Faculdade de Engenharia da Universidade do Porto

Past, Present & Future of Marine Automation

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Resumo

Desde o início da era moderna que a humanidade compreendeu as vantagens de passar de um processo manual para um processo automático de fabrico dos mais diversos tipos de produtos e / ou tipos de controle. Assim que a inovação técnica foi capaz de reunir o sensor, o atuador e o controle de processamento num sistema automatizado, as possibilidades de controle de processo passaram a ser infinitas. Hoje em dia, os sistemas modernos de automação são uma parte intrínseca da nossa vida diária sem mesmo nos apercebemos disso: desde a produção local de produtos de consumo/industriais até ao controle remoto de centrais nucleares, passando por aviões e veículos espaciais com seus sistemas de tripla redundância, atuando como um "parceiro" no progresso e evolução humana. Uma área onde os sistemas de automação são amplamente implementados é no controlo em terra de energia elétrica, que vai desde a produção de energia (térmica/Nuclear/Hidro), ao transporte de energia (subestações) e consumo de energia (fábricas) através de sistemas automatizados.

O objetivo desta tese é ilustrar o estado da arte dos sistemas atuais de Automação Marítima, onde estes mesmos princípios de controlo (aplicados individualmente em terra) são todos combinados em pleno alto mar, especificamente em embarcações com propulsão elétrica e equipados com posicionamento dinâmico. Esta é uma vasta indústria, onde a segurança e avanços tecnológicos mais recentes são primordiais e onde as apertadas regras operacionais são secundárias somente em relação às utilizadas para exploração do espaço. Também será descrito um projeto marinho completo para ilustrar o enorme esforço e tempo normalmente gasto para projetar um sistema moderno de Automatização Marina, a partir das soluções de Engenharia Marinha de um líder mundial.

Abstract

Since the beginning of modern age that mankind understood the advantages of moving from a manual to an automatic process of manufacture of the most diverse types of products and/or control types. As soon as technical innovation was able to bring together both the sensor, the actuator and the processing control of an automated system, the control possibilities were endless. Nowadays, modern automation systems are an intrinsically part of our daily life without us even knowing about it: from the production of local consumer/industrial products to controlling remote nuclear power plants, passing through planes and spaceships with its triple redundancy systems, acting as an enabler "sidekick" to the human progress & evolution. One area where automation systems are widely implemented is on the onshore control of electrical power, ranging from power production (thermal/Nuclear/hydro), power transport (substations) & power consumption (factories) automated systems.

This thesis main objective is to illustrate the state of the art of modern Marine Automated systems, where the same control principles (applied individually on onshore) are all combined together offshore, specifically on a vessel with electrical propulsion and equipped with dynamic positioning. This is a vast industry, where safety & latest technological enhancements are paramount and strict operational rules are second only to the ones applied to space exploration. A full marine project will also be described to illustrate the amount of time & effort normally spent to engineer a modern automated marine system, from a world leader of marine engineering solutions.

Agradecimentos

Gostaria de expressar o meu profundo agradecimento à minha família devido ao incansável suporte e encorajamento ao longo desta dissertação.

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Index

List of figures

List of Tables

Acronyms and Symbols

HMI	Human Machine Interface
IAS	Integrated Automation System
TLI	Tank Level Indication
VCS	Vessel Control System
CCR	Central Control Room
EER	Electrical Equipment Room
DC	Drillers Cabin
TPO	Tool Pushers Office
ACC	Accommodation & Public Spaces
ECR	Engine Control Room
DBR	DP Backup Room
W/H	Wheelhouse
VCS	Vessel Control System
STBD	Starboard
IAS	Integrated Automation System
DG	Diesel generator
LCP	Local Control Panel
OS	Operator Station
UMS	Unattended (or unmanned) Machinery Space

Chapter 1

Introduction

The history of Marine Automation is intrinsically linked to the evolution of Marine Electrical Propulsion. In fact, from the beginning of the 20th century, where the first steps to replace the operation of steam turbine vessels by their electrical equivalent, gave way to for the investigation to overcome the new challenges presented within the electrical realm usage on-board a vessel - in the middle of the ocean and connected to nothing in its vicinities.

This idea of a self contained, self powered & isolated electrical system was the first hurdle to overcome by the first of those brave enough. Later, as power, control & sea positioning technology evolved more control capabilities were being made available to an even larger number of vessels and in more industries/operating environments.

In one hand, the combination of several technologies for ship location (satellite, acoustic, laser), sea bed position (hydraulic), environmental (radar) & more robust computational ship model with enhanced signal filtering capabilities lead to more accurate vessel position control.

This would open the recent electrical vessel operation to a higher availability & more complex demands on high sea through Dynamic Positioning (DP), like offshore drilling operations or the tandem operation of several vessels together.

On the other hand, the ever increasing power/tighter operation requirements of the Marine Power Systems, ranging from Power Generation Systems (Diesel & turbine generators), passing though Power Distribution Systems (High/medium/low Switchboards with integrated CB/Busties protection systems) with such features as: High Resistive grounding, Dynamic Braking, Regenerative Energy Absorbing or Fault Ride Through Capabilities that, as before, contribute to the same impact on a vessels capacity for higher availability & more complex demands on high sea operations.

Finally, all these above main functionalities (Dynamic Positioning & Marine Power Systems) are only effectively coordinated and controlled from an automated system such as a Marine Distributed Control System (DCS).

This system, is the main remote operation & centralized control system for todays modern electric propulsion vessels. Its operations are paramount, making sure that all processes, electrical & non-electrical systems and their respective auxiliaries are all working synchronized together for the vessels effective control, allowing for small highly skilled operator crews to orchestrate a very high number of very complex operations on board a vessel. As an example: a wide range of ships type are used in the energy sector from basic tank ships to extremely complex industrial vessel such as dynamically positioned deep water drilling vessel and include other vessel such as offshore crane-ships, pipe-laying vessels, icebreaking supply vessels and semisubmersible drilling units.

The main purpose of this thesis is to describe, from a supplier professional's point of view, how the Marine Automation associated to Electric Propulsion has been used on numerous occasions to solve a particular design challenge, and to illustrate that there exists a significant knowledge base on the design, construction and operation of Automation Systems for Electric Ships - as indicated in chapter one.

The second introductory chapter goes through the reasons for adopting Marine electric propulsion and its past history on the several branches of Marine applications.

The third chapter talks about the present of Marine Automation system, starting with its position on the various markets and their major aim & challenges, following with encompassing & detailed view of the main two marine automation systems used nowadays: The Dynamic Position (DP) & the Vessel Control System (VCS), with an explanation of their main functionalities together with a, brief overview of the international marine regulatory scenario & its major entities.

After, on chapter four, a continuation of the Marine Automation journey, this time into its main future tendencies, where some of the main capital (CAPEX) & operational (OPEX) investments are made for major savings & efficiency gains together with an explanation of the main market functionalities demands and the products (from a major supplier) to answer these challenges.

Approaching the end, we find the fifth chapter, with a real large Marine Project Drillship for an American company, built by a Korean shipyard, where the main supplies are a DP and an Automation system, with integration of third party system together, showing the typical project phases, its planning & integration and the main documentation & drawings involve.

Finally, for this document ending, the Conclusion in chapter six, tries to reach a final summary judgment of this thesis subject, by tying together (in a synthetized way) the various issues discussed in the previous chapters, whilst reflecting the introductory thesis objectives and also highlighting this study limitation.

Chapter 2

Past

2.1 - References

Nikola Tesla was an early proponent of electric propulsion for ships. He wrote in the New York Herald, in February 25, 1917:

- “The ideal simplicity of the induction motor, its perfect reversibility and other unique qualities render it eminently suitable for ship propulsion, and ever since I brought my system of power transmission to the attention of the profession through the American Institute of Electrical Engineers I have vigorously insisted on its application for that purpose.”

His view on View of Early 20th Century Marine Propulsion:

- “The present turbines are extremely unsuitable for ship propulsion. They offer a striking example of an antiquated invention of small value elevated to a position of extraordinary commercial utility through profound research and astonishing mechanical skill.”

2.2 - Why Electric Propulsion

In todays land based Power Systems, the typical layout is to have three major groups organized into: power generation (thermal, hydro, wind, waves & solar), power transportation (substations, DC Links) & power consumption (home & industrial consumers), being all coordinated from central control centre called the Dispatch. This nevralgic control centre has remote control of all main power lines & production centres, with the main function of coordinating the different power generation sources flowing throughout different voltage power network lines according to known & calculated load diagrams, whether for a specific region or for an entire country – this means that historical power consumption data is used to try to predict the current & expected power consumptions over a day, month & even year.

On an electrical propulsion vessel, the above Power Systems concept, although very similar in terms of having the same major groups, cannot be applied the same way because the Marine Power Systems are isolated & self contained, with a fixed number of generation and distribution systems and the consumers (loads likes propulsion or drilling systems) are the ones that dictate the power needs and not a remote & external Dispatch centre, this is a different conception – the Power Station concept.

This concept matches the current load needs to the on-line generation capability (up to a maximum limit) by a Power Management System (PMS), whose main function is to provide the absolute maximum survivability of the Marine Electrical System, by preventing & recovering the vessel blackouts and/or any positional drift offs, which could lead to the destruction of equipment and/or the loss of lives, depending on the context of the vessels operation.

This Power Management System continuously evaluates the usage of combinations of large & small prime movers, in order to optimise the prime mover efficiency, which could result in fewer prime movers being required, due to the Power station concept.

Another major area of improvement of over previous propulsion system, where the conjunction of electrical propulsion combined with a Power Management Systems, can provide a tremendous flexibility usage in terms of the power system layout by, for example, using different generation capabilities like different capacity generation prime movers for operations like drilling & transit and different technologies, like Gas Turbines and Diesel Generators for different power scenario needs (for example Navy vessels) and finally, the assisted operation redundancy, where the electrical system as well as the automated PMS are normally designed, build & operated with parallel capacity for a similar operation, for example as minimum, the electrical propulsion vessel has a minimal of two Electrical Power Generation Switchboards with independent distribution & auxiliary systems, or, the PMS has processing, communication & operational redundancy inbuilt in its core, by means of redundant/triple/more processing central PLC units together with redundant & independent main communication networks and finalizing with multiple operator station control points, for maximum flexibility & redundancy of central remote control. This leads to:

- Low N&V signatures – Essential for Navy vessels
- Lower maintenance, higher availability
- Lower running costs with high level of automation

2.3 - Reasons for no early adoption

Although, from todays point of view, that the adoption of electric propulsion in marine application would seem a natural & expected evolution, but that wasn't the case and actually, the initial technological stage of Marine Electrical Systems left a lot to desire in terms of a formal usage due to most of the chosen solutions decided to apply a Direct Drive Electric Propulsion, which in comparison with most mature technology of that time, the mechanical drive steam turbines, would loose for being able to compete with the following construction & operational characteristic of the mechanical drive steam turbines offerings, such as:

- Lighter weight
- Superior energy conversion efficiency
- The accurate manufacture of gearboxes enabled the introduction of high speed GT and diesel prime movers

As an example from the UK Navy market, this propulsion system scenario (usage of mechanical drive steam turbines) remained until the introduction of the Royal Navy HMS Adventure, which was the first vessel to fully and uniquely to pioneer the use of Marine Electrical Systems & Propulsion.

Some examples of the Past usage of Marine Electrical Propulsion Systems are depicted in following s, accompanied by some description and novelties introduced.

2.4 - HMS Adventure (1922) – 1st Electrical Propulsion

The HMS Adventure was Cruiser Mine layer for the Royal Navy serving during the second World War, where she was damaged by German magnetic mine on the Thame estuary.

She was also the first Royal Navy vessel to install a new diesel-electric plant (2 x1600kW dc motors 2 x1650kW DC alternators) to increase cruising efficiency.

With the propulsion that was capable of being able to support either the Steam Engines or the diesel-electrical by a set of machinery through gearboxes.

Figure 2.1 - HMS Adventure [6].

Figure 2.2 - HMS Adventure – Brochure [6].

2.5 - SS Canberra (1960) – Tandem Synchronous Operation

The SS Canberra was an ocean liner, whit operations from 1960 to 1997. Was used during the 1982 Falklands War, as a troop transportation ship: “Great White Whale”.

It was the most powerful steam turbo-electric propulsion system for a passenger vessel and instead of being mechanically coupled to her propeller shafts, its steam turbines drove large electric alternators which provided power to electric motors driving the vessel's twin propellers.

They were the most powerful steam turbo-electric units ever installed in a passenger ship; at 42,500 hp (31,700 kW) per shaft, with the largest electric alternator units ever installed and a tandem 6kV Synchronous Motor operation, it allowed her to produce a speed of 27.25 knots (50.47 km/h).

Figure 2.3 – SS Canberra [6].

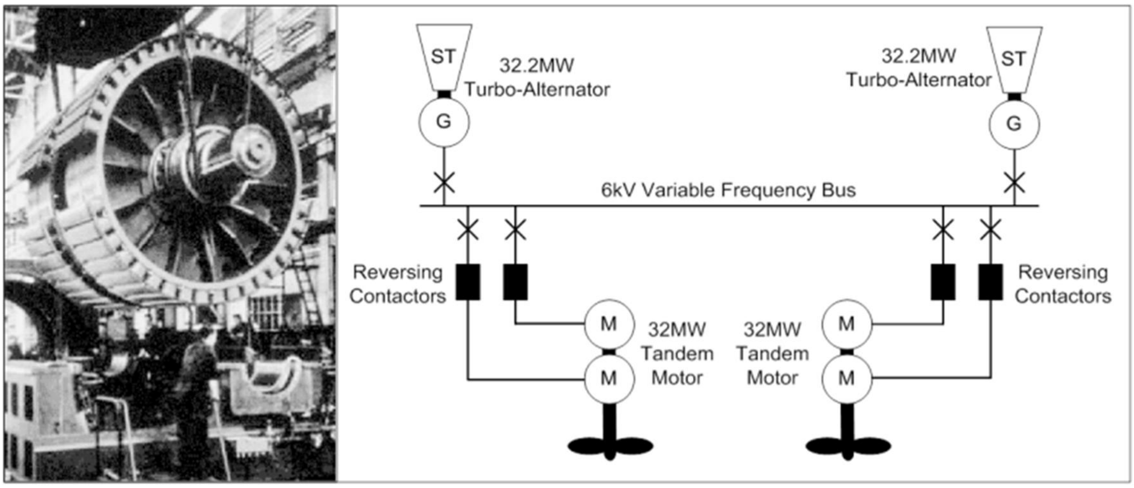


Figure 2.4 – SS Canberra - Motor & SLD [6].

2.6 - Queen Elizabeth 2 Refit (1987) – 9 DGs on 10kV Bus

The Queen Elizabeth 2 which was operated both a transatlantic liner (Southampton, UK, to New York,) and a cruise ship from 1969 to 2008. She was considered the last of the great transatlantic ocean liners until the construction of the Queen Mary 2 and the last oil-fired passenger steamship to cross the Atlantic in scheduled liner service.

In 1984, an electrical fire caused a complete loss of power and she was converted from steam power to diesel-electric, with the largest electric generation power so far: nine (9) MAN B&W 10.5MW diesel alternators on a 10kV Propulsion Bus, new propellers and a heat recovery system, to drive a largest built Synchronous Propulsion Motor rated at 44MW and 144 rpm.

Figure 2.5 – Queen Elizabeth 2 [6].

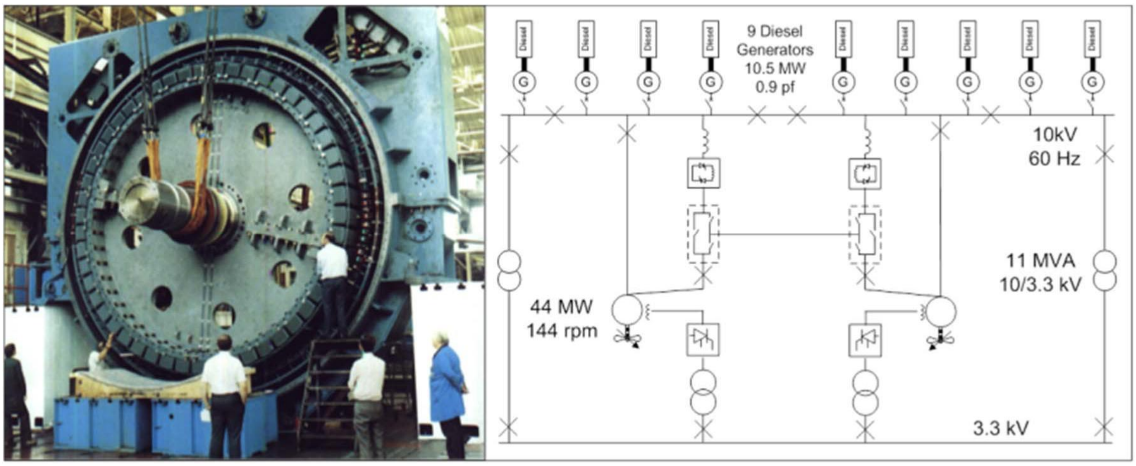


Figure 2.6 – Queen Elizabeth 2 - Motor & SLD [6].

2.7 - Queen Mary 2 (2001) – Podded Propulsion

Last but not least, the Queen Mary 2 in 2001 was the longest passenger ship ever built, and with her gross tonnage of 148,528 also the largest. Is was the first vessel to be propelled by four podded propellers extending beneath the hull. The two forward pods are fixed and the two aft pods are steerable. For reaching a maximum speed of 30 knots (56 km/h; 35 mph) and a cruising speed of 26 knots (48 km/h; 30 mph), she uses an integrated electric propulsion to achieve her top speed by integrating gas turbines to augment the power generated from the ship's Diesels.

Figure 2.7 – Queen Mary 2 [6].

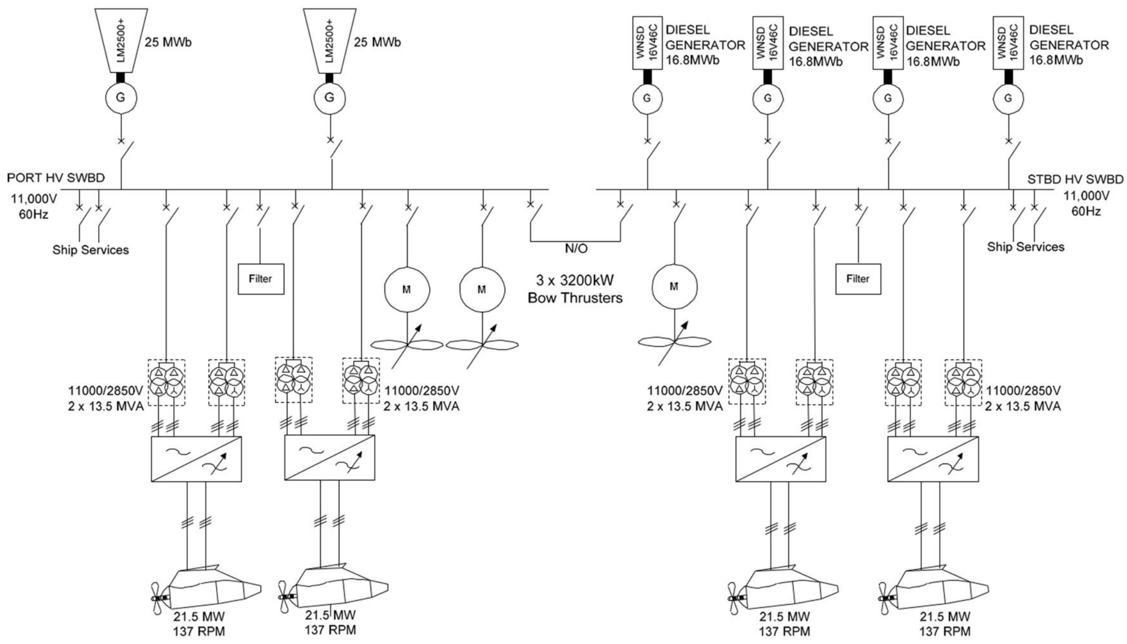


Figure 2.8 – Queen Mary 2 – SLD [6].

Chapter 3

Present

The aim of this chapter is to explain the current state of todays Marine Automation on electrical propulsion vessels.

Begins with summary on Marine Electrical propulsion. After, runs on the typical marine electrical systems usage and a walkthrough over the main markets aims & faced challenges and finally, it enters the the highly technical domains of the two main Marine automation systems: The Dynamic Positioning (DP) & the Vessel Control System (VCS).

It is in this chapter last part, their main functionalities, operating modes, components and main usages are explained together with a brief introduction into the Marine rules & main regulatory societies.

3.1 - Electrical Propulsion Summary

As shown in previous chapter, the Marine Electric Propulsion is not new and existed since the turn of the century. Since then, the modern Full Electric Propulsion has been heavily proven in both the Naval and commercial environments, ranging from the the most demanding operational conditions under fire (Navy) to impressive ice breakers for the Pole exploration & under severe environmental conditions

Electric Propulsion brings many benefits in comparison to the previous generation steam only mechanical generation and propulsion, specially if arranged into an integrate environment where reduced fuel consumption & reduced number of prime movers (engines) directly benefit the vessels with cargo & people carrying capability (Merchant) & Lower noise signature (Navy).

Like any engineering activity, the proposed Marine Electrical Propulsion solution needs to be tailored to meet the owner's requirement. Further more, in the present Marine technology state, the integration of Marine Generation & Propulsion must be designed as a system combining the needs of propulsion, ship service power supply and engine type, with the ultimate aim of mass automating the positioning capabilities of the vessel, with the operational efficiency & smaller crew benefits of employing a marine automation system.

3.2 - Typical Marine Electrical Usage

A modern Marine electrical system employ several industrial processes of converting motion into electricity & vice versa for the usage for the vessel power generation, distribution & consumption processes in a closed loop/island mode type of operation.

The below image shows the main & typical electrical components that allow this tight integration in a vessel (noting the nuclear role of Automation & Control):

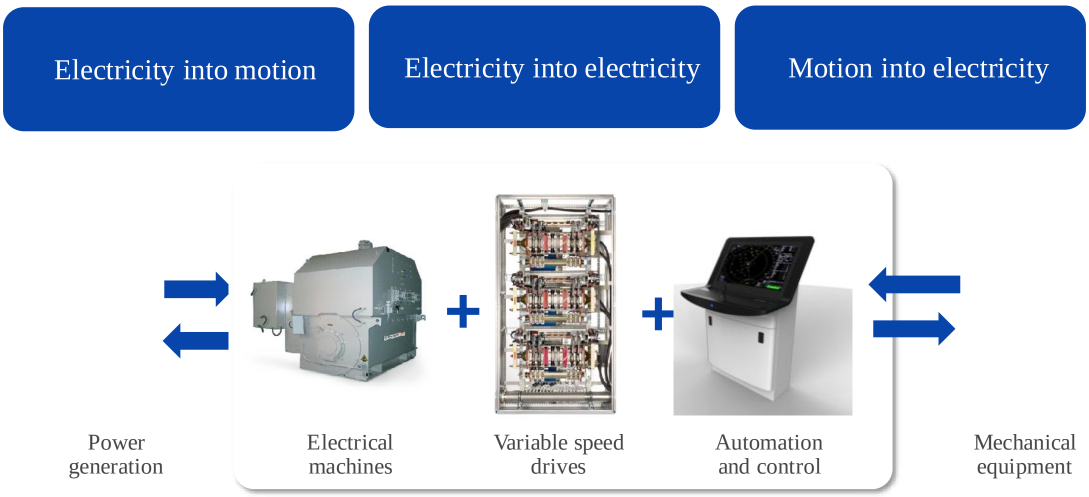


Figure 3.1 – Typical Electrical Components.

3.3 - Vessel Markets:

All over the marine sector, the major suppliers/builders, service providers & owners are now looking at the next industry challenges.

Below diagram is an example of the current industry challenges faced from a major market supplier, General Electric (GE).

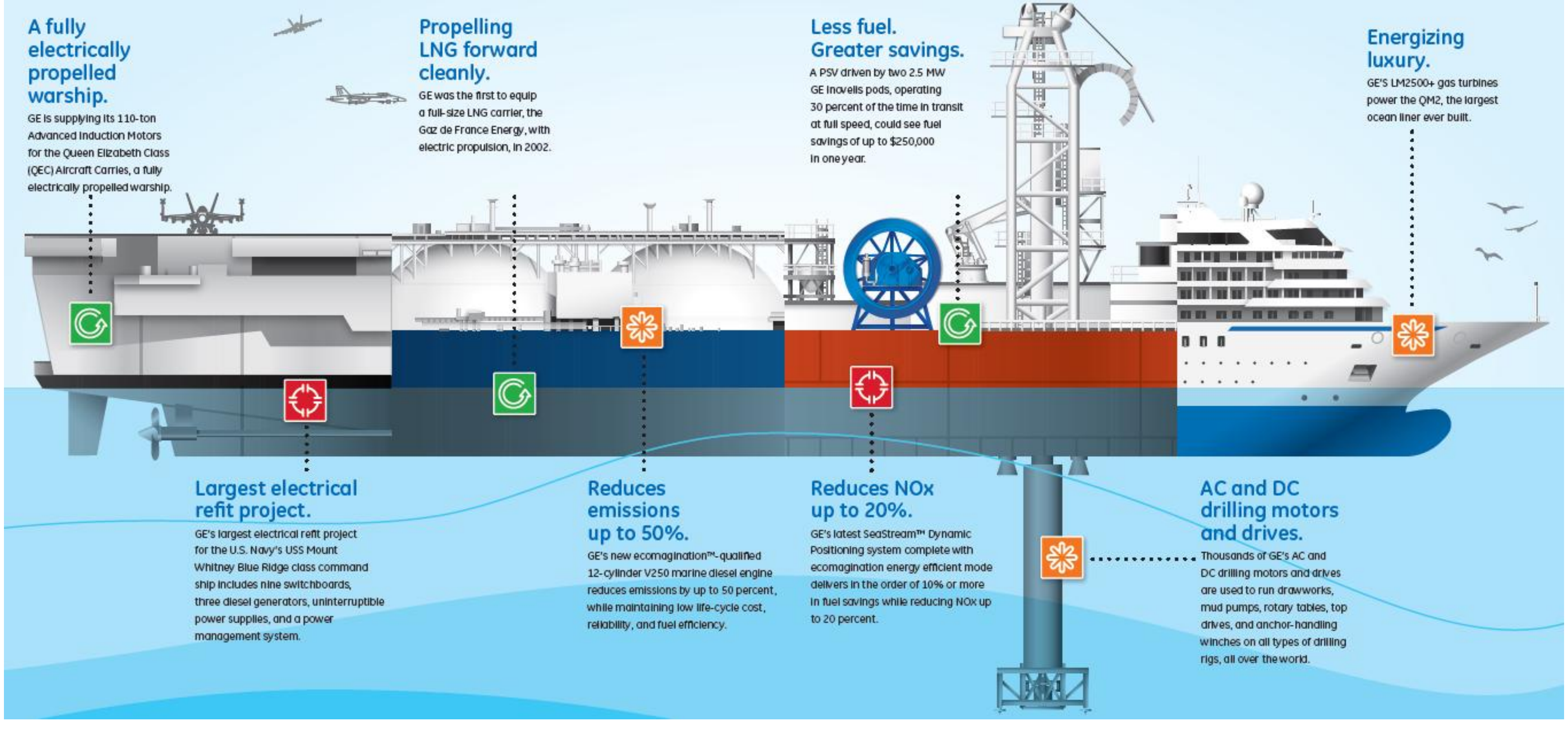


Figure 3.2 – Marine Industry Challenges [4].

3.3.1 - Offshore:

Main Aims & Challenges

One of the most important vessel market is the offshore, where the main main challenges faced are attempting to navigate in deeper waters and further away from shore. A lot of emphasis given to technologies that enable space-saving equipment & safety enhancing features for exploration and productions vessels, together with the most advanced solutions that that can enhance the operational flexibility for the support & service vessels.

Types

- Semi Submersible drilling rigs – see project example in Chapter 5.
- FPSO (Floating Production, Storage and Offloading) - Used to production & processing of hydrocarbons and for the storage of oil, similar to a land based oil refinery plant.
- FPU (Floating producing Units) – Used for developing wells through drilling structure placed on seafloor.
- FSO (Floating Storage and Offloading) – It's essentially a simplified FPSO, without the capability for oil or gas processing.
- TLP (Tension Leg Platform) – It's a buoyant production platform held in place by a set of tension legs or tendons attached to the platform and connected to the seafloor
- Spar – Similar to TLP but typically used in very deep waters with a one-piece cylindrical hull with ballast of the lower end
- Shuttle Tankers - Designed for oil transport from an off-shore oil field as an alternative to constructing oil pipelines.
- PSV (Platform Supply Vessel) - Ship specially designed to supply offshore oil and gas platforms with logistic support and transportation of goods, tools, equipment and personnel to and from offshore oil platforms and other offshore structures
- AHTS (Anchor Handling Tug Supply) - Vessels mainly built to handle anchors for oil rigs, tow them to location, anchor them up and, in a few cases, serve as an Emergency Response and Rescue Vessel (ERRV). They are also used to transport supplies to and from offshore drilling rigs.

3.3.2 - Merchant:

Main Aims & Challenges

We now move into the Merchant market, where the ultimate aim is to continuously increase the room space for more cargo and more passenger comfort.

In regards to the market challenges faced, these are different for cargo & passenger vessels. On the cargo vessels the main fundamental challenge is a simultaneous reduction in equipment footprint & its weight, now in the case of the passenger vessels it's the ever attempts to lower both the vibrations & the noise, fundamental for passenger vessel

Type

- LNG carrier - The LNG carriers enable large amounts of clean natural gas energy to be transported to the consumer over large distances, from the LNG Liquefaction Plant to the Re-gasification plant. Here it is warmed and converted back in to a gas before being delivered into the local gas pipeline network.
  In August 2005, there were approximately 50 LNG receiving terminals located world-wide, including Japan, South Korea, the United States and a number of European Counties. There are many more terminals planned.
  Liquefied natural gas, or LNG, is natural gas in its liquid form. LNG is neither corrosive nor toxic. During the process known as liquefaction, gas is cooled below its boiling point, at around -160°C.

Figure 3.3 – Example LNGC Carrier.

- Chemical tankers – It's a tanker ship designed to transport chemicals in bulk
- Crude oil carriers - Ultra large crude carriers with dimensions up to 470 m
- Cable layers – Are deep-sea vessels used to lay underwater cables for telecommunications, electric power transmission, or other purposes.
- Ro-Ro trailer ships – The roll-on/roll-off ship is as a passenger with cargo/car ferry capabilities, particularly on short- sea routes.
- Research vessels
- Fishing vessels
- Tugs – Are boats that manoeuvres others vessels (cannot move themselves) by pushing or towing them.
- Workboats
- Cruise ships
- Ferries & Yachts

3.3.3 - Navy:

Main Aims & Challenges

In the case of the Navy, the main aims & challenges are related to having a higher power density and keeping a low profile under fire, with low noise & vibration signatures, complemented by having high shock resistance and culminating with a big emphasis on the operational redundancy & flexibility because, even if the vessel has suffered a hit with partial damage, the other parts of vessel must still be fully operational for the appropriate and expected positioning & firing response.

New drivers of high power launchers, weapons and sensors will emerge for the major navies with the following characteristics:

- Based on Propulsion Systems Currently Available
- DC Low N&V but output limited
- Cycloconverter - High torque @ low speed
- Synchroconverter (LCI) - Low power density
- Pulse Width Modulated - High power density/low N&V

TYPES:

- Aircraft carriers
- Amphibious assault ships – A navy vessel employed to land and support ground forces on enemy territory by launching its amphibious crafts & helicopters.
- Cruisers – Are warships with multiple aims of air defence, commerce raiding, and shore bombardment
- Littoral combat ships - Relatively small surface vessels intended for combat operations in the littoral zone & equipped with autonomous air, surface, and underwater vehicles. Possessing lower air defence and surface warfare capabilities than destroyers
- Destroyers – Are fast manoeuvrable long-endurance warships intended to escort larger vessels in a fleet, convoy or battle group and defend them against smaller powerful short-range attackers.
- Frigates - Are used to protect other warships and merchant-marine ships, especially as anti-submarine warfare combatants for amphibious expeditionary forces, underway replenishment groups, and merchant convoys.
- Tankers & supply ships

3.4 - Dynamic Positioning (DP)

3.4.1 - Principles

The Dynamic Positioning (DP) is an automated computational marine system that enables a vessel to maintain the heading and station, whether fixed or moving, by use of thrusters to counteract the effects of displacing forces such as wind, current and wave action. This method of manoeuvring, although simple, allows the system to control very complex operations safely and efficiently.

Traditionally, the dynamic positioning systems were only used for a small amount of time during specialised operations. But today's integrated dynamic positioning solutions can provide manual lever control, combined joystick control with fixed and tracking control, which now form a major part of the integrated bridge solution.

3.4.2 - System Overview

The following block diagram gives an overview of typical system connections and signals:

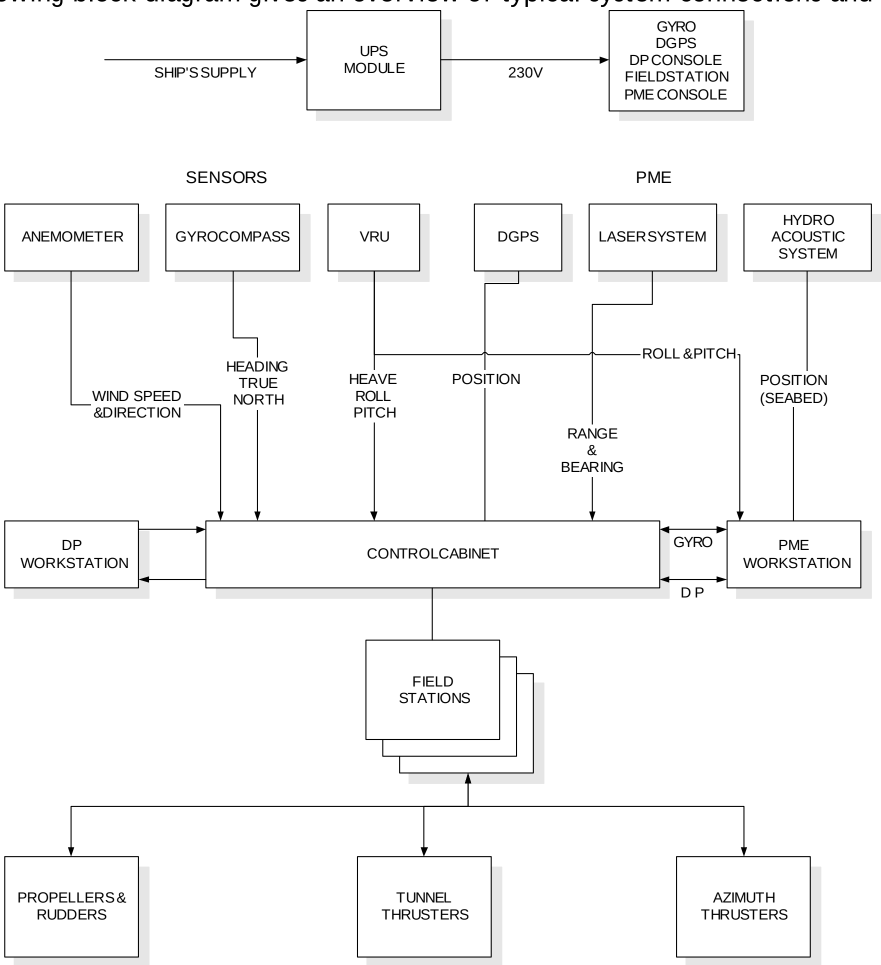


Figure 3.4 – DP - System Overview [14].

3.4.3 - Vessel Axes

The DP system controls three of its six axes of movement on a vessel:

- Surge (X axis)
- Sway (Y axis)
- Yaw (N axis)

The thrusters act to move the vessel in the X, Y and N axes to maintain the desired position/heading.

Sensors measure the environmental forces acting on the vessel such as wind direction and speed, roll, pitch and sometimes heave.

For the for movement axes and the pitch & roll sign convention refer to figure below:

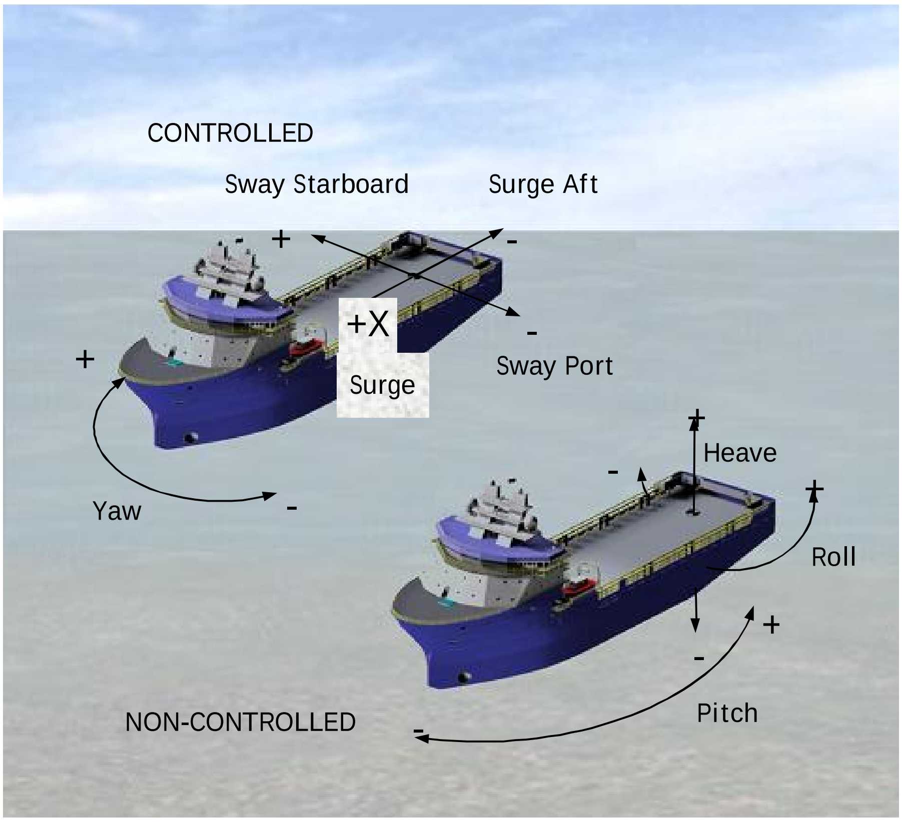


Figure 3.5 – DP - Vessel Axes [14].

3.4.4 - Mathematical model/filters

DP Model

For a modern Dynamic Positioning system, its mathematical model takes into consideration several the data from serval sensor sources. These, provide information to the control system which incorporates a mathematical model (including a Kalman filter) of the vessel including information about the vessel's dynamics, its machinery and its responses to environmental and other displacing forces.

The model information together with the sensor data enables the DP system to calculate the required output for each thruster and propeller to achieve and maintain the desired position and heading.

Kalman Filter

The Kalman filter [5] is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone.

The Dynamic Positioning (DP) system use this filtering technique to obtain optimal estimation of vessel motions and environmental forces from wind, waves and current. The Kalman filter algorithm works in a two-step process:

- <u>Prediction step</u> - In the prediction step, the Kalman filter produces estimates of the current state variables, along with their uncertainties.
- <u>Estimation step</u> - Once the outcome of the next measurement (necessarily corrupted with some amount of error, including random noise) is observed, where these estimates are updated using a weighted average, with more weight being given to estimates with higher certainty.

The algorithm is recursive. It can run in real time, using only the present input measurements and the previously calculated state and its uncertainty matrix; no additional past information is required.

3.4.5 - System Changeover

In an integrated Dynamic Positioning (DP) system, the Manual control of the thrusters is from the levers in the Manual Thruster Control (MTC) panel/desk.

In the process of a DP systems change over, each thruster has a ready to start signal that is comprised of signals that are cabled to its associated thruster Fieldstation, e.g. auxiliaries running, hydraulics healthy, drive available to start etc. Each 'ready to start' signal is then mapped & displayed in touch screens in its respective MTC desk.

The operator can then start each drive and the thrusters become available to the system. If a thruster becomes available for control, each control station flashes ‘Control here’. Once the thrusters are selected the vessel can be manoeuvred using the DP joysticks, IJS joystick or the manual lever desks (MTC), depending on which station is in control.

Changeover between the DP, IJS and MTC is via the control here button. Control can be offered between stations by pressing the on-line consoles control button whereupon the light will flash at all other stations that can take control. The IJS can take control from the DP at any time. If the DP fails completely the IJS is automatically offered control.

3.4.6 - Resilience against single point of failure

The Dynamic Systems (DP) system shares the same resilience to a single point of failure as the Automation system does.

The mechanics & main components are fully described and detailed in section 3.5.7 - 0.

This is applicable to both types of deployment of a DP system: a standalone DP system or a DP System integrated together with an Automation system.

3.4.7 - Positioning & environmental Sensors

DGPS

DGPS is an enhancement to the Global Positioning System (GPS) for improved location accuracy, from the 15-meter nominal GPS accuracy to about 10 cm in case of the best implementations. Uses a network of fixed, ground-based reference stations to broadcast the digital correction signal between the positions indicated by the GPS (satellite) systems and the known fixed positions.

The DP system uses above advanced satellites reception & filtering techniques through the the GPS, GLONASS & other satellite systems, to provides the necessary vessel position from absolute easting and northing coordinates of the vessel’s centre point, as measured by the DGPS.

ACOUSTIC

It’s an ultrasound distance measurement system which provides seabed distance of the acoustic transponders from the vessel’s centre point measured in fore/aft coordinates converted to northings and eastings, or the absolute position of the vessel centre measured by the acoustic system.

The DP system is designed for the following position measurement equipment (PME) and sensors, which are input into the system via serial links.

Table 3.1 — Typical Systems Supplier Equipment.

Device Type	Device	Interface	Protocol
Anemometer	Young 0901	RS422 4800-N-8-1	NMEA-0183 $MWV
Vertical Reference Unit (VRU)	TSS DMS-10/5	RS422 9600-N-8-1	TSS1 format
Gyrocompass	TSS Meridian Standard	RS422 4800-N-8-1	NMEA-0183 $HDT
DGPS	Veripos DGPS LD2	RS485 9600-N-8-1	NMEA-0183 $GGA
Acoustics	Sonardyne Marksman	RS232 9600-N-8-1	NMEA $PSIMSSB or $PSIMLBP

Table 3.2 — Typical Customer/3rd Party Equipment.

Device Type	Device	Interface	Protocol
Electric Riser	Electric Riser Inclination Data System	RS232/RS485 9600-N-8-1	NMEA $RIB NMEA $RIY
Doppler	Dual Axis Doppler Log	RS232 /RS422 9600-N-8-1	NMEA 0183 $VBW
ECDIS	Furuno ECDIS	RS232/RS422 9600-N-8-1	NMEA 0183 $RTE,$WPL

3.4.8 - Thruster Speed/pitch control and Angle

When the Dynamic Positioning (DP) is in full usage of its model (together with the Kalman filter), together with all the Positioning Measurement Equipment (PME) and all the Sensors, the outcome of the DP system is a set of calculated setpoints for: the thruster Speed (velocity of blade rotation), the thruster Pitch (angle of blade rotation) and, if the thruster is an azimuth type, the angle of thruster (acting like a rudder) which moves/rotates the thruster underwater body in one direction or the other, contributing to altering the heading of the vessel.

This is obviously done in an integrated & controlled way, that is, when the operator selects a certain number of thruster to be online and also PMEs & sensors for the DP control loop, together with the current electrical power capability, the outcome will be an orchestrated operation with all the these setpoint going to the online thrusters in regards to the current vessel operation (i.e. pipelaying or drilling) and within the rules of its vessel notation: DP1, DP2 or DP3, for a minimum system fall-back and redundancy of continuous operation.

3.4.9 - Components

CONTROLLERS (STANDALONE)

The DP controller software functionality is hosted in a PC based controller – Soft Programmable Logic Controller (PLC), similar to the automation counterpart as per section 3.5.2 - , but host a certain numbers of communication devices for all the internal equipment like: IJS, MTC or DP Fieldstations and also host communications for all the external Positioning Measurement Equipment (PMEs) & Sensor arrays and local I/O points. These communication devices have multiple serial port adapters in a high density connection package.

These controllers work in an online/offline duty/standby pair arrangement for a given set of functions. The online controller is the one running the plant and the offline controller shadows the action of the online controller and continually checks that the online controller is functioning correctly and provide the following features:

- Duty / Standby changeover
- Dual Ethernet communications with the rest of the system
- Alarm detection and time tagging

These controllers, can be grouped into several processing “cells”, which are located in different areas of the vessel according to near vessel notation for redundancy operator control & awareness, with DP2 & DP3 notations normally having the main DP controller on the Bridge and the secondary ones in a DP Backup room.

I/O VIA FIELD STATIONS (STANDALONE)

These provide the main DP system interface with the plant. They transfer the requests from and status to the DP controllers, over the dual Ethernet, with interfaces to physical or serial plant inputs and outputs.

The Fieldstation controller communicates with rails of I/O, using Ethernet connections, usually located in the same cabinet to provide the plant interface and any other supported communication medium and/or protocol.

WORKSTATIONS

The operator can control and monitor the vessel from dedicated panels and workstations. A workstation is defined as "a position where the operator can monitor or perform a function". This section will cover each type of panel and how these panels are arranged into joysticks and workstations.

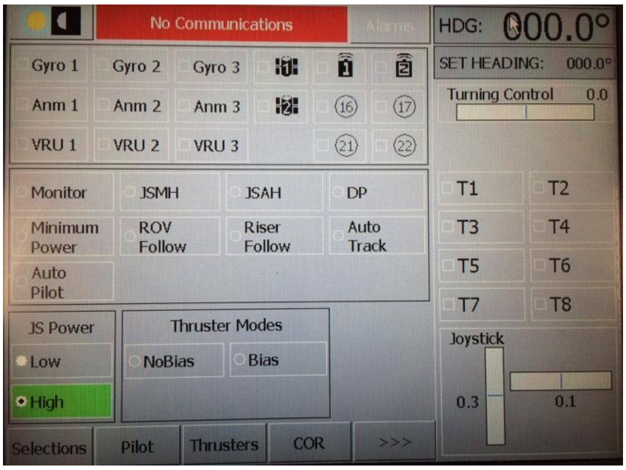


Figure 3.6 – DP – Table top panel.

A typical workstation is designed with three main components:

- Table top of panels (right image)
- Main display screen/Display
- Gear Tray containing the operator PC and power distribution

Figure 3.7 – DP – Workstation [14].

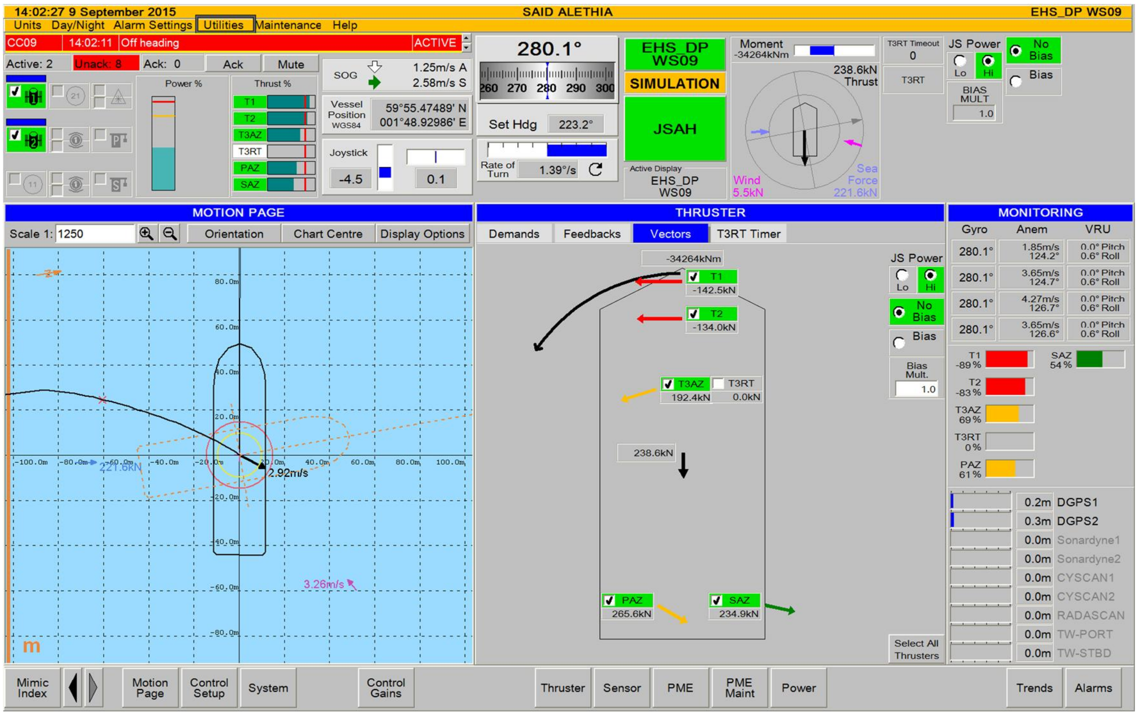


Figure 3.8 – DP – HMI main display screen.

Manual Thruster Control (MTC)

The following is a brief overview of the MTC console controls available.

MTC (Manual thruster control) consoles are typically installed in consoles adjacent to a main DP or IJS control console.

The top panels of the console are made up to contain controls for three types of thrusters – each panel has enough controls of each type to match the thruster configuration on the vessel.

Each console can face one of the four main directions on the vessel (forward, aft, port, starboard) Port/Starboard colours on thruster levers match the direction the console is facing.

Figure 3.9 – DP - MTC Console [14].

a) Touch screen display: Each thruster has a dedicated touch screen display that can show various items depending on type of thruster and signals available on this vessel:

i. Reference and feedback (e.g. speed, pitch, azimuth)
ii. Motor variables (load, spinning reserve, frequency)
iii. Start / Stop status
iv. Additional status indications
v. Day / Night mode selection
vi. Alarms for this thruster

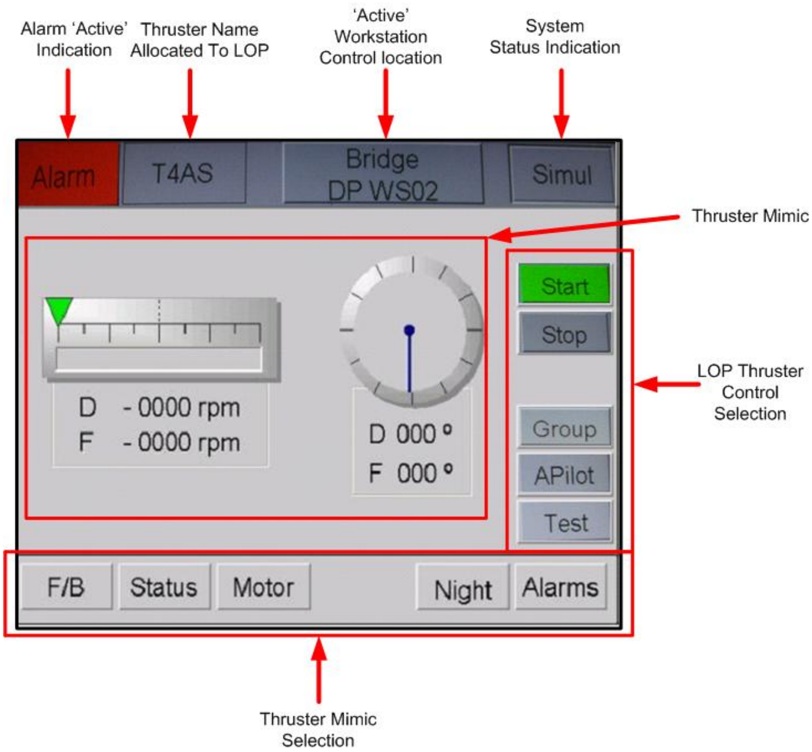


Figure 3.10 – DP - MTC Console Force & Angle Demand/Feedback [15].

Status provides an optional Interlock indication (depends on thruster types and interface on the vessel)

b) <u>Interlock Indication</u>: Each line of interlocks can show Green healthy, blank unhealthy. If available, the interlock may have a further detail interlock page that can be viewed by selecting the button to the left of the interlock indication. If there are no lower interlock details, then the button is hidden.
Status provides an optional Interlock indication (depends on thruster types and interface on the vessel).

c) <u>Azimuth thruster controls</u>: The picture shows a typical panel for a forward facing control console. The direction of thrust indication on each control lever is colour coded to indicate port and starboard, this colour matches the way the desk is facing. The control handle also incorporates a thruster forward and reverse control and indication. Each thruster has indications for System Alarm, Communications Fault, Stopped, Running, Control Here. Each thruster has controls for Alarm Mute, Start, Stop, Control Request, Emergency Stop (with cover).

Figure 3.11 – DP - MTC Console Azimuth Thruster Controls [14].

d) Communication Links:

Each lever connects directly by Ethernet to the respective propulsion Fieldstation.

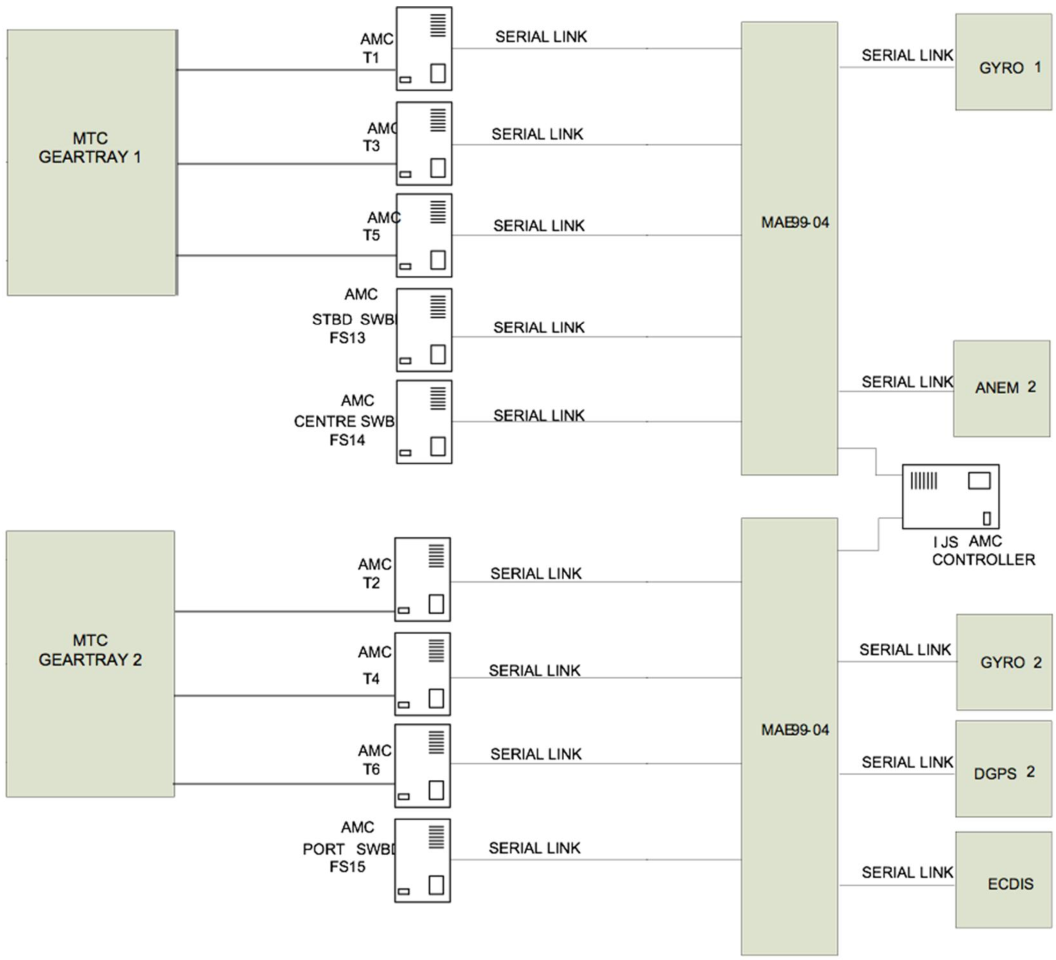


Figure 3.12 – DP – MTC/ IJS/PJS Console Communication Links [15].

Independent/Portable Joystick System (IJS/PJS)

The user interface for the IJS system has exactly the same look, feel and function as the main DP system, but with reduced options available to suit the lower level of control possible from this system.

The reduced set of main control modes provided by the IJS control system operate in the same way as the main DP modes described above.

To operate the vessel in a particular control mode requires specific inputs (sensors and PME) and specific thruster combinations to be selected, if available, before the control mode is permitted to be selected.

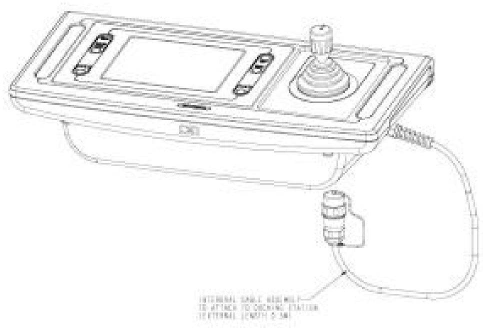


Figure 3.13 – DP – Joystick System [10].

Sensor, PME, thruster and mode selection is made from the active IJS workstation.

The Independent Joystick System (IJS) controls the thrusters via independent serial link connections to the Fieldstations for each thruster. The IJS controller monitors the switchboards by serial link to the respective Fieldstation (see previous figure).

The IJS Controller cabinet interface requirements are:

- Gyrocompasses – serial link using NMEA 0183 message protocol
- Anemometers – serial link using NMEA 0183 message protocol
- DGPS for time synchronisation
- Azimuth 1 – 6 Thruster Fieldstation
- Power system

Thruster Assisted Mooring (TAMS)

The TAMS position control solution for vessels uses a combination of thrusters and winched anchors to control vessel position and heading against the forces of wind, current and waves.

- Mooring System Control Modes:
- Anchor monitor
- Manual anchor assist
- Auto anchor assist
- Damped auto anchor assist
- Position Measuring Equipment:
- Taut wire, GNSS, laser, radar, hydro-acoustic, inertial platform, gyrocompass, wind sensor, motion reference unit

DP Alert System

The DP alert system, also know as the Drillers Alert System, enables a visual and audible alert whenever the vessel is not maintaining its position within a specified radius of the intended position, by measuring the error deltas and standardized in green, yellow or Red watch circles and its designed to advise to key operating locations (i.e. drilling, divers, ROVs) of a potential and mandatory disconnect sequence.

This system is installed in all the DP Console, also at Driller's Alert System, drillfloor and moon pools areas. The systems manual operated and provides a pushbutton or switch selection for: Yellow, Green and Red Condition and White (advisory). Absence of any of the previous (Y/R/G/W) conditions shall designate a Green (All Clear) condition.

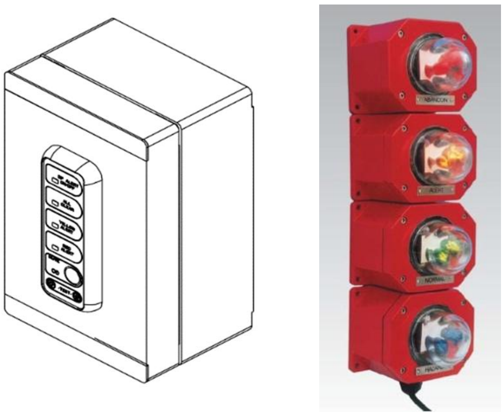


Figure 3.14 – DP – Alert System [10].

Normally, electronic sirens are provided at Drillfloor and Moonpool zones while the Yellow and Red status lights for the Drillfloor area and Moonpool areas typically the rotating type.

DP Networks

The network consists of a Redundant Ethernet between DP controller and DP workstation and VCS Fieldstations (which also cover Thruster I/O), there is no Ethernet control connection to the IJS Controller. A simplified network diagram is shown below:

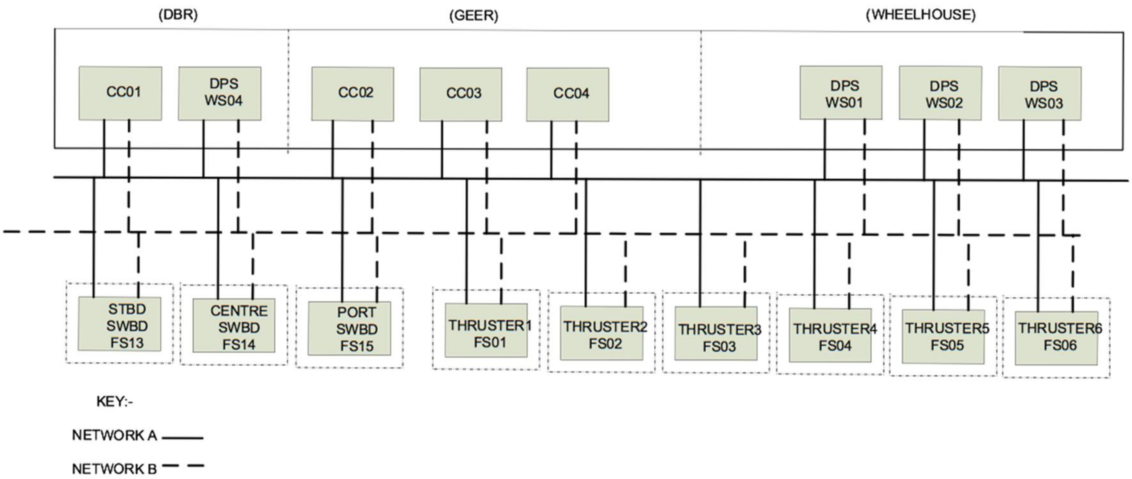


Figure 3.15 – DP - Typical Network [15].

3.4.10 - DP Classification

The DP system needs to meet all the major classification society and regulatory requirements such as Det Norske (DNV), Lloyd's Register, Bureau Veritas (BV), American Bureau of Shipping (ABS), Norsok, US Coast Guard and International Maritime Organisation recommendations (IMO).

Where appropriate, type testing needs to performed and systems should be custom-built to meet high level shock, vibration & temperature limits for special applications.

DP Class 1

The system may be stand-alone with discrete interfaces or may form part of a larger networked system. In addition to the Simplex DP system, some regulating bodies now require an independent joystick system as a back up. The joystick system can be expanded to provide further portable or fixed control panels for forward, aft or bridge wing locations.

The joystick can be upgraded to include dynamic positioning functionality with a simple software and hardware upgrade to provide Human Machine Interface (HMI) facilities.

DP Class 2

In Class 2 and above, any single failure must not render the system inoperable. This philosophy is applied throughout the vessel design including the switchboards, propulsion and power generation.

Where the regulating authority requires an independent joystick in addition to the redundant dynamic positioning system, the thruster communications are arranged to provide an extremely high level of isolation, with the DP and independent joystick systems using different interface methods.

With an integrated solution, the thruster changeover logic between the thruster manufacturer's local controls, bridge manual controls, joystick control and dynamic positioning can all be taken care of by the DP system.

Triple voting systems provide an even higher level of integrity, with three DP systems operating in parallel and with associated sensors also in Triplex. The system compares the three input signals and employs two out of three voting techniques. Output signals are conditioned in a similar way.

The DP equipment (controllers, sensors, PMEs) is considered to be in Class 2, from a system point of view, if the following conditions are met:

- At least two DP controllers are available as Online, Standby1.
- Three Gyrocompasses are selected.
- At least two operational control consoles that can fully support the current mode are operational (location is not important).
- There are a total of two PMEs selected across the vessel (any areas)
- Network A and network B are both healthy.

Note that the above does not specify any particular mode. One reason for this is that, before beginning operations, the operator would want to know whether the system was class 2 compliant before going into that mode.

DP Class 3

Class 3 provides triple redundancy in terms of equipment failure and must also remain operable in case of fire or flooding. This is achieved by having the third DP system located in a back up control room, separated from the main control room by an A60 bulkhead. Similarly, the sensors and position references associated with the back up system must have physical and electrical isolation.

This philosophy is employed throughout the vessel with engine rooms having A60 bulkhead separation and the power and propulsion system must be designed such that adequate power and thrust is available even under failure conditions.

The DP equipment (controllers, sensors, PMEs) is considered to be in Class 3, from a system point of view, if the following conditions are met:

- Three DP controllers are available as Online, Standby1 and Standby2 and one of them is in the Emergency area.
- Three Gyrocompasses are selected.
- The main area has at least two operational control consoles that can fully support the current mode.
- The emergency area has at least one operational control console that can fully support the current mode.

- There are a total of three PMEs selected across the vessel (any areas), as long as:
  - At least one selected PME is located in the main area.
  - At least one selected PME is located in the emergency area.
  - Network A and network B are both healthy.

Note that the above does not specify any particular mode. One reason for this is that, before beginning operations, the operator would want to know whether the system was class 3 compliant before going into that mode.

If the operator has selected control at an ancillary area (remote joystick or workstation) the system cannot be in class 3 mode.

3.4.11 - Ship control modes

The different types of DP vessel control are called control modes which are described in this section.

To operate the vessel in a particular control mode requires specific inputs (sensors and PME) and specific thruster combinations to be selected, if available, before the control mode is permitted to be selected.

Sensor, PME, thruster and mode selection is made from the active DP workstation.

Manoeuvring Mode

a) Manual Lever – Using individual levers to control each of the thrusters.

b) Joystick Manual Heading:

Combined control of all thrusters using a single joystick.

The joystick lever controls vessel fore/aft and port/starboard movements while the joystick turning control controls the heading by rotating the vessel about its centre of rotation.

Each axis can be independently controlled or in any combination of the three.

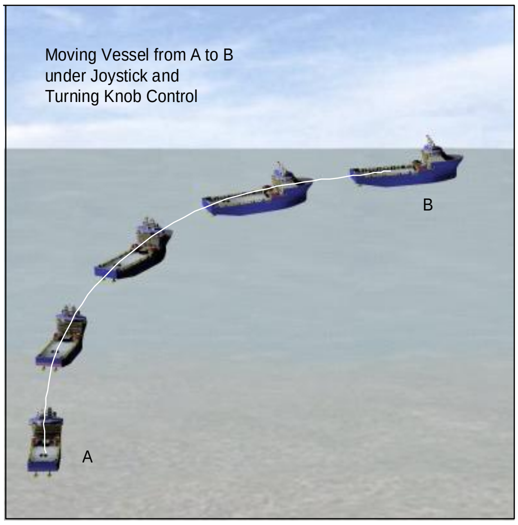


Figure 3.16 – DP - Joystick Manual Heading [14].

c) Hand Pilot – Manual control using the joystick for ahead/astern thrust with a turning moment control for rudder or stern azimuth control. This mode also incorporates conventional manual steering.

d) Joystick Auto Heading - Combined thrust control using the joystick in manual for speed control with automatic heading control. Typically used during slow speed manoeuvring.

The vessel's heading is automatically controlled about its centre of rotation whilst the Fore/Aft and Port/Stbd movements are controlled by the joystick as in Joystick Manual Heading above. The vessel's heading at the instant is selected becomes that which the DP system attempts to maintain. This set heading can be altered by the operator either through the screen or by use of buttons on the touch screen console.

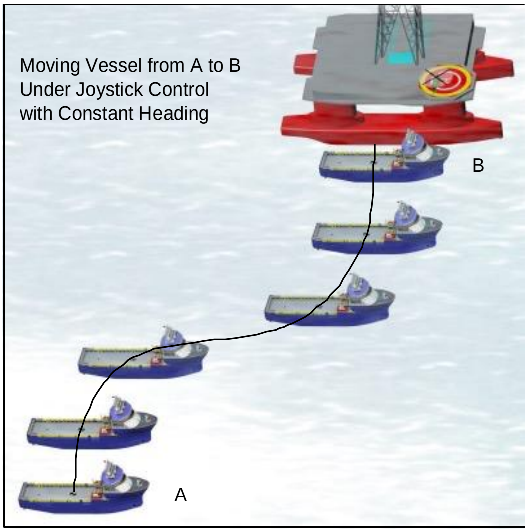


Figure 3.17 – DP - Joystick Auto Heading [14].

e) Autopilot: Ahead/astern thrust set by the operator via the joystick or the operator may manually enter the vessel speed or propulsion speed into the system. Automatic heading control using stern propulsion and/or rudders to steer the vessel.

Auto Pilot mode is a simple fast sailing transit mode to move the vessel on a constant set heading. The forward thrust demand is set by the joystick. The operator can make changes in the set heading from the screen or by use of buttons on the console panel. The system controls the heading using either props and rudders or stern azimuth thrusters.

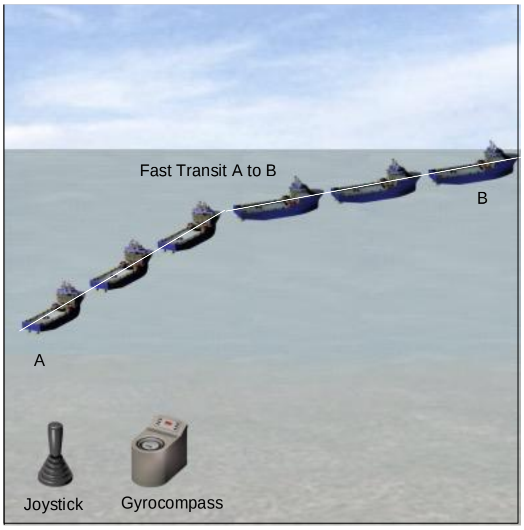


Figure 3.18 – DP - Autopilot [14].

TRACKING MODE

a) Autotrack: Automatic tracking and heading control along an operator pre-defined track. For slow speed tracking utilising all thrusters. Auto Track controls the movement of the vessel along a track between two or more operator defined points, on a set heading at a slow speed.

In auto track mode the vessel follows a moving target. The movement of the target is set up in the track follow page. The movement between each waypoint is defined in speed, course and heading. The progression of the vessel through the waypoints is also controlled by the operator from the track follow page. The waypoints can be entered manually, read from a file on a USB memory key or downloaded from an external computer via a serial link.

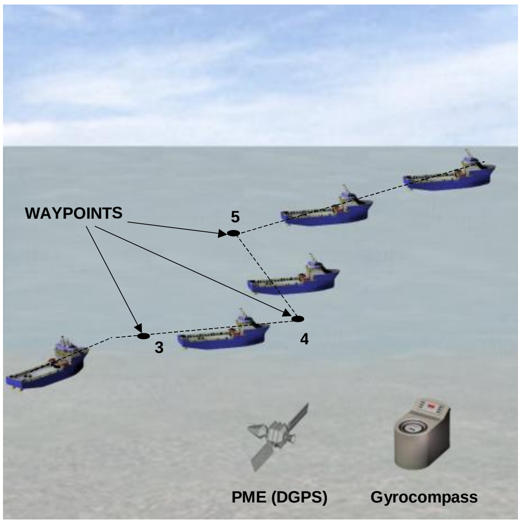


Figure 3.19 – DP - Autotrack [14].

b) Autosail: Automatic tracking and heading control along a pre-defined track. For high speed tracking utilising the stern thrusters and steering system.

In Auto Sail mode the vessel progresses through the waypoints keeping on track using position fixes from which the DP system calculates off track errors. The control system uses heading changes to reduce the off track errors to zero. Primarily the joystick sets the vessel forward thrust.

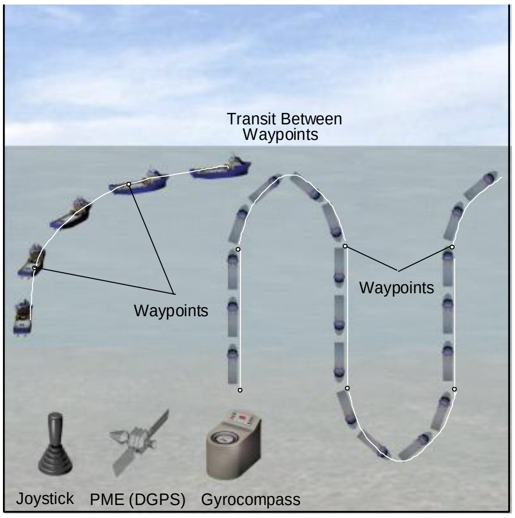


Figure 3.20 – DP - Autosail [14].

c) ROV Follow: Automatic tracking and heading control to follow a mobile beacon attached to a submerged vehicle. Absolute tracking and reaction radius options are also available. This mode requires an interface to an Acoustics system.

The vessel maintains a position relative to a moving ROV (Remotely Operated Vehicle). At the same time the vessel heading is automatically controlled. Two modes of ROV follow are available:

i. Fixed Position Reference
ii. Fixed Distance

If at least one PME (besides the ROV transponder/responder acoustics) is selected for use, the DP system will use fixed position reference ROV follow. The vessel is maintained in a fixed position and the ROV is allowed to move within its 'reaction radius' while the vessel maintains station. If the ROV moves outside its reaction radius the vessel and reaction radius are repositioned. This minimises unnecessary thruster activity. If the only PME selected is the ROV transponder/responder acoustics, then fixed distance mode is used. In fixed distance mode the centre of rotation (COR) of the vessel and the ROV's transponder/responder are maintained at a fixed distance apart.

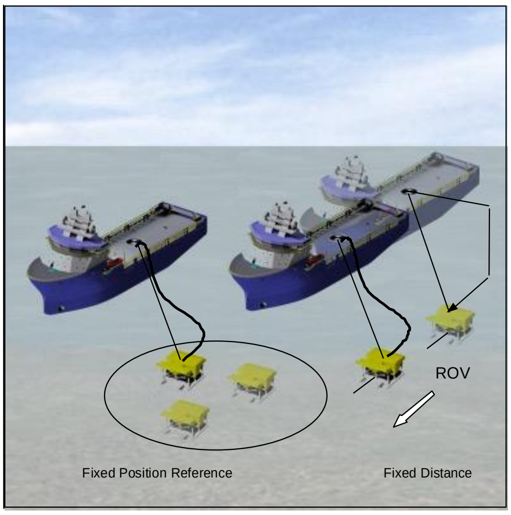


Figure 3.21 – DP - ROV Follow [14].

NOTE: Centre of Rotation (COR) – It is the position about which the vessel rotates, and acts as an offset when all measurements are referenced to the centre of the vessel.

d) Enhanced ROV Follow – Automatic tracking and heading control. Also includes deep-water application tracking depressor and ROV.

e) Riser Follow Mode: Riser Follow mode, which is typically used in drilling vessels, controls the position of the vessel to maintain the riser angle between the drill string and lower marine riser package (LMRP) close to zero. The LMRP is located above the blow out preventer (BOP) placed on the wellhead.

The control system receives inclinometer and position signals from the vessel. The system calculates the vessel position at which the riser angle will be zero. To avoid constant repositioning of the vessel, the riser angle is allowed to vary within a reaction angle from the zero position. The reaction angle is translated by the control system into a reaction circle around the vessel control point. If the riser angle exceeds the reaction angle, the vessel is repositioned to reduce the riser angle to zero.

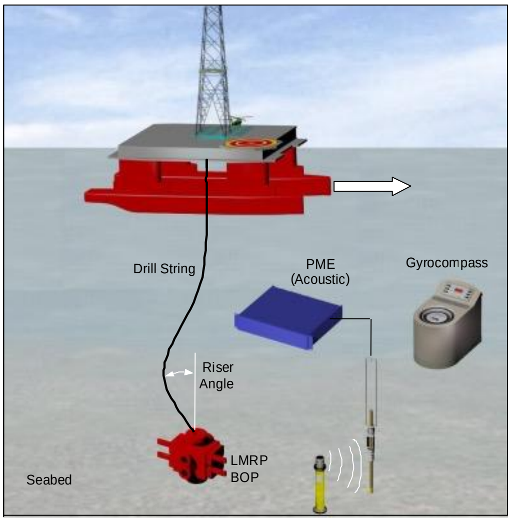


Figure 3.22 – DP - Riser Follow [14].

f) Ship Follow – Automatic tracking and heading control, tracking the relative movement and heading of another floating structure. Typically used in PSV applications alongside platforms or FPSOs.

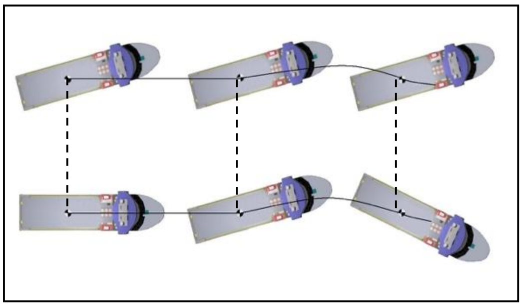


Figure 3.23 – DP - Ships Follow True Heading [14].

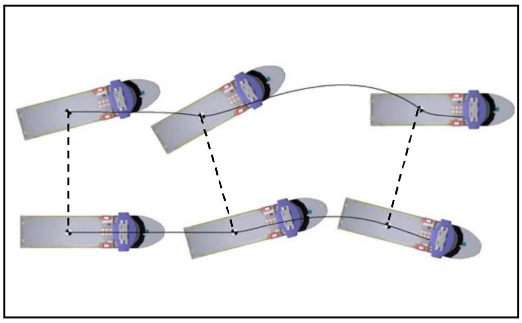


Figure 3.24 – DP - Ships Follow Relative Heading [14].

g) Enhanced Ship Follow – Automatic tracking and heading of fast moving structures such as barges.

STATION KEEPING MODE

a) Dynamic/Auto Position: Automatic position and heading control. Operator has the facility to change position and heading required.

This mode provides full automatic control of the vessel in all three axes (Surge/Sway/Yaw). The vessel's position and heading at the instant DP is selected become those which the DP system attempts to maintain. The desired vessel position and heading can then be altered by the operator either by use of the screen or by buttons on the console panel. DP can only be selected if sufficient thrusters are selected. The vessel must be able to provide fore/aft and port/Stbd thrust and also produce a turning moment. At least one gyro and at least one position measuring device must also be selected.

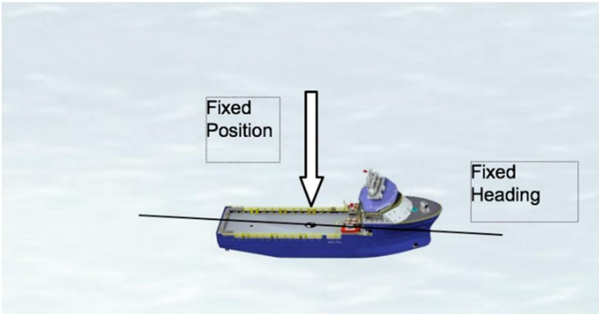


Figure 3.25 – DP - Dynamic/Auto Position [14].

b) Minimum Power: Automatic position and heading control. The system will automatically seek the optimum heading to reduce forces and power on the vessel. The vessel maintains position as in conventional DP but the system will rotate the vessel with the aim of heading into the nett environment (wind+current+tide) to reduce the total power requirements on the vessel. This mode is only available if the vessel is providing a nett positive surge thruster force.

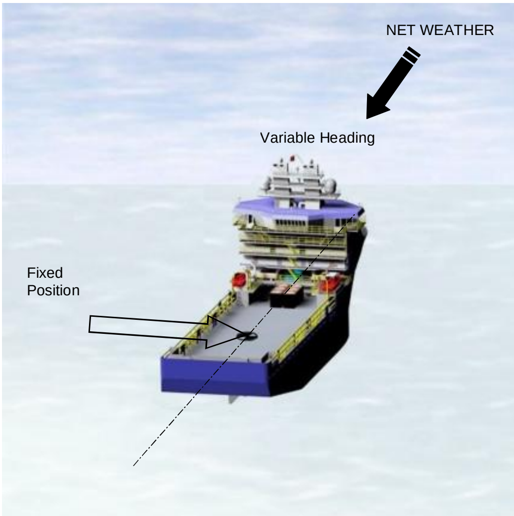


Figure 3.26 – DP - Minimum Power [14].

c) Weather Vaning – Automatic position control with heading allowed to settle into the environment. Typically used for standby operations enabling a reduction in power requirement.

d) Relaxed/Slowdown DP: Automatic position and heading control ensures a smooth thrust demand leading to fuel savings and a reduction of mechanical stress. This is also useful when only poor position measurement signal quality is available.

   This function allows the DP operator to enter DP mode without first steadying the vessel on the joystick. When selected the DP system places a target ahead of the vessel's current position calculated from the vessel's velocity before entering the mode. This allows for a smooth transition into normal DP mode.

e) Autospeed – Automatic fore/aft and port/starboard vessel speed control using the joystick, requires input from a Doppler log or DGPS. This also can be used with the joystick at zero position to provide a hover mode when main position reference systems are lost.

3.4.12 - Typical applications:

a) Survey, Cable Lay Ships – Automatic tracking and heading control with plough tension feed forward, product tension monitoring and protection, automatic vessel slowdown, and waypoint control for product or vessel track.
b) Shuttle Tanker Ships – Automatic tracking and heading control are provided in the form of approach, pickup and loading modes for ALP, FSU, FPSO and STL configurations.
c) Dredger Ships – Automatic tracking and heading control with drag head static load calibration, drag head tension feed-forward, drag head position compensation and poor mixture feed-forward.
d) Cruise Liner Ships – Automatic position and heading control with additional joystick anchor functionality.
e) Drilling Ships – Automatic tracking and heading control with riser follow, slow acoustic update rates, minimising loss of position on blackout recovery, Doppler log with model control.
f) Pipe Lay Ships – Position control for incrementing pipe lengths, improved gain control during transition from anchors to thrusters, dual barge operations and status information on the pipe laying equipment. Vessel tracks are calculated from pipe routes and displayed on the latest map overlays giving a comprehensive suite of operator features

POSITIONING CAPABILITY

The DP systems is capable of providing several scenarios/functions calculations capabilities, in order to further support the operator, such as the ones below:

a) DP Capability plots: A capability plot function on the DP system will allow the operator to enter scenarios based on system setup and forthcoming environmental conditions. The plot enhances and develops the operator awareness of the limitations of the vessel and its equipment (thrusters, generators etc.)

b) Consequence Analysis: This function examines the effect of a thruster or switchboard failure and alarms if a thruster or switchboard is predicted as essential. The analysis cycles through the thrusters and switchboards in turn and the results are displayed. Essential equipment alarms are an indication that the DP system may not be operating with sufficient redundancy.

c) Drift Off Calculation: The drift off facility is responsible for the calculation and display of the path that the vessel will follow in a drift off situation, i.e. if all thrusters fail. The operator has the capability of specifying:

   i. Specific environmental conditions, e.g. the wind speed and direction.
   ii. Specific initial vessel conditions, e.g. the vessel heading when thrusters fail.

   The extreme motion facility is responsible for predicting the likely maximum position error that will occur if the vessel’s control remains in a DP mode and the environmental conditions remain constant. The calculations are based on the observed position errors that have occurred recently.

3.4.13 - Interaction with Propulsion, Generation & Switchboards

Power System Overload Protection – “Power Chop”

For each generator the DP system measures the kW load (active power load) by means of a signal from a kW transducer. The DP system also receives input signals to indicate the open/closed state of each generator circuit-breaker and bus tie which enables it to determine whether the complete bus is connected together to form a single bus section or split into two or more bus-sections.

For each bus section the DP system compares the kW load on the generator(s) connected to that “bus-section” with the total kW ratings of those generator(s). If the kW load exceeds a pre determined percentage of the total ratings (known as the “critical margin” and typically set to 95%) the DP system automatically invokes the power system overload protection to reduce the risk of a black-out of the vessel.

The power system overload protection is referred to as “power chop”. Depending on the state of the bus-ties the “power chop” may affect one, some or all of the thrusters. When it is invoked in the way described above, the thrust demands for thrusters connected to the affected “bus section(s)” are rapidly reduced to reduce the power load. The thrust demands are then slowly ramped-up until the critical margin is reached.

The system will exit the “power chop” condition when the total thrust demands are met with the kW load for that bus-section below the “critical margin”.

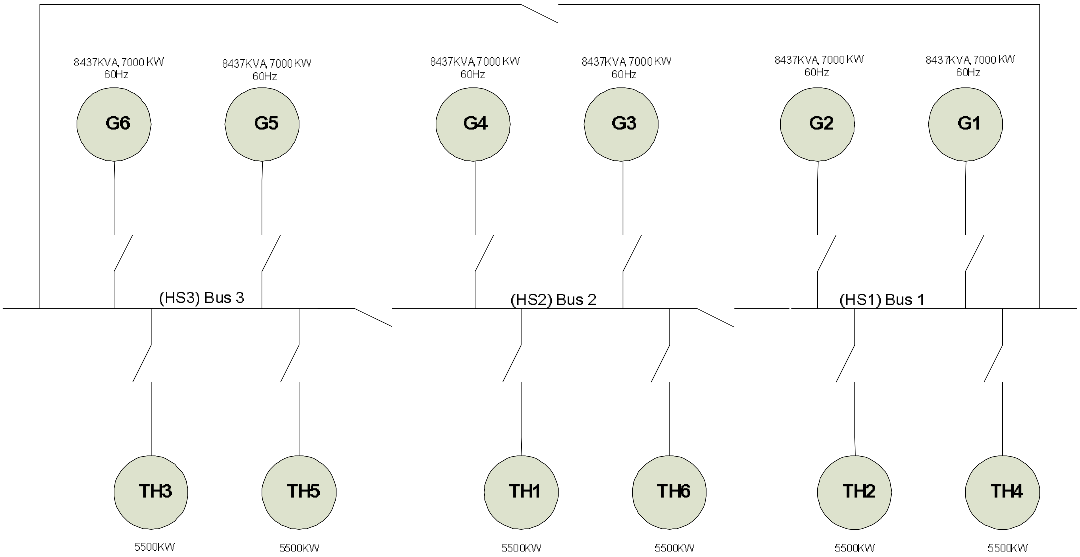


Figure 3.27 – DP - Power Chop Protection [15].

3.5 - Vessel Control System (VCS)

The Vessel Control System (VCS) is an integrated system that allows complete remote control and monitoring of systems for the merchant marine, navy and offshore markets.

This system has to meet the automation requirements of a whole range of ships such as offshore platforms, semi-submersible, cruise ships, naval ships, tankers, cable ships, etc.

The type of typical automation system used within this section is shown below:

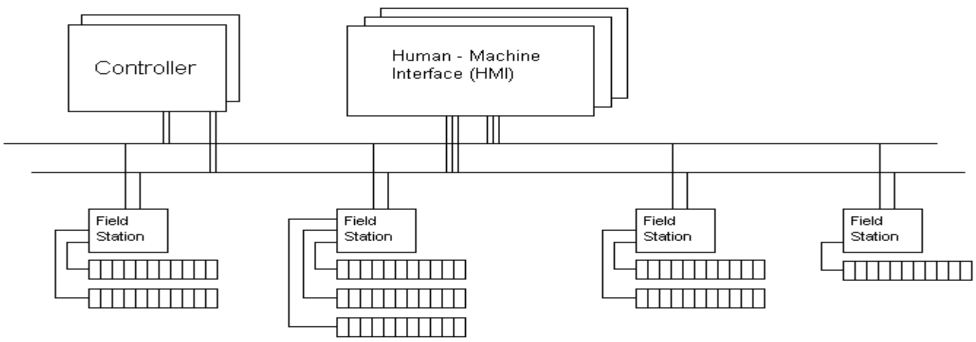


Figure 3.28 – VCS - The Vessel Control System.

The VCS is a hierarchical system, composed of the following main sub-systems that perform the following operational functions:

- Control & monitoring of all the electrical systems & their components by the Power Management System (PMS) – Details on section 3.5.3 -

- Control & monitoring of all the non-electrical systems & their components – Vessel Management System (VMS) – Details on section 3.5.4 -
- HMI Alarms and monitoring – Details on section 3.5.5 -
- Thrusters Management System – Details on section 3.5.6 -

The next section provides in-depth descriptions as well as the main system architecture, together with their main operational functions.

3.5.1 - Main Usage

Vessel Automation Control Systems are built for ease and flexibility of operation, by use of easy to follow operator menus and action buttons, including features such as:

- Self explanatory system menus
- Mimic displays to represent vessel systems
- Designed with the intention to avoid “human errors”
- Alarm system
- “Pop-up” menus and control windows

3.5.2 - System Architecture

The Vessel Control System (VCS) comprises the following key elements:

CONTROLLERS:

These perform the system control functionality and run all the several system control logic Software – These are the “brains” of the whole VCS system.

The controller software functionality is hosted in a PC based controller – Soft Programmable Logic Controller (PLC).

The controllers work in an online/offline duty/standby pair arrangement for a given set of functions. The online controller is the one running the plant and the offline controller shadows the action of the online controller and continually checks that the online controller is functioning correctly and provide the following features:

- Duty / Standby changeover
- Dual Ethernet communications with the rest of the system
- Alarm detection and time tagging
- Engineers watch call system

These controllers, can be grouped into several processing “cells”, which can have between 2 and 6 controllers on the same cell. These can be allocated to independent process systems functions like:

- Power Management systems – Details on section 3.5.3 -
- Vessels Management System – Details on section 3.5.4 -
- Ballast Management Systems

- Gas Management System
- Tank Management System

I/O VIA FIELD STATIONS:

These provide the main system interface with the plant.

They transfer the requests from and status to the automation controllers, over the dual Ethernet, with interfaces to physical or serial plant inputs and outputs.

The Fieldstation controller communicates with rails of I/O, using Ethernet connections, usually located in the same cabinet to provide the plant interface and any other supported communication medium and/or protocol.

Remote I/O rails are also supported, for example for embedding into other equipment such as switchboards

HUMAN-MACHINE INTERFACES (HMI) WORKSTATIONS:

PC based workstations provide the operator with 'live' mimics displaying the operating status, providing control of the various vessel systems and an alarm system.

The PC based workstations are based around an HMI SCADA package.

The workstations communicate to the controllers over the dual Ethernet via OPC protocol, using a dual Ethernet driver. The following functions are provided:

- User login with multiple privilege levels
- Alarm display, sounding and acceptance
- Historical alarms, event logging & Signal Trending
- System health monitoring –
- Vessel and power system mimics (allowing both control and monitoring)

Figure 3.29 – VCS – Workstations [10].

a) Control Areas: Workstations are situated in 'Control Areas'. For workstations to be in the same Control Area they must be in line-of-site of each other– according to IMO rules (see section 3.5.5 - .
b) Control Groups & Batons: Each item of plant in the system is allocated to one control group to suit the operating practices on the vessel. For example, all generators, switchboards and propulsion drives may be in the Machinery control group, whereas ballasting equipment may be allocated to a group called Ballast.

Operators are also allocated to the control groups. Note that an operator may be assigned to more than one control group as appropriate for vessel operation. For safety reasons, it is a classification society rule that control may only be effected over plant equipment from one control area at any time, this is implemented using a ‘control baton’ for each control group that only resides in one control area at a time. Note however that a baton applies to all the workstations in that control area.

Thus to control a plant item it is necessary for an appropriate operator to be logged in and have the baton for the relevant control group for the plant item. To obtain the control baton an offer-accept method is normally used. For example, to transfer a Machinery control baton from the engine control room to the bridge, a Machinery operator must be logged in at the engine control room to offer the baton to a Machinery operator logged in at the bridge who can then accept it.

c) Operator Login and Privileges: Operator logins are set up within the system, together with a password. Each operator is assigned a privilege level and set of control groups. The VCS operator privilege levels range from monitor only type, to vessel operators Control type (actions for plant devices), and to Supervisor type, which allows access to operations such as alarm editing, time-zone adjustment & ability to grab control batons.

DUAL ETHERNET NETWORK:

The following diagram illustrates the general principles of the network interconnections. The system typically comprises a number of nodes devices: workstations, Fieldstations and controllers. Each of these is connected to a port in each network switch box.

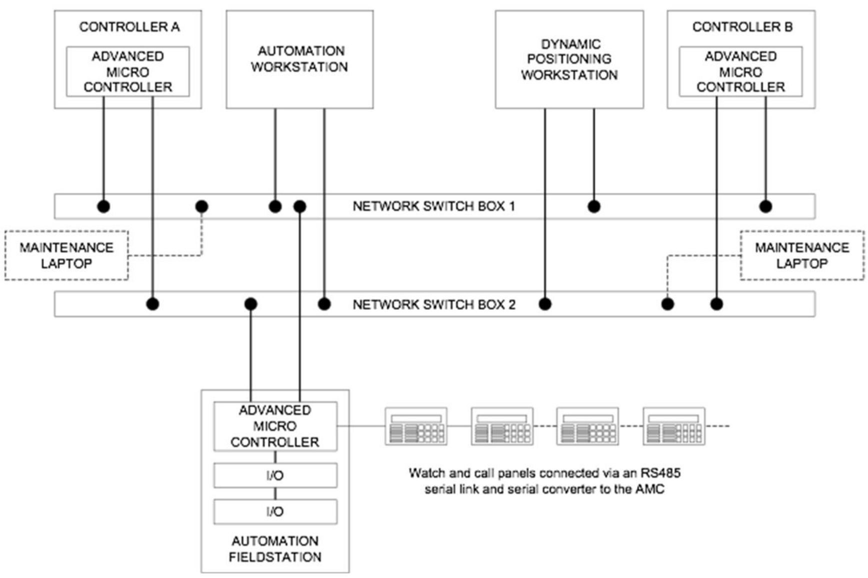


Figure 3.30 – VCS - Network Description.

a) <u>Communication medium:</u> This separated & dual Ethernet network can be implemented in copper media only, or in combination with fibre optic media. Copper runs are limited to 80m between points, and fibre optic to approximately 2000m. Fibre optic cables are normally used in cable runs which may be exposed to excessive Electro-Magnetic Interference (EMI). Classification societies do not allow yet the usage of Wireless communications for control functions, plus the metal structure of the vessels poses a major obstacle to its radio signal absorption capabilities.

b) <u>Description of Dual Ethernet Operation:</u> When each node starts up on the dual Ethernet network, they will all communicate by default on arm B (provided there are no network faults present). Once a node has powered up, then it will make a decision on how to communicate with every other node in the network based on any network failures that it has detected. I.e. it may communicate via arm A to some nodes and arm B to the others, if failures have been detected.

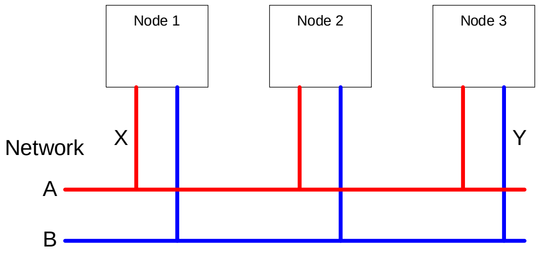


Figure 3.31 – VCS - Network Dual Operation.

WATCHCALL

A watch call system, also known as an engineer's alarm extension and emergency call system, is provided as an extension to the main VCS alarm system. It is used when the vessel is required to meet the Periodically Unattended Machinery Space (UMS) requirements of SOLAS chapter II-1 part E, IMO International code on Alarm & Indicators 1995 & major class society rules. The system is designed to meet the following Class notations as a minimum:

- Lloyds - UMS
- DNV - EO
- ABS -ACCU

When operating in UMS conditions, any engine control or other important alarm becoming active will cause an audible alarm to be sounded at watch call panels in the bridge (or other normally attended watch location), all public spaces and within the cabin of the selected duty engineer. At all times watch call panels will provide indication of the status of each alarm group, unless the group is blocked.

The VCS installed on-board any ship will monitor many important alarms. During unattended machinery space (UMS) operations it is necessary to have someone monitor the status of alarms. This is the responsibility of the watch keeper, usually the navigation watch officer as there is someone on the bridge at all times when at sea. A nominated duty engineer will be responsible to investigate any alarm conditions that arise.

The VCS alarm system groups alarms of certain types together and sends their status to the dedicated watch call panels, located in the watch position, duty engineer's cabin and public spaces. The nominated duty engineer's responsibility is to proceed to the control room as quickly as possible, and acknowledge and investigate the alarm's cause. If the engineer fails to acknowledge the alarm on the VCS within a certain time period then the emergency call is activated at watch call panels in all cabins, public spaces and the watch position, thus summoning additional help.

3.5.3 - Power Management System (PMS)

The Power Management System (PMS) is the responsible for the operational control & monitoring of all electrical based systems.

The PMS functionality is modelled using a series of standard SW functions, that are configured for the application as required by the project.

It is executed within the SW in the PMS controllers, providing comprehensive both manual and automatic control facilities for the electrical plant control.

a) Main functions:

- Starting, stopping and monitoring of diesel and gas turbine generators
- Closing/Opening of circuit breakers and bus ties
- Maintain control with open bus ties
- kW and kVAr Load sharing of active/reactive power, with F & V control
- Droop/Isochronous load control
- Full & partial Blackout Recovery of both HV & LV Switchboards
- Engine monitoring & shutdown – 1st & 2nd Stage shutdown
- Starting and stopping of large consumers & Load shed facilities
- Converter load phase back & Start inhibit of large loads/blackout prevention
- Optimised power configuration & Auto fuel selection (LNG dual fuel engines)
- Gas turbine and diesel engine Loadshare in same bus
- Gas turbine temperature dependent output de-rating
- Small offshore support vessels through to large tanker LNG vessels

b) HMI interface:

The main PMS functionality is accessed via a Generator Loading and Control Mimic such as the one below:

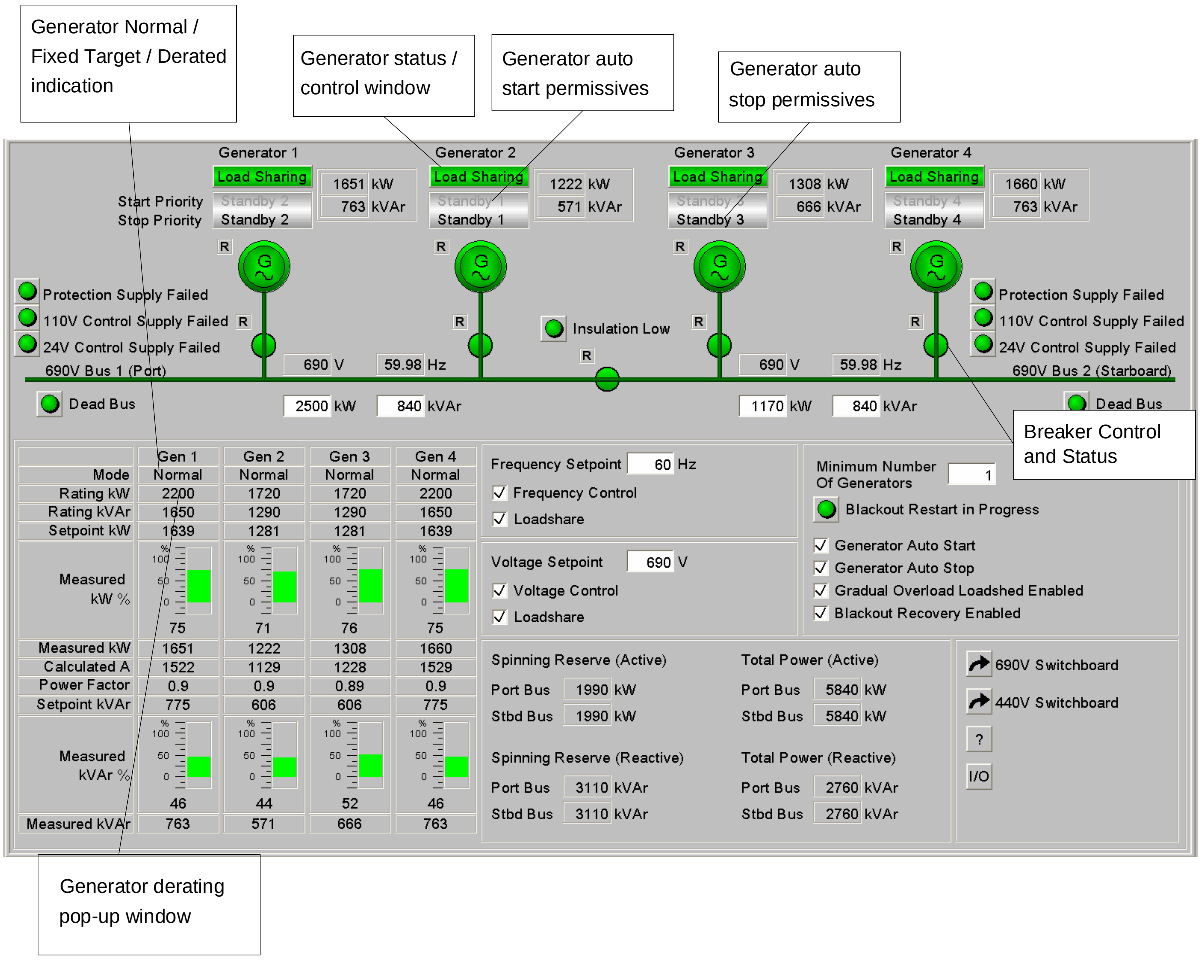


Figure 3.32 – PMS Generator Loading & Control Mimic [17].

Control and additional monitoring is achieved via pop up windows that are accessed by clicking on the sensitive areas and tick boxes on the mimic.

3.5.4 - Vessel Management System (VMS)

The Vessel Management System (VMS) is the responsible for the operational control & monitoring of all non-electrical based systems, such as auxiliary, fluid and cargo systems.

Similar to the PMS system, all the SW code is executed in the VMS controllers, providing comprehensive both manual and automatic control facilities for the auxiliary, fluid and cargo plant control.

Examples of the two main groups of VMS systems are depicted below:

a) <u>Auxiliary Systems:</u> Auxiliary systems cover the basic processes necessary for vessel operation. The health and efficiency of these systems is vital and the vessel control system provides constant monitoring of parameters such as pressures, temperatures and tank levels.

The system provides centralised status monitoring & control of machinery allowing regular routines like fuel oil transfer to be performed from the bridge or control rooms. Typical systems include main generation & propulsion auxiliary (Fresh/sea water cooling, Fuel oil and lube oil, Hydraulic systems & Compressed air), Fire and Gas systems (Fire Main, Detection & Watertight doors/water leak detection) and finally, Machinery running hours monitoring.

b) Fluid/Cargo Systems: Fluid management may vary from simple bilge level monitoring and manual control of ballast pumps (Pumps Standby start and lead-lag logic) and valves, to the more complex control of cargo pumps, calculation of load and stability information, etc. Features include:

i. Ballast - This system controls the balance of the vessel (FWD/AFT, PORT/STBD). It performs this task with the aid of the load and stability computer system. The ballast system is sometimes spilt into two or more separate parts e.g. forward and aft. This is because the system has to control and monitor several ballast tanks, valves and pumps, and a split provides a certain level of redundancy

ii. Bilge system - The bilge system controls and monitors the evacuation, via bilge pumps, of all liquids entering into dry compartments. The different types of devices associated with this system include bilge pumps and valves and in some cases bilge tanks.

iii. Multi-product cargo loading and discharging - with Cargo unloading 'Green Line' interlocks, Auto-fill/empty sequencing & flow meter interface

iv. LNG cargo & fuel/gas handling - This system controls the level and monitors the transfer and services of fuel oil to and from several different tanks and to the consumer. The different types of devices associated with this system include valves, pumps, purifiers, and tanks

v. HVAC - The Heating Ventilation Air Conditioning System (HVAC) ensures ventilation of machinery and accommodation areas. These systems include air conditioning units, dual/single speed fans and dampers

vi. Advanced process sequence control logic - with PIDs, Tank gauging with Draft, trim & list measurements, and finally, Load and stability calculator

3.5.5 - Alarm and Monitoring System

Machinery surveillance is an important part of vessel operations.

The vessel control system provides a comprehensive centralised alarm & monitoring system that can alert personnel to potentially hazardous conditions arising within the machinery spaces.

The alarms system provides unambiguous audio visual annunciation of alarms and warnings via a dedicated banner located at the top of each multifunction screen, irrespective of the systems being viewed at that time. A watch and call system extends the central alarm system to engineers' cabins and public areas when machinery spaces/control rooms are unattended.

As personnel safety is of paramount importance, the vessel control system may be configured to include additional features. Prime examples are: multi-zone Deadman/patrol man systems and pictograms/alarm columns providing much needed audio visual indication within noisy machinery spaces.

The Alarms system provides the facilities of handling both digital and analogue signal with High-resolution time tagging for plant signal as well as user configurable alarm parameters.

The alarm message handling includes comprehensive text description, time & date, with acknowledgement by individual alarm or alarm page, indication of its current status (active/reset, acknowledged, normal) and with tree separate alarm HMI Pages: Potential, Current & Logged alarms page w/ alarm blocking and finally, with interfaces to engineers watch call & Dead Man/Personnel Alarm system, with details on Project Chapter 5.

Operators are always alerted to alarms when they occur. This is achieved by the use of a dedicated alarms banner present in the header which is visible at the top of all mimic displays, irrespective of the system that is being displayed. The header also displays the total number of active alarms and total number of unacknowledged alarms. An audible device is also activated to attract attention.

a) <u>Control Group:</u> For acknowledgement purposes, each alarm is allocated to the same control group as the plant item it is associated with.
b) <u>Priority</u>: Each alarm is allocated a priority either 'Vital' or 'Non-Vital'. The object of alarm prioritisation is to help the operator decide in which order to take corrective action when a number of alarms are present. Different priority alarms are indicated and sounded differently.

c) <u>Alarm Groups</u>: Each alarm is allocated to one of up to 32 alarm groups and to one of 32 sub-groups within each group if required. When one or more of the alarms allocated to the group is active then the group becomes active. Alarm groups are used for filtering of alarms, and can be used to provide summary alarms for the engineer's watch call system. They can also be used to indicate alarms to external vessel systems.

A dedicated alarms page allows the operator to view current alarms, logged alarms or potential alarms from a full sized screen.

CURRENT ALARMS

The current alarms page shows all transitions of the currently alarms and events in a top down chronological order, in a real time manner.

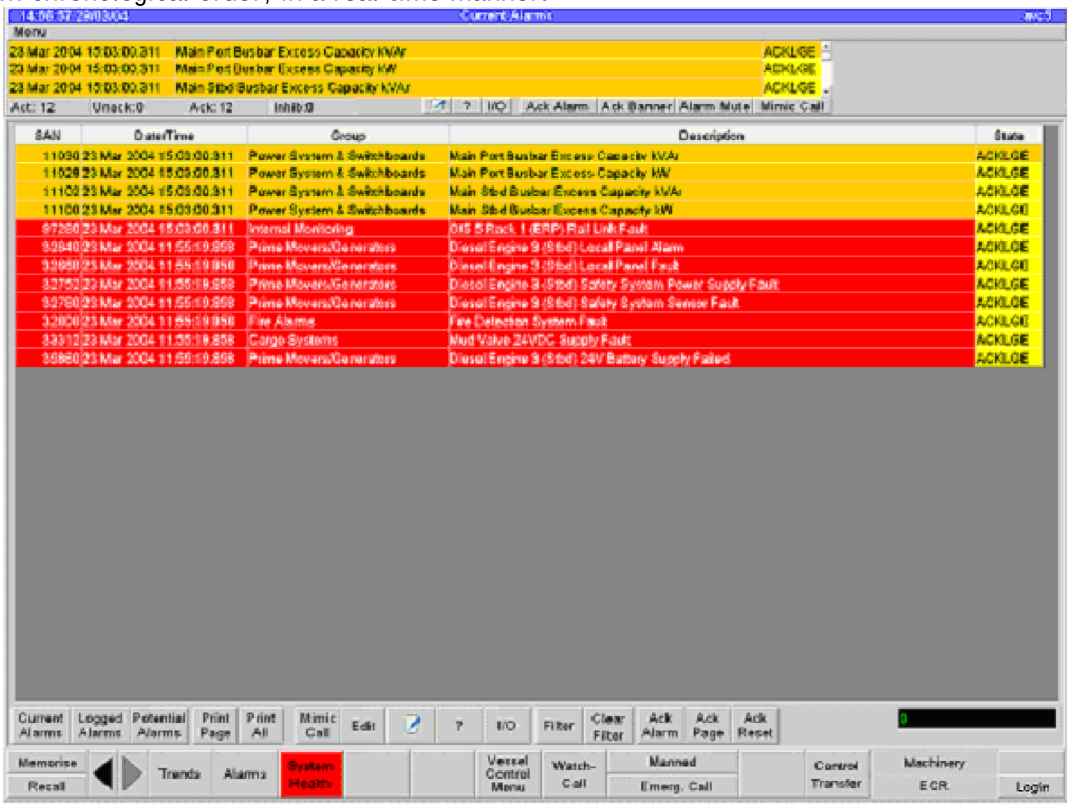


Figure 3.33 – Alarm System - Current Alarms [18].

LOGGED ALARMS

The logged alarms page shows all transitions of alarms and events (indication of state transitions for equipment & operator changes, not requiring alarm interventions) as separate entries in chronological order. The colour scheme for each line is based on the 'priority' as for the current alarms list, with the additional convention that events are shown as white on black. The same fields are shown as for the current alarms. 30 lines are shown per page.

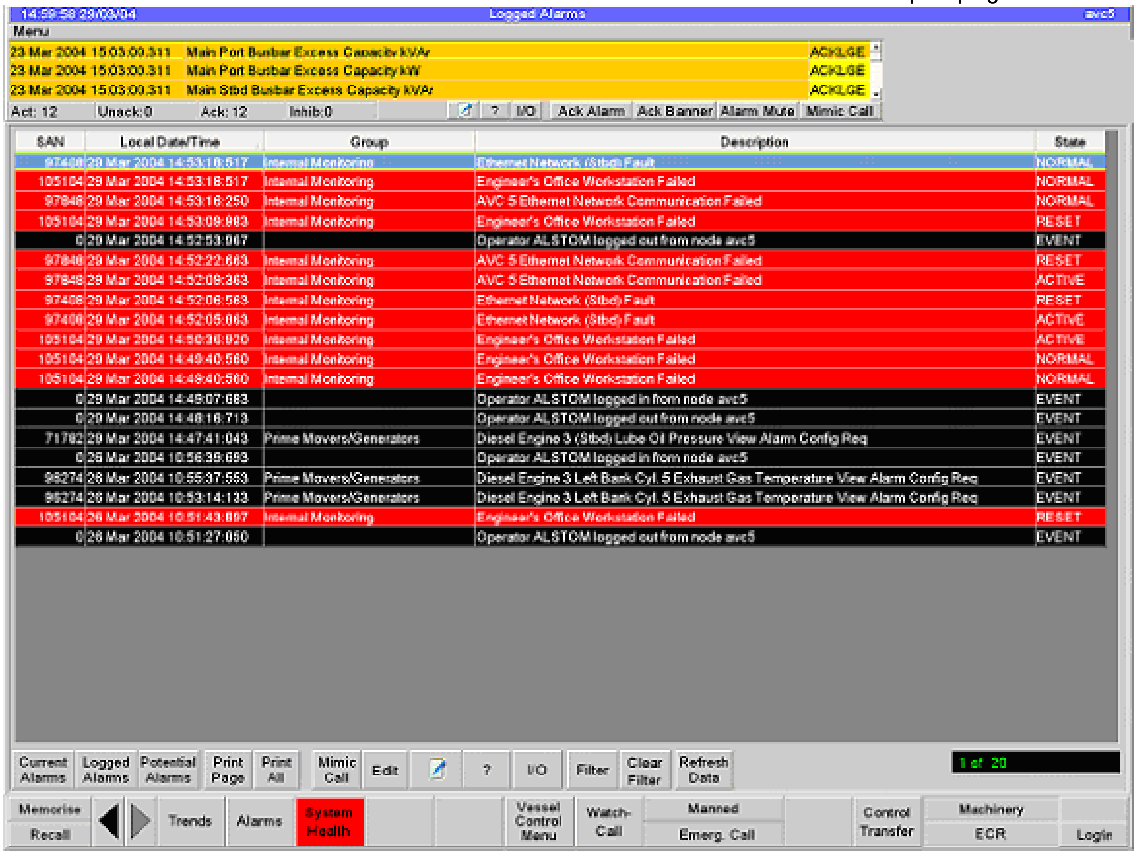


Figure 3.34 – Alarm System - Logged Alarms [18].

POTENTIAL ALARMS

The potential alarms page gives a complete list of all alarms & events configured in the system. The following information is shown for each configured alarm: SAN, Priority, Description and indicator as to whether an alarm is blocked, disabled or modified. The order of display is always by SAN (System Alarm Number).

TRENDS & SYSTEM DIAGNOSTICS

The Trends page page provides a complete review of historical trend data by usage of all signals configured in the system, for comparison over time and tendencies extraction.

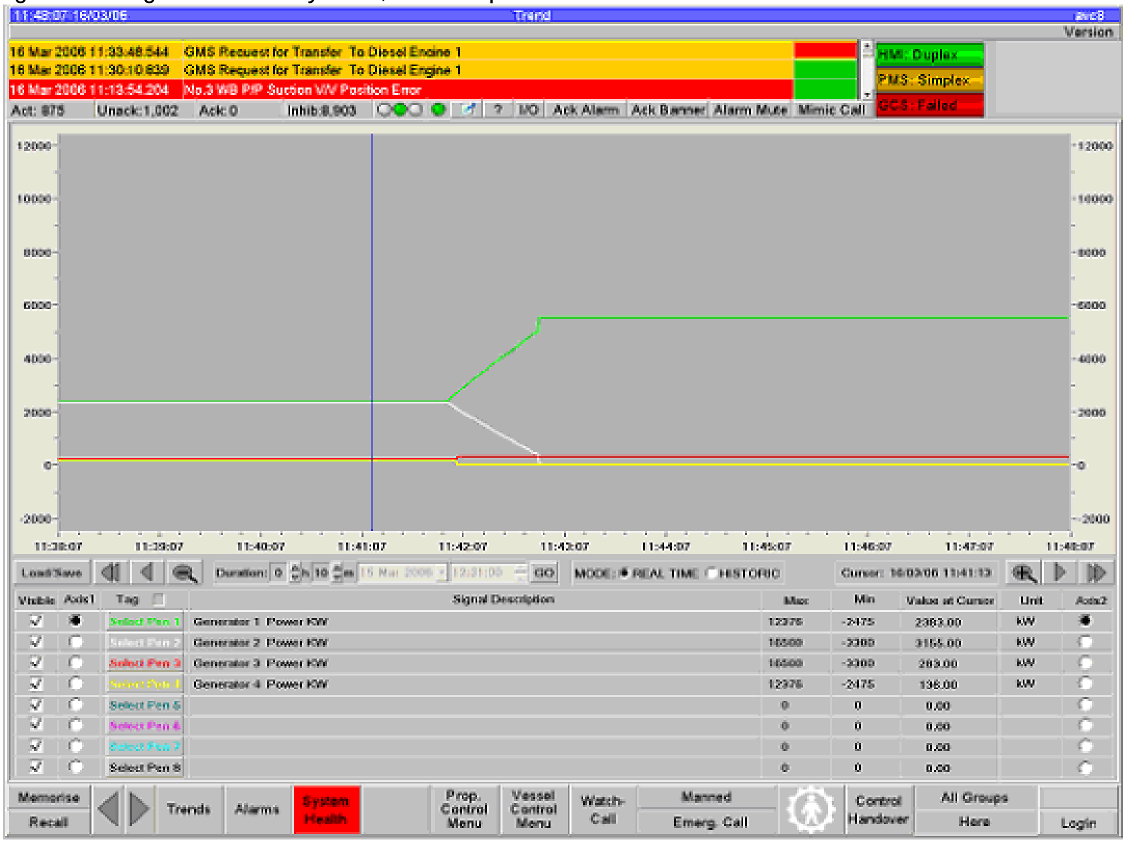


Figure 3.35 – Alarm System - Trends [18].

In the HMI capture above, its possible to see visual kW power impact of the operation of Loadshare functionality, where the Diesel Engine 2 (white) is being unloaded from the Swbd while Diesel Generator 1 increasing its kW power output to compensate for its removal.

3.5.6 - Thruster Management System

The VCS supplies complete remote, centralised manual and automatic propulsion/thruster/rudder auxiliary systems control and monitor capability:

- Drive & auxiliary systems control & monitor
- Azimuth auxiliary systems control & monitor
- Thruster sequenced start routines initiated by operator via VCS System HMI
- Thruster sequenced stop routines initiated by operator via VCS System HMI or fault conditions
- Temperature, pressure, flow, viscosity, level measurements, display and alarms

For more examples please check section 5.7.3 - for Propulsion mimics.

3.5.7 - Resilience against single point of failure

The VCS system, as any modern control system, must have the paramount concern of providing several levels of redundancy throughout its own system architecture and its main components.

Below the descriptions of the main components & architecture.

CONTROLLERS:

The controllers work in an online/offline (duty/standby pair) arrangement for a given set of functions.

The online controller is the one running the plant and the offline controller shadows the action of the online controller and continually checks that the online controller is functioning correctly. In the event of the online controller failing the offline controller assumes online responsibility.

The online automation controller monitors and issues commands to automation Fieldstations via a dual Ethernet network.

It is also possible to install the controller functionality into a Fieldstations.

FIELDSTATIONS:

a) As a single Fieldstation: For example, in a system with 2 Fieldstations for the Power Generation, if there were 4 generators in the VCS system, then the control and monitoring for two of them would be supplied by one Fieldstation and the other two by the other Fieldstation. Thus a worst case failure of one Fieldstation will lead to the loss of VCS Fieldstation control and monitoring for only two generators and not the whole generating system.
b) As dual redundant Fieldstations: Where there aren't multiple devices for the same system or the system is unique and requires a high availability of its plant data, then this system can be controlled & monitored by Dual redundant Fieldstations, where the I/O rails are shared between two controllers in the same or different cabinets are also supported.

   This provides an additional level of redundancy and means that loss of a single Fieldstation controller does not result in the loss of plant functionality, as per the next picture. If the left Fieldstation (controller AMC A & 3 Plant I/O Rails) loses it power supply or stops its processing, then the right Fieldstation (controller AMC A & 1 Plant I/O Rail) will still be able continue to send the plant I/O of left Fieldstation to the VCS controllers, together with the 5 shared plant I/O rails.

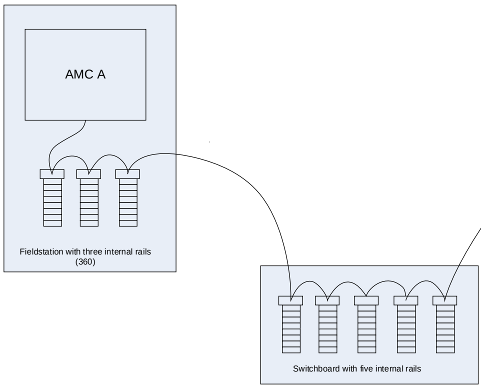


Figure 3.36 – Redundancy - Fieldstations.

WORKSTATIONS:

PC based workstations provide the operator with 'live' mimics displaying the operating status, providing control of the various vessel systems and an alarm system.

They're strategically placed on distinct compartments of the vessel, inclusive separated by an A60 barrier/bulkhead, to provide another redundant operator control workstation, with usage of the control transfer mechanism described in section 3.5.2 - .

DUAL ETHERNET NETWORK:

This dual Ethernet network is implemented using a Dual Ethernet Driver - in all its node devices (DP/VCS workstations, Fieldstations and controllers) - which supports standard Ethernet communications, but uses 2 physical Ethernet cables for each dual Ethernet network to provide redundancy of the physical media in case of damage.

If a fault occurs with transmission of data via one cable, then communications will be automatically switch to utilise the alternative physical Ethernet cable.

Figure 3.37 – Redundancy - Networks.

All paths on both networks are checked several times a second, to ensure a fast changeover (< 0.5 second) in the case of a communication failure.

Network state is shown on HMI mimics and faults are reported via the alarm system for operator actions, as per side picture:

Network faults are detected by every node broadcasting special diagnostics messages on both arms of the dual Ethernet network which are received by all other dual redundant nodes. This enables each node to build up a picture of the state of the overall network and to identify any path failures. B

Both transmit and receive paths are independently checked and the alternative arm will be utilised if either or both failures are detected on a cable.

UPS UNITS:

The VCS is powered via uninterruptible power supplies (UPSs). Each UPS (normally rated at 4MVA or 1.7MVA) is capable of powering the VCS equipment for at least 30 minutes in the event of input supply failure – This is a Classification Society requirement.

a) Power Distribution: Each UPS is to be supplied from independent switchboards. The UPS distribution is arranged in line with the required division of the power, propulsion and auxiliary systems to meet redundancy requirements. Each UPS supplies power to a selection of system equipment such that if the UPS fails, parts of the VCS would continue to operate.

   For example, in a system with 2 UPSs, if there were 4 generators in the VCS system then the control and monitoring for two of them would be supplied by one UPS and the other two by the other UPS. Thus a worst case failure of one UPS will lead to the loss of VCS control and monitoring for only two generators and not the whole generating system.

b) Standard UPS Operation Description: The UPS batteries are constantly on float charge in readiness for a failure of the main supply. If the main supply should fail, the batteries will supply the VCS. The changeover to battery power will be transparent to the operator other than an alarm being raised at the VCS workstation. The UPS can be switched such that the supply is bypassed and there is no battery back up in the event of main power failure. This mode of operation is to allow maintenance to be carried out on the UPS.

3.5.8 - PMS Control & Monitoring Functions

The control and monitoring functions of the Power Management System (PMS) are modelled using a series of standard functions, that can be configured for the application as required. These are instantiated as many times as the number of real devices for which they are modelling their behaviour.

Together with their functional SW block, most have an HMI popup window or HMI controls that enable the operator to command to the system from the Workstations and finally, system status and alarm messages are displayed to warn the operator of any urgent action or execution confirmation. The functions control and additional monitoring is achieved via pop up windows that are accessed by clicking on the sensitive areas and tick boxes on the mimic.

FUNCTION DIAGRAM

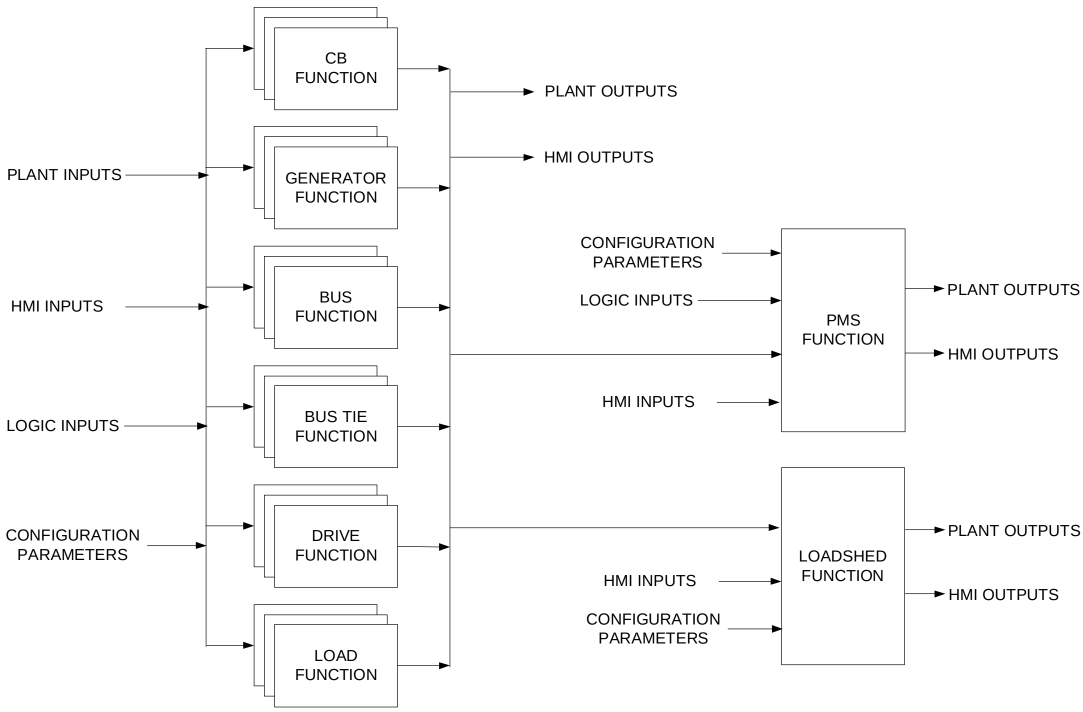


Figure 3.38 – VCS - Control & Monitoring Functions Diagram [17].

STANDARD SYSTEM COLOURS

For symbol animation & alarming the colour indication used is:

Table 3.3 — PMS – Symbol & Alarm System Colours

Condition	Colour
Running/Energised/Open	Green
Not Running or Not Energised	White
Fault Alarm/Closed	Red

Condition	Colour
Warning Alarm	Amber
Blocked	Cyan
Bad data	Blue

SWITCHBOARD CONTROL:

These functions are used to provide control of two types of Power Switching Devices: the circuit breakers and the busties.

The PMS uses bus tie breaker functions to determine how switchboards are split for control purposes.

a) Definitions:

i. Circuit Breakers: Used to control the power flow from generators onto the generation switchboards/busbars

ii. Busties: Used to interconnect two busbars or voltage level step up/down devices (transformers)

b) Main Functions:

i. Interlocking: Is the facility to inhibit the device from opening/closing based on defined system plant conditions, i.e.: Remote, No Lockout Trip, Available.

ii. Position check: The state of a breaker is determined using the inputs that are available and configured. The following options are possible:

1) Open and closed inputs only
2) Closed input only
3) Open and closed inputs and an analogue input - The analogue input can be used to determine the breaker state (e.g. current or power). If the open/close inputs are inconsistent the analogue signal is used to "vote" on the most likely breaker state
4) Closed input and an analogue input

iii. Low Confidence: A “low confidence” alarm state is raised after a configured time period if:

1) More than one indication is available and some or all are not consistent
2) A transducer fault is detected on the analogue parameter

c) HMI Symbols & Interaction:

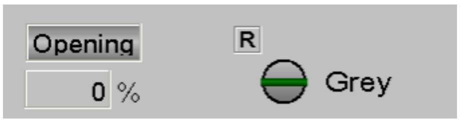


Figure 3.39 – VCS - Circuit Breaker/Bustie Symbol [17].

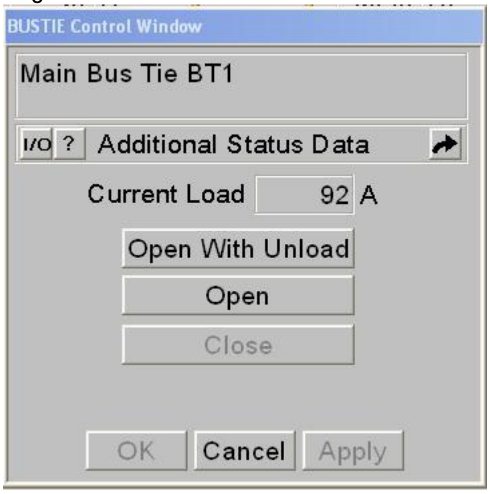


Figure 3.40 – VCS - Circuit Breaker/Bustie Control Window [17].

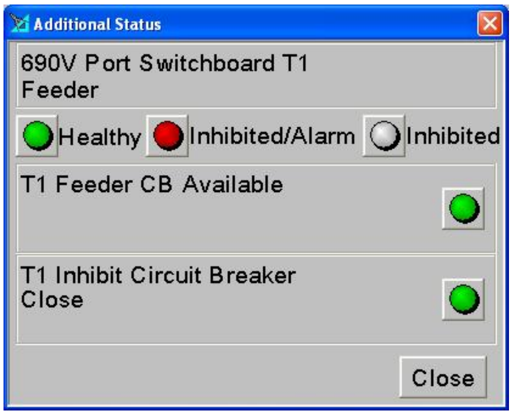


Figure 3.41 – VCS - Circuit Breaker/Bustie Status Window [17].

BUS SECTION

This function is used to provide monitoring of a bus section, and to define bus sections which form a part of the overall power system.

a) Main Functions:

i. Spinning reserve calculation: Spinning reserve is the total generator rating minus the total consumption on that bus. Note that the active power and reactive power values used may have been Derated.

ii. Bus section definition: The bus section identity is defined, which is used within the PMS to determine which devices are connected to the bus section.

iii. Low power margin/standby generator start: Facility provided so that on receipt of a low power margin signal, from the DP system, or other external system signal, the next available standby generator is started.

iv. Dead bar: A "dead bar" condition can be determined by a defined system condition, like an external Dead Bus relay. This is used to determine whether the bus section is in a blackout condition.

v. Auto start/stop permitted: Facility provided so that under certain system conditions the PMS can be inhibited from any automatic generator start/stop control for the bus section zone.

b) HMI Symbol:

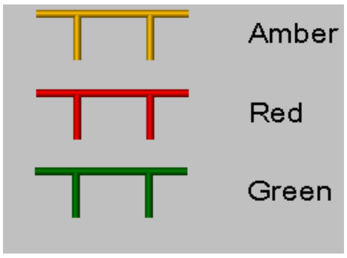


Figure 3.42 – VCS - Bus Symbol [17].

GENERATOR/TURBINE CONTROL

This function is used to provide generator & turbine control and monitoring facilities. The operations of Generator Start/Stop, Load/Unload, Fixed Target/Derating Volts/Frequency and fuel control are the main core ones.

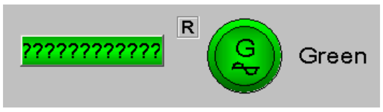


Figure 3.43 – VCS - Generator Symbol [17].

a) Main Functions:

i. kW & kVAr setpoints: Regardless of which Generator Ratings are available or which operating mode, this function is always calculating the kW & kVAr setpoints where the individual gen/turbine (or groups of them) need to contribute, as per the image on the right:

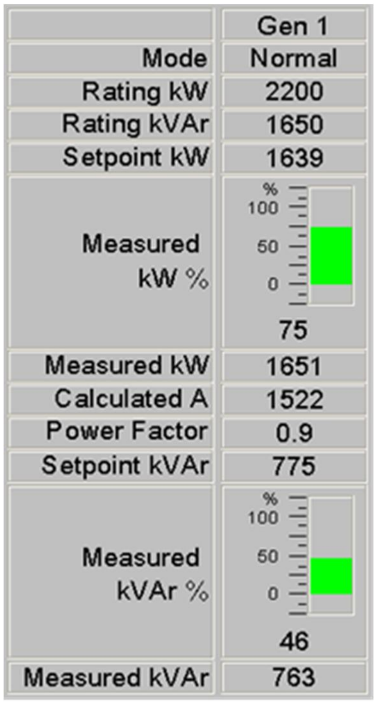


Figure 3.44 – VCS - Generator kW & kVArs Setpoints [17].

ii. Fuel Mode: A generator may be configured for single, dual fuel, or tri-fuel. A single fuel generator engine may be a diesel, or a gas turbine, but can only use one fuel. A dual fuel generator engine (as on a LNGC contract) can take marine diesel oil (MDO) and gas fuel. A tri-fuel generator engine (as on a LNGC contract) can take marine diesel oil (MDO), heavy fuel oil (HFO) and gas fuel. Typical function configuration parameters for diesel (MDO or HFO) and gas operation are:

1) Ramp up / down rates
2) Governor and AVR speed control characteristic
3) Rate at which load sharing calculations are carried out

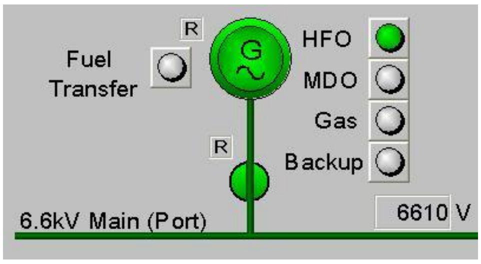


Figure 3.45 – VCS - Generator Fuel Mode [17].

iii. Start sequence: The generator start plant digital output is set. PMS then expects to receive the running at rated speed feedback signal within a certain time period.

iv. Load up control: Load up requests may be issued when the load up permissive is set and a generator is running at rated speed off the bars or is stopped. When a load up request is issued with the generator running at rated speed, the breaker close digital output is set immediately and PMS speeds up the generator to rated speed before setting the breaker close request. The breaker close digital output is normally taken to a synchroniser that ensures the generator and the existing supply is running in phase before the synchroniser gives the command to close the breaker. If configured for frequency and/or voltage control, after the configured settle down time the PMS loads up the generator by pulsing its governor and AVR.

Figure 3.46 – PMS - Generator Control Window [17].

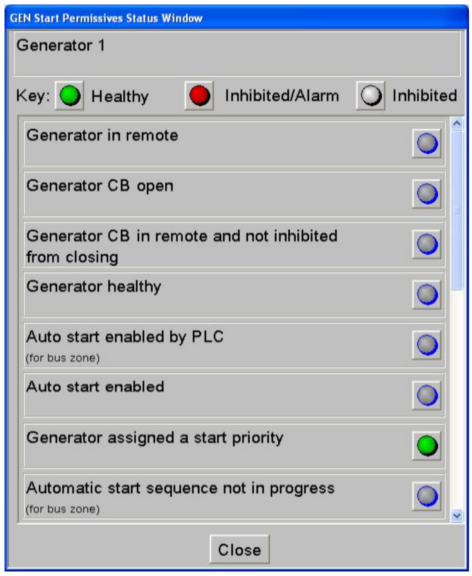


Figure 3.47 – PMS - Generator Permissives Window [17].

v. <u>1st Stage Shutdown:</u> Predefined Typical plant inputs can be used to activate a 1st stage shutdown such as oil temperature high, oil pressure low and engine cylinder high temperature. When a Stage 1 Shutdown is triggered, the next priority standby start generator is started and loaded on the bars. Once the standby generator achieves load sharing the faulty generator is unloaded and undergoes a normal stop sequence including the cool down period.

Note that once a shutdown is initiated it is latched and the sequence will complete even if the shutdown conditions no longer holds. If a Stage 1 Shutdown happens when no standby generators are available for starting, the affected generator stays running until a load dependent stop condition arises. The generator with Stage 1 Shutdown is stopped ahead of any other generator with a higher stop priority (lower numerical priority).

vi. <u>2nd Stage Shutdown/Fast Stop:</u> If the generator is running off the bars, then a stop request is issued to the engine straight away. If the generator is running on the bars, then a stop request is issued at the same time as an open request is issued to the generator breaker. If a generator is given a 2nd Stage Shutdown/fast stop command, its standby start priority is removed making it unavailable for standby start until the priority is reset by the operator.

vii. <u>Derating:</u> A gas turbine generator may require to be derated from its nameplate value as the ambient air temperature increases. However, if the load falls low enough that all set-points are below the minimum load share value, or are overloading then the system will exit fixed target load and return to normal load sharing. A fixed target machine is included in load dependent start and stop control based on its fixed target values. If configured, a generator is derated using an analogue input of temperature & separate derating curves based on the fuel currently in use (diesel or gas).

A generator may be individually derated by the operator, or automatically via SW code. The active power and reactive power may be derated independently. The operator entry, or auto setpoint is limited between the nameplate rating and the configured minimum load a generator may take when load sharing. When load sharing, the system will load the derated machine in proportion to its new rating. A derated machine is included in load dependent start and stop control based on its derated values.

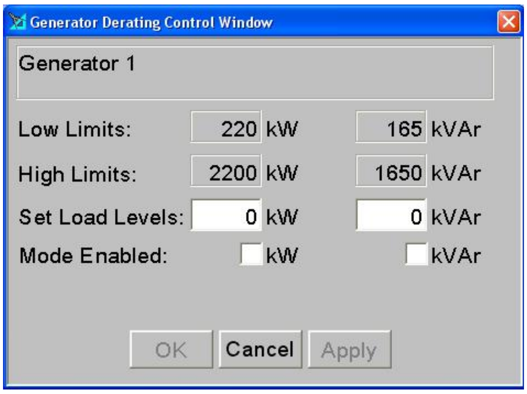


Figure 3.48 – PMS - Generator Derating Control Window [17].

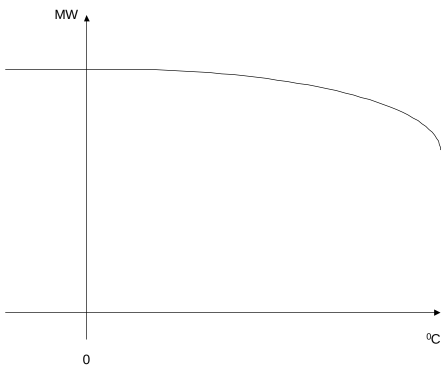


Figure 3.49 – PMS - VCS – Gen. Derating Curb [17].

viii. Fixed Target (asymmetric load sharing): A generator may be individually set to a fixed load by the operator, or automatically via SW coding. The active power and reactive power may be fixed independently. The operator entry or auto set-point is limited between the nameplate rating and the configured minimum load a generator may take when load sharing. If a fixed target load is applied to a generator, then that generator is fixed at that load and does not take part in the load share. The remaining load is shared amongst the other generators on the common busbar section.

If the system calculates that another sharing generator will overload its current rating, or will make its set point go below the configured minimum load a generator may take when load sharing, then the fixed target set point will be adjusted to prevent an over or under load on the generator. If normal load levels return, the fixed target set-point will be reinstated, and the system will return to controlling its fixed target.

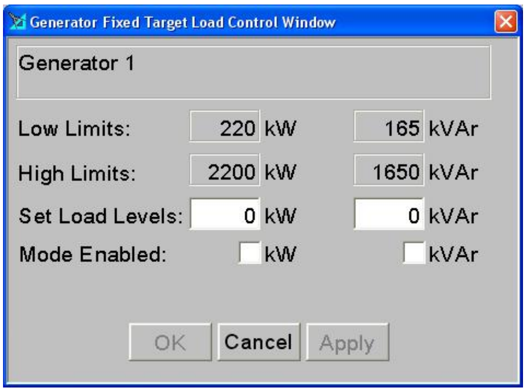


Figure 3.50 – PMS – Gen. Fixed Target Control Window [17].

POWER MANAGEMENT SYSTEM CONTROL

The Power Management function acts as the main maestro for all the power related functions, that is, it receives plant data from all the power functions and performs top level power control.

This function is used to provide overall functional control of the power system. It integrates the power system devices to provide full array of power management features.

Figure 3.51 – PMS - Main Control Window [17].

a) <u>Main Functions:</u>

i. <u>Automatic generator start/stop control</u>: The objective of automatic start and stop is to minimise the number of running generators while maintaining integrity of supply in the event of generator failure. A generator in standby may be started automatically under the circumstances:

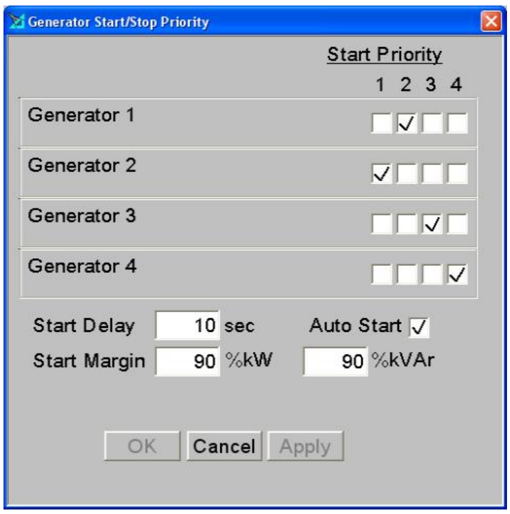


Figure 3.52 – PMS - Generator Start/Stop Priorities [17].

1) After a blackout
2) Load calculation shows deficit in generating capacity (load dependent start)
3) Less than minimum number of generators are running
4) The operator uses "start gen/motor" button to start a heavy consumer
5) A low power margin signal input is initiated by an external system

A running generator may be stopped automatically under the following circumstances:

1) A 1st stage shutdown condition is detected.
2) The load calculation shows a surplus in generating capacity (load dependent stop).

The operator uses the HMI to enable/disable automatic start and stop and to assign standby start and stop priorities for each generator.

ii. Load Dependent Start & Stop: There are two types of load dependent start:

1) Percentage Load: The system starts the next priority standby generator in a zone if an online generator has exceeded a fixed percentage of its active power rating or reactive power rating, for more than a configurable time period. Note that the active power and reactive power values used may have been derated.
2) Spinning Reserve: The system starts the next priority standby generator in a zone if the active power or reactive power spinning reserve for that zone is less than a pre-set value for more than a configurable time period. Spinning reserve is the total generator rating minus the total consumption on that bus. Note that the active power and reactive power values used may have been derated.

iii. Min no. of Generators: The operator can specify the minimum number of generators required to be running in a zone at any one time. If less than this number are running and a standby is available, then subject to the current load conditions the standby is requested to start after a configurable delay. Note that if the minimum number of generators is increased above the current number running, the next standby is requested to start after a configurable delay. If the minimum number of generators is reduced below the current number running, the load dependent stop functionality is activated and the next standby stop generator will stop only after an auto stop condition has been present for the configured delay period.

If the number of generators currently running in a zone is less than the value set, the system only starts the next priority standby generator if as a result all generators already on the bars will be loaded with more than the minimum load share value configured. An alarm is raised if this condition applies for more than a configured time period.

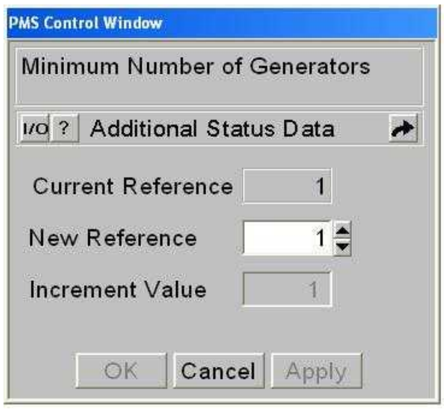


Figure 3.53 – PMS – Minimum Number of Generators [17].

iv. <u>Frequency/Voltage and Active/Reactive Power control:</u> As mentioned in previously, the PMS can maintain the whole electrical system around its operational frequency & voltage levels, even on situations when a big load is connected or disconnected, which could cause frequency & voltage fluctuations that can, on an ultimate case, cause an electrical black out. The system can be configured for one of the following types of control:

1) <u>No frequency/Voltage control by PMS:</u> Power control is performed solely by the governor & voltage regulator control systems (isochronous control of frequency & Voltage), not by the power management system. Operator derating and fixed target modes are unavailable. Unload commands are dealt with via an output to the governor control system.
2) <u>Frequency & Voltage control by PMS:</u> Generators which are connected in parallel and not in fixed target mode are controlled to:
    a. Maintain the steady state frequency & voltage of a common busbar to a demand set point
    b. Share the busbar active & reactive power loading in proportion to their respective ratings.

This is done by control of the prime mover governors & AVRs. To calculate the required pulse lengths, PMS uses the error between the frequency measurement and the frequency setpoint entered by the operator or the error between the active power measurements and the calculated active power setpoints for each generator. If the errors are not within a pre-defined dead band, speed & voltage raise or lower pulsed output commands are sent to the respective governor(s) & AVR(s) to adjust individual generator governor & exciter setpoints.

Each generator has a speed regulator, called a governor & an exciter that regulates voltage at the generator output terminals which is in turn controlled by an automatic voltage regulator (AVR). A generator is controlled by adjusting the speed reference to the governor & by adjusting the voltage reference to the AVR. When generators are running in parallel:

a. The system frequency is a function of the individual speed references, and the effect of increasing a generator’s speed reference is to increase its share of active power.
b. The system voltage is a function of the individual voltage references, and the effect of increasing a generator’s voltage reference is to increase its share of reactive power

For Generators selected for load sharing:

a. Their respective prime mover governor selecting to “droop” control. In this case generator speed is affected by changing load, i.e. as more power is taken a generator slows down and vice-versa.
b. Require their respective AVR selecting to “droop” control. In this case generator voltage is affected by changing reactive load, i.e. as more reactive power is taken the voltage falls and vice-versa.

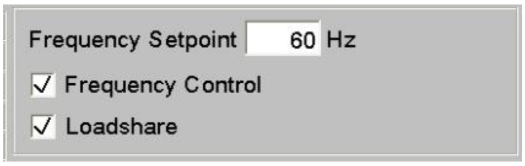


Figure 3.54 – PMS – PMS Frequency/Active Power Control [17].

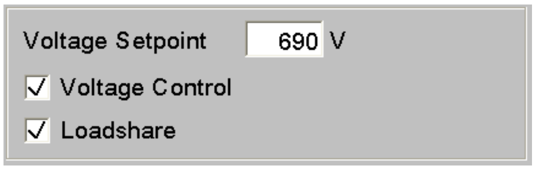


Figure 3.55 – PMS – PMS Voltage/Reactive Power Control [17].

LARGE CONSUMER START/STOP (DRIVE)

This function is used to provide start and stop control of large consumers, with functionality to avoid significant disturbance on the power system.

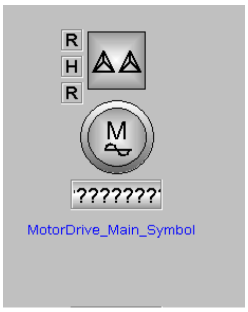


Figure 3.56 – PMS – Large Consumer/Drive Symbol [17].

Figure 3.57 – PMS – Drive Control Window [17].

A drive can be blocked from starting if there are insufficient spinning or starting reserves available for the zone. There is a choice from two strategies for start blocking, which applies to the whole PMS system.

a) Starting kVAr: The start of the drive is blocked if the drive active or reactive power rating is larger than the active or reactive spinning reserve respectively, or if the drive starting reactive power is greater than the starting reserve.
b) Transient voltage dip: The start of the drive is blocked if the drive active or reactive power rating is larger than the active or reactive spinning reserve respectively, or if the calculated transient voltage dip for the zone will be greater than a configured percentage.

   If the function instance has a large power rating when the operator wants to start it, the PMS function must decide whether there is enough spinning reserve in the system. If there isn't the Start button is altered to Start (G) to indicate that another generator will be started and loaded before the start of the device is carried out. If there isn't a standby generator, the Start (G) button will be shown but it will be unavailable.

LOAD SHEDDING (LOADSHED)

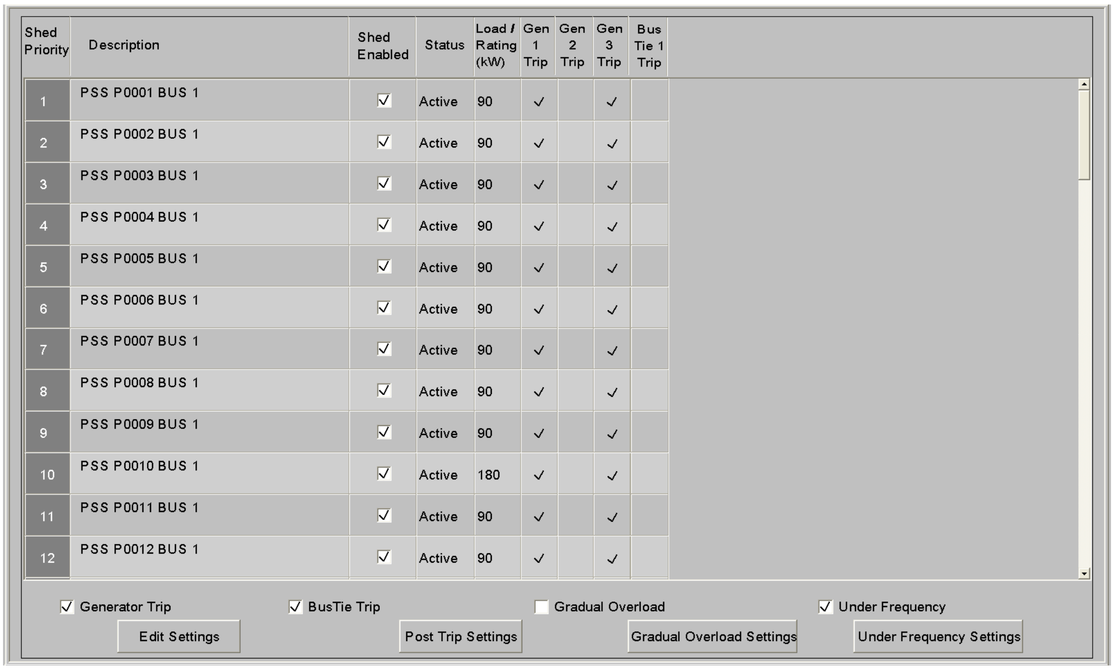
The objective of the load-shedding system is to maintain generation of power within capability by tripping any non-essential loads whenever a "load-shed" condition arises.

The capability is the current rating of the generator, which will be either the full rating or a derated value. There are four types of load-shed functionalities:

a) Device trip list: For each plan the system continuously generates a list of devices to trip, such that in the event of a trip of an associated bustie sufficient loads would be shed to ensure the generators on the bus section to which the power is being imported remain under a pre-set maximum percentage load value.
b) Generator trip plans: A trip plan can be provided for each generator in the system. For each plan the system continuously generates a list of devices to trip, such that in the event of a trip of that generator sufficient load would be shed to ensure the remaining online generators on that bus section remain under a pre-set maximum percentage load value.
c) Gradual Overload: The system accumulates overload integrals (Watt-Seconds), over a configured time period, for those online generators whose loads exceed their capabilities. The accumulated integral is reset each time the load falls below the capability. When the integrated value reaches a higher level system then attempts to shed enough load at the same time to reduce the load on all overloaded generators to

be equal to or less than their capabilities. When this has been achieved the integrals are reset.

d) Under frequency: The system monitors busbar frequency and raises a warning alarm if it falls below a pre-set warning level for a pre-set time. If it falls below a pre-set alarm level for the pre-set time, a further alarm is raised and load-shedding is initiated. The time delay prevents spurious alarms and load-shedding operating for a transient dip in busbar frequency, e.g. due to a sudden application of load.



Shed Priority	Description	Shed Enabled	Status	Load / Rating (kW)	Gen 1 Trip	Gen 2 Trip	Gen 3 Trip	Bus Tie 1 Trip
1	PSS P0001 BUS 1	☑	Active	90	✓		✓	
2	PSS P0002 BUS 1	☑	Active	90	✓		✓	
3	PSS P0003 BUS 1	☑	Active	90	✓		✓	
4	PSS P0004 BUS 1	☑	Active	90	✓		✓	
5	PSS P0005 BUS 1	☑	Active	90	✓		✓	
6	PSS P0006 BUS 1	☑	Active	90	✓		✓	
7	PSS P0007 BUS 1	☑	Active	90	✓		✓	
8	PSS P0008 BUS 1	☑	Active	90	✓		✓	
9	PSS P0009 BUS 1	☑	Active	90	✓		✓	
10	PSS P0010 BUS 1	☑	Active	180	✓		✓	
11	PSS P0011 BUS 1	☑	Active	90	✓		✓	
12	PSS P0012 BUS 1	☑	Active	90	✓		✓	

Figure 3.58 – PMS – LoadShed Control Window [17].

BLACKOUT RECOVERY

This is one of the most important functions functions and the main intended usage for a Power Management Systems, due its automated sequence & executed autonomously by the PMS (when configured) and its main purpose is to quickly recover the power system in order to minimize the time for vessel drift off, or re-connection of equipment and/or personnel.

a) Main objective: The primary function of the blackout recovery is to recover power to the following vessel switchboards should a total or partial blackout occurs:

i. Generation Switchboards: Typically, 6kV or 11kV level
ii. Auxiliary Switchboards: Typically, 480V or 690V level
iii. Non-Essential/Service Switchboards: Typically, 120V or 230V level. And the PMS will perform the above sequences based on:

1) Loss of one or two Generation switchboards (partial blackout)
2) Total loss of generation (total blackout)

The recovery sequence is applied to each dead Swbd independently & simultaneously.

b) Detection:

i. There are no generators connected to the Generation switchboard (the appropriate generator CB's are open) and the appropriate bus tie CB's are open or "dead bar" input is set for one, or more bus sections
ii. Generation Switchboard voltage is < 6kV (or 11kV) for longer than a certain amount of time.

c) Recovery sequence: The PMS blackout recovery sequence is divided into:

i. Blackout detection
ii. Generation Swbd blackout recovery:

   1) The PMS will attempt to start all available generators associated with the dead 6/11kV switchboards, with delays between each start
   2) The first generator to reach rated speed will be dead bar closed onto the switchboard by the PMS. If this close attempt fails, the PMS moves onto the next running generator.
   3) Once the Generation switchboard is live, the PMS moves onto the Auxiliary Swbd recovery

iii. Auxiliary Swbd blackout recovery: The PMS attempts to load up the Service Transformers, first incomer CB and after feeder CB, to bring the Auxiliary Swbds back to live
iv. Essential auxiliary restart: After, its time for MCCs (Motor Control Centres) to be reconnected, bringing all propulsion auxiliary systems to back to live
v. Thruster restart:

   1) PMS will attempt to start all previously running thrusters, as soon as power is restored to the appropriate aux. switchboard
   2) A 'Drive Fault Reset' command is issued to the drive in order to reset any alarms generated as a result of the blackout.

3) As soon as the appropriate pre-conditions have been met the PMS will issue a thruster start command to the appropriate thrusters

vi. Drilling reconnection: As part of the recovery sequence, the PMS will attempt to close the drilling transformer primary CB, to allow the previously running loads to be reconnected and resume drilling operations

vii. Non-Essential/Service Swbd blackout recovery: Finally, for systems like HVAC, kitchen, etc.…

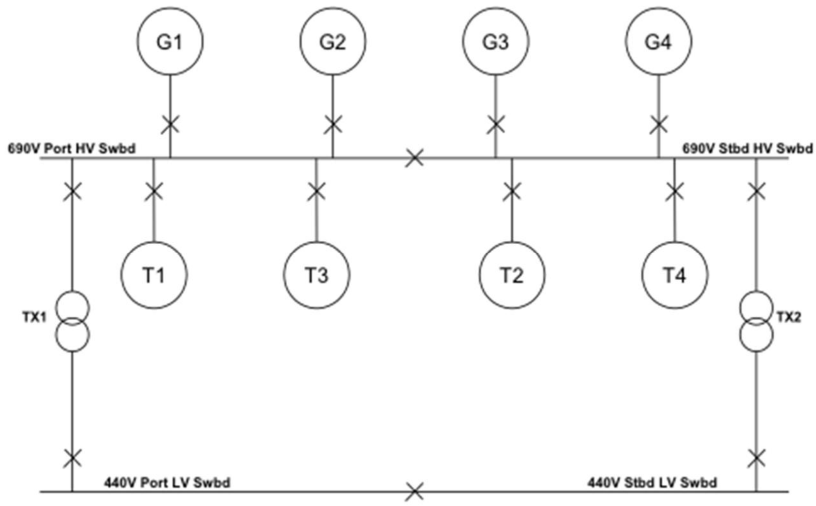


Figure 3.59 – PMS – Blackout Recovery Swbd [17].

3.5.9 - VMS Control & Monitoring Functions

As per their PMS counterparts, the control and monitoring functions of the Vessel Management System (VMS) are modelled using a series of standard functions for all non-electrical control & monitoring needs, with the same SW block, HMI control (popup or windows) and system status and alarm messages. Their functionality generally includes:

- Remote control & monitoring of pumps and valves via the VCS using the HMI
- Automatic starting of pumps & valves on detection of loss of pressure, temperature variation, on-line pump tripping & sensing of pressure/level switch contacts
- Tank level monitoring & control using valves and pumps
- Pressure and temperature monitoring of auxiliary equipment

This involves the process of “translating” a very large numbers of P&IDS (Piping &Instrumentation Diagrams), like the below example:

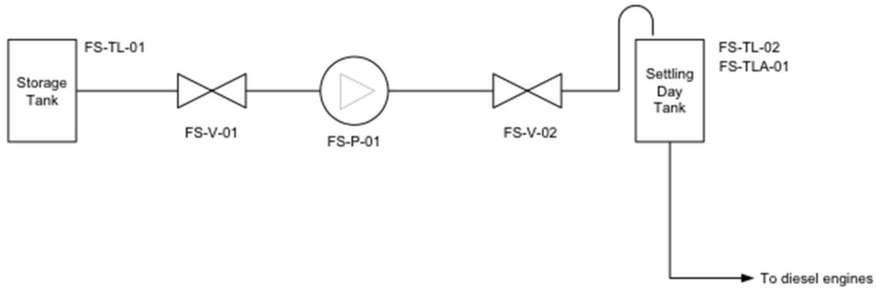


Figure 3.60 – VMS - Typical P&IDs Diagrams [22].

Into fully operational VMS HMI mimics for the operator as per below example:

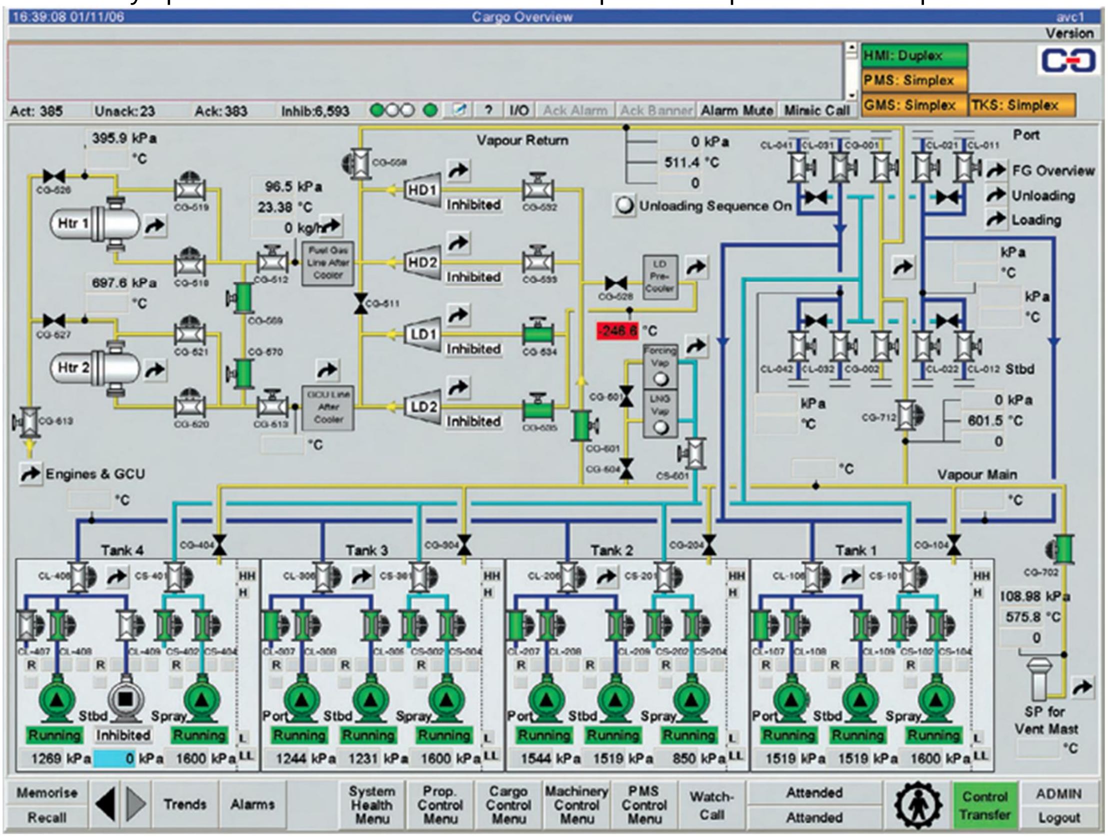


Figure 3.61 – VMS - Typical HMI Screen.

PIPING COLOURS

Piping colouring is normally used to indicate what kind of fluids or gas is circulating on them. For example, and considering the above VMS HMI screenshot, we can see a Starting Air system (cyan), together with a Lubricating Oil system (yellow) and a Compressed Air system (dark violet), all working towards a Cargo System.

VALVE CONTROL:

These functions are used to provide control of two types of valves: digital & analogue output commands.

a) VOO - On/Off valve: An on/off (open/close) valve is modelled using a VOO function. This function is used to provide individual digital open/close commands of the device as well as positional feedback.
b) VSR - Spring return valve: A spring return valve is modelled using a VSR function. This function is used to provide single digital open command of the device, as the the valve spring is always trying to close itself through the mechanical force applied from the spring. Also has the positional feedback.
c) VTH -Throttle valve with analogue position feedback: The VTH valve uses external hydraulic system to control a variable (0-100%) valve position. This is achieved by sending an analogue output signal with the new desired position setpoint and then receiving the current position feedback until it reaches the setpoint.

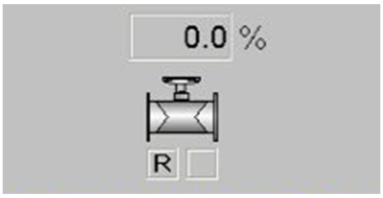


Figure 3.62 – VMS - VTH Valve Symbol [19].

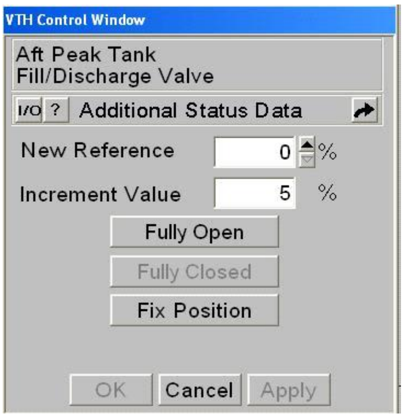


Figure 3.63 – VMS - VTH Valve Control Window [19].

PUMP CONTROL

These functions are used to provide control of several types of pumps & fans. These can be single, dual speed with standby & triple standby pair arrangement & finally, with forward or reverse direction.

a) PSS - Single speed device: A single speed, single direction device is modelled using a PSS function. This function is used to provide individual digital start/stop commands of the device as well as running status feedback.
b) PDSFR - Dual speed or direction device: This function is used to provide individual digital commands for Start Speed 1 & 2 and stop, together with Reverse or Forward direction, with individual status feedbacks for Running at speed 1 & 2.
c) P(2)3STBY – Standby/Triple standby configuration for single speed devices: The P2STBY & P3STBY functions are used to model the start/stop control of two & three single speed, single direction devices, in a standby arrangement. Typical devices include essential services pumps. The standby start of a device in standby mode is performed if the online device has tripped and the device to be started has the highest standby start priority or, after a delay period, if the standby start (pressure status) input signal is unhealthy & device to start has highest standby start priority.

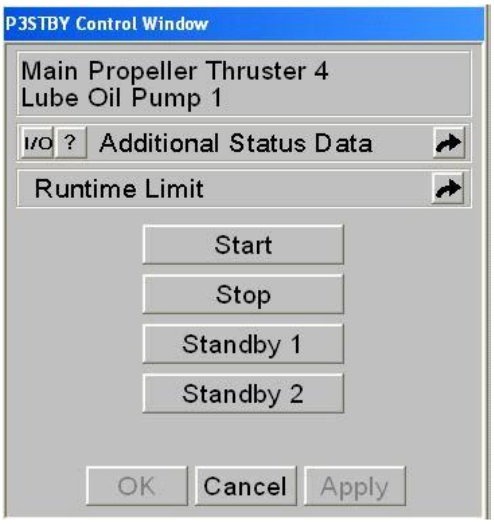


Figure 3.64 – VMS - P3STBY Pump Control Window [20].

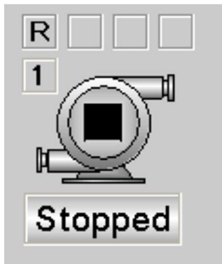


Figure 3.65 – VMS - P3STBY Pump Symbol [20].

RUNNING HOURS

The running hours for a device is monitored and recorded using a RUNHRS function. This function is used to provide monitoring of the running time of plant devices. It is associated with devices which include a running signal, e.g. pumps (PSS) and generators (GEN).

The facility to monitor the running state of items of equipment and maintain statistics on the run-hours of each item is provided. For each applicable item of equipment, a "Current" running hour value is maintained. The "Current" run-hours can be reset to zero by the operator (e.g. after maintenance or major repair to the equipment).

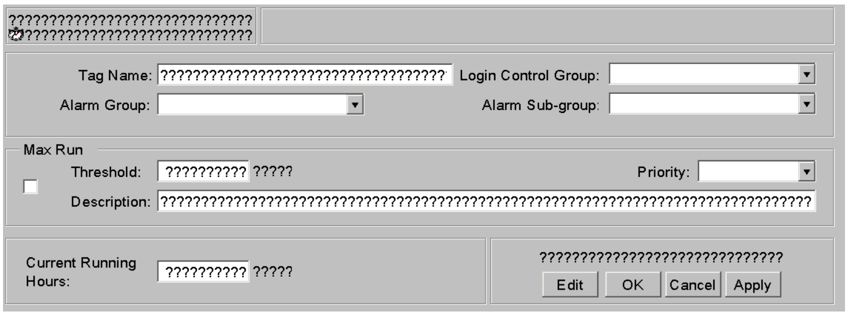


Figure 3.66 – VMS - Running Hours Control Window [21].

TANK GAUGING

The Tank Gauging functionality is provided using two standard functions:

- <u>TANK</u> - Used to correct level measurement for trim and list motion of the vessel and derive volume, weight and percentage fill estimates for the tank.
- <u>SHIP</u> - Used to calculate trim and list motion of the vessel. It also provides total and group volumes and weights of the tanks.

a) <u>Input Feedback type:</u>

i. Level
ii. Single Bottom Wet Pressure
iii. Bottom Wet and Dry Pressures
iv. Bottom and Middle Wet Pressures
v. Density, Volume & Weight

b) <u>Sensor Type:</u> Measurement is typically done in two ways:

i. Measurement is perpendicular to fluid surface (likely for pressure sensors).
ii. Measurement is perpendicular to bottom/top of tank (for ultra sonic sensors).

The measured level depends on the type of sensor used to measure the pressure. If a pressure sensor is used, the measurement *hp* is taken, which is perpendicular to the surface of the fluid. Another type of sensor (e.g. ultrasonic) may measure *hm* directly, which is perpendicular to the bottom of the tank in our example. The sensor offset from the bottom of the tank is given by *h0*.

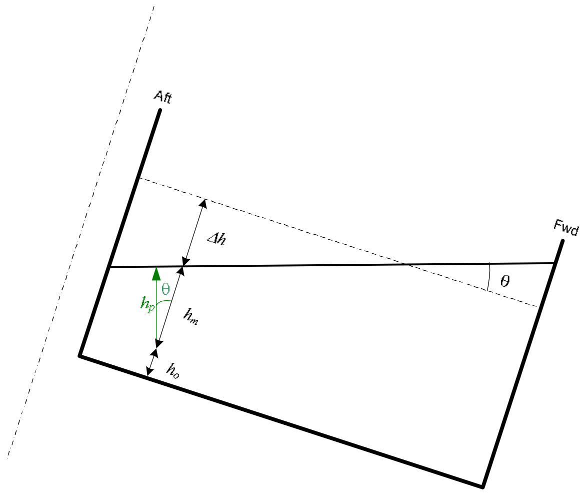


Figure 3.67 – VMS – Tank Gauging Sensor [21].

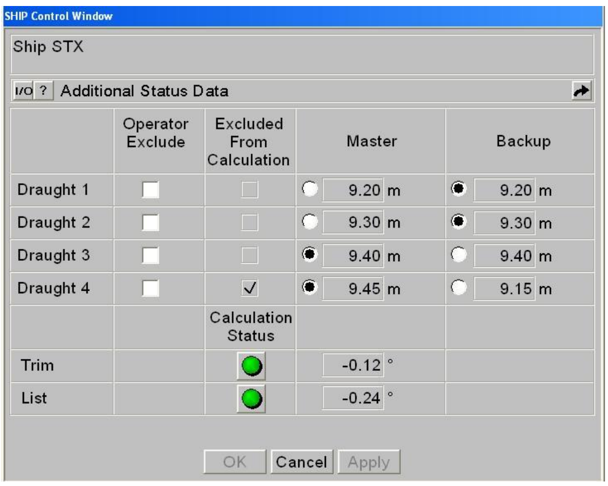
c) <u>Use tank table pressure:</u> A “wet” pressure feedback is available for a tank, and pressure is available in the tabular data from the ship yard, so the TANK function can convert the pressure measurement into a level by interpolating in the tank gauging configuration table, which is composed of some of the elements below:

i. Level, Volume, Pressure or Weight
ii. LCG - Longitudinal centre of gravity of the tank
iii. TCG - Transverse centre of gravity of the tank
iv. VCG - Vertical centre of gravity of the tank
v. FSMT - Free surface moment at tank surface in the transverse direction
vi. FSML - Free surface moment at tank surface in the longitudinal direction
vii. WPA - Water plane area of the tank

Table 3.4 — VMS - Tank Gauging Table Example.

#Tank 1 - NO.1 MDO SERV.TK		
LEVEL	VOLUME	VCG
0	0	6.301
0.2	1.6	6.4
0.4	3.2	6.5
0.6	4.8	6.6
0.8	6.5	6.7
1	8.1	6.8
1.2	9.7	6.9
1.4	11.3	7
1.6	12.9	7.1
1.8	14.5	7.2
2	16.2	7.3
2.2	17.8	7.4
2.4	19.4	7.5
2.6	21	7.6
2.8	22.6	7.7
3	24.2	7.8
3.2	25.9	7.9
3.5	28.3	8.05

In above table the following are constants: TCG=-12.9 & LCG=137.6.



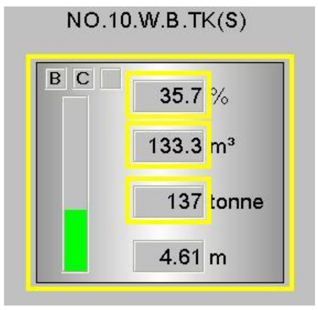


Figure 3.69 – VMS - TANK Symbol [21].

Figure 3.68 – VMS - SHIP Control Window [21].

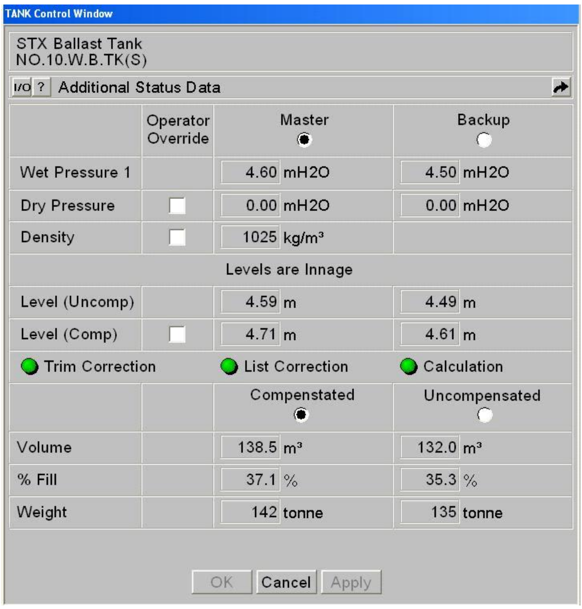


Figure 3.70 – VMS - TANK Control Window [21].

3.5.10 - Marine Regulation:

IMO

The International Maritime Organization (IMO), is a specialised agency of the United Nations which is responsible for measures to improve the safety and security of international shipping and to prevent pollution from ships.

It is also involved in legal matters, including liability and compensation issues and the facilitation of international maritime traffic. More recently the IMO has also increased its focus on air emissions from ships.

a) History: The IMO was established in Geneva in 1948 and came into force ten years later, meeting for the first time in 1959. Headquartered in London (UK), the IMO has 171 Member States and three Associate Members.

Figure 3.71 – Regulation – IMO [1].

b) Main Guidelines: The IMO's primary purpose is to develop and maintain a comprehensive regulatory framework for shipping and its remit today includes safety, environmental concerns, legal matters, technical co-operation, maritime security and the efficiency of shipping. IMO is governed by an assembly of members and is financially administered by a council of members elected from the assembly.

SOLAS

Safety of Life at Sea Convention (SOLAS), first adopted in 1914 following the Titanic disaster, has been accepted by more than 162 countries and covers all but a fraction of the world merchant fleet.

Main produce new and updated instruments across a wide range of maritime issues covering not only safety of life and marine pollution but also encompassing safe navigation, search and rescue, wreck removal, tonnage measurement, liability and compensation, ship recycling, the training and certification of seafarers, and piracy. However, the flag State ("Administration") may "entrust the inspections and surveys either to surveyors nominated for the purpose or to organizations recognized by it" (SOLAS Chapter 1, regulation 6).

More recently SOLAS has been amended to bring an increased focus on maritime security through the International Ship and Port Facility Security (ISPS) Code.

IACS & CLASSIFICATIONS SOCIETIES:

The International Association of Classification Societies (IACS) is a Non-Governmental Organization which was granted Consultative Status with IMO in 1969.Dedicated to safe ships and clean seas, IACS makes a unique contribution to maritime safety and regulation through technical support, compliance verification and research and development. More than 90% of the world's cargo carrying tonnage is covered by the classification design, construction and through-life compliance Rules and standards set by the twelve Member Societies of IACS.

CLASSIFICATION SOCIETIES/SURVEYORS

A classification society is a non-governmental organization that establishes and maintains technical standards for the construction and operation of ships and offshore structures. The society will also validate that construction is according to these standards and carry out regular surveys in service to ensure compliance with the standards. Classification societies are also responsible for classing oil platforms, other offshore structures, and submarines. This survey process covers diesel engines, important shipboard pumps and other vital machinery. Classification surveyors inspect ships to make sure that the ship, its components and machinery are built and maintained according to the standards required for their class.

Figure 3.72 – Regulation - Classification Societies [2].

All ships must be surveyed in ordered to be issued certificates which establish their seaworthiness, type of ship, and so on and this is the responsibility of the flag State of the vessel.

Most known Surveying Organizations part of the International Association of Classification Societies (IACS):

- ABS
- DNV
- Lloyds
- BV

a) Impact on Marine Automation Design: The impact of Classification Societies on the Marine Automation world is paramount, that is, it's present on the start of the proposal bidding process, defining boundaries & responsibilities to engage with Class, all the way through the design process, where all the drawings, functional & test specifications have to be submitted for its approval and finally, during the test phases, starting with the FAT "Factory Acceptance Test" (all finalize systems undergo an exhaustive & detailed testing of its operation & simulated main functionalities) performed at the suppliers facility and ending with the SAT "Site Acceptance Test", where all FAT tests are repeated this time on the equipment already installed & commissioned on-board the vessel, in a dock. Normally, to end up site testing, a final Sea Trials are also performed at sea, to evaluate the real ships performance & the effective response of the integration of very diverse systems.

b) Portuguese Classification Society/Surveyor: Portugal also has a Classification Society/Surveyor called RINAVE "Registro Internacional Naval" which was founded 1973 and has its headquarters in Lisbon. On 23 May 1974, RINAVE was officially recognised by the Portuguese Government as a Classification Society and authorised to perform surveys on their behalf in order to verify a vessel's compliance with international conventions, codes and resolutions covering safety at sea.

Figure 3.73 – Portuguese Classification Society – RINAVE [3].

Chapter 4

Future

Nowadays, there is a Marine Industry wide partnering throughout power, propel and position, enabling improved reliability, efficiency and precision gains in both vessel constructions & operation.

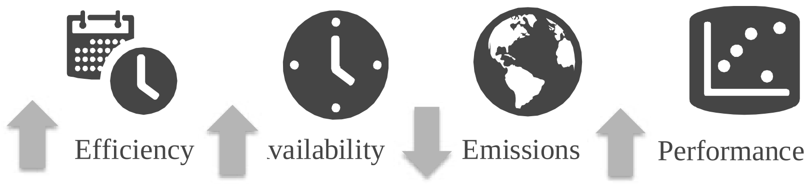


Figure 4.1 – Future Tendencies.

4.1 - Overall Target Trends

4.1.1 - Capex & Opex savings

Capital expenditure (CAPEX) as well as Operation expenditure (OPEX) are the main business savings objective of any ship or fleet vessel owner.

The initial investment for building a new vessel is a long & very hard working process: Starts by defining the vessel project type & intended world operational areas, also by choosing of the shipyard & the major suppliers for the on-board systems, while the Operation expenditure focuses more on the operation savings after the vessel has gone in operation, putting emphasis on lowering the fuel consumption, having the most efficient & trained crew, lower the maintenance while trying to maximize the daily operations, which can be as as much as $500k/day.

4.2 - Power Trends

The top key challenges for the future of marine power systems are:

- Reduced fuel consumption
- Reduced emissions
- Reduced maintenance levels

4.2.1 - Close Ring Operation - EGMS

Traditionally for DP vessels, system integrity has been achieved by operating with two or more separate power systems and all generators online. This, however, gives increased emissions and fuel consumption. In order to minimise fuel consumption and emissions, the number of online generators must be minimized, which means operating in closed bus to fully utilise available generating capacity.

The Enhanced Generator Monitoring System (EGMS), extends the functionality of the Protection System enabling safe and reliable operation in closed bus or closed ring configuration by detecting and, if necessary, isolating a faulty generator from the power system. This removes the faulty generator before the fault fully develops minimising the impact of the fault on the power system and mitigating the risk of blackout and subsequent loss of position.

ZONAL POWER SYSTEM CONCEPT & EGMS

The EGMS is an integral component of the Zonal Power System design, with one EGMS per Generator. The Zonal Power System design ensures safe operation of the vessel such that no single trip event or physical failure caused by fire or flooding results in an impact of that zone, minimizing the risk of loss of power and thereby position.

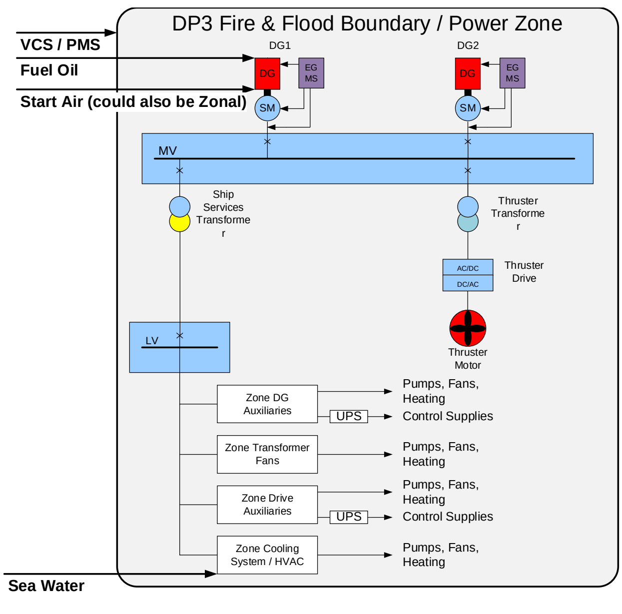


Figure 4.2 – EGMS - Zonal Power System [24].

By aligning the Zones within the Power System with the DP3 physical Zones, maximum advantage is taken of the redundancy built into the vessel design to manage the risk of fire and flood, to provide a robust solution.

This ensures that when the EGMS operates to either remove a faulty generator, or to remove a faulty bus-section where the fault cannot be isolated to a single generator, the impact on the power system is contained to that single Power System Zone.

SYSTEM HW & ARCHITECTURE

An overview of the EGMS hardware and architecture used is shown here.

The EGMS themselves are connected with a dual redundant network, to enable high speed data sharing.

This improves the speed of response to certain fault conditions.

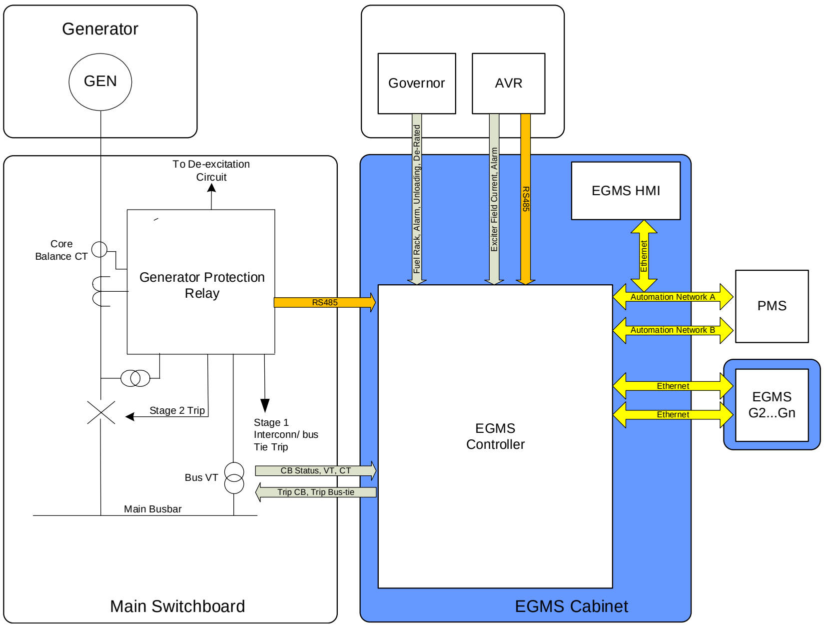


Figure 4.3 – EGMS - HW & Architecture [24].

4.3 - Propulsion:

The top key challenges for the future of marine propulsion systems are:

- Less operation time
- Fuel savings
- Less maintenance

4.3.1 - Propeller Pod Inovelis

This device, called the Inovelis pump jet, can swivel 360 degrees around its axis and push the ship in any direction without a rudder.

It is a motor placed in an external pod so in the water, which operates like a jet engine with fixed stator vanes inside a nozzle. The vanes straighten the water flow and guide it across the impeller blades. The blades get good water to attack and throw out the back. The result is a more efficient engine with a better thrust output.

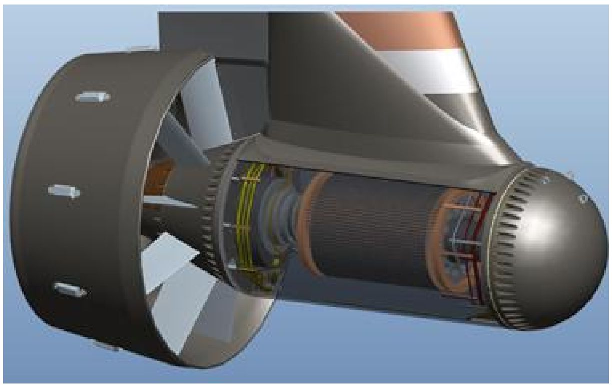


Figure 4.4 – Propulsion - Propeller Pod Inovelis.

Below are the key benefits of this propulsion technology:

- This electrical podded thruster is based on a pump-jet compact design with high efficiency over a wide range of operation.
- Pump jet arrangement with the stator vane in front of the impeller provides the same results as a contra-rotating system with simple arrangement.
- It can be used on starboard and port sides of the vessel for easier and more cost-effective management of spare parts.
- The electrical motor is based on reliable induction technology that can operate for extended periods without maintenance intervention.
- The fusion of electric propulsion and pump jet principles helps drive down fuel costs—for improved fuel efficiency compared to traditional solutions.

4.4 - Dynamic Position (DP):

The top key challenges for the future of marine DP systems are:

- Mariner focused
- Energy efficient mode
- Full system integration

4.4.1 - Fuel Efficiency Ship Mode

The Energy Efficient Mode is an automatic position and heading control.

Using predictive software to anticipate position variation and to limit thrust changes if the vessel is predicted to remain within the ‘soft’ operating window.

If the vessel is predicted to move outside its 'hard' operating window the system develops optimum thrust to remain within that window. Advanced algorithms are used to optimize vessel heading to further reduce power consumption & limit thruster/machinery wear/tear.

Table 4.1 — Fuel usage at different wind speeds [16].

Wind speed (m/s)	Fuel used in "Normal DP" (kg/hr)	Fuel used in Energy Efficient mode – fixed heading (kg/hr)	Fuel used in Energy Efficient mode – optimum head" (kg/hr)
5	947	835	834
10	966	852	848
15	1011	905	887
20	1115	1017	970
Weighted mean	971	860	854

Table 4.2 — NOx emissions at different wind speed [16].

Wind speed (m/s)	NOx in "Normal DP" (kg/hr)	NOx in Energy Efficient mode - fixed head (kg/hr)	NOx in Energy Efficient mode - optimum head" (kg/hr)
5	24.5	18.8	18.7
10	24.8	19.5	19.3
15	27.3	22.2	21.2
20	32.9	29.4	26.3
Weighted mean	25.4	20.0	19.6

The above two example tables, use the probabilities of the different wind speeds to produce a weighted mean figure, which reflects the average fuel and NOx rates over a one-year period. A 3600kW non DP load is also included.

4.5 - Automation:

The top key challenges for the future of marine automation systems are:

- Reduced fuel consumption
- Reduced emissions
- Reduced maintenance levels

4.5.1 - 3D HMI controls/Navigation & Multilanguage

For a mariner-focused solution, enhancing situational awareness and rebalancing attention from system management to true seamanship, while allowing Multilanguage HMI system for multinational crews, a new HMI visualization package has been developed & created as response.

This approach acknowledges the unique skills and high expectations of the mariners operating the system, allowing them to re-focus on seamanship and ship handling rather than becoming distracted by DP system management, as per below table:

Table 4.3 — Automation - 3D HMI controls/Navigation & Multilanguage.

Features	Benefits
Configurable displays show data in clear and uncluttered form	Easier and faster system navigation
Operator/task specific information prioritization	Improved focus on positioning the vessel rather than manipulating the control system
Screen display available in different language versions	Improved focus on the task in hand for non-English speakers
Intuitive in operation in both routine and adverse operating conditions	Helps improve decision-making in routine and pressurized operating conditions
Suitable for use by operators with all levels of experience	Helps minimize the time taken for operators to become proficient, including speedy transition from other manufacturers' systems
Directly connects user with the wealth of features and improves access, interpretation and manipulation of all connected data and systems	Helps reduce potential operator error

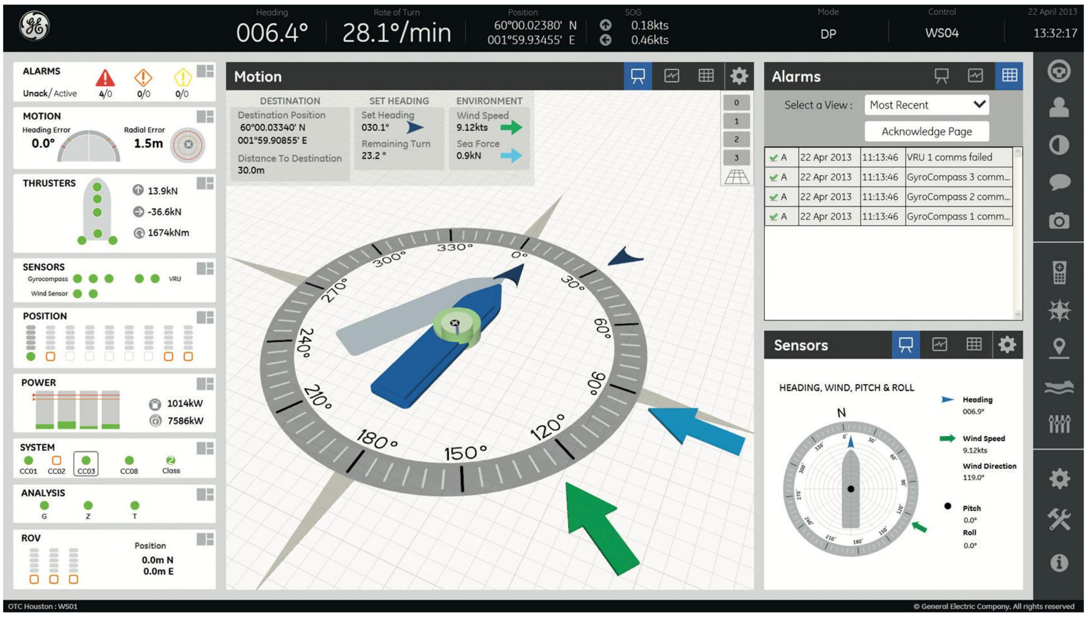


Figure 4.5 – Automation - New 3D HMI controls & Graphical Page Navigation [16].

4.5.2 - DIRAD (Navy)

Enhancements are also done on the Navy Automation systems, one of the most notorious is the Distributed Incident Recording & Display (DIRAD).

Historical development to attempt to move away from manual incident white boards, with decrease inefficiency & errors, which still exists nowadays on-board Navy vessels.

The main purpose of this system is to provides full, quick and accurate situational awareness of assets & internal incidents is compiled and distributed, enabling Command to make decisions based on accurate knowledge of situation in alignment with Command Aims.

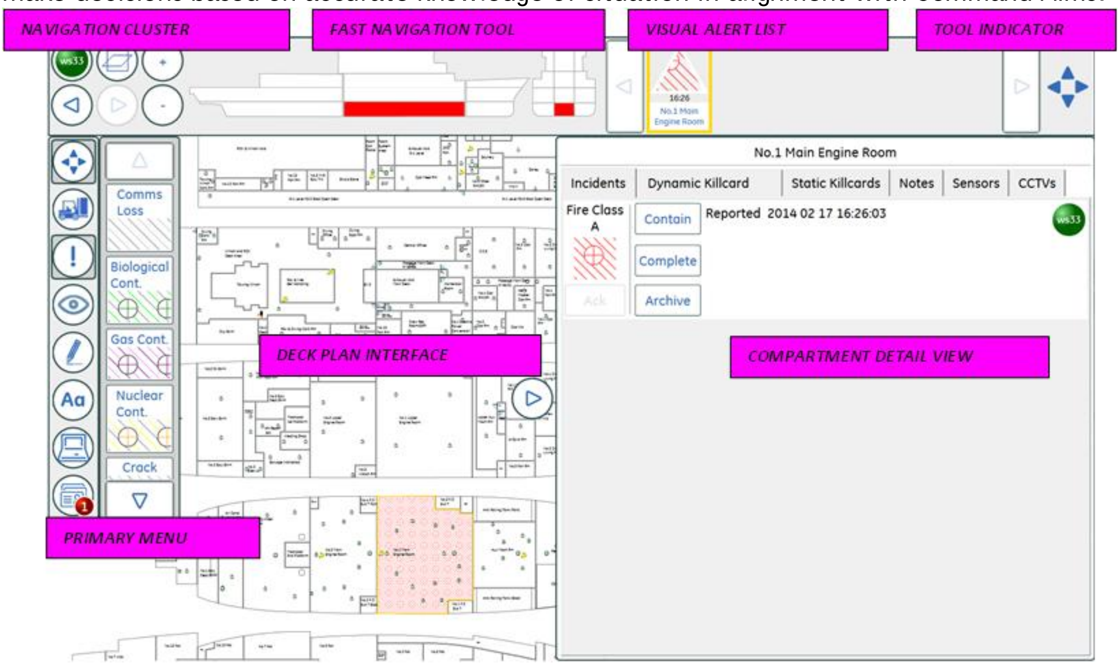


Figure 4.6 – DIRAD - System Architecture - Main View [25].

MAIN ELEMENTS:

- Assets - Consist of symbols or icons that can represent key pieces of equipment, response teams or people & reside on layers that can be toggled in and out and can be ‘preplaced’ onto the deck plan. For example, the locations of fire extinguishers or breathing apparatus.
- Layers - Consist of Assets, static drawn overlays or sensors and can be toggled on and off individually as required to add detail or improve clarity.
- Overlays - can be drawn onto a layer, detailing many subsystems on each layer. Example: Water Mist, Networking, Doors stairs and hatches, muster points.
- Freedraw & Freetext - enable the operator to enter text direct & add hand drawn comments/sketches directly onto the deck plan. Allows unforeseen events/comments/actions to be noted quickly and with little effort.

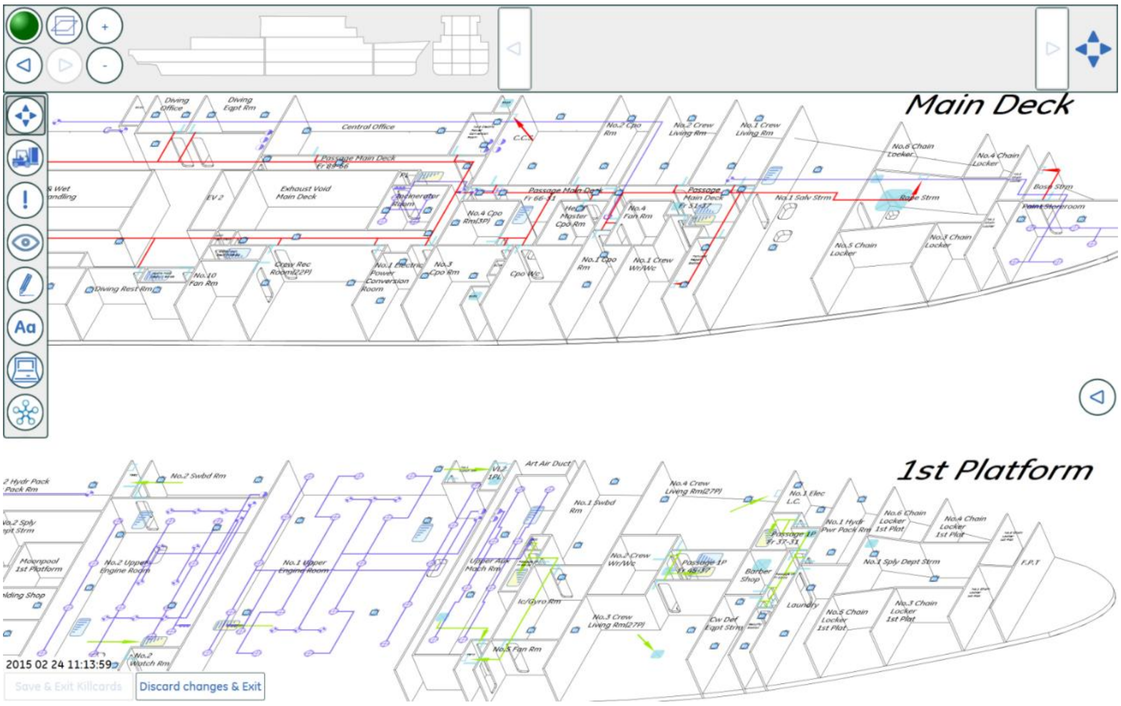


Figure 4.7 – DIRAD - System Architecture - 3D View [25].

COMPARTMENT VIEWS:

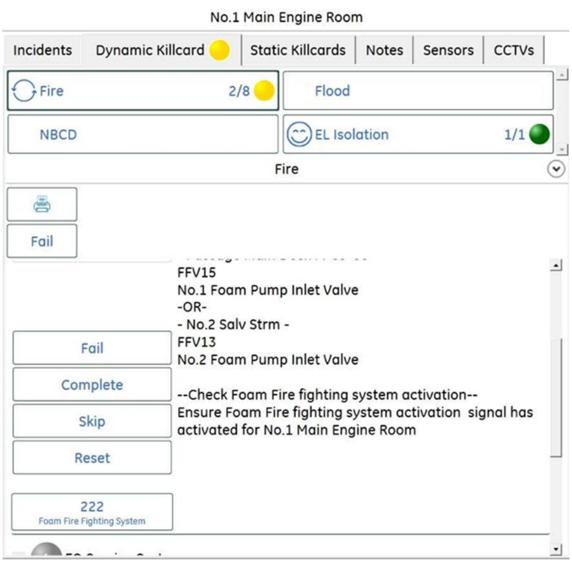


Figure 4.8 – DIRAD – Killcards [25].

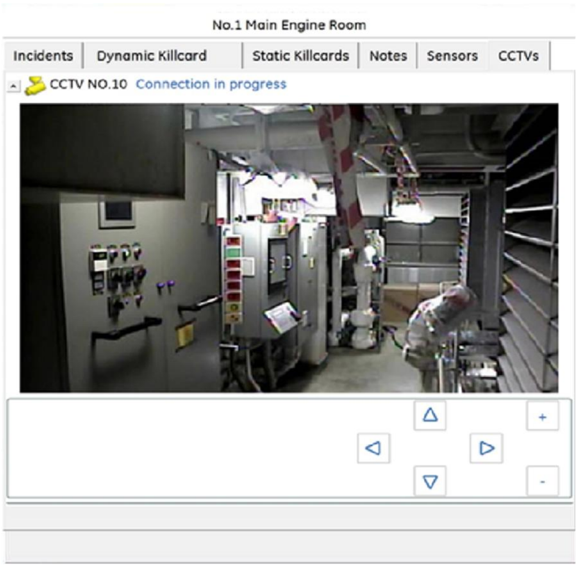


Figure 4.9 – DIRAD - CCTV [25].

- Static Killcards: Repositories of information which is more assets reference and usually information related to compartment equipment & materials, their fittings & Electrical isolation points, extinguishing units and details on intersecting subsystems like: HVAC, chilled water, networking etc.
- Dynamic Killcards: Repository of step by step execution instructions on how to isolate a compartment or a subsystem for a particular type of incident.
- CCTV: To help direct the damage control operations/isolation procedures by supplying the operator with live feeds of affected compartments.

4.5.3 - OBTS (Offshore/Navy)

The main purpose of the On-Board Operational Training (OBTS) is to enable the ship’s crew to effectively cope with unexpected situations, without delays caused by unfamiliarity with the Automation platform system, through a detailed and safe scenario training environment.

MAIN FEATURES:

- Training sessions held on same equipment & location as per PMS control
- Instructor-students class type teaching environment
- Online & team training sessions during pier side & underway conditions
- Virtual ship plant simulation for real time training scenarios execution
- There is automatic session recording for Students, which are only allowed to have OPERATOR credentials & associated functionalities
- Instructor uses the CHIEF credentials & associated functionalities and manages the training scenario & the Virtual Ship enhanced simulation flow

SYSTEM ISOLATION

The Enhanced Simulation only exists on the Virtual Ship, with the only physical connection between both systems is the Ethernet cable between the Real Ship & the Virtual Ship workstations.

Exchanged data is only Screen Output (RDP connection) from virtual system & keyboard/Mouse inputs from the real system.

Due to class rules, one Real Ship workstation has to be permanently available for real operation only - the “Station in command”.

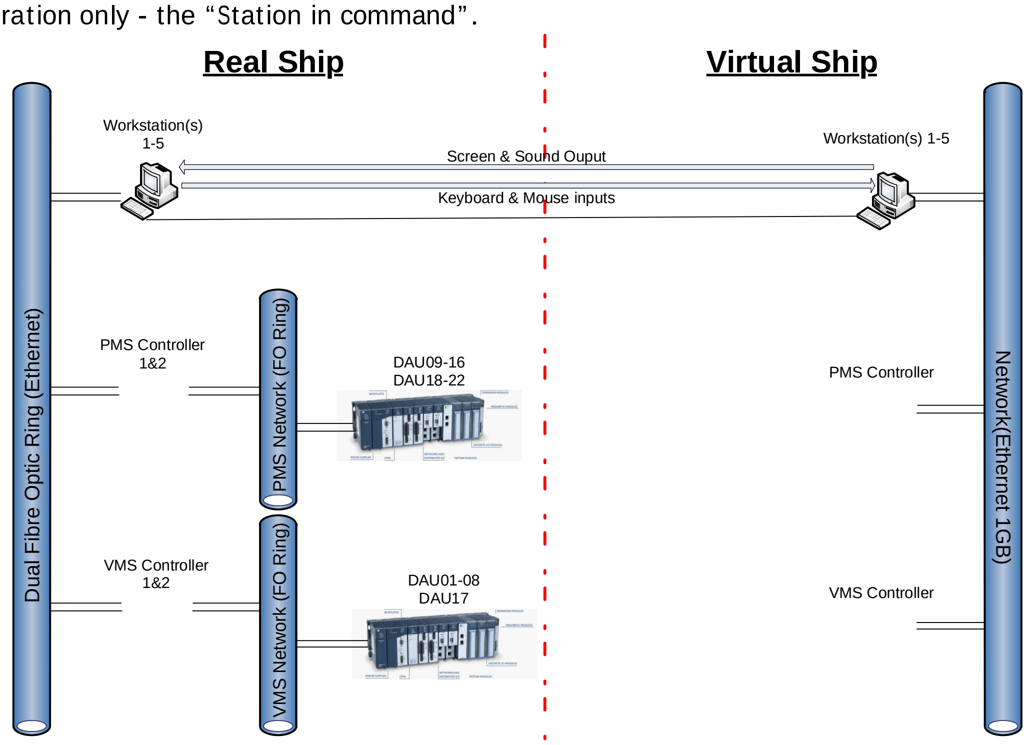


Figure 4.10 – OBTS - System Isolation [25].

TRAINING SCENARIOS

Training Scenarios are scripted instructions for executing specific training scenarios.

Instructor sets up training scenario, controls the Virtual Ship enhanced simulation & challenges the student's knowledge.

Students demonstrate theory & practice.

Virtual System reacts to instructor & student's actions, according to real SW code.

Figure 4.11 – OBTS - Training Scenarios [25].

2.3.7.3 Training Script

REF	INSTRUCTOR ACTION	EXPECTED STUDENT ACTION	SYSTEM RESPONSE
1.	• Exercise PMS Scenario 07 - Partial Blackout Recov • Check on Simulator Control Window that 'Automatic Voltage Control' is selected • **Ask student to setup the PMS as follows:-** ○ **Frequency Control to On** ○ **Frequency Set Point to 60Hz** ○ **Active Power Loadshare to On** ○ **Min. number of generators to 1** • **Ask student to check system status and PMS functionality settings**	• From HMI EPC Menu, load mimic 20 'Generator Loading & Control'. • Verify that Blackout Recovery is NOT enabled • Click on Frequency Control and set to ON. • Click on Frequency Set Point and set to 60Hz • Click on Active Power Load-Share and set to ON • Click on Min. number of generators and set to 1 • Verify Auto Start is OFF • Verify Auto Stop is OFF • Verify that DG1, 2, 3 then 4 are started in order. • Verify that DG1 then DG2 are brought online • Verify that BT1, then BT2 are Opened • Verify that DG3, then DG4 are brought online • Verify that all DGs are load sharing equally • Verify all Bus Voltages and Frequencies are stable at 60Hz, 459V • From mimics 10, 12, 14 & 16 verify that DGs 1-4 Cylinder Temperatures are set'.	• All DGs running • All DGs online and load sharing equally at around 44% kW • Both BT1 & BT2 Busties Opened • Cylinder Temperatures set • System stabilised, i.e. nominal Frequency and Voltage • Any Excess alarms that have appeared are reset

Figure 4.12 – OBTS - Training Script [25].

Chapter 5

Project

This chapter describes one of the projects worked by myself with pertinent information to overall link & further clarify all the previous systems descriptions up to this point.

Its meant to be a technical & procedural concluding chapter, cross referencing with previous chapters on a number of subjects, showing a real live implementation of the Marine automation engineering application, together with some major milestones & typical organization for a standard large project.

5.1 - Drillship Project - Cobalt Explorer

In 2014, GE was awarded the supply of IAS (Integrated Automation System), the DP system and both the Fire/Gas & ESD (Emergency Shutdown System) by the yard customer DSME (Daewoo Shipbuilding & Marine Engineering), South Korea, in behalf of the vessel owner Vantage Drilling, Houston, USA, for the 4th Drillship to be built in South Korea, the Cobalt Explorer.

From a business point of view, this required GE to use both the UK & South Korean offices, as well as to lead the consortium with suppliers such as Invensys & Sonardyne.

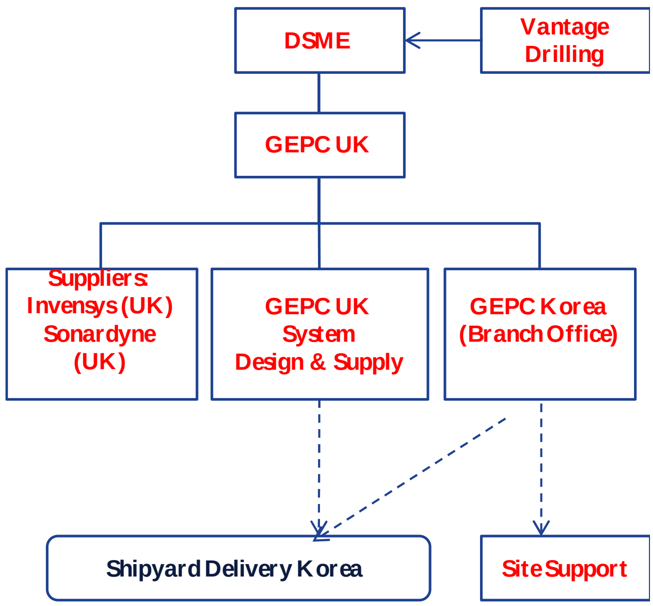


Figure 5.1 – Cobalt Business Organization Structure [9].

Invensys Systems would supply the Fire and Gas Detection and Alarm System, together with the Emergency Shutdown System, integrated into GE IAS system.

Sonardyne Systems would supply the Hydro-acoustic Position Reference (HPR) system, integrated into GE DP system.

Other sub-systems will be described in further chapters ahead. The Cobalt Explorer was the 4th Drillship for Vantage built at DSME shipyard with GE supply, after the previous:

- Platinum Explorer
- Titanium Explorer
- Tungsten Explorer

Figure 5.2 – Cobalt´s Sister Vessel [9].

5.2 - Engineering Design Process

5.2.1 - Project Phases

The idea of project phases, is that they subdivide the project programme into phases at the end of which there is a specific milestone achievement to be documented.

This section provides a summary of the engineering work involved in producing a Marine Automation System, by defining the project workflow according to the four different phases of a project, which are:

- Requirements – Capture of customer, proposal specification with initial SLD & programme plan productions, respecting the applicable Regulatory control & rules.
- Design – Production of detailed Functional Design Specs (FDS), HW, Drawings & I/O Signals documentation, under customer approval control. Start of equipment procurement.
- Build & Test – Production of PLC SW, I/O Signal database & Mimics. Purchase & assembly of HW. Production of Test Specs & Factory Testing with customer/class.
- Final – Site Testing, commissioning/Sea trials, followed by customer project signoff.

Each of these phases includes inputs, which are documents provided to the engineering team by customer & internal/external suppliers, and outputs which are documents produced by the engineering team.

Requirement Phase

INPUTS

- Customer purchase specification.
- Power Conversion tender technical specification.
- Classification Society and other standard regulations.

PROCESS

- Project engineer will read and familiarise with all project input documentation, in order to identify contractual requirements.
- Read contract plan and quality plan produced by project manager and quality assurance department.

OUTPUTS

- Production of programme and identification of work packages.
- Allocation of resources to work packages.
- System overview drawing.

Design Phase

INPUTS

- Customer detailed design requirements.
- AVC standard system design documentation.
- Outputs from the requirements phase.

PROCESS

- Starts with the data capture of the detailed system design information, including information regarding I/O signals, functional requirements and mimic display requirements.
- Project engineer will produce system functional design specifications, mimic format design, hardware purchase specifications, wiring diagrams, cable interconnection drawings and installation specification.
- Work with customer to populate project input/output signal database.
- Ensure all requirements of project plan, quality plan, and statutory & regulatory compliance plan are met.
- At the end of this phase, if not before design freeze items, all outputs will come under change management control.

OUTPUTS

- Functional design specifications, approved by customer.
- Hardware specifications and drawings, approved by customer where required.
- Input/Output Signal Schedule for all project signal interfaces, approved by customer.

Build & Test Phase

INPUTS

- Software Quality Plan and software programme.
- Outputs from the design phase.

PROCESS

- Software phase commences, for production, testing and integration of SW.
- System HW is purchased, manufactured and assembled.
- Project engineer produces test and commissioning documentation.
- Testing of system HW, either as individual items or as integrated system.
- Testing of system SW, as an integrated system.
- Factory acceptance testing with customer, followed by required corrections.
- Ensure all requirements of project plan and quality plan are met.
- At the end of this phase, SW comes under change management control.

OUTPUTS

- Factory acceptance test documentation and test records.
- Instruction books.
- First official release of software.

Final Phase

INPUTS

- Outputs from the test phase.

PROCESS

- Commissioning and sea trials.
- Project close out meeting/review
- Project documentation is archived.

OUTPUTS

- Completed 'as commissioned' documentation.
- Customer acceptance tests signed off by customer and classification society.
- Software for archive.

5.2.2 - Warranty Period

After the project close out meeting, the project continues to provide warranty support through either the Services or Fleet Management departments.

5.3 - Customer Information Required

Timely receipt of technical information and document approval from the customer, or from their suppliers, is critical to the design process. The information required is generally as follows:

5.3.1 - Drawings

Customer/third party Drawings, particularly piping and instrumentation drawings can provide enough information for an initial system design and signal schedule to be produced. Drawings are especially helpful if they include identification of remotely controlled and monitored devices, monitored instrumentation, piping layout to facilitate drawing of system mimics, and notes regarding the functionality of the system.

5.3.2 - Signal Lists

To enable full system design, ultimately every signal in the system must be identified, together with all relevant information regarding that signal such as Fieldstation allocation, alarm levels, alarm group, control group, automation features required and mimic for display. When the customer provides a comprehensive signal list, this provides a firm starting point for the project, as per below example:

System	Device tag	Component	Signal	Fieldstation	Signal type (at fieldstation)	Engineering unit	Range or sense	LL Alarm level	Low Alarm level	High Alarm level	HH Alarm level
Fuel Oil	FS-P-01	Transfer pump	Remote	3	Digital input		1=remote				
Fuel Oil	FS-P-01	Transfer pump	Running	3	Digital input		1=running				
Fuel Oil	FS-P-01	Transfer pump	Tripped	3	Digital input		0=tripped				
Fuel Oil	FS-P-01	Transfer pump	Start	3	Relay output		1=start				
Fuel Oil	FS-P-01	Transfer pump	Stop	3	Relay output		1=stop				
Fuel Oil	FS-V-01	Transfer pump suction valve	Opened	3	Digital input		1=opened				
Fuel Oil	FS-V-01	Transfer pump suction valve	Closed	3	Digital input		1=closed				
Fuel Oil	FS-V-01	Transfer pump suction valve	Open Cmd	3	Relay output		1=open				
Fuel Oil	FS-V-01	Transfer pump suction valve	Close Cmd	3	Relay output		1=close				
Fuel Oil	FS-V-02	Transfer pump discharge valve	Opened	3	Digital input		1=opened				
Fuel Oil	FS-V-02	Transfer pump discharge valve	Closed	3	Digital input		1=closed				
Fuel Oil	FS-V-02	Transfer pump discharge valve	Open Cmd	3	Relay output		1=open				
Fuel Oil	FS-TL-01	Storage Tank	Level	4	4-20mA	mm	0-5000	3%	5%	95%	98%
Fuel Oil	FS-TL-02	Settling Day Tank	Level	4	4-20mA	mm	0-3000	3%	5%	95%	98%
Fuel Oil	FS-TLA-01	Settling Day Tank	High level	4	Digital input						

Figure 5.3 – Project – Example Signal Lists [23].

5.3.3 - Functional Requirement

Functional descriptions for the systems to be controlled by the Marine Automation system provide the basis for the configuration and software production.

5.3.4 - Design Approval

Documents submitted to the customer for comment or approval require a timely response. Note that often the approval process will require more than one round of approvals, and areas of the system can be interconnected such that comments on one document may affect another that is in production.

5.3.5 - Design Review Meetings

Customer design review meetings are often required to finally approve key design documents. Wherever possible these meetings should be regarded as final stage reviews to achieve a completed design, further to a previous document review. These meetings can be instrumental in ensuring a full understanding of design issues and proposed design solutions by all parties involved.

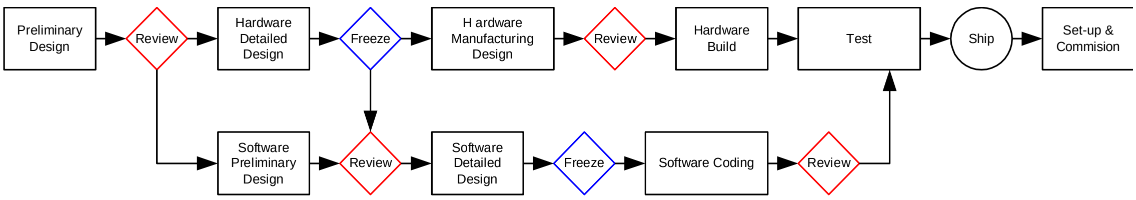


Figure 5.4 – Engineering Design Process [23].

5.4 - Project Team

The below organigram shows the GE & Invensys teams involve in the delivery of this project during its execution & commissioning phases and using colleagues from 3 regions in the world: South Korea, India & UK.

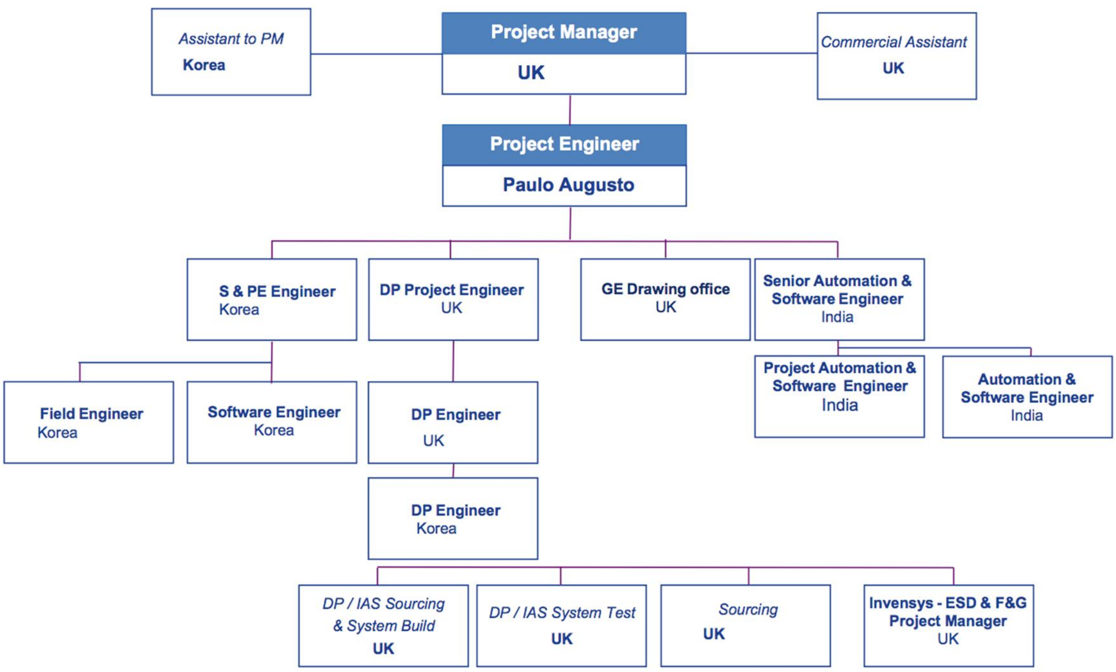


Figure 5.5 – Cobalt's GE Project Team.

5.5 - Ship's information & Classification

5.5.1 - Ships Data

- Ship Owner : Vantage
- Project Name : Cobalt Explorer Drillship
- Hull No. : 3618
- Registration (Flag) : The Bahamas
- Overall Length (m) : 238.0
- Length Between Perpendiculars (m) : 230.0
- Draft (m) : 12.0
- Underwater Area (m^2) : 2760.0
- Vessel Function : Drilling Vessel
- Operating Area : Worldwide
- Classification : ABS DPS-3
- Control System : DPS31 + IJS

5.5.2 - Classification Society

The Drillship, including its hull, equipment and machinery, was constructed under the survey of ABS (American Bureau of Shipping) and was the registered by the symbols of:

- ABS 1A, (E), "Drillship", AMS, ACCU, CDS
- DPS-3, SH-DLA, UWILD, CRC, HELDK(SRF), HAB+

5.5.3 - Language

English for all documents and drawings for design and construction, while the name plate, caution plate and identification plate was written in English and Portuguese.

5.5.4 - Environmental Data

The Drillship was targeted for operation in Gulf of Mexico, West Africa, Brazil and Asia.

All equipment and systems was engineered to comply with general Rules and Regulations and Classification Society requirements with regards to relative humidity of air within: 0 to 95 % and with following temperatures:

Table 5.1 — Project - Environmental Data Requirements.

Design Temperature	Min	Max
Ambient Outdoor air	-25 °C	45 °C
Ambient Indoor air	0 °C	45 °C
Ambient Sea water	0 °C	32 °C

5.5.5 - Safety Requirements

Safety of people, environment and assets is of paramount importance in Drillships. The primary safety requirement for equipment is that a single point failure should not cause any hazardous condition leading to injury or equipment damage.

Alarms, sensors and controls are meant be utilized to the utmost in order to prevent accidents resulting from human error or mechanical failure.

5.5.6 - Environmental Conditions - DP

The Dynamic Positioning (DP) system for station keeping must have the required station keeping capability and must satisfy the Class 3 requirement under the given environmental condition. The equipment and its system were designed for limiting environmental conditions as stated below:

Table 5.2 — Project – DP Environmental Conditions Requirements.

	Normal Operating	Maximum Operating
Sustained Wind Speed (1 minute, 10m above sea level) (m/s)	21.85	26.6
Current Speed (surface, m/s)	1.42	1.6
Significant Wave Height (m)	5.7	6.9
Wave Period (Tp, sec.)	13.7	14.62
Wave Spectrum	JONSWAP	JONSWAP
Gamma	1.55	1.61

5.6 - Scope of Supply

Below is the project summary for GE systems main scope of supply for this new vessel, the Cobalt Explorer, Hull 3618.

- Dynamic Positioning (DPS) including:
  - Position Measurement: Acoustics & DGPS
  - Independent Joystick System (IJS)
  - Thruster Control System
- Automation (IAS) System including:
  - Power Management System (PMS)
  - Vessel Management System (VCS)
  - ¤Alarm & Monitor System with Alarm Extension
  - Thruster Management System
  - Ballast/Bilge Management System
  - Drilling Systems
- Fire & Gas and Emergency Shutdown System
- Environmental Meteorological Platform (EMP) Data System

- Load/ Stability Calculator
- Riser Management Systems (RMS)

The following sections describes their main quantities, types & some of the functionalities included with each of them. The DP & Automation systems are further described in more detail in following chapters.

5.7 - Automation System

The Integrated Automation System (IAS) supplied on this vessel is composed of several operational functionalities, ranging from Power Management System (PMS) and the control of all sort of electrical devices, to the vessel management (VMS) where all the non-electrical devices & their sub-systems are controlled.

5.7.1 - Network Diagram

The VCS system uses a dual media Ethernet network to communicate between the various components. The VCS network runs at 100 Mbits/s.

The network system is directly integrated with the DPS system, with Manual Thruster Control (MTC) system using individual communications links that are separate from the network. The network is fully duplicated such that each item communicating on the network (called a node) has two connection points, and all network equipment is duplicated. This is to ensure that in the event of a failure on one network, the other will still be communicating. For security the cables are typically run separately, e.g. on opposite sides of the vessel.

The network configuration is based around network switches which provide a star connection arrangement to system nodes. For distributed systems, switches can be located in different areas and interconnected.

The following is a list of the main networked equipment's:

Table 5.3 — Project – Network Diagram.

Number of controllers on network	8 (4 for DP, 2 pairs for VCS)
Number of Fieldstations	22
Number of workstations on network	12
Number of network switch boxes	14 (7 pairs)
Backbone cables	Fibre
Drop cables	Copper

In next page Cobalt Network Diagram, the following stands out:

- For each Network Switchbox (NSB), the Blue Network Switches makeup the Arm A of the redundant network, and the Blue Network Switches makeup the Arm B and are independent of each other, showing their unique reference & location, i.e. "NS03A No.1 EER (Main DK) "
- All networked endpoint equipment (Controllers, Fieldstations, workstations & printers) have two independent network connection to both Arm A & Arm B, showing their unique reference & location, i.e. "FS16 LS1"
- Finally, all the Network Switchbox (NSB) of each arm have an interconnection backbone in Fibre optic over Ethernet, to overcome distances larger than 100 meters of the Ethernet copper limitation.

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

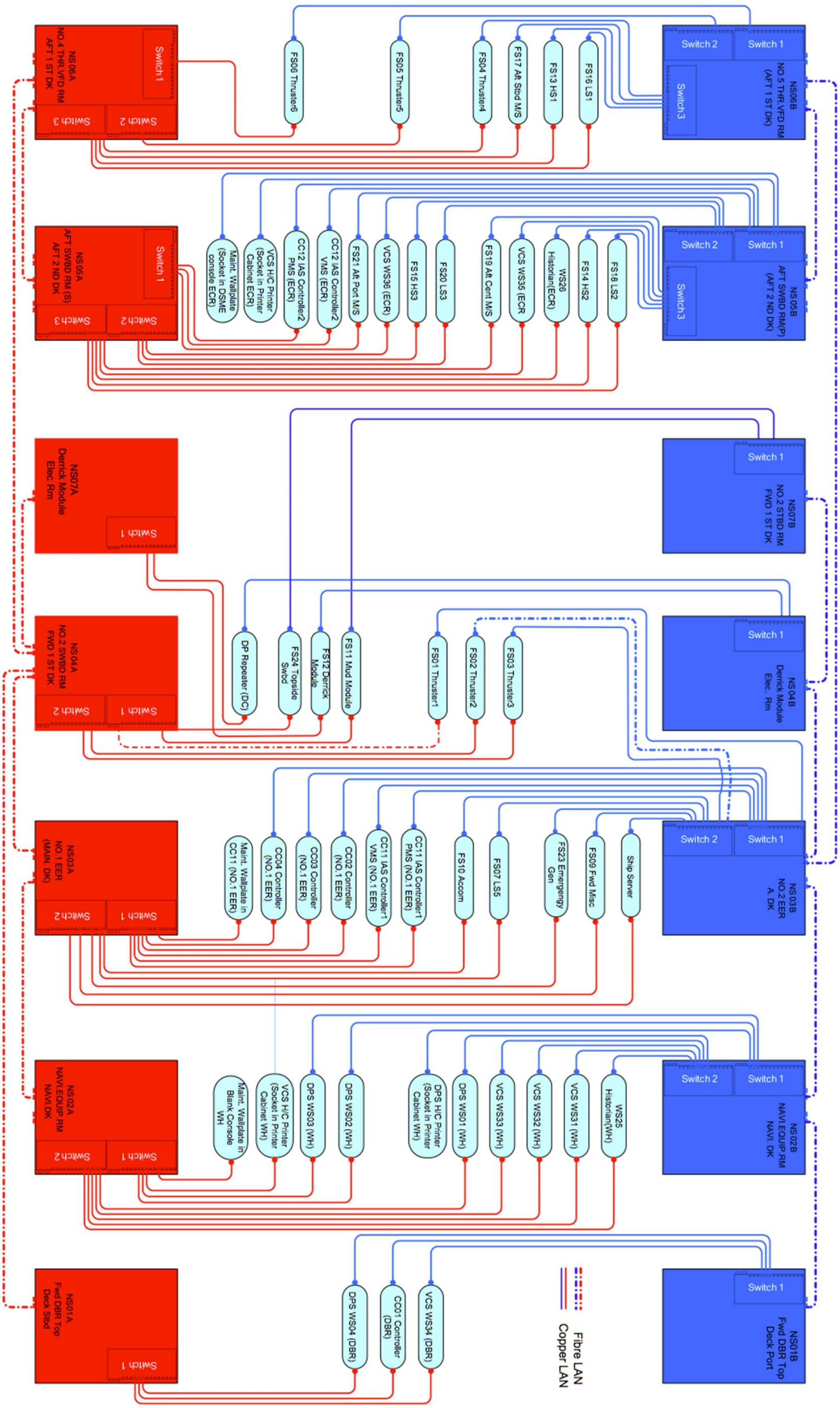


Figure 5.6 – Cobalt H3618 Network Topology [13]

5.7.2 - Equipment Location – Automation (IAS) System

The Automation (IAS) System is provided by GE.

For equipment list & their unique IDs, consult location using the Automation/DP SLD in section 5.15.2 - .

Table 5.4 — Project – Automation Equipment Location.

Function	Location	Quantity	ID
IAS Workstations	Wheelhouse (W/H) DP Back-up Room (DBR) Engine Control Room (ECR)	3 1 2	WS31, WS32, WS33 WS34 WS35, WS36
Blank Workstations (customer equipment)	Wheelhouse (W/H)	5	WS51, WS52, WS53, WS54, WS55
IAS Controller Cabinets	Electrical Equipment Room (EER1) Engine Control Room (ECR)	2 2	CC11 (PMS A & VMS A) CC12 (PMS B & VMS B)
IAS Fieldstations	Electrical Equipment Room (EER1) Thruster Rooms Fwd Ballast VRC Fwd Misc Aft Port M/S Misc Aft Stbd M/S Misc Aft Centre M/S Misc Stbd Aft Distribution & Auxiliary Centre Aft Distribution & Auxiliary Port Aft Distribution & Auxiliary No.3 Fwd Swbd Room Emergency Generator No.1 Fwd Swbd Room No.2 Fwd Swbd Room Derrick Module Stdb Power Gen. & HV Distr. & Aux Centre Power Gen. & HV Di. & Aux Port Power Gen. & HV Distr. & Aux	1 6 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	FS10 FS01 to FS06 FS08, FS22 FS09 FS21 FS17 FS19 FS16 FS18 FS20 FS24 FS23 FS07 FS11 FS12 FS13 FS14 FS15

Note, ID is the unique equipment reference used to identified it on PLC SW, drawings, Functional design & test specs.

HARDWIRED SIGNALS

The Automation System Input/output (I/O) signals used on Cobalt project are:

- Digital – 4100 points
- Analogue (±10V / 0-20mA / Pt100 RTD / K-type T/C) – 520 I/O points

The hardwired I/O count came to 5082, which includes 10% of fitted Spare I/O points for future upgrade needs during service phases.

Communications Links

The communications links of Automation system are depicted below:

Table 5.5 — Project – Automation Communication Links.

System	Function	Communications
Diesel Gens	Engine/Generator Status & Alarms	Modbus RTU RS485 Serial Link
Emergency Gen	Emergency Engine/Generator Status & Alarms	Modbus RTU RS485 Serial Link
11kV Swbds	Swbd Circuit Breakers Status & Alarms Switchboard Section Status & Alarms	Multi-dropped Modbus RTU RS485 Serial Link
Thruster Drive	Drive Train Status & Alarms	Profibus DP RS485 Serial Link
Drilling VFD Swbd	AC Drilling VFD Switchboard Status & Alarms	Profibus DP RS485 Serial Link
Drilling Control (DCMS)	Drilling Control System data Transfer of control data between DCMS and field devices	Profibus DP RS485 Serial Link
MCC Intelligent Protection Relays & Motor Starter System	LV Circuit Breakers Control & Status Motor Starter Control & Status	Multi-dropped Modbus RTU RS485 Serial Link
Fire, Gas Detection & ESD System	Fire, Gas & ESD alarms Transfer of control data between Safety System and field devices	Ethernet Modbus TCP/IP
Load & Stability	Tank Levels/Drafts/Volumes & Weights to Calculator	Modbus RTU RS485 Serial Link

System	Function	Communications
Calculator		
Ballast Water Treatment System (BWTS)	Principal System Devices Alarm & Monitor Transfer of control data between BWTS and field devices	Modbus RTU RS485 Serial Link
Voyage Data Recorder	Propulsion Thruster, Power System Data Critical Vessel Systems Data	NMEA RS485 Serial Link
Riser Management System		Ethernet Link Modbus RTU RS485 Serial Link
Vessel's Master Clock System	Time for synchronising with vessel systems	(Via DPS DGPS)

There are 46 total number of communication links, with 5280 Serial IO´s.

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

5.7.3 - Power Management System (PMS)

POWER SYSTEM DESCRIPTION

a) 11KV Swbds: The 11kV electrical power system consists of three identical switchboards HS1, HS2 and HS3, interconnected by cable bus ties and fed via 6 x 9000KVA 0.85pf Diesel Generator sets. Depending on requirements, the power system may be operated in the following modes:

i. 1-Split: All 3 Swbds interconnected together

ii. 2-Split: Swbds are split into two separate systems which operate independently.

iii. 3-Split: All Swbds are fully isolated and operate independently.

iv. Closed ring: All 3 Swbds & busties interconnected together. This is however allowed only for 30 sec for short term power transition.

The 11kV switchgear is split equally between the three Swbds and consists of the following:

i. 6 x 9000kVA Diesel Generators.
ii. 6 x Switchboard Interconnectors.
iii. 6 x Thruster Transformer (6500kVA) Feeders.
iv. 3 x Aft 11kV/690V Bus Transformer (3000kVA) Feeders (LS1, LS2, LS3)
v. 3 x Fwd 11kV/690V Bus Transformer (3000kVA) Feeders (LS5)
vi. 3 x Top 11kV/690V Bus Transformer (6400kVA) Feeders (Drilling)
vii. 3 x Top 11kV/690V Bus Transformer (3500kVA) Feeders (LS4)
viii. 3 x Earthing Transformer Contactors

For power equipment location, consult using the Power SLD in section 5.15.1 - .

b) Diesel Engine/Generator Details:

i. Engine: STX Mann BW (16V 32/40)
   a. Nominal speed: 720rpm
   b. Rating: 7650 kW (Maximum is 8000kW at 720 rpm)
   c. No. of Cylinders: 16
ii. Generator: Hyundai (HSJ7 1209-10P)
   a. Nominal speed: 720 rpm
   b. Rating: 9000 kVA
   c. Frequency: 60 Hz
   d. Voltage: 11 kV
   e. Current: 472.4 Amps
   f. Power factor: 0.85 Lagging

c) main engine control system: The main engine control system is provided by Heinzmann/Siemens. This system provides the following main functions:

i. Engine Speed Control - via PRIAMOS digital speed control unit
ii. Generator Synchronising - via THESEUS control unit
iii. Isochronous Load Control - via THESEUS control unit (only in Isoch Mode)
iv. Bus Tie Synchronising – via THESEUS control unit (only in Isoch Mode)
v. Group Load Sharing - via THESEUS control unit (only in Isoch Mode)

PMS FUNCTIONALITY OVERVIEW:

The main functions of the PMS are outlined below:

- Manual control for opening and closing principle 11kV, 690V, 230V and 440V switchboard circuit breakers and feeders.
- Operator initiated automatic synchronizing and dead bar closing of 11kV bus ties.
- Control, monitoring and alarm functions associated with power generation equipment in both droop and isochronous mode.
- Symmetric & Asymmetric (Fixed Target) load sharing of generator when in droop/isochronous mode
- Manual de-rating of generator sets (Droop mode only)
- Manual and automatic selection of diesel generator sets into droop mode upon defined operating conditions
- Control, monitoring and alarm functions of power distribution equipment.
- Operator initiated starting & stopping of diesel generator sets
- Automatic starting and connecting diesel generator on low spinning reserve (kW)
- Automatic stopping diesel generator set on high spinning reserve (kW)
- Manual configuration of load dependant start / stop priorities.
- Automatically restore 11kV, 690V and 230V switchboards on detection of an 11kV switchboard partial or total blackout.
- Re-start previously running thrusters upon restoration of supply after a blackout.
- Re-start essential auxiliaries upon restoration of supply after a blackout.
- Re-connect previously connected drilling transformers upon restoration of supply after a blackout.
- Display diesel engine exhaust gas temperatures and deviation alarms
- Calculate load limitation signals to the drilling system and thruster VFD's.
- Start blocking of heavy consumers.
- 11kV Bus Tie Unload – unload one bus section prior to opening a bustie to prevent potential blackout. In Droop mode only
- kW and kVAr Loadshare unbalance detection & action when in isochronous/droop mode.

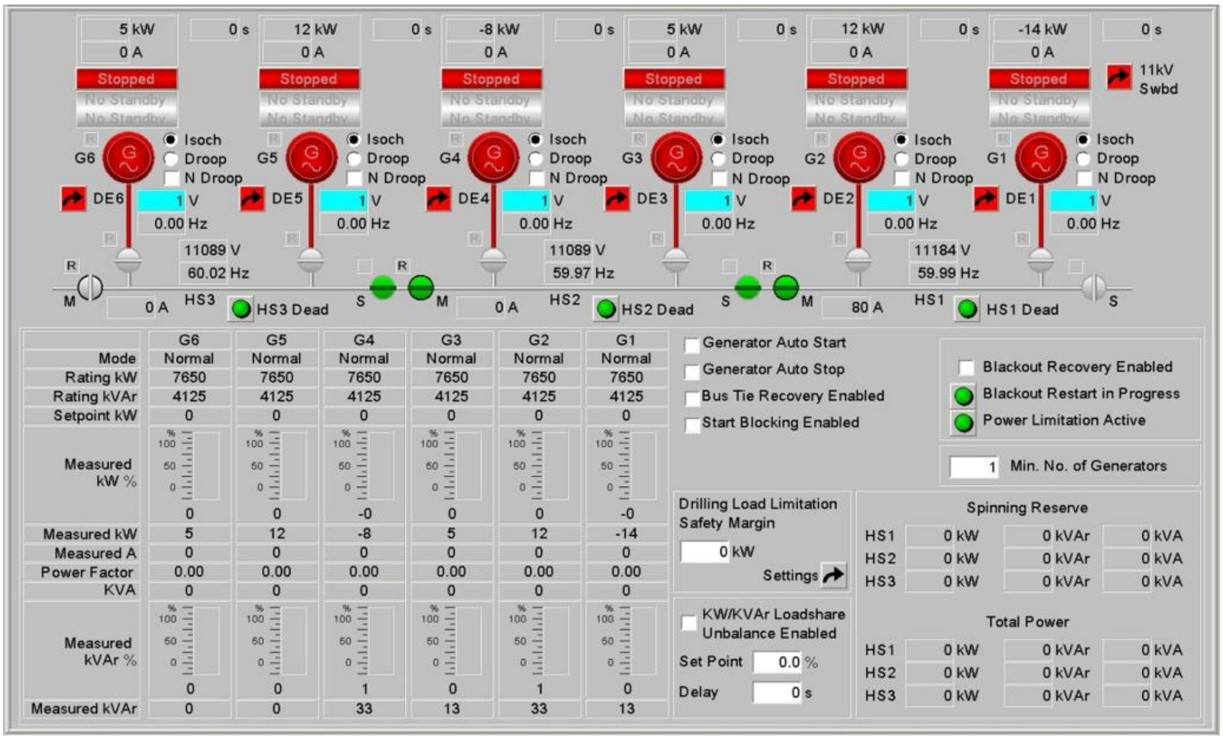


Figure 5.7 – Project - PMS Load & Control HMI [26].

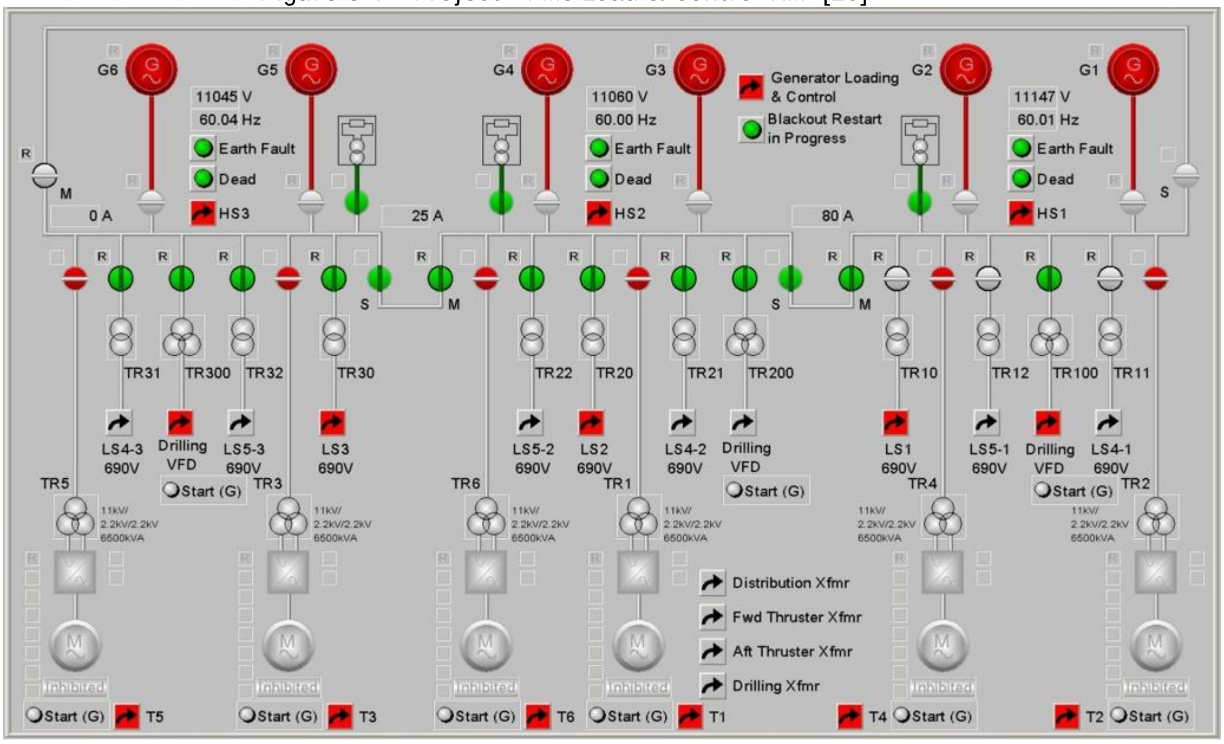


Figure 5.8 – Project - PMS Main HV Swbd HMI [26].

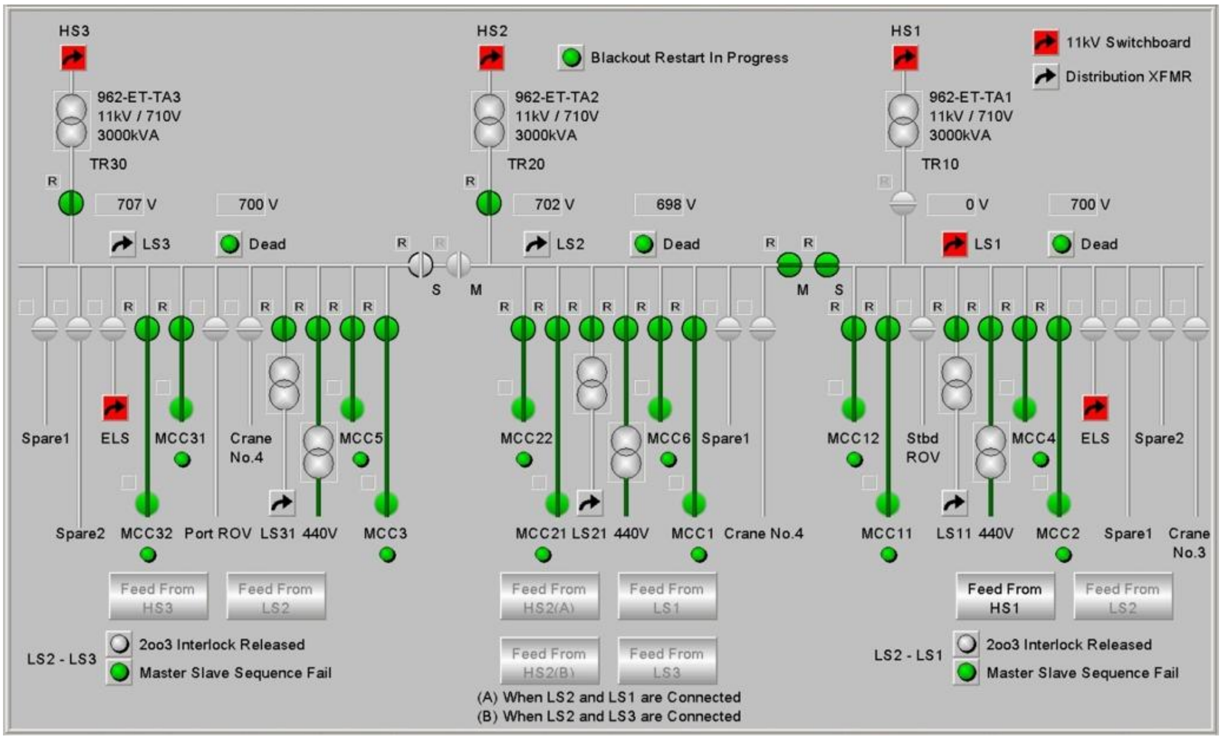


Figure 5.9 – Project - PMS Main LV Swbd HMI [26].

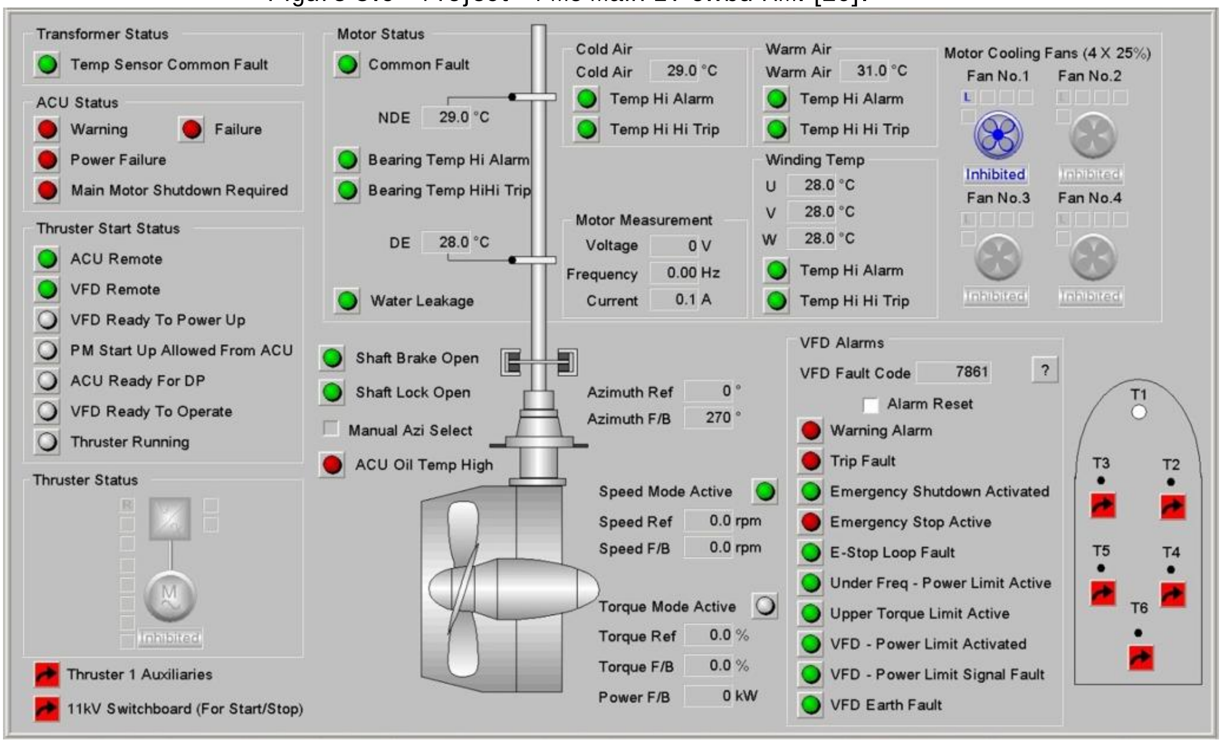


Figure 5.10 – Project - PMS Thruster System HMI [26].

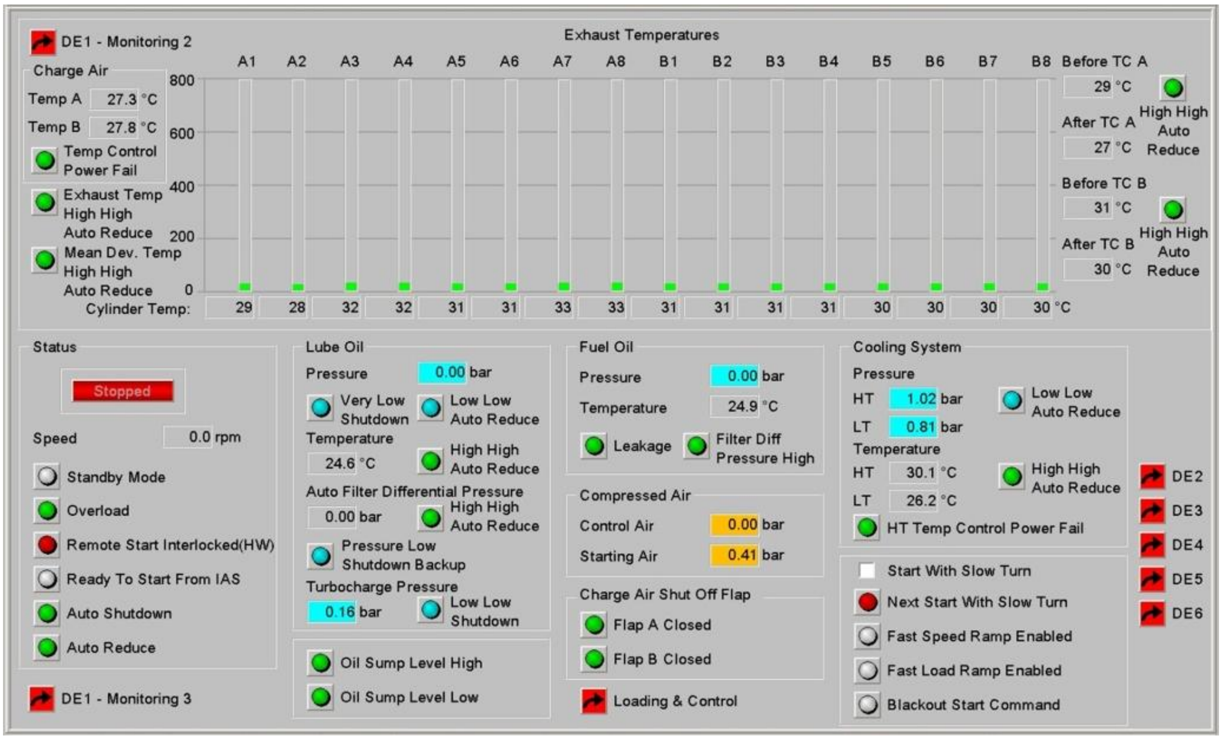


Figure 5.11 – Project - PMS Engine System HMI [26].

Figure 5.12 – Project – PMS Generator System HMI [26].

BLACKOUT RECOVERY

The primary function of the blackout recovery is to recover power to the following switchboards (as necessary) should a total or partial blackout occur on the 11kV system.

- 11kV Switchboards (HS1, HS2, HS3)
- 690V Switchboards (LS1, LS2, LS3, LS4, LS5)
- 230V Switchboards (LS11, LS21, LS31, LS41, LS51)

For power equipment location, consult using the Power SLD in section 5.15.1 - .

The PMS blackout recovery sequence is divided into the following sections:

1. Blackout detection
2. 11kV blackout recovery
3. 690V blackout recovery
4. 230V blackout recovery
5. Essential auxiliary restart
6. Thruster restart
7. Drilling reconnection

The PMS will perform the above sequences based on:

- Loss of one or two 11kV switchboards (partial blackout)
- Total loss of 11kV generation (total blackout)

The PMS detects a blackout on a 11kV/690V/230V switchboard, and raises an appropriate 'Dead Bus' alarm, as follows:

- There are no generators connected to the Swbd and its bustie CB's are open

OR

- Swbd voltage is < 1100V for 11kV (<70 V for 690V) for longer than 2 seconds

a) TOTAL - Blackout Recovery Sequence: The following steps are taken by PMS on detection of a total blackout, when the PMS blackout recovery function is enabled:

   i. At the time of blackout all 11kV, 690V and 230V incomers, feeders and bus ties will trip on under voltage protection. This is not a function of the PMS.
   ii. 1 sec after the blackout condition has been detected the PMS issues the "Inhibit Dead Bus Auto Transfer" signal to the appropriate 690V and 230V bus ties. This signal is maintained by the PMS whilst the PMS recovery sequence is in progress and released once the sequence is complete. Whilst the PMS inhibit is active the PMS receives a "Dead Bus Transfer Inhibited" conformation signal from the bus tie.1 sec after the blackout condition has been detected the PMS will also issue the "Blackout Start" command to each diesel generator associated with a dead Swbd. This signal is maintained by

the PMS whilst the recovery sequence is in progress and released once the sequence is complete. With signal active the engine control system will use the blackout engine start up when it receives a start command from the PMS.

iii. 5 secs after the blackout condition has been detected the PMS recovery sequence starts.

iv. The PMS provides a "Bus Tie Recovery" option from the Loading & Control mimic. During a total blackout this feature is ignored. The PMS will not attempt to close any 11kV bus tie's and move directly to step 5.

v. The PMS will attempt to start all available generators associated with the dead 11kV switchboards in accordance with the black-start priority matrix. The black start priority matrix is a mechanism similar to the standby start priority one, but it's entirely independent. The black start priority matrix is as follows:

a.	Priority 1	Generator 1	HS1
b.	Priority 2	Generator 3	HS2
c.	Priority 3	Generator 5	HS3
d.	Priority 4	Generator 2	HS1
e.	Priority 5	Generator 4	HS2
f.	Priority 6	Generator 6	HS3

vi. The PMS will first start the generator, on each switchboard, that has the highest black start priority. Priority 1 is highest and Priority 6 is lowest. The PMS will only attempt to start generators that are available for PMS control.

vii. After a 1 sec delay the PMS will attempt to start the generator, on each switchboard, with the next highest black start priority. The delay time is the time from the start of the "start request" on one generator, to the start of the "start request" on the next.

viii. The PMS blackout start requests are 'one shot' only. There will not be repeat start requests should the generator fail to start.

ix. The first generator to reach rated speed will be dead bar closed onto the Swbd by the PMS. If this close attempt fails the PMS moves onto the next running generator.

x. Once the 11kV switchboard is live, the PMS moves onto the 690V / 230V recovery detailed in the sections below.

xi. Once 690V switchboard is recovered the PMS will proceed to thruster restart.

b) <u>690V & 230V Swbd Blackout Recovery Sequence:</u> In the event of a 690V or 230V switchboard blackout occur due to an 11kV switchboard blackout the PMS will recover the appropriate 690V switchboards as part of its recovery sequence after first inhibiting the local LV recovery. Following an 11kV switchboard recovery the PMS will recover the appropriate 690V/230V Swbds in the following sequence (to prevent transformers closing simultaneously):

i.	690V Switchboards LS1, LS2, LS3	Immediately
ii.	690V Switchboards LS5	2 second delay
iii.	690V Switchboards LS4	4 second delay
iv.	230V Switchboards LS11, LS21, LS31	Immediately
v.	230V Switchboard LS51	Immediately
vi.	230V Switchboard LS41	Immediately

c) <u>Essential Auxiliary Restart:</u> As soon as a 690V switchboard becomes live and its associated MCC CB is closed the PMS will attempt to restart all essential auxiliaries detailed in the following tables. This restart feature will operate not only during a PMS recovery sequence but also if a 440V / 230V switchboard was manually blacked out and recovered (i.e. during a realignment of the power system or connection to shore supply). The devices will only be re-started by the PMS if they are selected to remote and available for PMS control.

d) <u>Thruster Restart:</u> As part of the recovery sequence the PMS will start all previously running thrusters. As soon as power is restored to the appropriate LV Swbd, a 'Drive Fault Reset' command is issued to the drive in order to reset any alarms generated as a result of the blackout. As soon as the appropriate pre-conditions have been met the PMS will issue a thruster start command to the appropriate thrusters.

e) <u>Thruster Re-Start Timings:</u> The following table gives timing estimates for the re-starting of a thruster following a blackout. These assume there has been a total blackout and are applicable for recovery on one section only (i.e Stbd, Port or Centre).

Table 5.6 — Black Out Recovery (BOR) – Thruster Re-Start Timings.

Time (secs)	Action(s)
T=0	• 11kV Switchboard becomes live
T=1.5	• Service transformer incomer is closed
T=3.5	• 690V switchboard incomer is closed and 690V switchboard becomes live.
T=3.5 - 30	• VCS issues thruster start command (if start per missives are met).
T=30	• VCS commences start sequence • VCS starts SW and FW pumps • VCS Issues 'Drive On' command

T=35	• VFD carries out internal checks and pre-charges DC link. • VFD closes transformer CB • After transformer magnetised "Ready to Operate" set
T=60	• VCS starts lube oil pump, hydraulic power pack and motor cooling fans • PM Start Up Allowed signal received from ACU • VCS issues 'Enable Inverter Command'.
T=70	• VCS issues 'Enable Inverter' • VFD issued 'Drive Running' • Ready for DP signal received from ACU
T=71	• Thruster available for remote control

f) Drilling System Reconnection: As part of the recovery sequence the PMS will attempt to close the drilling transformer primary CB when the following pre-conditions are satisfied:

Table 5.7 — Black Out Recovery (BOR) – Thruster Transformer Re-Start Timings.

Drilling Transformer CB	Pre-conditions
Drilling Transformer TR100 Primary CB	• CB closed prior to blackout • HS1 11kV switchboard live • LS1 690V switchboard live
Drilling Transformer TR200 Primary CB	• CB closed prior to blackout • HS2 11kV switchboard live • LS2 690V switchboard live
Drilling Transformer TR300 Primary CB	• CB closed prior to blackout • HS3 11kV switchboard live • LS3 690V switchboard live

LOAD SHARING

The PMS supports the following 'load sharing' modes:

- Symmetric
- Asymmetric (Fixed Target)
- Manual

The Power System can operate in the following 'load control' modes:

- Isochronous
- PMS Droop
- Natural Droop

a) Symmetric Load Sharing:

i. Isochronous: This is the standard mode of operation where kW load sharing is carried out by the THESEUS control system. The PMS will not issue raise/lower control pulses.

ii. PMS Droop: When operating in PMS Droop mode the load sharing control of THESEUS is not active. The PMS will issue corrective raise/lower control pulses to PRIAMOS in order to load share active power and maintain system frequency to 60Hz. It will not possible to adjust the frequency set point from the PMS.

iii. Natural Droop: When operating in Natural Droop mode the load sharing control of THESEUS is not active. The PMS will not issue raise/lower control pulses. The operator can manually issue raise/lower pulses from the HMI mimic. It is therefore the operator's responsibility to take care of the network frequency and load sharing.

b) Asymmetric: Fixed Target Load Sharing: Fixed Target load sharing is intended to allow carbon accumulation to be burnt off. Any generator may be individually set to a MW fixed target by the operator via the HMI. The operator entry is limited between the maximum generator rating and the minimum load share value. If the generator selected to fixed target is operating in isochronous mode, the PMS will first issue the 'Generator in Fixed Target' command to Heinzmann to allow the generator to be fixed in isochronous mode. The fixed target setpoint is then sent to Heinzmann for maintaining the generator at fixed load. When fixed target is deselected the generators remain in isochronous mode. Load sharing is taken care by Heinzmann system. The PMS does not provide "automatic asymmetric load sharing".

c) Manual Load Sharing: In order to operate in manual load sharing mode Natural Droop must be selected by the operator from the HMI. The operator can then manually issue raise/lower pulses from the HMI mimic.

d) Generator Derating: A generator active power can be manually derated by the operator. On the operator derating a generator the PMS will place all generators on the same island into PMS Droop mode.

For power equipment location, consult using the Power SLD in section 5.15.1 - .

START BLOCKING OF HEAVY CONSUMERS

To prevent a system overload, the PMS provides heavy consumer start blocking to large consumers. The only large consumers are considered to be the thruster and drilling drives.

One generator or one drilling transformer is required on line in order to start a thruster.

When a start request is made the PMS will check the available power for starting. If there is insufficient available power, then the PMS will automatically start a standby generator then issue the appropriate start/close command.

a) <u>PRE-MAGNETISATION BYPASS ON:</u> The Purpose of pre-mag circuit is to limit the inrush currents causing a voltage drop which may exceed class requirements during energisation of Thruster/Drilling transformer in normal operations. So in order to start a thruster/drilling transformer a pre-mag circuit is used to avoid the inrush currents and subsequent voltage drop. When circuit is healthy, "Pre-mag ready" status is sent to IAS. When there is an over temp or fuse failure or trip from VFD will cause a loss of 230V to the pre-mag control circuit, in this case IAS will get an Alarm Pre-mag circuit is NOT ready. Pre-Mag By-pass ON/OFF status is also sent to IAS. When bypass mode is selected the status is given to IAS. Pre-Mag ON and OFF status are indicated by Green and RED LED in Pre-Mag control panel. If Pre-mag fails, a pre-mag bypass switch can be used on the transformer junction box for bypassing the pre-mag function. When the pre-mag switch is in bypass condition, the following action takes place.

Case 1: Start blocking heavy consumer OFF

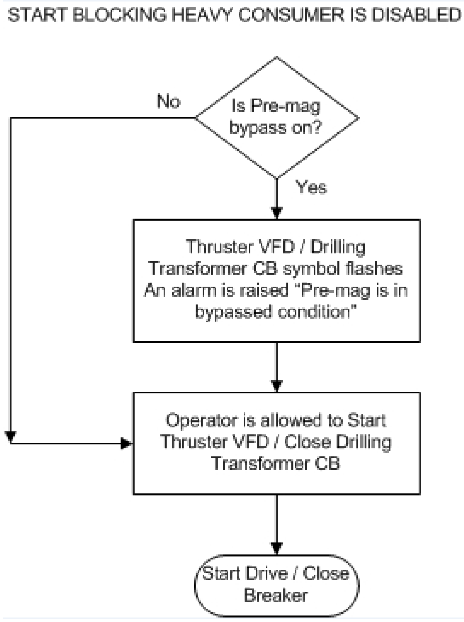


Figure 5.13 – Project - Heavy Consumer Start Blocking OFF [27].

This case is also applicable during Blackout recovery of Thrusters.

Case 2: Start blocking heavy consumer ON

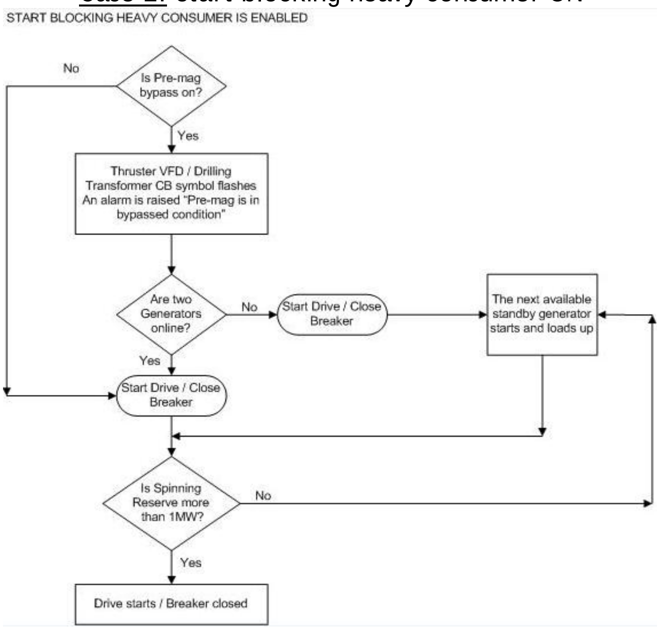


Figure 5.14 – Project - Heavy Consumer Start Blocking ON [27].

For power equipment location, consult using the Power SLD in 0 5.15.1 - .

POWER LIMITATION

The PMS provides the following power limitation functions.

- Load Limitation – Drilling Drives
- DP Power Chop (performed by DP and not PMS)
- Load Limitation – Thruster Drives

Each function is configured to operate at a pre-defined level which ensures the limitations are carried out in the correct sequence.

The levels at which the drilling and thruster reductions are triggered can be adjusted by the operator via the HMI. The option for entering a Start and Stop threshold are provided.

Figure 5.15 – Project - PMS Power Limitation Diagram [27].

The DP power chop threshold is fixed at 95%. All set points are adjustable by Operator. Drilling power limitation start margin is between 85 to 90% & stop margin is 90 to 95%. Thruster power limitation start between 95 to 100% & stop margin between 100 to 105%.

a) Load Limitation - Drilling Drives: The power limiting interface to the drilling VFD (Variable Frequency Drive) both hardwired and serial is shown here:

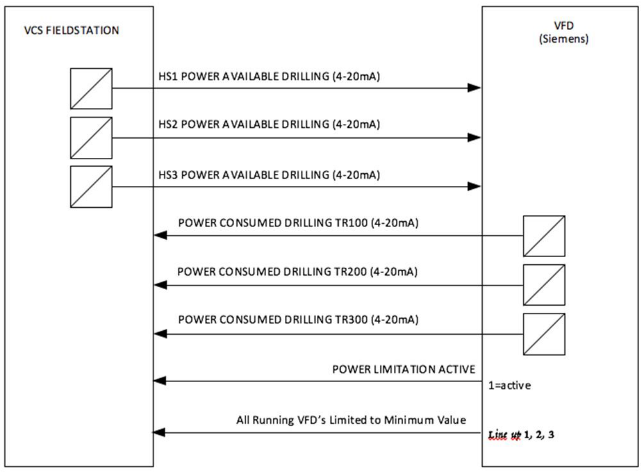


Figure 5.16 – Project - VFD Drilling Signals [27].

The power limiting interface to the Aker drilling system (serial link) is shown here:

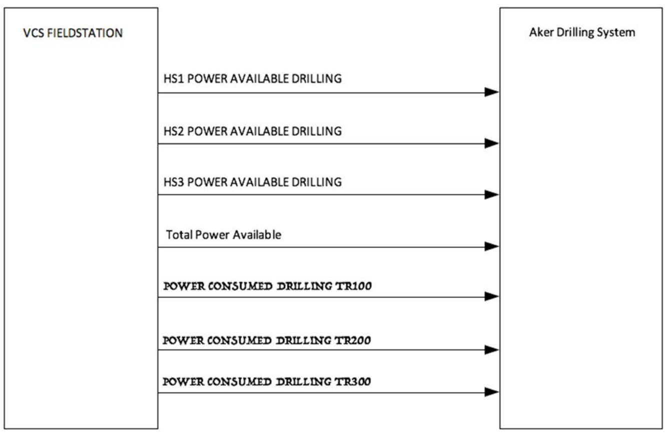


Figure 5.17 – Project - Drilling Signals [27].

The PMS continuously calculates the 'Power Available Bus' (spinning reserve) on each island based on (Total Generator Capacity - Total Bus Load), this calculation takes into account the status of the 11kv bus ties. The generator capacity is defined as {Name Plate Rating (kVA) * Power Factor (0.85pf)}, this equates to 7650kW and represents 100% generator capability. The system power factor will typically be in the region of 0.9pf. The operator has the ability to de-rate generators as required, and is taken into account when calculating 'Power Available Bus'. PMS will use a fixed power factor (0.85pf) on calculating the 'Power Available Bus'.

The generator's capacity is included in the 'Power Available Bus' calculation irrespective of the generators local / remote selection. The PMS provides an option for the operator to enter a 'Safety Margin' from the HMI. This value is configurable from 0 to 1000kW; it is added to the 'Total Bus Load' and advances the power limiting trigger point. This arrangement is shown in the diagram:

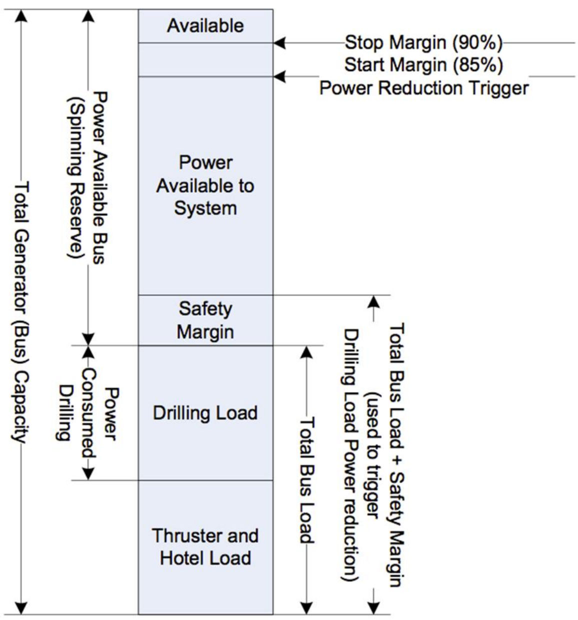


Figure 5.18 – Project - Thruster Limitation Diagram [27].

The 'Power Consumed Drilling' signal from the drilling VFD reflects the total power drawn from each drilling transformer. This must be true for all combinations of drilling VFD; DC bus ties being open or closed.

Each signal HS(n) 'Power Available Drilling' represents a total limit on how much power can be consumed by each drilling line-up. It is fixed at a maximum based upon the drilling supply transformer rating (kVA with unity power factor).

The hardwired 4-20mA 'Power Available Drilling' signal output from PMS to the Siemens VFD system corresponds to 0 – 6400kW. The hardwired 4-20mA 'Power Consumed Drilling' signal input to PMS from the VFD system corresponds to 0 – 6400kW. HS(n) 'Power Available Drilling' is always fixed at a maximum based upon the drilling supply transformer rating (100%). As an example:

i. Drilling Power limitation start limit at 85% & stop limit 90%
ii. Total Bus Load + Safety Margin at 85%
iii. Power Consumed Drilling = 3200kW then 'Power Available Drilling' will be immediately set to 12mA.
iv. If the total bus load continues to increase from 85% to 90% the PMS will reduce the 'Power Available Drilling' output from the initial 'chopped' value to 4mA (if not already at 4mA).

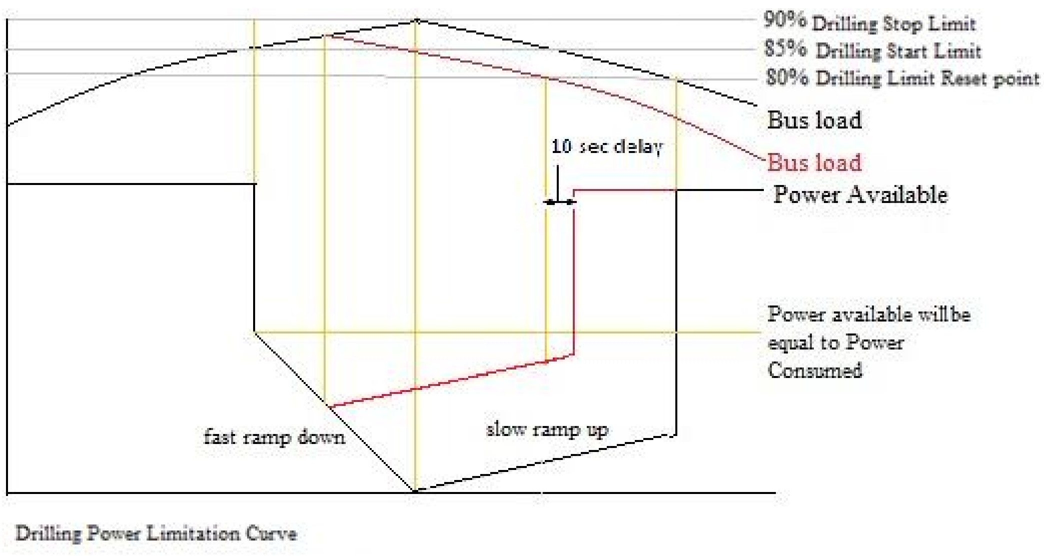


Figure 5.19 – Project - Drilling Power Limitation Diagram [27].

b) DP Power Chop: The DP system will also invoke its power system overload protection, known as Power Chop, if the system load exceeds a pre-configured critical margin, typically set to 95%. For more information on the DP power chop see section 5.7.3 - .

c) <u>Load Limitation:</u>
Thruster Drives: The power limiting interface to each thruster drive is shown here:

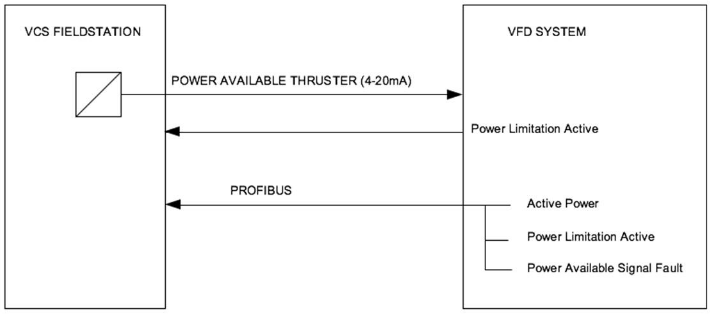


Figure 5.20 – Project - Thruster Drive Limitation Signals [27].

The PMS continuously calculates the 'available power' on each island based on total generator capacity minus the total bus load. This calculation takes into account the status of the 11kV bus ties.

The hardwired 4-20mA 'power available thruster' signal issued from the PMS to the thruster drives corresponds to 0 – 6500kW and is issued as a percentage: 4mA = 0% (0kW) & 20mA = 100% (6500kW)

The 6500kW upper limit is based on the rating of the motor (5500kW) and 1000kW extra margin to take into account the drive train losses, in order to give 100% shaft speed power.

6500kW relates to the rated thruster value and is fixed. The 'power available thruster' value will always be set at maximum (100%).

As an example:

i. Thruster power limitation start limit to 95% & stop limit to 100%
ii. Power Consumed Thruster = 3250kW then 'Power Available Thruster' will be immediately set to 12mA.
iii. If the total bus load continues to increase from 95% to 100% the PMS will reduce the 'Power Available Thruster' output from the initial 'chopped' value to 4mA (if not already at 4mA).

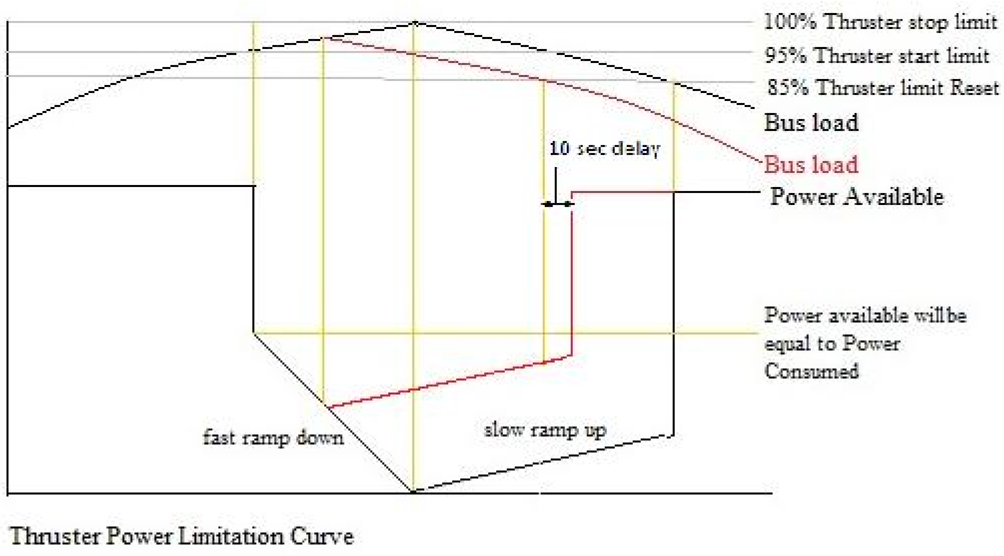


Figure 5.21 – Project - Thruster Power Limitation Diagram [27].

5.7.4 - Alarm & Monitor System:

PRIMARY & SECONDARY CONTROL AREAS

Primary areas are defined as ECR. Secondary areas are the Wheelhouse and DP Backup Room.

ALARM GROUPS

The alarm groups are defined in the following table. This table also identifies which alarm groups each control group hears enunciated, and which alarms cannot be muted by pressing the mute button (usually fire alarms cannot be muted).

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

Table 5.8 — Alarm System – Alarm & Control Groups.

Alarm Group	Description	Control Group						Can be muted
		Machinery (1)	Ballast (2)	HVAC (3)	Thrust (4)	Power (5)	Drilling (6)	
1	Power Generation	No	No	No	No	Yes	No	Yes
2	Power Distribution	No	No	No	No	Yes	No	Yes
3	Thrusters	No	No	No	Yes	No	No	Yes
4	Auxiliary Systems	Yes	No	No	No	No	No	Yes
5	Ballast & Bilge Systems	No	Yes	No	No	No	No	Yes
6	Drilling System	No	No	No	No	No	Yes	Yes
7	Fire & Gas System	Yes	No	No	No	No	No	Yes *
8	HVAC	No	No	Yes	No	No	No	Yes
9	Automation System	Yes	No	No	No	No	No	Yes
10	Bilge Level Alarms	Yes	No	No	No	No	No	Yes

* Please note, this alarm can be muted on the VCS as the same alarm on the Safety System cannot be muted, and the safety system is in the same locations as the VCS.

ALARM EXTENSION SYSTEM

The Alarm Extension System for watch and responsibility is com composed of 14 Watch call & 6 alarm columns, as per below list & HMI mimic:

- Wheelhouse
- Chief engineer cabin
- 1st, 2nd, 3rd engineer cabin
- Tool pusher & driller office
- PMS office
- IT cafe
- Quiet Recreation Room
- Recreation Room
- Library
- Office 8 person.
- Maintenance supervisor office
- Mess Room

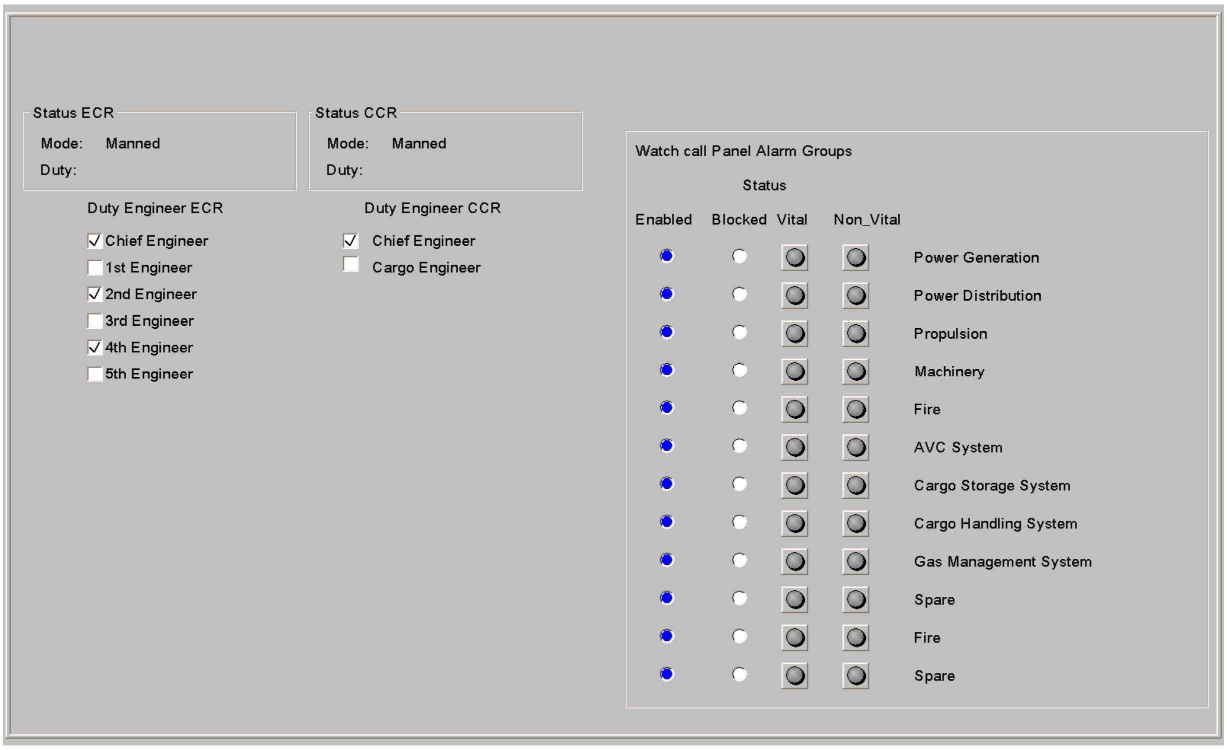


Figure 5.22 – Project - Alarm Extension HMI [26].

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

5.7.5 - Thruster Management System

GE PC has supplied a Thruster Management System.

Thruster locations are shown below:

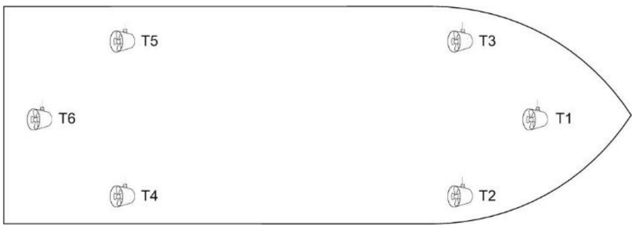


Figure 5.23 – Project - Thruster Locations [27].

THRUSTER - ROLLS ROYCE

Each thruster comprises a thruster unit (inboard and outboard components) and a propulsion room Aquamaster Control unit (ACU).

This equipment is supplied by Rolls Royce.

VARIABLE SPEED DRIVE SYSTEM - SIEMENS

Each variable speed drive system comprises a transformer, frequency converter and an electric motor.

This equipment is supplied by Siemens.

INTERFACE OVERVIEW

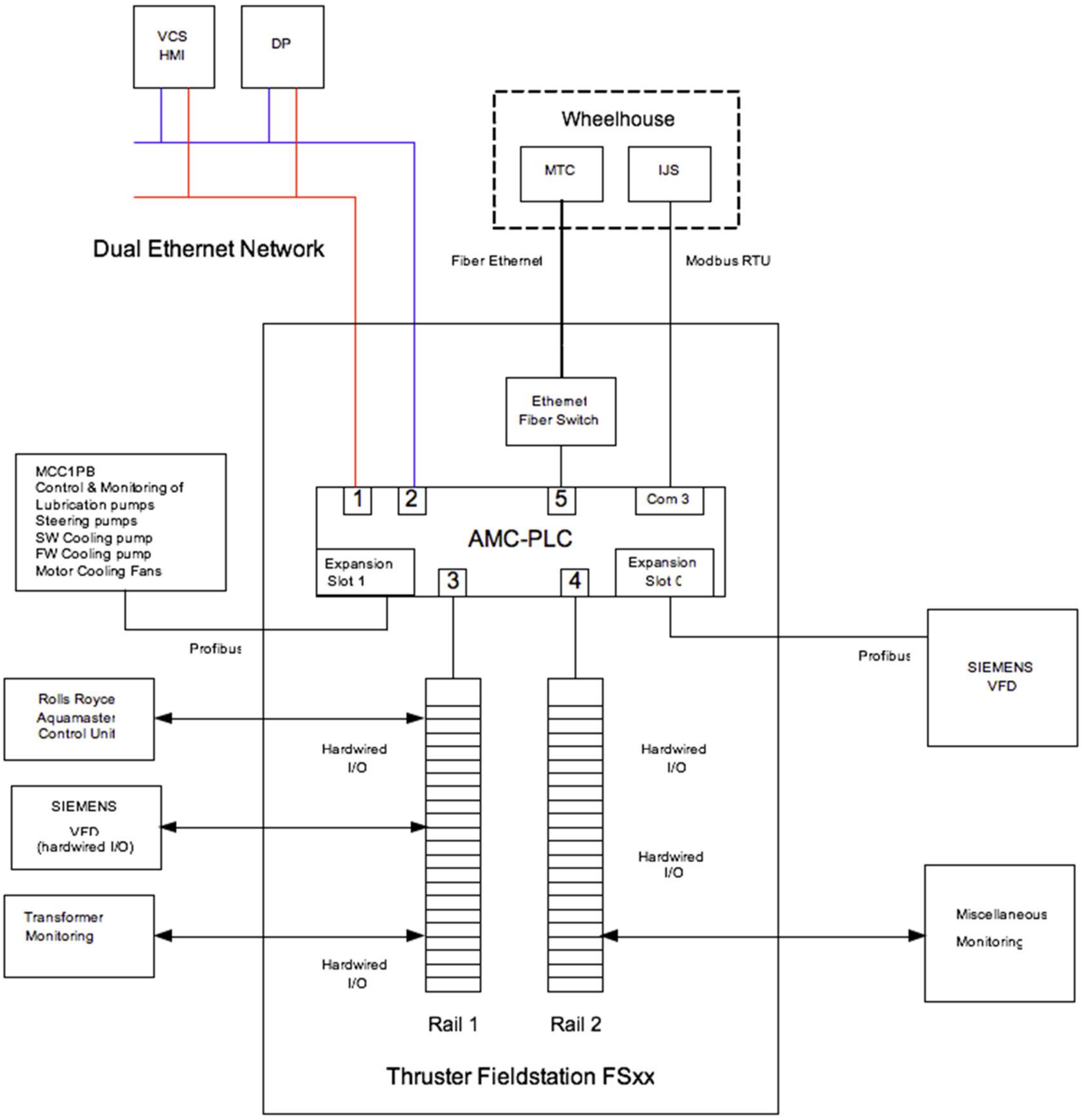


Figure 5.24 – Project – Drive Interface Overview [27].

When the operator issues a start command from the HMI, the VCS will carry out the following steps:

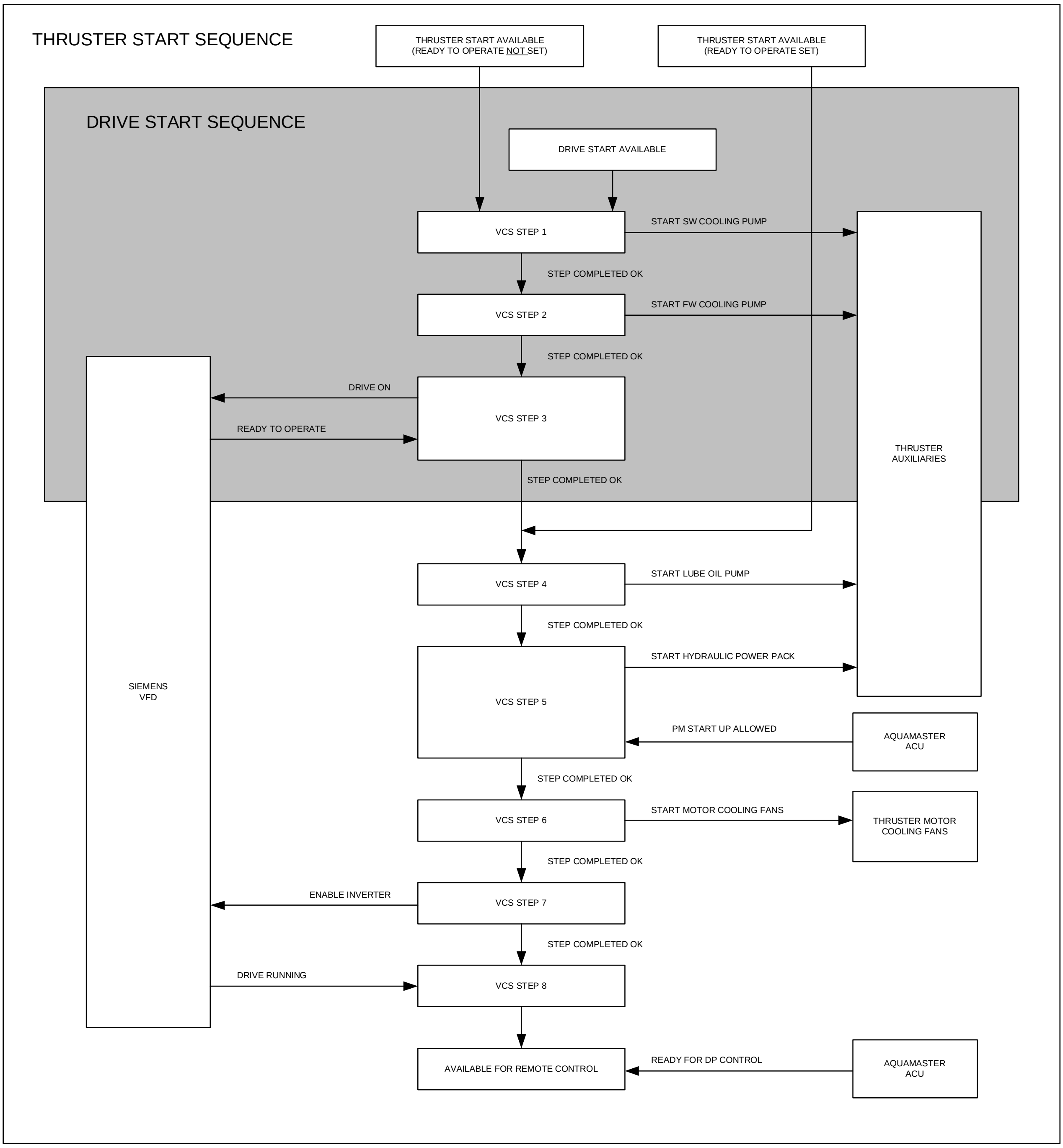


Figure 5.25 – Project - Drive Start Sequence [27].

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

The first 2 steps of this sequence initiate the start of the Sea Water (SW) & Fresh Water (FW) pumps for the Thruster's first auxiliary sub-systems. After, on step 3, its time to initiate the Thruster VFD by sending a "Drive On" command and then after its internal checking, receive the "Ready to Operate" feedback, before moving into step 4.

5.8 - Vessel Management System (VCS)

- HVAC
- Ballast
- Bilge
- Compressor (Starting/Service & Control/Bulk)
- Contaminated Drain
- Fresh Water Cooling
- Sea Water Cooling
- Fuel & Lubrication Oil
- Heli Fuel
- Portable Water
- Hydraulic Power Pack for Remote Valve Control
- EMP

5.8.1 - Ballast/Bilge Management System

The vessel ballast system is divided into three sub systems:

- Main ballast system
- Aft and forward trim bilge/ballast system
- Bilge systems

BALLAST

The system has the function of adjusting the draught, trim and heel of the vessel for various loads by flooding or draining the ballast tanks which are distributed along the cargo tanks, and in the fore and aft peaks of the vessel.

The system is capable of performing the following functions:

- Stripping the ballast tanks
- Free flooding the ballast tanks to exterior sea level through sea inlet valves located in the sea chests
- Flooding the ballast tanks by utilizing the ballast pumps.
- Emptying the ballast tanks to exterior sea level by gravity or by the ballast pumps.

There are eight modes in which ballast system can work. They are as follows-

- Warming up mode: Ballast pump will take suction from sea chest, pass through filter and UV sterilizer and discharge overboard. This mode is used to warm up UV lamps.
- Ballasting mode: Ballast pump will take suction from sea chest, pass through filter and UV sterilizer and discharge to ballast tanks.

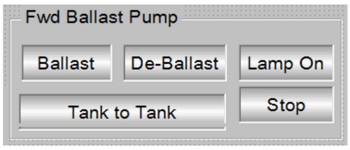


Figure 5.26 – Project - Ballast Pump Control [26].

- De-ballasting mode: Ballast-pump will take suction from ballast tank, pass through UV sterilizer and discharge overboard.
- Stripping mode: Stripping pump will take suction from ballast tank, pass it through UV sterilizer and discharge overboard.

Figure 5.27 – Project - Ballast Pump Control [26].

- Treatment mode: This mode is used for treating the water in the ballast pipeline. Stripping pump will circulate the water in the pipeline passing it through the filter and UV sterilizer.
- Back flushing (cleaning) mode: Stripping pump will take suction from ballast tank and pump to the BWTS. BWTS shall back flush the filter and water shall be discharged overboard.
- Tank-to-Tank transfer mode: Ballast tank will take suction from ballast tank and discharge to another side of the ballast tank via the bypass line. If suction is taken from port side ballast tank, discharge will be on Stbd side tank and vice versa.

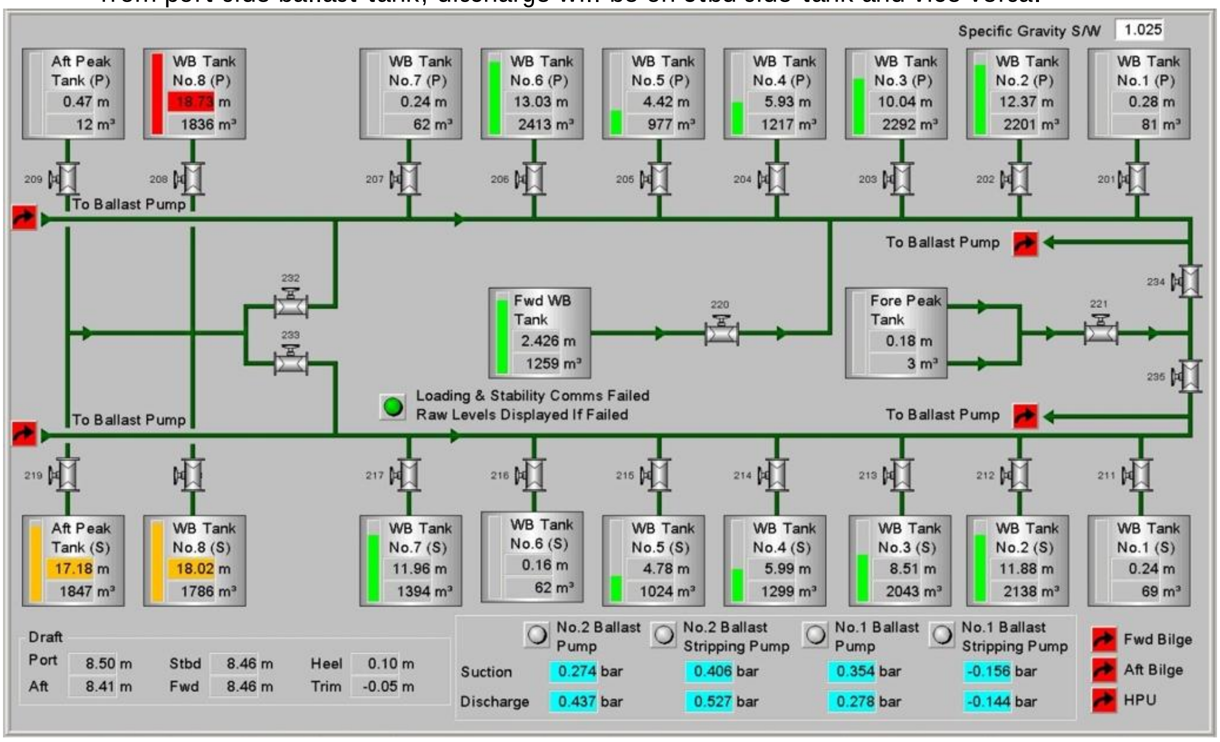


Figure 5.28 – Project - Ballast System HMI [26].

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

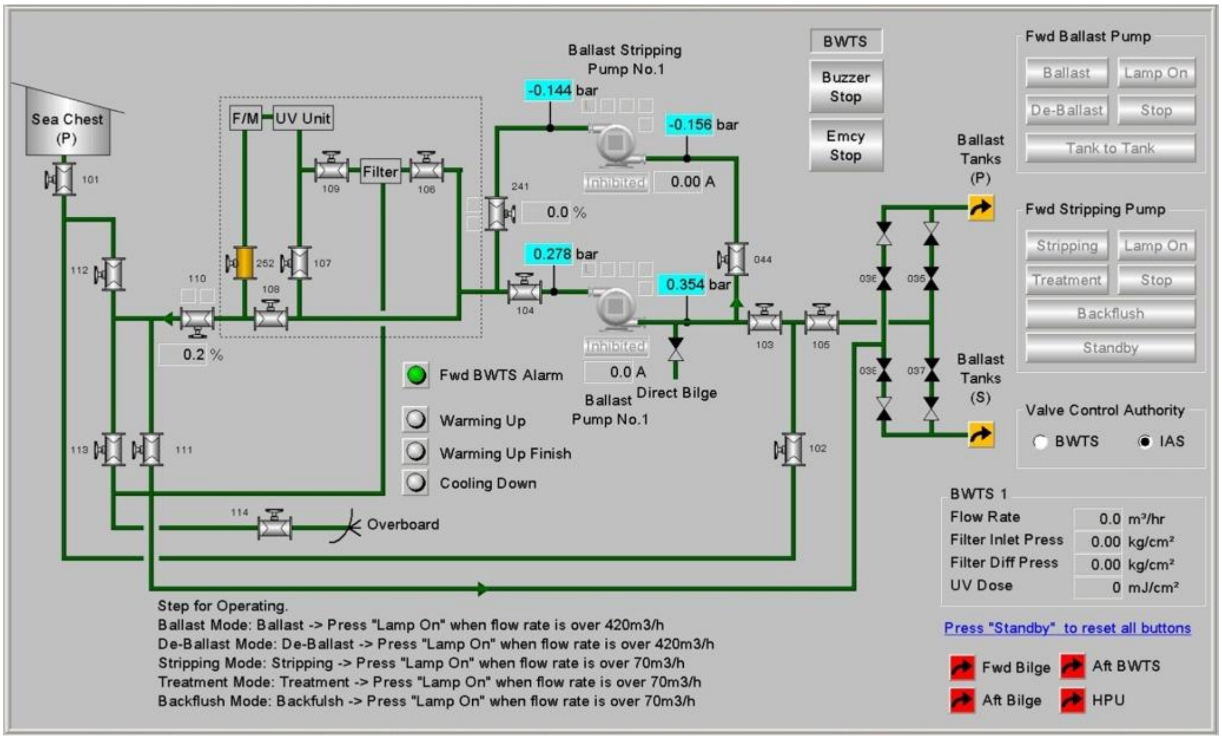


Figure 5.29 – Project - Detail Ballast System HMI [26].

BILGE

Various bilge wells in the aft machinery space are monitored for high level by level switches. When the level in these tanks exceeds the allowable level, it is alarmed in the IAS. The collected bilge can be discharged overboard by operating the Aft bilge pumps or can be transferred to the Aft Bilge Storage tank. The collected bilge can be transferred to the Aft Bilge Storage tank. When emergency case, collected bilge can be discharged overboard by operating the Aft bilge pumps.

Bilge separator is used to clean the collected bilge. The clean water is discharged overboard and the oil is transferred to the waste oil tank.

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

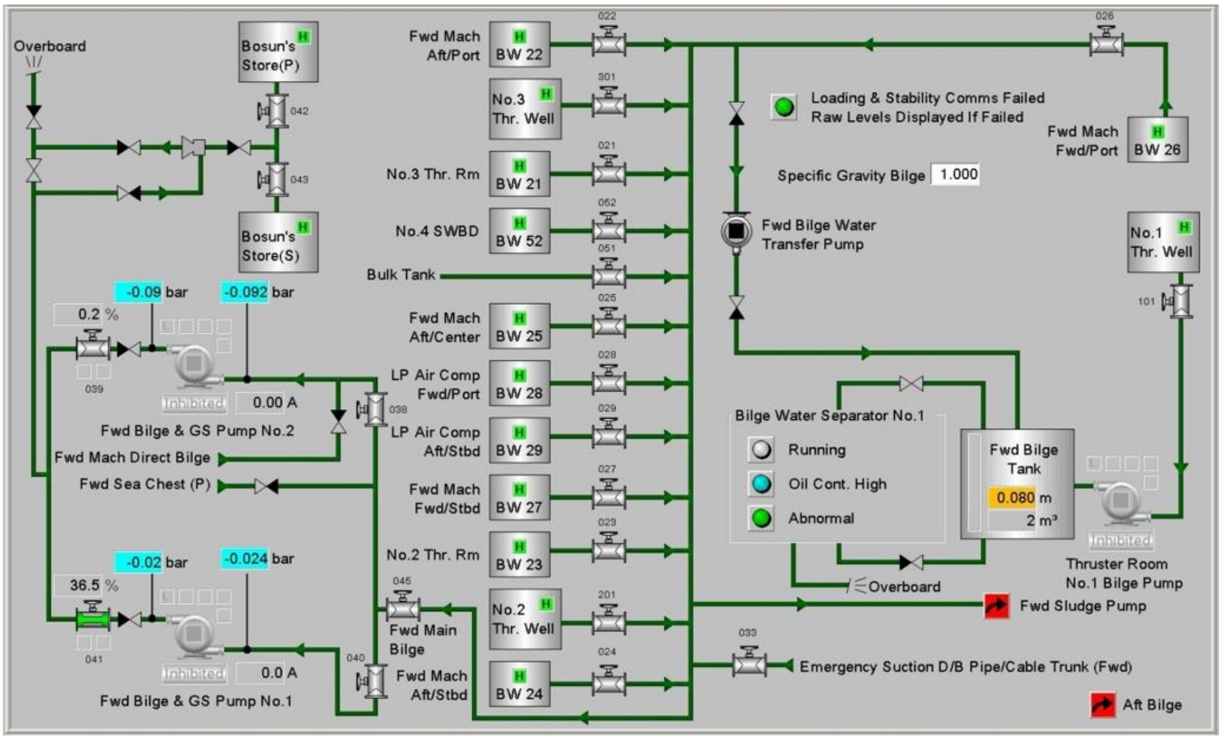


Figure 5.30 – Project - Bilge System HMI [26].

Fuel Oil

The vessel is designed to have three identical Fuel oil filling, storage and transfer system, one for each of the aft machinery space. Each independent system is cross connected at strategic points with normally closed isolation valves, so that if needed FO can be transferred among the tanks of these three systems. There are two fuel oil bunker stations on the vessel, located on port and starboard side. On each side there is common FO filling line. When bunkering, FO is routed through manually operated valves into the appropriate storage tanks.

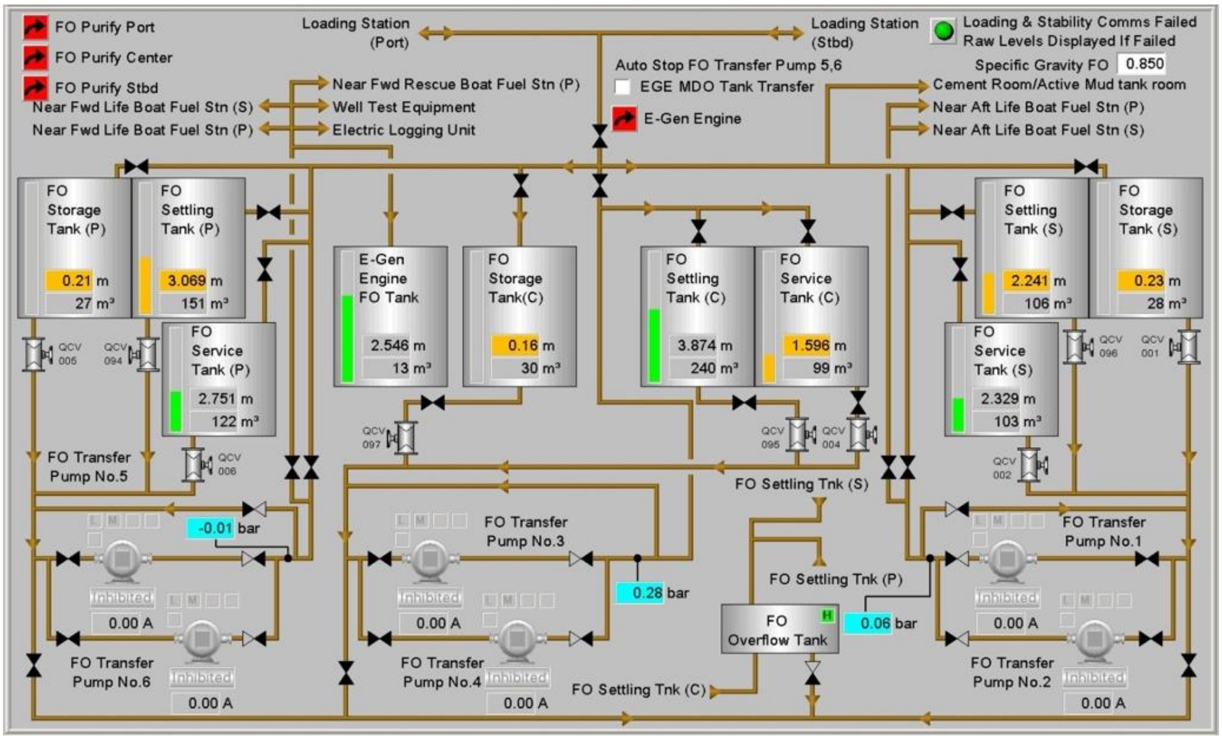


Figure 5.31 – Project - Fuel Oil System HMI [26].

5.8.2 - Compressed/Starting Air

The aft machinery area is divided into three compartments. Each compartment houses two main generators, with each pair of generators having a main engine starting air system.

Each of the main generator starting air systems comprises of one compressor and one reservoir. The compressors are electric motor driven. The compressor compresses the atmospheric air and charges the reservoir. The reservoirs are monitored for its pressure by IAS. A pressure switch is installed in each of the reservoirs. The compressor is automatically started if the pressure drops below a certain value (25 bar) and stopped when the pressure reaches a higher value (30 bar). The reservoir supplies starting air to generator engines.

The reservoirs’ outlets are connected to a common header line so that any of the reservoirs can be used to start any of the engines. Isolation valves are installed at compartment boundaries to keep the systems in separate compartments during normal working condition.

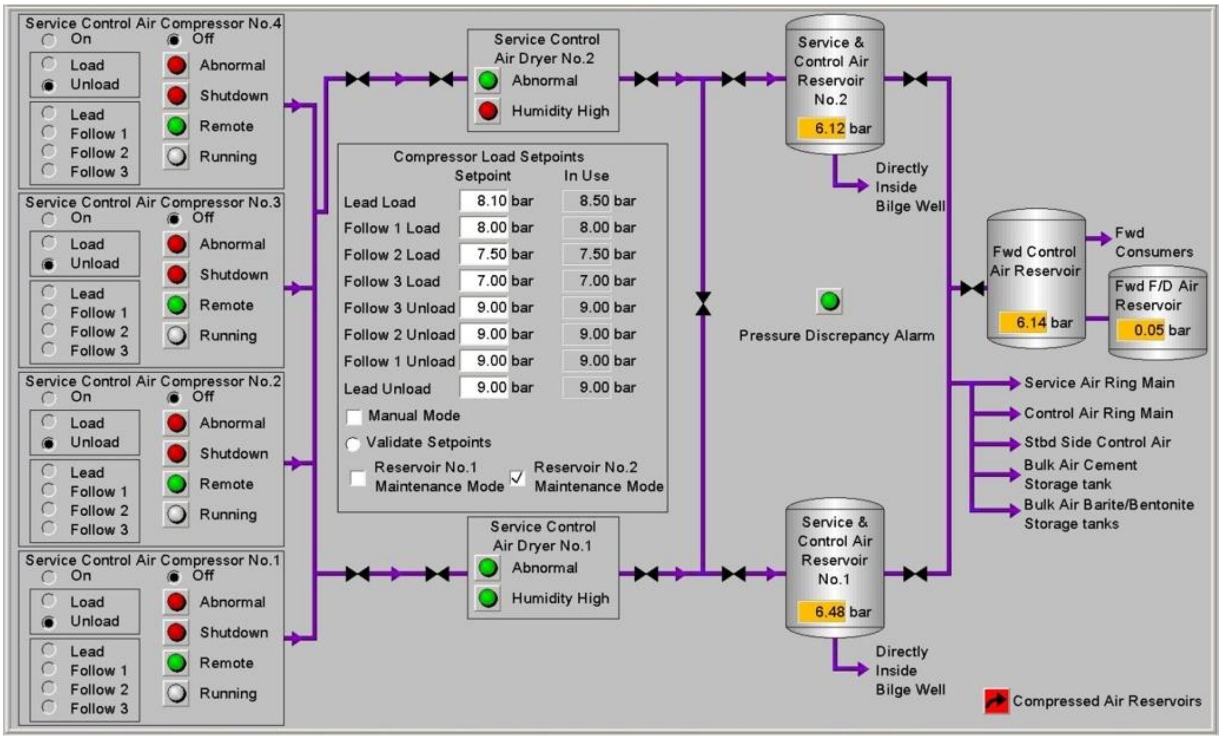


Figure 5.32 – Project - Compressed/Starting Air System HMI [26].

5.8.3 - Drilling Systems

The Drilling systems are supplied by both Siemens (Drives) & Drilling equipment/systems by Aker Systems. The IAS PMS has got Power Limitation & Busties control – more details in section 5.7.3 - . 20 HMI mimics were created to monitor & control this system, see below:

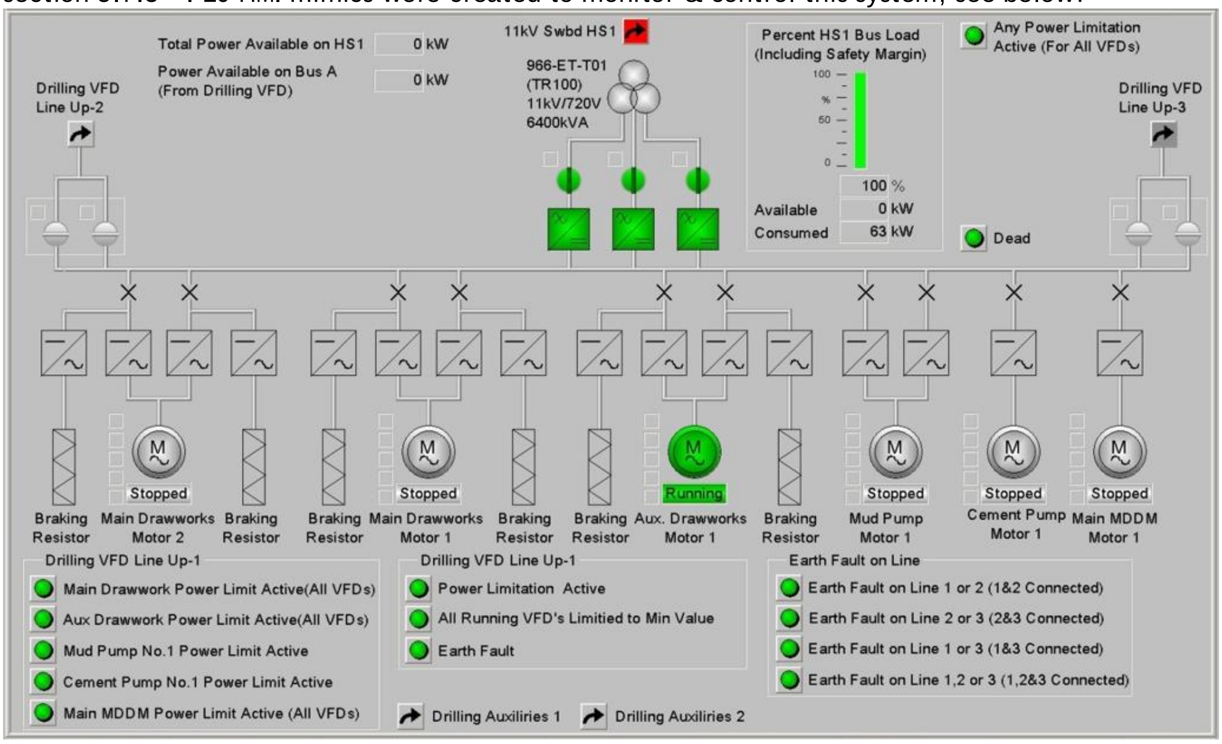


Figure 5.33 – Project - Drilling System HMI [26].

5.9 - DP System

GE PC has supplied the Manual Thruster Controls (MTCs), Independent Joystick System (IJS), and the Dynamic Positioning System (DP) for this vessel, Cobalt H3618.

GE DP system enables this vessel to perform safe and efficient drilling operation, by utilizing modern software technology such mathematical modelling of vessel behaviour, Kalman Filtering techniques and Optimal Controllers in order to provide the required positioning accuracy for the various modes of operation. ▫

5.9.1 - Operational Philosophy

The position reference system measurements are pre-processed, to determine the best position estimate based on all the operator selected reference and sensor systems. This requires simultaneous and online monitoring of all sensors and position reference systems. Furthermore, the weight factor on the individual position reference system are dynamic based on the quality of the individual system.

For measurement of the vessel position, DGPS and hydro acoustic have been used. For control of the vessel heading, three Gyros have been used to give the necessary heading reference. The system has been interfaced to three Wind Sensors and has been included with a Riser Angle Measurement system. ▫

The system shall include an ECDIS interface to perform automatic steering along the pre-planned route in straight and curved lines, together with a dual axis Doppler Log interface.

Three motion reference systems (MRUs) have been interfaced to the DP system to compensate position measurements for vessel roll and pitch. ▫This vessel also contains heave measurements (in phase with pitch and roll). ▫Wave force compensation are based on estimation techniques, based around Kalman filter techniques.

Finally, The DP system communicate with the thruster control system and the power management system via the redundant communication network.

5.9.2 - Triple redundant/DP3 System

This vessel was fitted with a triple redundant DP system, consisting of the main items:

- DP Operator Consoles with dual power input (3 consoles)
- Three redundant computer system with voting (triple redundancy)
- Redundant power system
- Hydro-acoustic position reference system
- Differential global positioning system
- Environmental sensors

The backup single redundant DP consists of the following main items:

- DP Operator Console
- Computer system

- Hydro acoustic position reference system
- Differential global positioning system
- Environmental sensors

5.9.3 - Station keeping capability

The positioning systems were designed so that the Drillship shall be able to continue all normal drilling operations in the environmental conditions defined as the normal drilling limit.

During the environmental conditions defined as standby, all drilling operations shall be suspended, the Drillship shall be at drilling draft, the riser shall be connected, and the drill stem shall be either pulled or hung off. During the environmental conditions exceeding the standby (survival), the riser shall be disconnected and pulled or hung off.

Environmental forces have been taken to act concurrently from the direction which maximizes the total force or creates the strictest operating constraint.

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

5.9.4 - Control Modes

The different types of DP vessel control are referred to as “Control Modes”.

To operate the vessel in a particular control mode may require selection of specific inputs (sensors and position measurement equipment) and specific thruster combinations before the control mode can be entered. The selection of sensors, PMEs, thrusters and control mode is made by the operator from the active DP workstation.

The following Control Modes are available to the operator at the DP Workstations:

- Monitor Mode & Dynamic Positioning (Auto Positioning)
- Model Control (Dead Reckoning)
- Simulation (for training purposes)
- Riser Follow (Hold on predetermined ball joint uniflex joint angle)
- Re-entry & DP Minimum Power (Minimum load)
- Auto Track (Slow Track Follow) & ROV Follow (Fixed Distance or Reaction Radius)

The following additional DP Features are available at each DP Workstation:

- Wind Compensation (Wind Feed Forward)
- Power Overload Protection (‘Power Chop’)
- Gain Selection (alter auto sensitivity)
- Centre of Rotation Selection
- Fast Learn Gains (Quick Model Update)
- Rate of turn (Rate of turn speed optimizing)
- Relaxed DP & Auto-draft Compensation
- Joystick Power (alter joystick sensitivity)

- Online Capability & Consequence Analysis
- Online Drift Off Analysis (Motion Prediction)
- Thruster Allocation Logic (Thruster Transform)
- Azimuth Thruster Free & Bias & Fixed Configurations
- Azimuth Thruster Barred Zones
- C-Maps Enabled & User defined save/load parameters
- Day/Dusk/Night settings & Data Logging
- Riser Angle Monitor

5.9.5 - DP/IJS/MTC Control & Changeover

Manual thruster control (MTC) is performed using the MTC levers located in the wheelhouse – see section 3.4.9 - for details.

Manual control of the thrust vector, with optional automatic heading mode, can be carried out using the independent joystick system (IJS), located in the wheelhouse.

Manual control of the thrust vector, with optional automatic heading and optional hold position control is implemented at three dynamic positioning (DP) workstations, located on the wheelhouse, and one DP workstation, located in the DP backup room (DBR).

Each thruster has a ready to start signal that is comprised of signals that are cabled to its associated thruster field station, e.g.: auxiliaries running, hydraulics healthy, drive available to start, etc. Each 'ready to start' signal is then mapped to its respective MTC panel. Ready to start thruster is displayed on the thruster touch screens. The operator can then start each drive and the thrusters that become available to the GE system.

If a thruster becomes available for GEPC control, each control station (MTC, WS01, WS02, WS03, WS04 and IJS) flashes 'Control here'. The operator presses 'Enable' – 'Control here' at the desired desk to take control of the vessel. Once the thrusters are selected the vessel can be manoeuvred using the DP joysticks, IJS joystick or the manual lever control (MTC), depending on which station is in control.

Changeover between the DP, IJS and MTC is via the control here button (physical button with enable or screen button with confirm). Control can be offered between stations by pressing the on-line consoles control button whereupon the light will flash at all other stations that can take control. If another station's button is then selected the indication will extinguish at the original station and show at the new station. The IJS can take control from the DP at any time. If the DP fails completely the IJS is automatically offered control.

The Independent Joystick System (IJS), uses the same thruster Fieldstations as used by the DP system, but IJS Controller communicates to them using a separate dedicated IJS serial link for each thruster Fieldstation. Transfer of control between IJS and DP Controllers is implemented using handshake signals relayed between the DP and IJS Controllers via the thruster Fieldstations.

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

5.9.6 - Control Philosophy

The DP system communicates with the Siemens Thruster control system for remote speed & torque reference setpoints/feedbacks and with the Rolls Royce Aquamaster system for Thruster Azimuth reference setpoints/feedbacks.

Two forms of Thruster speed/torque control will be transmitted:

- Whilst in DP control the Fieldstation will transmit speed reference only.
- Whilst in MTC control the Fieldstation will transmit torque reference only.

The speed demand is calculated at the DP controller and transmitted to the Fieldstation:

$$speed(\%) = \sqrt{\text{thrust}(\%)}, \qquad (1.1)$$

The torque demand will be calculated at the Fieldstation:

$$torque(\%) = \text{thrust}(\%), \qquad (1.2)$$

One form of Thruster Azimuth control will be transmitted:

The Azimuth reference is 4 to 20 mA proportional to ±180 degrees, where 4 mA = -180 degrees, 12 mA = 0 degrees and 20 mA = +180 degrees.

Azimuth feedback from the thruster controls is in the form of ±10V Sine and Cosine signals. (e.g. at 0° the Sine signal = 0V and Cosine signal= 10V).

5.9.7 - Swbd Monitoring & Overload Protection

For each generator, the DP system measures the kW load by means of a signal from a kW transducer. The DP system also receives input signals to indicate the open/closed state of each generator circuit-breaker and bus tie, which enables it to determine whether the complete bus is connected together to form a single bus section or split into two or more bus-sections.

For each bus section, the DP system compares the kW load on the generator(s) connected to that “bus-section” with the total kW ratings of those generator(s). If the kW load exceeds a pre-determined percentage of the total ratings (known as the “critical margin” and typically set to 95%) the DP system automatically invokes the power system overload protection to reduce the risk of a black-out of the vessel.

The power system overload protection is referred to as “power chop”. Depending on the state of the bus-ties, the “power chop” may affect one, some or all of the thrusters. When it is invoked in the way described above, the thrust demands for thrusters connected to the affected “bus section(s)” are rapidly reduced to reduce the power load. The thrust demands are then slowly ramped-up until the critical margin is reached.

The system will exit the “power chop” condition when the total thrust demands are met with the kW load for that bus-section below the “critical margin”.

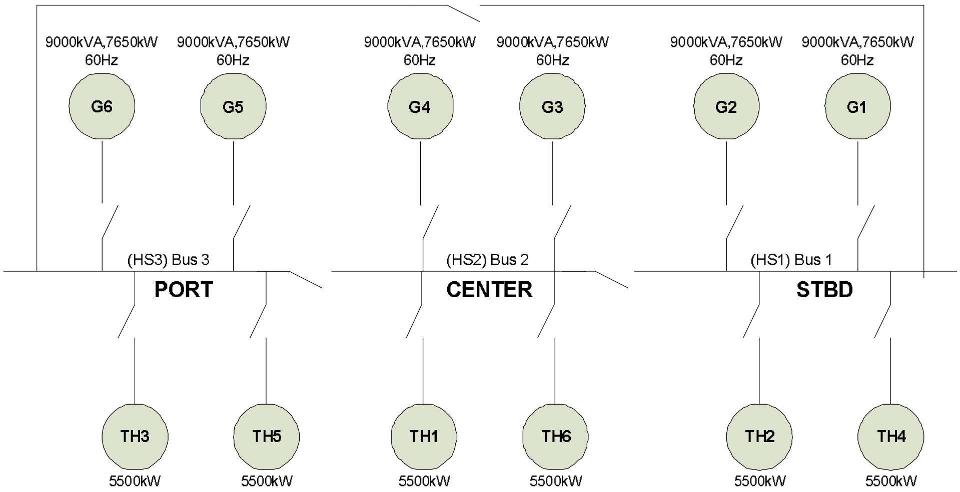


Figure 5.34 – DP Swbd Monitoring & Overload Protection.

5.9.8 - Equipment Location – DP System

The DP System is provided by GE. The Gyrocompass system & components are provided by TSS SG Brown. All with the respective SW being coded, installed & commissioned by the individual supplier.

For equipment list, consult location by using the Automation/DP SLD in section 5.15.2 - .

Table 5.9 — Project - DP System Equipment Location.

Function	Location	Quantity	ID
DP Workstations	Wheelhouse (W/H) DP Back-up Room (DBR)	3 1	WS01, WS02, WS03 WS04
DP Repeaters Workstations	Driller's Control Cabin (DCC)	1	WS05
DP Controller Cabinets	Electrical Equip. Room (EER1) DP Back-up Room (DBR)	3 1	CC02, CC03, CC04 CC01
IJS Portable Joystick	Wheelhouse (W/H) Wind Corridors	1 1	JS11 JS12
IJS Controller	Electrical Equip. Room (EER1)	1	CC09
IJS Docking Stations	Wind Corridors	3	DS11, DS12, DS13
MTC Control Desk	Wheelhouse (W/H)	2	MTC1, MTC2
Gyro Units	Wheelhouse (W/H) DP Back-up Room (DBR)	2 1	GYRO1, GYRO2 GYRO3
VRU Units	Electrical Equip. Room (EER1) DP Back-up Room (DBR)	2 1	VRU2, VRU3 VRU1
Anemometer Units	Wheelhouse (W/H) DP Back-up Room (DBR)	2 1	ANEM1, ANEM2 ANEM3

5.9.9 - Communication Links - DP System

Table 5.10 — Project - DP System Serial Links.

System	Function	Communications
Azimuth Thrusters	Main Propulsion/Thrusters/Steering	Dual Redundant Ethernet to IAS
Power System	Power System Generators, CBs & Busties Status	Dual Redundant Ethernet to IAS
RMS	Electric Riser Inclination Data System	RS232/422 Serial Link, Standard NMEA 0183
Doppler	Dual Axis Doppler Log	RS232/422 Serial Link, Standard NMEA 0183
Gyrocompass	Heading	RS422/485 Serial Link, Standard NMEA 0183
Anemometer	Wind speed & direction	RS422/485 Serial Link, Standard NMEA 0183
MRU	Motion Reference Sensor	RS422/485 Serial Link, Standard NMEA 0183
Tank/Draft Gauging System	Draft Sensors	Dual Redundant Ethernet to IAS

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

5.9.10 - Position Measurement: Acoustics & DGPS

The DGPS 1&2 are provided by Veripos Systems, DGPS 3 is provided by C-Nav, the HPR is provided by Sonardyne Systems. The DGPS & acoustics HPR workstations & repeaters are provided by GE, with the SW installed & commissioned by the individual suppliers.

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

Table 5.11 — Project - DP System Acoustics & DGPS Locations.

Function	Location	Quantity	ID
HPR Workstations	Wheelhouse (W/H) DP Back-up Room (DBR)	2 1	WS21, WS23 WS22
HPR Repeater Screens	Port ROV Van Stbd ROV Van	1 1	
DGPS Workstations	Wheelhouse (W/H) DP Back-up Room (DBR)	2 1	WS2, WS23 WS24
DGPS Repeater Screens	Wheelhouse (W/H)	2	

The communications links from GE to these two systems are depicted below:

Table 5.12 — Project - DP System Acoustics & DGPS Comm. Links.

System	Function	Communications
HPR	Sonardyne Acoustic System	RS422/RS485 Serial Link, GE standard format to DP system
DGPS	Differential GPS	RS422/RS485 Serial Link, Standard NMEA 0183 to DP system

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

Below is the typical Single Line Diagram (SLD) of the Sonardyne Acoustic Dual Inertial system:

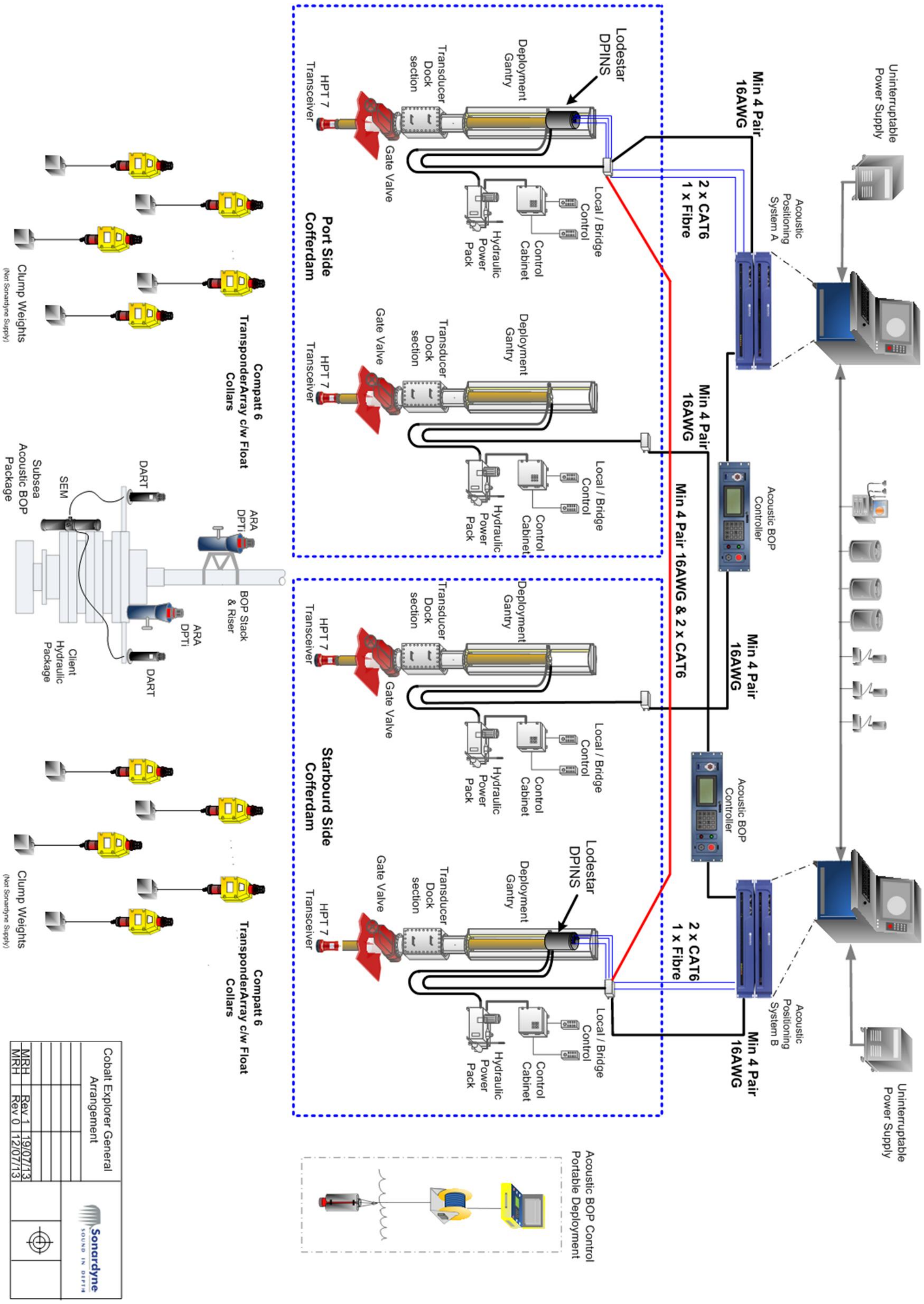


Figure 5.35 – HPR - Sonardyne Acoustic Dual Inertial System [10].

5.9.11 - Independent Joystick System (IJS)

The IJS Portable Joystick System is provided by GE.

For equipment list, consult location by using the Automation/DP SLD in section 5.15.2 - .

Table 5.13 — Project - IJS System Equipment Location.

Function	Location	Quantity	ID
IJS Portable Joystick	Wheelhouse (W/H) Wind Corridors	1 1	JS11 JS12
IJS Controller	Electrical Equip.Room (EER1)	1	CC09
IJS Docking Stations	Wing Corridors	3	DS11, DS12, DS13

The communications links of IJS Portable Joystick system are depicted below:

Table 5.14 — Project - IJS System Communication Links.

System	Function	Communications
SWBDs	Power System Generators, CBs & Busties Status	RS422/RS485 Serial Link
GE Thruster Fieldstations	Thruster control & monitoring, plus its auxiliary systems	RS422/RS485 Serial Link

For equipment list, consult location using the Automation/DP SLD in section 5.15.2 - .

The following Control Modes are available to the operator at the Independent Joystick Panel:

- Joystick Manual Heading
- Joystick Auto Heading
- Auto Pilot (IMO Compliant)
- Mixed Axis Mode (axis auto/manual control switching)

The following additional IJS Features will be available to the Operator at the Independent Joystick Panel:

- Wind Compensation (Wind Feed Forward)
- Power Overload Protection ('Power Chop')
- Gain Selection (alter auto sensivity)
- Rate of turn (Rate of turn speed optimizing)
- Joystick Power (alter joystick sensitivity)
- Thruster Allocation Logic (Thruster Transform)
- Azimuth Thruster Free & Bias & Fixed Configurations
- Azimuth Thruster Barred Zones
- Day/Dusk/Night settings

5.9.12 - IJS Blackout Prevention

The IJS Controller will provide blackout protection.

The IJS Controller monitors the power system using switchboard status information received from the switchboard Fieldstations. When any generator loading approaches maximum the IJS demands are automatically limited, at the IJS Controller, and an alarm is raised. This alarm is active while the limitation is held on.

This limitation is different to the MTC blackout prevention as the limit is implemented at the IJS Controller and not at the thruster Fieldstation.

5.9.13 - Manual Thruster Control (MTC)

The MTC System is provided by GE.

For equipment list, consult location by using the Automation/DP SLD in section 5.15.2 - .

Table 5.15 — Project - MTC System Equipment Location.

Function	Location	Quantity	ID
MTC Control Desk	Wheelhouse (W/H)	2	MTC1, MTC2

The communications links of the MTC Thruster systems are depicted below:

Table 5.16 — Project - MTC System Communication Links.

System	Function	Communications
GE Thruster Fieldstations	Thruster control & monitoring, plus its auxiliary systems	Discrete point-to-point fibre optic links

The following features will be available to the Operator at the MTC Console:

- Start/Stop/Emergency Stop per thruster
- Auto/manual Control indication per thruster
- Manual Lever control, one per thruster
- Lever Group select and control enabling control of multiple thrusters (from a single manual lever)
- Single Lever Control with all other thrusters in DPS control

5.9.14 - MTC Blackout Prevention

The MTC will provide blackout protection.

Each Thruster Fieldstation monitors the power system using switchboard status information received from the switchboard Fieldstations. When any generator loading approaches maximum the MTC demands are automatically limited, at the thruster Fieldstation, and an alarm is raised. This alarm is active while the limitation is held on. This limitation is different to the IJS blackout prevention as the limit is implemented at the thruster Fieldstation. The IJS blackout prevention is implemented in a similar way but the limit is implemented at the IJS Controller by limiting the thrust demands being sent to the thruster Fieldstations. The DP does the same.

Each thruster Fieldstation has the switchboard status data and will implement MTC power limited ramps depending on the number of generators, the generator capacity and rate limits, and the number of thrusters.

On failure of the switchboard status information from switchboard Fieldstations, due to network failure or switchboard Fieldstation failure, the thruster Fieldstation uses fast data drive frequency to prevent the generator overload. A switchboard communications fail alarm will be active while the switchboard data has failed. In addition to the MTC frequency thruster power limitation, the thruster drive will implement under frequency protection and will phase back at a much quicker rate than the previous protection.

5.9.15 - DP Alert System

The DP Alert System is provided by GE.

For equipment list, consult its location using the Automation/DP SLD in section 5.15.2 - .

Table 5.17 — Project – DP Alert System Equipment Location.

Function	Location	Quantity	ID
DP Alert Panels	Wheelhouse (W/H)	1	AS01
	DP Back-up Room (DBR)	1	AS02
	Engine Control Room (ECR)	1	AS03
	Company Main Office	1	AS04
	Tool Pushers Office	1	AS05
	Drillers Control Cabin (DCC)	1	AS06
DP Alert Columns	Port ROV Van	1	
	Stbd ROV Van	1	
	Moon Pool	2	
	Drill Floor	2	

5.10 - Fire Gas (F/G) & Emergency Shutdown (ESD) System

The ESD System and the Fire & Gas System (F&G) are based on Invensys Triconex Trident offerings.

5.10.1 - Description

It’s a Triple-Modular Redundant (TMR) safety controllers, Safety I/O Fieldstations & Safety workstations and Matrix LED Panels, along with an analogue addressable system and required field instrumentation, providing the following functionalities:

- ESD System
- Fire & Gas Detection

- Fire Fighting System

And the following mimics quantities:

- 200 off F&G Process Mimics
- 35 off ESD Process Mimics
- Online viewing of Fire/Gas & ESD System Cause & Effect matrix

The ESD system shall meet IEC 61508 SIL2 Requirements with their power supply system fed from two sources: one through the AC 230 V UPS system supplied from the emergency power and the other from normal power.

5.10.2 - Fire Detection Function

The primary function of the Fire Detection System is to monitor all addressable fire detection devices that are installed throughout the vessel for the detection of fire, alarm personnel, and provide signals to the ESD system to initiate shutdown functions for fire conditions.

This system is interfaced to the Automation (IAS) system by communications means.

5.10.3 - Gas Detection Function

A fixed installed automatic gas detection and alarm system was provided and arranged to monitor continuously all open or enclosed areas of the vessel in which an accumulation or presence of flammable gases (hydrocarbons or hydrogen sulphide) may be expected to occur.

This system is capable of indicating (in W/H and Technical office) by audible and visible means any presence and location of a hydrocarbon or hydrogen sulphide gas concentration and is interfaced to the Automation (IAS) system by communications means.

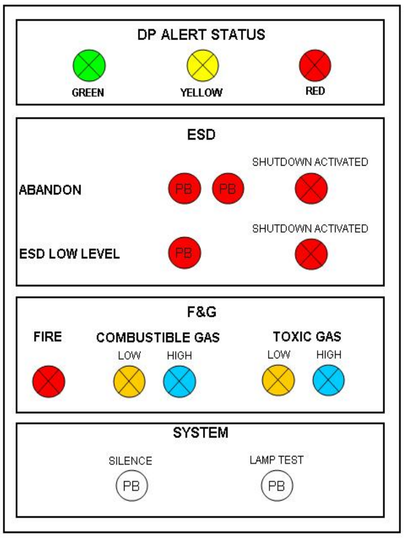


Figure 5.36 – Project - Matrix LED Panels [11].

5.10.4 - Equipment Location

All the Safety Workstations are provided by GE, with the SW being coded, installed & commissioned by Invensys Systems.

For equipment list, consult location by using the Automation/DP SLD in section 5.15.2 - .

Table 5.18 — Project – F/G & ESD System Equipment Location.

Function	Location	Quantity	ID
Safety Workstations	Wheelhouse (W/H) Technical Office (TO)	2 1	WS41, WS42 WS43
Safety Repeaters Workstations	Driller's Control Cabin (DCC) DP Back-up Room (DBR)	1 1	WS44 WS45
Matrix LED panels	Wheelhouse (W/H) DP Back-up Room (DBR) Engine Control Room (ECR) Drillers Control Cabin (DCC)	1 1 1 1	
Safety Fieldstations ESD	Engine Control Room (ECR) Electrical Equip. Room (EER1)	1 1	FS202 FS201
Safety Fieldstations F&G	Aft Swbd Deck 2nd Deck (Port) Aft Swbd Deck 2nd Deck (Stbd) Engine Control Room (ECR) Electrical Equip. Room (EER1)	1 1 1 2	FS303 FS305 FS304 FS301, FS302
Fire Detection Centrals	Engine Control Room (ECR) Electrical Equip. Room (EER1)	1 2	
Carbon Monoxide (H2) /Heat detector	(throughout the vessel)	36	
Optical smoke detector	(throughout the vessel)	555	
Triple IR flame detector	(throughout the vessel)	24	
Manual call point	(throughout the vessel)	108	
Hydrogen sulphide (H2S) Gas Detector	(throughout the vessel)	53	
Hydrocarbon (HC) Gas Detector	(throughout the vessel)	88	
ESD Level 5 Pushbutton	(throughout the vessel)	25	

5.10.5 - I/O Allocation - ESD System

Table 5.19 — Project – ESD System I/O Allocation.

ESD FIELD STATION NO.	FS201	FS202	-	-	TOTAL
ESD Analogue Inputs	69	29			98
ESD Digital Inputs (Monitored)	12	7			19
ESD Digital Output (Monitored)	92	157			249
	Including 10% fitted spare (at final ship delivery)				503

5.10.6 - I/O Allocation - F&G/Fire Fighting System

Table 5.20 — Project – F&G System I/O Allocation.

F&G FIELD STATION NO.	FS301/30	FS303	FS304	FS305	TOTAL
Fire Central Serial I/O's	573		130		703
F&G Analogue Inputs	107	4	40	1	152
F&G Digital Inputs (Monitored)	121	18	98	18	255
F&G Digital Output (Monitored)	321	64	94	59	538
	Including 10% fitted spare (at final ship delivery)				1264

5.10.7 - Categories of ESD shutdown levels

- Level 5: Low level at local (Ventilation in machinery space, Fuel oil, Lubricating oil system and thermal system, force draft fan)
- Level 4 & 3: Top side modules shut down, Level 4 Derrick module, level 3 Mud module.
- Level 2: Individual Engine room shut down (Port, Centre, starboard)
- Level 1: Emergency power generation shut down
- Level 0: Catastrophic shut down (Abandon platform)

5.10.8 - Ship Systems interfaced to ESD system

- Drilling Systems
- Fire Detection and Alarm System
- Gas Detection and Alarm System
- Integrated Automation System (IAS) & PA/GA
- Ventilation systems (Fans and fire dampers)
- Fire Fighting systems & Fuel Oil System
- Main Diesel generator engines
- Quick closing valves & Lubricating Oil System

5.11 - Riser Management System

The Riser Management system (RMS) is a monitoring and advisory system that provides real-time guidance for carrying out connected and disconnected mode drilling riser operations on board a vessel.

The system combines a simple, intuitive operator's interface with a state-of-the-art numerical 3D finite element model of the riser system that is used to predict the behaviour of the riser in the prevailing conditions, optimizing the performance and enhancing safety margins with respect the operational limits. ¤

5.11.1 - The need & History

The simplest (and most common) approach to determine the safe operation of a riser is to conduct analysis prior to carrying out drilling operations based on expected environmental conditions (wind, wave, current), vessel and riser physical form and properties (for quasi-static and dynamic responses). Typically, this will determine for specified riser tension safe operating envelopes of vessel lateral motion (restrained by the DP capability of the vessel). The limits of which are set by undesirable stresses, bending moments, and deflections of the riser.

This is not the optimal way of proceeding since the limits as set will generally be overly conservative because of unrealistic assumptions of the way in which the environmental forces act Also there are difficulties in perfectly accurately modelling the dynamic behaviour of the vessel (for example response in a random sea).

However, by measuring environmental conditions, vessel motions, and riser motions along with tensions, mud weight etc., it is possible to use this information within a computer model which is part of the RMS on the vessel to estimate the static and dynamic response of the riser. These estimates enable more reliable limits to be set than the former (shore based) analysis, and as a consequence the operability of the riser may be improved.

5.11.2 - Main functions

- Integrate and display riser-related data from existing vessel systems in a consistent and operator oriented manner
- Compute and display the rig envelope of operation and optimum rig location in the prevailing metocean conditions
- Compute the minimum/maximum top tension limits & the optimum top tension
- RMS automatically acquires data from other relevant vessel systems

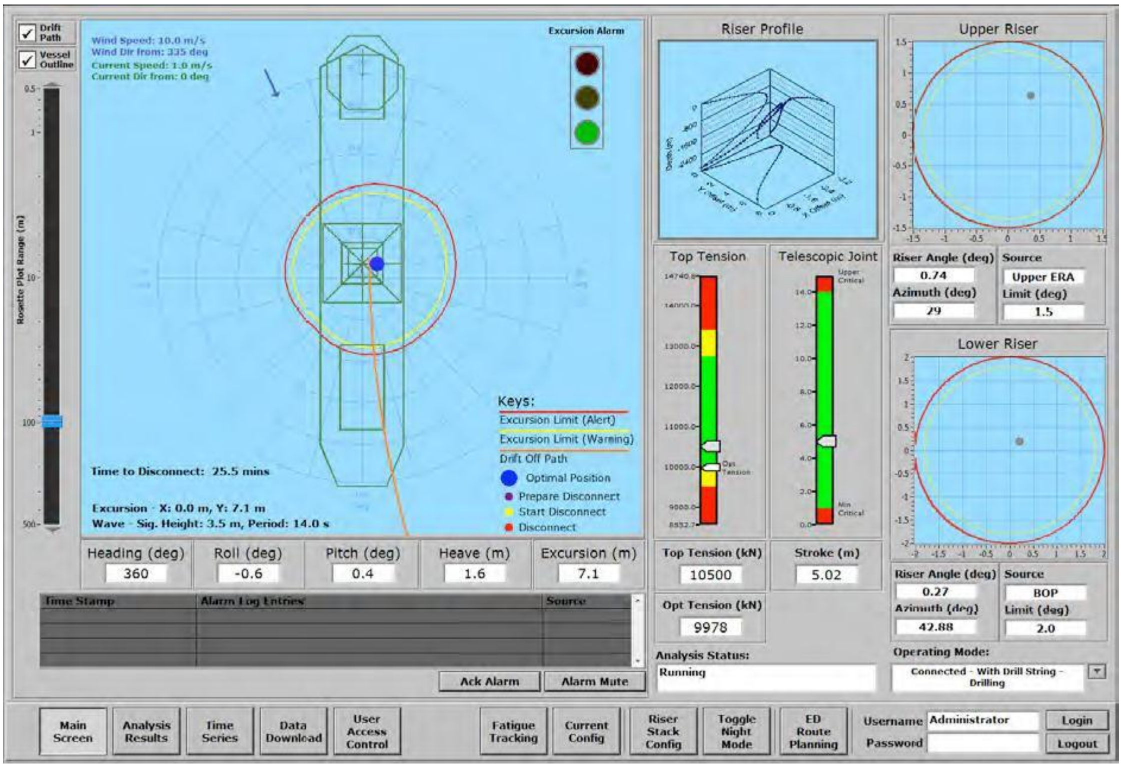


Figure 5.37 – RMS System Screen [10].

5.11.3 - Equipment Location

All the RMS Workstations are provided by GE, with the SW being coded, installed & commissioned by BPP Tech Systems.

For equipment list, consult location by using the Automation/DP SLD in section 5.15.2 - .

Table 5.21 — Project – RMS System Equipment Location.

Function	Location	Quantity	ID
RMS Workstation	Wheelhouse (W/H)	1	WS38
RMS Repeater display	DP Back-up Room (DBR)	1	

5.11.4 - Ship Systems interfaced to RMS system

Table 5.22 — Project - RMS System Communication Links.

System	Signals	Communications
Automation (through Drilling Control & Monitor System)	Mud Tank Weight/Volume Tensioner Stroke Length/Tension Barite/Bentonite/Cement Tank Weight Brine/Drill Water/Base Oil Tank Weight	Ethernet Link, Modbus TCP/IP

System	Signals	Communications
DP System	Vessel Position (DGPS) Stack X, Y Angle (Acoustics) Riser X, Y Angle (Acoustics) Vessel Heading (Gyro) Wind Speed/Direction (Anemometer) Roll, Pitch, Heave (MRU) UTC Timestamp (Master Clock or GPS)	Ethernet Link, Modbus TCP/IP
EMP System	Wave Height (Wave Radar)	RS422/485 Serial Link, Standard NMEA 0183
BOP System (through DP)	Stack X, Y Angle (Electric) Riser X, Y Angle (Electric) Upper Well Bore Shear Ram Pressure	Fibre Optic RS422/485 Serial Link, Standard NMEA 0183
RMS Upper ERA Sensor	Upper X, Y Angle (Electric)	RS422/485 Serial Link, Standard NMEA 0183

5.12 - Environmental Meteorological Platform (EMP) System

The Environmental Meteorological Platform (EMP) is a data collecting and display system that is installed in the Wheelhouse & Helicopter Reception Room and consist of main environmental instrumentation and displays for monitoring the Meteorological instruments/data for assisting operations of helicopter landing, with sensors for:

- Wind speed & Wind direction
- Air temperature
- Atmospheric pressure

5.12.1 - Equipment Location

All the EMP equipment is provided by HMS, together with all SW and the installation & commissioning phases.

For equipment list, consult location by using the Automation/DP SLD in section 5.15.2 - .

Table 5.23 — Project – EMP System Equipment Location.

Function	Location	Quantity	ID
EMP Workstation	Wheelhouse (W/H)	1	
EMP Slave display	Heli Reception Room	1	
Combined Air temperature, Air Humidity and Barometric Pressure sensor	Masts on top of the Wheelhouse	1	
Visibility sensor with Present Weather	Masts on top of the Wheelhouse	1	
Cloud Height sensor	Masts on top of the Wheelhouse	1	
Wave Radar (Height) sensor	Masts on top of the Wheelhouse	1	

5.12.2 - Ship Systems interfaced to EMP system

Table 5.24 — Project – EMP System Communication Links.

System	Signals	Communications
DP System	Wind speed and direction (Anemometer) Heading (Gyro) GPS interface Roll, pitch, heave (Motion Reference-MRU)	Ethernet Link, Modbus TCP/IP
Yard/Ship builder	Sea Temperature Sensor	RS422/485 Serial Link, Standard NMEA 0183

5.13 - Loading & Stability (L&S) System

The Load & Stability system is a Real Time and Predictive Load & Stability software package including the following typical features:

- Calculation and display of tank levels, volumes, densities
- Tank tables pre-installed with trim/heel correction
- Dead-weight, drafts, trim, list and displacement calculation
- Calculation of Heel due to Asymmetrical Loading
- Ship's stability (metacentric height, GM)
- Longitudinal stress calculations, i.e. shear forces and bending moments at locations decided by Class including maximum values
- Intact Stability calculations and Basic Damage Stability to IMO & Class limits
- Operator input tank data of level, weight, volume, ullage (or % filling)
- Warnings for overfill of tanks, over stress, exceeded dead weight, max. draft, trim & heel and insufficient stability
- Ship's Picture; drawing of the vessel showing one side view and one or more horizontal plans, including tank and deck plans
- Dry stores picture for entering of mass loads: crew, provisions & equipment.
- Deck Cargo planning facility & Printout of Ship Condition
- Bending moment & shear force calculation at the prescribed frame position
- Maximum value of bending moment & shearing force with position
- Volume/weight calculation for all tanks located in hull/topsides
- Manually adjustable specific gravity setting for contents of each tank

This L&S system receives the raw tank level and draft measurements via Serial interfaces from Automation (IAS) System.

5.13.1 - Equipment Location

All the L&S equipment is provided by NAPA, together with all SW and the installation & commissioning phases.

For equipment list, consult location by using the Automation/DP SLD in section 5.15.2 - .

Table 5.25 — Project – L&S System Equipment Location.

Function	Location	Quantity	ID
L&S Workstation	Wheelhouse (W/H)	1	

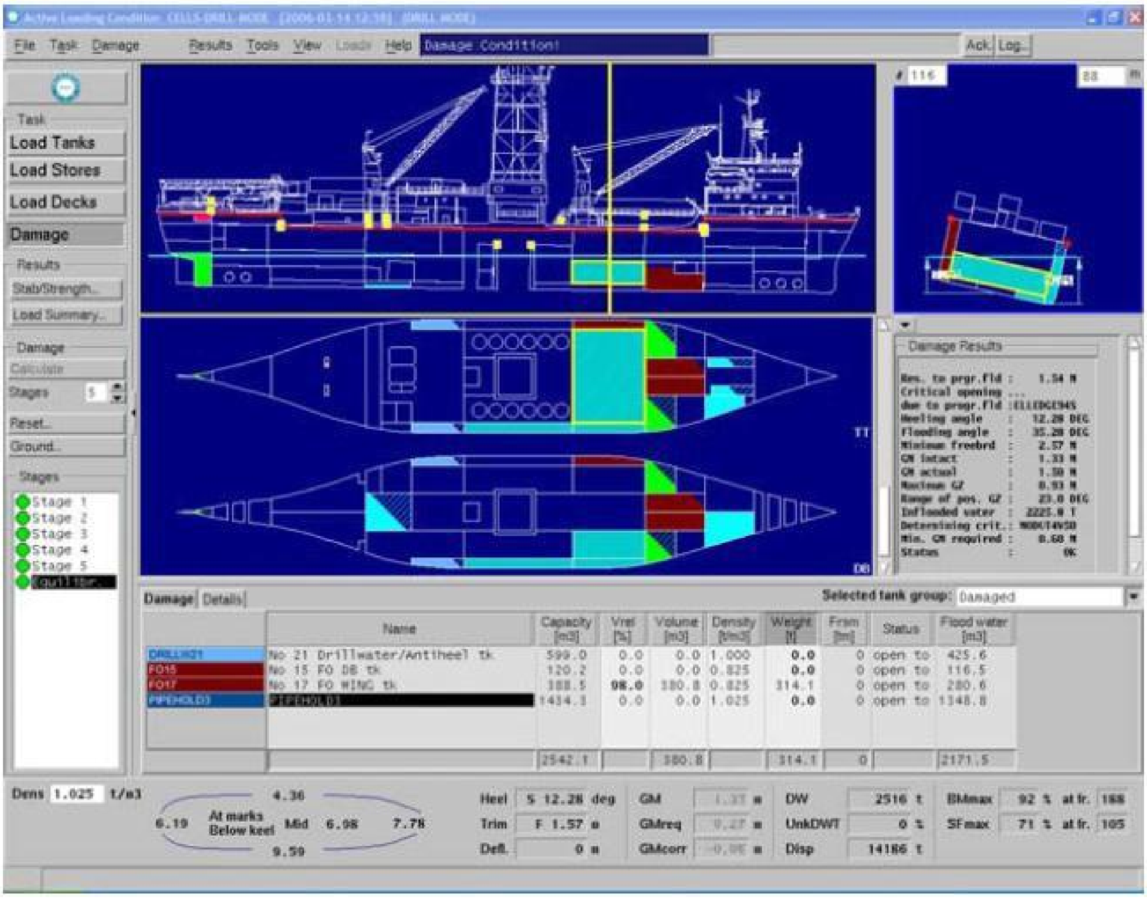


Figure 5.38 – Load & Stability System 1/2 [10]

In above example, L&S SW is warning the operator of a potential vessel Damage scenario after a virtual rupture of a few Fuel Oil (FO) tanks, by showing the impact on the vessels stability with coloured liquid fills in the affected areas/compartments and per deck.

This is very severe/alarming condition that needs to be taken into account on any loading operation, hence the forecasting aspect of this tool, prior to the actual physical loading operation on the vessels tanks.

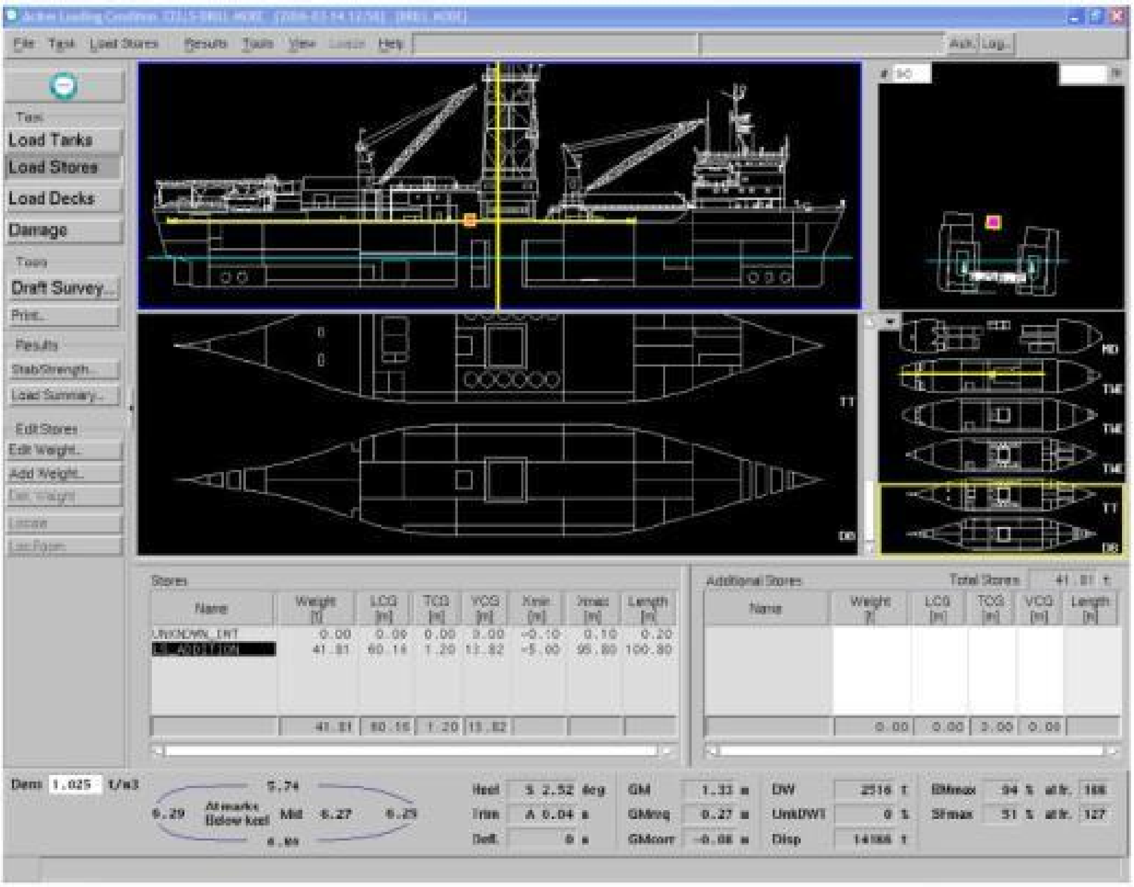


Figure 5.39 – Load & Stability System 2/2[10]

In above example, the operator is executing a forecast calculation of the impact of entering mass stores data from loads from crew, together with provisions and equipment.

The impact on the vessel stability is much lesser than on previous example and is considered a regular loading operation.

5.14 - Project schedule

The following dates are the GE (& consortium suppliers) contractually agreed dates with the customer/shipyard, DSME.

Table 5.26 — Project Schedule.

Milestone	Date
Contract effective date	6 Sept 2013
Initial client kick off meeting	11 – 13 Sept 2013
Delivery of early DPS / IAS hardware	1 March 2014 (ex-works)
Delivery of DPS / IAS hardware main items and fire & gas / ESD hardware	1 April 2014 (ex-works)
Delivery of DPS / IAS / Fire & Gas / ESD software	1 June 2014 (ex-works)

The customer (DSME) confirmed the following dates associated with the ship building process:

Table 5.27 — Project Dates.

Milestone	Date
Start Construction	27 Jan 2014
Keel Laying	14 July 2014
Vessel Launch	25 Oct 2014
Vessel Delivery	25 July 2015

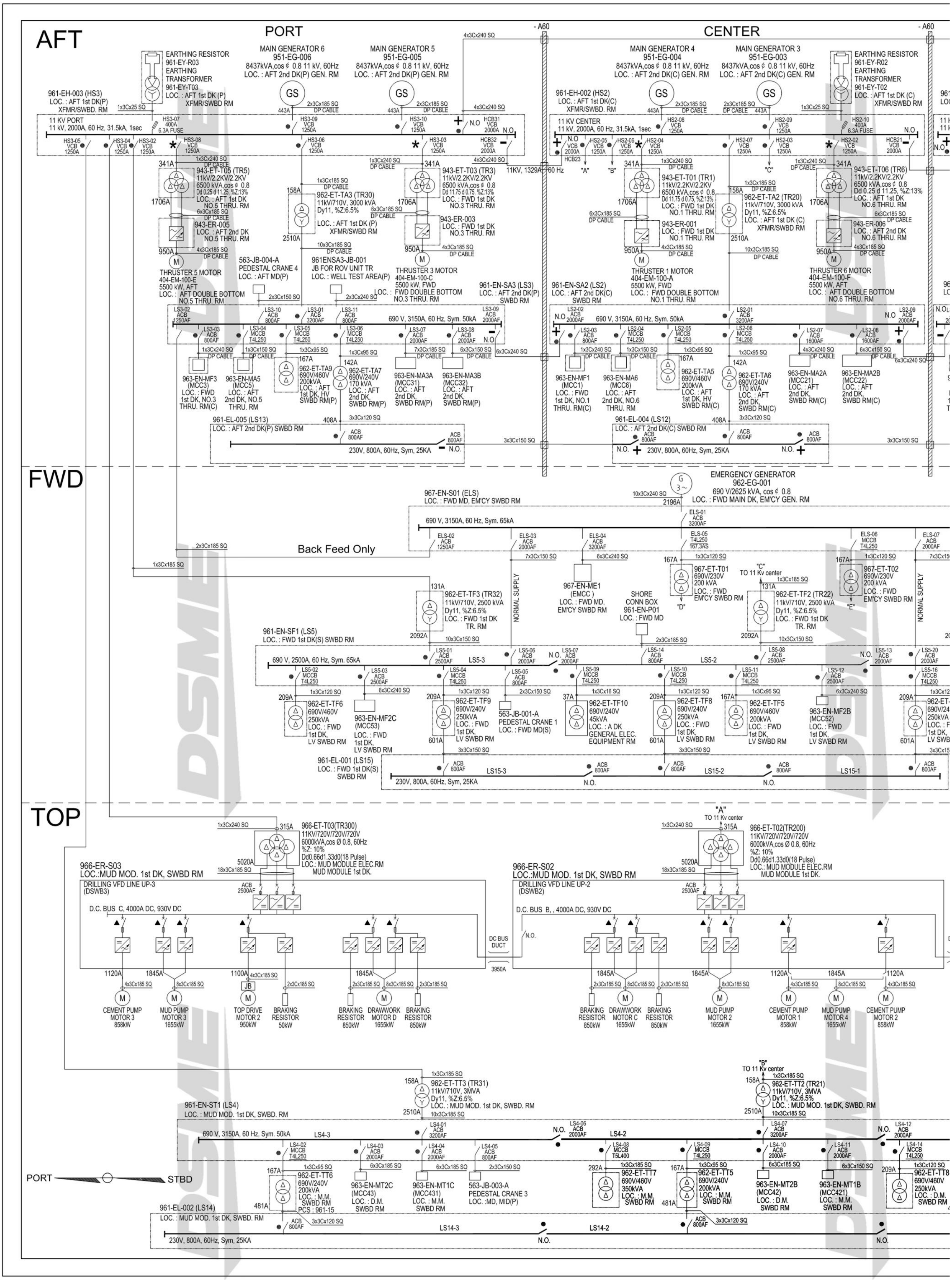
5.15 - Single Line Diagrams (SLDs)

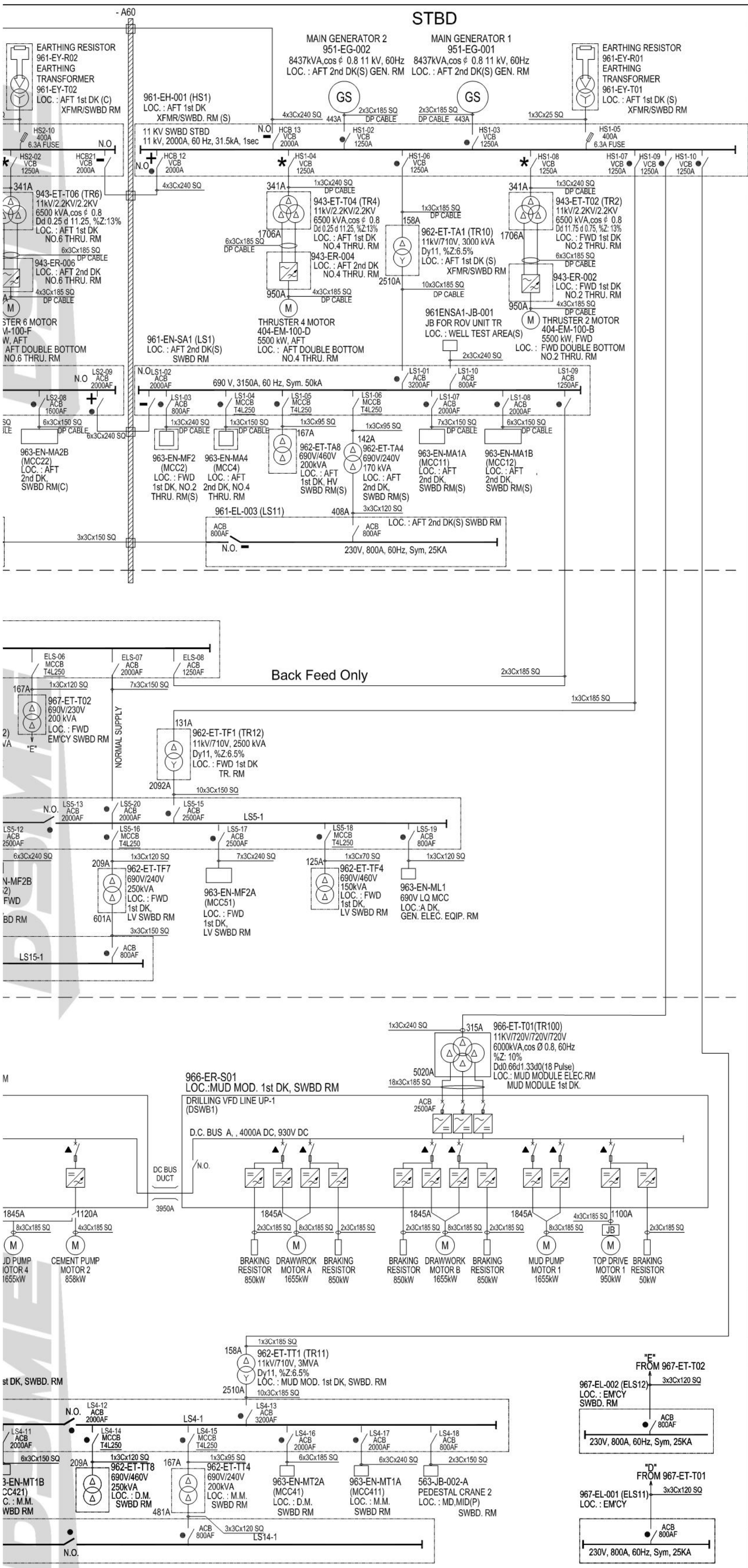
The Single Line Diagrams, are drawings that summarize the major components & their interconnections in a graphical form, with their identification/rating data & compartment allocation.

The main ones are the Power SLD & Automation/DP SLD and are normally used as the quick reference/cover documents of a project.

Normally, any technical or commercial discussion starts by looking first at these documents and then drill down to the specific issue, they are like portals for the remaining project documentation.

5.15.1 - Power SLD [12]



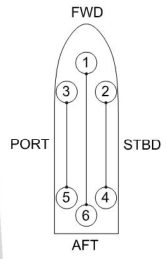


PLAN HISTORY

DATE	REV.NO.	DESCRIPTION	DWN.	CHKD.	APPD.
11.06.21	A	ISSUED FOR APPROVAL	S.H.LEE	T.Y.KANG	S.J.SEO
11.07.27	B	ISSUED FOR APPROVAL	S.H.LEE	T.Y.KANG	S.J.SEO
11.08.23	0	APPROVED FOR CONSTRUCTION	S.H.LEE	T.Y.KANG	S.J.SEO

NOTES :

1. CABLE RATINGS. HV=8.7/15KV, VFD=1.8/3KV, LV(690V, 440V & 230V)=0.6/1KV
2. THRUSTER MOTOR 5500KW IS BASED ON THE CONVENTIONAL AZIMUTH THRUSTER.
3. 690V SYSTEM NEUTRAL IS UNGROUNDED.
4. BUS-TIE BREAKERS IN 11KV SWBD SHALL BE NORMALLY OPEN IN DP3 OPERATION.
5. SHORE POWER CONNECTION BOX IS LOCATED ON FWD MAIN DECK.
6. "●": DENOTES BREAKERS WHICH ARE LOCAL/REMOTE CONTROLLED. ON SWITCHBOARD AND REMOTE CONTROLLED FROM PMS(IAS)
7. "*":DENOTES BREAKERS WHICH ARE ONLY REMOTE CONTROLLED FROM VFD.
8. "+":DENOTES MASTER BREAKER, "−":DENOTES SLAVE BREAKER.
9. " ": DENOTES BUS DUCT
10. "▲": DENOTES FUSE & 3 POSITION SWITCH FOR PRE-CHARGING
11. RISE (A60 RATED) IS USED FOR CABLES PASSING THROUGH THE A60 WALL.



THRUSTER COUPLING

도면배포처	
배포처	부수
해양배관 프로세스2	2
해양기계설계 3	2
해양전장배치설계 2	3
해양품질경영 1	1
DSEC	1
해양의장1팀	15
해양시운전팀	10
TOTAL	35

STAMP AREA

☐ FOR REFERENCE
☐ FOR APPROVAL
☑ FOR CONSTRUCTION
☐ FOR REVISION

A1 : 1

PROJ. NO. 3615 | PROJECT TUNGSTEN EXPLORER

APPD BY S.J.SEO (서석진) (TEL: 4896)

CHKD BY T.Y. KANG (강태영) (TEL: 4885)

DWN BY S.H.LEE (이상현) (TEL: 7991 HP: 010-4609-4133)

TITLE :

OVERALL ONE LINE DIAGRAM OF ELECTRICAL DISTRIBUTION SYSTEM

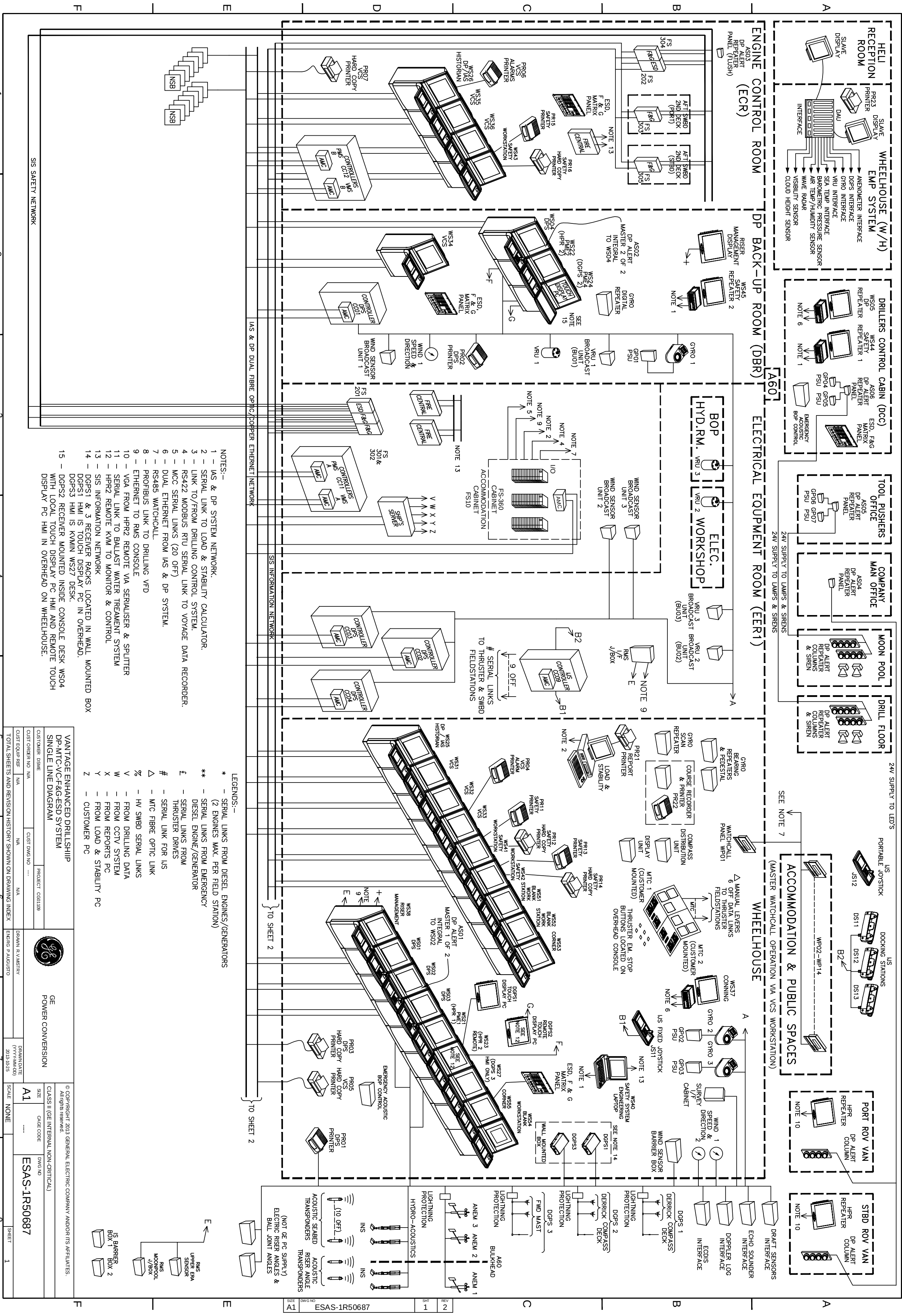
DEPT OFFSHORE ELECTRICAL & CONTROL DESIGN PART 2

SHEET 1/1

DATE	SCALE	DWG.NO. (BHP NO. 3615)	REV NO.
2011.08.23	NONE	DA961E001	0

DSME DAEWOO SHIPBUILDING & MARINE ENGINEERING CO.,LTD.

5.15.2 - Automation/DP SLD [8]



Chapter 6

Conclusion

Almost at the end of this long document, it is now time to wrap it up and present our main conclusions of this effort. Our main objective for this thesis was very clear: Present the current state of the art for Marine Automation Systems and describe a complex project involving Marine Automation systems, which we think was achieved with some very good/in deep contextual knowledge of the major systems, their evaluation through time and their technological contribution to a very specific industrial environment & operating scenarios.

As this was more of a research document applied within the context of an international professional organization (GE), rather than a typical laboratorial/investigation one and within the constrains of an external FEUP student, most of the source material & references was supplied from that same professional environment: the concepts, the technologies, the organization & structure of subjects all shared a common base, almost commercial and targeted at the knowledge & experience collected by this thesis author throughout the years on this industry.

This justifies the lesser detailed applied on the Past chapter, where the focus was done more on the Marine Electrical systems than rather on the past Marine Automation Systems and also helps to justify the greater focus and detail applied to the Present & Future chapters, where the writing flow and the depth achieved was, at some times, maybe more than what it would require, acting a bit in compensation for the Past Chapter.

The addition of a real project with all its extra phases, organization & planning stages, brought the necessary non-technical complementary overview and reality connection to the execution of modern Automation Marine projects, that a thesis like this one would definitely benefit and enhance the perception of the organization & major challenges of this unique and so paramount industry.

Strongly believe that the usage of land power system analogy allowed an immediate & more focused entrance into the several subjects that explained the Marine counterpart, together with a (probable), more than the average usage of diagrams, screenshots & tables, has enable a more visual positioning of the reader audience to greatly maintain the interest and almost, placing them in the driver's seat of the design, execution & operation phases of a modern Marine Electrical Propulsion Automation System.

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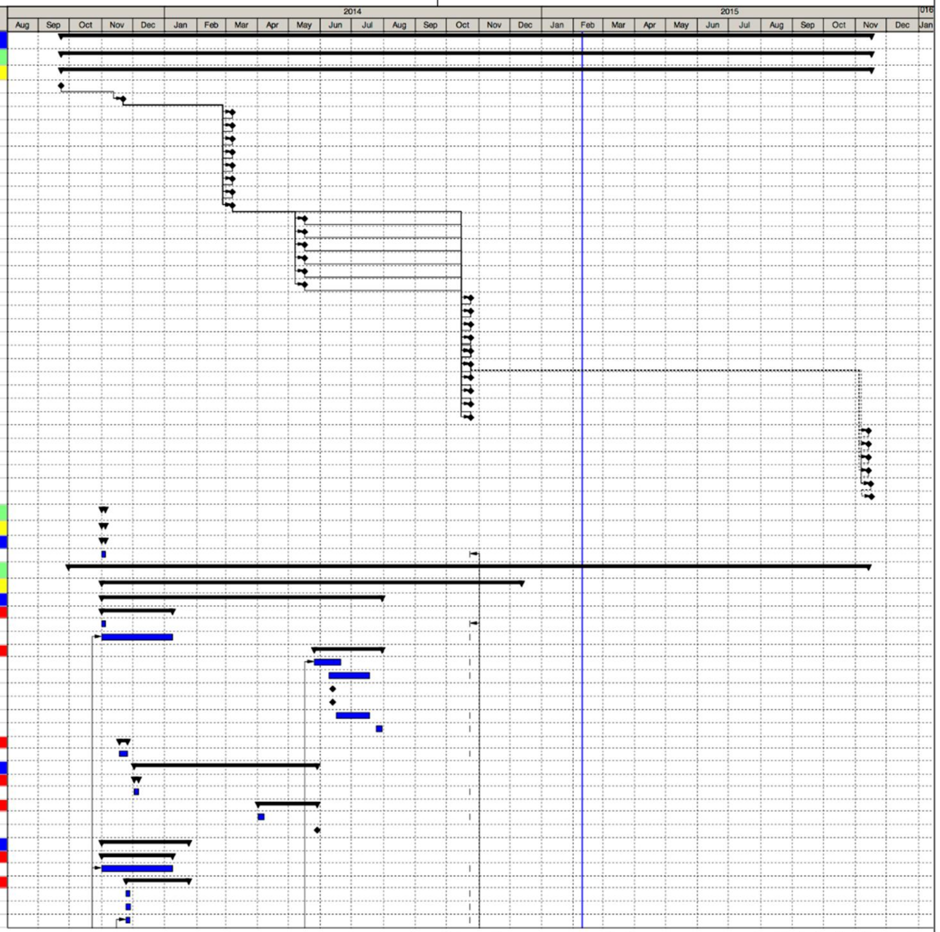
Annexes

Cobalt Project plan/Schedule

GE Scope [7]

All Activities

Activity ID	Activity Name	Original Duration	Start	Finish	EAD
DSME for Vantage Cobalt Explorer H3618		535.00	23-Sep-13 A	16-Nov-15	12-Dec-14
Project Summary		529.00	23-Sep-13 A	16-Nov-15	
Project Tollgates & Milestones		529.00	23-Sep-13 A	16-Nov-15	
PM1110	ITO-OTR HANDOVER TOLLGATE	0.00		23-Sep-13 A	
PM1100	PLATFORM LAUNCH TOLLGATE	0.00		21-Nov-13 A	
PM1120	Long Lead Time Items Released	0.00		07-Mar-14 A	
PM1160	Basic Design	0.00		07-Mar-14 A	
PM1170	Customer Approval of Basic Design	0.00		07-Mar-14 A	
PM1210	Complete BOMs and Drawings Released	0.00		07-Mar-14 A	
PM1220	Purchase Orders 100% Placed	0.00		07-Mar-14 A	
PM1280	Factory Acceptance Test (FAT) Plan	0.00		07-Mar-14 A	
PM1290	Ability to Produce	0.00		07-Mar-14 A	
PM1130	READY TO MANUFACTURE TOLLGATE	0.00		07-Mar-14 A	
PM1060	Installation & Commissioning Scope and Capacity Defined	0.00		16-May-14 A	
PM1230	Production Orders Released	0.00		16-May-14 A	
PM1240	Go For Assembly	0.00		16-May-14 A	
PM1250	Ready To Test	0.00		16-May-14 A	
PM1260	Pre-FAT / Test Ready, Including Software	0.00		16-May-14 A	
PM1270	Factory Acceptance Test (FAT)	0.00		16-May-14 A	
PM1000	Documentation of Site Ready	0.00		24-Oct-14 A	
PM1070	Control & Automation Defined & Pre-Commissioning Review	0.00		24-Oct-14 A	
PM1080	Punch List Review	0.00		24-Oct-14 A	
PM1090	Customer Software Ready	0.00		24-Oct-14 A	
PM1180	READY TO SHIP TOLLGATE	0.00		24-Oct-14 A	
PM1190	SITE START TOLLGATE	0.00		24-Oct-14 A	
PM1300	Site Team Handover	0.00		24-Oct-14 A	
PM1310	Detailed Installation & Commissioning Strategy	0.00		24-Oct-14 A	
PM1320	Site Survey	0.00		24-Oct-14 A	
PM1330	Pre-Site Meeting with Customer	0.00		24-Oct-14 A	
PM1010	Commissioning Complete	0.00		13-Nov-15*	
PM1020	Customer Acceptance	0.00		13-Nov-15*	
PM1030	As Built Documentation	0.00		13-Nov-15*	
PM1040	Punch List Closed	0.00		13-Nov-15*	
PM1200	SERVICES HANDOVER TOLLGATE	0.00		15-Nov-15*	
PM1050	Project Close Out	0.00		16-Nov-15*	
Engineering		5.00	01-Nov-13 A	05-Nov-13 A	08-Nov-13
System Design		5.00	01-Nov-13 A	05-Nov-13 A	08-Nov-13
Automation System Overview		5.00	01-Nov-13 A	05-Nov-13 A	08-Nov-13
V1P05C02	Automation System Single Line Diagram	5.00	01-Nov-13 A	05-Nov-13 A	08-Nov-13
Vessel Control Systems (Automation)		534.00	30-Sep-13 A	13-Nov-15	12-Dec-14
VCS Documentation		283.00	01-Nov-13 A	12-Dec-14 A	12-Dec-14
Functional Design Specifications		193.00	01-Nov-13 A	31-Jul-14 A	08-Aug-14
System Overview		36.00	01-Nov-13 A	09-Jan-14 A	10-Jan-14
AV1P01C01	VCS description	5.00	01-Nov-13 A	05-Nov-13 A	08-Nov-13
AV1P01C02	Networks description	36.00	01-Nov-13 A	09-Jan-14 A	10-Jan-14
System Functional Description		144.00	26-May-14 A	31-Jul-14 A	08-Aug-14
AV1P02C01	PMS Functional Description	10.00	26-May-14 A	20-Jun-14 A	27-Jun-14
AV1P02C07	System HMI formats	30.00	09-Jun-14 A	18-Jul-14 A	18-Jul-14
AV1P02C05	Alarm & monitoring system configuration	0.00		13-Jun-14 A	13-Jun-14
AV1P02C06	HMI system configuration	0.00		13-Jun-14 A	13-Jun-14
AV1P02C02	VMS Functional Description	25.00	16-Jun-14 A	18-Jul-14 A	18-Jul-14
AV1P02C03	Propulsion Functional Deign Specification	10.00	25-Jul-14 A	31-Jul-14 A	08-Aug-14
System Function Data Sheets		5.00	18-Nov-13 A	26-Nov-13 A	29-Nov-13
A2120	System function data sheets	5.00	18-Nov-13 A	26-Nov-13 A	29-Nov-13
Signals & Interface		143.00	02-Dec-13 A	29-May-14 A	27-Jun-14
Design Support		5.00	02-Dec-13 A	06-Dec-13 A	30-May-14
AV2P01C01	VCS system interface details	5.00	02-Dec-13 A	06-Dec-13 A	30-May-14
Interfaces		60.00	01-Apr-14 A	29-May-14 A	27-Jun-14
AV1P03C07	Data Historian functional description	5.00	01-Apr-14 A	07-Apr-14 A	11-Apr-14
AV2P02C03	Serial links definition	0.00		29-May-14 A	27-Jun-14
Installation & Hardware Specifications		144.00	01-Nov-13 A	24-Jan-14 A	30-May-14
System Installation		151.00	01-Nov-13 A	09-Jan-14 A	30-May-14
AV3P01C01	Installation specification	151.00	01-Nov-13 A	09-Jan-14 A	30-May-14
Purchase Technical Specifications		50.00	25-Nov-13 A	24-Jan-14 A	24-Jan-14
AV3P02C01	VCS Standard Equipment	5.00	25-Nov-13 A	28-Nov-13 A	29-Nov-13
AV3P02C03	Printers	5.00	25-Nov-13 A	29-Nov-13 A	29-Nov-13
AV3P02C08	Watchcall Panels	5.00	25-Nov-13 A	28-Nov-13 A	29-Nov-13



UK.C.G.01109-01 - DSME for Vantage Cobalt Explorer H3618

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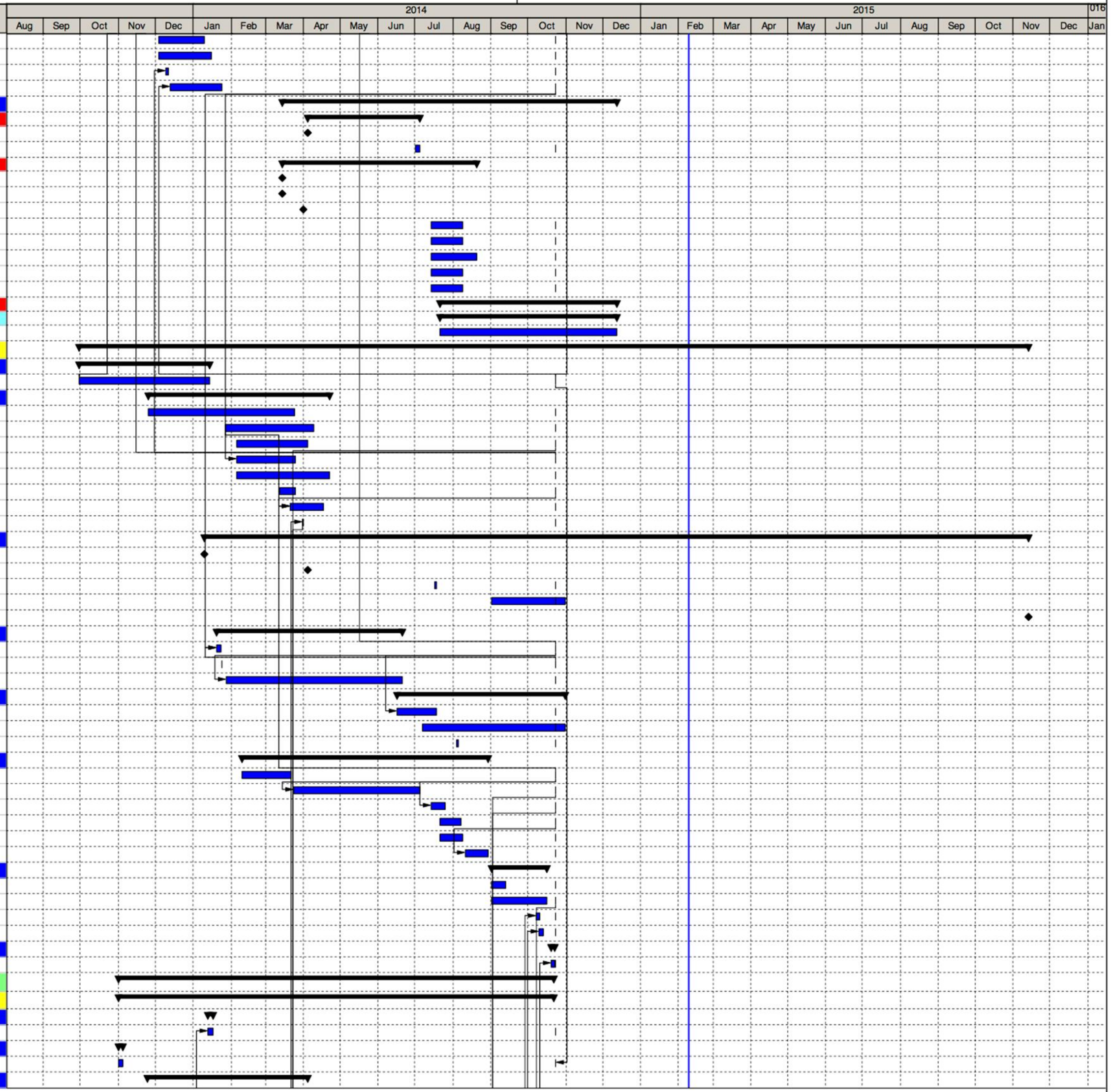
Date	Revision	Checked	Approved
12-Aug-14	H	J. Hurley	P. Riglar
05-Sep-14	J	J. Hurley	P. Riglar
09-Feb-15	K	J. Hurley	P. Riglar

All Activities

Activity ID	Activity Name	Original Duration	Start	Finish	EAD
AV3P02C06	Load & Stability Calculator	8.00	04-Dec-13 A	10-Jan-14 A	10-Jan-14
AV3P02C07	Additional PC Hardware	13.00	04-Dec-13 A	16-Jan-14 A	17-Jan-14
AV3P02C04	Software Licences	5.00	10-Dec-13 A	12-Dec-13 A	12-Dec-13
A1060	Hardware purchase technical specs	28.00	13-Dec-13 A	24-Jan-14 A	24-Jan-14
Testing & Commissioning		**190.00**	**14-Mar-14 A**	**12-Dec-14 A**	**12-Dec-14**
System Test Instructions		**61.00**	**04-Apr-14 A**	**04-Jul-14 A**	**05-Jul-14**
AV4P01C01	System test instructions	0.00		04-Apr-14 A	04-Apr-14
AV4P01C02	Pre-Testing Software Checks	4.00	01-Jul-14 A	04-Jul-14 A	05-Jul-14
Factory Acceptance Tests		**106.00**	**14-Mar-14 A**	**20-Aug-14 A**	**15-Aug-14**
AV4P02C03	Alarms & monitoring test procedure	0.00		14-Mar-14 A	14-Mar-14
AV4P02C04	Architecture & HMI test procedure	0.00		14-Mar-14 A	14-Mar-14
AV4P02C01	I/O schedule test procedure	0.00		31-Mar-14 A	31-Mar-14
AV4P02C02	Serial link test procedure	19.00	14-Jul-14 A	08-Aug-14 A	08-Aug-14
AV4P02C05	PMS test procedure	19.00	14-Jul-14 A	08-Aug-14 A	08-Aug-14
AV4P02C06	VMS test procedure	25.00	14-Jul-14 A	20-Aug-14 A	15-Aug-14
AV4P02C07	Propulsion test procedure	19.00	14-Jul-14 A	08-Aug-14 A	08-Aug-14
AV4P02C08	Data historian test procedure	19.00	14-Jul-14 A	08-Aug-14 A	08-Aug-14
Design Support		**104.00**	**21-Jul-14 A**	**12-Dec-14 A**	**12-Dec-14**
Classification Society		**104.00**	**21-Jul-14 A**	**12-Dec-14 A**	**12-Dec-14**
AV5P01C01	FMEA	104.00	21-Jul-14 A	12-Dec-14 A	12-Dec-14
VCS Engineering Activities		**534.00**	**30-Sep-13 A**	**13-Nov-15**	**13-Nov-14**
Architecture Design		**74.00**	**30-Sep-13 A**	**14-Jan-14 A**	**14-Jan-14**
A1020	Architecture design - SLD, instal spec networks	74.00	30-Sep-13 A	14-Jan-14 A	14-Jan-14
Product Definition		**101.00**	**25-Nov-13 A**	**22-Apr-14 A**	**19-May-14**
A1710	Mechanical equipment drawings	84.00	25-Nov-13 A	25-Mar-14 A	25-Mar-14
A1100	Procure & manufacture cubicles	55.00	27-Jan-14 A	09-Apr-14 A	16-May-14
A1050	Cable interconnections	43.00	05-Feb-14 A	04-Apr-14 A	04-Apr-14
A1070	Equipment drawings	35.00	05-Feb-14 A	25-Mar-14 A	04-Apr-14
A1720	Equipment electrical schematic drawings	35.00	05-Feb-14 A	22-Apr-14 A	21-Apr-14
A1130	I/O slice drawings	10.00	12-Mar-14 A	25-Mar-14 A	28-Mar-14
A1110	Procure & manufacture I/O	20.00	21-Mar-14 A	17-Apr-14 A	18-Apr-14
A1150	Delivery into system test	1.00	31-Mar-14 A	31-Mar-14 A	19-May-14
Application Design		**462.00**	**10-Jan-14 A**	**13-Nov-15**	**13-Nov-14**
A2460	End of requirements phase review checklist	0.00		10-Jan-14 A	10-Jan-14
A2000	End design phase review checklist	0.00		04-Apr-14 A	28-Apr-14
A1990	Applications to software handover checklist	2.00	17-Jul-14 A	18-Jul-14 A	18-Jul-14
A2020	SAT & Dockside Commissioning documents	65.00	01-Sep-14 A	31-Oct-14 A	31-Oct-14
A1980	Instruction manual review	0.00		13-Nov-15*	13-Nov-14
Software Requirements		**97.00**	**20-Jan-14 A**	**20-Jun-14 A**	**20-Jun-14**
A1160	Application design - data sheets	5.00	20-Jan-14 A	24-Jan-14 A	31-Jan-14
A1620	End of requirement phase review	1.00	24-Jan-14 A	24-Jan-14 A	24-Jan-14
A1170	Final information from customers	95.00	28-Jan-14 A	20-Jun-14 A	20-Jun-14
Software Design		**99.00**	**16-Jun-14 A**	**31-Oct-14 A**	**31-Oct-14**
A1180	Applications detail design - functional design specs	25.00	16-Jun-14 A	18-Jul-14 A	25-Jul-14
A1190	Applications detail design - FAT & SAT specs	84.00	07-Jul-14 A	31-Oct-14 A	31-Oct-14
A1200	End of design phase review	2.00	04-Aug-14 A	05-Aug-14 A	02-Jul-14
Code, Configure, Unit test		**185.00**	**10-Feb-14 A**	**29-Aug-14 A**	**01-Sep-14**
A1080	Develop / analyse I/O schedule	47.00	10-Feb-14 A	21-Mar-14 A	01-Apr-14
A1230	HMI (Static)	71.00	24-Mar-14 A	04-Jul-14 A	08-Jul-14
A1210	PMS	10.00	14-Jul-14 A	25-Jul-14 A	01-Sep-14
A1220	VMS	14.00	21-Jul-14 A	07-Aug-14 A	01-Sep-14
A1240	HMI (Tagging)	19.00	21-Jul-14 A	08-Aug-14 A	08-Aug-14
A1540	Software functionality testing at EDC	14.00	11-Aug-14 A	29-Aug-14 A	01-Sep-14
System Validation		**34.00**	**01-Sep-14 A**	**16-Oct-14 A**	**16-Oct-14**
A2070	Signed off completed Pre-FAT test procedure	10.00	01-Sep-14 A	12-Sep-14 A	12-Sep-14
A2100	End of test phase review checklist	34.00	01-Sep-14 A	16-Oct-14 A	16-Oct-14
A2080	Signed off completed FAT test procedures & class certification	3.00	08-Oct-14 A	10-Oct-14 A	10-Oct-14
A2090	As tested software archived	2.00	10-Oct-14 A	13-Oct-14 A	15-Oct-14
Commissioning		**3.00**	**20-Oct-14 A**	**22-Oct-14 A**	**22-Oct-14**
A2110	Pre commissioning review checklist	3.00	20-Oct-14 A	22-Oct-14 A	22-Oct-14
Dynamic Positioning System		**249.00**	**01-Nov-13 A**	**22-Oct-14 A**	**27-Oct-14**
DP Documentation		**249.00**	**01-Nov-13 A**	**22-Oct-14 A**	**27-Oct-14**
Work package Handover		**5.00**	**13-Jan-14 A**	**17-Jan-14 A**	**31-Jan-14**
A2150	End of requirement phase review checklist	5.00	13-Jan-14 A	17-Jan-14 A	31-Jan-14
Architecture Design		**5.00**	**01-Nov-13 A**	**05-Nov-13 A**	**08-Nov-13**
A2160	DP / VCS Single Line Diagram	5.00	01-Nov-13 A	05-Nov-13 A	08-Nov-13
Product Definition		**82.00**	**25-Nov-13 A**	**04-Apr-14 A**	**04-Apr-14**



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12-Aug-14	H	J. Hurley	P. Riglar
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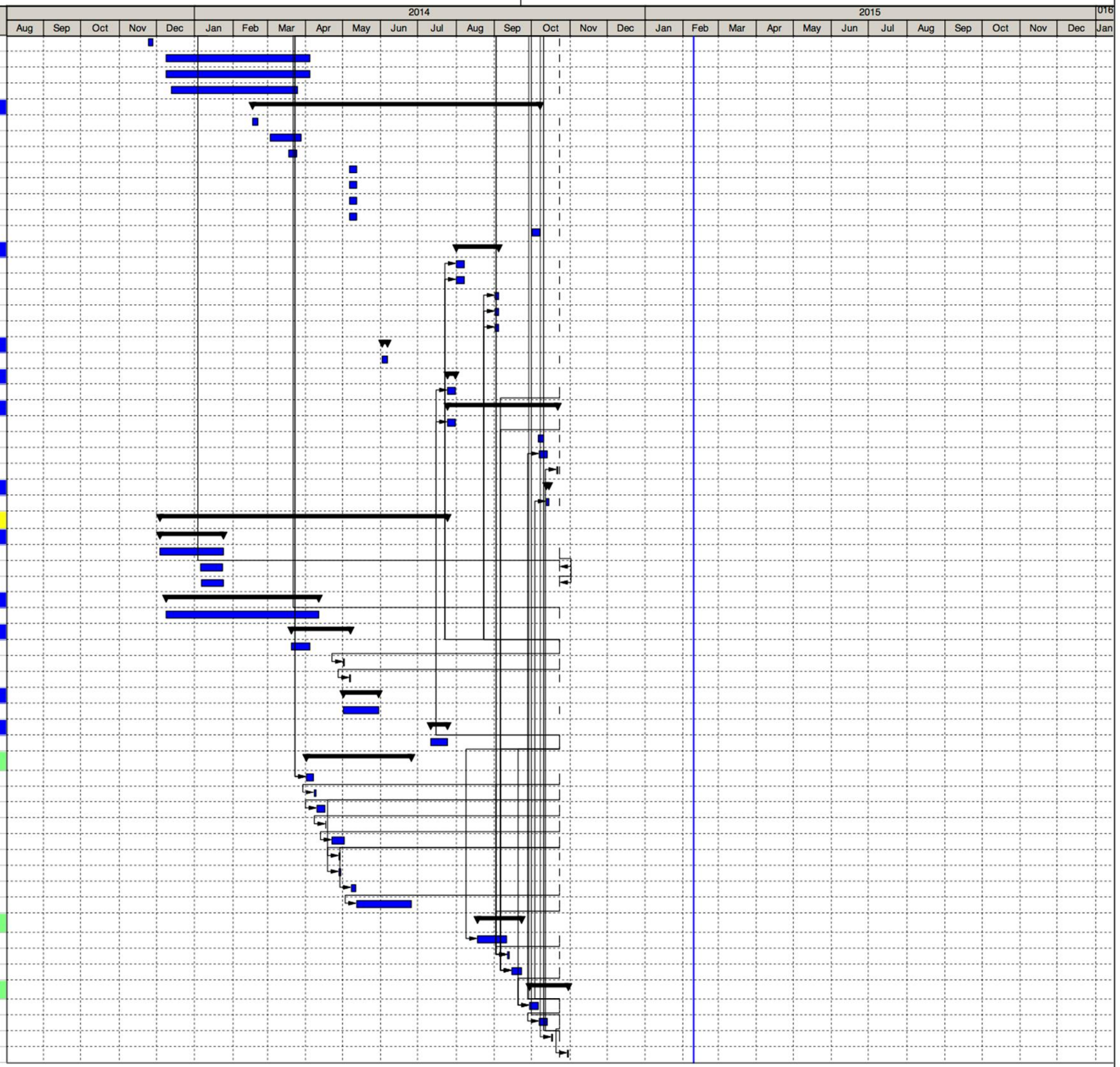
All Activities

Activity ID	Activity Name	Original Duration	Start	Finish	EAD
DV3P02C01	Purchase technical specification	5.00	25-Nov-13 A	28-Nov-13 A	29-Nov-13
A2190	Mechanical equipment drawings	82.00	09-Dec-13 A	04-Apr-14 A	04-Apr-14
A2200	Equipment electrical schematic drawings	82.00	09-Dec-13 A	04-Apr-14 A	04-Apr-14
A2210	Cable interconnection diagram	70.00	13-Dec-13 A	25-Mar-14 A	25-Mar-14
Application Design		162.00	17-Feb-14 A	07-Oct-14 A	10-Oct-14
DV3P01C01	Installation Specification	5.00	17-Feb-14 A	21-Feb-14 A	28-Feb-14
DV1P02C02	DP power & propulsion system interface	20.00	03-Mar-14 A	28-Mar-14 A	28-Mar-14
DV3P02C05	DP Hardware FAT Inspection	5.00	18-Mar-14 A	24-Mar-14 A	24-Mar-14
DV1P02C01	DP functional design spec	5.00	06-May-14 A	12-May-14 A	30-May-14
DV1P02C04	DP software loading guide	5.00	06-May-14 A	12-May-14 A	30-May-14
DV1P02C07	FMEA	5.00	06-May-14 A	12-May-14 A	30-May-14
DV1P02C06	Capability Plots	5.00	06-May-14 A	12-May-14 A	30-May-14
DV1P02C03	DP operator guide	5.00	01-Oct-14 A	07-Oct-14 A	10-Oct-14
Software Design		25.00	01-Aug-14 A	04-Sep-14 A	05-Sep-14
DV3P02C02	Factory Acceptance Test	5.00	01-Aug-14 A	07-Aug-14 A	08-Aug-14
DV3P03C01	Dockside commissioning instructions	5.00	01-Aug-14 A	07-Aug-14 A	08-Aug-14
DV3P03C02	Sea trials	5.00	01-Sep-14 A	04-Sep-14 A	05-Sep-14
DV3P04C01	Customer acceptance test	5.00	01-Sep-14 A	04-Sep-14 A	05-Sep-14
A2360	End design phase review checklist	5.00	01-Sep-14 A	04-Sep-14 A	05-Sep-14
Code, Configure, Unit Test		5.00	02-Jun-14 A	06-Jun-14 A	06-Jun-14
A2370	Complete DP software units	5.00	02-Jun-14 A	06-Jun-14 A	06-Jun-14
System Integration		5.00	25-Jul-14 A	31-Jul-14 A	31-Jul-14
A2380	Complete DP compatability	5.00	25-Jul-14 A	31-Jul-14 A	31-Jul-14
System Validation		66.00	25-Jul-14 A	22-Oct-14 A	27-Oct-14
A2390	Signed off completed pre-FAT test procedures	5.00	25-Jul-14 A	31-Jul-14 A	31-Jul-14
A2400	Signed off completed FAT procedures & class clarification	5.00	06-Oct-14 A	10-Oct-14 A	10-Oct-14
A2410	As tested software (archived)	5.00	07-Oct-14 A	13-Oct-14 A	13-Oct-14
A2420	End test phase review checklist	5.00	21-Oct-14 A	22-Oct-14 A	27-Oct-14
Commissioning		5.00	13-Oct-14 A	15-Oct-14 A	13-Oct-14
A2430	Pre-commissioning review checklist	5.00	13-Oct-14 A	15-Oct-14 A	13-Oct-14
DP Engineering Activities		160.00	04-Dec-13 A	24-Jul-14 A	24-Jul-14
Work Package Handover		76.00	04-Dec-13 A	24-Jan-14 A	24-Jan-14
A1380	Vessel questionnaire & installation spec (2 specs)	13.00	04-Dec-13 A	24-Jan-14 A	24-Jan-14
A1400	End of requirements phase review	19.00	06-Jan-14 A	24-Jan-14 A	24-Jan-14
A1390	Final information from customers	15.00	06-Jan-14 A	24-Jan-14 A	24-Jan-14
Product Definition		90.00	09-Dec-13 A	11-Apr-14 A	11-Apr-14
A1450	Procure & manufacture equipment	90.00	09-Dec-13 A	11-Apr-14 A	11-Apr-14
Software Design		32.00	20-Mar-14 A	07-May-14 A	09-May-14
A1480	Test (FAT) specifications FMEA	12.00	20-Mar-14 A	04-Apr-14 A	30-Apr-14
A1490	Class submittal	2.00	01-May-14 A	02-May-14 A	02-May-14
A1500	Class approval	2.00	06-May-14 A	07-May-14 A	09-May-14
Code, Configure, Unit test		20.00	01-May-14 A	30-May-14 A	30-May-14
A1510	Code,configure, unit test	20.00	01-May-14 A	30-May-14 A	30-May-14
System Integration		10.00	11-Jul-14 A	24-Jul-14 A	24-Jul-14
A1520	DP Software compatability	10.00	11-Jul-14 A	24-Jul-14 A	24-Jul-14
Hardware System Integration (UK)		58.00	01-Apr-14 A	25-Jun-14 A	
A1250	System test set-up	5.00	01-Apr-14 A	07-Apr-14 A	
A1270	Software integration	2.00	08-Apr-14 A	09-Apr-14 A	
A1420	HMI Upgrade	5.00	10-Apr-14 A	16-Apr-14 A	
A1410	Pre-FAT	1.00	17-Apr-14 A	17-Apr-14 A	
A1280	Architecture FAT (with ABS & customer)	9.00	22-Apr-14 A	02-May-14 A	
A1290	Post FAT bug fix	2.00	28-Apr-14 A	28-Apr-14 A	
A1550	Hardware I/O test & fix	3.00	28-Apr-14 A	29-Apr-14 A	
A1300	Pack	4.00	08-May-14 A	11-May-14 A	
A1310	Shipping to Korea	33.00	12-May-14 A	25-Jun-14 A	
Software System Validation (Korea)		29.00	18-Aug-14 A	23-Sep-14 A	
A1590	System set up	17.00	18-Aug-14 A	10-Sep-14 A	
A1260	Software loading	2.00	11-Sep-14 A	12-Sep-14 A	
A1330	Pre-FAT testing	10.00	15-Sep-14 A	23-Sep-14 A	
Software FAT (Korea)		24.00	29-Sep-14 A	30-Oct-14 A	
A1340	Automation Customer software FAT	6.00	29-Sep-14 A	06-Oct-14 A	
A1350	Post FAT bug fix	5.00	07-Oct-14 A	13-Oct-14 A	
A1370	End of test phase review	1.00	17-Oct-14 A	17-Oct-14 A	
A1360	Deliver software Korean Shipyard	1.00	30-Oct-14 A	30-Oct-14 A	



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Date	Revision	Checked	Approved
12-Aug-14	H	J. Hurley	P. Riglar
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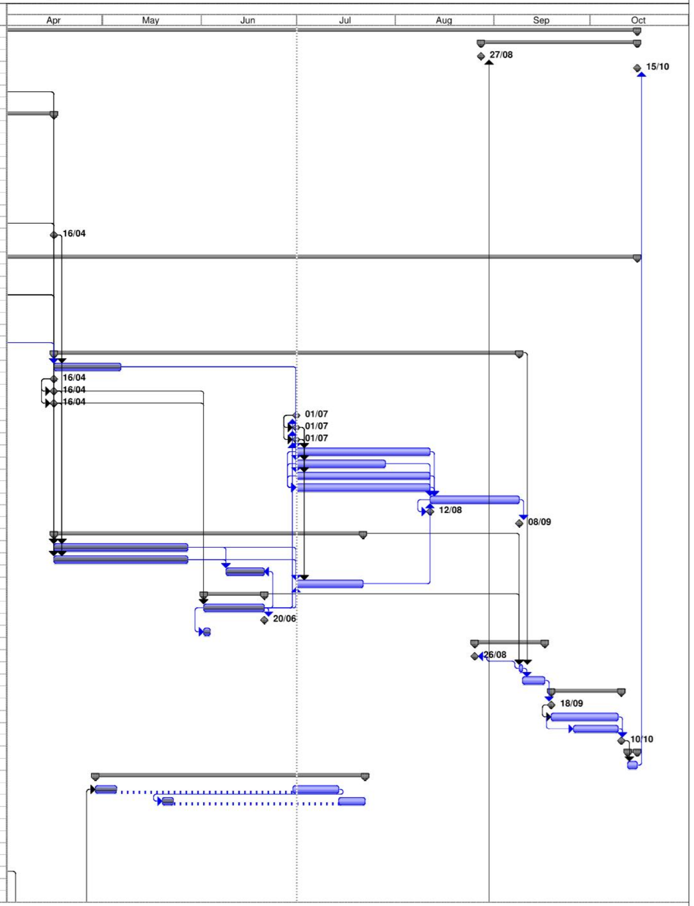
INVENSYS Scope

GE Drillship - Vantage DSME - Rev 15.mpp

ID		Task Name	Duration	Start	Finish	Predecessors
1		**General Electric Drillship (DSME/Vantage - Cobalt Explorer)**	**307 days**	**Mon 05/08/13**	**Wed 15/10/14**	
2		**Key Milestones**	**35 days**	**Wed 27/08/14**	**Wed 15/10/14**	
3		Hardware FAT Complete	0 days	Wed 27/08/14	Wed 27/08/14	139
4		Software FAT Complete	0 days	Wed 15/10/14	Wed 15/10/14	83
5	✓	PO Accepted	0 days	Fri 18/10/13	Fri 18/10/13	
6	✓	FDS Approved	0 days	Mon 06/01/14	Mon 06/01/14	11
7	✓	Mobilisation	10 days	Fri 18/10/13	Thu 31/10/13	5
8		**Preliminary Engineering**	**106 days**	**Mon 11/11/13**	**Wed 16/04/14**	
9	✓	Functional Design	30 days	Mon 11/11/13	Fri 20/12/13	7,14SS-20 days
10	✓	S/W Interface Test	10 days	Mon 02/12/13	Fri 13/12/13	9SS+10 days
11	✓	FDS Approval by Client	5 days	Mon 23/12/13	Mon 06/01/14	9,10
12	✓	GA External Cabinet (Preliminary)	10 days	Mon 23/12/13	Mon 13/01/14	9
13	✓	P&H Calcs (Preliminary)	10 days	Mon 23/12/13	Mon 13/01/14	9
14	✓	**FDS - Client Supplied Information (Approved For FDS)**	**0 days**	**Thu 28/11/13**	**Thu 28/11/13**	**5FS+6 wks**
20	✓	**Design - Client Supplied Information (Approved For Construction)**	**25 days**	**Fri 22/11/13**	**Mon 06/01/14**	**5FS+2 wks**
27	✓	Approve Instrument Index	16 days	Fri 06/12/13	Mon 06/01/14	26
28	✓	**SW/HW Bld - Client Supplied Information (Approved For Construction)**	**0 days**	**Fri 17/01/14**	**Fri 17/01/14**	**6**
39		Late C&E (Issued for review)	0 days	Wed 16/04/14	Wed 16/04/14	
40		Late Inst Index (Approved for Construction Rev 0)	0 days	Tue 04/02/14	Tue 04/02/14	
41		**Vantage Drillship**	**307 days**	**Mon 05/08/13**	**Wed 15/10/14**	
42	✓	**Client Data**	**0 days**	**Mon 06/01/14**	**Mon 06/01/14**	
43	✓	Hardware Definition Freeze	0 days	Mon 06/01/14	Mon 06/01/14	20
44	✓	Database Design Freeze	0 days	Mon 06/01/14	Mon 06/01/14	20
45	✓	**I/O Allocation**	**18 days**	**Mon 06/01/14**	**Wed 29/01/14**	
46	✓	Hardware Definition Data Validation (Accelerated)	8 days	Mon 06/01/14	Wed 15/01/14	43,44,20
47	✓	BoM (Accelerated)	7 days	Tue 07/01/14	Wed 15/01/14	46SS,20,27
48	✓	I/O Allocation (ESD and F&G)	10 days	Thu 16/01/14	Wed 29/01/14	44,46,27
49		**Safety System SW**	**104 days**	**Wed 16/04/14**	**Mon 08/09/14**	
50	✓	PT2 files IO conditioning	15 days	Wed 16/04/14	Tue 06/05/14	44,48,6,28,39
51	✓	Late Inst Index (GE - Approved to proceed Rev B-03)	0 days	Wed 16/04/14	Wed 16/04/14	
52	✓	Late C&E F&G (Issued For Information and Static Graphics Build)	0 days	Wed 16/04/14	Wed 16/04/14	51SS
53	✓	Late C&E ESD (Issued For Information and Static Graphics Build)	0 days	Wed 16/04/14	Wed 16/04/14	51SS
54		Late Inst Index (Approved for Construction Rev B-03)	0 days	Tue 01/07/14	Tue 01/07/14	70
55		Late C&E F&G (Approved for Construction)	0 days	Tue 01/07/14	Tue 01/07/14	54SS,70
56		Late C&E ESD (Approved for Construction)	0 days	Tue 01/07/14	Tue 01/07/14	54SS,70
57		PT2 Files (F&G System)	30 days	Tue 01/07/14	Mon 11/08/14	50,55,56
58		PT2 Files (ESD System)	20 days	Tue 01/07/14	Mon 28/07/14	50,55,56
59		F&G Addressable System	30 days	Tue 01/07/14	Mon 11/08/14	50,55,56
60		Database Work	30 days	Tue 01/07/14	Mon 11/08/14	57SS,58SS,59SS
61		S/W Internal Testing	20 days	Tue 12/08/14	Mon 08/09/14	57,58,59,60,68
62		Preliminary (Modbus Map)	0 days	Tue 12/08/14	Tue 12/08/14	61SS
63		Final (Modbus Map)	0 days	Mon 08/09/14	Mon 08/09/14	61
64		**Graphics**	**69 days**	**Wed 16/04/14**	**Mon 21/07/14**	
65	✓	Build ESD Static Graphics	30 days	Wed 16/04/14	Tue 27/05/14	44,6,28,39,52,53
66	✓	Build F&G Static Graphics	30 days	Wed 16/04/14	Tue 27/05/14	44,6,28,39,52,53
67	✓	Approval of Graphics by GE	10 days	Mon 09/06/14	Fri 20/06/14	65,66,70FF
68		Dynamic Build Graphics	15 days	Tue 01/07/14	Mon 21/07/14	65,66,70,55,56
69		**Boat Yard Support (GE Office Busan)**	**15 days**	**Mon 02/06/14**	**Fri 20/06/14**	
70	✓	Mimic/HMI Workshop and C&E Review	15 days	Mon 02/06/14	Fri 20/06/14	52,53
71		Draft (Modbus Map)	0 days	Fri 20/06/14	Fri 20/06/14	70
72	✓	HMI Workshop (Information only)	2 days	Mon 02/06/14	Tue 03/06/14	70SS
73		**S/W internal Test**	**16 days**	**Tue 26/08/14**	**Tue 16/09/14**	
74		GE Supplied workstations	0 days	Tue 26/08/14	Tue 26/08/14	75SF-10 days
75		Set up work stations	1 day	Tue 09/09/14	Tue 09/09/14	49,64,69
76		S/W Internal Testing	5 days	Wed 10/09/14	Tue 16/09/14	75
77		**Software FAT**	**16 days**	**Thu 18/09/14**	**Fri 10/10/14**	
78		Start FAT	0 days	Thu 18/09/14	Thu 18/09/14	76FS+2 days
79		FAT	15 days	Fri 19/09/14	Thu 09/10/14	78SS
80		Close TR's	10 days	Fri 26/09/14	Thu 09/10/14	79SS+5 days
81		FAT Complete	0 days	Fri 10/10/14	Fri 10/10/14	79FS+1 day,80
82		**Finalise Docs & SW Ready for Despatch**	**3 days**	**Mon 13/10/14**	**Wed 15/10/14**	
83		Update Test Documentation	3 days	Mon 13/10/14	Wed 15/10/14	81
84		**Test Documentation**	**60.75 days**	**Tue 29/04/14**	**Tue 22/07/14**	
85		Detail FAT Documentation	15 days	Tue 29/04/14	Mon 14/07/14	135SS-10 wks
86		Client Approval of Test documentation	10 days	Tue 20/05/14	Tue 22/07/14	85
87		**Cabinet/Matrix Design**	**30 days**	**Mon 03/02/14**	**Fri 14/03/14**	
88		**F&G System**	**30 days**	**Mon 03/02/14**	**Fri 14/03/14**	
89	✓	GA Drawings (Accelerated)	7 days	Mon 03/02/14	Tue 11/02/14	48
90	✓	Wiring Drawings (Accelerated)	7 days	Mon 03/02/14	Tue 11/02/14	89SS
91		Cross wiring schedule	10 days	Mon 17/02/14	Fri 28/02/14	89,40
92		**Documentation Approval**	**23 days**	**Wed 12/02/14**	**Fri 14/03/14**	
93		GA Drawings	10 days	Wed 12/02/14	Tue 25/02/14	89
94		Wiring Drawings	10 days	Wed 12/02/14	Tue 25/02/14	90



Project: General Electric Drillships
Date: Tue 01/07/14

Task · Split · Progress · Milestone · Summary · Project Summary · External Tasks · External Milestone · Deadline

Page 1 of 2

GE Drillship - Vantage DSME - Rev 15.mpp

ID		Task Name	Duration	Start	Finish	Predecessors
1		**General Electric Drillship (DSME/Vantage - Cobalt Explorer)**	**307 days**	**Mon 05/08/13**	**Wed 15/10/14**	
2		**Key Milestones**	**35 days**	**Wed 27/08/14**	**Wed 15/10/14**	
3		Hardware FAT Complete	0 days	Wed 27/08/14	Wed 27/08/14	139
4		Software FAT Complete	0 days	Wed 15/10/14	Wed 15/10/14	83
5	✓	PO Accepted	0 days	Fri 18/10/13	Fri 18/10/13	
6	✓	FDS Approved	0 days	Mon 06/01/14	Mon 06/01/14	11
7	✓	Mobilisation	10 days	Fri 18/10/13	Thu 31/10/13	5
8		**Preliminary Engineering**	**106 days**	**Mon 11/11/13**	**Wed 16/04/14**	
9	✓	Functional Design	30 days	Mon 11/11/13	Fri 20/12/13	7,14SS-20 days
10	✓	S/W Interface Test	10 days	Mon 02/12/13	Fri 13/12/13	9SS+10 days
11	✓	FDS Approval by Client	5 days	Mon 23/12/13	Mon 06/01/14	9,10
12	✓	GA External Cabinet (Preliminary)	10 days	Mon 23/12/13	Mon 13/01/14	9
13	✓	P&H Calcs (Preliminary)	10 days	Mon 23/12/13	Mon 13/01/14	9
14	✓	**FDS - Client Supplied Information (Approved For FDS)**	**0 days**	**Thu 28/11/13**	**Thu 28/11/13**	**5FS+6 wks**
20	✓	**Design - Client Supplied Information (Approved For Construction)**	**25 days**	**Fri 22/11/13**	**Mon 06/01/14**	**5FS+2 wks**
27	✓	Approve Instrument Index	16 days	Fri 06/12/13	Mon 06/01/14	26
28	✓	**SW/HW Bld - Client Supplied Information (Approved For Construction)**	**0 days**	**Fri 17/01/14**	**Fri 17/01/14**	**6**
39		Late C&E (Issued for review)	0 days	Wed 16/04/14	Wed 16/04/14	
40		Late Inst Index (Approved for Construction Rev 0)	0 days	Tue 04/02/14	Tue 04/02/14	
41		**Vantage Drillship**	**307 days**	**Mon 05/08/13**	**Wed 15/10/14**	
42	✓	**Client Data**	**0 days**	**Mon 06/01/14**	**Mon 06/01/14**	
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52	✓	Late C&E F&G (Issued For Information and Static Graphics Build)	0 days	Wed 16/04/14	Wed 16/04/14	51SS
53	✓	Late C&E ESD (Issued For Information and Static Graphics Build)	0 days	Wed 16/04/14	Wed 16/04/14	51SS
54		Late Inst Index (Approved for Construction Rev B-03)	0 days	Tue 01/07/14	Tue 01/07/14	70
55		Late C&E F&G (Approved for Construction)	0 days	Tue 01/07/14	Tue 01/07/14	54SS,70
56		Late C&E ESD (Approved for Construction)	0 days	Tue 01/07/14	Tue 01/07/14	54SS,70
57		PT2 Files (F&G System)	30 days	Tue 01/07/14	Mon 11/08/14	50,55,56
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69		**Boat Yard Support (GE Office Busan)**	**15 days**	**Mon 02/06/14**	**Fri 20/06/14**	
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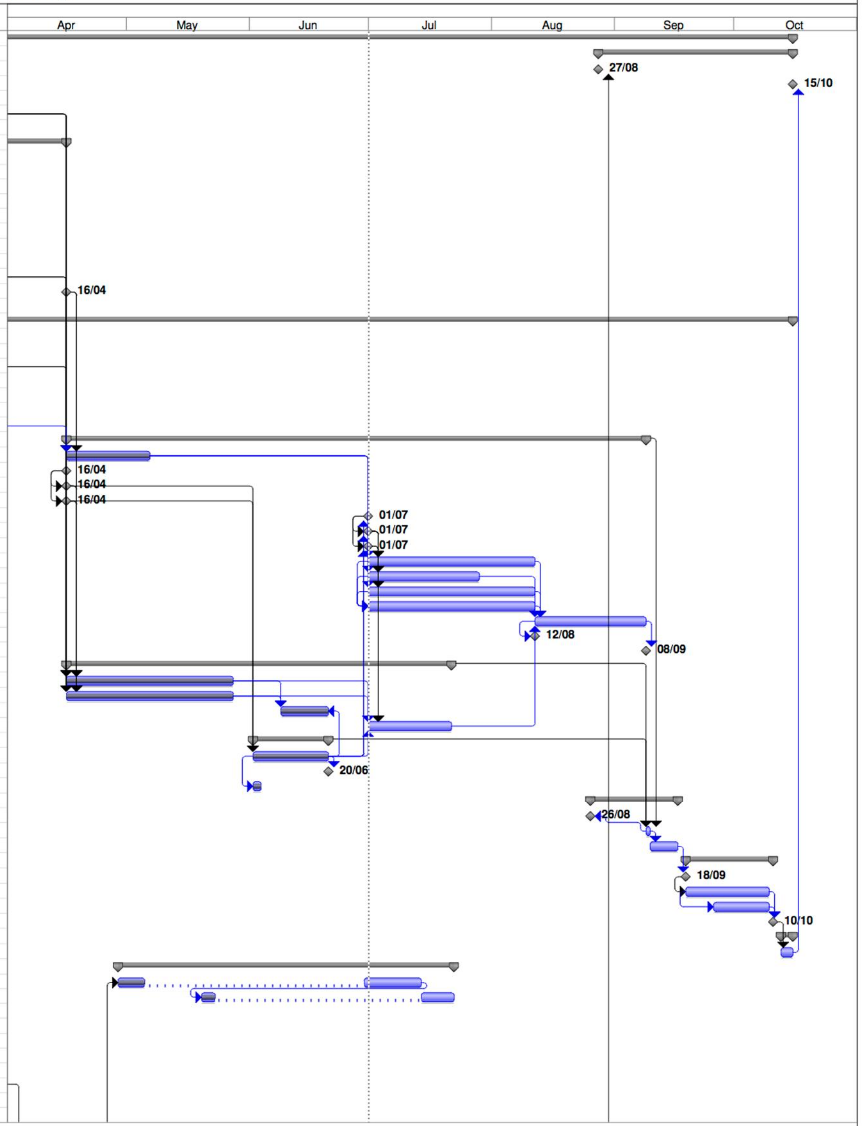

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Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline