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Risk

Blackout Prevention & Recovery

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Abstract

Blackout is a condition where a ship experiences a total loss of electric power. The term "partial blackout" is sometimes used to describe loss of electric power in parts of the electric system, e.g. in one part of a redundant system.

For DP vessels and drilling rigs, a total loss of electric power is of course one of the most severe failures that can occur, where all electric systems are lost unless powered by battery back-up, and thrusters driven by electric motors are unavailable for station keeping. Blackout is therefore a condition to be avoided by all practical means, and if it yet should occur, restoring of the power plant should be reliable and within an adequate time. The term "adequate" time is used since it not necessarily means "as fast as possible"; the different vessel and their operational requirements influence the targeted recovery time. With an "as fast as possible" approach, the systems will become more complex to operate, using additional components and functionalities with new failure modes, and hence the required start up time must be considered during the design, without compromising the overall safety of the operations.

In this paper, various techniques that are used for black-out prevention, such as PMS load limitation, event based load reduction, frequency based load control, and advanced techniques for monitoring of the health of the power plant is being presented.

Black-out restart time sequences should be carefully defined in order to avoid unnecessary delays of the recovery of the electric power system. The paper presents methods to reduce the time sequence by critically evaluating the order and delay of events, both in conventional systems, and in system with enhanced recovery time functionality.

Introduction

Prevention of black-out and availability of electric power is essential for ships with electric propulsion and for DP vessels in particular.

As any man made technical system sooner or later inevitable will fail, efforts must be used in order to reduce the likelihood of failure by proper design, monitoring, and maintenance; but at least equally important, to reduce the consequences of failures. The starting point for a reliable and available electrical power plant is to use proper and proven engineering methods in the design and engineering phase, in particular with respect to analysis of any possible fault scenario.

Analysis of actual incidents from operations gives valuable insight in the real causes of black-out and other undesired behavior, which should be used when deciding where the main efforts should be made in order to gain the best effect on safety. Though there do exist some data bases of incidents, they are to some extent inadequate due to lack of reporting and not sufficient details on the root cause. Statistics from Petrobras was presented by Pallaoro at the DPC 2005 /1/ and then categorized the root cause for black-out incidents into;

- Human error
- Protection system
- Fail / lack of maintenance
- Project and commissioning
- Lack of procedures

The statistics were gathered from 1992 to 2004; and the distribution of the root causes were shown as total over the 13-years period, and then for the last 5-year period, see Figure 1. In this 5 years period, several of the drilling vessels being built in the late 90's were put in operation, concurrent with DP vessels of earlier origin.

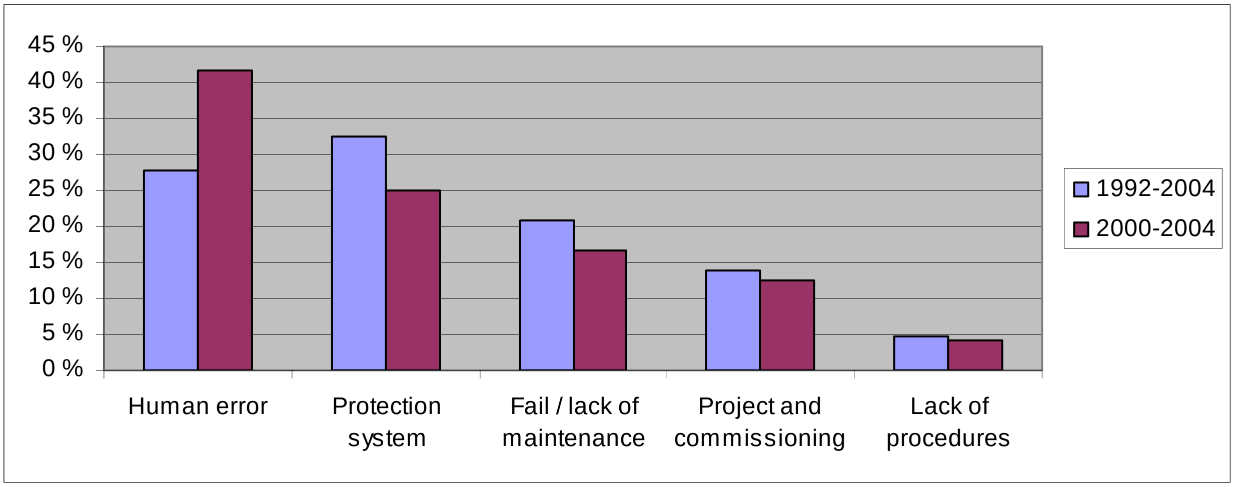

Figure 1: Root causes for black-out, data from Petrobras /1/.

Although the statistic material is limited, 43 incidents totally, and 24 incidents in the last 5-years period, some considerations can be made. The more important is the conspicuous increase in the ratio of human errors; while more technical reasons showed some slightly reduction in the trend, most obvious those related to the protection system.

It is in authors' view, likely that contributing to this positive trend on the technical side is the introduction of newer vessels, such as the 5th generation drilling rigs, with a new generation of variable speed thruster and drilling drives with far better characteristics than the fixed speed or current source inverter drive thruster drives and DC drilling drives that was state-of-the-art during the late 80's and early 90's. In particular, the technology transfer to the use of VSI (voltage source inverter) technology was a leap forward in order to optimize the power plant and enhance the black-out prevention performance.

Also, during the 90's more sophisticated electric power system protection systems and black-out prevention functionalities were implemented in marine electric systems. Digital, multifunction protection systems that are introduced in the latest past open for more advanced and compound protection functionalities than possible, only few years earlier.

On the other hand, although the later electrical power plants are more reliable than before, each incident is one too many; and further efforts to enhance the reliability of the power plant is needed and also achievable. This paper presents methods and solutions being developed and implemented in the recent past for DP vessels and ships with electric propulsion. It is not the intention to introduce total new concepts to the already proven systems, but to focus on the areas where experience and operational statistics show to have greatest improvement potential and too maintain the simplicity of the existing systems.

Power Management and Load Reduction

The power management system is an essential function to provide optimal and safe operation of the electric power plant and diesel engines. It shall ensure that sufficient power is available for the intended operations, and at the same time optimize the power plant for reduced fuel consumption, and thereby better operational economy and reduced environmental emissions.

One of the critical functions in the power management system is the load reduction function. This shall not only provide a function for avoiding overload of the power plant by increasing load demands of the thrusters and other loads, but also to provide fast load reduction for power controlled consumers, such as the thrusters, in the event of sudden loss of power generator capacity that will occur if a diesel engine should stop.

Such fast acting load reduction systems have shown to be challenging to implement in the power management systems, since the required time response is short. Figure 2 indicates from typical systems, what the capability of a diesel-generator set has to provide sudden steps in loads. The physic behind these curves is based on, that the governor of the diesel engines cannot act fast enough to prevent the initial drop in speed when the load increases suddenly, as will happen at the healthy diesel engines upon a trip of an engine that is paralleled at the electric power plant. During the first instant after the trip of the paralleled engine, the load increase must be provided by the inertial of the diesel engine and the generator, as well as other rotating loads in the network.

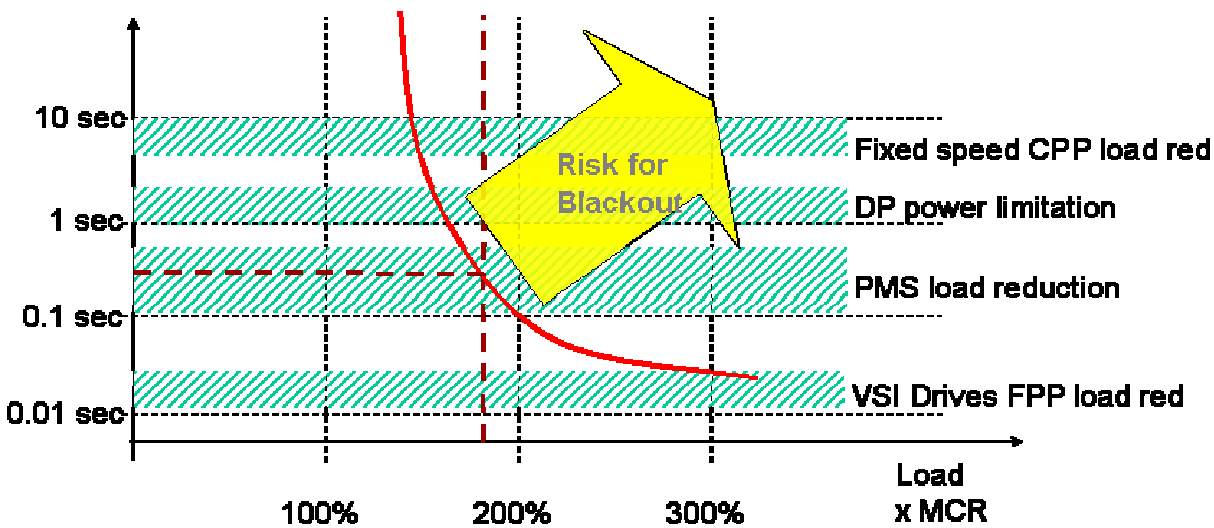

Figure 2: Typical curve for a diesel engine driven generator; showing the inherent capability of the diesel engine driven generators to provide sudden load steps before driving into under frequency.

As seen, using fixed speed controllable pitch propeller (CPP) thrusters, as was commonly used in the early 90's, the time to control the load was unacceptable long, and the only way to prevent black-out was to shed the thrusters from the network; leading to loss of positioning capability and capacity. Also, the load reduction that is a requirement for DP control system is far too slow to avoid black-out in situations with sudden loss of generator capacity.

The load reduction of the power management may, if made fast acting and event based, give a response time that is short enough to prevent most of the overload scenarios; however, it has been observed that the response time of even relative new power management control systems are up to 1000ms from the event to the actual load reduction signal is being issued. Normally, maximum 300ms is required, meaning that the frequency converter of the variable speed thruster drives must have a built in monitoring of the power plant; either by monitoring the network frequency or the generator circuit breakers, in order to achieve a sufficient fast acting black-out preventing load reduction. Such functionality has now become common in ABB's thruster and propulsion control systems, and proven in tests to give ultra fast response times, and even with high step loads of the power plant and excessive overload of the healthy engines, able to reduce the power demand quick enough to avoid intolerable frequency drops. Figure 3 shows the results from a vessel with electric propulsion, and the behavior of the system frequency upon trip of one by one of the four dual fuel engines. It must also be noted that the three first engines to be stopped had a rating of two times the last engine to be on-line, meaning that the last and smallest engine was short time exposed to a 3x nominal peak power. As seen, the load was reduced fast enough to keep the frequency of the network well within the operational limits (+/-10%). In this particular case, the generator incomer breakers to the main switchboard were monitored.

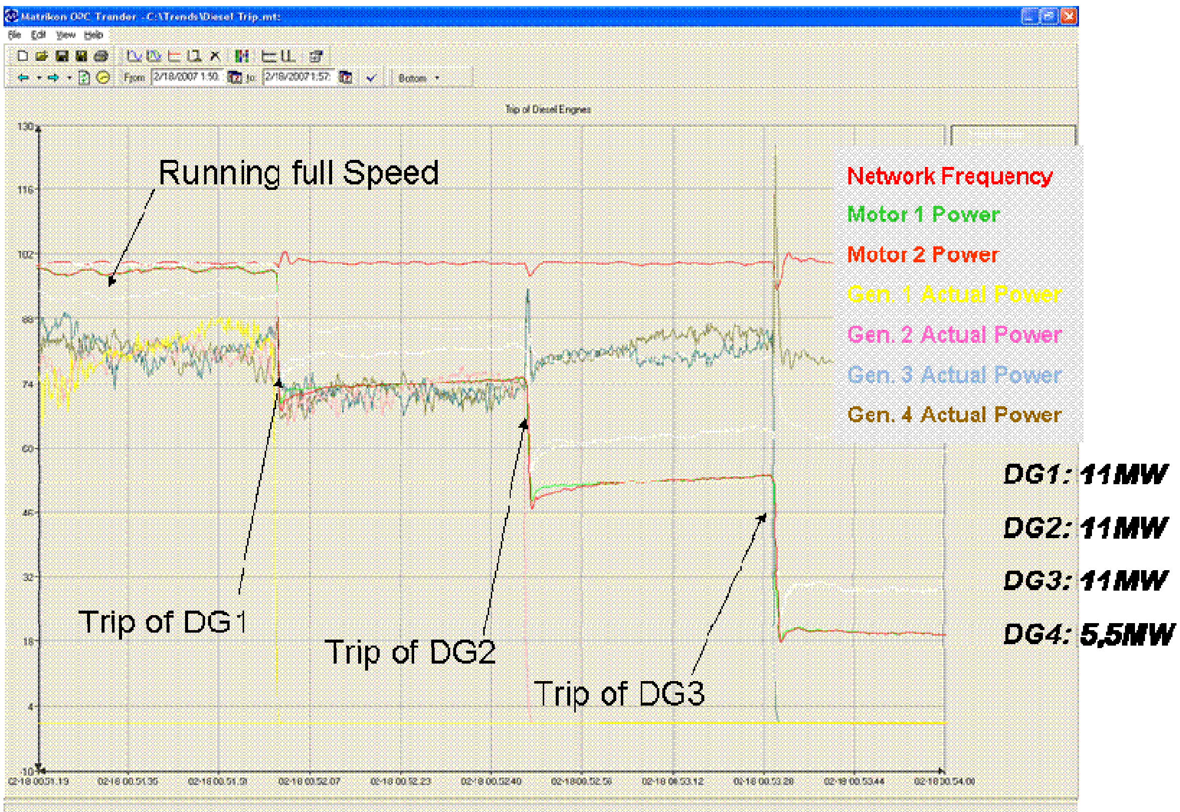

Figure 3: The load and frequency behavior after sudden trip of engines in a vessel with electric propulsion. Load reduction in the propulsion control ensured that the network frequency kept well within the operational constraints.

Diesel Generator Monitoring System

A traditional marine power system for mobile offshore units consist of power generation, power distribution, and variable speed thruster drives as the main parts of the vessel electric power and propulsion systems. In addition each vessel type has certain power consumers corresponding to their operational characteristic, e.g. drilling equipment on drill ships/rigs.
Power generation is the most essential part in these "all-electric" vessel concepts. Even though it usually consists of several generating units, these are most commonly operated in parallel and electrically

connected via the main switchboard. The worst case scenario is then a single failure leading to a total blackout of the power system.

The most obvious and common case to avoid this kind of situation is to split the power plant into several independent units. This is anyway incorporated in the design as usually 3 or 4 split configurations for drilling vessels, however with the possibility to operate with closed bus breakers. The advantage of operating in closed breaker condition is the possibility to optimize the power loading of the running generators in order to consume as less fuel as possible. However this has not been allowed for the most severe DP operations in harsh weather conditions or in general for operation with DP class 3.

Protection of the power plant against the most severe electrical failure conditions are done by protection relays which continuously monitors the voltage and current at each feeder or incomer in the switchboards. These relays disconnect equipment exposed to electrical failures as short circuit, over current, abnormal voltages, etc, in order to avoid/minimize component damages. Even though the relay settings are done in a selective way in order to minimize the affected area, there are no guarantees that the relays will not trip the whole production plant for certain failures. The root cause for such trip and disconnections may be difficult to discover, as they may differ from the direct cause of the trip (current, voltage or frequency out of safe operation range).

The Diesel Generator Monitoring System (DGMS) from ABB is designed to detect such failures that are not directly detected by the protection relays. The main purpose for the DGMS is to issue an alarm enabling the operator to make some protective actions before a blackout situation occurs, and in the outmost consequence isolate and trip the faulty generator set.

Figure 4: DGMS cabinet with standard dimension of 830 x 410 x 1140mm (LxWxH)

ABB introduced DGMS as additional generator monitoring in 2003, and it was installed on the pipe layer "Sunrise 2000" in 2004. This first installation was a tailor made product according the vessel electrical particulars. In this section we will present the next modular version of the DGMS which is designed for use on power systems including up to 8 generators and 8 switchboard splits. The basic concept is to install one cabinet per installed generator. Each cabinet consist of an AC800 PLC, with corresponding I/O modules, power supply, etc. See Figure 4 for an example picture of the wall mountable cabinet.

Interface:
Each cabinet is interfaced to the generator, Automatic Voltage Regulator (AVR), switchboard, engine and governor as shown in Figure 5.
In addition there is a possibility of connecting each DGMS cabinet to each other via an Ethernet ring for data sharing. This feature is required for systems operating in isochronous speed mode where data sharing is necessary to detect which of the generator sets that are running with faulty conditions. This feature can be disabled on systems where only speed droop operations mode is used.

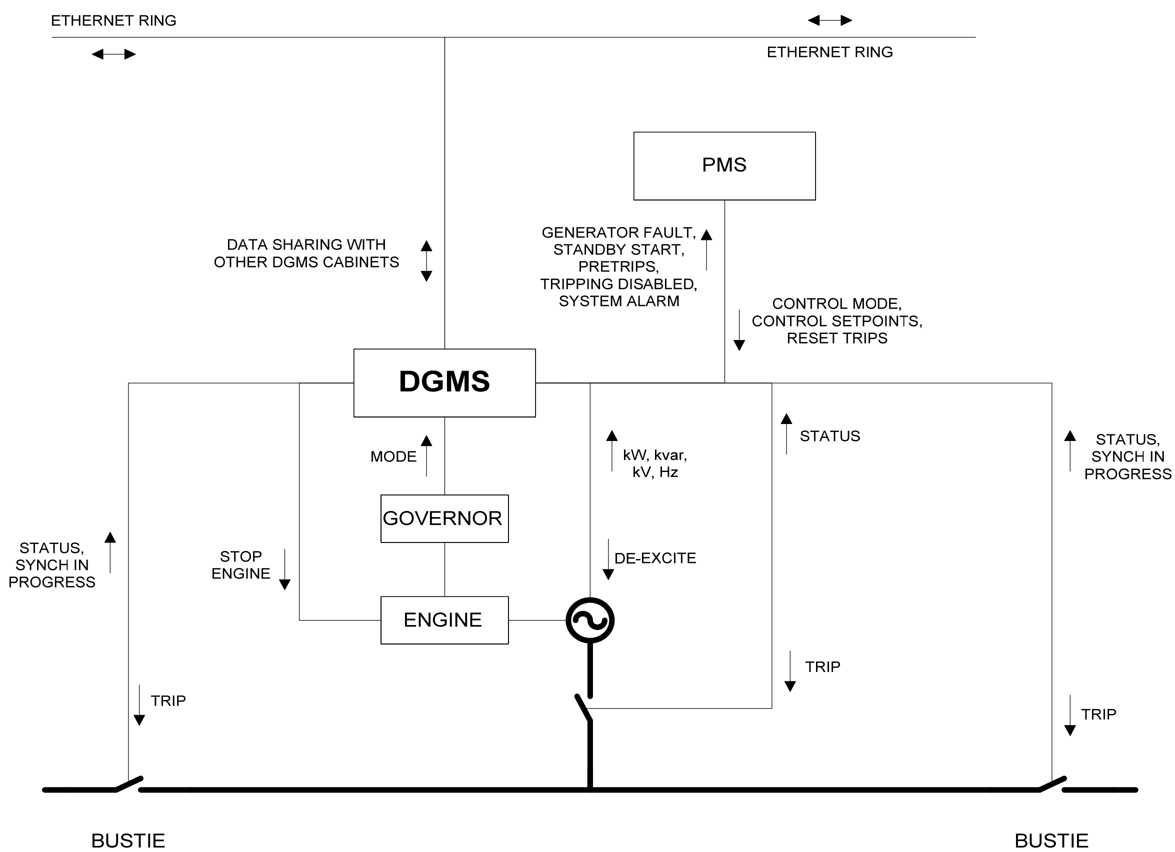

Figure 5: Interface schematic for the DGMS and related equipment.

Functional description:
The functionality of the DGMS extends that of the normal protection functions from the relays. The DGMS does not interfere with these; hence any failure of the DGMS itself will not introduce reduced performance compared to the traditional design without DGMS. This add-on functionality also makes this product suitable for installation on existing vessels for functional upgrade of the power generation protection and monitoring system.

The design philosophy includes following features:
- Detect failures
- Create alarm
- Start standby diesel engines
- Isolate faulty engine before blackout condition occur (only when the system is crossing pre-set trip limits)
- Isolate faulty switchboard section (only if isolation of faulty engine fails)

Following failures are detected by the DGMS that are not detected by standard protection relays:
- Over/Under fuelling by comparing system frequency and generator active power to expected behavior in current operation mode.
- Over/Under excitation by comparing system voltage and generator reactive power to expected behavior in current operation mode.

Fast Restart After Blackout

In the unlikely event of a blackout it is also important that the system is designed to recover as fast as possible. The traditional way this is handled is that all available generators get a start signal, and the first one that is up and running connects to the dead bus. As soon as the bus is live the process of restoring the loads are started. For the variable speed thruster drives this implies starting of all auxiliaries as cooling pumps and fans, lubrications pumps etc., and charging of the DC link in the frequency converter. This has been done in a sequential way until now with the result that the restart process may take up to several minutes.

With relative small and simple adjustments of the equipment and philosophy it is possible to reduce this starting time by parallel processing. For the ABB ACS 6000 converter following upgrades are available:
- Hot standby feature during main and auxiliary supply interruption, e.g blackout
- Standby time up to 10min without auxiliary supply feeding the water cooling unit
- During standby converter remains energized and enable restart of drive with minimum delay after main and auxiliary supply is restored in the power network.
- Available as in-build feature for new deliveries or as upgrade kit for already delivered and operating converters.
- Autonomous thruster system restarts control functionality within drive control unit (optional).

Figure 6 shows the details of the converter charging topology and the modified sections are given in blue color.

Following modifications are undertaken:
Charging Circuit
- Backup charging branch fed from UPS powered control voltage supply maintaining intermediate dc-link voltage level during power interruption
- Charging transformer with additional tapping for backup charging supply

DC Intermediate Circuit
- Air cooled balancing resistors withstanding water flow interruption.

Software
- Additional functions for supervision and control supporting new feature.

As a consequence of these modifications the converter can be kept charged for up to 10 min during a blackout, and without any auxiliaries running. Further the staring sequence can be described as follows:

- Blackout/power interruption shorter than 3s, covered by Ride-Through and under-voltage function in drive, no restart required.
- Blackout/power interruption longer than 3s, restart time after power restored in the network appr. 6s for typical drillship application however highly depending on the rotor time constant determining the motor magnetization time.
- Auxiliary and steering pump is restarted simultaneously with the thruster converter and restart time assumed to be within the converter restart time (to be verified with IAS, thruster and auxiliary system supplier).
- Optional: Thruster converter, auxiliary and steering restart is autonomous controlled in the Drive Control Unit (DCU).

See Figure 7 for a block diagram representation of the starting sequence.

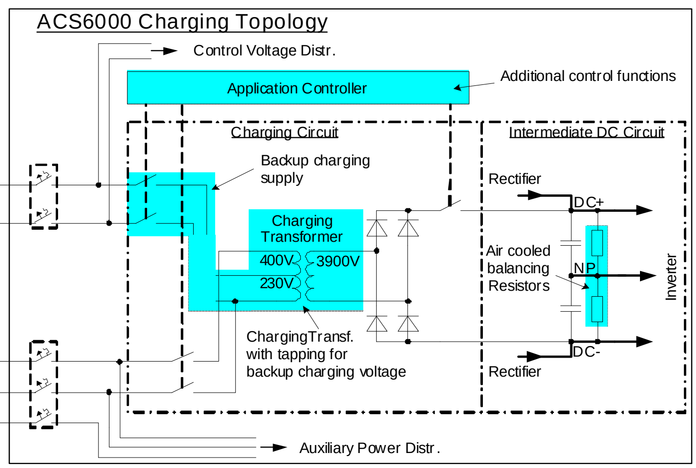

Figure 6: Schematic diagram of converter charging topology.

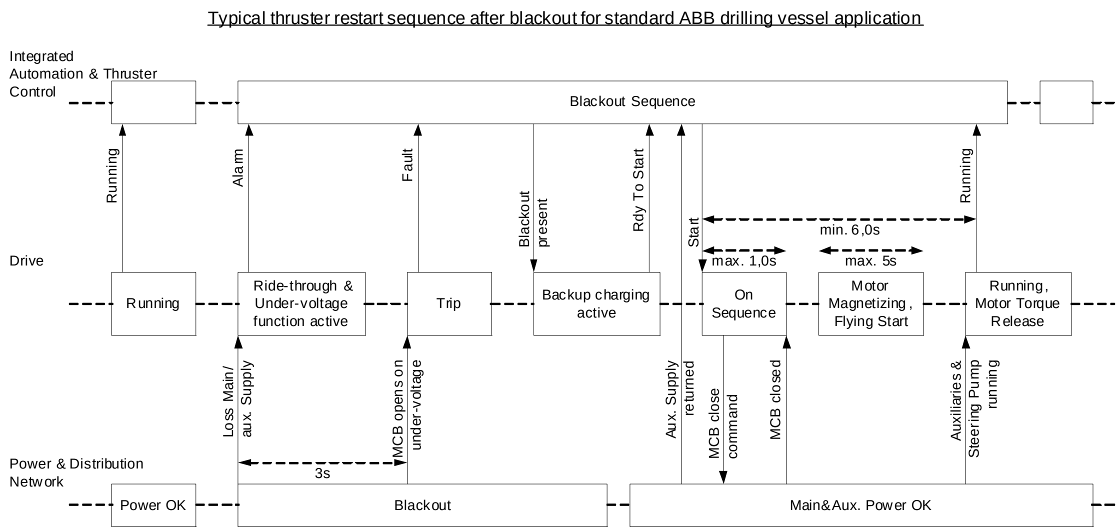

Figure 7: .

Black-out restoration

In the event of a black-out, the power plant should restore automatically. The configuration of the power plant after restoration must carefully be determined to ensure available power to thrusters and other essential loads, but avoid entering into a potential new fault condition.

Typically, the black-out restoration is controlled by the vessel management system, using a logical sequence of events leading to start-up and synchronization of diesel engines and generators, and connection of auxiliaries and essential loads. It is essential that this time sequence is thoroughly made with the involved suppliers, in order to avoid both unnecessary time delays, but also to ensure that the start-up performs with high reliability and without failures from exceeding operating limits of system and equipment.

The use of battery backed up supplies for essential auxiliaries and control systems, may reduce the start-up time. It should, however, be noted, that the more equipment and systems being installed and which the start-up sequence being dependent on, the higher the risk of failures which could not be detected during normal conditions. This is particularly to be considered if the additional systems are not active during the normal operations. The need for monitoring and fault detection increases as the complexity increases, and for practical solutions there must be a balance between what is required performance, versus what complexity of the system is necessary to achieve that performance. If the system can be recovered within the time required; a simpler solution which has less likelihood for failures may be preferable.

As the solutions will reflect the requirement for each vessel, it is necessary to address these in the early specification phase of the functionality of the installation, involving all the parties necessary to implement a cross-discipline functional integration.

Concluding Remarks

Electric power plants have become more reliable with less black-out. It is the authors' view, that this is contributed by better protection systems, and the wide use of variable speed thruster drives with VSI technology that was introduced in the 5th generation DP drilling vessels in the end of the 90's. Further improvements have been introduced later, by utilizing digital protection relays and programmable controllers to implement more sophisticated protection functions. However, there are still potentials for improving the systems, and a continuous effort to enhance the availability of the power plant and reduce the restoration time is necessary. Although this should be done, not necessarily be replacing the proven systems with completely new topologies, but rather be a focused effort to improve within the areas where experience and operational statistics shows the greatest potential for improvement. Certain statistics indicate that the human factor is the greatest contributing effect to undesired incidents. A human interaction is necessary for safe operation regardless of how much automatic systems is being used, it is therefore important to keep the system simple and thereby intuitive for the crew to operate in safe manner when needed.

With additional generator protection as the diesel engine monitoring system (DGMS), the risk for blackout can be reduced. This product adds on to the standard protection relays, without interrupting the relay functionalities. By comparing several variables from the diesel generator set with normal operating curves it is possible to detect failures that are emerging on the engine or generator control system before it would be detected and tripped by the protection relays. The DGMS is also suitable for retrofit on existing vessels.

With usage of the fast restart modifications of the ACS 6000 converters it is possible to reduce the thruster restart time to 6s after the voltage is restored on the main switchboard. It is essential to keep this restart time as short as possible in order for the vessel to keep its position during a possible blackout phase.

References

/1/ Pallaoro, A.A.: DPPS – A Petrobras DP Safety Program; Keynote Speech DPC 2005.