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DYNAMIC POSITIONING CONFERENCE
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NEW APPLICATIONS SESSION

Low Loss Concept Comparison Study

By Brian Cheater,
Peter Lammers
Friede & Goldman, Houston, Texas, USA

Jeroen van Keep
Wärtsilä, Drunen, Netherlands

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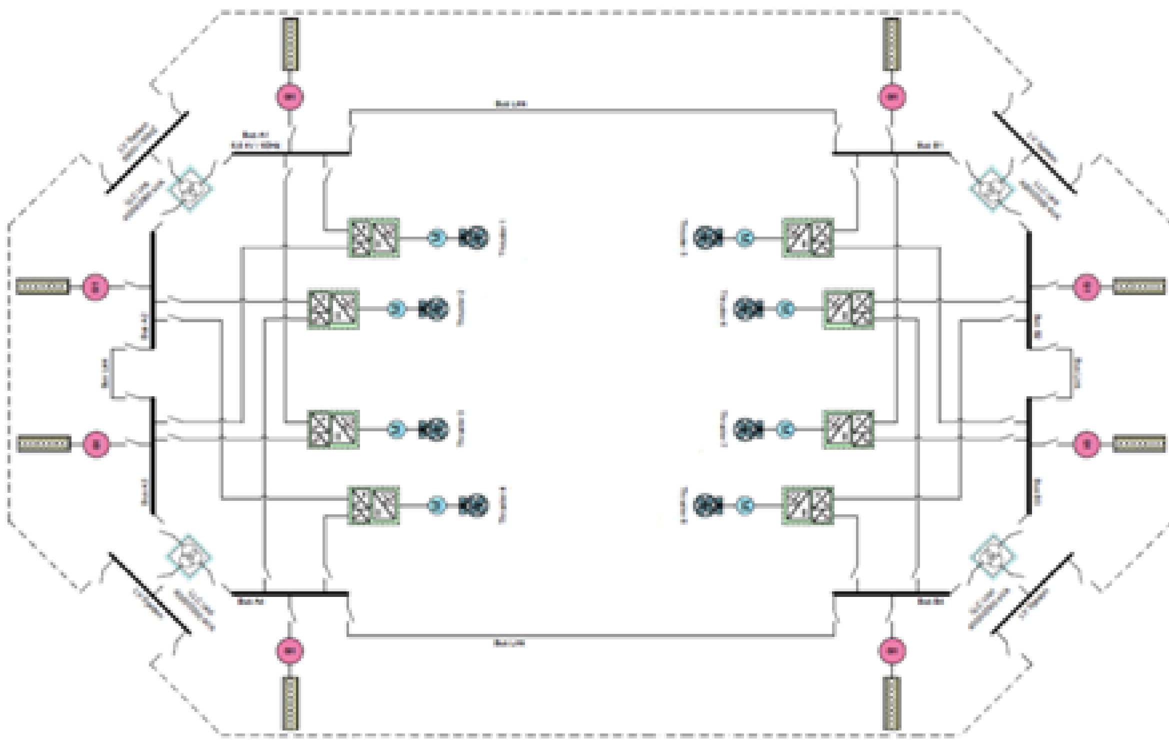
1.0 INTRODUCTION

Friede and Goldman Ltd. has performed a comparison study of the Wärtsilä Low Loss Concept on a Friede & Goldman rig design. The ExD is a dynamically positioned semi-submersible drilling rig suitable for operations in moderate environments such as the Gulf of Mexico, Brazil, West Africa and South China Sea.

The Wartsila Low Loss Concept is a concept based on a symmetrical design for the power generation, power distribution and thruster supply. A general sketch of the concept is given below.



This system was adapted to the ExD design so that now the power system consists of 4 main switchboards, each with 2 main generators connected to one half of the switchboard. The four switchboards are connected through 4 LLC transformers, thus making a power ring, with different phases between the switchboard sections. Under normal operating modes the system is operated with all bus tiebreakers closed, which allows an optimal use of generators, diesel engines and thrusters.

Advantages of the LLC concept include the following.

- Increased thuster robustness by higher availability at the occurrence of a major failure.
- Improved dynamic positioning capability as a major failure does not result in a complete loss of thrust.
- Segregated switchboard into two sections, bus connections through buslinks increases operational flexibility and availability
- Fuel savings and reduction of environmental pollution by reduction in losses in the electric system by 15 to 20%
- Personnel safety significantly increased due to reduction of short circuit level.
- No inrush current at thruster start-up, since the transformers are always energized.
- Weight reduction; as the usual thruster transformers will not be required, the LLC phase shift transformers are equipped with a secondary winding used to supply some of the vessel's power requirements.
- The Low Loss Concept allows an elimination of the thruster transformers on the rig, gives a more efficient distribution of power during damage scenarios and reduces the losses in transformers.

To study the impact, a comparison was drawn between a baseline DP 3 ExD and one fitted with the Low Loss Concept.

General Arrangement Drawings and single line diagrams for the baseline Generic ExD and the LLC ExD are given in Appendix A and Appendix B respectively.

2.0 UNITS AND COORDINATE SYSTEMS

2.1 Units

SI units are used through-out.

2.2 Coordinate System

A right-handed Cartesian coordinate system is used. X is positive forward of the well center. Y is positive port of the well center. Z is positive up from the baseline.

Environmental headings are measured relative to the bow; 0 degrees represents wind, wave, and current flowing from stern to bow, 90 degrees starboard to port, etc.

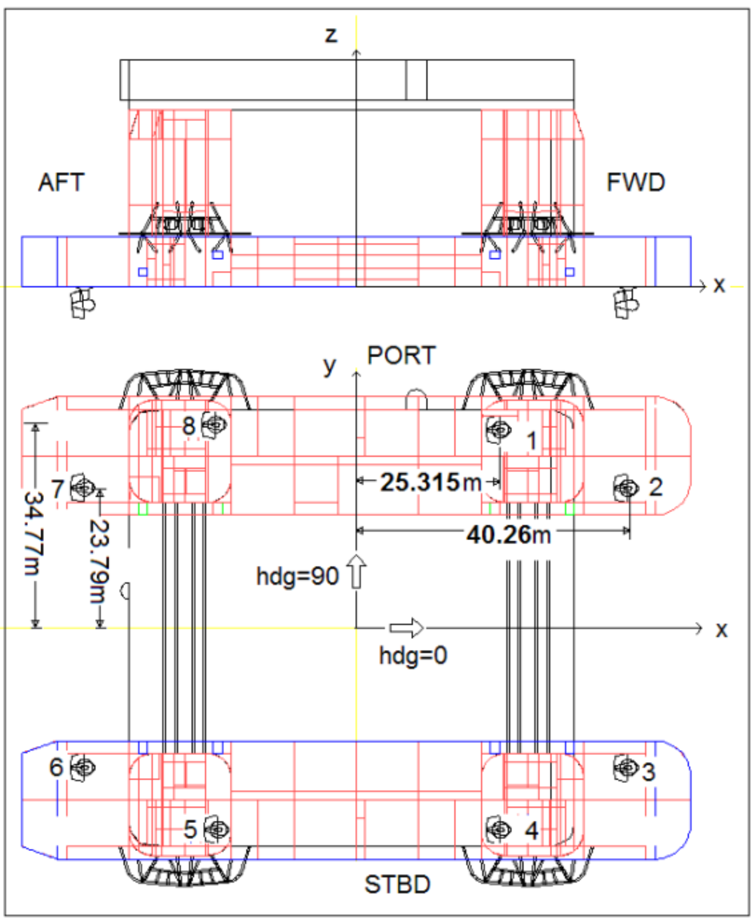


Figure 2.1: Coordinate System and Sign Conventions

3.0 ANALYSIS METHODOLOGY & ASSUMPTIONS

3.1 General

The purpose of the DP system is to maintain the position of the rig within an acceptable watch circle under the operating environment.

This imposes limitations on the allowable horizontal excursions. These limitations are normally expressed as maximum allowable riser joint angles. Due to geometry, the radius of the watch circle is proportional to the water depth. At shallower water depths the watch circle radius is relatively small and the DP system must respond hard to maintain position and performance of the vessel is limited by available power and performance. In deeper water, the watch circle is bigger and the performance of the vessel is usually governed by sea keeping issues such as riser slip-joint travel in response to heave motions.

The DP system is designed to counter the mean environmental loads and dampen out low frequency surge and sway motions. Wave frequency (sea keeping) motions cannot be controlled using a DP system.

The analysis procedure is as follows:

1) establish an operating environment and a vessel heading
2) calculate the global surge, sway and yaw loads due to wind, waves and currents.
3) Determine the required output of each individual thruster based on an appropriate thruster allocation algorithm
4) Determine the available thrust for each thruster
5) Calculate the total available thrust and compare to global environmental load. Global environmental load must be less than or equal to 80 % of available thrust for the intact condition and less then 100 % for the damage condition.
6) Repeat for different headings or operating environments

3.2 Metocean Criteria

The environment will be based on the Campos Basin offshore Brazil which is a typical design environment for a moderate environment rig.

The wind speed will be taken as 41 knots.

The current speed will be taken as 2.33 knots.

The significant wave height will be taken as 6 m with a peak spectral period of 9 seconds.

The environmental forces are assumed to be collinear and omni-directional.

3.3 Power Available from Baseline ExD

The rig is equipped with eight 4600 kW main diesel generators. It is also fitted with a 1680 kW emergency diesel generator. However, the emergency generator is not used for DP and will be ignored.

A copy of the single line diagram is included in appendix A. The main engines are located in four separate engine rooms and tie into four separate 11 kV main switchboards. The 11 kV switchboards are connected through tie breakers and switchboard no. 4 ties back to switchboard no. 1 to form a closed loop power ring main. Each main 11 kV switchboard is connected to two main generators and supplies power to two thrusters which are located on opposites diagonals in the lower hull.

Under normal operation, a peak total power of 36800 kW is available. Combined power loss from the generator, through the distribution system, converters, motor and gear boxes is typically in the region of 6-8 %. It will be taken as 7 %.

It is assumed that a hotel load of 1000 kW is always connected to the switchboards.

The drilling load is taken as 6000 kW maximum. In a damaged condition, it is assumed that drilling will be reduced or suspended; however there might still be substantial electrical demands for shut-down and securing or other un-anticipated events. For sizing purposes, the expected load will be taken as the draw-works load on the port switchboard. This is 3690 HP or 2750 kW which is rounded up to 3000 kW to also allow for operation of emergency equipment (eg fire pumps)

3.4 FMEA for Baseline ExD

The main damage scenarios are:

1) A fire in an engineroom which would result in loss of two main generators but power could be redistributed from the remaining generators along the main ring and all thrusters could remain in operation
2) A loss of one 11 kV main switchboard. This would result in the loss of two generators and two thrusters.

The full results of the high-level FMEA are shown below.

No.	ITEM	FAILURE	EFFECT
1	Main Engines	Fire in E/R	Loss of 2 Engines (25 % power loss) 100 % power on thrusters, drilling phase back
		Engine Failure/Damage	Loss of 1 engine (12.5 % power loss) 100 % power on thrusters, drilling phase back
		Lose of Ventilation	Loss of 2 Engines (25 % power loss)
		Loss of Auxiliary (Cooling, Fuel)	All components 2 x 100 % so no loss
2	Main 11 kV SWBD	Fire in one of the four SWBD Rooms	loss of 2 gensets and 2 thrusters simultaneously 25 % power loss
		Short Circuit on SWBD	loss of 2 gensets and 2 thrusters simultaneously 25 % power loss
3	Thruster Transformer/VFD	Burnout/Short	Loss of Transformer => loss of 1 thruster
		Flood/Fire in Compartment	Loss of Transformer => loss of 1 thruster
4	Thruster Motor	Burnout	Loss of 1 thruster
		Flood/Fire in Compartment	Loss of Transformer => loss of 1 thruster
5	480 V Switchboard	Burnout of SWBD	Loss of Auxiliaries to two gensets. Loss of 25 % power But drilling phase back so 100 % power on thrusters possible
			Loss of Ventilation. Reduced power on thruster
6	2000 kVA transformer	Burnout of XFER	Loss of Power to 480 V SWBD. But, can bus-link to others

Table 3.4.1: FMEA results for Generic ExD

Scenario 2 (loss of one of the main 11 kV switchboards) governs. For the purposes of this analysis, it is assumed that 2 generators and 2 thrusters are out of service. The power supply to thrusters 4 and 8 is considered damaged, these thrusters will not operate.

3.5 Power Available from LLC ExD

The rig is equipped with eight 4300 kW main diesel generators. It is also fitted with a 1680 kW emergency diesel generator. However, the emergency generator is not used for DP and will be ignored.

A copy of the single line diagram is included in appendix B. The main engines are located in four separate engine rooms and tie into four separate 6.6 kV main switchboards. Each 6.6 kV switchboard is divided in two bus sections, which are connected through a phase shifting transformer. The secondary side of this 2,000 kVA transformer will also supply 600 Volt to the users on the vessel (electric motors, ventilation, lighting, etc.) The switchboards are paired with one side of the 6.6 kV switchboard in the next main electrical room, where another phase shifting transformer sits across the two halves of the board. This sequence is repeated to the last switchboard room and one half of the last switchboard is then paired with the first part of the first switchboard, generating a power supply ring, with phase differences between board halves.
The thruster rectifiers are each directly connected to a half of one switchboard and an out of phase half of another switchboard, thus eliminating the 6000 kVA thruster transformers used in the conventional design. No additional transformers are required for the low (600) Voltage side any more, as the four phase shifting transformers supply the need for this power.
The same theory also applies to the drilling power, this is derived from two phase shifted switchboard halves in adjacent switchboard rooms. Due to the fact that the drilling motors required a lower voltage, 6.6 kV to 600 Volt transformers will be required. Since these transformers are fed from switchboards with different phases, the transformers can be of the Δ/Δ type.

Under normal operation, a peak total of 34400 kW is available. Combined power loss from the generator, through the distribution system, converters, motor and gear boxes will be taken as 5.5%. This reflects the reduced transformer losess in LLC.

It is assumed that a hotel load of 1000 kW is always connected to the switchboards.

The drilling load is taken as 6000 kW maximum. In a damaged condition, it is assumed that drilling is suspended; however there might still be substantial electrical demands for shut-down and securing or other un-anticipated events. For sizing purposes, the expected load will be taken as the draw-works load on the port switchboard. This is 3690 HP or 2750 kW which is rounded up to 3000 kW to also allow for operation of emergency equipment (eg fire pumps)

3.6 FMEA for LLC ExD

The main damage scenarios are:

1) A fire in an engineroom which would result in loss of two main generators but power could be redistributed from the remaining generators along the main ring and all thrusters could remain in operation
2) A loss of one 6.6 kV main switchboard room. This would result in the isolation of two generators and their feed to four thrusters. Four thrusters would loose 40% of their power.
3) A loss of 600V distribution to the thruster auxiliaries (eg. cooling water, hydraulic steering, lube oil). This would result in the loss of one thruster.

The full results of the high-level FMEA are shown below.

No.	ITEM	FAILURE	EFFECT
1	Main Engines	Fire in E/R	Loss of 2 Engines (25 % power loss) 100 % power on thrusters, drilling phase back
		Engine Failure/Damage	Loss of 1 engine (12.5 % power loss) 100 % power on thrusters
		Lose of Ventilation	Loss of 2 Engines (25 % power loss) 100 % power on thrusters, drilling phase back
		Loss of Auxiliary (Cooling, Fuel)	All components 2 x 100 % so no loss
2	Main 6.6 kV SWBD	Fire in one of the four SWBD Rooms	All thrusters will be in operation, Four reduced by 40% of power capacity.
		Short Circuit on SWBD	All thrusters will be in operation, Four reduced by 40% of power capacity.
		Loss of 2000 kVA LLC transformer	loss of power to 600V board but this can be bus-linked to another board. 100 % power on thrusters
3	PWM Thruster Drive	Burnout/Short	Loss of 1 thruster
		Flood/Fire in Compartment	Loss of 1 thruster
		Loss of Water Cooling	Loss of 1 thruster
		Loss of Ventilation	Reduction in Power then controlled shutdown
4	Thruster Motor	Burnout	Loss of 1 thruster
		Flood/Fire in Compartment	Loss of 1 thruster
		Loss of Ventilation	Reduction in Power then controlled shutdown
5	600 V Switchboard	Burnout of SWBD	Loss of 2 Engines (25 % power loss) Loss of one thruster by auxiliaries, drilling phase back
6	2000 kVA transformer	Burnout of XFER	Loss of Power to 600 V SWBD. But, can bus link to others

Table 3.6.1: FMEA results for LLC ExD

Scenario 2 (loss of one of the main 6.6 kV switchboards) governs. For the purposes of this analysis, it is assumed that 2 generators are out of service and that the power supply to thrusters 1, 4, 6 and 7 are reduced to a maximum 60% of full power. At 60% of full power 70% of full thrust will be available because of improved efficiency at part load.

3.7 Thruster Performance

For the baseline, eight (8) Wärtislä type FS3500/NU azimuthing thrusters were assumed for DP propulsion. These thrusters have a propeller of 3600 mm in diameter with a Wärtsilä HR nozzle. Open water thruster performance curves were provided by Wartsila and are included in Figure 3.7.1

POWER (kW)	THRUST (te)
3700	64.6
3500	62.3
3000	55.9
2500	49.6
2000	42.7
1500	35.3
1000	26.9
500	17.2
250	10.8
125	7.1
0	0

Table 3.7.1 Delivered Power vs Thrust for LIPS 3600mm

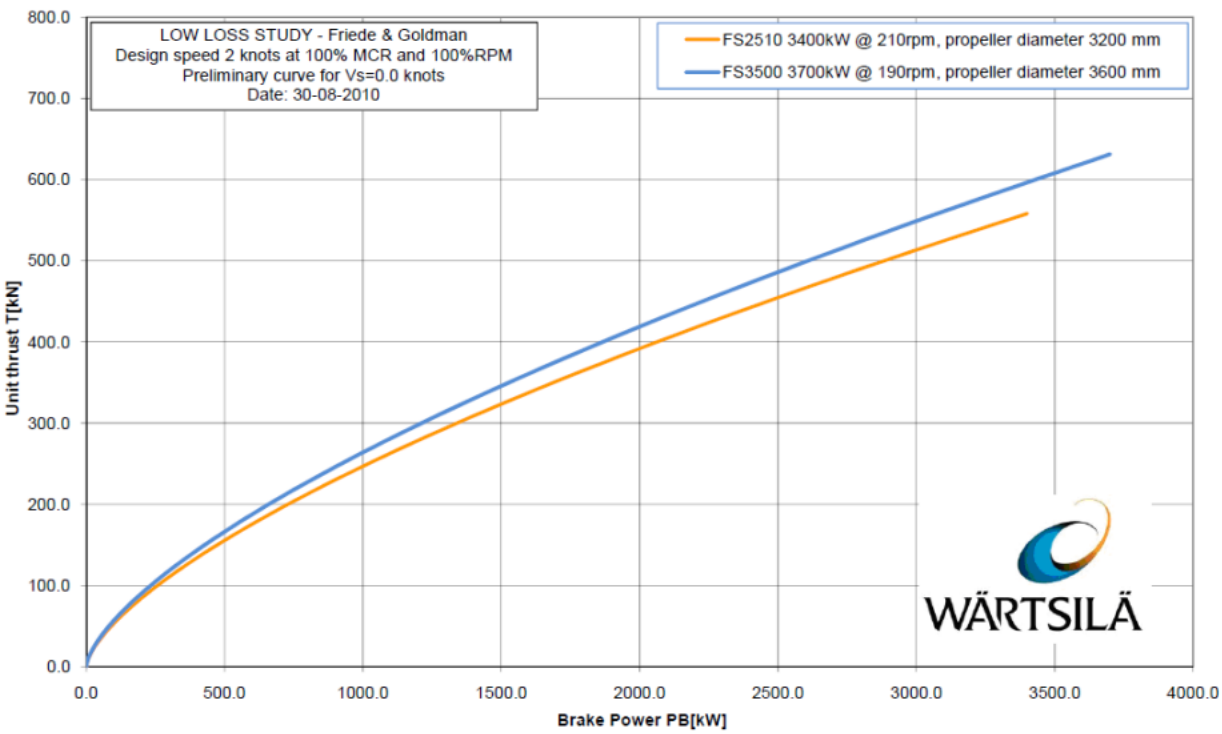


Figure 3.7.1: Plot of Delivered Power vs Thrust and Regression Curve for 3600mm

These open water efficiencies are reduced due to forward speed (current) effects, thruster-thruster interactions and thruster-hull interactions.

In its most elementary formulation, a propeller works by imparting momentum to an incoming flow of water. This momentum transfer is most effective when the incoming flow velocity is zero. At forward speed or in the presence of a current, there is a reduction in efficiency as shown in Table 3.7.2 below.

SPEED (knots)	Thrust Ratio
0	1
1	0.942
2	0.889
3	0.83
4	0.773

Table 3.7.2: Fwd Speed Effect on Thruster

Thruster-thruster interactions occur when the wake from one thruster impinges on the wake from another thruster. Thruster-hull interactions arise from the Coanda effect and impingement of thruster wakes on the other pontoon. Both of these effects are included in the thruster efficiency curves which range from 0.67 to 0.97.

3.8 Thruster Allocation Algorithms

The thruster allocation algorithms were defined using Lagrange multipliers to minimize a cost function. The objective of the optimization problem is to hold station while minimizing power.

Power is minimized subject to the constraints that the rig maintain static equilibrium as defined by the following equations:

$$\sum_{i=1}^{8} T_{xi} = X_{REQ}$$

$$\sum_{i=1}^{8} T_{yi} = Y_{REQ}$$

$$\sum_{i=1}^{8} (d_{xi} T_{yi} - d_{yi} T_{xi}) = M_{REQ}$$

Where

X_{REQ}, Y_{REQ} and M_{REQ} are the total environmental loads in the x,y and yaw senses.

Txi and Tyi are the x,y components of the thrust vector from thruster i

dxi, dyi are the x,y coordinated of thruster i from the center.

The coordinate system and thruster numbers are as per Figure 2.1

This leads to the following cost function in which the three LaGrange multipliers are applied to the constraint equations:

$$COST = \sum_{i=1}^{8} T_{xi}^2 + \sum_{i=1}^{8} T_{yi}^2 + \lambda_1\left(\sum_{i=1}^{8} T_{xi} - X_{REQ}\right) + \lambda_2\left(\sum_{i=1}^{8} T_{yi} - Y_{REQ}\right) + \lambda_3\left(\sum_{i-1}^{8}\left(d_{xi}T_{xi} - d_{yi}T_{xi}\right)\right)$$

This cost is minimized by taking the partial derivative of the cost function with respect to each variable. Noting that the minima will occur when the first derivative is zero, we get a set of independent linear equations which can be solved by matrix inversion to yield expressions for the thruster components.

For the intact condition, the following equations were derived:

$$T_{x1} = 0.125 X_{REQ} - 0.0014312 M_{REQ}$$
$$T_{x2} = 0.125 X_{REQ} - 0.0009739 M_{REQ}$$

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.

$$T_{y8} = 0.125 Y_{REQ} - 0.0019083 M_{REQ}$$

A similar procedure is followed for the damaged condition. The only difference being, that the damaged thrusters are removed from the set of equations.

These coefficients define how much thrust/power is demanded from each thruster by the DP system in order to resist the mean environmental load. It does not account for wave dynamics or position correction demands. These will depend on the set-up of the system and the actual algorithms used in the DP software which cannot be known early in the design phase. The 20% margin is intended to cover these uncertainties.

The Power Management System (PMS) system will allocate power to the thrusters based on the demands of the DP control system. The power allocation is simply assumed to follow the same distribution as thruster demand.

4.0 RESULTS

4.1 Generic ExD Stationkeeping Results

The size of the thrusters for the Generic Exd is governed by the damaged condition. With two thrusters damaged, the demand is shed to the remaining 6 thruster which become highly saturated. Saturation occurs when the thruster is at 100 % and cannot supply anymore thrust. With the thrusters at saturation some drift will occur until the imbalance is corrected. To compensate, the thruster sizes are increased.

The thrusters had to be 3900 kW in order to pass damage.

Thruster utilizations are presented in figure 4.1.1 and 4.1.2 for intact and damage conditions

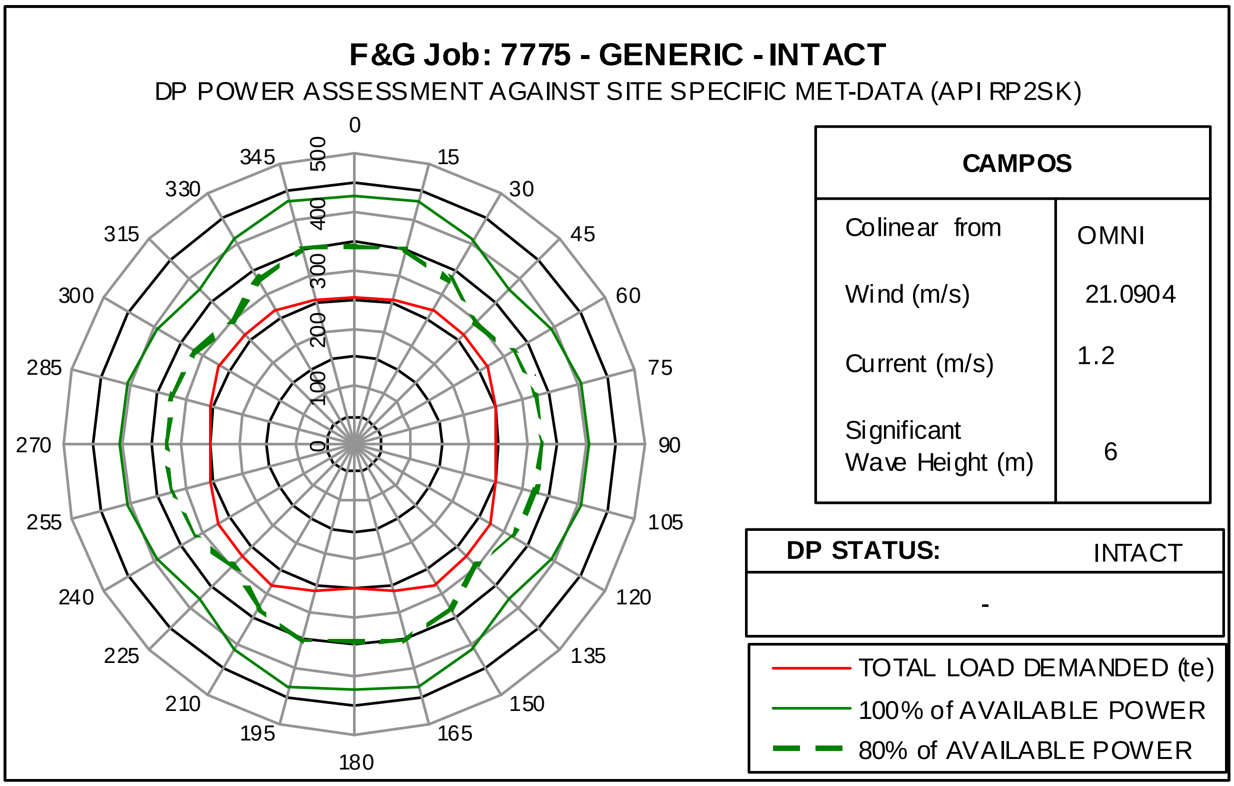


Figure 4.1.1: Thruster Utilization (as a % max available thrust) for Generic ExD - Intact

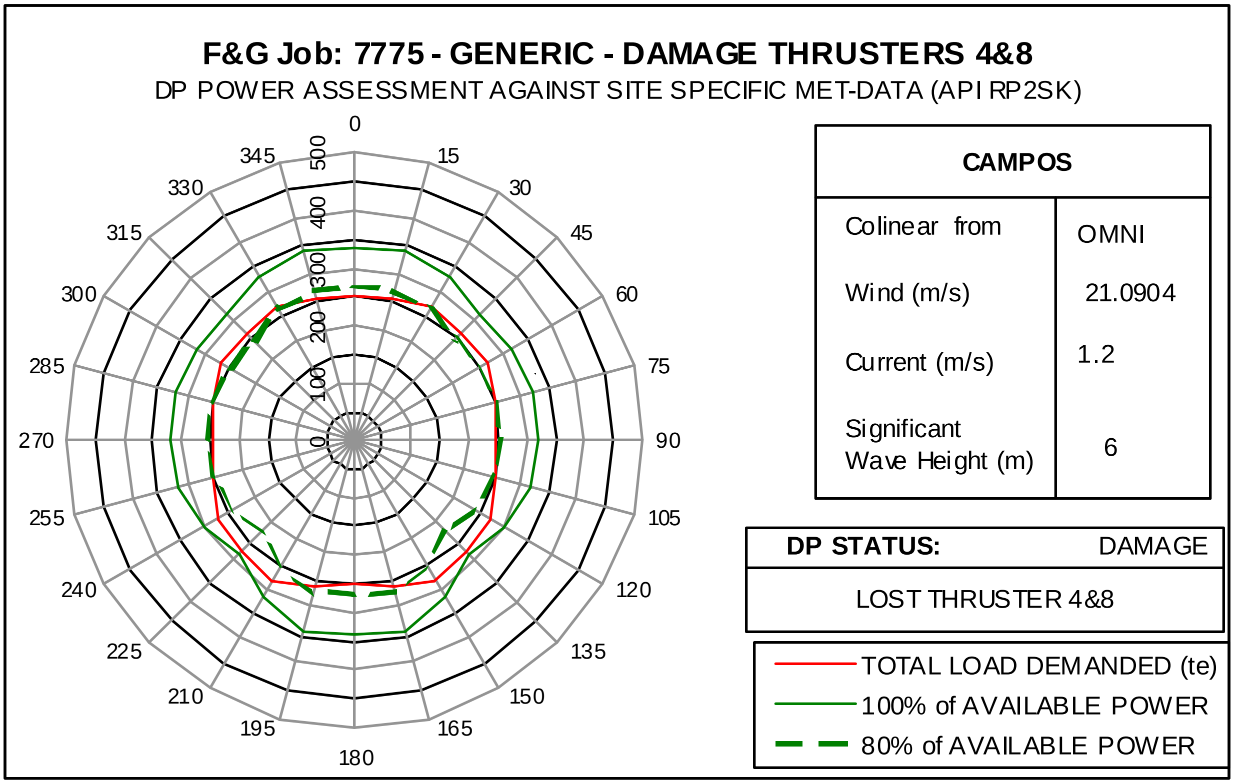


Figure 4.1.2: Thruster Utilization (as a % max available thrust) for Generic ExD - Damaged

4.2 LLC ExD Stationkeeping Results

The LLC concept provides greater redundancy in distribution of the loads. In the worst case scenario, a switchboard room maybe damaged thus isolating two generator sets but the thrusters are all connected to two switchboards and can be partially supplied by another. This means that all thrusters can remain online. This reduces the amount of thruster saturation and allows a reduction in the size of the thrusters and the gensets. The LLC rig is governed by the intact condition not the damaged condition.

The LLC gensets had to be 4300kW and the thrusters had to be 3375 kW in order to pass intact.

Thruster utilizations are presented in figure 4.2.1 and 4.2.1 for intact and damage conditions

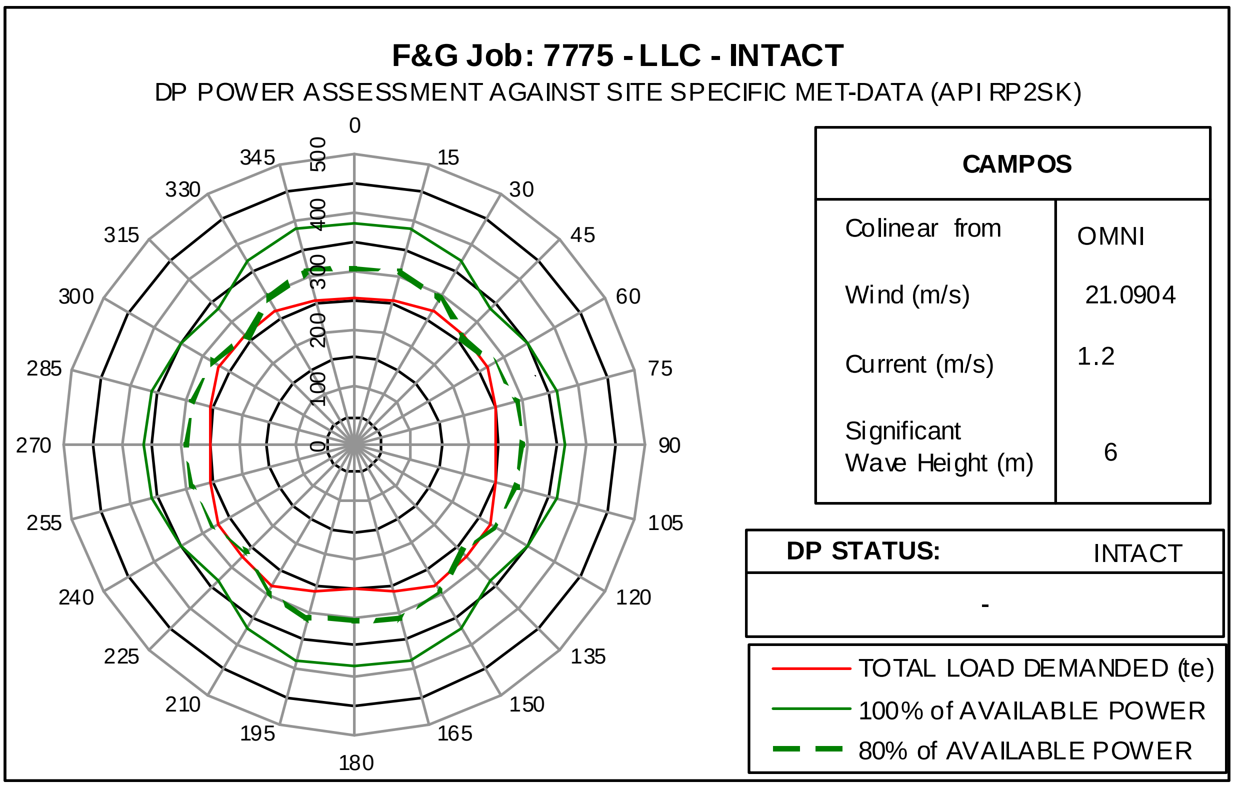


Figure 4.2.1: Thruster Utilization (as a % max available thrust) for LLC ExD - Intact

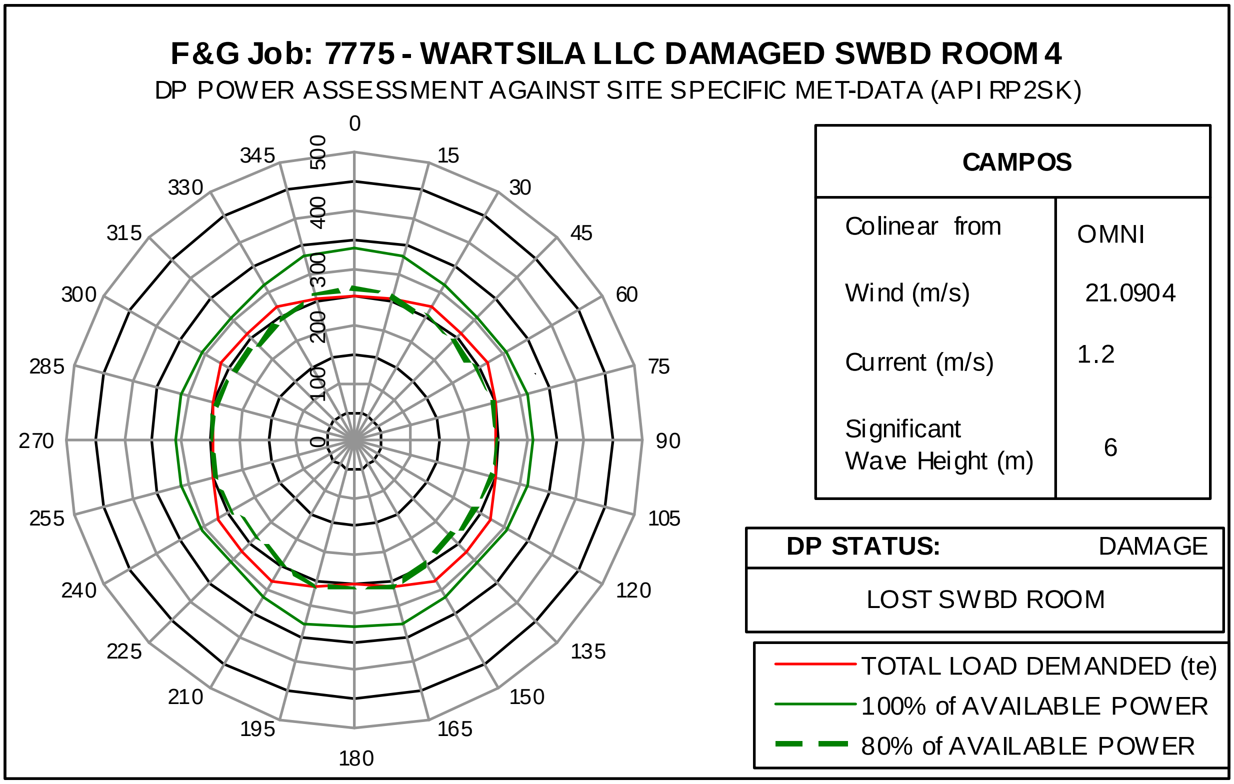


Figure 4.2.2: Thruster Utilization (as a % max available thrust) for LLC ExD - Damaged

5.0 CONCLUSIONS

5.1 Stationkeeping Benefits

The LLC concept provides greater redundancy in distribution of the loads in case of damaged conditions. All thrusters are kept operational so thruster saturation is reduced.

This allows the size of the thruster to drop from 3900 kW to 3375 kW and main generator to drop from 4600kW to 4300kW compared to the generic.

5.1 Weight and VDL Benefits

The primary weight benefit is the removal of the thruster transformers and reduction in the size of the gensets. Also the smaller thrusters reduce the weight by 8x15=120tonnes.

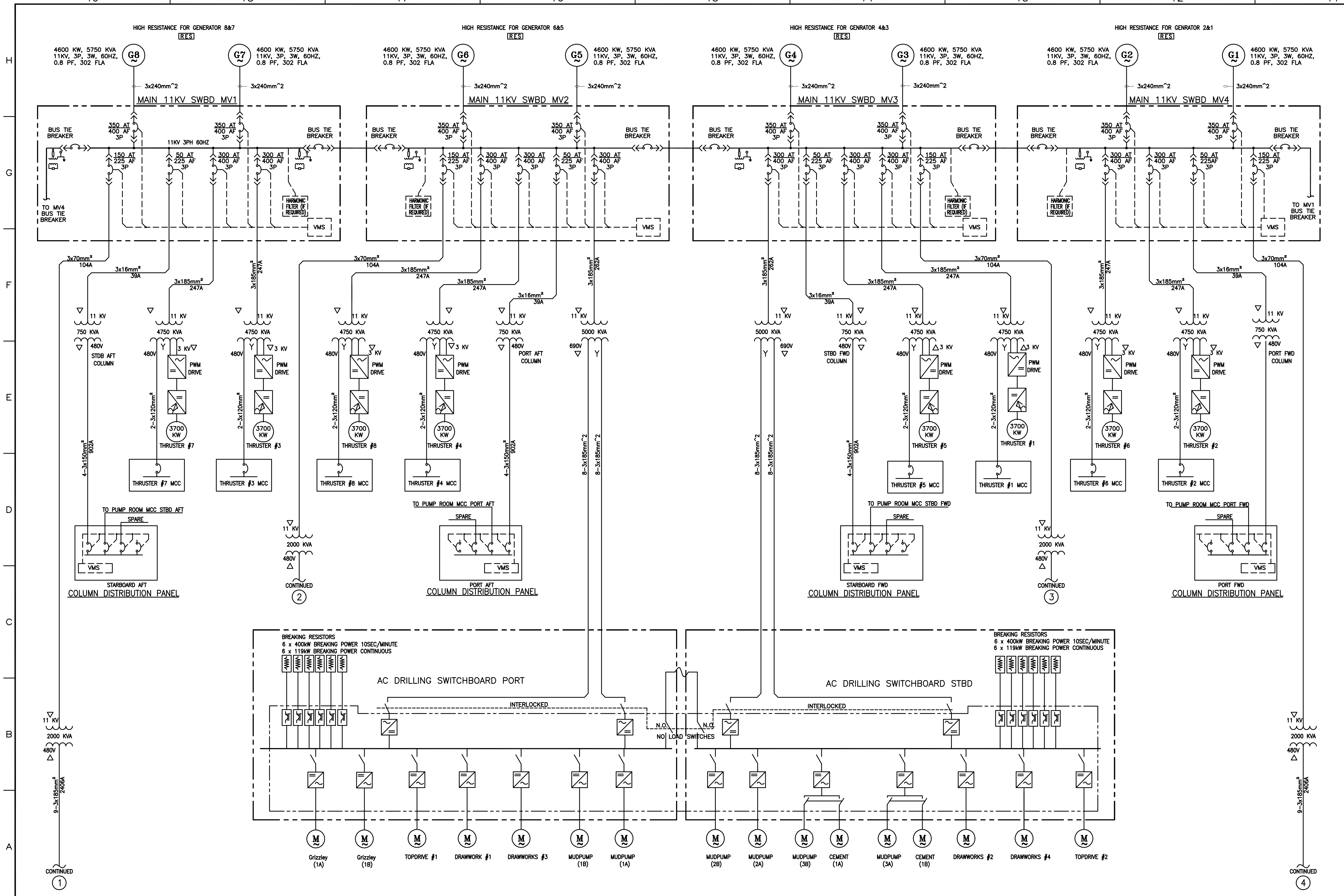
This frees up approximately 517 tonnes which can increase variable deck by 5-7%.

6.0 REFERENCES

1) International Maritime Organization (IMO), *Code for the Construction and Equipment of Mobile Offshore Drilling Units (Consolidated Edition 2001)*

2) American Petroleum Institute (API), *Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures,* RP 2SK, 1 March 1997

APPENDIX A
GENERAL ARRANGEMENT AND SINGLE LINE DIAGRAM FOR GENERIC EXD



REVISIONS

NO.	DESCRIPTION	BY	DATE
A	GENERIC CONCEPT STUDY	JB	04/07/10
B	1. GEN SET RENUMBERED.	JB	09/01/10
	2. THRS KW, T'FMRS SIZES & ASSOCIATED. CBLS & CBs UPDATED (PREV. VALUE 3300KW & 3700KVA)	JB	09/24/10

GENERAL NOTES

1. ALL ELECTRICAL INSTALATION SHALL BE IN ACCORDANCE WITH THE LATEST MODU CODE & IEC STANDARD.
2. MOTOR RATINGS INDICATED IN KW.
3. EQUIPMENT RATINGS IS SUBJECT TO VENDOR CONFIRMATION.
4. TRANSFORMER SIZING IS SUBJECT FINALIZATION OF THE EQUIPMENT VENDORS.
5. ALL ELECTRICAL CABLES SHALL HAVE AN INSULATION MATERIALS SUITABLE FOR CONDUCTOR TEMPERATURE OF AT LEAST 95°C AND SHALL BE OF FLAME-RETARDANT TYPE, AS PER IEC-332-3A.
6. MOTOR CONTROLLERS SHALL BE PROVIDED WITH MOTOR RUNNING LIGHTS, DOOR MOUNTED OVERLOAD RESET BUTTON AND MOTOR SPACE HEATER ON/OFF SWITCH WITH INDICATING LIGHT (IF MOTOR FITTED WITH SPACE HEATER)
7. MOTOR FEEDERS WITH STARTER SIZE 3 AND ABOVE SHALL HAVE PROVISION WITH SPACE HEATER POWER SUPPLY.
8. ALL MOTOR STARTERS SHALL BE EQUIPPED WITH LOCAL START/STOP PUSH BUTTONS MOUNTED ON MCC PANELS.
9. EACH PANEL/MCC SWITCHBOARD IS TO BE EQUIPPED WITH GROUND FAULT DETECTION AND INDICATION.
10. THE CONTROL CABLE CONFIGURATION DOES NOT INCLUDE CABLING TO THE RIG MANAGEMENT SYSTEM, EMERGENCY SHUTDOWN SYSTEM, POWER MANANGEMENT SYSTEM, ETC.
11. VENTILATION MOTORS SIZING AND NUMBERS IS SUBJECT TO FINAL DESIGN.
12. HAZARDOUS AREAS ARE TO BE FITTED WITH EQUIPMENT APPROVED FOR USE IN THE HAZARDOUS AREA.
13. CABLES FOR THRUSTERS MOTORS, MUD PUMPS, TOP DRIVES & DRAWWORKS SHOULD HAVE SYMMETRICAL DISTRIBUTED GROUND CONDUCTORS.
14. THE MV SYSTEM IS HIGH RESISTANCE GROUND SYSTEM.

NO.	DWG. NO.	TITLE

REFERENCE DRAWINGS

PATENT 6,378,450

FRIEDE & GOLDMAN, LTD.™
NAVAL ARCHITECTS AND MARINE ENGINEERS
HOUSTON, TEXAS

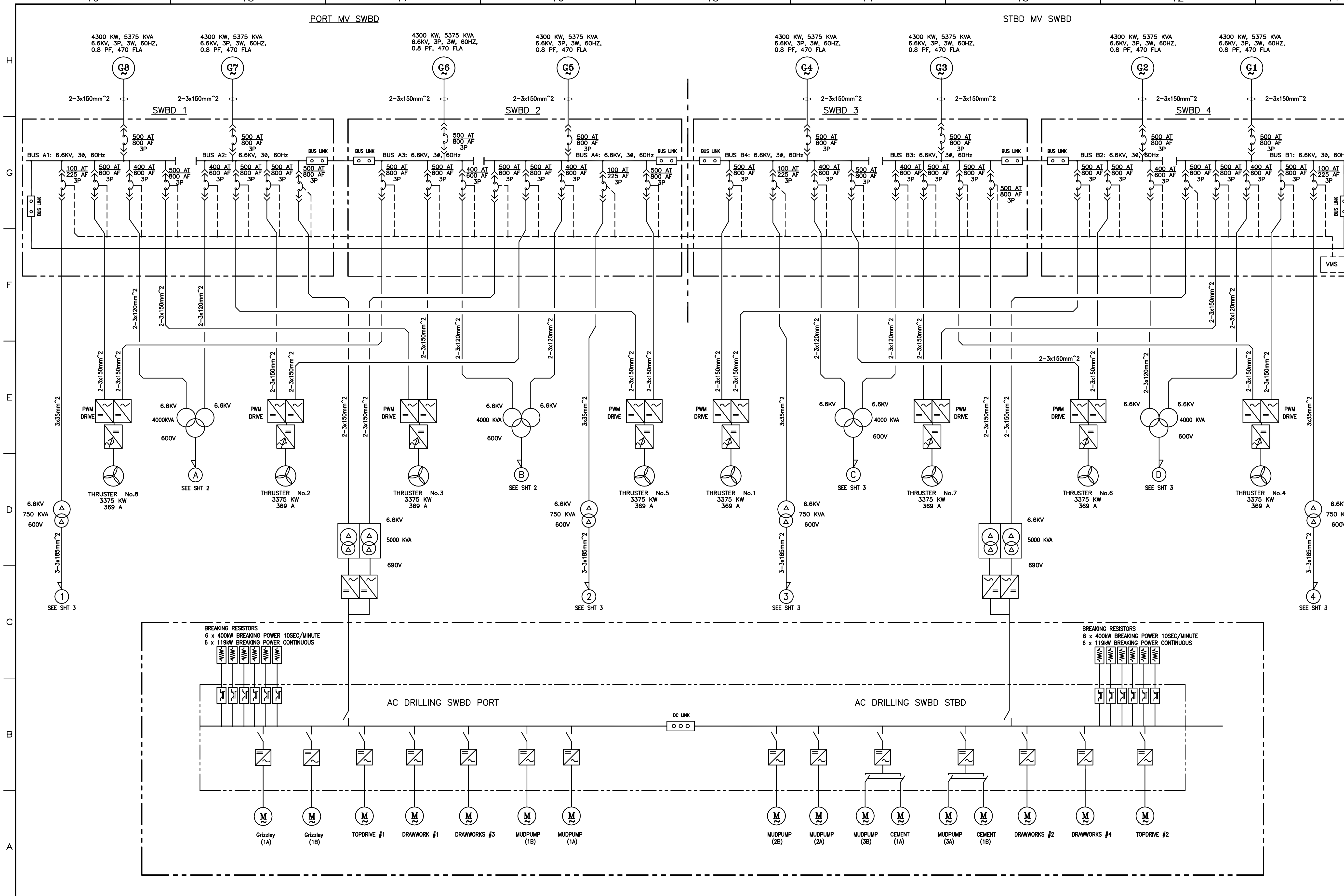
"F&G EX-D"
SEMI SUBMERSIBLE DRILLING UNIT (DPS-3)
FOR WARTSILA
(GENERIC)

ONE LINE DIAGRAM
OF
POWER SYSTEM

DRAWN BY JB	DATE : 30 MAR 2010	SHEET SIZE : 1295 x 762
CHECKED BY PL	SCALE : NTS	TASK NO. : 301
APPROVED BY RC	SCALE FACTOR : N/A	FILE NAME : 7775AS-301-01-0B

DWG. NO. 7775A-S-301-1 | SH 1 OF 3 | REV. B

APPENDIX B
GENERAL ARRANGEMENT AND SINGLE LINE DIAGRAM FOR LLC EXD



REVISIONS

NO.	DESCRIPTION	BY	DATE
A	LLC CONCEPT STUDY	JB	04/07/10
B	MODIFIED PER LATEST COMMENTS.	JB	04/21/10
C	THRUSTERS RENUMBER PER LATEST FMEA.	JB	06/17/10
D	1.CORRECTED THRUSTERS NUMBERING PER P.L. 2.GEN SET KW RESET TO 4300KW; CBL & CBs CHG. 3.MOD. THRS KW; SVC T'FMRS & ASSO. CBL & CBs.	JB JB	09/01/10 09/21/10

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HOUSTON, TEXAS

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