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Design & Control

Power Management Control of Electrical Propulsion Systems

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1. Summary

Abstract -- DP 2007 conference.

The paper will focus on the importance of having an efficient and reliable Power Management System (PMS) in a DP operated vessel.
Many of the larger DP operated vessels have electrical drive systems with frequency converters controlling the propellers or thrusters.
It is important to understand the use of frequency converter systems in a total PMS strategy.
The converter will be an integrated part of an efficient PMS during power ramping and survival during fault scenarios.
Important issues will be ride through capabilities during serious electrical network faults and torque control of the propeller.
The relations between a DP system and a reliable Electrical Propulsion (EP) system are essential in critical operational conditions.
Redundancy philosophies and PMS control will be discussed in the paper.

2. Abbreviations and definitions

DDG	Diesel Driven Generator
IAS	Integrated Automation System
I/O	Inputs and Outputs
OS	Operator Station
PLC	Programmable Logic Controller
PMS	Power Management System
UPS	Uninterrupted Power Supply
FPSO	Floating Production Storage Offloading unit
DP	Dynamic Positioning
DC	Direct Current
AC	Alternating Current
IEC	International Electrotechnical Commission
EMS	Energy Management System
THDv	Total Harmonic Distortion voltage
VMS	Vessel Management System
MDO	Marine Diesel Oil
CBM	Condition Based Maintenance

3. Electrical propulsion system

3.1 General description

Many of the new DP operated offshore supply vessels are equipped with diesel electric propulsion.

Larger DP operated offshore oil & gas production vessels and semi-submersible units will normally be designed with an electrical propulsion system. For conversion project the existing system may also be used.
In normal production the electrical power system will supply all electrical consumers in the vessel.
The trend today is driven by environmental tax regimes and regulations where emissions to air are important. Production vessels use different fuels as natural gas or marine diesel oil.
For medium size installations piston engines will normally be used. For large installations turbines are normally used in combination with piston engines or combined power and heating.

For electrical propulsion system the engines will run a generator producing all necessary electrical energy onboard.
With introducing new fuels or dual fuel concepts the requirements for controlling and monitoring the dynamic performance will also be different.

The electrical power system will be distributed throughout the total installation to the end user via transformers, switchboards and converters.
The total power system will be monitored and controlled with one or several control systems depending how integrated these systems are. Power Management Systems (PMS) can be a separate system or integrated in a total Vessel Automation system. Other functionality as Energy Management, Environmental Management may be integrated in the PMS system.

3.2 Power generation system

The total installed power onboard this type of vessels will depend on the purpose they are serving, but are normally between 6 and 10 MW except for larger construction and anchor handling vessels which can be above 20MW.
Typically in these vessels the power requirement in transit at economic speed is in the order 3500 – 4000 kW. When the ship is unloading / loading at the offshore platforms she is operating on dynamic positioning, DP, with a total power demands in the order 600 – 1500 kW in calm weather increasing to 3000 – 5000 kW in rough weather. In transit at full speed the total power demand is approx. 7500 kW.

Figure 3.1 shows a single line diagram for a typical offshore vessel. The electrical solutions require an extensive use of power electronics and a modern Power Management System (PMS). The PMS must manage a highly dynamic electrical network.

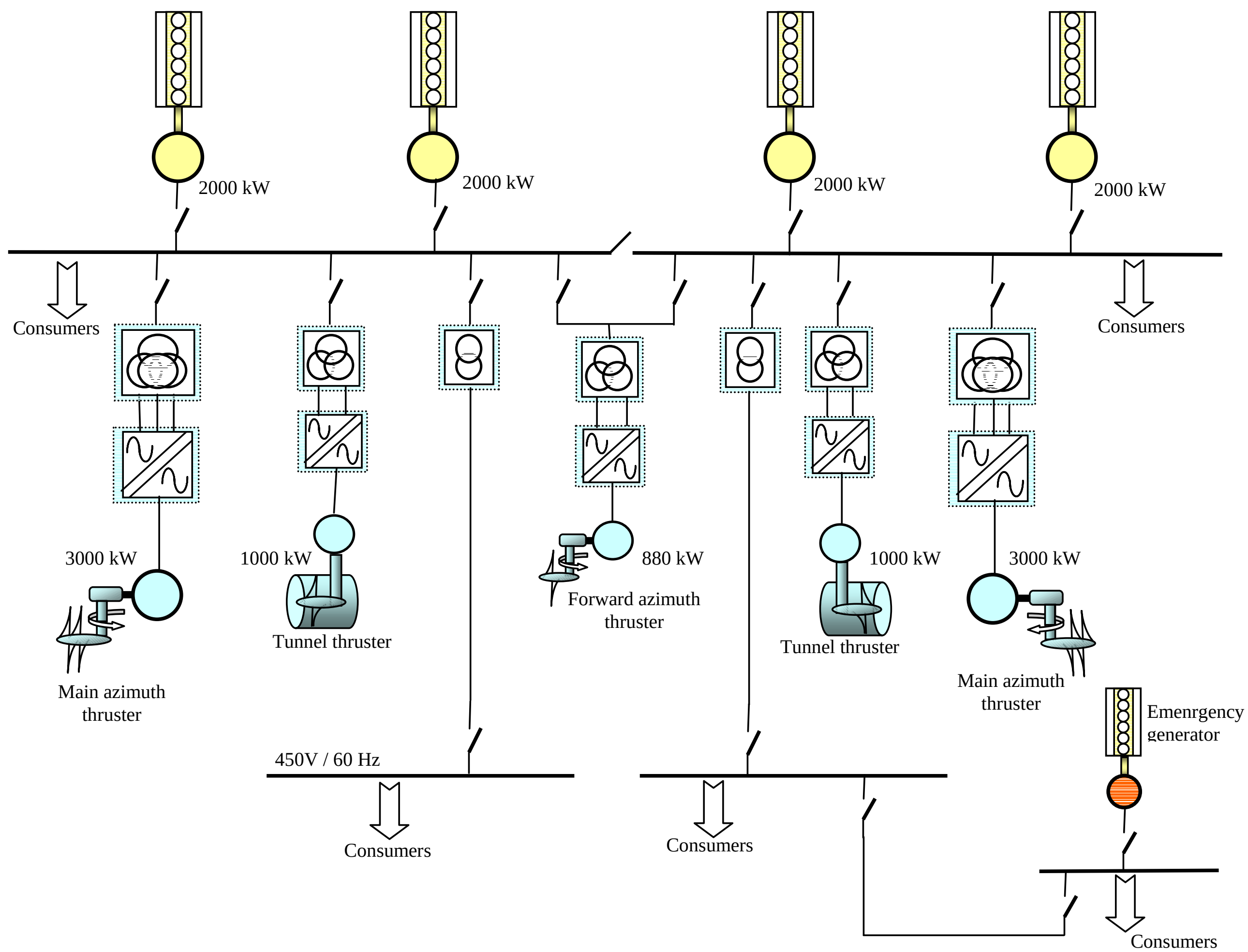

Figure 3.1 : Simplified single line -offshore service vessel

A typical oil & gas production vessel will have more power installed and the generation and distribution of power is split between several generators and switchboard units.
A four split configuration is normal for these types of vessels.

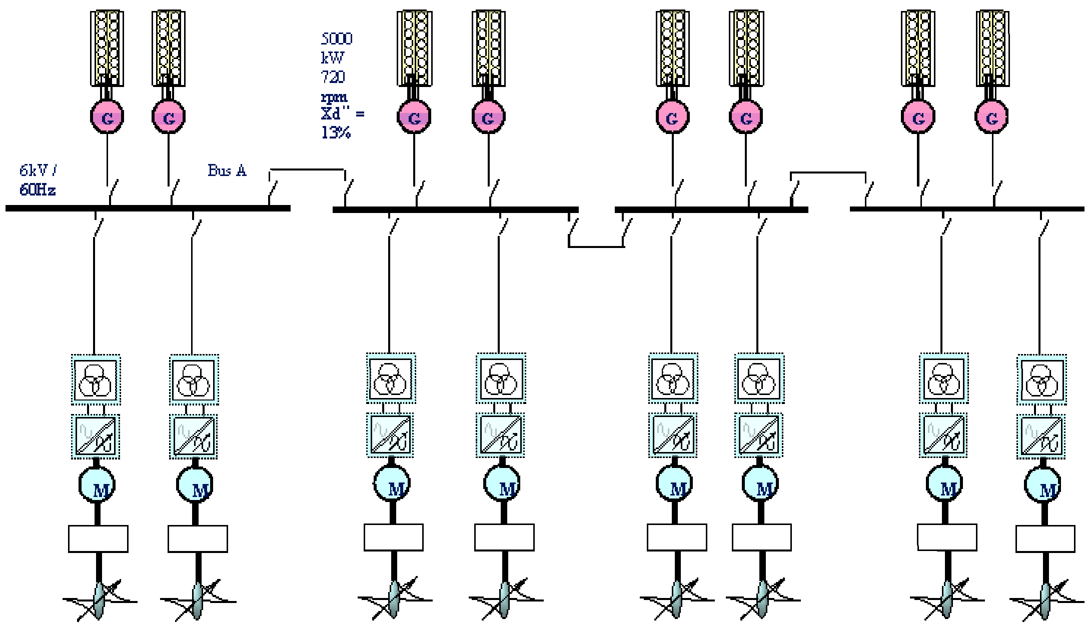

Figure 3.2 Simplified single line - production vessel

The load conditions for FPSO vessels can be summarized in following practical terms for evaluation of power generation capacity:

Normal production and offloading

Process systems are running normally including utility power for the process.
Other vessel utility systems are running normally.
Propulsion system running according to required power from DP system.

100 year weather condition (marginal production or no production)
In this situation all thrusters may be in operation .
Production will be minimum or shut down.

The load profile is mainly based on load variations in DP operation during normal production. These profiles have to be verified after the DP operating profile has been established.

Normal power requirements will depend on the process requirements, but may vary from 20- 50MW.

3.3 Main power distribution system

Distribution systems may have two or more switchboard parts connected with bus-tie breakers. A typical drilling rig configuration will be a four split switchboard to allow for a flexible arrangement where each main thruster's drive can be connected to each switchboard section.

A medium voltage main distribution system is typical 6kV,6,6kV or 11kV bus voltage and main breakers have a breaking capacity of 20-40kA rms .

For low voltage main distribution switchboards 690V is a common voltage level with fault level capacities preferably below 50kA rms.

Large generation capacity may increase the short circuit level above acceptable values. In these cases additional current limiting devices or restrictions in operation of connected switchgear units has to be implemented. This will give restrictions in how the bus-bar sections can be connected together, but this will anyhow be controlled by the PMS.
During bus-tie transfer the breakers can be connected together by a controlled make-before-break system.
The alternative is to install new short circuit limiting units in the network. With this arrangement any breaker connections can be allowed.

3.4 The propulsion drive

The main electrical drive system may be traditional propellers fixed or pitch controlled or azimuth thrusters or podded propulsors.
In addition the tunnel thrusters will be a part of the DP operated propulsion system.
Frequency converters control propulsion motors and can vary the thrust based on variable frequency and voltage. Frequency converters have the ability to fully operate the speed from zero to above nominal speed in both directions.
Modern converters can be run in different mode as rpm, torque and power.
There are different available converter technologies on the market. Voltage source technology has became the most promising technology within medium power ranges and has further a huge development potential together with asynchronous motors or with modern permanent magnet synchronous motor technologies.

Frequency converters have the ability to regulate very fast and have such no practical time constant limits with modern control systems. The time constant limits within the total regulation of propellers is mainly in the mechanical system due to torque limitation, in the power generation system and also on hydrodynamic efficiency.
A normal parameter setting of the converter will be ramping curves for loading of propeller in area 15-30sec from 0-100 % load.
Also torque limitation and speed limitations will be controlled in the frequency converter system.
Survival during electrical faults in the electrical network or in the converter itself is important when considering energy availability.
Faults within the converter may cause different availability scenario. Future drives should be able to blank out faulty parts and further run with limited power. Anyhow this will depend on the modularity of the converter system.
Faults in the network will limit the power availability in the total network for a short period , but should not lead to total loss of propulsion power. The converter system itself will have the ability to maintain energy in the DC circuit if there is sufficient energy in the rotating system and such be ready for operation after a network fault.

The interface with the DP system and PMS and thrusters/propulsion control is normally via 4-20mA reference signals. The thruster /propulsion control is normally a separate control system, but may also be integrated in modern converter systems. The actual thrust reference signal will be calculated and set by the DP system, but in today’s systems there is no actual thrust measuring feedback. This will be a future challenge in a more environmental friendly use of energy.

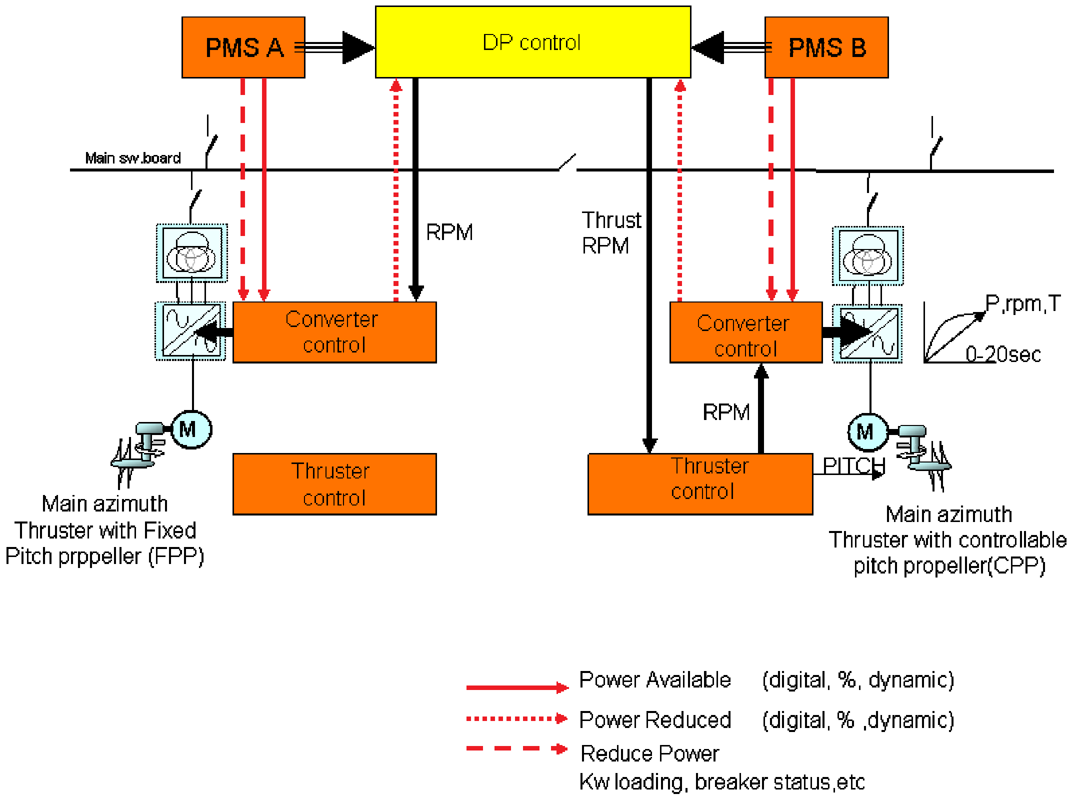

Figure 3.3 Typical PMS system

The line side of the converter (the rectifier) may be 12-pulse or more in order to minimise the harmonic current feedback. Alternatively active rectifiers can be used to allow for 4-quadrant operation.

The frequency converters will normally be water cooled to avoid heat emission to the equipment room and to limit the noise level.

4. System design

4.1 Specific requirements for DP mode

The requirements in DP-mode for a DP 2 Class vessel are given in the class society rules.
The most important requirement is that each of the power generation systems must be running. It is not accepted that a system is in stand by. Secondly, should one of the systems fail, the other has to be able to increase its power generation up to the previous level before the failure.

Requirement from Class (DP 2)
The vessel must be able to maintain the ability to keep position after worst case failures. This implies that the vessel needs a redundant power supply. In case of one failure that makes the vessel dependant on one power generator (loss of redundancy) the vessel must safely terminate the operation.

The vessel owner has quit often more strict requirements then the class requiremnts.DP operations are in nature critical operations and require always necessary power to abort an operation in an emergency situation.
This will also require a design of the total electrical propulsion system and the PMS that has necessary redundancy to support these requirements.
A typical consequence will be to build in a dynamic performance of the converter control and the generating plant.

Typical requirement from owner/operator
The vessel must be able to maintain DP 2 class, i.e. redundant power supply after worst case failures.
This implies that the vessel needs a redundant power supply that in case of loss of one power generator can start or already have operational a third power generator that secures redundant power supply, maintaining DP 2 class. The practical consequences for the propulsion drives is that there should always be available power to the drive motors.

4.2 Redundancy Design Principles

The design of the total electrical propulsion system is always important.
The design phase should evaluate different configurations and use evaluation tools and reviews to understand and document the consequences. HAZID and HAZOP reviews can be a good way to understand the different fault and operational scenario.

The next step will be how to install a redundancy philosophy that is sufficient for the operation of the vessel. This will involve the commercial side as it may increase the price, contractual philosophies may be a barrier for implementation and owner's standardisation may be another barrier.

For an offshore supply vessel, redundancy in power supply system is crucial. Any single failure shall not cause/prevent the vessel from "station keeping".

The electrical system is arranged minimum as two separate systems, which are completely independent of each other. When operating in DP mode, the bus-tie may be open or closed depending on the protection philosophy and the transient stability during network faults.

A generating system will have to be segregated in a similar manner.

This principle has to be consistent for all components within the system, like:

- Fuel supply
- Air supply
- Water supply
- Cooling system/pumps
- Power inverters (DC/AC)
- Transformers
- Switchboards

A reliable design for a large vessel or drilling rig is based on a four split redundancy philosophy, where one or two gen-sets feeding one main switchboard of each voltage level, and one thruster drive are included in each redundancy segregation zone. Based on this redundancy philosophy any electrical or auxiliary technical single failure in the installation, excluding fire and flooding, shall not lead to loss of energy availability with more than needed for the most critical operational situation.

The worst case single fault with respect to class requirements DP2 or 3 is a fault on one of the main bus-bar sections or a fault in a main propulsion motor.

Auxiliary systems not using the same redundancy philosophy should be carefully evaluated so they maintain continuous operation after single faults. This is typically valid for ventilation and water cooling systems.

Each machinery room is equipped with a fresh water cooling system with heat exchangers connected to the sea water cooling system. The fresh water cooling system is equipped with duty/standby pumps for cooling of the diesel engine, generators, and if necessary other equipment in the machinery room.
The fresh water cooling loop will also be used for cooling of other equipment in the same redundancy zone, such as transformers, thrusters, and thruster drive systems.

Major electrical faults in the network:

A short circuit in the network or in one drive will result in trip of switchboard feeder breaker or fuses.
Estimated trip time 50-150ms depending on the type of protection..
From the feeding generators this has been seen as a short circuit.
In a situation like this there will always be a momentary voltage drop that is depending mainly of generator sub-transient reactances and time constants.
If the complete network is connected together this voltage drop will be seen in the entire network.
This kind voltage drop will always be present during short circuit conditions and all consumers connected to these networks may trip or stall if not the voltage can be maintained.

In case of the frequency drive survival during such a network voltage drop there are different solutions on a normal drive.
Inverters will trip if no or very little rotating energy and low voltage is present on the rotating motor side.

To be able to survive and have a "ride through" capability the rotating energy should be in an area so it is possible to maintain the DC link voltage during the network fault. In such a case the drive would be working normally after this type of fault.
There are different techniques to maintain the DC voltage even with low rpm.

If the DC link voltage can not be maintained the next step for the inverter control is to trip the inverter and further to trip the feeding circuit breaker.

The normal way of restoring the situation after a trip is to reset the drive alarm and have a new start (flying start) either with exited or un-exited motor.
This procedure can be performed either manually or automatically.

A split network generating plant will secure at least one half of the generation and propulsion system is live.

4.3 Redundancy philosophies for drives

The new IEC standard for Electrical Propulsion will come into force this year. This will be the first international standard defining a complete electrical propulsion system. The system responsible is in this standard defined as "one responsible body" to ensure a complete integration of the complete propulsion system.

To abort a vessel DP operation will have a major consequence for the owner/operator, so the owners approach will be important for the design of future PMS/EMS and also stricter requirements for essential equipment like converter drives.

In the short term future we will see a much more dynamical PMS functionality outside the PMS control system. This functionality will be built into for instance converters where we will see a more dynamic power/thrust availability both after faults or overloading.
Wartsila will have converters that will be modularized and blanked out after faults and will have automatic restart and new power availability. In addition the converter will have self protection function for all thermal overloading of a drive. This will in total give a much higher availability of propeller thrust after critical faults.

The only way to achieve this is modularized hardware and advanced diagnose control functions to control the status of the drive.
This will be an important part of the PMS regime onboard as there still will be power available after a fault condition.

4.4 Harmonic content

A harmonic analyse has to been performed and show that the harmonic content will be below required THDv with the worst configuration of rectifier load and with maximum tolerances added on the generator reactances .
The pulse number seen from the bus-bar should be high enough to avoid too high distortion values in high rectifier load situations estimated to <80% rectifier load..

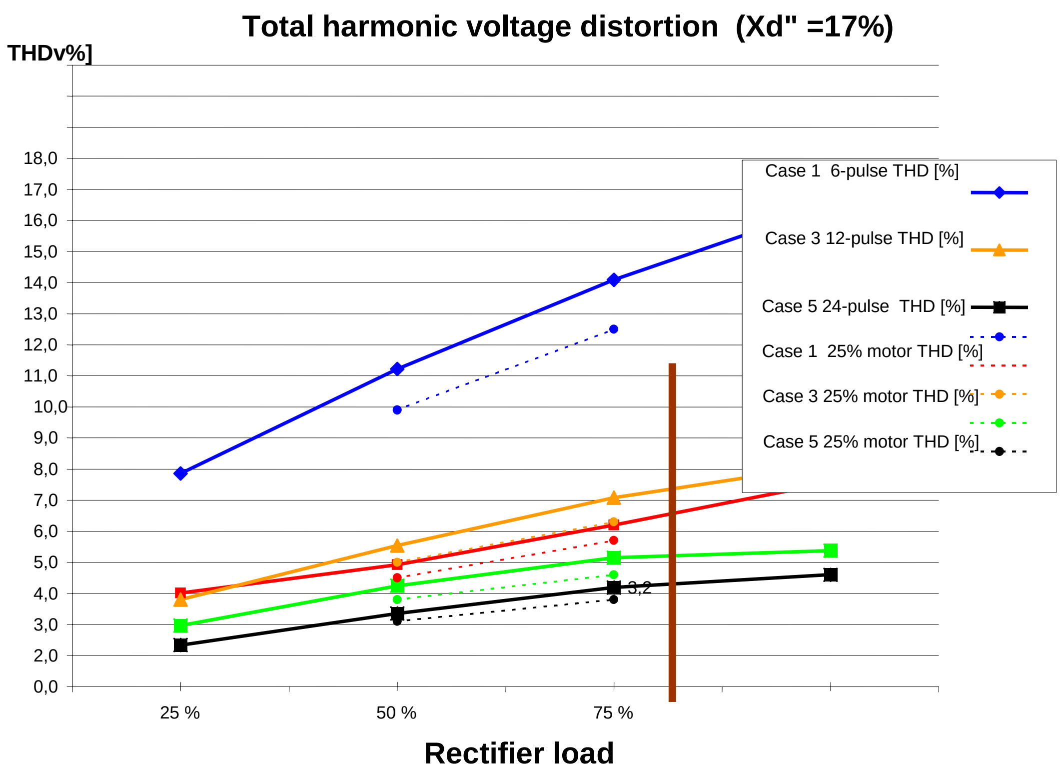

Figure 4.1 **Total harmonic distortion level for 25, 50, 75 and 100 % rectifier load for conventional converter systems without any damping. The dash lines for 50% and 75 % rectifier load show the total harmonic distortion level with damping for running induction motors (motor rating = 25% of total installed converter load)**

4.5 Shut down philosophy and safety levels

The safety level of the vessel must be documented through a quantitative risk analysis.
The results from the HAZID have identified key areas in which the design may have a high risk if not proper safety systems, arrangements and measures are implemented and documentation of system performance is provided .

A production vessel certified as DP 2 or 3 or Posmoor ATA class will need a shut down philosophy that secure power to keep heading under control in critical situations.
The main air inlets to the local equipment rooms and to the switchgear rooms have to be carefully study so the heading can be maintained in a secure way. In case of a total blackout the PMS system shall be able to re-connect the power generation and propulsion system.

5. Operation of power generation system

5.1 Operational profiles of a DP operated vessel

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In DP mode, all thrusters are used in order to keep the ship in correct position, regardless of wind and sea influence. In calm weather, the total power consumption will be as low as 700 kW for a typical offshore service vessel.
In rough weather the level will be between 2 and 3,5 MW, and the variations will be larger. +/- 30% during a period of 15 seconds is indicated, due to variations in propulsion power. Due to requirements from the DP system, the frequency converters are normally operating in “rpm” mode.

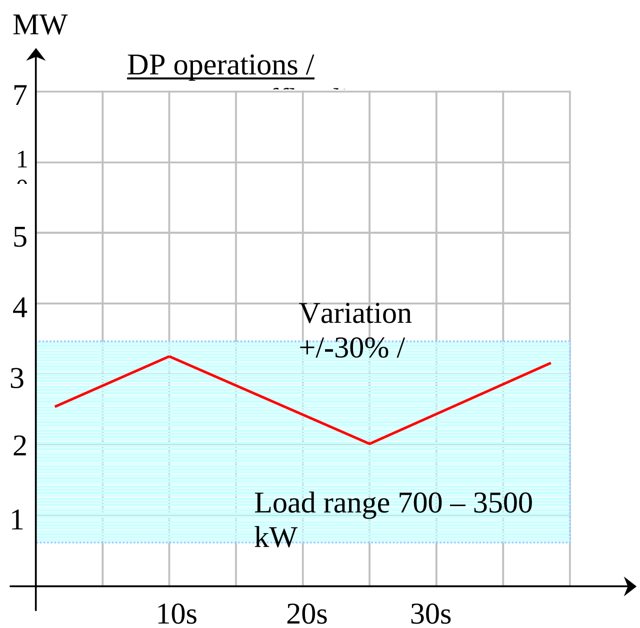

Figure 5.1: Typical load levels in DP operations/offloading

Three or more generators running in parallel and closed bus tie are normally used. For critical operations requiring full redundancy, the bus tie may be opened, and three or four generators must be running.

In DP or transit mode and rough weather conditions, the main propellers can come into free air, due to heavy seas.

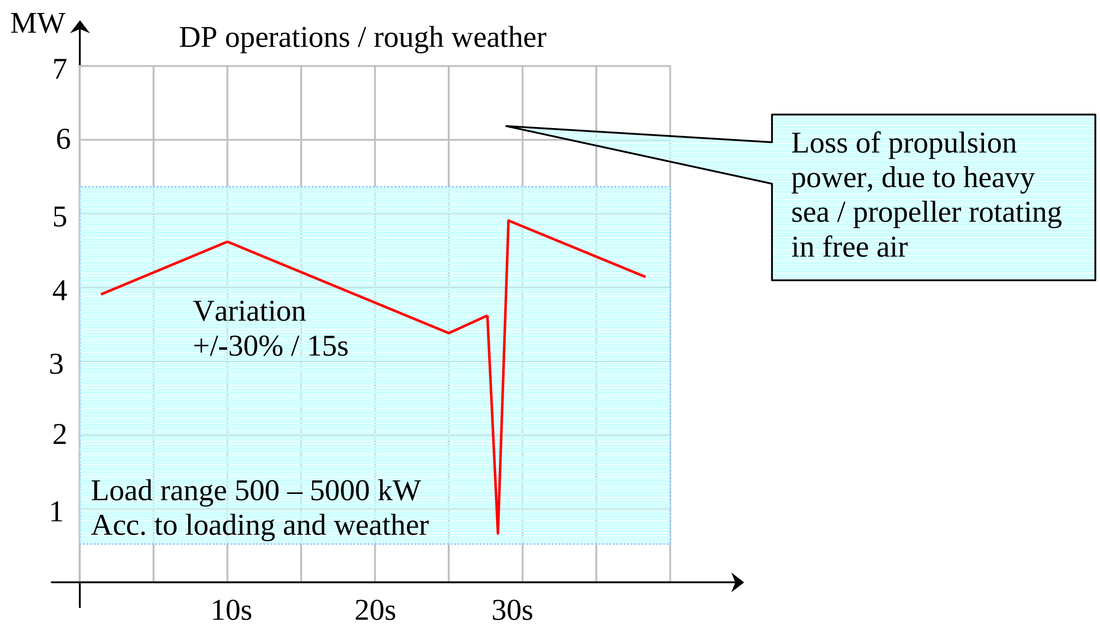

Figure 5.2: Propellers in free air.

This situation will represent the largest known load transient for the propulsion system. If the electric frequency converters for the main propulsion are running in “rpm modus”, this load transient will be reflected to the power station. If the frequency converters are running in torque or power mode, this transient will be reduced and smoothened.

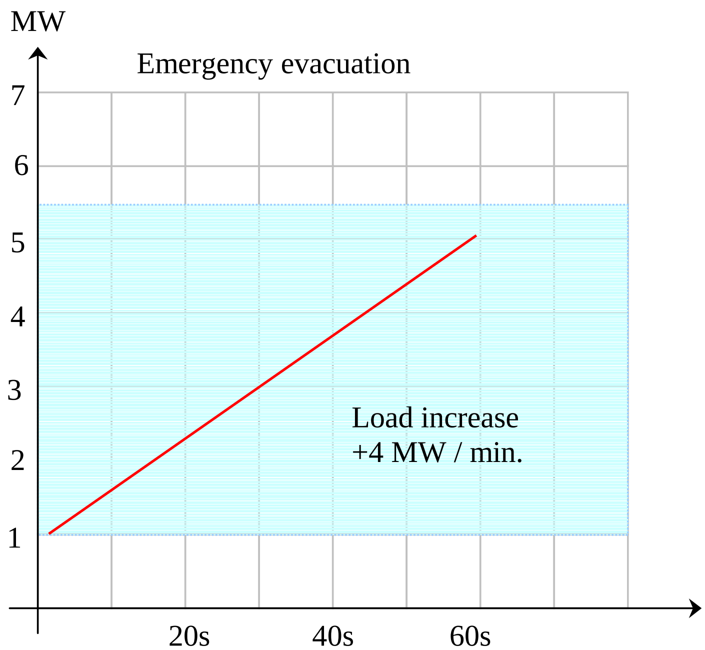

Figure 5.3: Emergency evacuation.

A vessel in "DP mode" laying closed to offshore installations may in an emergency situation need all power available to bring the ship away from the installation as fast as possible. For this vessel this may be a power requirement from approximately 1 MW to 5 MW. The operational requirement is to establish full propulsion power within 1 minute for the onboard power station.

The basis for installed electrical energy production is to keep the vessel in a stable condition during all production and weather conditions based on the worst single failure.

The PMS system will take care of all control and protection of the energy production and energy stability. The PMS system will automatically start up and stop the generators necessary for the actual load demand.

5.2 Failure modes.

The following failures will have large impact to the power generation.

Trip of one generator

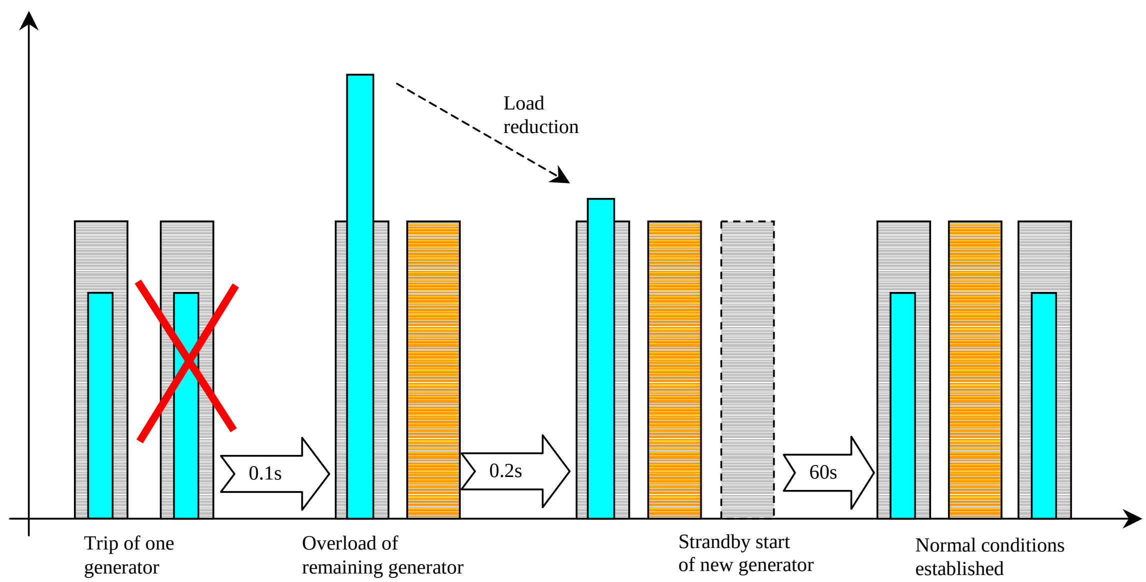

Figure 5.4: Power management in case of trip of one generator.

Loss of one main thruster at full load

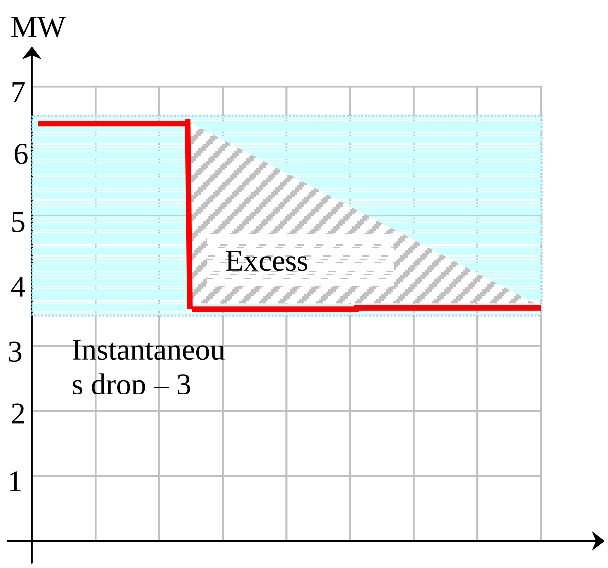

Figure 5.5: Power management in case of trip of one generator.

6. Power Management System (PMS)

6.1 Introduction

Power Management System (PMS) is a group function and comprises control and monitoring of electric power production and consumption. The system controls and monitors the engine driven generators, switchboards and consumers. In the case of an electrical system fault the power management system restore power in a minimum of time.

- PMS is the sum of human experience and an efficient automated control and monitoring system
- Secure a safe, reliable and efficient monitoring and control of the electrical power to important vessel functions in all operational conditions.

PMS for propulsion should care for available power to executing required thrust in any operational condition

- Thrust Management is important in DP operations and is today administrated of the DP system. Future systems will involve different methods to measure actual thrust.
- There are different control and management function that can be integrated as one system or separate systems
  - Power Management System (PMS)
  - Energy Management System (EMS)
  - Power and Energy Management System (PEMS)
  - Reliability Management system (RMS)
  - Integrated Platform Management System (IPMS)
  - Integrated Vessel Automation System (IAS)

For electrical propulsion plants there are normally different system interfacing each other.

Following functions are normally standard functionality in a PMS:

Power generation management

Gen-sets control

- Automatic start and connection of engine driven generators (DDG), when trip or pre-warning of a connected DDG has occurred.
- Load dependent start and connections of DDG's.
- Load dependent stop and disconnections of DDG's.
- Monitoring of critical parameters.
- Mode control
- Max./min generators
- Synchronization and load shearing
- Power and voltage control
- Active and Reactive Power Control

- Load management

Available power

- Load Control of “dynamic” consumers (Power available to bow thrusters and available power signal to propulsion converters) to prevent overload on generators
- Transformer Control
- Motor Control
- Network Configuration Determination
-

Load shedding

- Circuit breaker Control

Blackout restoration

Re-Starting

6.2 PMS functionality

The PMS is divided in two, PMS A and PMS B. One for each side of the ship. Feedback from tiebreaker is used to decide the switchboard mode (Split or Connected mode).

With open Bus Tie, each half has a PMS that operates independently, PMS A and PMS B.

Both PMS A and PMS B (two separate controllers) is getting active power (kW) signal from all DDG's and calculates available power for the plant. Available power signal is given from each PMS to each frequency converters. If PMS A load control fails the PMS B load control will take over.

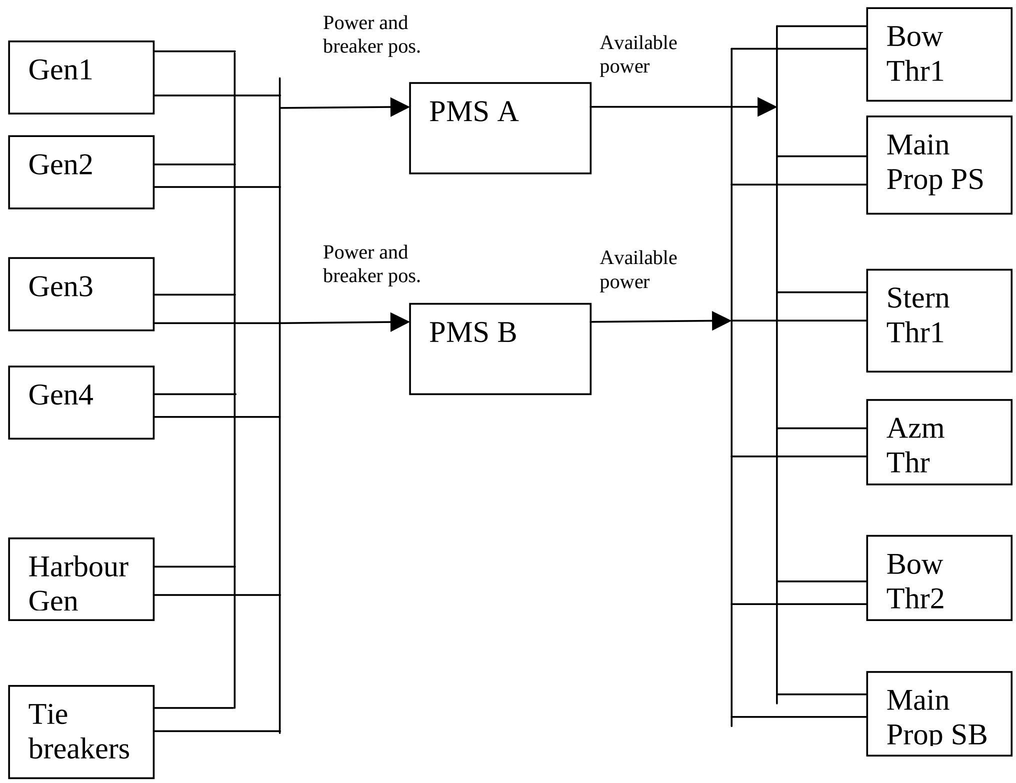

Figure 6.1 PMS topology

When bus bars are connected they will perform as one system regarding Power Calculation, Generator Standby selection, Load dependent start / stop and Load Monitoring.

Load Calculation and Monitoring

PMS calculates available power for the busbar. Only DDG's that are connected and in Isoc or Droop Fix load mode are taken into account in the calculations. The available power is displayed for both Bus bars 1 & 2, on the main PMS VDU. If connected, a common available power will be shown.

Generator standby selection (Control mode)

The DDG's control mode (Manual/Auto) and priority (DDG standby number) is taking care of by this function.

DDG's in "Auto" mode are started and stopped automatically by the PMS. DDG's in "Manual" can be started and stopped from the operation menu.

The standby number for each DDG must be unique in standby mode. If operator selects an already used standby number, this function will automatically switch the standby number.

If an abnormal situation regarding a DDG in "Auto", (initiated from "DDG common fault" function) the DDG will be set to "Manual".

Load dependent start / stop

This function handles the load-dependent start/stop of diesel driven generator (DDG) set in AUTO. Standby start/stop will be given on request from PMS.

Load dependent start:

A load-dependent start request is initiated by:

Spare capacity on the bus is less than a user-defined limit.

- Load reduction request from another connected DDG.

To prevent start request signal based on short load peaks the signal is delayed. The time delay depends on how many DDG that is connected to the bus and the user-defined start delay limit.

Load dependent stop:

A load-dependent stop request is initiated if:

- Spare capacity on the bus exceeds a user-defined limit.

To prevent stop request signal based on short load peaks the signal is delayed. The time delay depends on how many DDG that is connected to the bus.

Blackout Restart

Reconnection of consumers:

The propulsion has frequency-controlled drives and the feeders are supported with UVT (Under Voltage Trip).
In the event of a dead-bus, these feeders will trip. All other feeders will stay in closed position. The thrusters have to be started manually.
The Tie-breaker will open if there is a blackout.
If a short circuit in one of the busbars causes the blackout, the short circuit protection will open the Tie-breaker.

Restart of DDG's:

All generators selected as Remote on switchboard will start and the first generator with approved Voltage and Frequency will be connected to the switchboard.

Load control

Load control is used to control the power admission for large dynamic consumers (thrusters drive).

The ship's propulsion drives are controlled by Frequency Converters, which can be controlled by the power management system. PMS is controlling the maximum power the frequency converter by adjusting the Available power signal.

Overload/Blackout is avoided by monitoring total energy consumption compared to available power generation and quickly reducing loads to avoid overload or in worst case blackout, for sudden engine/generator trips.

Heavy consumers

To prevent overload of the power generation plant, the PMS contains "start blocking" of the largest consumers.

Function step by step:
- Start of heavy consumers are initiated local or from IAS.
- PMS gets a "Power request" signal from the heavy consumers.
- PMS has a reference table over heavy consumers and limit for spare capacity.
- Based on this table PMS determine if sufficient available power.
- If sufficient power the PMS deactivate the blocking signal.
- If there is not sufficient power the PMS will start a new generator.

If no running feedback within the predefined start time, the blocking is activated.
A new start has to be initiated.

6.3 Blackout Prevention

Blackout can be avoided by monitoring total load compared to available power. In case of overload the system will quickly reduce load to avoid overload on the generator.

If a generator trips the PMS is detecting this and takes action by reducing the power available signal to frequency controlled thrusters and bow thrusters to a predefined level (safe load) on available power signal to ensure that the remaining generator will not overload.

After 5-10 seconds (adjustable) the predefined level is removed from the available power signal and the frequency converters will increase load as fast as the ramping curve in the converter.
The ramping will stop when the Thruster has reached its set point or if the available power on switchboard is 0 kw. If the available power is 0kw the PMS will regulate the power available to frequency converter so it can not take more loads. (See section Load Control)

Dynamic blackout prevention

In DP operation the PMS and frequency converter will rapidly reduce power consumption to a preset value.
DP system ramp up the rpm/thrust based on available power
In case of lack of available power eventually load shedding or other priority of thruster load will be initiated

- **Overload :**
  - load ramping rate function, based on acceptable load ramping for engines
  - overloading of thrusters based on dynamic overload curves in the converter and electrical motor and the thruster/gear/propeller
  - The signal is transmitted to the frequency converter, which reduces the load to a preset value. The execution time and load reduction time in the converter is approximately 100 milliseconds. Faster tasks may be initiated if this can be acceptable for the engine and electrical network

Load shedding
Load shedding in an electrical propulsion system may have different level based on the type of plant. The load shedding may be triggered by temperature signals, trip of other loads then propulsion system itself in prioritized steps.

6.4 New PMS functionality

New PMS functionality challenges

- Multifuel strategies
  - MDO
  - Natural gas with different methane content
  - New fuels like methanol or other bio fuels
    - New vessels will require a mixed fuel power generation with different energy content, different dynamic engine performance, different power loading and maintenance.
    - Will require a dynamic PMS setting

- Environmental profiles
  - New environmental regulations and strategies will set new standards for energy efficiency
    - Optimal use of power for thrust allocation
    - New functionality for regulation of propeller regards to ramping, anti spin functionality measuring of actual propeller thrust
    - Combined power plants –with combination of gas turbines and diesel (dual fuel) engines
    - Fuel cells –power regeneration

- Reliability monitoring
  - Condition Based Measuring(CBM) of propulsion electrical and mechanical system
    - Calculation of probability of breakdown or reduced power
    - Dynamic available power calculation

- Available thrust/power always present for propeller
  - Vessel owners require all propellers to be in operation all the time
    - Higher availability requirements specially for the electrical and control system
      - One responsible body for design
      - HAZID and HAZOP execution
      - Extensive testing and maintenance of software
      - Redundant design of PMS
    - Some power better then none power
      - Modularized converters with dynamic available power (25-50-75-100%)
      - More flexible distribution concept
      - Condition based monitoring of thrusters, gears and propellers
      - Self protected converter units with dynamic loading curves