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POWER PLANT

Power Management System With Fast Acting Load Reduction For DP Vessels

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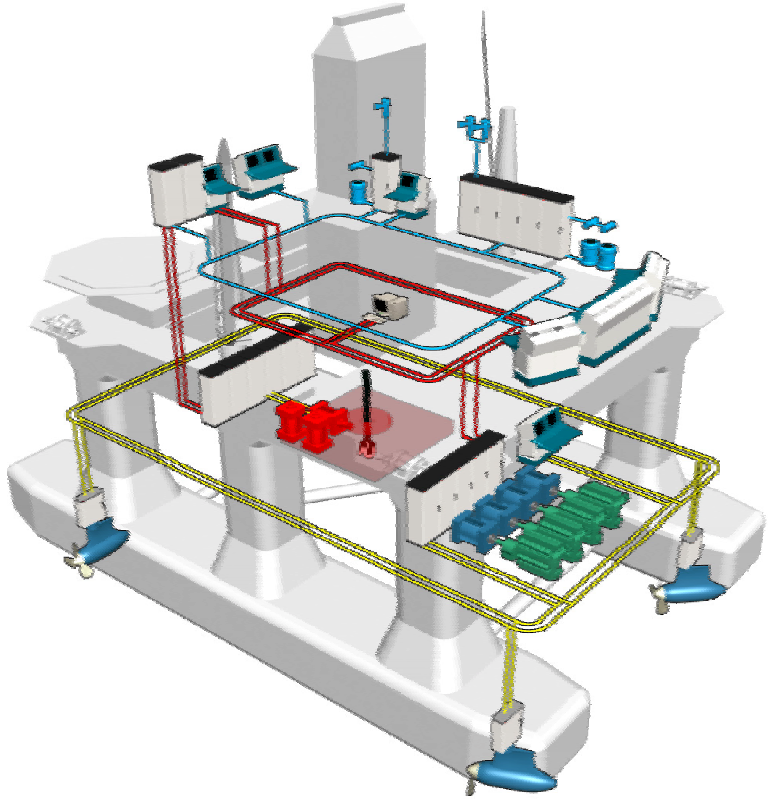
Power Management System with Fast Acting Load Reduction for DP Vessels

The last years, a number of DP class 2 and 3 vessels have been built for deepwater drilling, pipe and cable laying, etc. The majority of these modern vessels are equipped with a diesel-electric power generation plant and variable speed thrusters for positioning. In order to obtain the required redundancy, with a minimum of installation, the generation, distribution and thruster system is designed in several sections, divided by firewalls and may be separated by cross-bus feeders or bus-ties. One of the worst scenarios for a DP class 2 or 3 vessel is blackout of the power system, and a big effort is made by ship owners and vendors to increase the system's integrity towards failure. A key part of the blackout prevention functionality is found in the Power Management System. ABB has made significant improvements in the area of Energy or Power Management, introducing high-speed algorithms for quick power reduction and optimizing the thruster allocation for fuel optimization and utilization of running generator capacity. Results from this development are presented with full-scale data from sea trials of deepwater drill ships and semi-subs. It is shown that with an event-based load reduction function it is fully possible to prevent the feared domino effect of a fault in a DG-set. The key success factor is the close and coordinated link between power generation, frequency converters for thruster and drilling drives, dynamic positioning, and the power management system.



Introduction

Until recently, huge oil and gas resources were accessible in shallow water and could be exploited by fixed drilling and production units. In the North Sea, as in several other areas, the new resources are found in smaller and less available fields at deeper sea in hostile environments. The strong requirements to vessel *performance*, *environmental aspects* and *overall safety* have resulted in increased focus on the total vessel concept and the interactions between the different equipment and systems installed. Flexibility in operation has enabled electrical power generation and distribution systems for propulsion, positioning, oil production, drilling, and loading, where all equipment and control systems are integrated into a common power plant network and automation network. Use of floating concepts for deep sea drilling, floating production and shuttle tankers have become possible with dynamic positioning or thruster assisted position mooring. Together with the production, drilling, utilities, and hotel loads, the installed power may typically be in the magnitude of 25-50 MW. There is a potential for substantial cost savings and energy optimization for such vessels by applying new solutions based on so-called *in-between technology* within the fields of control, electrical power and marine technology integrated with conceptual design of vessel hull, thruster system, mooring system, etc.

Positioning systems have been commercially available for marine vessels since the 1960s. However, it is only in the 1990s that fully integrated electrical power, automation and positioning systems have become commercially available. In the international marine, oil and gas market, ABB is unique as a total supplier with uniformed in-house products, and this uniqueness is applied to create the most optimal solution for the environment and customer with respect to vessel mission, energy consumption, availability and safety.

Power system

1.1 Power Generation and Distribution System

The power generation and distribution system is divided into the following main parts:

- Power plant with prime mover and generator.
- Medium voltage switchboards and bus tie breakers or bus transfers for cross feeding between switchboards.
- Voltage conditioners or filters for reducing harmonic interference.
- Transformers for feeding of alternate voltage levels.
- Low voltage switchboards and motor control centers.
- Rotating converters for frequency conversion and clean power supply.
- Uninterruptible power supply of sensitive equipment and automation systems.

1.2 Power Plant

The electric power plant consists of turbine or diesel engine driven generators. Due to requirements of local control and fast response times, the speed and voltage regulators are dedicated systems that are located near the power plant.

By rules and regulations, the vessels must be equipped with emergency generators. A recent trend is to certify main machinery and generators for emergency power supply giving savings in cost and even more important, space.

The generating power and number of units are to be selected from maximum load conditions and redundancy requirements. The operational profile should also be regarded in order to avoid non-optimal low-load operation of engines.

1.3 Power Distribution

The power distribution system consists of main switchboard, usually split in two, three, or four sections. For DP vessels, there is a trend to use three or four sections in order to obtain the redundancy requirements. For moored vessels with thruster assistance, two or three may be sufficient.

Safety is an issue of concern when yards and ship owners changes from low to higher voltages, often leading to a misunderstanding effort to keep voltages as low as possible. In the context of safety, it should be regarded that medium voltage switchboards is designed to prevent personnel to get contact with conductors, even in maintenance of the switch gears. The normal and fault currents are similarly smaller, giving less forces on the conductors and cables during e.g. short circuit.

Although short circuits inside the switchboards are extremely rare, arc-proof design (IEC 298-3) should be standard in order to prevent person injury and limit the equipment damages if worst case should occur.

ABB Integrated Solution

In the operation of vessel, there are several sub-systems working together, and the merging of software and hardware platforms in automation systems has enabled totally integrated automation system comprising:

- Propulsion and thruster control.
- Dynamic positioning / Position mooring.
- Power management system.
- Vessel automation system.

- Cargo control.
- Ballast control.
- Process automation system.
- Emergency shutdown system.
- Fire and gas detection system.
- Off-loading control system.
- Drilling control system.
- HVAC control system.

Each subsystem may be allocated to separate units in the integrated control systems, e.g. the emergency systems, or their functions may be distributed in several units, sharing the computer and I/O capacity with other subsystems. In contrast to the traditional architecture with separate control systems, the integrated control system interfaces each signal loop only once. The information is then distributed between the subsystems in the control network. Also, the subsystems cannot longer be regarded separately, since the functionality and data flow may be common for several subsystems.

Very much of yard's engineering and production work is related to interfacing the various control systems. In an integrated automation system, this work is significantly reduced and the responsibility is transferred to the vendor. Extensive testing and simulation may be carried out before installation, reducing the effort and duration of commissioning.

Since all control systems are implemented on the same hard- and software platforms, user interface and documentation are unified and the effort on training for installation, operation and maintenance is rationalized. The largest challenge for the yard and vendor of integrated automation systems is to structure the process interfacing and software program. Since the software platforms usually are very flexible, there are possibilities for non-optimal structuring if this issue is not attacked properly. Process sectioning and software structuring must be strongly focused in the early design specification of the integrated automation system. It is a necessity that this work is supported by built-in features of the control system and in the design tools, as in the ABB Advant products.

1.4 ABB Positioning System

The ABB Positioning Systems comprise Dynamic Positioning System, Position Mooring System, Autosail System and Manual Thruster Control System. The ABB Positioning System is based on a modern control philosophy that reflects the non-linear characteristics of the vessel dynamics:

- Advanced signal processing: Signal variance, derivative, frozen signal and wild points handling, and signal voting and weighting
- Non-linear observer that provides velocity estimation, wave filtering and dead reckoning.
- Non-linear model-based feedback controller and reference and wind feed forward control.
- Nonlinear reference model providing smooth trajectory operations
- Advanced thrust allocation that handles arbitrarily thruster configurations.

MANUAL THRUSTER CONTROL – MTC

The ABB Manual Thruster Control system provides individual lever control of the thrusters (pitch/RPM, azimuth angle), start/stop of thruster motors and hydraulics, and thruster status indication. The thrusters device can be enabled and controlled from the MTC panel at any time, even when other positioning control modes, e.g. when DP Station Keeping, are enabled.

AUTOSAIL

The ABB Autosail system is an advanced autopilot system, and is used for long distance sailing. The main objective is to perform automatic course keeping and course changing. If gyro compass measurements are temporarily unavailable, the Autosail observer produces heading feedback signal (dead reckoning). The Autosail system handles any thruster/rudder configuration, and has excellent performance even for vessels that only are equipped with azimuth thrusters.

DYNAMIC POSITIONING (DP) SYSTEM

The ABB Dynamic Positioning system basically provides the required thruster action for manual and automatic control of the vessel heading and position:

- Manual joystick control
- Velocity damping control
- Set point control (position/heading keeping)
- Tracking control

ABB provides a single system that complies with DP class 1 and redundant systems (dual and triple) that complies with DP class 2 and 3.

POSITION MOORING (PM) SYSTEM

The ABB Position Mooring system is used for manual or automatic thruster assistance when the vessel is attached to a mooring system. The thruster assistance is complementary to the mooring system that provides most of the position keeping. The PM system control functions are similar to the DP system control functions. Heading control and damping control of oscillatory motions are most the adequate functions for position mooring automatic thruster assistance. The PM system also provides automatic line break detection and line break feed forward control action. ABB provides redundant (dual) systems that comply with e.g. DnV Posmoor ATA class notation.

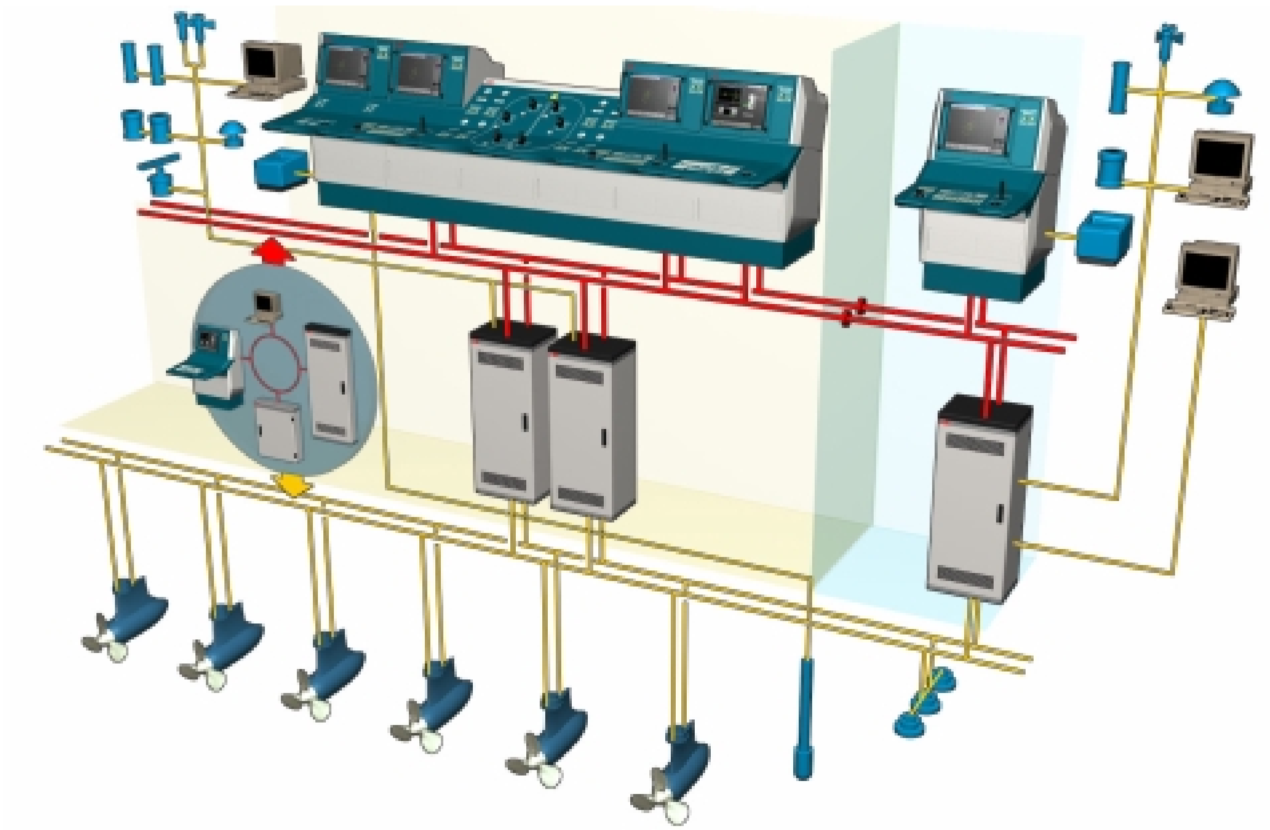


Figure 1, Example of configuration for ABB Dynamic Positioning system.

OPERATOR PLANNING AND ADVISORY SYSTEMS

ABB has developed highly sophisticated vessel simulators for operation planning, operator training and decision support. Class rules for DP class 2 and 3, and thruster assisted mooring systems also require consequence analysis and simulation systems. The different simulator software modules include detailed vessel hydrodynamic model in 6 degrees of freedom (wave-frequency and low- frequency motion), sensor noise models, thruster models, including thruster loss effects, thruster motor and gear models, power system models and environmental models (wind, waves and current).

1.5 ABB Power Management System

In a system of electrical power installations, vessel and process automation system, and positioning system, the various parts of the automation system controls their parts of the power system. E.g. the dynamic positioning system controls the thruster drives, the off-loading control system uses cargo pump drives, the process control system interacts with compressors and cooling/heating systems etc. The interconnecting point for all installed power equipment is the power distribution system. By starting and inrush transients, load variations, and network disturbances from harmonic effects the load and generators are interacting and influencing each other. Optimum operation and control of the power system is essential for safe operation with a minimum of fuel consumption. The power management's main functions can be grouped in:

POWER GENERATION MANAGEMENT

Overall control with frequency and voltage monitoring with active and passive load sharing monitoring and possibly control, and load dependent start and stop of generator sets. Since control logic and interlocking functions are a significant part of the power system switchboard design, the functionally of these systems must be coordinated.

LOAD MANAGEMENT

Load power monitoring and coordination of power limitation functions in other systems, load shedding and start interlock of heavy consumers based on available power monitoring.

DISTRIBUTION MANAGEMENT

Configuration and sequence control of reconfiguring the power distribution system. The distribution system is configured to fit the requirements in the actual operational mode for the vessel.

Energy Management

Energy Management is a new approach to control and monitor the energy flow and control in marine, oil and gas installations. The Energy Management System (EMS) extends the concept of power management in the direction of controlling and coordinating the energy generation and consumption, by optimization of the instantaneous power flow and also energy usage. As it is the energy management system that monitors and has the overall control functionality of the power flow, it will be the integrating element in a totally integrated power, automation and positioning system. This includes:

- Power management.
- Blackout prevention.
- Power control of thrusters and other speed controlled loads.
- Fuel Optimization.

The new generation production vessels and also drill ships/rigs have a complex power system configuration with advanced protection and relaying philosophies. There are close connections between the functional design and performance of the power management system and the power protection system functions. It is a challenge for involved parties to obtain an optimal and functional solution with several suppliers involved and a yard being responsible for all coordination.

Fault situations

There are several possible faults in a power system, and the main task for the operator and control systems is to ensure that a fault in the system does not grow to the most serious fault, a total blackout. Some of the most common faults that in worst case can give a blackout are described in the following (example of faults not described in detail are loss of local controller, governor, AVR, sensor faults, etc.).

1.6 Generator trip

The most frequently occurring fault in a power system is sudden trip of a connected generator. There are several reasons for a generator trip to occur, and the consequence is that this will give a sudden increase in the load of the remaining generators. Hence, if the remaining generators are overloaded and no action is taken to reduce the generator load, the power system will experience a blackout.

1.7 Equipment fault

Fault in installed equipment is also an error that occurs from time to time in electrical power system. It the error occurring is an electrical short circuit, the voltage will immediately drop to zero if no actions are taken. Hence if no proper action is taken when a short circuit occur, all connected switchboards will experience a blackout.

Since this paper concentrates on PMS functionality, the solution to this fault situation will not be described in detail in this paper. However, in case of a short circuit in the power system, the short circuit protection devices will isolate the fault by opening the appropriate breakers. With correct design of the selectivity coordination in the protection devices, the fault isolation will happen fast and the healthy part of the system will continue to operate properly. Provided overload of the healthy system does not occur, the vessel can hold its position and, depending on design philosophy, and continue to operate until the fault is taken care of.

1.8 Overload

The power producing capacity on modern vessels are usually less than the total power of the installed consumers, e.g. pumps, thrusters, compressors, etc. The reason is that operational profile is used to reduce the generator ratings to again reduce the investment cost. In addition to this, the use of automatic start / stop functionality of power management system to reduce fuel consumption implies that in operation there will not be enough power for all consumers to use maximum power simultaneously. Obviously, this introduces the possibility for overload of the generators, which again can give a blackout in the overloaded system.

Operational philosophies

There are two principles of operating power systems on offshore installations, open or closed bus tiebreakers. In the Norwegian sector of the North Sea, rules and regulations from the government prohibit the operators to run all switchboards connected. The main argument for these rules is that under critical operation a total blackout must be avoided since the consequence can be a severe incident. Thus, by splitting the power system, total blackout is avoided and worst case scenario is a partial blackout. The drawback of this approach is that the risk of having a partial blackout increases since each subsystem is more vulnerable to generator trip and that it is not efficient with respect to fuel consumption. A consequence of the former is that the installation must be design such that secure operation can be maintained with blackout on one of the switchboards. In addition, power system design based on open tiebreakers and redundancy with respect to lost subsystem will in many cases have the highest investment costs.

Even though normal operation in DP vessels, in particular for class 3 operations, is to split the network in order to be tolerant to failure of one section, rules and regulations in other areas now allows for operation with closed tie breakers. The requirement for such operation is protection circuits that are designed to detect and isolate faulty parts without tripping the healthy parts. The advantages is that the system will be more robust to the most common faults, a sudden generator trip, and that it is the most efficient operation with respect to fuel consumption. A drawback of operating with closed tiebreakers is that the possibility of a total blackout cannot be neglected even though protection devices are design to avoid such a fault. However, the probability of such a fault is low.

Standard Blackout Prevention

1.9 DP power limitation

In normal operation it is vital that no consumer can create a blackout situation, and in dynamically positioned vessels, the largest consumers are the thrusters. Hence, properly handling of the thruster power is important to avoid thruster-induced blackout. The ABB Dynamic Positioning system has state of the art power limitation functionality and blackout due to thruster overload is not possible in normal operation.

The ABB Positioning System receives the available power from the energy management system. If the desired pitch/rpm setting is found to give a total load, which exceeds the available power in the system, the thrust set point is reduced.

Under normal circumstances, e.g. when no operating limits are exceeded, the DP system will reduce its power consumption sufficiently to avoid load shedding to be activated. However, under critical situations, the DP system must be allowed to use as much power as available, and have priority above other heavy consumers. This is obtained by subtracting a preset and configurable value from the available power value received from the PMS. This value should be sufficient large to prevent shedding, but small enough to start a new generator if available. If a critical situation should occur, the DP system will be allowed to utilize all available power even with the possible consequence of shedding heavy consumers.

Figure 1 shows full-scale results of the power limitation function on West Venture. The power system consists of four switchboards, each with two generators and two thrusters. During testing, the system was run in 4-split mode and the available power for thruster was reduced in order to verify power limitation. As indicated in the figure, available power was reduced to 0,3 MW on three of the busses in three steps. The final 10 minutes of the trial, only two thrusters had sufficient available power. In the right plot, the corresponding position is shown, and no deterioration of positioning performance was experienced.

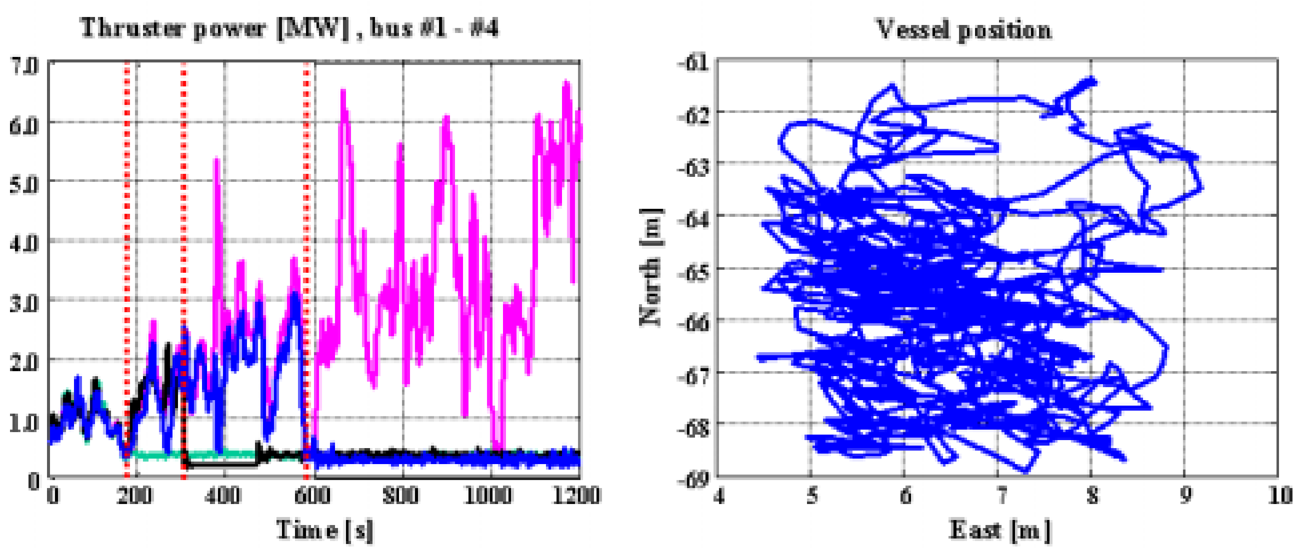


Figure 2, Full-scale data from West Venture. Left plot: The dotted lines indicate when available power on the busses are reduced to 0,3 MW. The solid line shows the total thruster power on each bus. Right plot: Vessel position.

The power reduction by use of PWM converters is very fast, limited only by the system's response times and mechanical limitations. This is under normal conditions sufficient to avoid overloading of the power generators by the DP system but cannot under all circumstances be fast enough to prevent blackout in case of sudden and large drop in generated power capacity, e.g. tripping of generator due to failure, see Chapter 0.

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1.10 Automatic start/stop of generators

The Power Management System includes functions for load dependent auto start / auto stop of diesel-generator sets. The objective is to ensure that the actual load is supplied by an appropriate number of generators to achieve best possible energy efficiency.

When the available power becomes below a preset limit a timer is trigged. If the available power remains under the limit for a preset time period (when the timer reaches zero) a start signal is given to the next generator in sequence. This is started and synchronized to the power bus automatically by a starting sequence which typically take 15-20 seconds. The limit for available power, time period, and starting sequence are configurable parameters. A typical time delay for auto start is 10 seconds. Opposite, when available power exceeds the limit where one generator is superfluous another timer is trigged. This will eventually give stop signal to the last running generator in the starting sequence. Also these limits and parameters are configurable.
Figure 2 shows a typical scenario from West Venture. The thruster load is increasing until the load on the generator exceeds 85 %. Then a start generator sequence is initiated to reduce the generator load. Starting and connecting a new generator take typically 30 sec, and in this time period the thruster load is increasing further. However, the power limitation function in the DP system avoids overload by reducing the thruster load until the new generator is connected.

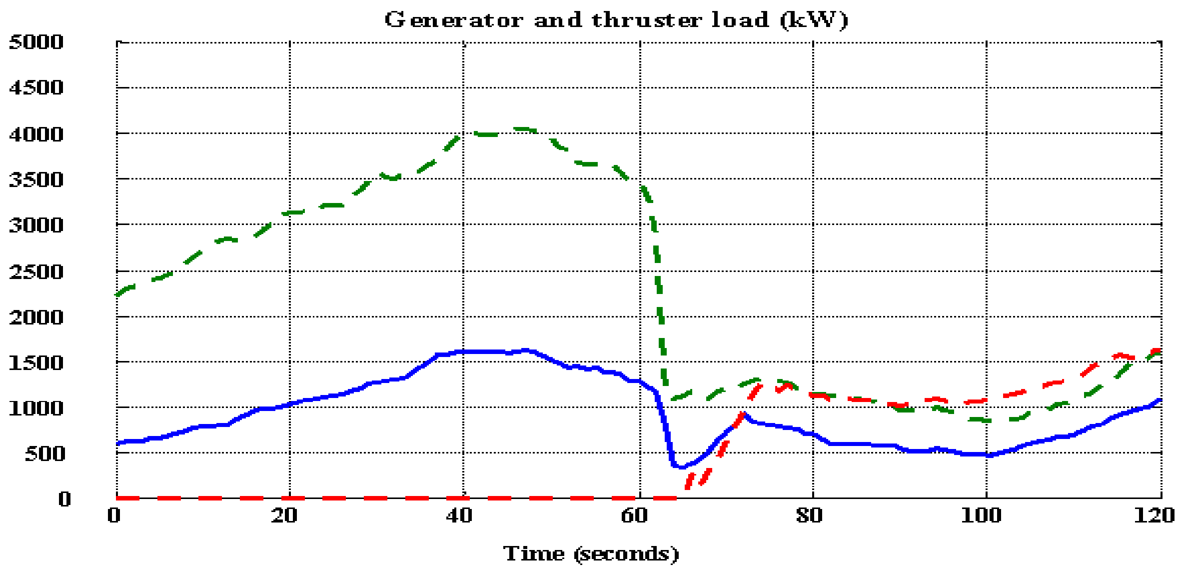

Figure 3, Full-scale data from West Venture. The solid line shows thruster power and the dotted generator power. After approximately 30 sec the generator load is so high that a new generator is started. The new generator is connected at 65 sec and is delivering at 75 sec. Notice that between 38 and 48 sec the DP system limits the thruster power to avoid overload.

The final setting of the auto start / auto stop and load shedding parameters should be finalized in cooperation with the customer, in order to ensure that operation philosophy is matched by the protection system. The setting should, however, fulfill at least following requirements:

1. Starting of new generator should be trigged before shedding is activated.
2. Stopping of generator should not lead to insufficient available power, initiating shedding or new auto start.
3. Consumers' priority should be reflected in the load shedding level for each consumer.
4. The minimum available power which is valid for the ITCS under normal operation, $P_{A,normal}$, should be higher than the limit for the load shedding functions, at least for those consumers which are essential for operation

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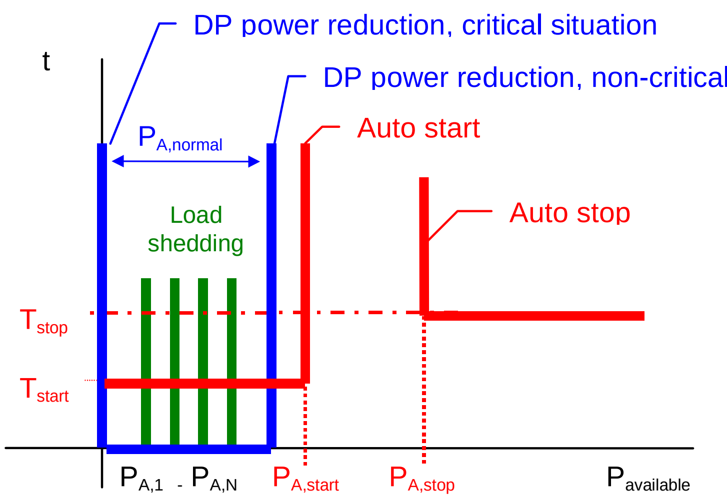
and production. It should, however be lower than the limit for auto start, in order to invoke the auto start function.

1.11 Load shedding

Power reduction and the auto start functions are not fast enough as black-out prevention after rapid and large loss of power generating capacity, e.g. after tripping of a generator. For this purpose, the load shedding function is implemented. This is a fast executing function for shedding of heavy consumers in a prioritized order when the available power comes under a preset limit. Each of the high voltage motors has individual settings for the limit of available power when they will trip. This level in terms defines the priority of the consumers.
It is also possible to define a time delay for each consumer as shown in the figure below. However, this is usually set to zero to ensure that generators do not trip before the shedding is activated. In practice, the time delay is given by the executing time of the load shedding function, typically less than 200 ms, and should be faster acting than generator protection relays.



1.12 Power limiting functions

The Safety and Automation System may comprise process control, safety systems, marine control systems, power management system, and positioning system. There are different levels of automatic control functions, which ensure power availability to critical consumers, maintaining black out prevention philosophy for the actual operating conditions. E.g. the local thruster controller in the frequency converter of a variable speed drive is parameterized to avoid excessive power, torque and speed levels, including their rise times, which would deteriorate the mechanical parts of the thruster drive. It is also protecting the electrical parts from thermal overloading and against failures.

1.13 Start acknowledge

In power system on vessels, there are usually a number of direct on line motors, e.g. constant-speed motor drives used with controllable pitch propellers (CPP). The motors are usually cage-type induction motors and may be designed with pole-changing switches to allow for two operating speeds. When started direct on line (DOL), the induction motor has a large starting current transient, typically 5-7 times the nominal current, with significant shaft torque transients and voltage drops in the network. To maintain voltage drop within the limit specified by rules and requirements, a minimum running generator capacity must be defined to be able to start a large motor. Star-delta switching is often used to provide higher starting torque with reduced transients, but is often not the best solution. Soft-starting devices such as auto-transformers have been shown to give better results. Solid-state soft starters are not commonly used for high power levels.

Independent of soft-starting devices, proper handling of motor starting is vital to avoid an overload situation during the startup transient. The ABB Power Management System has start acknowledge functionality and all motors specified as heavy consumers must ask for permission to start. If the PMS detects enough available power/current, connect acknowledge signal will be issued to the consumer which will then start. If there are not enough available power, the PMS will start a new generator and allow the consumer to start after the new generator is delivering.

Fast load reduction

The algorithms described in Chapter 0 are more or less standard in modern power systems. As mentioned in Chapter 4, the major fault situations with respect to number of occurrences are generator tripping and to the authors knowledge handling of these faults are by no means standard functionality.

In case of a generator trip, the main problem is the time aspect. In case of few generators running, a generator trip may result in generator load in the range of 140 – 160%, and thus the load must be reduced very fast to avoid trip of the remaining generators. Requirements from engine manufacturers like Man and Wärtsilä is that

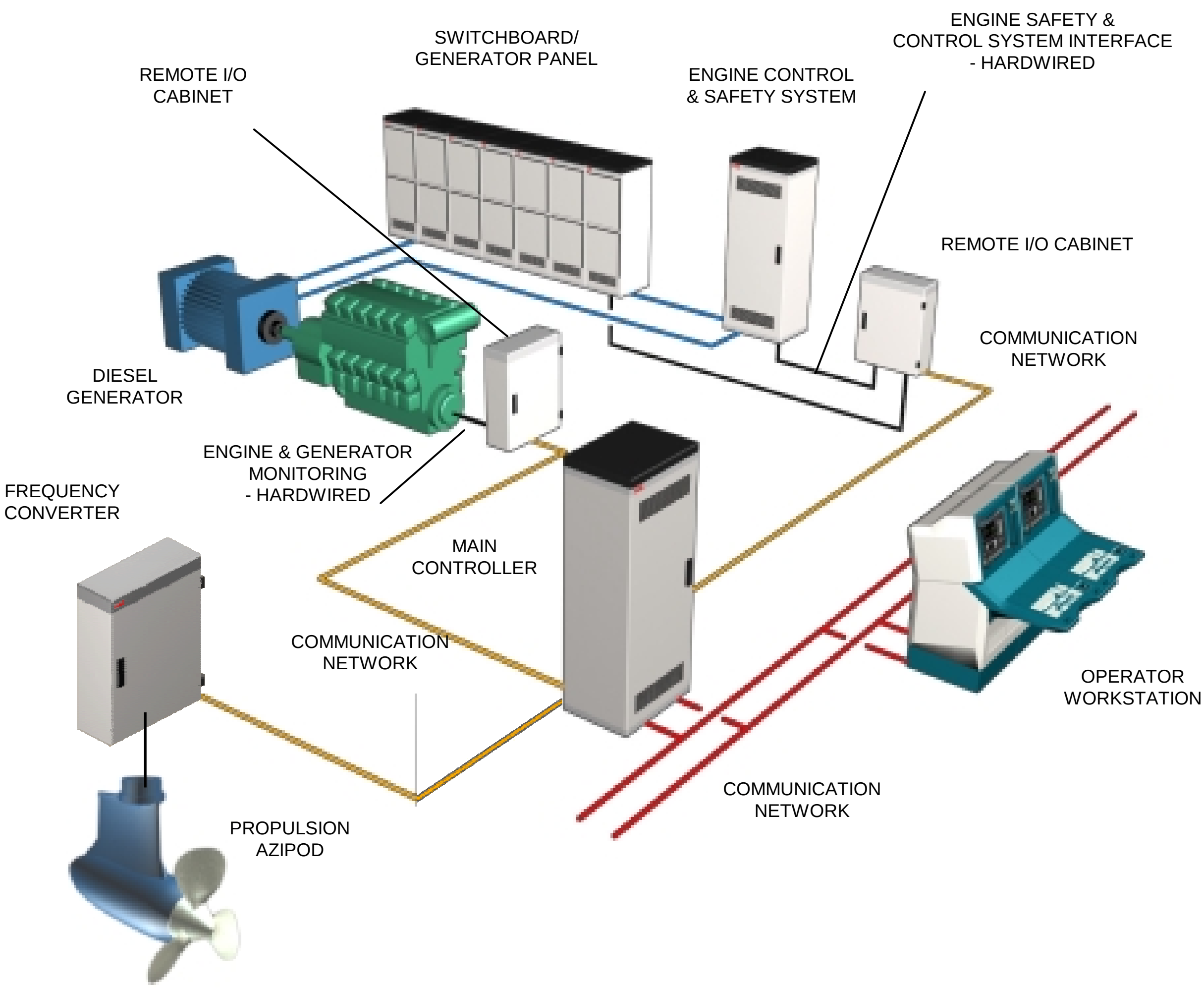


Figure 4, Typical hardware configuration in an ABB system.

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the load must be reduced within 0.5 – 1 second to avoid trip of the overloaded engine.
To handle this situation, ABB has developed an event-based load reduction algorithm that is fast enough to avoid blackout. Figure 3 shows a typical hardware configuration of an ABB automation system. When a generator breaker is tripped in the switchboard, the signal is hardwired to the remote I/O unit located near the switchboard. Next, the signal is transmitted to the PMS controller via fieldbus and made available for the event-based load reduction program. The time from trip to signal is received by the PMS controller is negligible. The PMS program initiating load reduction on the thrusters are dedicated to this task and its execution time is set to 50 milliseconds, five times faster than the rest of the PMS. Consequently, worst case scenario from signal is received to command is sent to converter is 100 milliseconds. Then a "reduce load signal" is transmitted to the converter, which again reduces the load to zero. The execution time and load reduction time in the converter is approximately 100 milliseconds. Hence, the total time from breaker is tripped until load is reduced is less than 250 milliseconds and thus well within the required 0,5 seconds. After a configurable number of seconds the "reduce load signal" is reset and thrusters are allowed to use the available power.

Extensive lab experiments has verified that the fast load reduction algorithm is fast enough to avoid blackout in case of generator trip, and it has been installed in recent deliveries.

Functional integration

The different philosophies of operating the power systems on vessels have both their strengths and weaknesses. However, functional integration can be used to operate the system such that the strengths from both philosophies are combined. A novel algorithm integrating the positioning system with the power management system has recently been developed by ABB. This function, which is a part of the positioning system, takes into account the power situation on each switchboard when calculating the thrust on each individual thruster. While conventional DP systems only try to minimize the total power used by thrusters, the ABB DP can be configured to take other criteria into account. Examples are fuel optimality, maximized power margins, equal load on each

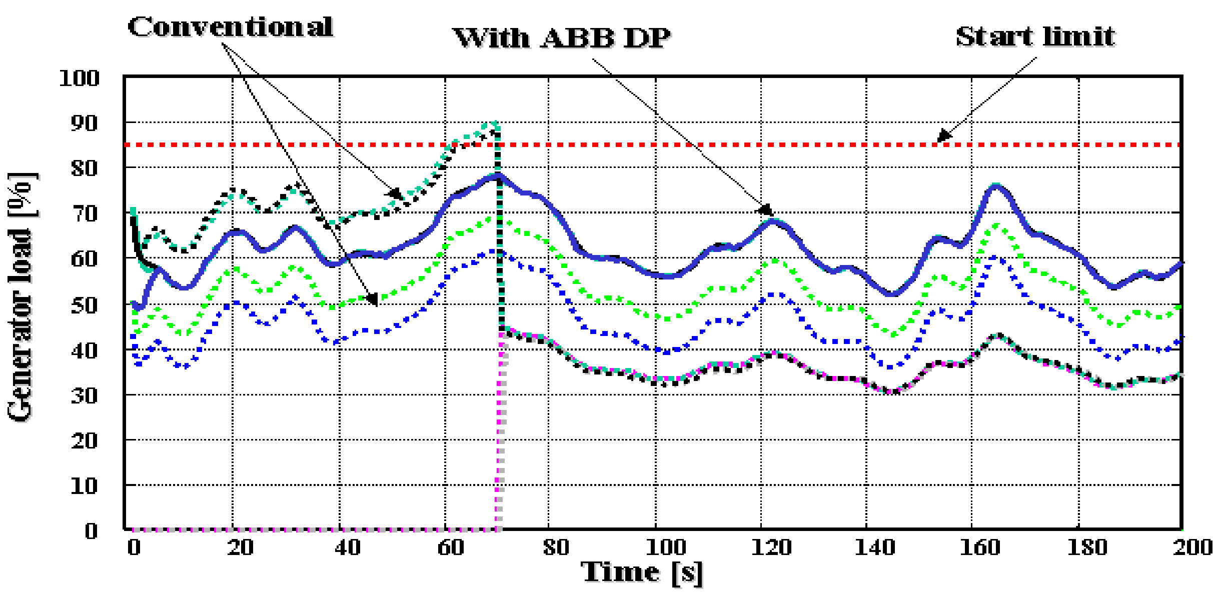

Figure 5, Simulation result for West Venture. The dotted lines show the generator load with a conventional DP system in 4-spli operation. It is seen that due to different load on the four switchboards (exclusive thrusters), two generators has to be connected at time 70 sec. With ABB DP (solid line), uneven thruster power is used to get equal load on each switchboard. Hence, it is not necessary to connect two new generators.

physical switchboard in split operation, etc. This is possible since the ABB system utilize the fact that usually there are a large number of thrusters installed compared to the number of directions to be controlled (surge, sway and yaw). This makes it possible for the DP system to move power from one switchboard to another using uneven thruster power. This algorithm together with the fast load reduction algorithm of Chapter 0 reduces the drawback of split operation since it will be robust to generator trip and fuel-efficient.

Figure 4 show a simulation case for West Venture. Uneven load on the switchboards (exclusive thrusters) is compensated for through uneven thruster load to maximize the margins on each switchboard.

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