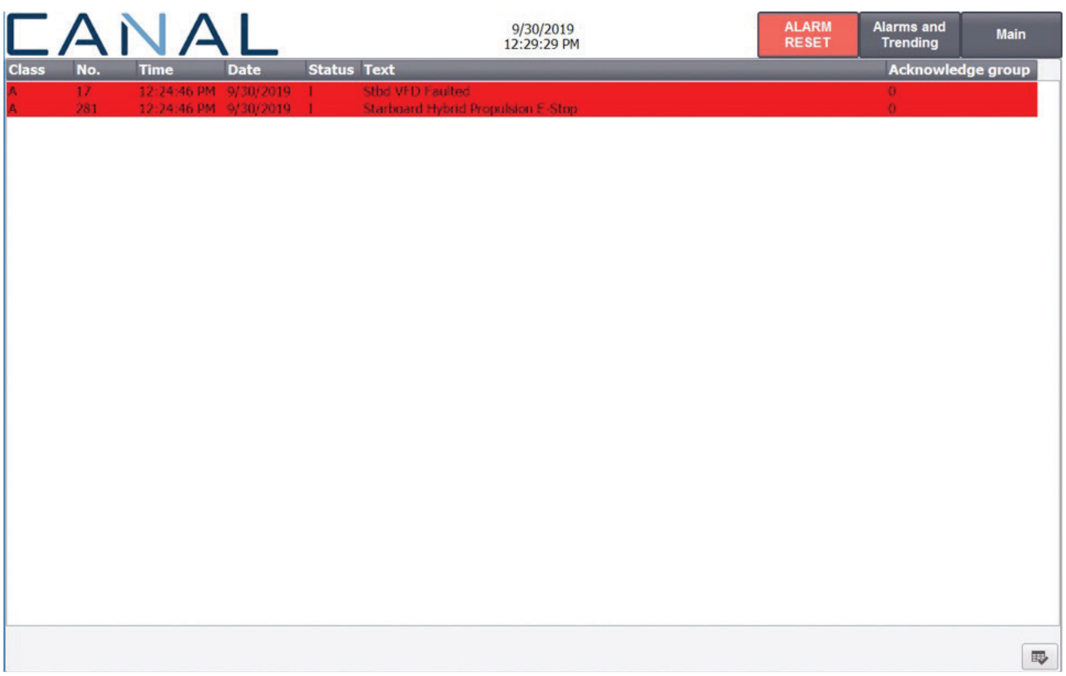
4.4 Alarms and Warnings

The hybrid system includes an alarm and monitoring system. This is not intended to cover all elements of the vessel; only those directly related to hybrid operation. For example; a main engine fault condition will be communicated to the hybrid system and will result in an alarm. The hybrid system will see that the engine is no longer available and adjust the mode availabilities accordingly. But for full details of the fault, it remains necessary to consult the engine's dedicated control panel display.

New alarms are indicated in the red bar across the top of the graphical window. New alarms also result in an audible alarm from the sounder built into the wheel-house control panel. The captain can use the 'silence' pushbutton to halt the audible alarm. However, the alarm remains in the system and can only be acknowledged from the below-decks. Once the alarm has been acknowledged, and the cause has been addressed, the alarm will be cleared. Cleared alarms are still viewable on the special alarm history screen.

- An alarm that is active is shown as in, or "I" on the screen
- An alarm that is acknowledged is shown as "A" on the screen
- An alarm that is no longer active is shown as out, or "O" on the screen.
- An alarm that is no longer active but has not yet been acknowledged will continue to be shown on the screen
- The most recent active alarm also appears on a red band at the top of the main overview screen (an example can be seen in Figure 2-2)

Figure 4-3
Alarm screen with active "In" alarms



The above shows two active 'in' alarms. Neither has been acknowledged or cleared. The alarms will continue to be shown in red until acknowledged.

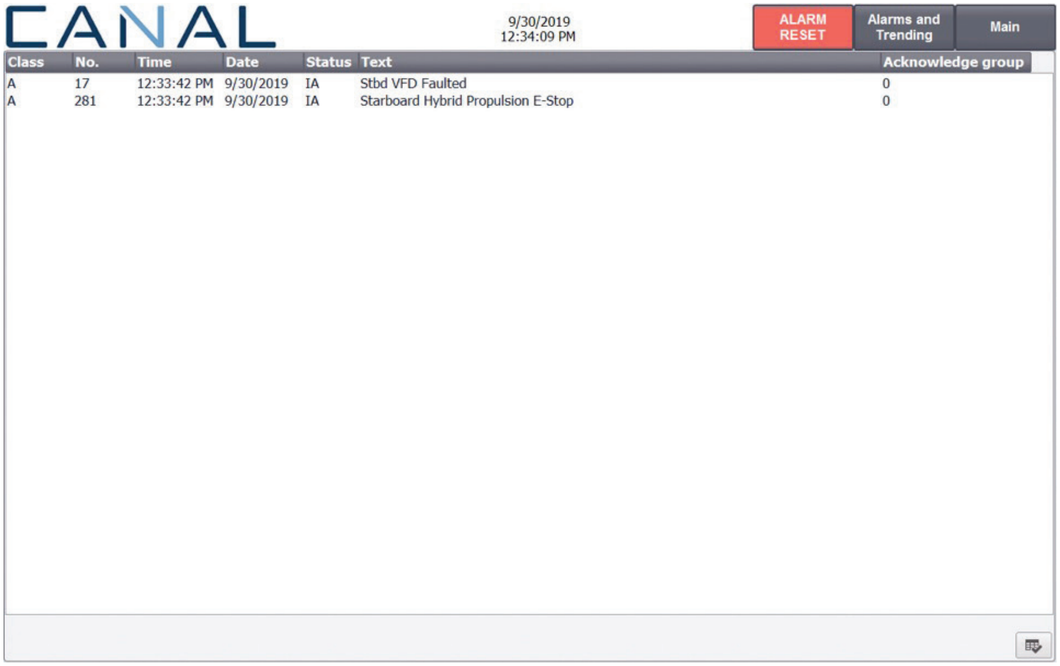


Figure 4-4
Alarm screen with"In and Acknowledged" alarms

The previous screenshot shows that the two alarms have been acknowledged. They are 'in and acknowledged' as shown by the status IA. They continue to be displayed until cleared, at which point they are recorded and viewable on the history screen.

The acknowledge button is bottom right of the screenshot.

5. USING THE PROPULSION CONTROLS IN HYBRID MODE

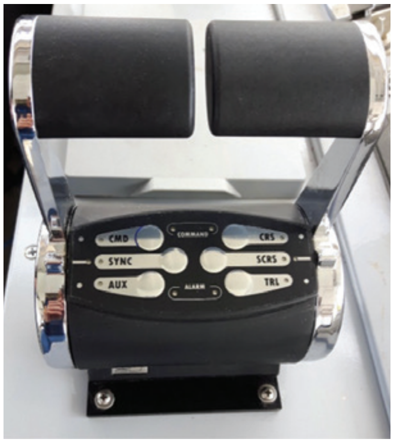


Figure 5-1
Propulsion control levers

The propulsion control levers are used in much the same way as for a conventional vessel of the same design. Control of the primary and secondary clutches occurs at the first detent in either direction (forward or reverse) whether the vessel is being used conventionally or is in a hybrid propulsion mode. Note that in hybrid Stop mode the propulsion is disabled.

In diesel-electric modes of operation the speed will follow the reference from the sticks (with a similar scaling to the main engine response). However, at some point, the motorized propulsion will meet its limits of performance (remembering that the motors are rated at less than 10% of the engines in terms of power). Once the motors reach their maximum ability to create torque, the prop speed will no longer follow the sticks as they are pushed forward. Alternatively, if the diesel generator/s supporting propulsion reach optimal loading (85%) the prop speed will cease following the sticks.

It is perfectly ok to throw the sticks quickly forward to their maximum positions in diesel electric modes of operation. The motorized propulsion will simply perform to its maximum capability on each side (either limited by motor torque or genset loading).

6. USEFUL FACTS ABOUT THE HYBRID SYSTEM

The following background information and useful facts are presented in no specific order. They provide additional information for captains of the vessel, beyond the basics necessary for operation of the system from the wheelhouse:

- Hybrid systems like this one, that provide diesel electric propulsion from small gensets, while keeping main engines off, are known to achieve significant reductions in fuel consumption (typically down 25%) and in emissions such as nitrogen oxide, carbon monoxide and particulate matter (all typically down more than 50%). In addition, maintenance costs on the large engines are reduced.

  Source: Evaluating Emission Benefits of a Hybrid Tug Boat, California Air Resources Board/ University of California, Riverside

- The vessel's electric motors drive the propulsion shafts through 2:1 reduction gears. The motor speed shown on the HMI is therefore twice the equivalent engine speed

- There are three types of power converter used in the system:

  1. Each generator supports the common DC bus via an active front end (AFE). This converts the AC output of each diesel generator to DC and takes care of load sharing (if the other genset is also online).

  2. The grid converter supports the vessel service AC bus using the DC Bus as a source

  3. The variable frequency drives (VFDs) run the propulsion motor-generators (MGs) at variable speed (determined according to stick position). In Main Engine mode, the VFDs control power flow in the opposite direction, supporting the DC bus by applying a negative torque to the propulsion shaft through the MGs.

- All the power converters are 'regulators'. We sometimes refer to them as 'active' rather than 'passive' devices. We use them to regulate DC Bus voltage, AC bus voltage/frequency, motor speed and motor torque.

- The power converters perform regulation by opening and closing their internal semiconductor switches 3,600 times per second. This is well within the audible frequency range and results in the distinctive 'buzz' that can sometimes be heard (particularly when standing close to the main hybrid system enclosure).

- The entire hybrid system is "non-essential". With the hybrid system completely disabled and powered down, it is still possible to operate the vessel conventionally (like other non-hybrid vessels in the same fleet).

- The hybrid system controls the master clutch, opening or closing it according to the selected modes. The primary and secondary clutches, however, are not controlled directly by the hybrid system. These operate according to the stick position in the same way as for a conventional vessel. The status of the primary/secondary clutches is shown on the HMI.
- The HMI does not directly control the hybrid system. Therefore, if the wheel-house HMI should fail, the short-term operation of the vessel will not be affected. The vessel will continue to operate in the existing hybrid mode while, obviously, changes of hybrid mode will no longer be possible. The HMI is not necessary for running the vessel in non-hybrid (conventional) mode. However, if left running, it can continue to display some equipment statuses which may be useful.
- The hybrid system's alarm & monitoring function only covers the hybrid system itself and equipment directly relating to it.
- The hybrid system does not interface with steering in any manner.
- When operating in non-hybrid configuration, either diesel generator (but not both) can be connected manually to the AC bus, just like a conventional vessel of the same general type. In hybrid modes of operation, the diesel generators support the common DC Bus via the active front ends and the grid converter supports the AC vessel service bus using the DC bus as its source.
- In main engine mode, the motor-generators create a small negative (opposing) torque on the propulsion shafts. This is considered to be so small, relative to the main engine's capabilities, that it can be ignored as a factor in operation of the vessel.
- If the vessel has been tied at the dock on shore power and the crew forgets to disconnect the shore power umbilical, the hybrid system will prevent the selection of a propulsion mode (meaning that the vessel remains in 'stop' mode with the sticks disabled).
- Main engine pre-lube is automated and takes place at regular intervals so that the engines are always ready to start. This keeps mode transition times to a minimum.
- During cool down of diesel generators and main engines, a cool down timer appears on the HMI screen next to the corresponding machine.
- The master clutch systems each rely on an external HPU (fed from the vessel's 24V, battery backed, control power). The external HPU is only required until the master clutch is closed with main engine running, after which a PTO system pump provides all the necessary hydraulic power and lubrication. When the external HPU is running an indication appears on the HMI next to the clutch/gearbox graphic.

- In Diesel Electric modes, the external HPU for the master clutch is not needed.
- The hybrid system closes the master clutch before starting the main engine. This is also a good method for the crew to use when manually operating the clutch (in non-hybrid operation).
- Note that all the usual interlocks are present between the main engines and their primary/secondary clutches. The main engines cannot be started with the sticks in the ‘clutched in’ position (irrespective of hybrid or non-hybrid operation of the vessel).
- At any time, tapping on a sub-system icon (genset, main engine, mater clutch or power converter) on the HMI screen will open a window providing more details about the current status.
- The master shut-down E-Stop pushbutton works in the same way as it does for a conventional vessel. In an emergency (typically a fire), it shuts down all engines and engine room ventilation. The Hybrid System will also die by default, as all sources of power are removed. It is recommended that the crew also turns off the hybrid system using the keyswitch in the control room and/or the two position switch in the wheelhouse. This will prevent any possibility of an unexpected re-boot of the hybrid system later, when the master shutdown is removed.
- After the master clutch is closed (during a transition to Main Engine mode or Assist Mode) you may notice a short delay (approximately five seconds) before you are able to close the primary/secondary clutches. This deliberate delay ensures that system pressure is established prior to loading the main engines.

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