DSEC

NATIONAL SECURITY MULTI-MISSION VESSEL

POWER SYSTEM CONTROL PHILOSOPHY

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CONTENTS

1. GENERAL

1.1 OVERVIEW

This document describes the top-level electrical power system control and operating philosophy for the National Security Multi-Mission Vessel (NSMV) for DSEC. This document forms part of the complete electrical design package supplied by GE Power Conversion. The Electric Power & Propulsion System is described in the later sections of this specification.

The vessel employs an Integrated Electric Propulsion architecture where the generation of propulsion power and vessels service power is provided by a common generation and distribution system.

The power system is designed in accordance with American Bureau of Shipping (ABS) class requirements and Philly Shipyard power system overall architecture.

The power system is a robust system designed to operate for all defined operating scenarios. The power system is divisible into four systems such that in the event of failure of one system, the other three systems shall remain in operation with sufficient power generation and thruster capacity to maintain the position with all essential and emergency loads in operation.

The power system can operate in various configurations. The Thruster systems are connected to the divided electrical systems such that there is enough thrust for Sailing, Manoeuvring and other critical operation following a failure of one of the 6.6 kV switchboard section.

The Power Management System (PMS) is a sub-system of the Vessel Management System (VMS). The PMS provides remote control and monitoring facilities when the power system is operating in REMOTE.

1.2 RULES AND REGULATIONS

The Vessel power system shall be designed, built and classed according to the main following rules.

Classification – American Bureau of Shipping (ABS) MVR January 2020

IEC

Refer to the “Classification, Standards and Environmental Conditions” document for the full list of regulations and rules that apply to this project.

1.3 REFERENCE DOCUMENTS

1.3.1 Customer Documents

Document Name	DSEC Reference
Electrical Functional and Operating Philosophy	DA880E002
General Specification	1033-POS-0000000
Electrical Motor Propulsion	1033-POS-0062101
Main Generator Engine with EGR	1033-POS-0065101
Alternator	1033-POS-0095101
Power Plant High Voltage	1033-POS-0096121
Ship Service Switchboards	1033-POS-0096141
Ship Service Emergency Switchboards	1033-POS-0096142
Power Management System	1033-POS-0096143
Local Motor Control Centers & Starters	1033-POS-0096144
440V, 220V Distribution Boards	1033-POS-0096145
Test Panel	1033-POS-0096146
Battery Switchboard	1033-POS-0096147
Remote Pushbutton Box	1033-POS-0096148
Transformer	1033-POS-0096221
One Line Diagram	DA888E011
Wiring Diagram	DA888E012
Electrical Load Analysis	DA888E001

1.3.2 GE Power Conversion Documents

Document no.	Document title
SV1P01C01S02	Power and Propulsion SLD
PV1P01C01	6.6kV Power System Control Philosophy (This Document)
PV1P02C01	Power and Propulsion System Signal Interface List
PV3P01C01	Load Flow Studies/Load Analysis
PV3P01C02	System Fault Level Calculation Report
PV3P01C03	6.6kV System Harmonic Analysis
PV3P01C04	Protection Co-ordination Report
PV3P01C05	Arc Fault Calculations
PV3P01C06	Ground Fault Calculations
PV3P01C07	Transient Stability Study
AV3P01C01	Propulsion System Design document (SYDD)

1.4 GLOSSARY OF TERMS

ACB	Air Circuit Breaker
AVR	Automatic Voltage Regulator
CB	Circuit Breaker
ECP	Engine Control Panel
ESD	Emergency Shutdown
FS	Field Station
GCP	Generator Control Panel
GP	Generator Protection
GPT	Ground Potential Transformer
HRG	High Resistance Grounding
IAC	Internal Arc Containment
LOP	Local Operator Panel
MCC	Motor Control Centre
MV7306	Thruster VFD
MSB	Main Switchboard
PMG	Permanent Magnet Generator
PMS	Power Management System
SWBD	Switchboard
TBC	To be advised by customer
VCB	Vacuum Circuit Breaker
VFD	Variable Frequency Drive
VMS	Vessel Management System

2. POWER SYSTEM OVERVIEW

Refer to for the Overall Power System Single Line Diagram.

2.1 DIESEL GENERATORS:

The electrical power generation system consists of four main diesel generators; one generator connected to each section of switchboard. All four generators can feed a section of 6.6 kV switchboard depending upon power system configuration. Following are the specifications of main diesel generators:

Diesel Engines	**4 off**
Prime Mover:	WABTEC
Type:	16V250MDC
Rating:	4200 kW
No. Of Cylinders:	16 cylinders
Rated Speed:	900 RPM
Engine Start / Stop System:	Engine Local Control Panel
Fuel:	Diesel
Governor Controller:	Built into the ECM software
Generator	**4 off**
Generator Manufacturer/\Maker:	Hyundai ELECTRIC AND ENERGY SYSTEMS CO., LTD
Type:	HSJ9 913-08P
Rating:	5066.25 kVA, 6.6 kV, 60 Hz
Overload capability:	in line with ABS class rules
Power Factor:	0.8 lagging
Current:	443.2 A
Speed:	900 RPM
No of poles:	8 poles
Auto Voltage Regulator:	HDEC 2000
Synchroniser:	TBC (Part of 6.6kV Switchboard)
Response:	To meet ABS performance requirements

2.2 6.6KV SWITCHBOARDS

The Switchboards and switchgear are rated for 6.6kV and a short circuit withstand current of 25kA for 3 seconds. The worst-case fault level calculated on the 6.6 kV system 14.6kA (RMS symmetrical) and 47.05kA (Asymmetrical peak) for 1 sec, considering 4 generators connected.

Refer to the Fault Level Study for full details of fault levels on the power system.

The 6.6kV switchboard essential control systems (including closing, tripping and protection / monitoring circuits) are supplied by the dedicated 110Vdc battery charger supply. Each battery charger (2 off in total) has the capability of supplying all the 6.6kV switchboard sections whilst each switchboard section has dual fed supplies from both battery chargers. This ensures that failure of a battery charger will not result in any loss of a switchboard section and bump-less transition between battery charger supplies.

For specific 6.6kV switchboard feeder details refer to GE Power Conversion document 6.6kV Switchboard Functional Design Specification.

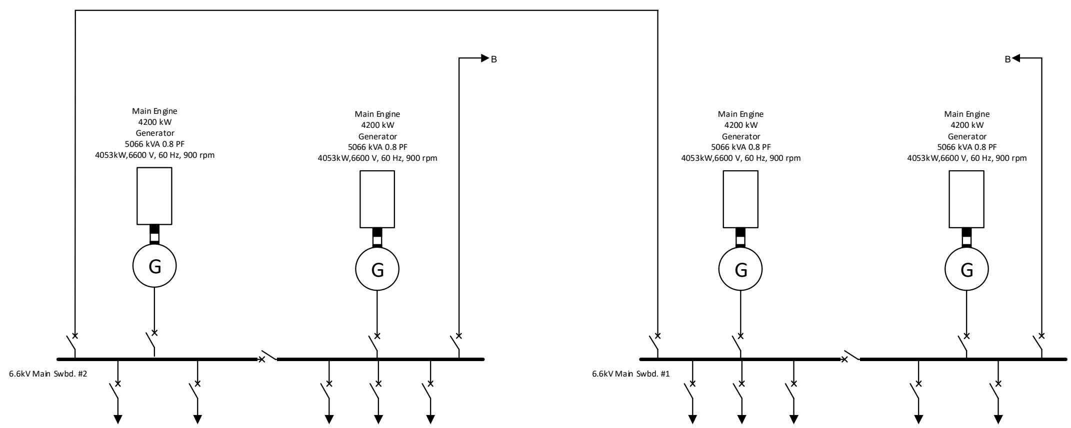

Figure 1: 6.6kV Switchboards Interconnection

Each switchboard comprises two bus-bar sections connected with a bus-tie circuit breaker. Each section of the busbar has one generator connected to it. Both the 6.6kV switchboards are connected by interconnecting circuit breakers. The generator incomer and interconnecting circuit breakers are provided with synchronizer. The bus-tie sections are provided with Check-sync relay.

The switchboards are arranged in such a way that a failure in one switchboard bus section leads to the loss of the affected section, leaving the other bus section and switchboards unaffected.

All breakers in the switchboard can be controlled either locally or remotely.

6.6kV Main Switchboard HM1

Panel 1: No.1 Bus GPT

Panel 2: No. 2 Propulsion Transformer

Panel 3: No.1 HV Main Transformer

Panel 4: No.1 AMP Shore Power (STBD)

Panel 5: No.1 Interconnector BUS-1 to BUS-3 (HM2)

Panel 6: No.1 Main Generator

Panel 7: Bus-tie & Synchronizing

Panel 8: Bus Riser and No.2 Bus GPT

Panel 9: No.2 Main Generator

Panel 10: No.2 Interconnector BUS-2 to BUS-4 (HM2)

Panel 11: No.2 HV Main Transformer

Panel 12: Bow Thruster Feeder

Panel 13: I/O Panel

6.6kV Main Switchboard HM2

Panel 1: No.3 Bus GPT

Panel 2: Stern Thruster Feeder

Panel 3: No.3 HV Main Transformer

Panel 4: No.3 Interconnector BUS-3 to BUS-1 (HM1)

Panel 5: No.3 Main Generator

Panel 6: Bus-tie & Synchronizing

Panel 7: Bus Riser and No.2 Bus GPT

Panel 8: No.4 Main Generator

Panel 9: No.4 Interconnector BUS-4 to BUS-2 (HM1)

Panel 10: No.2 AMP Shore Power (PORT)

Panel 11: No.4 HV Main Transformer

Panel 12: No.1 Propulsion Transformer

Panel 13: I/O Panel

2.3 6.6KV AMP SHORE CONNECTION PANELS

The vessel is equipped with two AMP (Alternate Marine Power) Shore connection facilities, one on the Port Side and other Starboard that feed HV AMP Shore Connection Panels located in the HV Shore Power Room on the second deck.

Each panel is rated for 6.6KV, 60HZ, 8MVA and a short circuit withstand of 25KA for 3 seconds.

Each panel has a Shore Power Incoming circuit breaker section and an outgoing section that feeds shore power to the ships main HV Switchboard Incoming circuit breakers.

ABS guidelines for HV shore connections recommend all AMP panel circuit breakers are operated remotely, with the AMP room empty of personnel and doors closed.

Although final operating and safety procedures are the responsibility of others, GE recommend AMP breakers should be selected to remote control and operated via the PMS system. For maintenance purposes, the AMP breakers can also be selected to local control and opened and closed using controls on the AMP panel. It is recommended that AMP breakers are racked into the test position before any local operation.

Necessary controls and Instrumentation are provided to check shore power compatibility (Voltage, Frequency and Phase Rotation)

2.4 6.6KV POWER SYSTEM EARTHING

The 6.6kV Power System employs a High Resistance Grounding (HRG) system and the provision of ground fault monitoring to keep earth currents low and to maintain continuity of service during earth faults.

2.4.1 Grounding Potential Transformer (GPT)

For all ships the use of a solidly earthed AC neutral point is not allowed as it gives very high levels of earth fault current, which makes it impossible to operate with an earth fault on the AC supply.

The Grounding Potential Transformer (GPT) circuit uses three earthing transformers with their primaries connected in star configuration with the neutral point earthed and the three secondary windings connected in an open delta configuration with a resistor across the open delta connection see Figure 2.

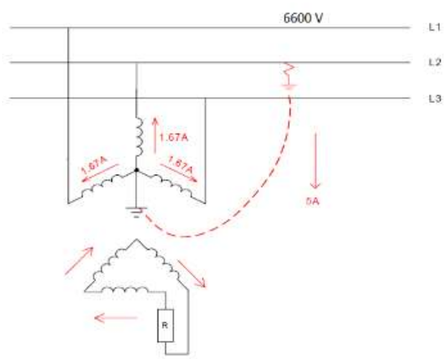

Figure 2: High Resistance Grounding Protection

When the AC system is healthy, the open delta circuit is at zero voltage and no current flows in the earthing transformers. When there is an earth fault in the AC system a voltage is produced in the output of the open delta circuit and a current then flows in the open delta circuit set by the output resistor, and a corresponding current flows in the primaries of the earthing transformers limited by the resistor.

Each main bus bar is equipped with earthing transformers and a resistor to ensure that the system earthing is always maintained when the system operates with the bus-ties/bus-interconnectors open or closed. The earthing transformers are rated for operation with an earth fault for the time required for the system to identify and isolate the earth fault. The open delta resistor is also be rated to withstand worst case earth fault for the duration required to isolate and clear the earth fault.

The presence of the GPT in the earth fault path limits the prospective earth fault current to a value lower than 5A per switchboard section (depending on system voltage) and can therefore limit damage to the connected equipment. Without GPT's, the fault current reduces to a level determined by stray system capacitance, which becomes the predominant factor. When this occurs, the system is effectively unearthed. Therefore, GE Power Conversion select a value of earthing resistance which for a system line to earth fault, carries a current greater than the stray capacitive current at the power frequency. The current flowing through the resistor is monitored by the GPT protection circuit and is configured to provide back-up protection to the sensitive earth fault protection.

For earth fault in the busbar section, stage 1 of the HRES will trip the Interconnector and bus tie circuit breakers and generate an Alarm. If the fault remains in that busbar section, then the Stage 2 will trip generator circuit breakers. The selection of the GPT is detailed on the Ground Fault Calculation document which calculated the earth fault currents in the system and evaluated and confirmed the GPT resistance value and ratings.

2.5 PROPULSION CONVERTERS (MV7000)

Propulsion of the vessel is provided by one fixed pitch propellor, driven by two in number induction motors connected on the same shaft. A dedicated 3-level Pulse Width Modulated (PWM) MV7306 converter powers each main thruster motor. The MV7306 converter is connected onto the 6.6 kV system via a 12-pulse transformer (with two secondary windings)

Due to the rating of the main thruster transformers (5400 kVA) and a requirement to pre-charge the converter DC bus, a combined pre-magnetisation/pre-charge transformer and its associated control circuit are built into the converter to ensure that the propulsion can be started even with only a single generator connected to the 6.6 kV system without the severe voltage dip normally experienced due to the large transformer inrush currents. Since the drive DC bus needs to be pre-charged prior applying the input voltage to the drive, is not possible to override the pre-mag sequence.

The MV7306 drive is a water-cooled converter with a diode-rectifier supply bridge and a PWM IGBT output bridge.

The converter hardware is controlled by a PECe controller running GE Power Conversion developed software. Interface to the MV7306 converter is via hardwired digital and analogue input/output (I/O).

Variable thrust is achieved by varying the speed of the propulsion motor. The speed is controlled smoothly from 3rpm to 110rpm, by the associated MV7306 Converter.

The speed references to each drive are sent from the Propulsion Control System to the drives.

The MV7306 converters are explained in detail in the GE Power Conversion Propulsion System Functional Design Specification. All alarms & monitoring of the Main Thruster Drive Train (including the transformer, converter and the thruster motor) are available from the associated MV7306 converter Local Operator HMI Panel (LOP), as well as the PMS.

The MV7306 converter control system is supported by a dedicated two 230V ac supply provided by a dedicated UPS, each propulsion drive has its own dedicated and independent UPS unit.

All the drive auxiliary supplies (cooling pump supply, heaters, etc.) are fed from the relevant distribution system.

2.6 450V DISTRIBUTION SYSTEM

There are two 6.6kV/450V ship service transformers per switchboard, each rated at 4100kVA, feeding the main 450V switchboards. No.2 LVMSB 450V bus section is supplied by Ship Service Transformers No.3 HV TR and No.4 HV TR respectively. The transformer is energised from the main 6.6kV Switchboard via No.3 Main Transformer and No.4 Main Transformer VCB's. No.1 LVMSB 450V bus section is supplied by Ship Service Transformer No.1 HV TR and No.2 HV TR respectively.

The ship service transformer 450V incomers shall be prevented from closing if the upstream 6.6kV circuit breaker opens such as to prevent possible back-feed from the 450V system. In addition, tripping of the 6.6kV ship service transformer circuit breaker will inter-trip the 440V incomer circuit breaker.

The main 450V LV switchboards are interlocked such that only a maximum of 2 out of 3 (two incomers and one 450V bus-tie) circuit breakers are closed. It is the responsibility of the 450V LV switchboard supplier to ensure that this interlock is in place and signals are made available for the use.

The main 450V LV switchboards can also be supplied via the shore supply when the vessel is in harbour where it is deemed uneconomical to run the main generators. The shore supply feeder breaker at the main 450V LV switchboard is interlocked with the ship service transformers circuit breakers and the emergency generator to prevent parallel operation when using the shore supply.

Refer to the relevant 450V LV switchboard drawings/functional design specification for details and operation of these distribution switchboards.

No.1 and No.2 LVMSB's are interconnected with a cross feed that can be used in an emergency situation where both transformers have failed on one LVMSB. This interconnect is to be locked shut in normal operation and only utilised via manual intervention and monitoring by personnel.

3. SYSTEM OPERATION

The vessel power systems main operating configurations and main operating modes are:

Transit

- Sea going at 18 knots
- Sea going at 12 knots
- Manoeuvring mode
- Safe return to Port mode (via main propulsion or bow thruster)

At Port

- Power Generation from shore
- One/two generators running in case of no shore power

The configuration of the power system is achieved manually. The operator opens and closes the bus-tie/Interconnector circuit breakers depending on the required configuration. It is the responsibility of the operator to ensure that all re-configuration operations do not lead to any overload, blackout or loss of propulsion/thruster power supply. The re-configuration can be done from the PMS or locally at the 6.6kV Switchboards.

The 6.6kV Switchboards can operate in various configurations depending upon the status of the 6.6kV bus-tie/interconnector circuit breakers.

Note that a single bus configuration (all bus-ties and interconnectors closed) is not allowed. There are mechanisms in place (Remote PMS and switchboard interlocking) to prevent closed ring operation.

Some of the expected configurations detailed in “ELECTRICAL FUNCTIONAL AND OPERATING PHILOSOPHY” by DSEC are as follows:

3.1 TRANSIT

3.1.1 Sea going at 18 knots

All the four diesel generators are running in this mode.

Both 6.6 kV Main Switchboards are energized and will be configured by operator to operate in open ring mode, with the bus-tie of either one open with both interconnecting breakers between them are closed.

Both the propulsion motors are operating to meet the thrust demand.

Each main 450V LV switchboard is fed via redundant transformers, each one rated to carry 100% of the total load.

Normal operation is with bus-tie open and each transformer feeding its own bus. Interlocking will be provided to only allow maximum two out of three circuit breakers to be closed at the same time.

In the event of a transformer failure the bus tie shall be closed, and the remaining transformer will supply both buses. Interlocking will need to be provided to prevent closing the LV bus-tie if the HV bus-tie is open.

The Emergency Switchboard is fed via redundant feeds from either No.1 or No.2 LVMSB, these breakers will always be closed. The two redundant feeder breakers located at the Emergency Switchboard will be interlocked so that only one of them can be closed at the same time. On the loss of the primary power source, an auto changeover function will repower the Switchboard by closing the other breaker. In this scenario, a minimal time delay should be included in the Emergency Generator start circuit to allow the changeover to complete without starting the generator.

3.1.2 Sea going at 12 knots

This mode of operation is used with machinery of either engine room shutdown for training purposes, with the power system being energized from the other engine room equipment.

Two diesel generators with one propulsion motor will be operating at about 60% of its nominal power, either propulsion motor can be used.

Both 6.6 kV switchboards are active and will be configured to operate in open ring mode, with the bus-tie of either one open with the interconnecting breakers between them closed.

Each main LV 450V switchboard is fed via redundant transformers, each one rated to carry 100% of the total load.

Normal operation is with bus-tie open and each transformer feeding its own bus. Interlocking will be provided to only allow maximum two out of three circuit breakers to be closed at the same time.

In the event of a transformer failure the bus tie shall be closed, and the remaining transformer will supply both buses. In this mode, the four main 440V Load Centre Panel primary feeders would all be fed from the active engine room LVMSB. In this case all load centres would receive power from the active switchboards only with no back-up supply.

3.2 MANOEUVRING MODE

All the four diesel generators, both Propulsion motors, Bow and Stern Thrusters will be operating in this mode.

6.6kV Interconnecting breakers will be open and both switchboard bus-ties closed resulting in two independent power systems. This is to minimize the consequences of a fault on all main busses during such critical manoeuvring operation.

In the case of an overload resulting from generator tripping, the load shedding scheme has to take into consideration that the No.1 Load Center Panel may be fed from the opposite non-failure switchboard

Each main LV 450V switchboard is fed via redundant transformers, each one rated to carry 100% of the total load.

Normal operation is with bus-tie open and each transformer feeding its own bus. Interlocking will be provided to only allow maximum two out of three circuit breakers to be closed at the same time.

In the event of a transformer failure the bus-tie shall be closed, and the remaining transformer will supply both buses.

3.3 SAFE RETURN TO PORT (VIA OWN PROPULSION)

Safe return to port can be via one propulsion motor with two generators running.

3.4 SAFE RETURN TO PORT (VIA BOW THRUSTER)

Transit speed of approximate 8 knots via the 1800KW Bow Thruster and one generator running.

3.5 AT PORT FULL COMPLIMENT (AMP)

At port, the ship's generators will be shut down and power will be supplied from shore via either of two 6.6kV shore supplies. This mode of operation may be entered with machinery of either engine room shutdown.

Necessary interlocking and synchronizing equipment are provided to allow for momentary synchronizing of shore to vessel power supplies for bump less transfers.

In this mode, the two 6.6kV switchboards shall operate in open ring mode, with the bus-tie of either one open with the interconnecting breakers between them closed.

Each main LV 450V switchboard is fed via redundant transformers, each one rated to carry 100% of the total load.

Normal operation is with 450V bus-ties open and each transformer feeding its own bus. Interlocking will be provided to only allow maximum two out of three circuit breakers to be closed at the same time.

In the event of a transformer failure the bus tie shall be closed, and the remaining transformer will supply both buses. If the shore power is unavailable or trips, then one or two diesel generators will be run depending on ship's load.

3.6 BLACKOUT MODE

In the case of a complete power failure the Emergency Generator will automatically start, come on-line on the dead bus and supply power to all consumers connected to the Emergency Switchboard and emergency distribution boards.

Both Engine Room switchboard interconnecting breakers at the Emergency Switchboard will both trip via undervoltage coils on a blackout.

Upon blackout the black start sequence to restart the main generators and switchgear is initiated by the PMS.

Upon completion of blackout recovery sequence the operator must manually trip the emergency generator incomer breaker, a main emergency switchboard incomer will automatically close.

4. POWER GENERATION & CONTROL

There are four main generators, each rated at 5066.25kVA 0.8pf, 6.6kV, 60Hz driven by Diesel Engines. The excitation system comprises HDEC 2000 Digital Voltage Regulator are provided by the diesel generator supplier.

The auxiliaries for the diesel engines are supplied from the 450V LV switchboards.

The system has two locations where local/remote modes can be selected, one is at the Engine Control Panel and the other is at the 6.6kV main switchboards.

Engine Control Panel

From the engine control panel, the engine can be selected to the following modes

Local: Engine Control Panel (ECP)

Remote: Control authority released from GCP to 6.6kV Generator Control Panel (GCP) in either No.1 HVMSB or No.2 HVMSB switchboards

Engine remote indication sent to 6.6kV Switchboard to allow operations from the 6.6kV switchboard.

6.6kV Main Switchboards:

At the 6.6kV switchboards (generator section) the generator circuit breakers can be selected to the following modes:

Local and **Remote**

A separate local/remote switch exists for each generator.

Under normal operation, the power system should be selected to REMOTE. This is achieved by selecting REMOTE at the engine control panel and selecting the generator circuit breaker selector switches to REMOTE at the 6.6kV switchboard GCP.

In this condition full remote manual and automatic control of the generator is available via the PMS.

LOCAL and REMOTE control and its operation/procedures are detailed below:

4.1 ENGINE STARTING/LOADING PROCEDURES

Starting and stopping of an available Diesel Engine may be performed manually by the operator at the Engine Control Panel(ECP), manually at the switchboard Generator Control Panel (GCP), or remotely at the PMS.

4.1.1 Local Control

When LOCAL is selected at the ECP, the engine can only be manually controlled from the engine ECP. Engine control from both the 6.6kV switchboard and the PMS are inhibited. This mode is typically used during commissioning and maintenance only.

The ECP should normally be selected to REMOTE control.

With REMOTE selected at the Engine Control panel (Engine Remote lamp ON at the 6.6kV switchboard), the generator set to LOCAL at the respective 6.6kV main switchboard generator Incomer Control Section, and the engine is running at rated speed (indicated by the Engine Running lamp at the main switchboard), the operator can manually adjust the speed/voltage to match the busbar frequency/voltage by operating the raise/lower spring return switches at the 6.6kV switchboard. The operator is permitted to close the generator circuit breaker, providing it is permitted by the check-synch or dead bus close circuitry.

Following the closing of the generator circuit breaker at the 6.6kV switchboard, the engine can be manually loaded by the operator utilising the raise spring return switch for speed (and kW load) and the raise spring return switch for voltage (and kVAr load) if operating in parallel with other generator sets.

Load sharing between the paralleled generators is controlled by the governors in Droop control.

Note, under local control at either ECP or GCP, engine auxiliaries must be started manually by the operator before an engine can be run.

It is recommended that for full manual operation of the power system, it is done with bus ties closed and bus interconnectors open, such that each switchboard is set up independently. Once both engines are connected to a switchboard and the load sharing set up using the raise/lower voltage and speed switches, the engines will continuously load share via droop. If it is deemed necessary to operate manually with all four bus sections operating in an open ring and all four generators online, then a procedure can be developed for the vessel operational manuals.

4.1.2 Remote Control

This is the **normal** operating mode of the engines.

The engine local control panel and the 6.6kV switchboard generator control section must be selected to REMOTE mode. This will select the PMS control for the starting/stopping of the associated diesel generator.

There are two ways an operator can manually start the engine from the HMI:

START	Upon a ‘Start’ request being made by the operator the PMS will issue a start command to the engine which will run up and continue to run offline. No further action taken by the PMS.
LOAD UP	Upon a ‘Load Up’ request being made by the operator the PMS will issue a start command to the engine. Once running at the rated speed, the PMS will issue a ‘CB Close’ command. This will initiate the Generator’s Automatic Synchroniser which will adjust the speed/voltage to match the busbar frequency/voltage by energising its

raise/lowers commands to adjust the frequency and voltage of the incoming generator. The Automatic Synchroniser will automatically close the generator circuit breaker, provided it is permitted by the synchronisers check synch function and the frequency, phase angle and voltage are matched or via dead bus close circuitry if applicable.

The PMS can also start an engine automatically with the above LOAD UP procedure. In this case, the manual load up request from operator is not required.

The PMS can automatically start an available generator for the following:

- In the event of a blackout
- A load dependent start request
- In the event of an on-line generator developing a 1st stage fault.
- Minimum number of generators not satisfied

More details of the PMS functionality can be found in the PMS Functional Design Specification document.

Under normal remote operation the diesel pre-lube system should be set to automatic, such that standby engines remain lubricated and ready to start at any time. In this way any engines set for remote control will be available to re-start on blackout recovery. In addition, the PMS can issue a ‘pre-lube override’ request to start the diesel under blackout conditions. Other support systems such as sea water cooling pumps will be on a group started panel and will automatically re-start on power recovery.

4.2 ENGINE UNLOADING / STOPPING PROCEDURES

4.2.1 Local Control

When LOCAL is selected at the engine control panel, the engine can only be controlled from the Engine control panel. Engine control from both the 6.6kV switchboard and the PMS are inhibited. This mode is used during commissioning and maintenance only.

The engine should normally be switched to REMOTE control.

With REMOTE selected at the Engine Control panel and LOCAL-MANUAL selected at the respective 6.6kV main switchboard generator incomer control section, unload / Stopping control of the Diesel Engine is performed manually by the operator using the dedicated speed adjustment switch and Push button at the main 6.6kV switchboard generator control section.

Any of the online engines can be manually unloaded by the operator utilising the speed adjustment switch for speed (and kW load) from the 6.6kV main switchboard in LOCAL control. It is the operator’s responsibility to ensure that the breaker should only be opened when the generator loading is reduced to approximately 10%. The breaker is then manually opened/tripped at the respective switchboard generator control panel. This is to minimise any load disturbances when the CB is opened.

Once the engine is unloaded and running offline, the engine should be allowed to run at idle speed to cool down for 10 minutes to avoid head soaking prior to manually stopping the engine at the 6.6kV switchboard. It is also recommended that the emergency stop contacts only be used in an emergency stop situation as it is a little harder on the fuel system.

4.2.2 Remote Control

This is the **normal** operating mode of the engines.

The Engine Control Panel and the 6.6kV switchboard generator incomer control section must be selected to REMOTE mode.

In this mode the engine can be stopped by a direct operator stop command from the HMI. The PMS can also automatically stop an engine, for example in the event of a load dependent stop threshold being met.

There are two ways an operator can manually stop the engine:

UNLOAD	Upon an ‘Unload’ request being made by the operator the PMS will carry out the following: PMS will issue lower pulses to the governor (via 6.6 kV Switchboard Remote interface). When the load on the engine is 10% or less the PMS will issue an open command to the generator CB. Once the engine is running offline the PMS will take no further action.
STOP	Upon a ‘Stop’ request being made by the operator an unload sequence will be carried out as detailed above. Once the CB has been opened the PMS will allow the engine to run for its configured cool down period before issuing a stop command. (If the engine is already running offline and the ‘STOP’ request is made the PMS will immediately issue the stop command). The generator is automatically de-excited when the engine speed falls below 90% of rated speed.

When the PMS stops an engine automatically, the UNLOAD procedure is used with no operator intervention.

The PMS will automatically stop an available generator for the following:

- A load dependent stop request
- In the event of an on-line generator developing a 1st stage fault.

More details of the PMS functionality can be found in the PMS Functional Design Specification document.

4.2.3 Engine Fast Stop (PMS)

This mode is only available if the relevant generator is selected to REMOTE at the 6.6kV switchboard generator control panel.

The operator can initiate a fast stop at the HMI.

A fast stop automatically trips the generator circuit breaker without unloading the engine.

The engine is stopped automatically by the PMS as soon as the breaker is opened without a cool down period. This is achieved by the PMS sending a stop signal to the engine local control.

Note that this is the normal mode to stop the generator when the generator is single running i.e. not in parallel with any other generators (unload and stop functions are not available at the HMI).

(**Caution**: It will lead to blackout in vessel. Alternate source of supply shall be arranged)

4.3 DIESEL ENGINE GOVERNOR CONTROL AND LOADSHARING

Frequency control by governors is provided to meet the ABS requirements of ±5% nominal frequency in steady state conditions and ±10% (recovering within 5 seconds) nominal frequency in transient conditions.

Engine speed governors are mounted on the engine.

The governors are configured to droop i.e. the engine speed drops in proportion to the applied load.

4.3.1 LOCAL Operation

With the generator control selected to LOCAL at the main 6.6kV switchboard, the Governor can be controlled using the speed raise and lower switches (discrete volt-free contacts) at the main 6.6kV switchboard. When not operating in parallel the raise/lower switch will vary the engine speed. When operating in parallel, the raise/lower switch will vary the engine active power / load.

It is recommended that for full manual operation of the power system, it is done with bus ties closed and bus interconnectors open, such that each switchboard is set up independently. Once both engines are connected to a switchboard and the load sharing set up using the raise/lower voltage and speed switches, the engines will continuously load share via droop. If it is deemed necessary to operate manually with all four bus sections operating in an open ring and all four generators online, then a procedure can be developed for the vessel operational manuals

4.3.2 REMOTE Operation

The PMS causes the active load (kW) to be shared symmetrically between parallel generators by raising or lowering the speed of individual diesel engines by changing the speed set points of the engine governors.

The PMS system monitors the active load sharing performance and raises alarms in the event of deviation of load sharing outside a set deadband, or in the event of governor failure.

In addition, the PMS provides functionality to either de-rate or assign a fixed target load to any one generator (Asymmetrical load sharing).

4.4 GENERATOR AVR CONTROL AND REACTIVE LOADSHARING

Generator AVR equipment, HDEC 2000, and its associated control circuitry are mounted in the 6.6kV switchboards.

The HDEC 2000 receives voltage sensing signals from VT's and a compounding signal from a CT in the 6.6kV switchboard.

The main supply for the generator excitation is from the generator shaft mounted permanent magnet generator (PMG). The control power supply shall be dual 110Vdc supplies fed from the battery charger.

The AVR is only energised at 90% of rated speed using the 'Engine Running' signal from the engine local control panel.

Should a lockout protection in the 6.6kV generator protection occur (such as generator differential trip), the AVR is de-energised and the generator exciter field is rapidly de-fluxed through the discharge resistor.

The HDEC 2000 AVR will trip the generator circuit breaker on detection on the following faults:

- AVR Watchdog Trip
- Diode Short Circuit
- Loss of Voltage Sensing

The HDEC 2000 AVR will revert to manual excitation control and send a common alarm signal to the 6.6kV switchboard & PMS shall show available individual alarms on detection of the following faults:

- Generator Over Voltage
- Excitation over current alarm

The AVR alarm can be reset by an alarm reset pushbutton on the AVR panel.

The REMOTE control is from the voltage raise/lower input from the PMS for synchronising. The LOCAL control is from the raise/lower spring-loaded switches on the 6.6kV switchboard. Normal kVAr control is from the PMS which sends a voltage raise/lower signal to the AVR to achieve the required kVAr.

The AVR is configured for the droop compensation at all times (regardless if LOCAL or REMOTE is selected), i.e. the generator voltage will droop with an increase in reactive load, but PMS trimming will compensate for the voltage drop when selected to REMOTE mode.

The generator output must meet requirements of +10%/-6% nominal voltage in steady state conditions and -20%/+20% (recovering within 1.5 seconds) nominal voltage in transient conditions.

4.4.1 LOCAL Operation

With the generator control selected to LOCAL at the main 6.6kV switchboard, the AVR can be controlled using the voltage raise and lower spring-loaded switches (discrete volt-free contacts) at the main 6.6kV switchboard.

It is recommended that for full manual operation of the power system, it is done with bus ties closed and bus interconnectors open, such that each switchboard is set up independently. Once both engines are connected to a switchboard and the load sharing set up using the raise/lower voltage and speed switches, the engines will continuously load share via droop. If it is deemed necessary to operate manually with all four bus sections operating in an open ring and all four generators online, then a procedure can be developed for the vessel operational manuals.

4.4.2 REMOTE Operation

When the generator control is selected to REMOTE at the main 6.6kV switchboard, the Generator AVRs remain in droop control.

The PMS system has the facility to share reactive load symmetrically between parallel generators by raising or lowering the voltage of individual generators by changing the set points of the AVR.

The operator is also able to pre-set the system nominal voltage from the HMI screen.

Interface to the AVR system is via discrete volt-free contacts from the PMS.

4.5 GENERATOR SYNCHRONISING

A Synchronising facility is provided for each generator with the following functionality:

4.5.1 LOCAL (via manual common synchronising panel):

Synchronising incoming generator to bus

- Manual (live bus) synchronising using a common check synch relay and the manual synchronising selector switch to select the incoming Generators G1, G2, G3, G4
- Manual Raise/Lower controls to match engine frequency and generator voltages.
- Closing of circuit breaker at switchboard when check sync relay enable is energised.
- Dead bus closure (by dead bus relays monitoring all three phases) is permitted.

4.5.2 REMOTE

- Remote (live bus) synchronising is triggered by requesting a breaker close at the PMS. The synchronization is carried out using an auto-synchroniser and its check synch function is selected on 6.6kV switchboard.
- The auto-synchronizer adjusts the incoming generator voltage and frequency until the generator is in synch with the bus, at which time the check synch passes the close command to the breaker.
- Dead bus closure (by dead bus relays monitoring all three phases) is permitted.

4.6 INTERCONNECTOR SYNCHRONISING

A local remote switch is provided for each interconnector breaker. A Synchronising facility is provided for each interconnector with the following functionality:

4.6.1 LOCAL (via manual common synchronising panel):

Synchronising interconnector to bus

- Operator must close one opposite interconnector breaker first from its dedicated switchboard

- Manual (live bus) synchronising using a common check synch relay and the manual synchronising selector switch selected to interconnector.

- Closing of interconnector on dead bus (via dead bus relays in switchboard monitoring all three phases).

4.6.2 REMOTE

The following functionality is provided

- Each interconnector has two associate breakers, one on each switchboard. One breaker should be closed first by selecting the close command at the PMS

- The second breaker may then be closed (live bus). The PMS controls voltage and frequency of the incoming bus until synchronization occurs. At this point the check-synchroniser (ANSI 25) passes the close command to the breaker. Both associated circuit breakers and all connected generators must be selected to "REMOTE" on the 6.6kV switchboard for this to occur.

- Closing of interconnector on dead bus (via dead bus relays in switchboard monitoring all three phases) by PMS close command.

4.7 BUS-TIE SYNCHRONISING

A local/remote switch is provided for each bus-tie breaker. Common sync check (ANSI 25) within each switchboard is provided for LOCAL (MANUAL) sync verification.

4.7.1 LOCAL

The following functionality is provided:

- Manual (live bus) synchronising using a common check synch relay and the manual synchronising selector switch selected to Bus-tie breaker.

- Closing of bus-tie breaker on dead bus is permitted (via dead bus relays in switchboard monitoring all three phases)

4.7.2 REMOTE

The following functionality is provided:

- A breaker close command is issued from the PMS

- The PMS controls voltage and frequency of the incoming bus until synchronization occurs. At this point the check-synchroniser (ANSI 25) passes the close command to the breaker. The bus tie circuit breakers and both connected generators must be selected to "REMOTE" on the 6.6kV switchboard for this to occur.

- Closing of bus-tie breaker on dead bus is permitted (via dead bus relays in switchboard monitoring all three phases)

4.8 AMP SYNCHRONIZING

A momentarily synchronizing facility is provided for each AMP incoming breaker. Hardwired interlocks exist such that the system must be reduced to a single online connected generator before closing the AMP supply on to the Main HV Switchboards. The following functionality is then provided:-

4.8.1 LOCAL

- After connection of the AMP reel to the shore supply, the supply should be checked for compatibility using instrumentation provided on the appropriate AMP panel.

- Supply voltage, frequency and phase rotation must be correct before the AMP panel outgoing breaker can be closed. Interlocks prevent the breaker from closing if the supply is incompatible with the ships system.

- The selector switch on the 6.6 KV Main Switchboard AMP incomer, should be set to the “Shore” position, to indicate intent to draw power from shore services.

- The AMP incomer should be closed remotely via the PMS system.

- After supply compatibility has been checked, the feeder breaker located on the AMP shore connection panel, connecting to the Main HV Swbd. may be closed. In line with ABS requirements, GE recommend the AMP feeder breakers are operated remotely via the PMS system.

- The incoming AMP supply at the main switchboard is manually synchronizing on to a live bus, using the common check synch relay and the manual synchronizing system with the selector switch selected to AMP.

- Closing of bus-tie breaker on dead bus is permitted (via dead bus relays in switchboard monitoring all three phases).

- IF the AMP supply is connected to a live bus the operator must promptly unload the online generator and open its circuit breaker.

4.8.2 REMOTE

- Once shore supply has been established by closing of shore side breaker (on the dock), the status of incoming supply should be checked via the voltage, frequency, and phase rotation instrumentation at the incoming AMP panel.

- Breaker in the appropriate AMP panel should be selected to remote. When selected to remote, the AMP breaker will only be available for control by PMS if the supply is compatible.

- AMP Panel breaker may then be closed remotely via the PMS.

- Main switchboard AMP incomer and autosynchronizer should be selected for “remote” operation.

- A button is provided on the PMS to “Shore Connect”, when selected, the PMS will initiate a remote (live bus) synchronizing (for short time) of the incoming AMP supply to the main HV Swbd. using an auto-synchronizer and via a common check synch relay.

- When the Main Swbd. AMP incoming breaker is closed on to a live bus, the PMS system will automatically unload the online generator and open its circuit breaker.

- Remote closing of bus-tie breaker on dead bus is permitted (via dead bus relays in switchboard monitoring all three phases), allowing the operator to re-establish 6.6kV to all bus sections remotely from the PMS system.

5. PROPULSION / THRUSTER SYSTEM AND CONTROL

This section provides a top-level overview of how the main propulsion system and the tunnel thruster system are controlled under local and remote operation.

The main propulsion and tunnel thruster feeder circuit breakers can be open and closed either locally from the 6.6kV main switchboard or remotely from the PMS/HMI.

5.1 MAIN PROPULSION DRIVE SYSTEM

The MV7000 range of Power Conversion converters are a family of medium voltage; press-pack IGBT encoder-less vector-controlled converters. Specifically designed for marine applications, these drives, use 3-level, neutral point clamped inverter topology.

The MV7000 converter also incorporates an RXi Controller as part of the complete propulsion drive train, which permits simple integration into the Power Conversion PMS.

The MV7000 converter is supplied with a drive train field stations placed within close proximity of the converter, which incorporates a local operator panel with a separate speed control facility.

The operator must initiate closing of the main propulsion feeder circuit breaker either locally at the 6.6kV switchboard or remotely from the PMS HMI before starting the drive. The CB can only be closed if all drive ‘CB Close Inhibit’ alarms are healthy. The closing of the breaker will initiate the starting of the converter’s auxiliaries and initiate the pre-charge/pre-magnetisation sequence of the MV7000 converter and its associated transformer, so to minimise the inrush current.

The feeder circuit breaker should only be opened after the drive has stopped.

General

The propulsion motor fan will be started as part of the drive train start sequence once the drive is running and will be stopped 20 minutes after the drive stops. The propeller auxiliaries shall be started via the propulsion system.

Frequency spill over functionality is contained within the drive by continuously monitoring the busbar frequency. This removes an overload on the busbars by reducing drive output power when a busbar frequency reduction is seen. Propulsion power is limited to the available power capacity.

A Fast Phase Back signal from the feeder to the drive is also provided to ensure that the drive performs a controlled stop in advance of the opening of the circuit breaker.

Refer to the Propulsion System Functional Design Specification for details for the above Frequency Spillover and Fast Phase Back functionality.

For full details of main propulsion local and remote operating philosophies please refer to the following document:-

S20021378	Propulsion System Design document (SYDD)

6. MAIN 6.6 KV SWITCHBOARDS

The switchboards are designed to comply with the latest IEC 62271-200 requirements in terms of Internal Arc Classification (IAC).

To comply with Annex A (Internal Fault) of IEC 62271-200, the switchgear assembly will be tested and certified to Classification IAC – AFLR and values covering magnitude and duration of Internal Arc withstand will be advised based on switchgear construction & fault rating.

The 6.6kV Switchboards consist of two separate switchboards No.1 HVMSB and No.2 HVMSB connected by cables interconnecting circuit breakers. In addition, each switchboard has a bus-tie breaker allowing split bus section operation if required.

The switchboards can be operated in common bus. Split bus mode with all the interconnector closed and one of the bus-tie breakers open will be the preferred mode of operation.

Each bus section will have multiple circuits/panels comprising generator incomers and feeders.

The metal clad switchgear will comprise of a continuous air insulated busbar section for all circuits/panels per switchboard section.

Each circuit /panel will be fitted with a pressure relief flap located on top rear for venting in the event of an internal arc fault in the switchboard; this is in accordance with IEC-62271-200 as described above.

6.1 CIRCUIT BREAKER CUBICLES

Each circuit breaker is to be equipped with a separate, front access, low voltage (control) compartment mounted directly above the circuit breaker enclosure. This compartment contains auxiliary control equipment including fuses, transducers, control relays and terminals associated with the control of its associated circuit breaker.

Also located on the front door of the LV control compartment are control and selector switches, push buttons, status lamps and discrete metering allowing safe operation of the circuit breaker when under LOCAL control.

6.2 GENERATOR, FEEDERS AND CABLE BUS-TIE CIRCUIT BREAKERS

The functionality, control and protection are defined within the 6.6kV Switchboard Functional Design Specification

6.3 PROTECTION

The protection system is based on Sepam protection relays with door mounted operator interface. The end user preference for the 6.6kV Switchboards main busbar protection will be provided in 6.6kV switchboard sections is described in detail the 6.6kV Switchboard Functional Design Specification.

For detailed information including device settings, reference should be made to the Protection & Coordination Report.

6.4 ANTI-CONDENSATION HEATER SUPPLY

The following equipment have internal 120Vac anti-condensation heaters. These are fed and controlled from the appropriate 6.6kV main switchboard. Additionally, the heater will be thermostatically controlled to remove the power when the temperature exceeds a recommended level.

- Generators
- Ships Service Transformers
- Thruster Transformers
- Ground Potential Transformer (GPT)

The following equipment have internal 120Vac anti-condensation heaters. These are fed direct from a shipyard supply. Additionally, the heaters will be thermostatically controlled to remove the power when the temperature exceeds a recommended level.

- Main Switchboard
- Thruster Frequency Converter
- Thruster Motor
- Dynamic Braking Resistor (DBR)

6.5 ALARMS

Alarms shall be raised at the PMS HMI to indicate that the circuit breakers have been tripped due to the actuation of a protection function.

If the breaker has been opened due to local/remote open command the breaker must be shown as opened and no alarm must be raised.

Also, when a breaker failure or trip coil supervision alarm has been flagged by the protection relays, an alarm should appear at the PMS HMI and locally at the respective protection relay HMI.

6.5.1 Cable Interconnectors

In case of the cable interconnectors, the same philosophy is followed

- If one of the interconnectors trips (with alarm) the adjacent interconnector is expected to "open" (without alarm).
- If one of the interconnectors opens (without alarm) the adjacent interconnector is expected to "open" (without alarm).

7. TRANSFORMERS

7.1 TRANSFORMER TEMPERATURE MONITORING

Three sets of winding temperature RTDs are provided as requirement, positioned at, or as close as practical, to the transformer hot spot in each of the LV (secondary) windings.

One set is connected to a winding temperature indicator (WTI) device located at the transformer. This has a trip signal connected to its corresponding 6.6kV circuit breaker trip circuit and an alarm signal to the PMS or thruster converter as appropriate.

The second set is connected to provide continuous temperature indication to the PMS as appropriate.

There is a third set of spare RTD's for each of the transformers

Temperature monitoring will be provided on all the 6.6kV transformers and will provide alarms and trip protection to the 6.6kV switchboard breaker trip circuits, via the Winding temperature indication units (WTI)*.

* The High Temperature TRIP signal from the WTI unit to the switchboard is Open = Healthy, Closed = Trip. Therefore, a wire break between the WTI and the switchboard will not cause the loss of a transformer. This is applicable to both Service Transformers and Thruster Transformers

The WTI unit also has its sensor fault function enabled. This ensures that should a winding RTD become faulty or an RTD wire becomes loose or broken, the WTI unit will detect this and inhibit the trip or alarm signal from being issues. Instead the sensor fault signal will be triggered.

For the service transformers the fault signal will be routed to the PMS for alarm purposes.

For the propulsion transformers the fault signal will be routed to the propulsion VFD which, depending on its operating state at the time the fault signal is triggered, will either Close Inhibit the VCB (if not pre-charged) or Start Inhibit the VFD (if in Ready state) or issue a Warning (if already Running).

7.2 PRE-MAG CONTROL

7.2.1 Ship Service Transformer Pre-Mag Control

Pre-mag circuit is provided on the ships service transformers. The pre-mag circuit is included within the transformer enclosure and is controlled by the 6.6kV Switchboard. The pre-mag sequence is initiated once a close command is issued to the transformer feeder panel at the 6.6kV switchboard. Once the pre-mag sequence is complete, the circuit breaker feeding the transformer is automatically closed.

Because all four Main Ships Service transformer pre-magnetizing circuits are fed from the Emergency Switchboard, an emergency pre-magnetizing, key operated, override switch will be provided for the unlikely event that the Emergency Generator does not start on a blackout. These switches will be mounted inside the transformer feeder cubicles to prevent inadvertent use. These override switches should not be used for any purpose other than to re-establish LV suppliers if the emergency generator fails to start. The key switches will be arranged such that the key can only be removed in the normal (non-bypass) position. Note that frequent operation of the transfomers in pre mag bypass could reduce life of the power generation and distribution system. As such it is suggested these keys would be maintained and controlled by the Chief Engineer.

Refer to the 6.6kV Switchboard Functional Design Specification, for further details on the pre-mag sequence.

It should be noted that the pre-magnetization supply is from the emergency switchboard.

7.2.2 Main Propulsion Transformer Pre-Mag Control

Due to the rating of the main propulsion transformers (5400 kVA) and a requirement to pre-charge the converter DC bus, a combined pre-magnetisation/pre-charge transformer and its associated control circuit are built into the main propulsion converter to ensure that the propulsion can be started even with only a single generator connected to the 6.6 kV system without the severe voltage dip normally experienced due to the large transformer inrush currents. Since the drive DC bus needs to be pre-charged prior applying the input voltage to the drive, is not possible to override the pre-mag sequence.

Refer to the MV7000 Thruster Drive Functional Description, for further details on the pre-mag sequence.

8. 6.6KV SYSTEM INTERLOCKS AND SAFETY EARTHING

The power system is designed with interlocks for safe and reliable operation.

This specification describes the mechanical and hardwired electrical safety interlocks and safety earthing between the individual 6.6kV circuit breakers, between the 6.6kV switchboard No.1 HVMSB & No.2 HVMSB and between the 6.6kV and No.1 LVMSB & No.2 LVMSB 450V switchboards.

In addition to safety earthing, electrical safety interlocks, mechanical interlocks are in place to ensure that access to 6.6kV equipment by maintenance personnel can only be carried out under controlled conditions. Appropriate procedures such as ‘Permit to Work’ and ‘Proving Dead’ procedure must still be followed for access to a high voltage system.

8.1 CIRCUIT EARTHING

All generator incomer, interconnect/bus-tie and load feeder circuit breakers are equipped with an integral earth switch on both sides of the circuit.

Mechanical interlocking between the circuit breaker and the earth switch only permits the closure of the earth switch if the circuit breaker is open and withdrawn from the service position. Additionally, mechanical interlocks prevent the circuit breaker from being moved back to the service position and re-closed whilst the respective earth switch is closed.

For the interconnector circuit breakers, an earthing switch is provided at both ends of the interconnector to earth down the cable circuit. Withdrawing the circuit breaker on one end of the interconnector will trip and inhibit re-closure of the interconnecting circuit breaker at the other switchboard.

For the thruster circuit breakers, the earthing mechanism will release a key which forms part of the access procedure to the MV7306 converters.

8.1.1 6.6kV CIRCUIT BREAKER EARTHING & INTERLOCKS

All 6.6kV circuit breakers have two operating positions, In Service (when the circuit breaker is inserted into the switchboard compartment and the door closed ready for operational use) and withdrawn to a Test position, where it is not connected to the 6.6kV busbars or the load circuit. From the Test position the circuit breaker can be removed from the switchboard entirely for replacement or for maintenance.

The circuit breaker can be opened and closed in either position (electrical or mechanical interlocks permitting).

Each compartment is fitted with an Earth Switch that is used to earth the load circuit (or in the case of the generator sections, the generator circuit). Only 1 earth switch per pair of interconnector circuit breakers is fitted.

When in the “earthed” position a key fitted to the breaker can be removed which locks the earth switch in the closed position, this is accomplished by moving a cover over the earth switch actuator thus preventing the manual earth switch handle from being used.

Mechanical interlocks shall prevent the simultaneous operation of the circuit breaker and the earth switch as follows.

8.1.1.1 6.6kV Circuit Breaker “In Service”

In this position the circuit breaker is connected to the 6.6kV main bus and to the load circuit, and

- It can only be withdrawn to the test position if the circuit breaker is open (mechanical interlock)

- The earth switch cannot be closed (mechanical interlock - and this also prevents closing the earth switch until the CB is in the test position).

8.1.2 6.6kV Circuit Breaker "In Test"

In this position the circuit breaker is not connected to the 6.6kV main bus or to the load circuit, and

- The earth switch can be closed, and when closed the circuit breaker is locked into the test position and cannot be moved (mechanical interlock).
- It can only be returned to the In-Service position if the circuit breaker is open (mechanical interlock).
- It can only be returned to the In-Service position if the earth switch is open (mechanical interlock).
- Internal mechanical shutters cover the circuit breakers connections to the 6.6kV bus and the load circuit to prevent accidental contact by operators.
- Additionally, when the any interconnecting circuit breaker is in this position an electrical interlock trips and prevents re-closing of its adjacent interconnecting CB on the connecting switchboard.
- Cannot be operated remotely by the PMS / HMI.
- Can be operated locally using the buttons mounted on the breaker and locally at the switchboard panel. When the breaker is closed an interlock prevents the breaker being racked back into the service position.
- An earth switch solenoid is fitted with a timer relay for the generator incomer CB.
- The earth switch for the generator circuit can only be closed when the engine is stationary, no generator voltage is detected when the CB is in Test position. The earth switch pushbutton will illuminate when the earth switch is ready to be closed. In order to close the earth switch, the operator will need to press the illuminated pushbutton and close the earth switch before the pushbutton extinguish within 40 secs. Otherwise, push the button again.

8.1.3 6.6kV PROPULSION TRANSFORMER AND CONVERTER EARTHING & INTERLOCKING

A mechanical key operated interlocking scheme is provided between the Propulsion Transformer feeder and the MV7306 Thruster Converter, the mechanism for this is described in GE Power Conversion document Propulsion System Functional Specification.

8.2 6.6KV BUSBAR EARTHING

Each switchboard section (two on each Switchboard) shall be equipped with a busbar earthing switch (effectively Bus A & Bus B). This switch can only be operated using a mechanical key. This key is normally trapped and can only be released when all the respective generators, bus-ties, bus-separators and transformer feeder circuit breakers that feed the switchboard split section are all effectively isolated.

The main busbar is usually earthed for maintenance purposes.

8.3 6.6KV SYSTEM ELECTRICAL INTERLOCKING

Electrical interlocking exists between No.1 HVMSB & No.2 HVMSB 6.6kV switchboards

8.3.1 Interlocks between 6.6kV switchboards

The following interlocks are implemented,

- The Local-Manual synchronising of each switchboard section will only operate if all other 6.6kV Main switchboard synchronising section sync select switches are in the ‘OFF’ position.

8.3.2 General Switchboard Interlocks

- All circuit breakers will have a local/remote switch, to allow control from the PMS when selected to remote EXCEPT the main propulsion drive feeders, where the local/remote switch is located at the MV7000 propulsion drives.

- All feeder circuit breakers shall be prevented from closing onto a dead bus (this is done by the dead bus voltage trip). This excludes generators and bus-ties/interconnectors. The bus-ties/interconnectors are only prevented from closing if both switchboards (main and partner bus) are dead.

- Incoming circuit breakers such as the generator and AMP shore panel feeds will be able to close onto a dead bus.

- In the event of a lockout trip the circuit breaker is prevented from closing if the fault is not cleared and lockout manually reset.

- The generator circuit breakers cannot close if the engine is not running.

- The generator circuit breakers trip on engine shutdown, governor major fault, AVR watchdog fault, diode short circuit or loss of sensing, protection relay fault and ESD Emergency shutdown.

- The generator is only available for remote control (PMS control) if the Engine is in Remote and selector switch at the generator incomer is selected to remote and all lockout protection trips are healthy.

- The diesel engine is inhibited from starting (both remote and local) if the generator circuit breaker is earthed or if the lockout fault is not cleared and manually reset.

- The switchboard trips the diesel engine and the generator excitation (fast de-excitation) on lockout protection fault.

- The propulsion transformer circuit breaker cannot close if the propulsion converter (MV7306) pre-charge and the propulsion transformer pre-magnetisation are not complete, and all CB inhibits are not healthy (this interlock is an MV7306 converter function; refer to Propulsion System Functional Design Specification). The propulsion transformer CB trips in the event of a drive system fault or Emergency Stop.

- The propulsion MV7306 converter is inhibited from pre-charge if the feeder circuit breaker is in Test position.

- Propulsion Transformer and Ship Service Transformer Feeder circuit breakers trip on winding over temperature.

- In the event of any lockout trip, it is imperative that the nature of the fault is investigated before any lockout relays are reset and before the appropriate circuit breakers are attempted to be reclosed. Where multiple lockout trips are reported (e.g. generators and bus-ties), this would imply a fault on the busbar or interconnecting cable is present and as such must not be made live until a thorough investigation is made by authorised operations personnel.

- Closed ring configuration is not an allowed operation mode. Interlocking shall prohibit closed ring operation and ensure that at least one bus section stays open.

- Necessary interlocking to be provided to allow for only momentary synchronizing of shore to vessel power supplies.

8.3.3 Interlocking between 6.6kV and LV Systems

The electrical power system is designed so that all four generators can feed the 6.6kV system at the same time in single island mode.

To ensure that the electrical power system operates in a safe and reliable manner, the following electrical interlocks are provided,

- In the event of a ship service transformer 6.6kV circuit breaker opening, an inter-trip command (inter-trip = 1) will be sent to the downstream equipment to open the corresponding 450V LV circuit breaker.

- In the event of a ship service transformer 450V LV circuit breaker opening, an inter-trip command (inter-trip = 1) will be sent to the upstream equipment to open the corresponding 6.6kV circuit breaker.

8.3.4 Interlocking at 450V Main and 450V Emergency Switchboard

- Necessary interlock to be provided to ensure one out of three breakers (i.e. two transformer incomers or LV bus-tie circuit breaker) are opened at the 450V LV switchboard.

- Necessary interlocking to ensure that the shore supply connected on 450V LV switchboards are not running in parallel with ship’s main supply.

- The Emergency Switchboard is fed via redundant feeds from either No.1 & No.2 LVMSB interconnector, one of the interconnectors will always be closed. The both these interconnectors at the Emergency Switchboard will be interlocked so that only one of them can be closed.

- Necessary interlock to be provided to ensure one out of three breakers (i.e. emergency generator incomer or two interconnectors from the 450V LV switchboard) are connected at emergency switchboard.

- Interlocking will be provided for 450V LV switchboard interconnector breakers such that they may only be closed if both incomer breakers on the receiving switchboard are open. Further details to be provided as schematics are developed.

9. MAIN 450V SERVICE SWITCHBOARD OPERATION

9.1 TRANSFORMER INCOMERS

Normal operation of the LV system is in split island, with all interconnectors and bus ties open, and a transformer incomer feeding each LV bus section.

Each main LV switchboard had 2 transformer incomers.

A local remote switch is provided on each incomer. In remote the breaker may be controller remotely from the Power Management System. In local, the breaker is controlled via a three position “open/neutral/close” switch.

Interlocking is provided such that the incomer will automatically trip if the transformer primary feeder breaker on the HV switchboard opens.

Interlocking is provided to ensure the incoming transformer feeder can only be closed on to a dead bus, ensuring the breaker cannot be closed out of phase.

Transformer incomer panels are each provided with a “Circuit Breaker Control” switch, which can be selected to “Lockout”, preventing automatic closure of breaker when the ships service transformer is energized. When selected to the “Normal” position, auto closing functionality will be restored.

9.2 BUS TIES

A local remote switch is provided on each bus tie. In remote the breaker may be controller remotely from the Power Management System. In local, the breaker is controlled via a three position “open/neutral/close” switch.

9.3 LV SWITCHBOARD EMERGENCY INTERCONNECT

An interconnect is provided between Main LV bus 2 and bus 3. This is only intended to be used in emergency conditions and not as part of normal vessel operations. As such the interconnector breakers are provided with manual control only.

The interconnector can feed bus 3 from bus 2, with interlocking to ensure the interconnector can only be used if bus 3 is dead prior to interconnect close.

The interconnector can feed bus 2 from bus 3, with interlocking to ensure the interconnector can only be used if bus 2 is dead prior to interconnect close.

A 2 position, lockable enable switch, “Interconnect Enable”, will be provided on each interconnect breaker where the operator can select the mode of operation.

- Disabled: Interconnector not in use and breaker cannot be closed, if interconnect is closed, selecting normal will trip the breaker and inhibit reclosure. Key may be removed when the switch is in the normal position.
- Enabled: Breaker may be closed. Key cannot be removed in this position.

Interlocking is included to ensure the interconnnector on the live switchboard can only be closed if BOTH bus sections on the remote switchboard are dead.

NOTE: Use of this switch is intended for emergency operation only. It is the responsibility of the operator to set the selector switches appropriately at BOTH switchboards before use.

9.4 LV SHORE SUPPLY

It is assumed that all four LV busses will be dead (IE All 6.6kV/450V transformers are open) before LV shore supplies are connected.

LV shore supply incomers are provided on bus section 1 and 4. The supplies may only be connected onto a dead bus section.

If shore supply is feeding bus 4, the bus tie to bus 3 can only be closed if the transformer and interconnector breakers on bus 4 are open, this ensures the bus tie can only be closed if bus 3 is dead, preventing paralleling shore supply to main ships supply.

Similarly, if shore supply is feeding bus 1, the bus tie to bus 2 can only be closed if the transformer and interconnector breakers on bus 2 are open, this ensures the bus tie can only be closed if bus 1 is dead, preventing paralleling shore supply to main ships supply.

The capability to use the bus interconnect for shore supplies is provided, using the interconnect 3 position switches as described in the section above.

10. 450V EMERGENCY SWITCHBOARD OPERATION

The 450V emergency switchboard is supplied by GE Power Conversion. The emergency switchboard is to be supplied during normal operation from the main switchboard by an interconnector feeder which is to be protected at the main switchboard against overload and short circuit and which is to be disconnected automatically at the emergency switchboard upon failure of the main source of electrical power. The circuit protection/coordination will be arranged such that all the outgoing circuits from the main ship service switchboard will coordinate with the ships service transformer protection.

Note: The main ship service switchboard is a switchboard which is connected to the secondary of the step-down transformer producing the required voltage.

The Emergency Switchboard is fed via redundant feeds. A selector switch will be provided for 3 modes of operation, either Normal, Manual or Test operations, described below.

10.1 NORMAL OPERATION

The emergency switchboard will be fed from either No.1 LVMSB or No.2 LVMSB interconnector, one of the interconnectors will always be closed. Both interconnectors at the Emergency Switchboard will be interlocked so that only one of them can be closed. On the loss of the primary power source, an auto changeover function will repower the Emergency Switchboard by closing the other breaker. In this scenario, a minimal time delay is included in the Emergency Generator start circuit to allow the changeover to complete without starting the Generator.

On a black start or a blackout recovery where both of the main 450V switchboards are dead, the Emergency Switchboard Feeders will automatically open/trip on under-voltage. The Emergency Generator will automatically start and connect to the Emergency Switchboard within 45s. The main essential loads on emergency switchboard will be manually recovered by the user. This will allow the diesel engines to be started by the PMS as part of the main 6.6kV blackout recovery performed via the PMS.

On restoration of power to the 6.6kV and 450V main switchboards, the operator must manually trip the emergency generator incomer. Hardwired logic is provided to automatically close a live feeder onto the Emergency Switchboard, ensuring a minimal disruption in emergency supplies.

10.2 MANUAL OPERATION

Under manual operation no facilities are provided to automatically close incomers or start the emergency generator.

On recovery from blackout, the operator can trip the emergency generator feeder and then close a feeder breaker from one of the main switchboards.

10.3 TEST OPERATION

In test position, functionality to automatically close the standby incomer breaker is removed. This allows the operator to select test and trip the duty feeder breaker causing a dead emergency board. In this way testing can prove that the Emergency generator will start and automatically close onto the emergency bus.

After the emergency generator test, the operator should select manual control, then trip the emergency generator incomer, close an appropriate feeder to re-establish power at the emergency board. Followed by shutting down the emergency generator.

The switchboard should then be returned to the Normal operating mode to ensure the system will automatically recover under blackout conditions.

11. EMERGENCY STOPS

Emergency stops are an essential requirement to allow rapid disconnection/isolation of electrical equipment in the event of an abnormal, unsafe condition arising.

11.1 THRUSTER CONVERTERS

There is a total of 5 emergency stops of which 4 are external, and 1 is on the drive.

- Engine Control Station
- Control Room 1
- Control Room 2
- Switchboard
- Internal MV7306 Drive

After receiving an emergency stop, two actions are performed:

- Opening of the 6.6kV circuit breaker through the circuit breaker trip supply
- Disabling the converter output

Refer to MV7000 Thruster Drive Functional Design Specification for further details.

11.2 6.6KV MAIN SWITCHBOARD

Each 6.6kV Switchboard incomer, feeder, bus-tie and bus-separator circuit breaker control circuits have provision for emergency shutdown trips, will be driven by the ships remote shutdown system (RSD).

After receiving an emergency stop, two actions are performed:

- Opening of the 6.6kV circuit breaker.
- Circuit breaker is inhibited from closing until the emergency stop is cleared.

12. POWER MANAGEMENT SYSTEM (PMS)

This section provides a brief overview of the Power Conversion PMS functionality. For detailed information, reference should be made to Power Management System Functional Design Specification.

The PMS interfaces to the vessel power system (prime movers, generators, switchboard etc.) via Fieldstations, which incorporate I/O interface modules and serial links.

Operator interface to the PMS is via HMI screen.

The main functions of the PMS are outlined below,

- Indication via HMI of 6.6kV and 450V switchboard circuit breaker status.
- Manual facilities via HMI for opening and closing of 6.6kV circuit breakers.
- Manual facilities via HMI for opening and closing of LV switchboard incoming transformers and bus-tie circuit breakers.
- Manual facilities via HMI for opening and dead-bus closing of Main 6.6kV switchboard incomer and cable tie circuit breakers (dead bus logic part of 6.6kV Switchboards).
- Control of the power system steady state voltage to an operator pre-set level.
- Control of the power system steady state frequency to an operator pre-set level.
- Symmetric sharing of active (kW) and reactive load (kVAr) between interconnected 6.6kV generator sets.
- Initiate starting, stopping and synchronising of 6.6kV generators by operator via the HMI. (Automatic synchronising equipment/dead bar logic is part of the 6.6kV switchboard supply).
- Initiate starting, stopping and synchronising of 6.6kV generators depending on load demand. (Automatic synchronising equipment/dead bar logic is part of the 6.6kV switchboard supply).
- Initiate automatic synchronising and dead bar closing of 6.6kV bus interconnectors circuit breakers via the HMI. (Automatic synchronising equipment/dead bar logic is part of the 6.6kV switchboard supply).

- In the event of a 1st stage shutdown condition being detected on a running diesel generator, initiate start, synchronise and load up stand-by generator and shutdown faulty unit.
- Restore 6.6kV and LV switchboard power in the event of a full or partial system blackout.
- Prevent overload of the power system by limiting or reducing propulsion load in the event of an overload. Prevent overload of the power system by providing a power available signal to the thruster control systems
- Prevent overloading of generator by preferential tripping/load shedding.
- Prevent overloading by start blocking of heavy consumers based on spinning reserve below preset value.

13. BLACKOUT RECOVERY

Also refer to the Power Management System Functional Design Specification

13.1 BLACKOUT RECOVERY FUNCTION

The primary function of the PMS Blackout Recovery sequence is to recover the 6.6kV and 450V power supply to enable the restart of essential vessel auxiliaries and to restore the vessel propulsion system as quickly as possible.

In the event of blackout, all the incomers, interconnectors and feeder circuit breakers on the 6.6kV system will trip on dead bus detection.

In the event of blackout, the 450V Switchboard incomers and interconnectors under voltage release.

When the Emergency Switchboard blacks out, as a result of either partial or total blackout, the emergency generator will start immediately. This process is independent of the PMS.

Please refer to the Power Management System Configuration for details in recovery sequences.

13.2 PMS PARTIAL BLACKOUT RECOVERY

Partial blackout occurs when the PMS detects that one or more sections of the 6.6kV Switchboards are dead (but not all). E.g. a partial blackout could occur if the power system is being operated in two island mode (all interconnectors open), and one 6.6kV Switchboard blacks out.

On partial blackout of a single 6.6kV Switchboard section, the PMS will start a sequence to recover power generation onto the dead section by starting and connecting diesel generators (refer to full blackout recovery below). This will include recovery of auxiliaries and thrusters as appropriate for the section in blackout only.

13.3 PMS FULL BLACKOUT RECOVERY

If selected to do so, the PMS automatically starts the blackout recovery sequence. Briefly, the blackout recovery sequence is summarized as follows:

- Upon detection of a blackout, the PMS generates a 'Blackout Condition" alarm. All the circuit breakers on the 6.6kV system have tripped due to under voltage.
- Issue a start command to the first standby generator and once the standby generator is running, the PMS closes the generator incomer circuit breaker. If the generator failed to start after the pre-defined number of attempts, the PMS starts the next standby generator.
- **NOTE**: Diesel engines should be left with their pre-lube system in auto, so the engine is available to start immediately following a blackout.
- Once the 6.6kV busbar section is live, the PMS issues a close command to it's 6.6kV ship service transformer feeder breaker, which triggers the transformer pre-magnetization and closure. The 450V ship service transformer incomer breaker a close by the PMS to restore 450V power.
- When each 450V Switchboard becomes live the PMS will attempt to start:
- Any previously running services that do not have under-voltage release starters and that have been identified for automatic recovery.
- Any previously stopped services that have been identified to start as part of blackout recovery, e.g. required diesel engine services.
- Once a 450V Switchboard becomes live, the PMS will restart the main propulsion drives/motors if they were running prior to the blackout.

Closing of the subsequent CBs and starting of the loads/auxiliaries are carried out manually by the operator.

13.4 440V EMERGENCY SWITCHBOARD

The 440V emergency switchboard is supplied by GE Power Conversion. The emergency switchboard is to be supplied during normal operation from the main switchboard by an interconnector feeder which is to be protected at the main switchboard against overload and short circuit and which is to be disconnected automatically at the emergency switchboard upon failure of the main source of electrical power. The circuit coordination is to be arranged such that all the outgoing circuits from the main ship service switchboard will coordinate with the step-down transformer protection.

Note: The main ship service switchboard is a switchboard which is connected to the secondary of the step-down transformer producing the required voltage.

The Emergency Switchboard is fed via redundant feeds. A selector switch will be provided for 3 modes of operation, either Normal, Manual or Test operations, described below.

13.4.1 Normal Operation

The emergency switchboard will be fed from either No.1 LVMSB or No.2 LVMSB interconnector, one of the interconnectors will always be closed. Both interconnectors at the Emergency Switchboard will be interlocked so that only one of them can be closed. On the loss of the primary power source, an auto changeover function will repower the Emergency Switchboard by closing the other breaker. In this scenario, a minimal time delay should be included in the Emergency Generator start circuit to allow the changeover to complete without starting the Generator.

On a black start or a blackout recovery where the 450V switchboard is dead, the Emergency Switchboard Feeder will automatically open/trip on under-voltage. The Emergency Generator will automatically start and connect to the Emergency Switchboard within 45s. The main essential loads on emergency switchboard will be manually recovered by the user. This will allow the diesel engines to be started by the PMS as part of the main 6.6kV blackout recovery performed via the PMS.

On restoration of power to the 6.6kV and 450V main switchboards, the operator must manually trip the emergency generator incomer. Hardwired logic is provided to the automatically close a live feeder onto the Emergency Switchboard, ensuring a minimal disruption in emergency supplies.

13.4.2 Manual Operation

Under manual operation no facilities are provided to automatically close incomers or start the emergency generator.

On recovery from blackout, the operator can trip the emergency generator feeder and then close a feeder breaker from one of the main switchboards.

13.4.3 Test Operation

In test position, functionality to automatically close the standby incomer breaker is removed. This allows the operator to select test, and trip the duty feeder breaker causing a dead emergency board. In this way testing can prove that the Emergency generator will start and automatically close onto the emergency bus.

After the emergency generator test, the operator should select manual control, then trip the emergency generator incomer, close an appropriate feeder to re-establish power at the emergency board. Followed by shutting down the emergency generator.

The switchboard should then be returned to the Normal operating mode to ensure the system will automatically recover under blackout conditions.

14. POWER LIMITATION AND BLACKOUT PREVENTION PHILOSOPHY

Management and prevention of blackout is based on action by several strategies designed to give a stable and manageable power system in all modes of vessel operation. The main parts of this are:

- PMS management of online generation, with MW and MVAr load sharing.
- PMS management of available generation spinning reserve – load dependent start/stop.
- Main propulsion drive, generator load dependent anti-overload load limitation
- Main propulsion drive, bus frequency dependent anti-blackout load limitation
- PMS Load shedding via preferential trip of non-essential consumers

14.1 PROPULSION POWER LIMITATION SYSTEM

GE propulsion system is the largest power consumer on the vessel as such the propulsion control scheme can be most effectively used to manage any overload event to prevent vessel blackout.

As the electrical propulsion is the main consumer on the electrical network of the ship, a propulsion Power Limitation System (PLS) is implemented to prevent any black-out due to an overload/under-load on the generators.

The PLS function has two functions as described below.

14.1.1 Anti-OverLoad Limitation (AOLL)

AOLL is designed to ensure the propulsion system does not drive the power generation system into overload and limits propulsion power when required. The system checks the load of each generator regarding active and reactive power against predefined power thresholds and determines if an overload is imminent. AOLL is a continuous and smooth process that generates a regulated torque limitation when the generator real or reactive power thresholds are reached. The response time of the AOLL system is approximately 100ms plus any delay induced by the generator power transducers. By default (adjustable on site during commissioning) the AOLL system becomes active when generator active load is greater than 103% or reactive load greater than 100%. Note, if a generator has been derated by the PMS system, then the new target rating of the generator is passed from the PMS to the propulsion and is used when checking to see if a generator is in overload.

14.1.2 Anti-BlackOut Limitation (ABOL)

ABOL is designed to respond to sudden power system disturbances, such as unexpected tripping of a generator or failure of an engine. ABOL checks the frequency (minimum / maximum) and voltage (under voltage) of the network. ABOL is a fast process that generates a strong torque limitation in case of a power system network disturbance, where the network disturbance is regarded as a precursor to a blackout. The ABOL system has a fast response of around 4ms and is able to very rapidly reduce load on the propulsion system. If the ABOL system detects the system frequency fall below 97.5% of nominal (58.5 Hz), an indication of an active power overload, then the drive is rapidly phased back until the system frequency is able to recover. Similarly, if the system voltage falls below 90% of rated (5940 Volts), an indication of reactive power overload, then the drive is rapidly phased back until the system voltage is able to recover. This rapid phase back prevents sustained overload of all online generators and provides time for the generator protection scheme to determine which generator is at fault and trip offline in accordance with the protection co-ordination study, preventing a cascade trip resulting in blackout.

Further details of the AOLL and ABOL systems may be found in the project “Propulsion System Design Document”, filename “S20021378_002_SYDD_PROPULSION_NSMV”.

14.2 POWER MANAGEMENT SYSTEM PREFERENTIAL TRIPPING SCHEME (PTS)

In addition to the propulsion AOLL and ABOL systems, the PMS system incorporates a “Preferential Tripping Scheme”. It is expected that during normal seagoing conditions, the AOLL and ABOL would prevent both gradual overload (for example by the operator demanding more power from the propulsion system than the available engines can provide) and prevent blackout by responding to electrical network disturbances.

As such it is expected the Preferential Trip System is more likely to operate during in port scenarios, where there is no propulsion being used and hence the propulsion system is unable to be used to rapidly reduce load. The PTS will still occur during seagoing operations, but only as a last resort if the propulsion PLS fails to bring the online generators out of an overload condition.

For this project, two groups of loads have been assigned for preferential tripping.

- Preferential Trip Group 1 (PT1) are associated with galley and laundry systems.
- Preferential Trip Group 2 (PT2) are associated with vessel’s HVAC system.

Full details of consumers in groups PT1 and PT2 may be found in DSEC document DA881E011, Wiring Diagram of Power System (Low Voltage)

The loads assigned to PT1 and PT2 may be tripped on occurrence of system overload or system underfrequency as follows:-

System Overload: If a generator goes into overload (>100% active power) for greater than 5 seconds, then the a preferential trip signal is sent to the first group of loads. If the overload remains for greater than 10 seconds, then the preferential trip would trip the second set of loads.

System under frequency: If system frequency falls below 57Hz for a period greater than 5 seconds, then the first group of loads will be tripped, followed by the second group if the frequency remains below 57Hz for greater than 10 seconds.

Further details of the Preferential Tripping may be found in the PMS functional description, filename “AV1P02C01_002_PMS Functional Description”.

14.3 EQUIPMENT OVER-TEMPERATURE

Any over-temperature on the Propulsion Transformer or Propulsion Motor will limit the maximum motor power to 90% of the rated. The power limit will be applied by reducing the drive torque limit.

Refer to MV7000 Thruster Drive Functional Description for further details.

15. MODIFICATION RECORD

Revision	Date	Author	Details
000	2020-10-23	Sharma, Manojkumar	Initial Issue
000r2	2020-11-30	Sharma, Manojkumar	Revised changes
000r3	2020-12-01	Miller, Chris	Further additions
000r4	2020-12-01	Miller, Chris	Comments incorporated after review with the US team
001	2021-01-27	Johnson, David	Comments incorporated after joint review between GE/PSI and DSEC
002	2021-02-10	Johnson, David	Incorporating final comments and mode clarifications
003	2021-02-19	Johnson, David	Minor corrections, removed remaining references to CCC
004	2021-04-28	Johnson, David	Detailed added to Sections 10 and 11 for LV main and Emergency switchboard functionality and operation
005	2021-05-18	Johnson, David	Extensive changes to section 14, Power limitation and blackout prevention, to better describe propulsion and PMS power limitation systems. Section 3.1.2 Modified in line with latest revision of DA880E002, Electrical Functional and Operating Philosophy as issued by DESC
006	2021-05-20	Johnson, David	Correction on grounding methodology (GPT not HRG). Section 3.2 and 3.5 Modified in line with latest revision of DA880E002, Electrical Functional and Operating Philosophy as issued by DESC
007	2021-08-17	Johnson, David	Updates in-line with findings and changes implemented during switchboard FAT. New section (2.2) added describing AMP panels. Sections 4.8.1/4.8.2 Updated to provide more detailed operation description of AMP system. Added detail to section 7.2.1 for transformer remagnetisation override. Detail added to section 9.1 LV Main switchboard transformer incomers, describing lockout functionality and interlocks. Detail added to section 9.3 for LV switchboard emergency interconnector operation.
008	2022-03-24	Johnson, David	Minor changes in Section 2.4.1, Grounding Protection Transformer. Appendix A added to provide a summary of all interlocks included in the MV/LV power distribution system.

16. APPENDIX A – POWER SYSTEM INTERLOCKS

The following is a list of all interlocks in the HV/LV power distribution system. This is provided for convenience for operation and testing purposes.

16.1 MAIN HV SWITCHBOARDS

The following interlocks are provided in the main HV swbd.

- 5 out of 6 logic is provided to prevent connecting the 2 main switchboards into a closed ring. Only 5 out of the total 6 bus-tie and interconnector breakers can be closed at any one time. Each bus-tie/interconnect monitors the status of all others. When a breaker sees five other breakers closed it becomes unavailable to close and is indicated as unavailable on PMS screen.

- Main Transformer feeder/LV incomer inter-trip. If the Main transformer feeder trips, an inter-trip will cause the associated incomer on the LV switchboard to trip. On trip of LV incomer by the protection relay, a signal will be sent to also trip the main HV transformer feeder.

- LV switchboard 2 out of 3 logic allows only 2 breakers out of the 2 incomers and the bus tie to be closed, preventing possibility of closing LV feeders out of phase.

- If any interconnector is racked out, this will cause a trip and prevent reclosure of the associated interconnector breaker on the other main HV switchboard

- The system must be reduced to a single on-line generator before attempting to close the AMP incoming breaker at one of the main HV switchboards. Note the generator must be directly connected to the same HV switchboard as the AMP connection that is to be used.

- Main propulsion feeder breakers are interlocked with their associated propulsion drives and may only be closed in service position when there are no active 'CB Close Inhibit' alarms at the drive. Pre-magnetization of the transformer must be in phase with the main bus supply for the breaker to be able close. The feeder breaker may still be opened or closed if racked into the breaker test position.

- All HV breakers may only be withdrawn to test position if they are open (mechanical interlock)

- Main generator incoming breakers earth switch can only be operated when the engine is stationary, no voltage is detected, and the circuit breaker is in the test position.

- Main generator incoming circuit breakers may only be closed if the engine is running at rated speed and voltage is at nominal.

- Engines cannot be started if its associated breaker is earthed or has an active lock-out fault. This interlock will prevent the engine from being started locally at the engine, remotely from the switchboard or from the PMS.

- Certain protection trips at the DG incomer will stop the engine. Refer to protection coordination study for details of trip configuration.

- Propulsion and Service transformers feeders will trip on winding over temperature.

- Interlocks are provided such that manual synchronization can only be carried from a synch panel if the synch selector switch on the opposite switchboard is set to the off position. This is to prevent two operators from trying to synchronize simultaneously.

- Ships Transformers cannot close unless Pre-mag Circuit has been completed.

- Stern/Bow Thruster breakers cannot close unless sufficient power Interlock is available.

- Cable Interconnector Cross Trips.

    - If one of the interconnectors trips (with alarm) the adjacent interconnector is expected to "open" (without alarm).
    - If one of the interconnectors opens (without alarm) the adjacent interconnector is expected to "open" (without alarm).

- A circuit earthing mechanical interlock/key exchange system is provided.

    - All generator incomer, interconnect/bus-tie and load feeder circuit breakers are equipped with an integral earth switch on both sides of the circuit.
    - Mechanical interlocking between the circuit breaker and the earth switch only permits the closure of the earth switch if the circuit breaker is open and withdrawn from the service position. Additionally, mechanical interlocks prevent the circuit breaker from being moved back to the service position and re-closed whilst the respective earth switch is closed.
    - For the interconnector circuit breakers, an earthing switch is provided at both ends of the interconnector to earth down the cable circuit. Withdrawing the circuit breaker on one end of the interconnector will trip and inhibit re-closure of the interconnecting circuit breaker at the other switchboard.
    - For the thruster circuit breakers, the earthing mechanism will release a key which forms part of the access procedure to the MV7306 converters.

- All feeder circuit breakers shall be prevented from closing onto a dead bus. This excludes generators and bus-ties/interconnectors. The bus ties/interconnectors are only prevented from closing if both switchboards (main and partner bus) are dead.

- The generator is only available for remote control (PMS control) if the Engine is in Remote and selector switch at the generator incomer is selected to remote and all lockout protection trips are healthy.

- The propulsion MV7306 converter is inhibited from pre-charge if the feeder circuit breaker is in Test position.

- Interlocking is provided to allow for only momentary synchronizing of shore to vessel power supplies.

16.2 MAIN LV SWITCHBOARDS

The following interlocks are provided in the main LV swbd.

- Main transformer incomers are interlocked so they can only be closed on to a dead LV bus.

- The transformer incomer has a “circuit breaker control” switch. When selected for ‘normal’ operation, when a service transformer feeder is closed at the main HV switchboard, the transformer incomer at the Main LV switchboard will be automatically closed. When the switch is selected to the ‘inhibit’ position, the transformer incomer cannot be closed. If the LV incomer is closed when the switch is set to ‘inhibit’ the LV incomer will be tripped.

- LV switchboard interconnect breakers (interconnecting opposite busses BUS.2 TO BUS.3 of the LV main switchboards) are intended for emergency use only. They are provided with a key switch “Interconnect Enable”. When selected to ‘Disabled’ the interconnector breakers can not be closed. Breakers may be closed if the key switch is selected to the ‘Enabled’ position.

- When the “Interconnect Enable” switch is set to the “enable position”, interlocking will prevent the local interconnect from closing unless both remote (opposite) LV main bus sections are dead.

- All LV busses should be dead before LV shore supplies are connected; shore supply incoming breakers are interlocked such that they can only be closed with the bus is dead

- If shore supply (STBD) is feeding bus 1, the bus tie to bus 2 can only be closed if the transformer (T2) and interconnector breakers (IC1) on bus 2 are open, this ensures the bus tie can only be closed if bus 2 is dead, preventing paralleling shore supply to main ships supply.

- Similarly, if shore supply (PORT) is feeding bus 4, the bus tie to bus 3 can only be closed if the transformer (T3) and interconnector breakers (IC2) on bus-3 are open, this ensures the bus tie can only be closed if bus 3 is dead, preventing paralleling shore supply to main ships supply.

- LV switchboard bus tie will be tripped if the associated main HV bus tie opens.

16.3 EMERGENCY SWITCHBOARD INTERLOCKS

- The Emergency switchboard has 3 incoming feeders, one from each main LV switchboard and the emergency generator incomer. Interlock provided so only one of these can be closed at any one time.

16.4 AMP SWITCHBOARD

- Incoming shore supply will be checked for compatibility in terms voltage, frequency, and phase rotation. If the supply is NOT compatible, then hardwired interlocks prevent closing of the Amp reel breakers at the incoming AMP panel.