DYNAMIC POSITIONING CONFERENCE
October 17 – 18, 2000

POWER PLANT

Power Management System for the "Deepwater Horizon" a Dynamically Positioned All Weather Semisubmersible

John J. May

R&B Falcon Drilling Inc.

and

Halvard Foss

Kongsberg Simrad AS

Introduction

In order for a fully dynamically positioned drilling rig to perform safely in deep water, the design of the power generation and distribution plant along with the control and protection systems, is of vital importance. The paper reflects the installation on the Deepwater Horizon where the electric power plant by its multiple bus system is designed for a minimum of disturbances to the drilling operation should any problems in the power plant occur.

Deepwater Horizon after superlift in Ulsan, Korea, Aug. 2000

Design of the Power System

For the design of a power system, one must first start with the design requirements then proceed with the design development by optimizing the design parameters to suit the overall design goals.

Design Requirements

- Vessel Design Environment - The rig is contractually obligated to continue drilling operations during severe environmental conditions. Gulf of Mexico - 10 Year Winter Storm with 10 Year Eddy Currents and West of Shetlands - 5 Year Storm
- ABS designation for **DPS-3** and/or DNV notation for **AUTRO**
- Eight (8) 5 mw thrusters, two (2) per quadrant

Design Goals

- High reliability, quick response, variable frequency thruster drives, thruster motors and azmuthing thrusters
- Upper deck size and weight restraints to preserve Variable Deck Load as required by design on a Semi-submersible Drilling Vessel
- High Voltage Switchgear supplier with capabilities to provide high level of system protection which can detect and remove faults quickly and guarantee service continuity
- Understandable, reliable, and effective power management system

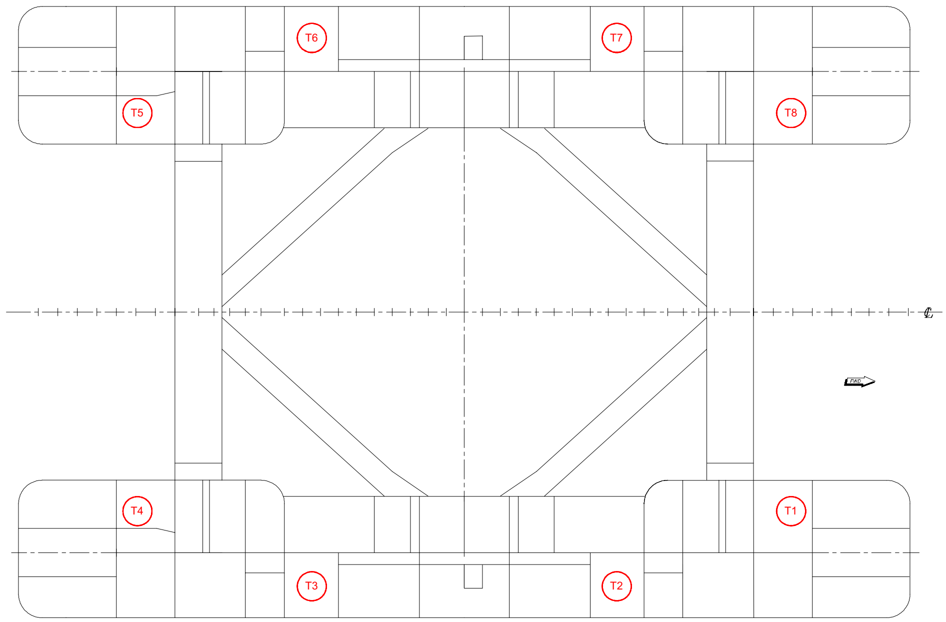
Thruster Arrangement

One of the first design considerations for a DP drilling rig must be the number and size of the thrusters to be used. This is determined by the configuration of the vessel being constructed, the thrust required to maintain station, and the physical limits of the thrusters and the ability to fit them within the hull design. Additionally, the engineers have to consider the rig's DP capabilities if any single piece of equipment or compartment is lost.

The lower hull design for the Deepwater Horizon was already established, based on the design and construction of the Deepwater Nautilus, a moored semisubmersible. Considering the hull design of the Deepwater Horizon, 8 thrusters of 4.5 to 5.5 mw capacity each were chosen, with two thrusters to be installed in each of the four quadrants.

To meet the DPS-3 criteria set for this rig by common thruster sizes and the thrust requirements for the rig (i.e., no casualty could cause the loss of more than a single thruster) it was necessary to separate the thrusters and their drive motors and auxiliary equipment, as well as the thruster Variable Frequency Drives by an A-60 bulkhead or two or more A-0 bulkheads and a cofferdam.

PONTOON LAYOUT – "DEEPWATER HORIZON"



Engine Generator Set Arrangement

When considering engines and engine rooms for any DP vessel, it is necessary to consider the criteria that have been set for loss of a portion of the power plant. A further consideration for any semi-submersible vessel (like the Deepwater Horizon) is the severe restrictions of weight and space available in the upper hull for the prime movers. Once the size and number of thrusters are known, the basic power plant size can be determined by adding the anticipated marine/hotel and drilling loads to the propulsion loads. It is then necessary to determine how many engines, in how many engine rooms, will be required to meet these requirements.

For multiple engine rooms, the amount of installed power is equal to: Power Required (n/n-1) where n is the number of engine rooms.

For example if 35 mw are needed to power the thrusters, hotel, and drilling equipment in a "design storm" conditions and only two (2) separate and independent engine rooms are allowed by the design, the total installed prime power must be 70 mw (35 mw per engine room).

If a three (3) engine room design is considered the total installed prime power is 52.5 mw.

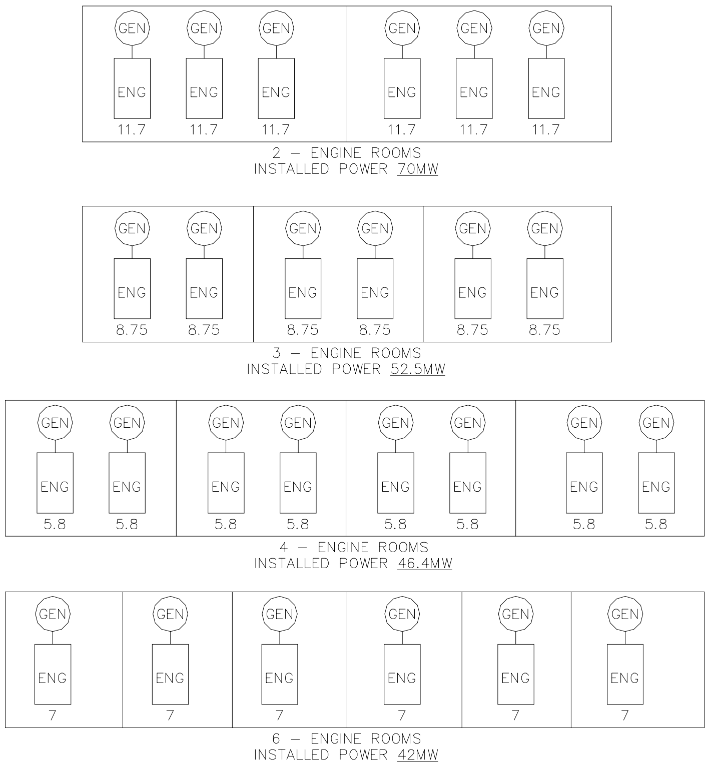
For a four (4) engine room design the total installed prime power is 46.6 mw.

For a five (5) engine room design the total installed prime power is 43.75 mw.

For a 6 engine room design the total installed prime power is 42 mw

For symmetry of design an even numbers of prime mover spaces is favored.

Based on this logic, the design team elected to install six (6) engines with 7 mw capacity each, with each engine being located in a separate engine room. The engine rooms are separated from each other by water-tight A-60 bulkheads, so the power plant can never lose more than one engine due to a single failure, including the loss of a single compartment due to fire or flooding, the DPS-3 or ATURO criteria.

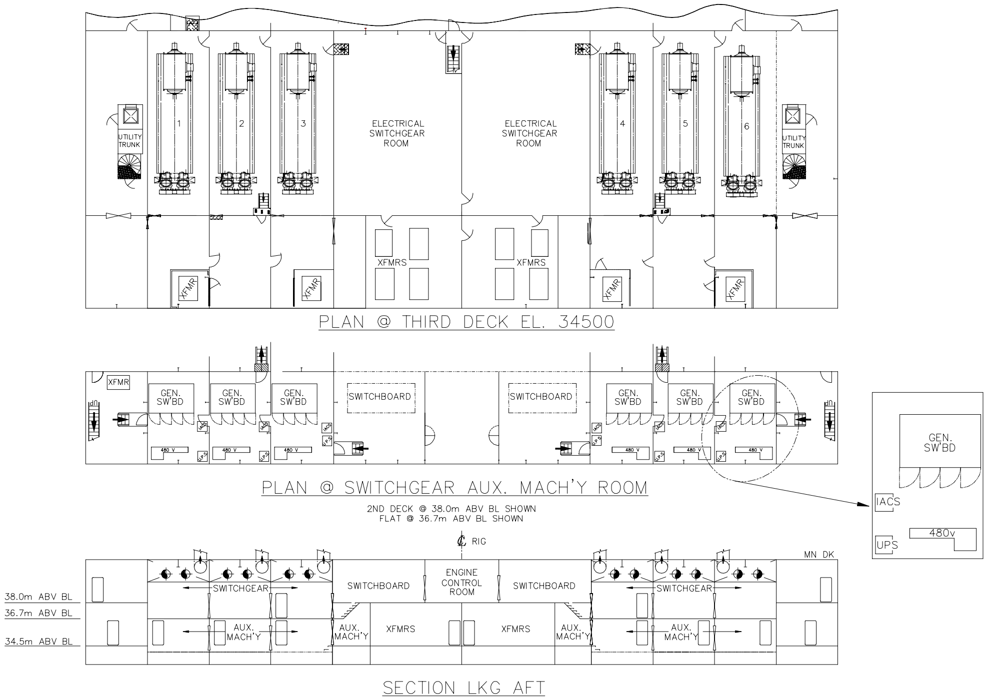


2, 3, 4, and 6 engine room arrangements with required installed KW

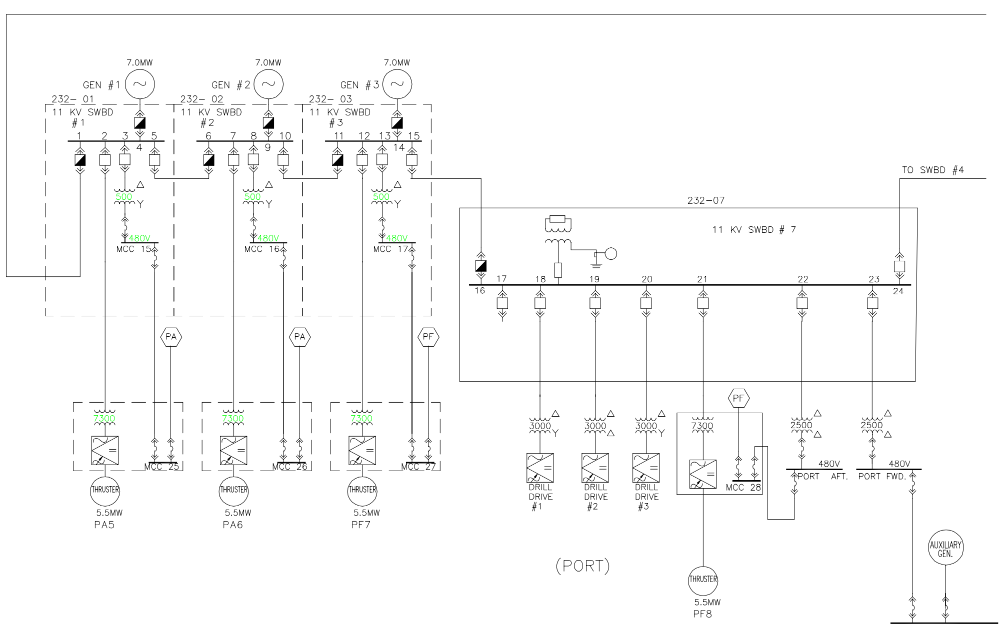
Generator Control and Distribution Switchgear Arrangement

Based on prior experience, RBF had decided to use an 11 kV primary generation and distribution system. To comply with the loss of one space design premise discussed above (loss of any one compartment would not result in more than the loss of one thruster and one main generator) required that the main 11 kV switchboards be located in eight (8) separate spaces, i.e. one thruster feeder in each of the eight (8) spaces. Six of these spaces also include the controls for one (1) main generator.

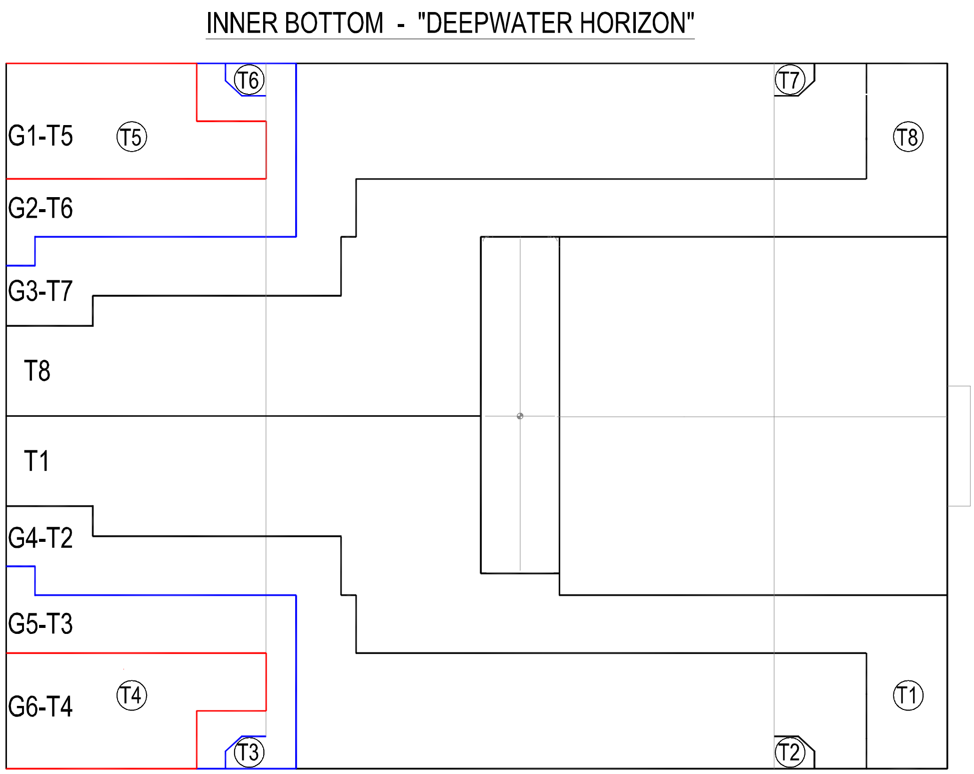
ENGINE / SWITCHGEAR LAYOUT – "DEEPWATER HORIZON"



ONE–LINE DIAGRAM – "DEEPWATER HORIZON"
PORT SIDE SHOWN – ST'BD SIDE SIM. TO OPP. HAND



It is important to note that all of the power and control cabling of the separate 11 kV switchboard rooms, engine rooms, and thrusters must be separated by A-60 bulkheads or two A-0 bulkheads and a cofferdam to comply with the DPS-3 requirements. This required that the inner bottom of the upper hull be arranged as a virtual maze, with many spaces separated by A-60 bulkheads.



Inner Bottom Arrangement

Other very important issues deal with the selection, design and grouping of auxiliary systems for the separate engine rooms, and switchgear rooms. Based on the underlying design premise that limited worst case losses to the loss of a single engine and a single thruster, the power generation system employs a single thread design premise for ventilation, lube oil priming, starting air, voltage regulator, and governor control systems. Duplex vessel systems were provided for cooling water, and fuel oil. All of the engine auxiliary power originates in the associated 11 kv generator control switchboard space, with the associated motor control centers, etc. located in the associated 11 kV switchboard room.

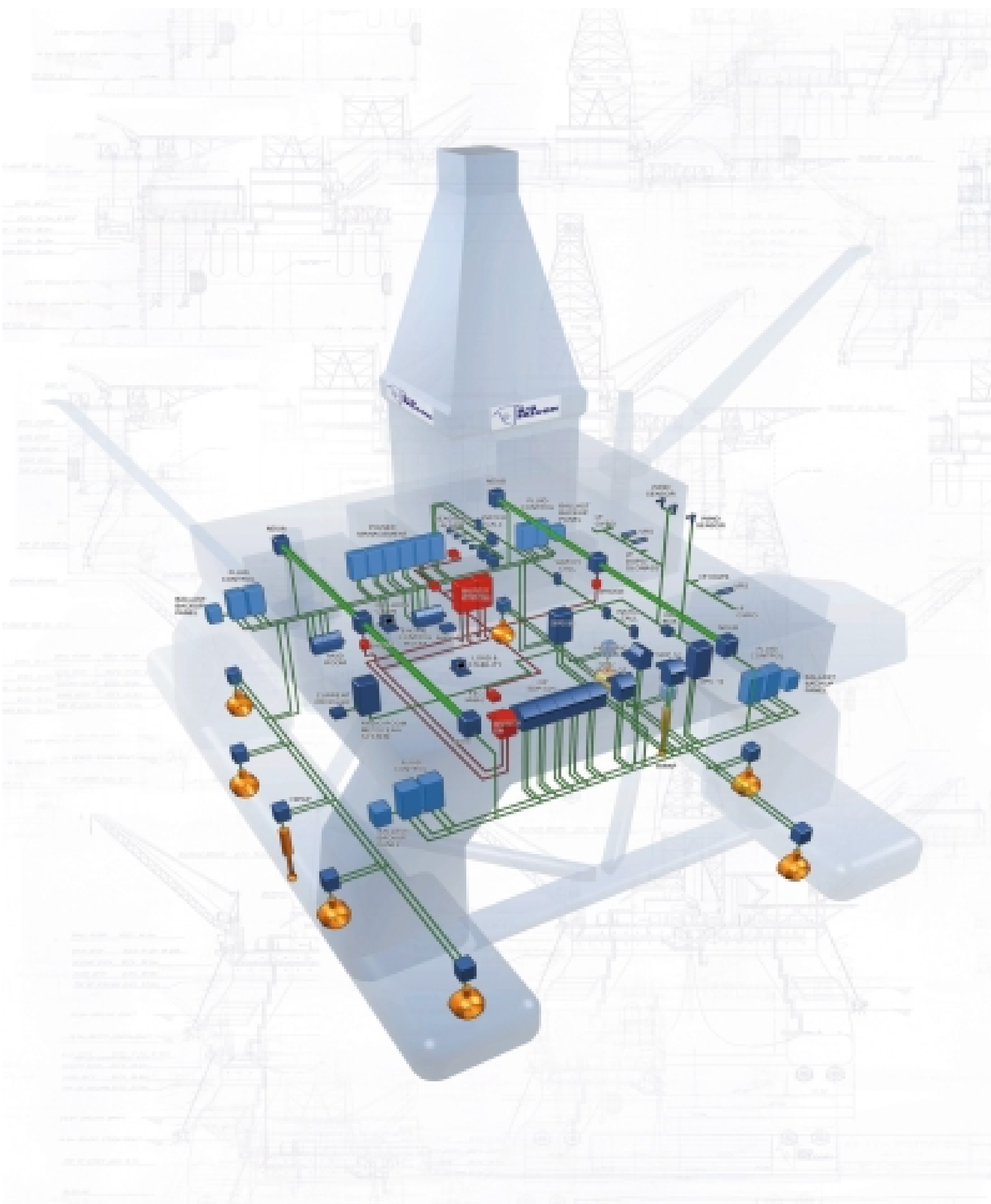
Similarly, the thruster auxiliaries were designed on a single thread system, i.e. salt water cooling system, fresh water cooling system, lube oil system, thruster drive and thruster motor. All of the thruster auxiliary power originates in the associated 11 kv switchgear spaces, with distribution centers located in the specific thruster and thruster drive compartments.

Design of the power management system for this vessel, with it's six (6) separate and independent engine rooms, and 8 separate and independent thruster compartments presented many different challenges. Not the least of these challenges was that the power management system must have the capability of operating as a single system with all eight 11 kV switchboards connected in a ring configuration or as up to eight (8) separate and independent power management systems if all tie circuit breakers are opened.

The PMS must be understandable by the operations personnel, reliable, and easy to operate. It should keep the operational personnel informed about the condition of the electrical power system, and should act promptly to prevent and/or correct situations which might result in an electrical blackout. And if a blackout should occur it must be able to effectively isolate any faulted equipment and restart the propulsion plant in a hands off manner in 2 to 3 minutes.

The Integrated Control System

The power management system is an integral part of the total Integrated Control System for the rig. In general terms, the Integrated Control System consists of operator stations and distributed process control stations hooked up to the double data network as illustrated below.



The main components of the Integrated Control System are:

Dynamic positioning:
- SDP-32 (triple redundant) Dynamic Positioning System
- SDP-12 (single) Dynamic Positioning System (fire backup)
- Two HiPAP Hydroacustic Position Reference System
- Four DPS-200 DGPS Position Reference System

Vessel Maneuvering:
- STC Thruster and Propulsion Control System

Vessel Control:
- Alarm and Monitoring System
- Power Management System
- Mode Control and Redundancy and Criticality Assessment System (RCA)
- Ballast and Bilge Control System
- Drill water, Brine, Mud and Bulk Material System

Vessel Safety Systems:
- Emergency Shutdown System
- Fire & Gas System

The Power Management System

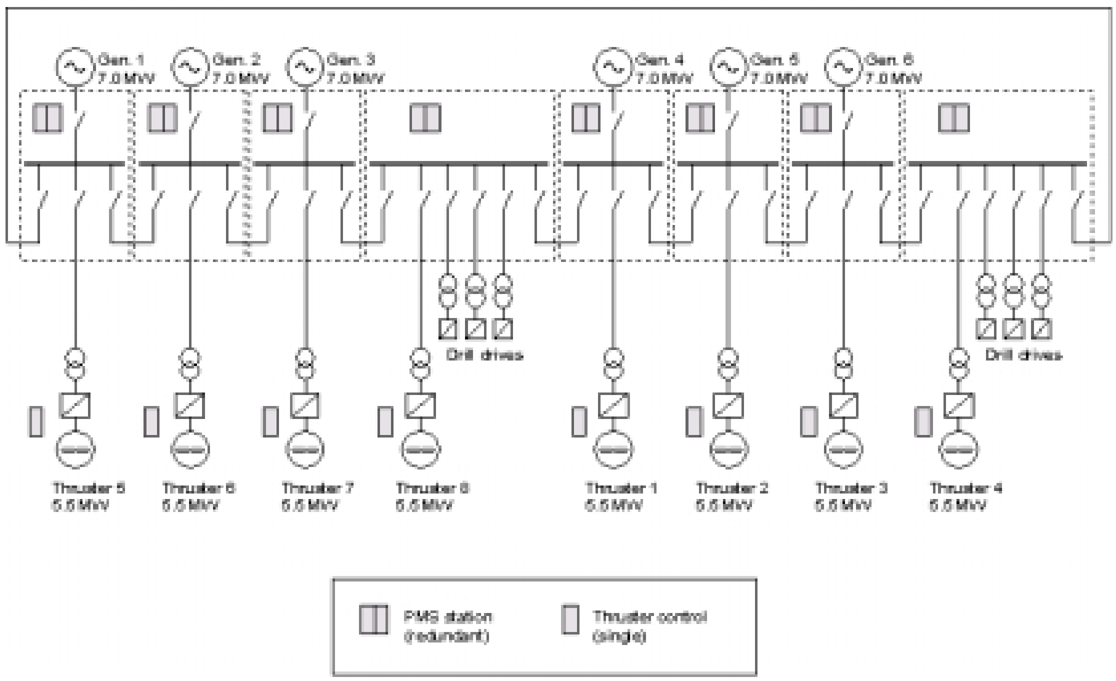
The purpose of the Power Management System is to assure adequate and reliable electrical power supply to the various consumers. This is achieved by the following main tasks:

- The PMS will control the number of generators online at any time according to the operational conditions and perform load sharing of the generators.
- The power consumption of Variable Frequency Drives (thrusters, drilling) is controlled in order to avoid overloading the generators. Should an overload occur e.g. caused by a shut down of a generator set, the PMS will force load reduction of some or all of the Variable Frequency Drives until the situation is recovered.
- The amount of regenerated power from the drilling drawworks is limited to avoid a reverse power situation for the generators.
- The PMS will perform blackout restart of the power system in the event of a total or partial blackout.

Further, the PMS includes the *Redundancy and Criticality Assessment* system, an operator support system that monitors the "health" of the electric power system. All generators, switchboards and thruster drives, including all auxiliary systems, are monitored and compared with specific requirements for the defined operational modes of the vessel. Any important alarm or non-conformance with respect to equipment condition or set-up is reported to the engineers as well as to the DP-operators.

Topology of the Power Management System

The PMS is distributed in a similar way as the power plant itself. Each 11 kV busbar segment is controlled from a dedicated process control station located in the switchboard room, total 8 units. The process control stations are equipped with dual processors and power supply units. In addition each thruster is controlled from a dedicated process control station located in the thruster room, total 8 units.



The process control stations in the generator busbar compartments perform monitoring, control and protection of the diesel engine and auxiliaries, control and monitoring of the electric generator as well as control of all breakers for the segment. The process control stations in the drilling busbar compartments handle all related breakers and interface to drilling equipment.

All PMS substations (i.e. the process control stations that take part in the PMS) are performing PMS calculations based on information received from it's own bus segment in addition to information from the other PMS substations. If a bus segment is isolated the corresponding PMS substation will act as an isolated PMS system. If a bus segment is connected to other buses, the PMS substation will calculate load setpoints, automatic start / stop criteria etc. for it's own generator taking into account the situation in the other bus segments.

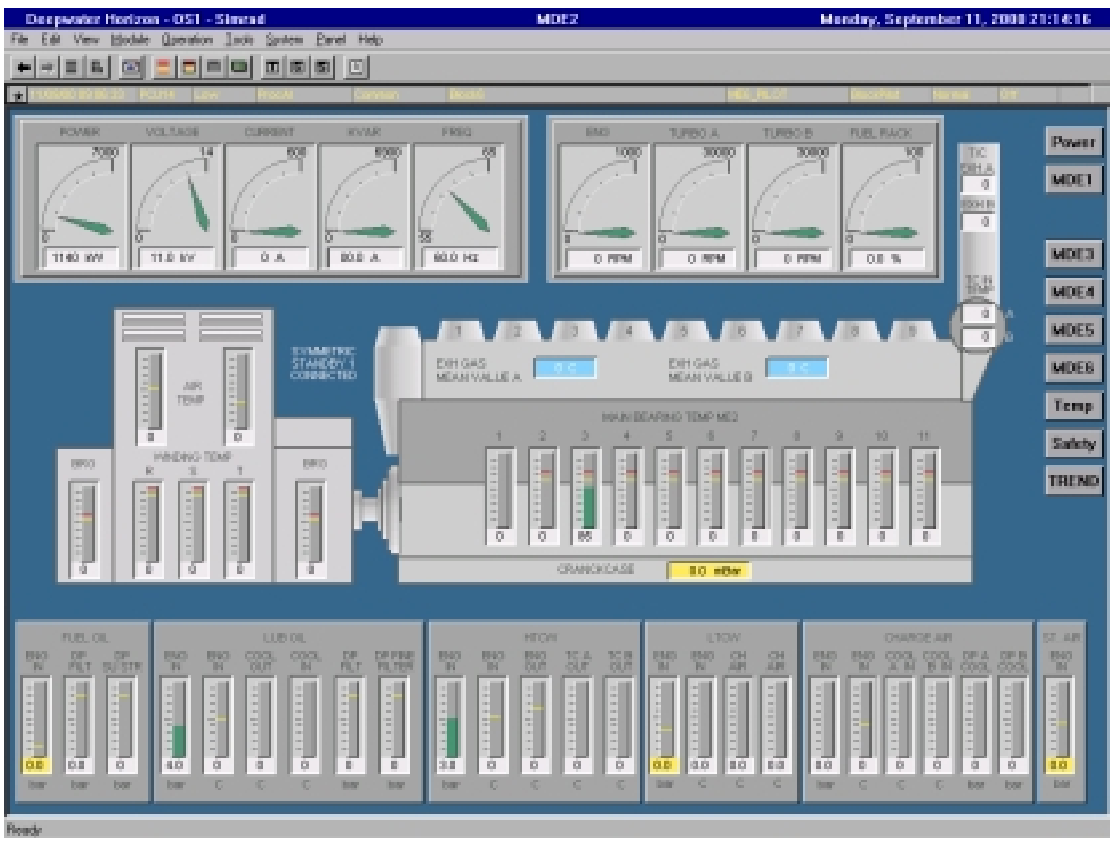
In this way, each PMS substation is acting as an autonomous unit and the system is not dependent on a single main computer. If a PMS substation should completely fail (i.e. both main and standby computer fail) the remaining parts of the system will still be operative. However as the situation in the corresponding bus section no longer could be monitored it is advisable to shut down the generator in that section. The redundant and physically separated communication networks eliminates the risk of a breakdown of inter-communication between PMS stations.

Return to Session Directory ►

Prime Mover Control

The diesel engine monitoring, control and safety system is integrated in the PMS substations. This eliminates any time-delays in communication with dedicated control systems, and provides flexibility with respect to total PMS functionality.
The PMS substation performs start and stop sequences and, in addition to the safety shutdown system, the PMS will perform generator change-over in the event of pre-alarm on any main temperature or pressure reading.
Engine auxiliaries (lubrication pumps, cooling water pumps, fuel pumps) are automatically started as part of the engine sequences.

The main monitoring picture of the diesel generator is shown below. In addition there are dedicated displays for exhaust gas temperatures, safety conditions, start inhibits, trends, etc.



Generator Control

The generator control features synchronizing and loadsharing. The electronic governors, running in "droop" mode, are controlled from the PMS system that will adjust engine speed to comply with the calculated load setpoint.

The loadsharing modes are either symmetric or asymmetric, for maintenance purposes also fixed load and manual loadsharing may be selected. The asymmetric loadsharing mode, which is most suited during situations where the load is stable and relatively low, runs one generator at a high load for a given interval before the next generator takes over. The purpose of the asymmetric loadsharing is mainly soot-blowing.

The PMS will automatically compensate for switchboard frequency deviations, i.e. "semi-isochrone" mode.

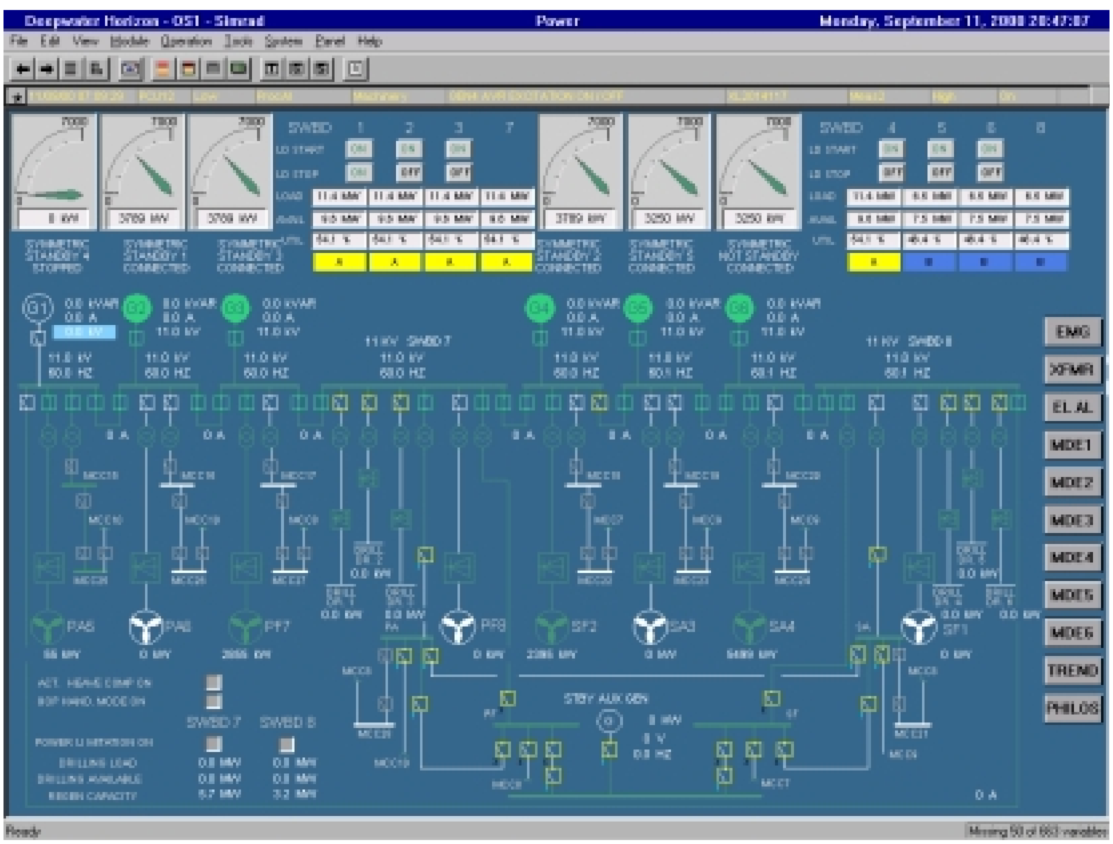
Control of switchboards and distribution

All 16 11 kV tie breakers are operated from the PMS. 8 breakers are fitted with synchronizing possibilities while the remaining can be closed only with no voltage on one or both sides.

All 11 kV tie breakers are operated by fast-acting differential protection relays to isolate bus sections in case of fault in one of the bus sections.

All distribution and drilling transformer breakers are operated from the PMS. The same counts for the 480 V switchboards interconnection breakers.

The main PMS display is shown below. It provides the main information on the electric power system, and enables the user to control generators and breakers. Automatic settings such as automatic start / stop priorities are set from the PMS display.



Power Reservation Program

The load-dependent start / stop program will automatically start and connect the next standby generator when the grid load exceeds given limits. Standby start / stop priority is given by the operator. There are two start criteria with individual setting of load and time delay, the first varying from 70 % to 84 % load dependent on the number of generators connected, with a time delay of 10 minutes. The second start criteria vary from 85 to 89 % with 7 seconds time delay. Additionally, the standby generator will be started immediately if any generator exceeds 105 % load.
When the load decreases the next standby generator will be loaded down, disconnected and stopped when the load has been below 60 % of the remaining capacity for 30 minutes.

In addition to the load dependent start / stop program the PMS will reserve additional power for the drawworks during Active Heave Compensation mode (2.5 MW) and Heavy Weight Handling Mode (5.0 MW).

The power reservation program takes into account the configuration of the electric plant.

Load Limiting of Variable Frequency Drives

Under normal operating conditions (i.e. generator loading less than 100 %) the Power Management system will prohibit an excessive load increase by controlling the maximum individual consumption of thruster and drilling units. This is achieved by a “power limit” signal to each thruster and the two drilling plants (port / starboard). The frequency converters will control that the consumption of respective unit does not exceed the given limit.

The power limit signals are calculated by adding a portion of the total unused generator capacity (the “spinning reserve”) to the present consumption of the consumer. The calculation ensures that the power plant never is overloaded and at the same time any consumer are allowed to increase its consumption until a specified % loading of the power plant is reached. The maximum % loading can be individually set for each consumer, allowing a priority selection between the consumers. On the Deepwater Horizon the maximum generator utilization is 100 % for the drilling plant and 105 % for the thrusters.

The power limit signals also features a load increase rate function (dP / dt), which is utilized for the thrusters (0-100 % load increase in 4.0 seconds with 2 or more generators connected).

The power limit calculation takes into account the actual configuration of the power plant, assuring that only generators that are able to supply the individual consumer are included in the calculation.

Load Reduction System

By implementing the Load Limiting program above, normal operations of the propulsion and drilling plants should not overload the power generating capacity. However in the event of a generator trip, or should the consumption of other consumers suddenly rise, an overload situation may occur.

In the event that any generator is overloaded the Power Management system will respond by a corresponding reduction in the “power limit” signal to the Variable Frequency Drives. The level at which each consumer will be reduced is identical to the maximum % power plant load for the load limiting function, i.e. the same priority philosophy is used.

Whenever the PMS sees that one or more generators are loaded above the maximum level for a consumer, the consumer load will be reduced by the same amount (in kW). If there are more consumers having the same threshold they will all be reduced with the total amount which means that the network will be unloaded more than strictly necessary. For safety reasons this is the preferred way, since the time response from the individual drives may be different. When the overload situation is recovered the drives are allowed to increase up to maximum generator loading again.

The power limit calculations are performed at 10 Hz scan rate, also the necessary communication between the different Process Control Units are run at the same speed. Responses in the drilling and propulsion plants are specified to 20 and 75 ms respectively.

Should by any cause the load reduction system fail to work, additional safety precautions are made by monitoring network frequency:

- At 58.5 Hz (1.5 seconds delay) the PMS will reduce the power limit signals to 75 % of actual consumer load
- At 57.5 Hz (3.5 seconds delay) the drilling drives will shut down (independent of PMS)
- At 57 Hz (0.3 seconds delay) the thruster drives will be reduced to 50 % of load order (independent of PMS)
- At 57 Hz (5 seconds delay) the 11 kV bus will be split into two systems (by PMS)

Control of drawworks re-generated power

The drawworks will generate power while in active heave compensation mode. To prevent tripping of generators on reverse power, the amount of re-generated power will be limited by the Drilling Control System in accordance with signals from the Power Management System. The PMS will calculate the maximum power the drawworks can re-generate taking into acount the current switchboard configuration and the individual loading of the connected generators.

Blackout Restart

In the event of a full or partial blackout, the corresponding transformer / distribution breakers will open by undervoltage release. The 11 kV bustie breakers do not open except if tripped by the switchboard protection relays, however the PMS will split the busbars into two sections in the event of a full blackout.

At blackout, the PMS will start all available generators and connect them to the bus as they reach nominal voltage and frequency. The PMS will prohibit connection of more than one generator at the time. All transformers / distribution breakers will be closed in sequence (individual per bus segment) provided they were closed prior to the blackout and no interlock situation exists. The same applies for switchboard interconnection breakers in the 480 V systems. Electric motors including thrusters are automatically started, in sequence.

Reconnection of 11 kV bus ties is a manual operation. The same applies for the drilling plant.

The 480 V auxiliary (emergency) generator will automatically start and connect to the auxiliary switchboard if power is not re-established to this switchboard within 10 seconds (separate control system, not part of PMS).

Mode Control

For the Deepwater Horizon a number of vessel operational modes are defined. The operator can select the desired mode from the Vessel Control system, from the DP system or manoeuvring station. This will initiate predefined sequences that automatically bring generators, switchboards, thrusters and auxiliary systems on line as defined for the selected mode.

The following modes are available:

Mode	Generators (minimum)	Thrusters	Switchboard configuration	DP / ref. Systems
Harbor	1	0	No specific requirement	-
Transit	2	2	No specific requirement	-
DP 1	1	2	No specific requirement	Class 1 req.
DP 2	2	3	Ring configuration	Class 2 req.
DP 3	3	4	Ring configuration	Class 3 req.
Posmoor	Not implemented			

DP class 1/2/3 requirements define number of computers online, reference systems availability etc.

The operator can monitor the mode transfer sequence in details from the Vessel Control system, and in more general terms from the DP and maneuvering systems. Any failure or timeout in the sequence is reported.

A message is displayed in the event that a mode is not available. Special dialogues will inform why the mode is unavailable, such as: Number of generators cannot be obtained.

Redundancy and Criticality Assessment - RCA

The RCA system is a tool developed to inform the vessel operators (engineers, officers, DP-operators) whether the entire propulsion system is operating according to the present mode definitions.

All parts involved in the positioning operation are monitored:

- power generation and distribution including auxiliary systems
- thrusters and auxiliaries
- DP-equipment (computers, reference systems, sensors)
- Vessel Control system including PMS and local thruster control system

The state of the process equipment is compared with the mode definitions, including requirements for standby equipment (generators, pumps). Mismatches are presented with clear identification of the faulty (or unavailable) unit or system. For instance, the system will detect whether a switch is in “local” position, or a valve is left in “manual” mode (while it should have been in automatic). All process alarms that may influence on the current operation are reported, with 3 levels of criticality (reflected by different colors).

The Vessel Control System will display the state of the various units and their auxiliary systems. Any alarms or condition mismatch will be identified at unit / system level. The DP and the Maneuver control system will display status for the main plants (propulsion, power generation, etc.)

The main Mode Control / RCA display in the Vessel Control System is shown below. Alarms are present in the seawater cooling system for generator # 3, in thruster # 7 drive, and in the corresponding DP class criteria. The alarm(s) for generator # 1 are shown in the display but will not be reflected in the RCA general status as the generator is not part of the mode definition.

Return to Session Directory ►