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Integrated power and automations system for enhanced performance of DP class drilling vessels

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ABSTRACT

With the introduction of IEC 61850 communication standard in marine power systems new opportunities for increasing the operational performance (efficiency and safety) of DP drilling vessels are made possible. The first drilling vessels are now under construction using this communication technology, and new functionalities are gradually being implemented. Firstly the functionality of faster communication between protection systems and control systems make it possible to operate with closed bustie in DP2 and DP3 operation. This is achieved by introducing enhanced feature such as:

- Block based protection functions.
- Ultra-fast load reduction schemes.
- Enhanced engine and generator protection functions integrated in the main power switchboards.

Secondly, with more Intelligent Electronic Devices (IEDs) such as IEC61850 enabled protection relays onboard, the Power- and Automation systems are getting closer than ever. The ABB System 800xA automation platform is tailor-made to fully utilize the new communication standard in a way that power- and automation are not merely two systems exchanging data with each other, but more like one single system where all information is available anywhere instantly. This again opens the door to real-time condition-based monitoring and maintenance, and fully fledged asset management.

The 800xA platform supports the fast horizontal communication of IEC 61850 enabling advanced control loops, but IEC 61850 also support vertical communication where large amount of data can be collected and used for diagnostic and monitoring, typically using the protocol OPC on Windows computers. Such diagnostic data can be accessed locally through dedicated terminals or as an integrated part of the automation system, e.g. through the power management system user interface

This opens for cost effective solutions for collecting and monitoring data from entire drive-train e.g. protection relays, frequency converter, motors, generators, control and automation systems. This in result allows introducing techniques known nowadays as multi-sensor data fusion. Crew onboard, that is equipped with such a diagnostic system gain on receiving precise information about the origin of the fault and can immediately be supported from remote by expert technicians.

1. Introduction

In the last couple of years there has been a growing market demand for operating DP class drilling vessels with closed bus power system, even under the strictest DP requirements. The main motivation for going in this direction is to utilize the full potential of an electric power and propulsion system with respect to fuel efficiency, emissions and flexibility. For other ship types (e.g. cruise vessels and LNG carriers) this operation mode has been a standard ever since the electric propulsion principle was introduced for fuel saving reasons. However also for these vessels, redundancy and blackout prevention are, and have always been, essential requirements. This means that for whatever ship type under discussion using electric propulsion with centralized power plant principle, the power generation and distribution have always been split into minimum two or more sections. The difference lies within the operational principles established for each vessel segment, where ocean going vessels have had fuel efficiency as the main focus while station keeping DP vessels have had blackout prevention as the main focus. The easiest way to achieve up to 100% blackout free operation has been to run the power plant with open transfer breakers between switchboard sections. This means usually that the number of running power producing engines is higher than necessary, and thereby ran at lower load and lower efficiency than the optimal point of operation.

Today the fuel efficiency is getting higher priority also for drilling vessels, and thereby pushing the requirements for closing the transfer breakers under operation. However the safety requirements are still of equal or even higher importance than before, such that provisions must be made to existing power plant designs in order to prove an equal integrity towards any imaginable fault condition. This has led to added requirements from operators and classification societies for the design of the power and propulsion plant.

The technology development of products and system design is also moving forward. New generation of protection relays, new communication standards like IEC 61850 and automation systems supporting this standard is enabling a design being able to fulfill the new requirements for closed bus operation. Also, the possibility for all systems to communicate at the same level implies that a huge amount of data is available for diagnostic and monitoring. The basic principles with the implementation of the new relays and the IEC 61850 standard were discussed in detail in [1].

In this article we will focus on how this technology is used to comply with requirements for closed bus operation on DP drilling vessels. Further the potential for integrating the power and automation system in one uniform design built around the same IEC standard is discussed. Finally diagnostic and monitoring possibilities are highlighted.

2. Closed bus operation

Operating electric ship power systems with closed transfer breakers or bustie breakers is not a technical challenge as such, but a question of safety philosophy. Since the electric propulsion system using the centralized power plant principle was introduced in the 80s to a various number of ship and vessel types, the designs were basically always done with two or more separated switchboard systems. But operational wise they were designed to operate as one unit by use of transfer or bus-tie breakers. The protection system was designed with traditional time/current selectivity such that electrical faults anywhere in the system should not lead to total blackout. However the risk of blackout was never zero, and occasionally blackouts happened due to unforeseen failure modes or underestimated ride through capacities of healthy parts of power plants exposed to disturbances from faulty parts.

Today for DP Class 3 drilling vessels the question of closed bus operation is therefore a matter of minimizing this risk to the same level as operating in a split bus mode. Achieving this goal is done by close cooperation between ship-owners, suppliers and classification societies. The requirements have been market driven, and the suppliers have developed new solutions to fulfil these requirements. In parallel the classification societies have published

revised rules, additional notations, and guidance notes on how the integrity can be kept at the highest possible level.
It is, however, important to notice that most of the basic technology development, both in component level and system level has been done independent of closed or open bus operation. For example bringing the IEC 61850 communication standard as described in [1] into shipboard electric power distribution system, is a technology shift leading to several benefits of simpler design, more robust design and more information available for supporting monitoring, maintenance and serviceability.

2.1 Requirements for closed bus operation

Both DNV and ABS have issued new and revised rules for Dynamic Positioning systems, with requirements for closed bus operation [2], [3]. Together with market driven requirements and the technology development both in more advanced and intelligent devices and system configurations we have summarized the main closed bus operational requirements as follows:

- **Enhanced and robust power plant design;** Implemented zone protection with fast failure detection and discrimination of failed components or system. The zone protection act then as the primary protection function, and ***the traditional time-current selectivity settings will still function as backup protection*** in case of severe communication faults (see Figure 1).
- **Resistance to hidden failures;** Protection with backup arrangement as alternative action to isolate faulty system or components, self-diagnostic.
- **Enhanced Generator Protection system;** Protection for over- or under-fuelling and excitation as well as load sharing. These are failures that are normally not covered by the traditional protection relays, however considered as protection system and should be an integrated part of the overall protection system.
- **Autonomous systems;** Autonomous and decentralized thruster and generator systems to achieve segregation in order to minimize the effect of failures and dependencies.
- **Blackout prevention;** Fast load reduction to avoid overload due stopping of one or more generators in large consumers (mainly thruster and drilling Variable Speed Drives).
- **Fast blackout recovery;** with no manual interaction and full thruster control on DP within 45s, according to [2]
- **Transformer pre-magnetising;** For reduction of large inrush current and related voltage drop (mainly thrusters and drilling supply transformer) especially with one generator out of service.
- **Fault ride through capability;** For essential systems, especially on the low-voltage distribution side. It is important that faults are cleared as quickly as possible so time delay in under voltage devices and other fault tripping delays can be minimized.

Most of these functions would be natural to implement also for DP power systems without any closed bus requirements, and they are gradually included in what would be part of standard offerings to DP vessels.
Specifically for closed bus operation the additional requirements would be to prove that the new system has the same or higher integrity as the traditional designs. The only principle to get acceptance for this is to perform comprehensive FMEAs and full scale testing on-board after installation and commissioning.

2.1 Advanced power system with integrated intelligence

In this section we will concentrate on the main new technology features designed to fulfill above requirements. The basic starting point was the release of ABBs new generation of protection relays, the Relion® series. The new feature with this relay is the possibility to communicate with IEC 61850 standard using GOOSE (Generic Object Oriented System Event) for fast and accurate communication between relays and between switchboard and surrounding control and automation systems.

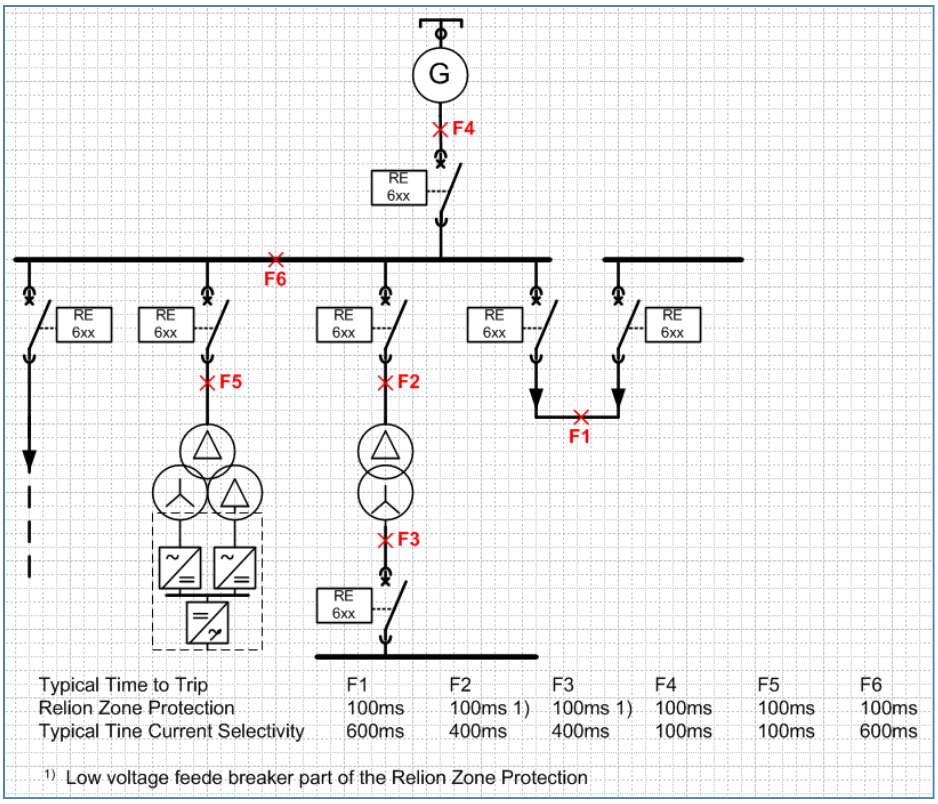

Figure 1. Comparison block based zone protection vs. traditional time-current selectivity

The new feature with this relay is the possibility to communicate with IEC 61850 standard using GOOSE (Generic Object Oriented System Event) for fast and accurate communication between relays and between switchboard and surrounding control and automation systems. The IEC 61850 defines communication between so called IEDs, (Intelligent Electronic Devices), and as such the protection relays are just another IED being able to communicate and share important values with other control systems and the integrated automation system (IAS). The basic description of the relays and the IEC 61850 features important for marine systems given in [1]. Here we will give more details about the two most important functions designed and adjusted also to fulfill the closed bus requirements.

<u>Switchboard Zone Protection:</u>
The switchboard configuration reflects the division of systems in redundancy groups throughout the design concept of the vessel. The switchboards are separated where each redundancy group has assigned an independent switchboard. Through switchboard segregation and selective protection functions the worst single failure within the main distribution system is limited to the loss of the switchboard which is exposed to the failure – following the basic design philosophy that any single failure will not cause total blackout. Figure 2 shows the basic zone and redundancy configuration for a four split power plant typically applicable for semi-submersible drilling rigs.

As busbar short-circuit zone protection the blocking based principle is used. Basic principle in this protection scheme is that an upstream circuit breaker instantaneous over-current stage selectively is allowed to trip or is blocked depending on location of the fault as detected and identified by the feeder circuit breaker. In case of an outgoing feeder circuit breaker protection relay detects a short circuit (fault out of the zone) this event is published throughout the switchboard communication network. The high speed GOOSE communication makes this information instantly available in the upstream circuit breaker protection relay. The upstream circuit breaker protection relay will block the instantaneous over-current stage and let the downstream feeder breaker clear the fault.

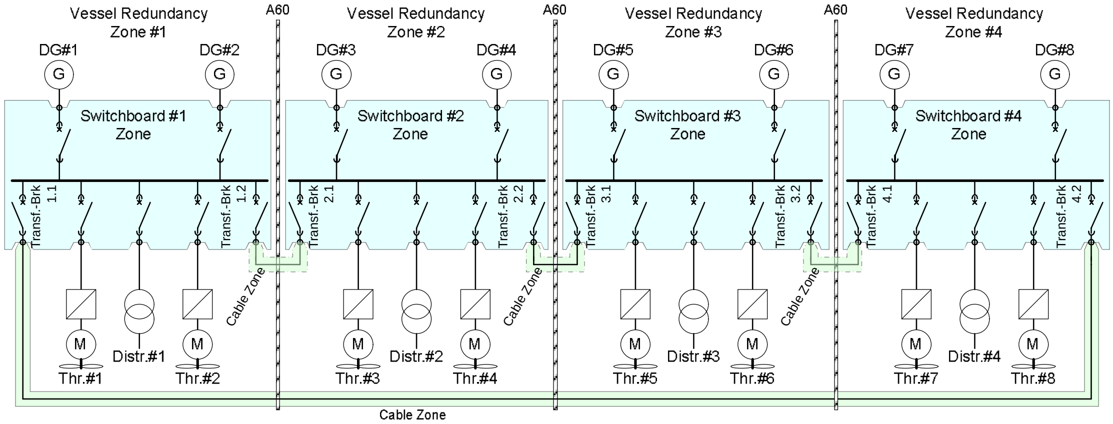

Figure 2. Four split SWBD zone configuration.

In case of an outgoing feeder circuit breaker protection relay detects a short circuit (fault out of the zone) this event is published throughout the switchboard communication network. The high speed GOOSE communication makes this information instantly available in the upstream circuit breaker protection relay. The upstream circuit breaker protection relay will block the instantaneous over-current stage and let the downstream feeder breaker clear the fault. In case of busbar short –circuit fault no outgoing feeder circuit breaker protection relay detects a short circuit (fault in the zone). The upstream circuit breaker protection relay will not receive block command, thus will not block the instantaneous over-current stage and issues a trip of the circuit breaker based on the instantaneous over-current stage settings and clears the fault on the busbar. Delay setting for instantaneous over-current stage in upstream circuit breaker is determined by the detection delay of the over-current detection in downstream feeder breaker (ca. 45-65ms) and GOOSE communication delay (<10ms).

In MV-Switchboard configuration with closed transfer-breaker (closed bus-tie) forming a line or ring to be able to selective isolate only the faulty switchboard segment the switchboard system is subdivided into zones. The zone definition follows the worst case failure design intent of the power plant. As the basic design intent a failure within a zone shall not propagate into the neighboring zones. This can only be achieved by opening the transfer breakers which connect the faulty zone with the healthy neighboring zones. With the faulty zone isolated the remaining healthy system continuous operation within the performance of its power plant configuration. Within the faulty zone standard protection functions will clear the failure and set the subsystem into to a safe state. For fast and selective zone failure detection and isolation each switchboard zone has its own independent zone protection.

With the definition of switchboard zones, inherently the cables connecting the switchboard section form a zone of itself. This cable zones allows for a fast and selective detection of cable short circuit failure and cable zone isolation. Cable zone failure detection is based on the same principles as the switchboard zone protection. Figure 3 shows the main principle and signal flow of blocking based zone protection. The zone bus-bar short circuit protection follows the blocking based principle where the zone transfer circuit breakers instantaneous over-current stage selectively is allowed to trip or is blocked depending on location of the fault as detected and identified by the feeder circuit breaker in the zone.
The blocking logic is failsafe. If no blocking command is received both transfer circuit breaker open and isolate the switchboard zone. Usually the protections relays have at minimum three over current stage instances available, mainly used as instantaneous (3I>>>), fast (3I>>), and slow (3I>) acting over-current stages. In the blocking based scheme only the instantaneous over-current stage can be blocked, the fast and slow over-current stages remains active all the time. The fast (3I>>) over-current stages ensure protection on standard time coordination selectivity between generator, transfer and feeder circuit breakers and function as a fallback and backup.

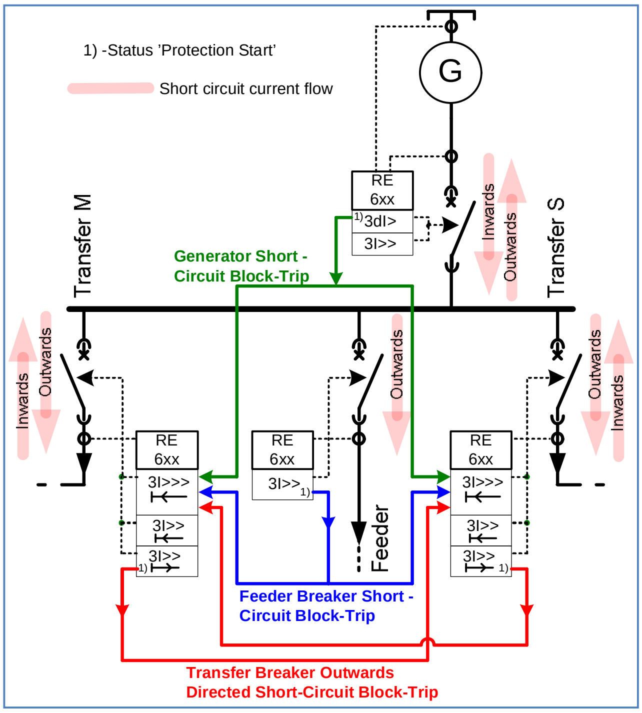

Figure 3. SWBD Zone protection principle.

<u>Enhanced Generator Protection System</u>

The early versions of enhanced generator protection were made based on the acknowledgement of certain failures that were difficult to catch by normal protection relays and apparently led to trip of healthy generators in first stage and then led to partial or full blackouts. Examples of such failures could be a fuel rack stuck in a fixed position leading to over or under fuelling of one engine. This could lead to other connected engines taking all load variations and thereby trip on overload or reverse power, leaving only the faulty generator on the network. ABB designed a DGMS (Diesel Generator & Monitoring System) to handle such faults by using various types of algorithms (as illustrated in Figure 4) as voting between three or more generators or looking at the expected correlation between certain parameters that should follow each other in normal situations, but not necessarily in faulty situations. Examples of such correlation are the Voltage – Reactive Power Output and Frequency – Active Power Output.

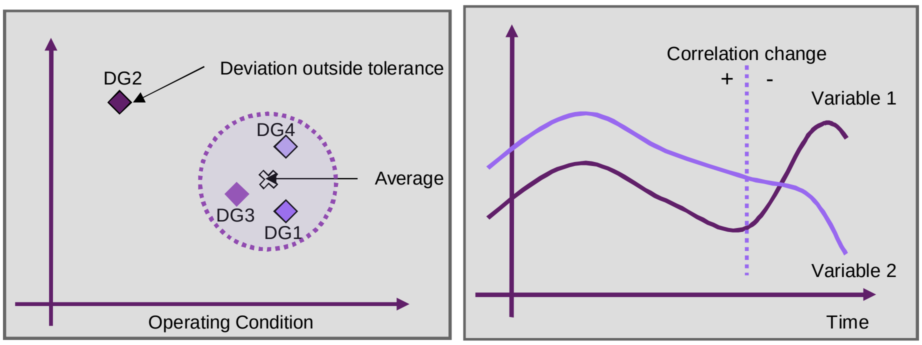

Figure 4. DGMS voting and correlation algorithm illustration.

Since the DGMS functions are programmed in PLCs being able to communicate on the same IEC 61850 standard as the protection relays, it is natural to integrate this system into the main swbd in such a way that the main swbd is self-contained with necessary protection functions to fulfill the closed bus requirements. The enhanced protection functions are also specified directly in the new enhanced DP class requirements from ABS [3] and DNV [2].

3. Integrating Power and Automation

3.1 IEC 61850 vertical communication

In section 2 we have discussed the GOOSE communication. GOOSE is one type of communication defined in IEC 61850. IEC 61850 standardizes the set of "Abstract Communication Service Interface services" – ACSI, allowing for compatible exchange of information among components. GOOSE is a publisher-subscriber model distribution of data with analogue and digital multicast which makes it suitable for the high speed demanding applications between devices described above.

For vertical communication from the devices up to the system level a Client/Server type of communication services model is defined for IEC 61850. This type of communication will not fulfill the hard real-time requirements of GOOSE, but is better suited for larger amount of information and other generic communication. This can provide measured and calculated data to the server level for e.g. visualization and debugging, it can provide data for logging etc. Both for operation of a vessel and for asset management issues, IEC 61850 enable valuable extension of the existing communication solutions necessary for a properly integrated power/automation system solution. We look here at solutions for operator interfaces and asset management where IEC 61850 is one of the communication solutions.

3.2 Operational information

The goal for a user interface is to support the safe vessel operation in all situations. Especially, when handling a critical event, fast access to critical information is the best way to ensure correct decisions. For a DP vessel, efficient and correct actions in a situation where there is an incident with the electrical system is essential and this is more likely to be successful if the user interface provides the right information in the right way.

To make it easy for the operator to navigate to the correct information in big systems, the system needs to be categorized into smaller more easy-to-grasp interface pictures. A well proven concept of presenting a system is the use of tabbed navigation. One tabbed navigation example is shown in Figure 5. Here the main marine systems have a top level tab with symbol and name and for each top level there are one or more sub-levels for reaching the relevant view. This provides a fast navigation.

Figure 5. Tabs improve the situational awareness without losing the ability to quickly navigate.

Figure 5 has modern design and gives a partly three-dimensional impression, but is kept in gray color. This is intentional because even more important than navigation in normal situations is the ability to navigate fast in emergency cases. Figure 6 illustrate how this navigation concept changes in an alarm situation. In this example a value reach an alarm level in the starboard shaft line. In this case there is a red indication on the "Propulsion" tab, under this on the "Starboard line" tab and finally on the "Shaft line" tab. In this way the engineer will very fast navigate to the view where he can get overview of the situation and be able to get more details about the problem. For alarms from electrical equipment detailed information can be available from IEC 61850 data from this view.

In Figure 7 a full screen with an example of a PMS overview picture is shown. Here we see that alarms are both displayed in a traditional alarm list, but also the generator that has an alarm is made very visible as this is the only big red symbol on the screen. This will be understood before any details are obtained. As a final example of this "high-performance HMI" design a detailed view of a diesel engine and generator is given in Figure 8.

Figure 6. Alarms are presented in the navigation to increase the situational awareness of the operator.

This illustrates a warning where yellow color is used to highlight the element of attention. This figure also illustrates the focus on displaying analogue values graphically which is much easier to read fast than numerical values. It also shows how modest graphical shadows are used to indicate the engine without taking attention from the measurements displayed here. This shows that information flow to get all relevant data to the operator is critical, but it can be done a lot of improvements on how the data is presented. Efficiency of a user interface for a DP vessel should be measured on how good it helps the crew to make the right decisions in critical situations.

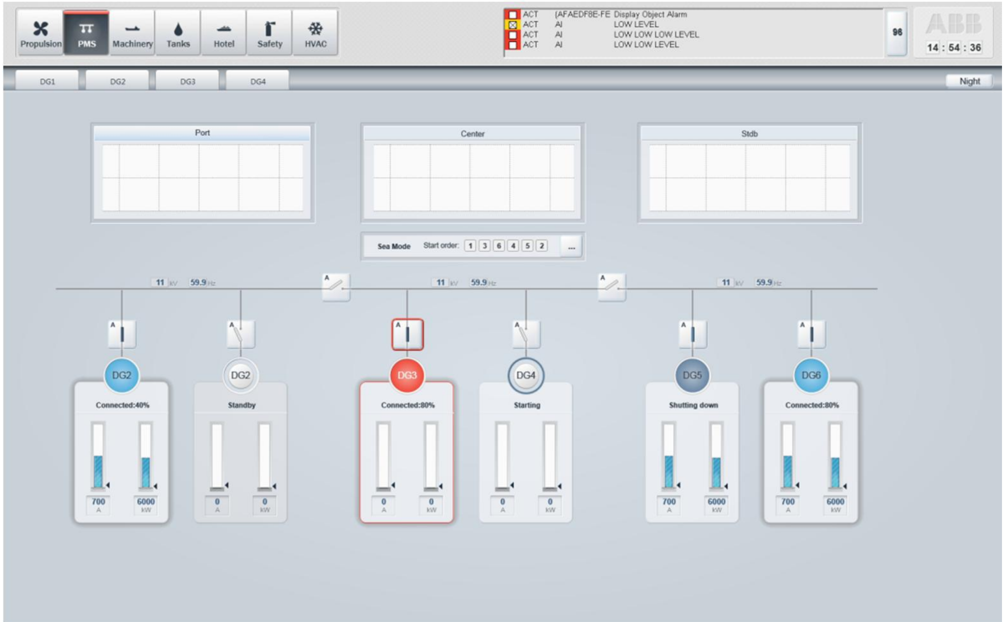

Figure 7. Diesel Generator graphical element with an alarm in the Power Management System overview picture

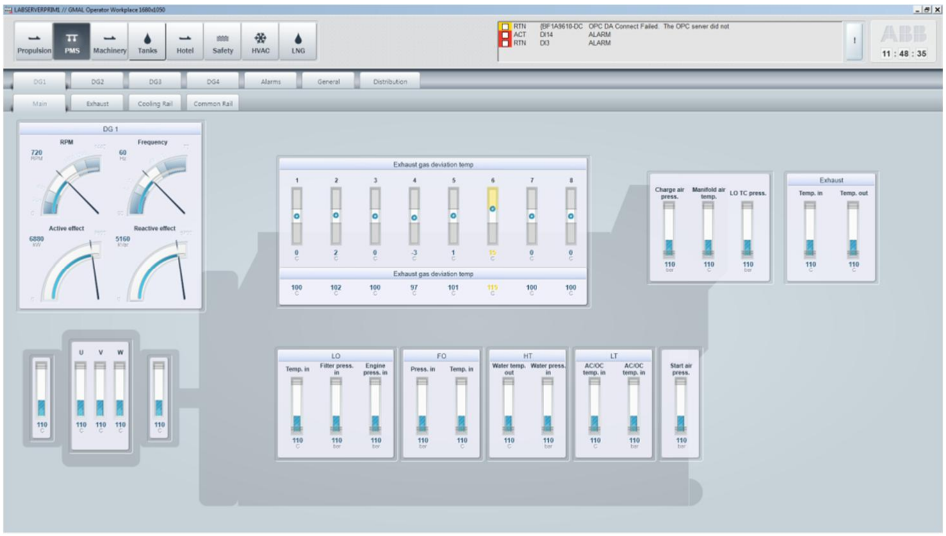

Figure 8. Static and dynamic graphically elements

3.3 Maintenance solutions with examples

Figure 9 provides a conceptual overview of an advanced asset management solution. Maintenance can be very much improved and made more efficient with advanced use of computer systems and combination of communication solutions such as IEC 61850. As illustrated, the system is based on that there exist monitors for the equipment under supervision and these monitors is connected to various other systems. Operator interfaces receives alarms and warnings, remote connection to service centers gives fast access to equipment experts and reports can be given to ship owners/operators and it is even possible to automatic generation of work orders to the maintenance people.

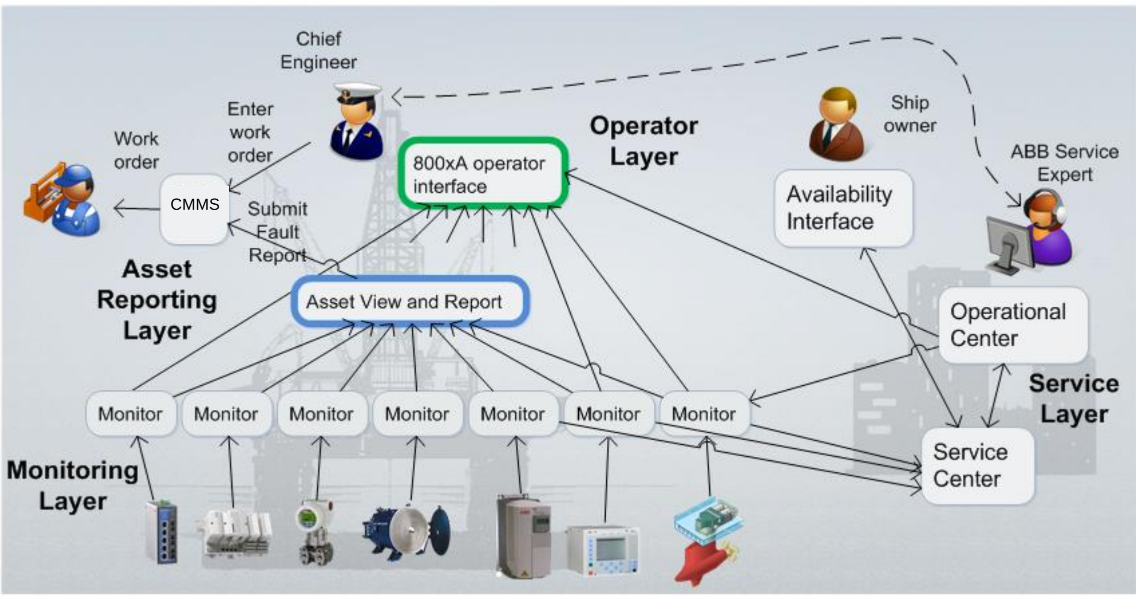

Figure 9 Integrated automation solution

As long as Figure 9 presents an overview of variety of information that the automation system may bring on operator's panel, Figure 10 gives a closer look on the building blocks of advanced monitoring and maintenance system, and how information is shared between the layers of the integrated system, taking all advantages of intelligent devices, protocols and condition monitoring techniques.

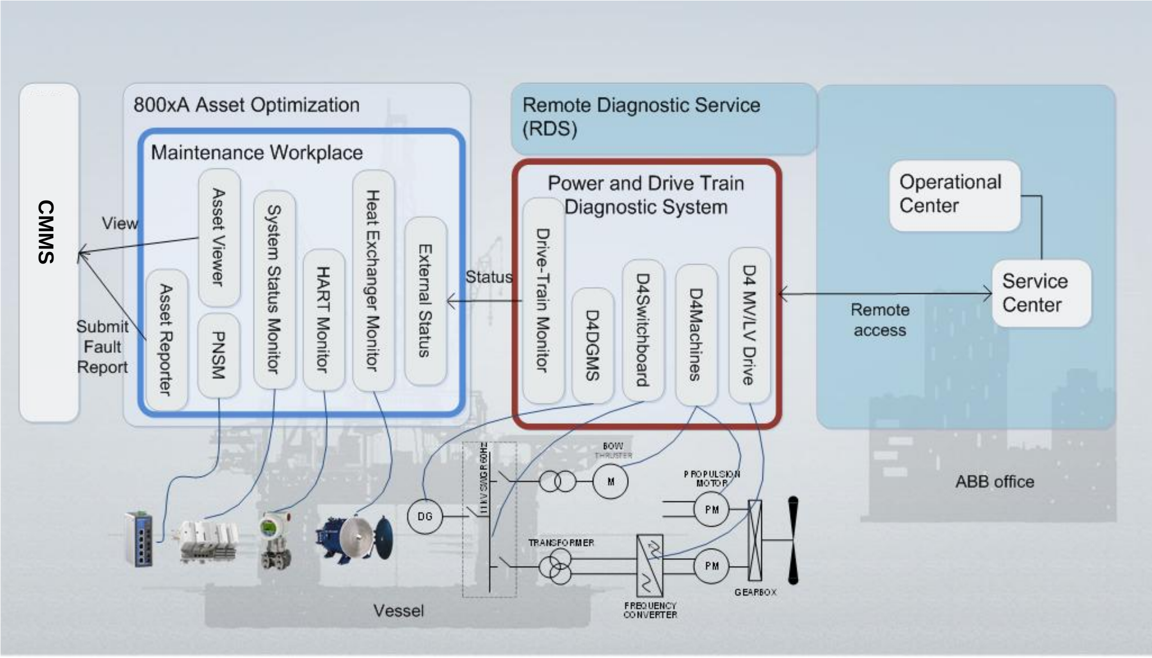

Figure 10 Maintenance solution in details

Examples of diagnostic solutions presented in this section of the article are related to monitoring of electric power-drive train system on its component and subsystem level. In practice, monitoring system for electric propulsion or drilling train can be delivered with or without integration to upper automation system. Both cases are discussed in the following chapters.

3.4 Quality of information – from troubleshooting to preventive maintenance

The operator workplace of integrated automation system (as shown on Figure 9 framed with green) is designed so it presents all necessary information in a way it is very intuitive to determine the status of machinery. Such an assessment has to be done with a single glance at the process panels. For the panel design, the goal here is to find a perfect optimum between presenting as many indicators as it is required to react correctly and on the other hand as few of them as it is needed to avoid information overload.

In an undesired case when one of the critical system components gets to faulty state and the process is tripped, quick and safe rectification of the problem becomes a task with highest priority for everyone onboard. In such a case looking at the operator workplace itself may and will not help at all. The typical example could be a thruster system trip – operator workplace may tell the operator that system tripped due to common fault from frequency converters lineup. In a good scenario, navigating on the operator panel one step deeper may identify the source of trip into single inverter module. However, the possible cause of the failure and hints for rectification stay unknown as they never were intended to be displayed on the operator panel.

Modern integrated automation systems have however a functionality of changing the view depending on what is currently of highest interests. In a discussed case the natural choice for the operator is to switch to maintenance workplace (see Figure 10 framed with blue) and read exact fault message generated by the intelligent device itself (frequency converter) together with all troubleshooting hints that are associated with it.

In case the crew onboard is very well familiar with the equipment, and based on the information received from the maintenance workplace are able to fix the faulty component, the rectification process ends at this point and the system is put back to operation. This may not however be the usual case if there are still several candidates in the system to be the

primary reason for a trip. Calling service specialists from the original equipment vendor may be required in this case, and will lead to even longer downtime and additional expenses.
This however, can be avoided as modern, advanced integrated automation systems like the ABB System 800xA, can be equipped with secure, satellite link to onshore support center that is to be used by the same service specialist within minutes after it is requested (see Figure 10, dark blue box). Support engineer in this case would look yet into another layer of automation system – a diagnostic and monitoring system that is specifically designed to continuously collect all necessary, high-resolution measurement from critical components (Figure 10, marked with red).
The principle of data logging and analysis that takes place on the diagnostic system level is to take all advantages of intelligent electronic devices (IEDs - such as protection relays, frequency converters and PLC controllers) and use it exclusively for troubleshooting and condition monitoring purposes. Type, resolution, quality and amount of data collected by diagnostic system may be to some extend similar but in most of cases go beyond requirements of what typical control system needs. On the other hand since physical wiring and cabling is usually limited to interfaces defined for control and protection purposes, there is quite limited scope and quality of signals available at the upper level of control and automation system that can be effectively used by diagnostic system for detailed troubleshooting and advanced condition monitoring.

The solution is utilization of communication standards such as the IEC 61850, together with all additional connectivity - means that modern IEDs offer nowadays. In the scenario of the fault rectification presented earlier in this chapter, the same support engineer would access high resolution data loggers (sampled with e.g. 10kHz) recorded by the device itself at the moment it was tripped and stored for further fault tracing analysis by diagnostic system. Such an analysis, performed from remote would identify exact root cause of the problem and lead to rectification and system restart in shortest possible time.
Typical example where enabling MV protection relays with horizontal, ethernet based IEC61850 communication is facilitating key signals acquisition into diagnostic system without necessity of pulling extensive wiring is presented in Figure 11.

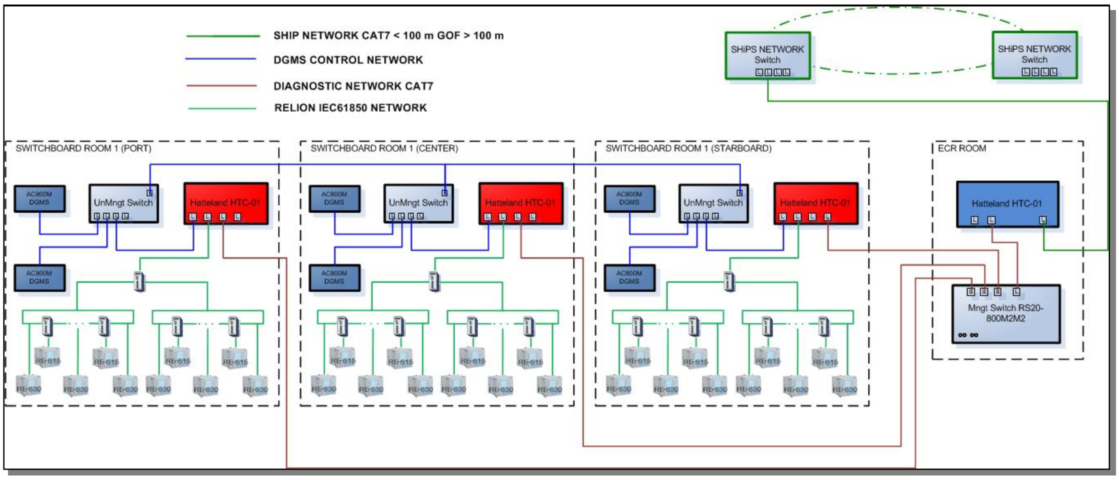

Figure 11 DGMS and protection system with diagnostics

Events and transient recorders from each individual protection relay are uploaded to the diagnostic system and presented on the same chart having common time axis. Since protection relays implement SNTP time synchronization and are synchronized to the same master clock, the analysis of electrical fault propagation across the MV switchboard can be done on the system level with the time span manipulated from single milliseconds to several seconds.
In the real case presented in Figure 12, the primary source of the blackout can be identified as under-voltage fault caused by malfunction of the automatic voltage regulator.

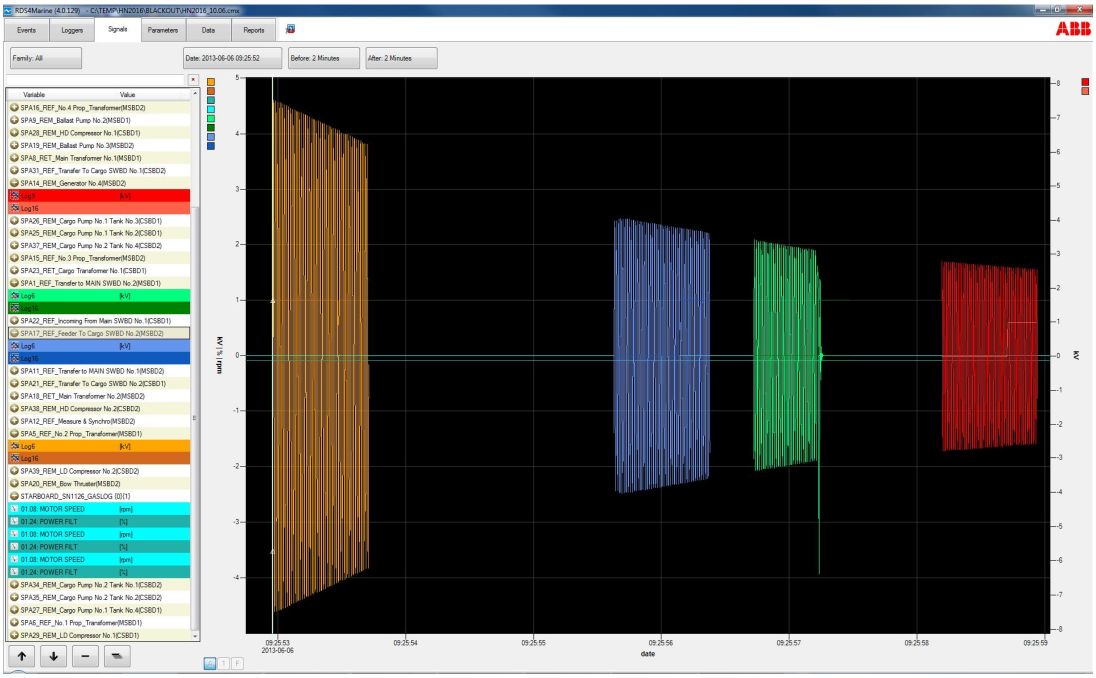

Figure 12 Blackout analysis

Finding root cause of the failure and solving the problem in shortest possible time obviously brings a lot of added value for system operators. But the same high quality information collected by diagnostic system for troubleshooting purposes can be effectively used for preventive maintenance by introducing techniques that can elaborate a condition of the device. One of the very good examples is an advanced monitoring of rotating equipment, such as generators, propulsion or thruster motors. These components also belong to the power and drive train, and in order to get the best possible quality of condition assessment a combination of different techniques and physical measurements is applied.

For typical, asynchronous thruster motor driven by frequency converters, mechanical failures are primarily detected by analyzing vibrations measured and collected by additional accelerometers and data acquisition units. The analysis itself typically takes place onboard diagnostic systems. Vibration measurements are scanned with different types of algorithms to isolate typical faults e.g. roller bearing component failures, motor misalignment, rotor eccentricity, broken rotor bars, etc. As a result, corresponding message is generated by a diagnostic system indicating detection of specific faults in the earliest possible stage and is shown either on the local HMI of the diagnostic system or can be forwarded to IAS and its maintenance workplace.
Other type of analysis is based on electrical measurements and typically involves spectrum analysis of motor phase currents. Since installation of additional current and voltage probes for retrofit projects proves to be troublesome, the advantage of having measurements available already onboard intelligent devices is fully utilized. The example could be the same thruster motor with 6 poles rotor and rated speed of 1200RPM. With the capabilities of protection relay to measure transient recorders with 1920Hz sampling frequency, the effective frequency span for spectrum analysis is up to approx. 800Hz which allows analyzing rotor bar defects or rotor eccentricity very efficiently basing only on measurements acquired by diagnostic system from protection relay.

Diagnostic system dedicated for monitoring power and propulsion or drilling train can act as a standalone application with its own local HMI and secure link to remote connection but the real benefit for the end customer is when information processed and derived by diagnostic system is forwarded to maintenance workplace implemented on integrated automation system.

The direction of information flow may not only be limited to a scenario where diagnostic system feeds automation system with asset condition related information. The IAS contains itself a lot of measurements that can only enhance monitoring solutions once fed to diagnostic system. Example is generator - typically journal bearing temperatures and lubrication oil cooling system temperatures are directly wired from generator to IAS. They are not used by any protection or control system, but once provided to the diagnostic system (show the arrow on the picture) they enhance condition monitoring of journal bearing with typically very robust prognostics based on temperature measurements.

4. Concluding Remarks

Introduction of intelligent electronic devices (IEDs) and protocols based on the IEC61850 communication standard makes it possible to implement autonomous control systems that address novel class requirements such as closed bus operation and blackout prevention and fast recovery. In addition, as an added value it opens almost unlimited possibilities for acquiring and processing data from various sub systems with the specific purpose those system are designed for. This article gives an overview on how the same type of low level measurements derived from both power and automation systems can be equally efficiently used for protection and control purposes as well as with additional processing by dedicated diagnostic system, in order to provide comprehensive information about the root cause of the fault or actual condition of the asset. In addition, through smart integration with high level, integrated automation systems we create an overview of all assets condition and facilitate inventory management by automatic order generation sent to Computerized Maintenance and Management Systems.

References

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