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Alternative Approaches for Demonstration of Fault Ride-through Capability on DP Vessels with Closed Bus Operation

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Abstract

In order to prove that electrical systems on dynamic positioning vessels (DP-2 and DP-3 class) can be safely operated in a closed bus configuration, recent marine industry guidance has been published recommending that fault ride-through testing be conducted on DP-2 and DP-3 ships and offshore vessels. The main purpose is to prove that, in a closed bus configuration, the protective devices for generators, thrusters, and essential loads necessary for station keeping will “ride through” a fault on a main switchboard bus segment or a major feeder circuit without tripping before the bus-tie breaker opens to isolate the faulted side of the system. Demonstration of fault ride through capability for closed bus operation is not a simple task and the marine industry is still searching for standards in terms of the extent of the testing, testing methods, and other details. This paper will provide a brief background, rationale, and pros/cons for closed bus fault ride through testing (live short circuit testing) and will present a list of alternative testing methodologies to be considered.

Introduction and Background

Dynamic positioning vessels with redundancy notations such as DPS-2 and DPS-3 have traditionally operated in an open (split) bus configuration for maximized redundancy. Recent changes to efficiency and emission regulations have driven DP operator preferences towards closed bus operation to enable operation with fewer generators online and at a higher percent loading to improve efficiency, reduce fuel consumption, decrease maintenance time/running hours, and reduce emissions. Marine pollution (MARPOL) regulation changes have pushed operators to operate engines at higher loading levels, which reduces emissions. Consequently, closed bus is the ideal configuration because the load can be shared among a minimum number of diesel-generator sets online as required to service the load. However, concerns have been raised regarding closed bus operation. A single failure such as a main bus fault can compromise system redundancy if the system is unable to ride through the fault or if uncoordinated tripping of circuit breakers occurs. During short circuit conditions a severe voltage transient or uncoordinated tripping can occur causing a loss of redundant loads required to maintain vessel position during dynamic positioning operations. Additionally, an inadequate system response to an increase in load may cause generators, thrusters, or other essential DP loads to trip off line further degrading station keeping capability. Furthermore, due to several significant dynamic positioning incidents resulting in a loss of position on drill-ships that were attributed to electrical system failures, industry concerns regarding electrical system failures on DP vessels have recently been heightened. Consequently, industry has issued new guidance calling for live short circuit testing on DP vessels in order to prove that the electrical system has a fault ride-through capability while operating in a closed bus configuration such that redundancy will not be compromised in the event of a major fault.

This paper will examine the rationale and purpose of live short circuit testing and provide a list of alternative methodologies to demonstrate or simulate fault ride through capability for DP vessels where ride-through capability is an essential part of the DP redundancy concept.

Discussion

In a common bus (closed bus) arrangement, a major fault can cause a severe system-wide voltage disturbance, which will impact all connected equipment simultaneously. If the transient is severe enough, some equipment such as circuit breakers, motor drives, or motor controllers, may trip off-line. This can occur when protective devices such as circuit breakers or under-voltage (UV) relays take automatic action when the voltage drops below specified UV trip settings. In a similar manner, large thruster motor drives with software based under-voltage protection may also automatically shut down if the low voltage protection setting limits are reached for the specified time duration. Downstream auxiliary DP equipment required for station keeping such as propulsion auxiliaries (including fuel pumps, lube oil pumps, cooling pumps, cooling fans) may also trip off line because the magnetic main coil within a conventional motor controller may drop out during a momentary severe voltage drop which in turn causes a loss of auxiliary services and subsequent thruster shutdown. Lack of proper circuit breaker coordination may also cause a cascading failure if the breaker closest to the fault fails to trip. Because the fault is not cleared in time, other major upstream breakers, including generator breakers, may trip resulting in loss of power to all thrusters and consequently a loss of station keeping.

Due to these inherent susceptibilities as well as recent actual incidents as outlined in a recent USCG Safety Bulletin[1] on the topic, it has been determined that DP Failure Modes Effects Analysis (FMEA) proving trials and annual DP trials conducted in line with current practices need to be updated to more fully verify and validate fault ride through capability on DP vessels that operate in a closed bus configuration. The USCG has recommended “Where ride-through capability is an essential part of the DP redundancy concept it should be proven by live short circuit and ground fault testing per Section 9.2.5 of the Marine Technology Society “DP Vessel Design Philosophy Guidelines”. Subsequently, MTS has developed a detailed testing methodology[2] involves intentionally inducing a low level short circuit onto a main bus feeder in order to prove that the breakers will trip in a coordinated fashion and no generators or thruster motors will trip during the fault. Appendix A, Figure A-1 illustrates the testing arrangement. The power plant is tested in its weakest DP configuration in terms of the number of generators connected. Typically, two generators are online with all thrusters and other DP consumers on line as well as typical at-sea loads. This is necessary to ensure any malfunction or lack of voltage dip ride-through can be identified.

This test induces a short circuit with the minimum impedance possible so as not to limit the short circuit current and so demonstrates the capabilities of the system to ride through this condition without losing power to the propulsion systems.[3] The main advantage of this test method is that the test results may be used to validate the analysis provided by advanced computer modelling and simulation and it is important to understand that this test supports the model and associated simulations by demonstrating an actual fault ride through and that it is not to be used in isolation from modelling and simulation.

The disadvantages are that the test needs to be carefully managed to avoid exposing persons to danger and the risk of damaging equipment, inducing potential latent equipment failures thus reducing its expected life. Some equipment manufacturers may not honour the terms of their warranties if such testing is carried out. There is no certainty that the short circuit created is the condition most likely to result in a loss of power. Operators need to be aware that equipment is only capable of accommodating a limited number of short circuit tests before needing replacement, this is particularly pertinent if the initial testing is not seen as validating the expected modelled and simulated analysis.

In addition to USCG and MTS guidance, the American Bureau of Shipping (ABS) has issued new updated guidance for DP vessels as part of the recently published ABS Guide for Dynamic Positioning Systems (2013, updated 2014, 2015). In this new ABS DP guide, for vessels with DPS-3 Notation, "Fault ride through capability” is required when the DP system is designed to include closed bus configuration.

[1] USCG Marine Safety Alert 05-13, June 17, 2013, RECENT FAILURES OF DYNAMIC POSITIONING (DP) SYSTEMS ON MOBILE OFFSHORE DRILLING UNITS

[2] Dynamic Positioning Committee Marine Technology Society (MTS) TECHNICAL AND OPERATIONAL GUIDANCE (TECHOP), TECHOP_ODP_09_(D), “METHOD FOR PROVING THE FAULT RIDE-THROUGH CAPABLITY OF DP VESSELS WITH HV POWER PLANT”, SEPTEMBER 2014

[3] IMCA Information Note, DP2 and DP3 Common Power Bus Operation

For ABS enhanced power system EHS-P Notation, the test procedures are to be based on the simulation of failures and is to be carried out under as realistic conditions as practicable.

However, unlike the MTS Techop, the ABS DP Guide does not specify what methods are to be employed in order to demonstrate this capability. Some organizations have been very reluctant to perform the live short circuit test method recommended by MTS and have asked for alternative methods to demonstrate compliance for fault ride through capability. While it is generally agreed that the live short circuit test can be done safely with proper planning, test procedures, and qualified test personnel, some organizations within the DP industry have pointed out that there are some inherent risks and safety concerns associated with this type of testing. In response to the increasing interest in vessels operating with DP equipment classes 2 and 3 in a common power (closed bus) mode, the International Marine Contractors Association (IMCA) has developed an information note (per reference 3) that provides a list of alternative testing and analysis methodologies that can be used to establish the dependability of a common power bus arrangement (see Appendix B). These methods should be considered as possible alternatives for live short circuit fault ride through testing on DP vessels. While there is no one method to do a complete test of all three key system characteristics that are affected during a short circuit event (voltage transient, selectivity, and stability), they may be used in different combinations to achieve the same purpose as live short circuit testing.

Another proposal that has been considered is to assign a special “Closed Bus” notation to represent the type and level of testing/studies to be performed and then leaving it up to the vessel owner to select the desired notation as appropriate for the specific vessel design and level of redundancy. The notation would represent the type and level of testing and analysis to be performed. This may range from the normal DP FMEA and DP FMEA Proving Trials, to special studies and simulations in a controlled environment, to full-scale fault ride through (live short circuit testing) on the ship as per the MTS Techop with built-in, full-scale (full voltage, full current) test capability for periodic testing. The selected notation would be based on the specific design attributes of the system, the level of redundancy/risk associated with the system, and to what degree the owner would like to verify and validate the dependability of the common (closed bus) arrangement.

Lastly, for DP vessels where electrical systems that rely on software based safety functions (i.e. circuit breakers with electronic trip units, automatic power management, DG set auto-start/stop, automatic load shedding, heavy consumer start blocking, thruster load limiting, rate of change limiting) there are rigorous software verification and validation procedures that can be adopted (i.e. Hardware in the Loop (HIL) testing, Software in the Loop (SIL) testing) as outlined in the ABS Guide for Systems Verification (SV Notation) to enhance safety for safety critical functions (Safety Integrity Level 2 or 3). Additionally, rigorous software quality assurance procedures can be adopted as outlined in the ABS Guide for Integrated Software Quality Management (ISQM Notation) in order to enhance the reliability of safety critical software based functions on DP vessels.

Conclusion

Live short circuit testing in tandem with advanced computer modelling and simulation has been established as one standardized method of verifying and validating fault ride through capability of DP-2 and DP-3 class vessels operating in a closed bus configuration. In response to queries for possible alternative approaches to live short circuit testing, viable alternative testing methodologies have been proposed and are being considered by industry.

Recommendations

- Standardized test methods should be discussed further with industry and regulatory agencies.
- A definitive list of alternative standardized test methods should be fully developed and distributed for industry comments.
- Once consensus is reached, the list acceptable methods for testing or simulating fault ride through should be published for guidance.

APPENDIX A

TYPICAL ARRANGEMENT OF FAULT RIDE-THROUGH TEST

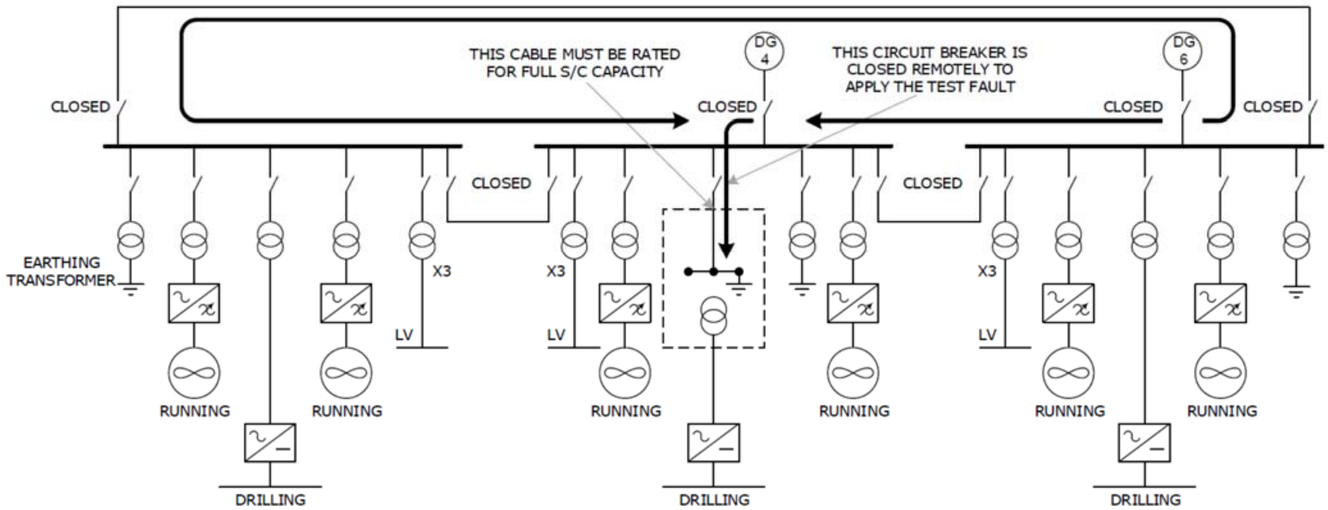

Figure A-1 – Typical Arrangement of Fault Ride-Through Test

APPENDIX B
LIST OF ALTERNATIVE FAULT RIDE THROUGH TEST/SIMULATION METHODS

Table B-I – Methods to Demonstrate the Dependability of Common Power Bus Arrangements

Method	Description	Pros/Cons
Formal risk assessment	This method presents no risk of damaging equipment and may be inexpensive if compared to other options. Risk assessment is a relatively mature field with numerous methodologies and tools available, supported by a wealth of expertise in bodies such as classification societies, DP system suppliers and third party DP assurance specialists.	The disadvantages are that risk assessment, particularly quantified risk assessment, is sensitive to the quality of input data. If this data cannot be adequately verified and validated, then the risk assessment conclusions may not be reliable. If the risk assessment conclusion is not verified and validated by field-testing, then this is especially pertinent. Regulatory bodies and classification societies may be unwilling to accept a risk assessment as demonstrating the dependability of the DP system unless supported by further studies (such as system modeling) and field-testing.
Advanced computer modeling and simulation	May be inexpensive depending upon the complexity of the model. Exploiting the potential offered by simulation allows for an infinite number of configurations and scenarios to be considered and for the system configuration settings to be altered with no need for physical testing. There are recognized tools available to validate simulation processes. The software package and any other modeling and simulation tools selected should be suitable for the intended application, as with any other tools the critical requirement is that they are the right ones for the job. Bodies such as classification societies, DP system suppliers, switchboard manufacturers and third party DP assurance specialists have a wealth of expertise and experience in undertaking complex system simulations.	If the simulation results are not verified and validated by field testing, then regulatory bodies and classification societies may be unwilling to accept a simulation as demonstrating the dependability of the DP system unless supported by further studies (such as system modeling) and field testing. More complex models may become very expensive, particularly since the model will need to simulate all potential system configurations and operating scenarios to be truly effective in demonstrating the dependability of a complex system. For the model to be valid then it is essential that the model build data and parameters reflect the as built and commissioned system and that this is maintained through the life of a vessel, this may be time consuming and expensive.
Simulating a voltage transient by starting a large load	This is a simple and economical method of demonstrating the response of the system to a voltage dip, requiring no additional or specialized equipment. Despite its simplicity this test can provide a useful demonstration of how the system responds to a transient voltage, system stability and the function of protective devices.	However, it is only viable where the vessel has a large enough consumer to create a large enough voltage transient, this may be assisted by disabling soft start arrangements (subject to the appropriate risk assessment). This test does not simulate a short circuit current.
Creating a voltage dip using the automatic voltage regulator (AVR)	This is a very simple and inexpensive test and presents minimal risk however it is only suitable where the AVR can create a large enough voltage dip. Modern electronic AVRs should be capable of this.	This will only test the system's response to a voltage transient and the transient induced may not be representative of an actual system fault. AVRs may be damaged if they are of inappropriate design for inducing such voltage dips.
Use of variable speed/frequency drives to simulate bus fault conditions	This is a simple and inexpensive test and presents minimal risk, however it is only suitable where the installed equipment and variable speed/frequency drives are suitable for the testing. Provided that large frequency convertors are available (for example, thrusters, main propulsion motors) then it should be possible to replicate a range of conditions including voltage dip and system instability).	The disadvantages are that frequency convertor settings need to be adjusted with the consequential risk that if they are not properly restored on completion of testing then equipment damage could result. The test will only be viable if the frequency convertors are large enough and they may be damaged if testing is not suitably controlled.
Inducing a voltage dip by automatic cycling circuit breakers	Again, this test is inexpensive and can be managed using already installed equipment. Although it will only induce voltage transients these can be quite representative of transients created by fault conditions.	The principal disadvantage is that the test may result in damage to circuit breakers, and the induced voltage dip may not necessarily be entirely representative of real bus fault conditions.
Simulate circuit breaker fault response by injecting a measured control signal into the breaker controller/programmable logic controller (PLC)	This test can demonstrate the trip response of circuit breakers with no requirement to simulate actual transient or fault conditions on the bus. Therefore it is a safe test with minimal risk to persons or equipment. This allows for a variety of potential fault conditions to be tested. The test could be performed at the equipment manufacturer's factory.	The disadvantages are that this is only a test of the breaker protection settings and response. Simultaneous testing of multiple breakers is needed to test system response, which can be more difficult whilst factory testing will not necessarily be representative of the on-board conditions. The test does not test breaker response to an actual bus transient or fault. There is a consequential risk if any control settings, which are adjusted during testing, are not properly restored on completion of testing then equipment could be damaged as a result of a real in service fault.

Table B-I – Methods to Demonstrate the Dependability of Common Power Bus Arrangements		
Method	**Description**	**Pros/Cons**
Use of a load bank to simulate short circuit conditions	With a suitable load bank the bus current could be raised incrementally to replicate fault conditions. Since this is a controlled process it reduces risks associated with other forms of inducing a short circuit fault current.	The disadvantages are the costs of hiring a suitable load bank and associated system reconfiguration and subsequent reversion to the as designed arrangements. The overcurrent is not as realistic as an actual short circuit fault. To allow the system to reach the necessary overcurrent, system protection would need to be adjusted. There would then be a consequential risk that if settings are not properly restored on completion of testing then equipment could be damaged as a result of an in service fault. The costs and potential risks of this option mean it is unlikely to be attractive.
Construct a replica switchboard in a testing facility	This would remove the risk to ships' crews and persons managing testing and would fully remove the risks of damaging the on-board system as a result of testing. In a controlled laboratory environment it would be possible to replicate a wide range of actual fault conditions and so evaluate the true response of the system to these conditions.	In reality, constructing such a replica is likely to be prohibitively expensive unless it is intended to serially produce a significant number of identical systems. A partial replica may be viable however this would then mean the replica was not truly representative of the on-board power system. Although constructing such a replica may be viable for smaller systems and where serial production of a system is intended, it is unlikely to be attractive for larger, more complex systems or where serial production is not intended. Where this option may be useful is to allow manufacturers to demonstrate the efficacy of software based simulation tools and so potentially negate regulatory and classification demands for testing on-board.