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Electrical Power Plant and Thruster Systems Design Considerations for Dynamically Positioned Vessels

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Abstract

The quest for more oil is taking hydrocarbons exploration to much deeper waters offshore. To satisfy this need, a number of semi-submersible rigs are currently being converted and new innovative ships are being built around the world. During drilling, these vessels are required to be held on station in a reasonably tight watch circle and under very difficult environmental conditions. They thus have a large complement of high capacity thrusters, complex electrical power plant and distribution systems. This paper first discusses the impact of classification society requirements on the design and layout of DP systems and then presents solutions for their optimal and cost effective operation.

Introduction

Hyrdocarbon reserves have been discovered in numerous deepwater locations worldwide, notably West of the Shetlands, Norway, Brazil and Gulf of Mexico. The premier deepwater area is Brazil's Campos Basin where oil reserves of over 3 billion barrels are located in water depths of 400m-1000m and over 2 billion barrels in water depths greater than 1000m. In the Gulf of Mexico, reserves exceeding 4 billion barrels have been identified in water depths of 500m-1800m and approximately 700 blocs have been leased in greater than 1500m of water.

The above deepwater exploration activity has resulted in a significant increase in the demand for rigs capable of drilling in deep water. Hence the reason for the recent large number of mobile offshore drilling unit conversions, upgrades and new builds (mostly semi-submersibles and monohulls). Many of the new generation drill ships are multi-purpose vessels based on an oil (shuttle) tanker hull with facilities for drilling as well as processing, storing and offloading of crude produced during wellhead testing. Most of these vessels are designed for drilling up to about 3000m (10,000 ft) of water and are DP (Dynamically Positioned) Drillships. A typical example of the new generation of DP Drill ships is the Transocean (formerly Sonat) `**Discoverer Enterprise**' Class with many innovative features in the drilling methodology. The vessel is described elsewhere (Ref. 1) but its single line electrical diagram is shown in Figure 1.

There are six thrusters, each rated at 5222kW and producing a thrust of 89 tonnes approximately. The power for the thrusters, drilling equipment and ship's services is generated at 11kV by six diesel driven generators, four rated at 7030kW each and two at 4690kW each. The medium voltage switchboard consists of two completely independent sections each housed in a separate compartment but connected by a cable tie with breakers at each end. The number of thrusters, generators, switchboard sections and their physical location are determined by the Class Notation required for the vessel as described in the next Section.

Class Notation and Classification Society Requirements

When a vessel is equipped with a dynamic positioning system (designed, built and tested in accordance with Ship Rules and Rules for Mobile Offshore Units), it is assigned an additional Class Notation; DYNPOS by (DNV), DPS (by ABS), DP (by LRS). Depending upon the technical design, physical arrangement and redundancies that are incorporated in various sub-systems, control panels and back-up systems of the dynamic positioning system, the Class Notation DYNPOS (for DNV) will be complemented with the letters **T, AUTS, AUT, AUTR, AUTRO**. The equivalent Class Notations by other Classification Societies are listed in Table 1.

Table 1 - Class Notation equivalence between different Classification Societies

DNV	**ABS**	**LRS**
DYNPOS T	DPS-0	DP (CM)
DYNPOS AUTS	Not applicable	Not applicable
DYNPOS AUT	DPS -1	DP (AM)
DYNPOS AUTR	DPS - 2	DP (AA)
DYNPOS AUTRO	DPS - 3	DP (AAA)

Exact definitions of various Class Notations, as given by various Classification Societies, for the above Class Notations are reproduced in Appendix A.

The classification of systems for dynamic positioning comprises the following sub-systems, control panels, and back-up systems:

- power system
- controller
- measuring system
- thruster system
- remote thrust control system
- control panels

The minimum requirements for system arrangement by DNV for different notations **T, AUTS, AUT AUTR,** and **AUTRO** are summarised in Table 2 and form the basis of electrical power plant and thruster system design. Similar requirements are also stipulated by ABS and LRS. A single line diagram of an electrical power plant/thruster system satisfying the highest Class Notation of AUTRO, DPS-3 or DP (AAA) is given in Figure 2.

Table 2 - System Arrangement

Subsystem or component			Minimum requirements for group					
			T	**AUTS**	**AUT**	**AUTR**	**AUTRO**	
Power system	Generator and prime movers		Non-redundant	Non-redundant	Non-redundant	Redundant	Redundant separate compartments	
	Main Switchboard		1	1	1	1 with bus-tie	2 with normally open bus-ties in separate compartments	
	Bus-tie breaker		0	0	0	1	2	
	Distribution system		Non-redundant	Non-redundant	Non-redundant	Redundant	Redundant, through separate compartments	
	Power management		No	No	No	Yes	Yes	
Thrusters	Arrangement of thrusters		Non-redundant	Non-redundant	Non-redundant	Redundant	Redundant, in separate compartments	
Control	Auto control: no. of computer systems		0	1	1	2	2 - 1 in alternative control station	
	Manual control: joystick with auto heading		Yes	No	Yes	Yes	Yes	
	Single levers for each thruster		Yes	Yes	Yes	Yes	Yes	
Sensors	Pos. ref. Systems		0	1	2	3	3 whereof 1 in alternative control station	
	External sensors	Wind	0	1	1	2	2	Whereof 1 in alternative control station
		VRS	0	1	1	2	2	
		Gyro compass	1	1	1	2	3	
		Other necessary sensors	n/a	1	1	2	2	
UPS			0	0	1	1	1 - 1 in separate compartment	
Alternative control station for back-up unit			No	No	No	No	Yes	

Electrical Power Plant System Design

The reliability of the DP system is dependant to a large extent on the electrical power generation and distribution system. Whilst thruster units may have their own dedicated diesel prime movers, most ships have electrically driven units with centralised electrical generation to minimise fuel consumption and engine maintenance.

Although it is possible to mix successfully diesel and gas turbine generating sets in a vessel's centralised power plant (Ref 2), this combination is generally best avoided because of their different governor and load take up characteristics.

The number and rating of the installed generating sets and complexity of the distribution arrangements are then dependent upon the specified operational modes of the vessel and the associated redundancy requirements by the Society.

Although the minimum number and rating of the generating sets is dependant upon the required thruster power to maintain position and heading of the vessel under the specified most severe environmental conditions, ship's services load and the auxiliary systems e.g. drilling or cargo handling loads etc, the actual number and total installed capacity is governed by the available power after a single fault. The most onerous single fault, although very rare, is the busbar fault which can reduce the available power generation and thruster capacity to half for a two section switchboard with one or two bus-tie breakers (see Fig.1). In this case therefore the vessel will qualify for DPS-3 or equivalent Class Notation provided there are enough generators and thrusters left after the fault to hold position and meet other redundancy requirements in physical arrangement. Loss of installed generating and thruster capabilities can be reduced to 33% or 25% by sub-dividing the switchboards into three or four sections each located in separate compartments. It should be noted that the generating sets as well as thrusters and their auxiliaries/services will have to be housed in separate compartments also thus adding to the overall ship cost.

Depending upon whether open or closed bus-tie systems are used, (discussed later), the open bus-tie arrangement with further sub-divisions of the switchboard will invariably result in the installation of a larger number of generating sets thereby increasing the initial cost of the vessel even further.

It is for these cost reasons that many owners/operators choose the low cost option of DPS-2 Class Notation on the assumption that switchboard bus-bar faults, fire or flooding of compartments are rare occurrences.

Thrusters and Thruster Systems

Dynamically positioned vessels usually employ a variety of thruster types. The following are available:

a) Lateral thrust units or tunnel thrusters with fixed or controllable pitch propellers.

b) Azimuth (rotatable) thrust units with either fixed or controllable pitch propellers, controlling both magnitude and direction of thrust.

c) Gill jet thrust units.

d) Cycloidal propellers.

e) Fixed or controllable pitch main propellers (used also for transit purposes).

f) Water jets.

g) Podded azimuthing thrusters

The debate between controllable pitch propellers (CPP) and fixed pitch propellers (FPP) is an ongoing one but most of the new build vessels have azimuthing type thrusters with fixed pitch propellers driven by variable speed electric motors. When thrusters are used for transit, the propellers will absorb the rated power at different rotational speeds depending upon the ship speed. Therefore the propeller prime mover must be capable of providing reducing torque as the shaft RPM increases and this is easily achieved by weakening of the field of an electric motor. Typically 10% field weakening (constant HP) range is provided for thrusters to be used in transit.

The location of the thrusters requires careful consideration. Obviously the prime objective is to produce the maximum vessel turning moment possible for the available thrust, which in simple terms would require the thrusters to be as far apart as possible. This objective cannot always be achieved because account must always be taken of

a) t he available structural space within the hull in view of the Class Notation redundancy requirements in technical design and physical arrangement redundancy;

b) the effect of the wash of one thruster upon the other (often referred to as thruster-thruster interaction);

c) the effect of the wash from a thruster on the hull (referred to as thruster-hull interaction) and the possible detrimental effects that thrusters could have on the drilling operation or on position feedback sensors.

System Operation

In a diesel electric ship, the "Central Power Plant" concept for generating power is of fundamental importance as it brings with it the following advantages:

a) **Increased vessel safety**: Redundancy in the power generation plant and propulsion/thruster drives enable the system to continue supplying power to propellers and other critical auxiliary or operational loads in the event of multiple failures.

b) **Higher Flexibility**: In addition to facilitating flexible machinery layouts, for example to contain fire and flood damage, the concept allows the power plant to be electrically configured to suit the vessels operating profiles.

c) **Lower Operating Costs**: Achieved from savings in fuel and maintenance costs by running the minimum number of generating sets at their optimum loads.

d) **Enhanced availability, reliability and maintainability**: Achieved by operating the inherently robust plant most efficiently and by carrying out preventative maintenance work during voyages.

From the above it therefore follows that in order to take best advantage of the vessel's diesel electric power and propulsion plant, the main switchboard should be operated as a single bus-bar system i.e. all bus-ties closed. However, there are owners/operators, and even classification societies, who believe that a 'two section' switchboard system should run with the bus-ties open so that a busbar short circuit would, in the worst case, result in the loss of one section of the HV switchboard only leaving the generators on the other switchboard unaffected. The advantages and disadvantages of the open bus-tie arrangement are given in Table 3 (Ref 3).

TABLE 3: OPEN BUS-TIE ARRANGEMENT	
ADVANTAGES	**DISADVANTAGES**
• In a correctly designed system, no single failure should result in a total loss of power.	• Increased generation required for redundancy purposes • Less economical • High risk of half blackout on failure of one machine • Starting of largest electrical drive may not be possible with split bus, consequently the systems have to be paralleled for starting periods and then split - synchronising across the bus-section when both sides have fluctuating loads is fraught with potential difficulties and can lead to operator error • More reliance on the availability of all machines • Increased running hours and maintenance of all machines • Complete system is far less flexible

It can be seen that the main advantage of the open bus-tie arrangement is that no single failure will result in total loss of power. The main disadvantage of this arrangement arises from the fact that to avoid half blackouts from diesel generator failure, governor failure or AVR failure **both sides of the switchboard must have spare capacity.**

The advantages and disadvantages of the closed bus-tie arrangement as outlined in (Ref 3) are given in Table 4.

<table>
<tr><th colspan="2">TABLE 4: CLOSED BUS-TIES ARRANGEMENT</th></tr>
<tr><th>ADVANTAGES</th><th>DISADVANTAGES</th></tr>
<tr><td>• More flexible:
- any engine can be assigned to whole system rather than dedicated to one side
• Less vulnerable to the effects of control failures:
- voltage regulator (over and under excitation)
- governor (over and under frequency)
• More economical:
- generally less engines required for spinning reserve
• Less susceptible to transient voltages and frequency problems during starting of large machines
• Load shedding is not normally necessary on one machine failure
• Less running hours on each machines, therefore reduced maintenance cycles
• Generally one machines is available for maintenance</td><td>• Very small risk of a single point failure causing total loss of power</td></tr>
</table>

Successful operation of the closed bus-tie arrangement requires that on the rare occasion that the bus-ties are required to operate, they do so correctly. The protection must be properly designed, tested and checked regularly as part of the planned maintenance.

The inter-relationship between the Power Management System and the DP System is important since in environmental conditions worse than calm weather the electrical load is predominantly propulsive. If the on-line generation capacity is matched to demanded load to minimise fuel consumption, then large/sudden changes in demand leading to the loss of a running generator will result in system overload where the preference tripping (if installed) of non-essential loads will be insufficient to prevent the total system failure. Accordingly the control system must be arranged to provide thrust limitation in the event of increasing load or thrust reduction in the event of loss of supply capability. In the event of thrust reduction the vessel will slowly drift off station, usually with heading priority, giving the operator time to make a decision and take corrective action. The Power and Thruster Alarms are usually set by the operator at about 80% of MCR. leaving 20% reserves for transient variations.

In modern DP systems, help is however at hand for the operator because all DP systems complying with DPS-2 and DPS-3 Class Notation incorporate a computer system based **"Consequence Analyser"** that monitors the vectorial thrust necessary to maintain position under the prevailing environmental conditions and performs calculations to verify that in the event of a single failure there will be sufficient thrust to maintain position in steady state and during transients. A warning is given to the operator when a failure will cause loss of position in present weather conditions. A typical single failure may be a single thruster, a complete switchboard, one engine room or group of thrusters which is subject to a common failure mode.

More sophisticated Consequence Analysis Programs have a very useful function which allows the operator to check what thrust and power reserves he will have in the event of a worst case failure in worsening weather conditions before they actually occur. The operator manually inputs the expected or anticipated weather trend or changes in thrust and/or turning moment and the system carries out normal consequence analysis. This facility is very useful for operations which require long lead time for them to be terminated safely; thereby allowing the power generation plant to run with smaller spinning reserve margins than would be possible otherwise.

Conclusions

The Class Notation and system reliability requirements of the new generation of the dynamically positioned vessels deployed in ultra-deep water oil exploration and production are such that no single fault may cause total loss of DP capability. They are therefore leading to more complex power generation, propulsion and distrubution arrangements in order to satisfy Class Notation requirements. Although the initial cost of such vessels might be high but their operating costs can be reduced by running the generating plant as a single switchboard with all bus-ties closed provided the protection

philosophy is properly designed, tested and checked regularly as a part of the planned maintenance.

For DP vessels, the Power Management System is an important sub - or co-system and should form an integral part of the DP system so that the power/propulsion/auxiliary plants can be operated optimally but stably under all operating conditions. Extra monitoring and prediction features in the modern DP system will enable the operator to manage the electrical power plant confidently and safely without the excessive and expensive redundancy margins.

REFERENCES

1. JC Cole, "Drilling Rig for deep waters", The Journal of Offshore Technology, Vol 5, No. 2, May 1997, pp 19-21

2. H Rush and P H Craig, "The BP Swops Vessel", Trans I Mare, Paper 22, Vol 98 (April 1986).

3. "Reliability of Electrical Systems on DP Vessels," Report GM - 1611/14-0195-21345, DP Vessel Owners Association, 1995.

APPENDIX A: Various Class Notation Definitions for DP Systems

A.1	**Classification Society**	-	ABS (American Bureau of Shipping)
	Rules	-	Guide for Thrusters and Dynamic Positioning Systems 1994

ABS Class Notations are as follows:

DPS-0: Vessels are to be fitted with a dynamic positioning system with centralized manual position control and automatic heading control to maintain the position and heading under the specified environmental conditions.

DPS-1: Vessels are to be fitted with a dynamic positioning system which is capable of automatically maintaining the position and heading of the vessel under specified maximum environmental conditions having an independent centralized manual position control with automatic heading control.

DPS-2: Vessels are to be fitted with a dynamic positioning system which is capable of automatically maintaining the position and heading of the vessel within the specified operating envelope under specified maximum environmental conditions during and following any single fault **excluding** a loss of compartment or compartments.

DPS-3: Vessels are to be fitted with a dynamic positioning system which is capable of automatically maintaining the position and heading of the vessel within a specified operating envelope under specified maximum environmental conditions during and following any single fault **including**
` complete loss of a compartment due to fire or flood.

A.2 **Classification Society** - LRS (Lloyds Register of Shipping)
Rules - Rules and regulations for the Classification of Ships Part 7, Chapter 4, January 1997 - Rules for Construction and Classification of Dynamic Positioning Systems Installed in Ships.

LRS Class Notations are as follows:

DP(CM) This notation may be assigned when a ship is fitted with centralized remote manual Controls for position keeping with position reference system(s), environmental sensor(s), and specified machinery arrangements.

DP(AM) This notation may be assigned when a ship is fitted with automatic and standby controls for station keeping and with reference position system(s), environmental sensor(s) and specified machinery arrangements.

DP(AA) This notation may be assigned when a ship is fitted with automatic and automatic standby controls for station keeping and with reference position system(s), environmental sensor(s), and specified machinery arrangements.

DP(AAA) This notation may be assigned when a ship is fitted with automatic and automatic standby controls for position keeping together with an additional/emergency control unit located in a separate compartment and with position reference system(s), environmental sensor(s) and specified machinery arrangements.

A.3 **Classification Society** - DNV (Det Norske Veitas)
Rules - Rules for Classification of Ships, Part 6, Chapter 7, January 1990 - Dynamic Positioning Systems

DNV Class Notations are as follows:

DYNPOS T:	A semi-automatic position keeping system without redundancy.
DYNPOS AUTS:	An automatic position keeping system without redundancy.
DYNPOS AUT:	An automatic position keeping system with a remote thrust control back-up and a position reference back-up.
DYNPOS AUTR:	An automatic position keeping system with redundancy in technical design*.
DYNPOS AUTRO:	An automatic position keeping system with redundancy in technical design and physical arrangement**.

* Redundancy in technical design is intended to compensate for single failures in components and systems.

** Redundancy in physical arrangement is intended to compensate for incidents of fire and flooding in addition to the typical technical failure.

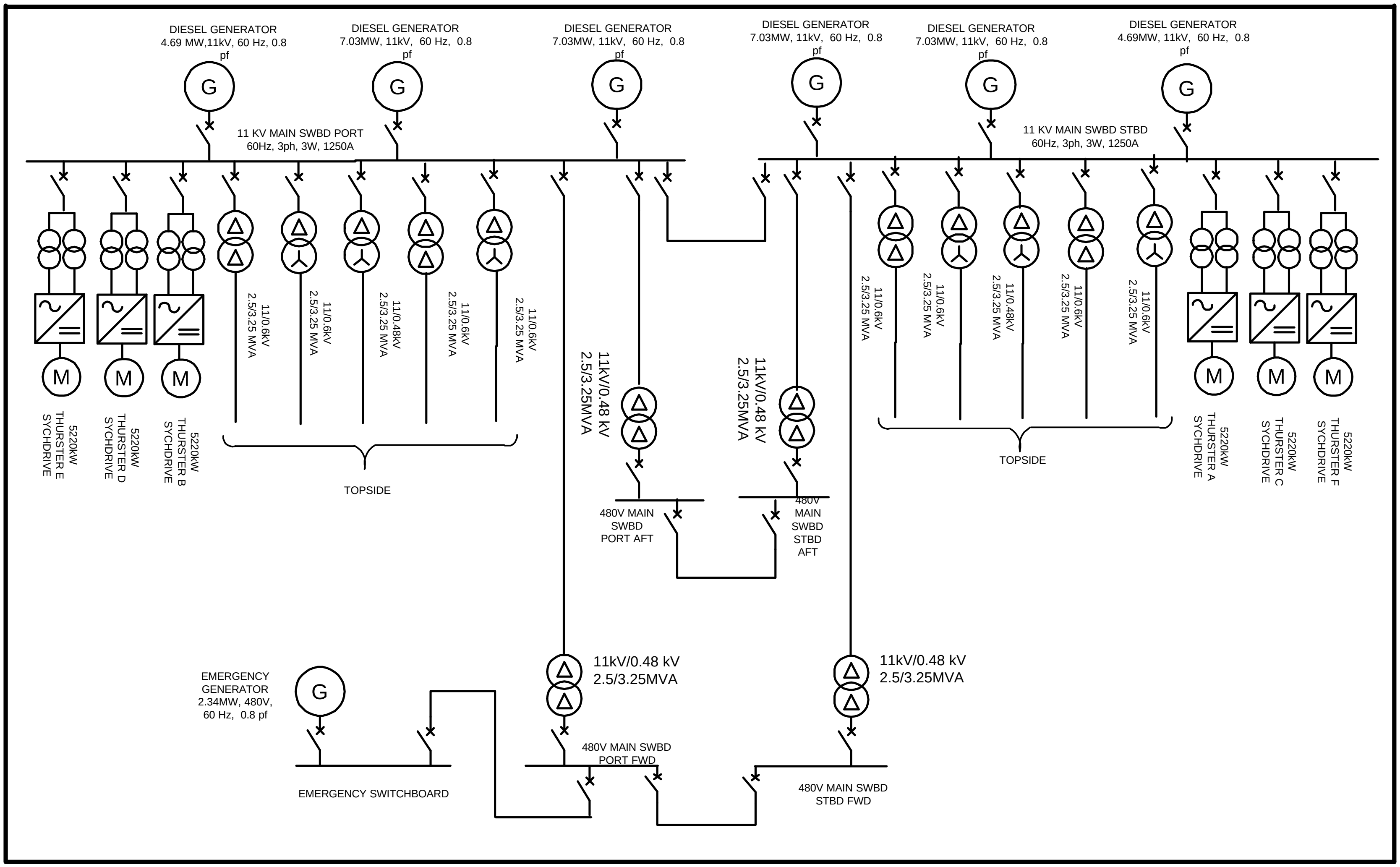

Fig 1. - Typical electrical power plant for a DPS-2 vessel
Transocean ' Discoverer Enterprise' class drill ships