TECHNICAL AND OPERATIONAL GUIDANCE (TECHOP)

TECHOP (D-12 – Rev1 – Dec22)

MANAGEMENT OF INTERMITTENT FAULTS IN DP SYSTEMS

DECEMBER 2022

DRAFT

For comment until 23 April 2023

DISCLAIMER

SUMMARY

Intermittent faults have been identified as causal or contributory factors in a number of high-profile DP incidents.

Historically, such faults have not benefited from the same level of scrutiny as hard (permanent) faults in the verification and validation processes applied to prove the single fault tolerance of DP vessels. This Techop is intended to assist stakeholders in addressing risks and consequences of intermittent faults. Important issues to consider include:

- Intermittent faults can cause loss of redundancy or reduced post failure DP capability and should be treated as a Yellow condition in the ASOG / WSOG in the same way as a permanent fault.
- The repetitive nature of intermittent faults can lead to escalatory effects which have the potential to exceed the worst-case failure design intent compared to permanent faults of the same basic type. It is for this reason that intermittent faults need to be considered separately as a category of fault in their own right and may require additional and specific mitigating measures. It is emphasized that, the mitigations applied for a hard fault of a particular type may not be effective against the intermittent version. This has particular importance for protection systems in power plant operating with closed busties.
- Intermittent faults may recur following the occurrence of a (new) single fault elsewhere in the DP system. This can happen because the equipment with the intermittent fault is placed under greater stress when called upon to compensate for the loss of other equipment associated with the new fault. This situation can lead to a loss of position and / or heading when the new fault and the pre-existing intermittent fault are in different redundant DP equipment groups.
- Intermittent faults should not be ignored even if they appear to have resolved themselves as they can recur following failure of some other part of the DP system (as per the examples in the case for action). This leads to failure effects with a severity exceeding that of the worst-case failure design intent. The consequences of the ensuing loss of position and/or heading will depend on the nature of the vessel’s industrial mission.

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1 INTRODUCTION

1.1 PREAMBLE

1.1.1 The guidance documents on DP (Design and Operations and People) were published by the MTS DP Technical Committee in 2011, 2010 and 2012, respectively. Subsequent engagement has occurred with:

- Classification Societies (DNV, ABS)
- United States Coast Guard (USCG)
- Marine Safety Forum (MSF)
- Oil Companies International Marine Forum (OCIMF)

1.1.2 Feedback has also been received through the comments section provided in the MTS DP Technical Committee Web Site.

1.1.3 It became apparent that a mechanism needed to be developed and implemented to address the following in a pragmatic manner:

- Feedback provided by the various stakeholders.
- Additional information and guidance that the MTS DP Technical Committee wished to provide and a means to facilitate revisions to the documents and communication of the same to the various stakeholders.

1.1.4 The use of Technical and Operations Guidance Notes (TECHOP) was deemed to be a suitable vehicle to address the above. These TECHOP notes will be assigned the following categories:

- General TECHOP (G)
- Design TECHOP (D)
- Operations TECHOP (O)
- People TECHOP (P)

1.2 TECHOP NAMING CONVENTION

1.2.1 The naming convention, TECHOP (CATEGORY (G / D / O / P) – Seq. No. – Rev.No. MonthYear) TITLE will be used to identify TECHOPs as shown in the examples below: Examples:

- TECHOP (D-01 - Rev1 - Jan21) Addressing C^3EI^2 to Eliminate Single Point Failures
- TECHOP (G-02 - Rev1 - Jan21) Power Plant Common Cause Failures
- TECHOP (O-01 - Rev1 - Jan21) DP Operations Manual

Note: *Each category will have its own sequential number series.*

1.3 MTS DP GUIDANCE REVISION METHODOLOGY

1.3.1 TECHOPs as described above will be published as relevant and appropriate. These TECHOPs will be written in a manner that will facilitate them to be used as standalone documents.

1.3.2 Subsequent revisions of the MTS Guidance documents will review the published TECHOPs and incorporate as appropriate.

1.3.3 Communications with stakeholders will be established as appropriate to ensure that they are notified of intended revisions. Stakeholders will be provided with the opportunity to participate in the review process and invited to be part of the review team as appropriate.

2 SCOPE DEFINITIONS AND IMPACT

2.1 SCOPE / OBJECTIVE

2.1.1 The scope of this TECHOP is to provide guidance on the management of intermittent faults in DP systems with particular focus on intermittent faults that have the potential to compromise the DP system's redundancy concept and reduce, or remove, post failure DP capability

2.2 IMPACT ON PUBLISHED GUIDANCE

2.2.1 None

2.3 DOCUMENT REFERENCES

2.3.1 Wakil Ahmad Syed, Samir Khan, Paul Phillips, Sureh Perinpanayagam, '*Intermittent fault-finding strategies*', 2nd International Through-life Engineering Services Conference, 2013.

2.3.2 Samir Khan, Paul Phillips, Chris Hockley, Ian Jennions, '*No Fault Found (NFF) events in maintenance engineering Part 2: Root causes, technical developments and future research',*2013.

2.3.3 Bryan Steadman, Floyd Berghout, Nathan Olsen, '*Intermittent Fault Detection and Isolation System*', IEEE AUTOTESTCON 2008 Salt Lake City, UT, 8-11 September 2008.

2.4 MTS GUIDANCE AND STANDARDS ICONOGRAPHY

2.4.1 The MTS DP Subcommittee on Guidance and Standards developed the icon shown in Figure 2-1 to bring together (in one graphical form) all the imagery and vocabulary that captures many of the important principles and concepts underlying the delivery of incident free DP operation.

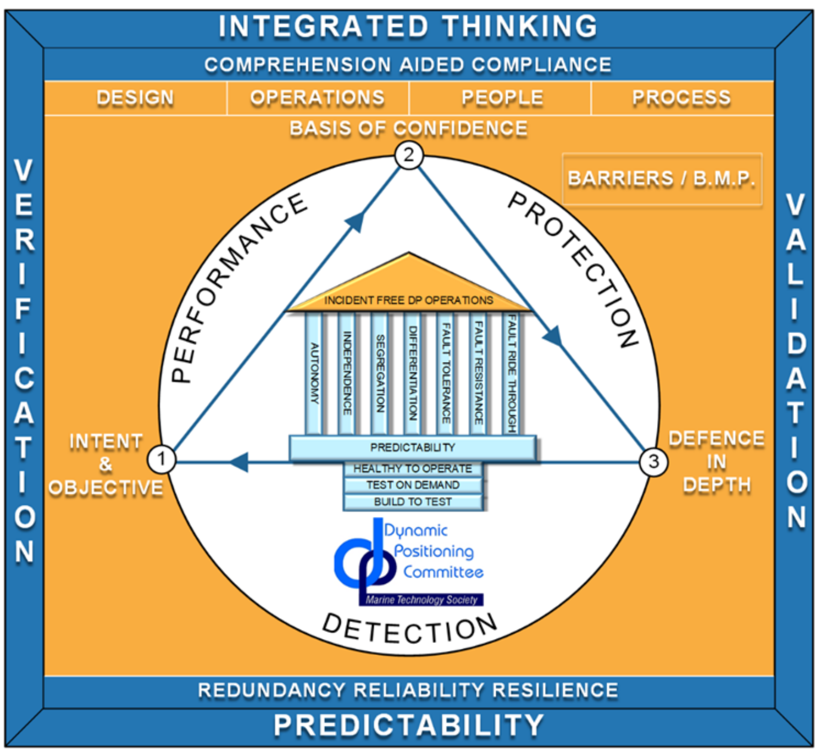

Figure 2-1 Icon of MTS DP Subcommittee for Guidance and Standards

2.4.2 Of particular importance to the discussion that follows is the concept of **Predictability** and the trifecta of **Performance, Protection and Detection**.

2.4.3 Intermittent faults are capable of:

- Degrading or eliminating the performance of a redundant DP equipment group in an unpredictable manner.
- Affecting the operation of more than one redundant DP equipment group if fault propagation paths exist between the groups.
- Disabling protection and alarms (detection) and creating intermittent alarms.

Note: *Mitigation of intermittent faults may require different forms of mitigation from that used to mitigate the effects of hard faults (non-intermittent faults)*

2.4.4 If critical intermittent faults occur in a redundant DP equipment group, that group can no longer be considered to contribute to redundancy predictably, until such time as the fault condition has been rectified and confidence in the performance and reliability of that redundant DP equipment group restored.

2.4.5 The temptation to continue conducting DP operations on a vessel where intermittent faults have been experienced, on the basis that the vessel has other 'fault free' redundant DP equipment groups should be avoided. regardless of whether the intermittent fault is active or not. The consequences of a failure occurring in a fault free redundant group combined with the potential for unpredictable performance of the redundant group with the intermittent fault has led to failure effects that exceeded the worst-case failure design intent and significant loss of position events.

2.5 DEFINITIONS

2.5.1 **Failure** – A cessation or deviation from normal operation caused by a fault.

2.5.2 **Fault** – The cause of a failure.

2.5.3 **Intermittent fault** – An intermittent fault is said to occur when a system or piece of equipment malfunctions and either:

- Resumes normal operations without intervention

or

- can be restored to normal operations following corrective action which does not of itself prevent recurrence – e.g., resetting protective functions (MCB or fuse). Typically, a reset and restart are all that is required. In other cases, a defective component may be replaced but that component failure is a consequence of the intermittent fault and not the cause.

2.5.4 **Transient faults** – A transient fault has been defined in literature as similar to an intermittent fault in so far as it may cause a temporary deviation from normal performance, but it is caused by interaction between the system and its environment rather than degradation. For example, a lightning strike near an antenna may cause a communication system to cease operation until restarted or cause a temporary service outage from which the system recovers without intervention. The cause of this deviation from expected behaviour is external to the system.

Notes:

1. *The frequency of recurrence does not influence the definition of an intermittent fault. The definition used in the context of this Techop is that normal operation can be restored without addressing the root cause of the failure eventually leading to recurrence.*

2. *The frequency of recurrence may, however, influence the severity of the failure effect. For example, electric faults occur so close together that their effects are superimposed – the cumulative voltage dip of several sequential faults exceeds the ride through capability of the systems but is not sufficient to cause the over current protection to operate.*
3. *The frequency of recurrence may exceptionally be considered when developing strategies to use the vessel in its degraded state. This should only be considered if the frequency of recurrence is very low (the time between recurrences is very long – example several weeks) and the activity the vessel is consulting is very short (example hours). This is not a reliable strategy as the frequency of recurrence of intermittent faults is neither predictable nor constant. Other barriers to escalation should be in place.*
4. *A fault condition can be visualised as a deviation from specified performance norms. While it is common to think of an intermittent fault as one which causes a total cessation of service for a period of time it may also manifest itself as a deviation from expected performance from a period of time. That is to say a generator may intermittently be unable to produce more than 75% power because of an intermittent fault in its fuel control system.*
5. *The effects of faults propagate through a system from local effect to end effect – So an intermittent fault may cause a system to fail completely but the end effect may be loss of redundancy. It is important to understand that the vessel is no longer fully single fault tolerant once redundancy is lost.*

3 CASE FOR ACTION

3.1 DP REDUNDANCY AND SINGLE FAULT TOLERANCE

3.1.1 One of the central tenets on which delivery of incident free DP operations relies is the use of DP vessels with acceptable levels of station keeping integrity based on the provision of redundancy to achieve single fault tolerance. DP operations may progress until such time as it is detected that redundancy has been lost. DP operations must be suspended, and the vessel moved to a safe location as soon as loss of critical redundancy has been detected.

Note: *Critical redundancy is that upon which the DP system relies for its fault tolerance and post failure DP capability such as thrusters and generators, or to ensure that errant sensors can be rejected by voting etc (example gyro compasses). Loss of a third SW pump when only two are required to provide redundancy is not considered a loss of critical redundancy.*

3.2 MANIFESTATION OF INTERMITTENT FAULTS

3.2.1 Intermittent faults may manifest themselves as:

- Temporary loss of critical DP related equipment (can be restarted).
- Spurious malfunction or alarms (often unexplained).
- Temporary deterioration in performance.

3.2.2 These conditions may appear to resolve themselves (often not reappearing for days or weeks) or the equipment can be restored to operations following a restart. Unfortunately, it can be the case that these intermittent failures recur at the worst possible time following a failure of some other part of the DP system. This may occur because the surviving equipment (with the intermittent fault) is placed under additional demand or stress which causes the fault to reappear, but it may also occur coincidentally because of the random nature of the intermittent fault.

3.3 THEORY OF INTERMITTENT FAULTS

3.3.1 The operational condition of a device or system can be categorised into three states as shown in Figure 3-1 below.

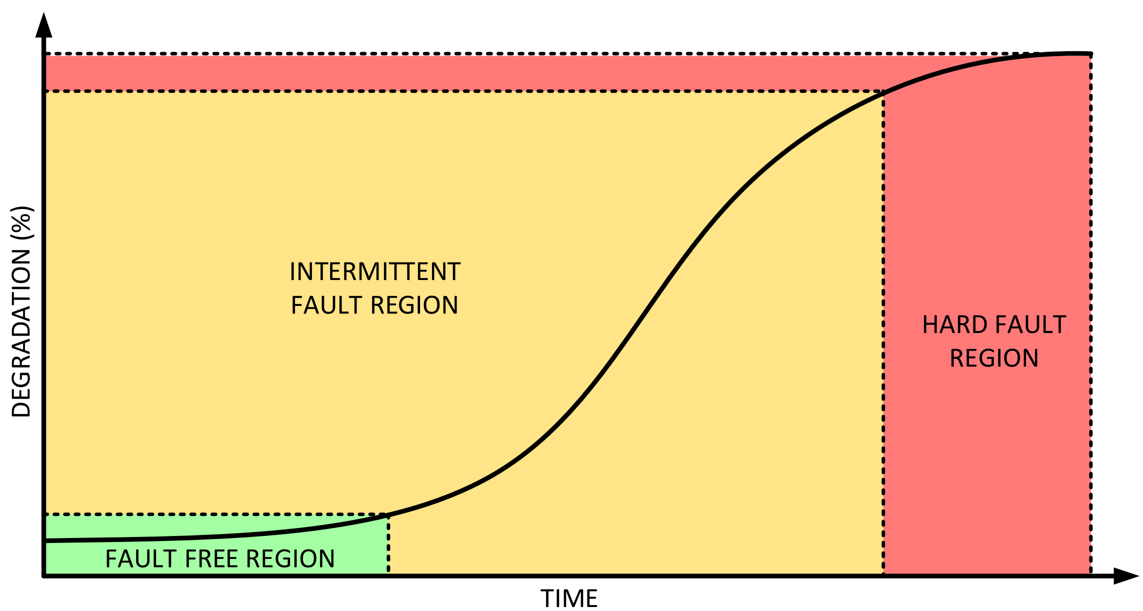

Figure 3-1 Fault Regions (derived from Wakil Ahmad Syed et al - '*Intermittent fault-finding strategies'*)

3.3.2 These states or regions are:

- The fault free region.
- The intermittent fault region.
- The hard fault region.

Note: *Faults may develop without passing through the intermittent region. That is to say hard faults may develop and become permanent immediately without recurrence*.

3.3.3 The paper from which Figure 3-1 is derived makes two important assumptions:

- Intermittent faults are a symptom or manifestation of the degradation of some physical property of a system component.
- The nature of the intermittent fault signal will change with this degradation.

3.3.4 This type of fault model envisages that degradation is ongoing through the development of the failure mechanism. During the fault free region, the device or system may be deteriorating simply with the passage of time or wear & tear but the effect of this has not yet developed to the point where it impacts performance. In the intermittent fault region, it is envisaged that deterioration has now progressed to the point where abnormal system behaviour can be observed but full performance can be restored by intervention or normal operation may simply resume randomly.

Note: *The system does not return to the fault free region when the intermittent fault is not active*

3.3.5 In the hard fault region, performance never recovers, and deterioration may continue in this state until the device or system no longer operates at all, and a system reset has no effect. The system cannot be returned to normal operation without repairing the root cause of the fault.

3.3.6 **Intermittent Faults and Transient Faults** - Those working in the field of intermittent fault identification [1], have identified two different types of intermittent abnormal behaviour:

a. **Intermittent faults** in which there is a recurrent and temporary deviation from specified performance due to the effects of degradation within the faulty system.

b. **Transient faults** which may appear similar to intermittent faults but are caused by interaction of the system with its environment causing it to exhibit abnormal behaviour. (a transient overload condition for example).

Note: *These definitions apply to electrical and electronic faults which account for a large range of DP related failures and are likely applicable to some mechanical faults. Deviations from specified behaviour caused by software related issues are typically modelled by other means.*

3.4 INDUSTRY CHALLENGES AND DEVELOPMENTS

3.4.1 Literature on intermittent faults [2] and the problems of ‘No Fault Found’ (NFF) identifies some of the current gaps in literature and knowledge on this subject and provides guidance on where industry should focus to improve on issues associated with NFF and intermittent fault identification in general. Although this information originates from the aerospace industry in 2013 it appears to remain current and directly applicable to dynamic positioning systems in 2022 and aligns well with MTS guidance developed independently for the DP community and also with recent initiatives to include the failure effects of controllers which is the subject of the Joint Development Project on DP System Integration.

3.4.2 Identified challenges include:

- There is a lack of understanding of intermittent faults. (*The case for action for this TECHOP*).
- Modelling of intermittent faults will need to consider fault detection and the effects intermittent failures have on other dependant systems. (*This process has already begun in the DP community and is the subject of revisions to some 'requirements management' processes*).
- There is a lack of technology for detecting and locating intermittent faults *(designs are already being developed following DP incidents in which intermittent faults were causal and contributory factors*).
- Systems with greater fault tolerance are being created by incorporating built-in redundancy and self-testing mechanisms. (*e.g., Build to Test, Test on Demand & Healthy to Operate from MTS DP design philosophy guidelines*).
- Understanding the effects of intermittent faults relies on the ability to describe the various interactions accurately. In particular, how mechanical, software and electronic elements all have to interact together. (*JDP on DP System Integration has been initiated to address software in controllers which was not part of DP system FMEAs*).
- **Integrity Testing** [2]: "Integrity testing: Most standard maintenance procedures employ only functional testing which determine if the equipment is within appropriate tolerances for service. They do not capture the level of 'damage' or 'degradation' within the equipment, information which could be vital for predicting the probability of intermittency or other failure modes. Integrity testing should be incorporated into the maintenance process and data management techniques should then be developed to provide a diagnostic history and prognostic capability.

3.5 EXAMPLES OF INCIDENTS WHERE THE FAILURE EFFECT EXCEEDED WCFDI

3.5.1 **Example 1** - A DP class 3 diving support vessel operating with its busties open temporarily lost DP control of all forward thrusters when a data communications 'storm' developed on the network connecting its three bow thrusters. This storm lasted for a period of about 90s during which time the DPOs repeatedly reselected the thrusters to DP control preventing loss of position. The situation, depicted in Figure 3-2, was caused by deterioration in several parts of the transmission medium (fibre optic cables) to the point where it caused repeated, attempts to reconfigure the network and restore communication as shown in Figure 3-3. The network storm caused the heartbeat between main and backup controllers to be lost and control defaulted to 'Manual' mode leading to loss of the DP ready signal and thus loss of DP control capability during the storm.

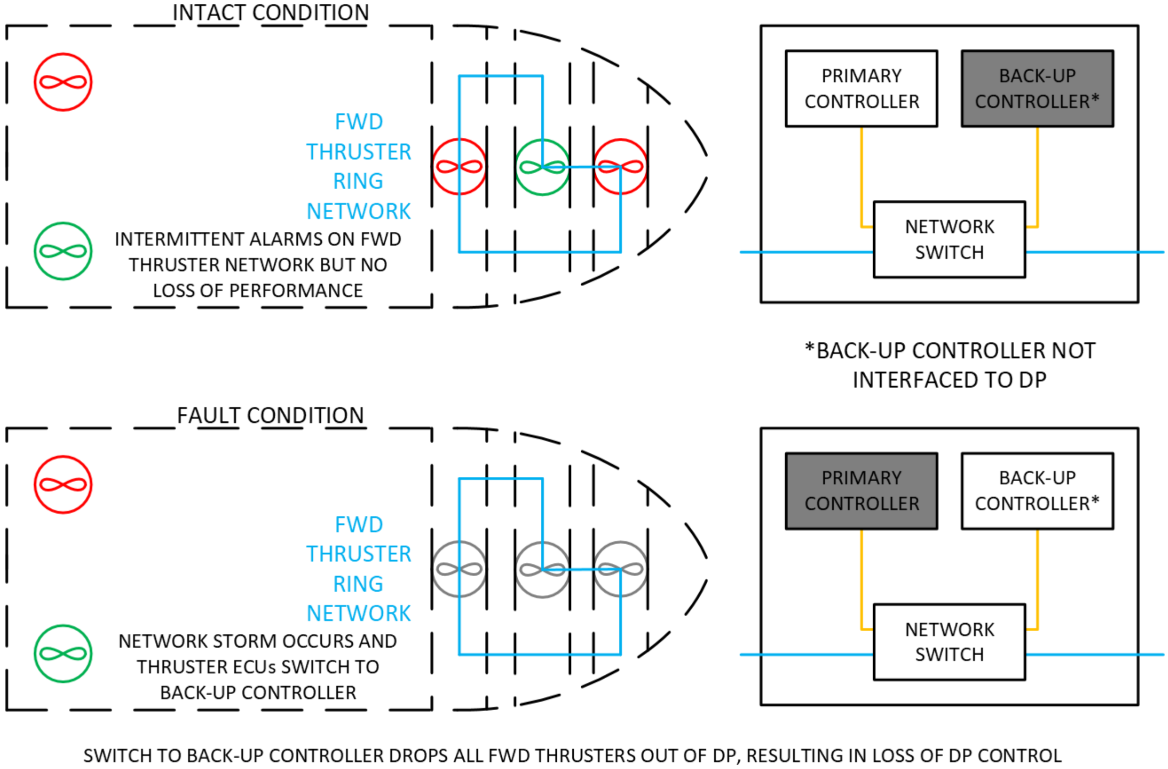

Figure 3-2 Network Deterioration

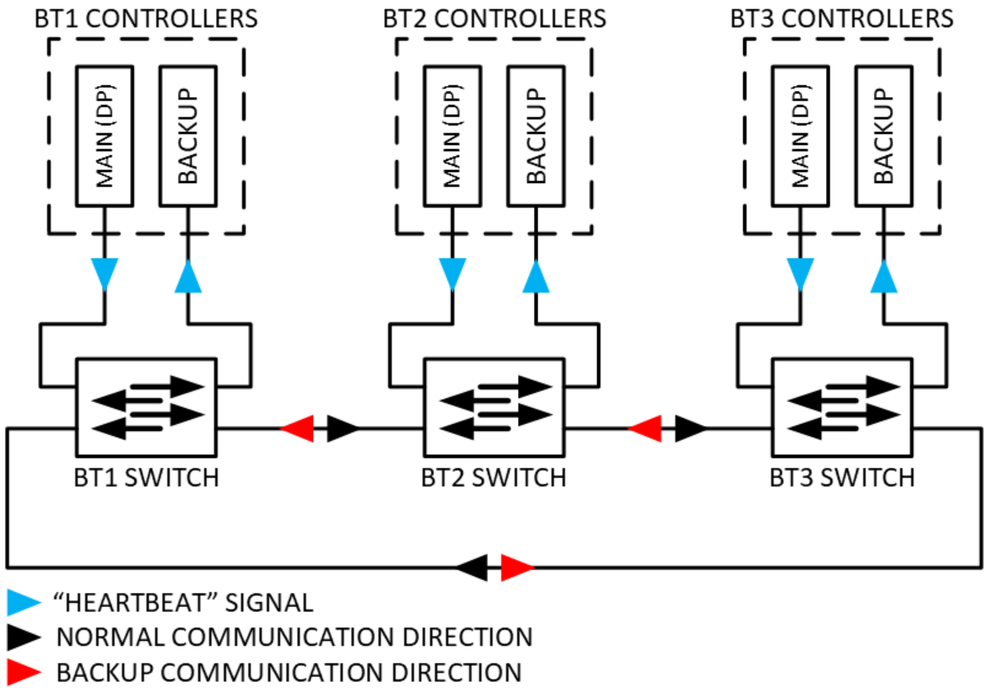

Figure 3-3 Thruster Ring Network

Note: *Investigation revealed that two of the three alarms provided to indicate a network fault had been deemed to be nuisance / spurious alarms and were inhibited by the OEM.*

3.5.2 **Example 2** - A DP class 3 diving support vessel lost all stern propulsion while leaving port A known intermittent fault on a thruster control network caused false indication of a run-away thruster which was subsequently stopped by the crew. The other propulsion stern thruster tripped on an over current fault (as illustrated in Figure 3-4) when it was manually operated to arrest the motion of the vessel. The thruster that tripped had experienced two intermittent over current trips during transit in the weeks leading up to the incident. On those occasions operation was restored following a reset and restart to allow operations to continue (including DP operations). The intermittent overcurrent trip was a clear indication that the performance attributes of the DP system were compromised and the vessel was no longer fault tolerant for DP operations.

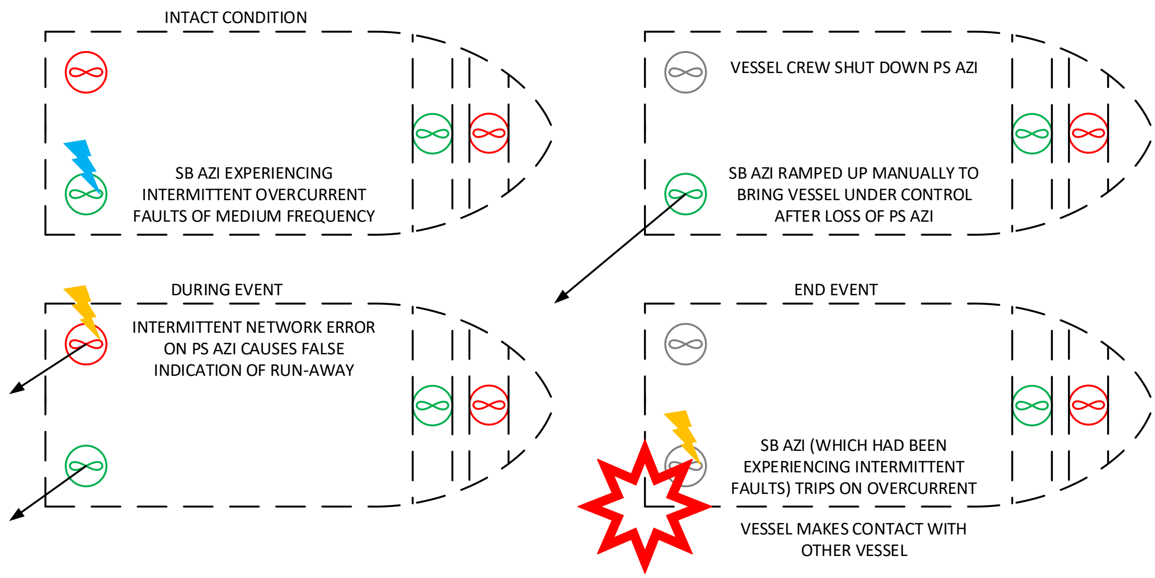

Figure 3-4 Thruster Drive Intermittent Overcurrent Trip

3.5.3 **Example 3** - A DP class 3 MODU operating with its busties closed had been experiencing unexplained ground fault alarms for several weeks as shown in Figure 3-5. These ground fault alarms indicated the onset of a more serious failure which defeated the redundancy concept and led to a loss of multiple thrusters and generators exceeding WCFDI.

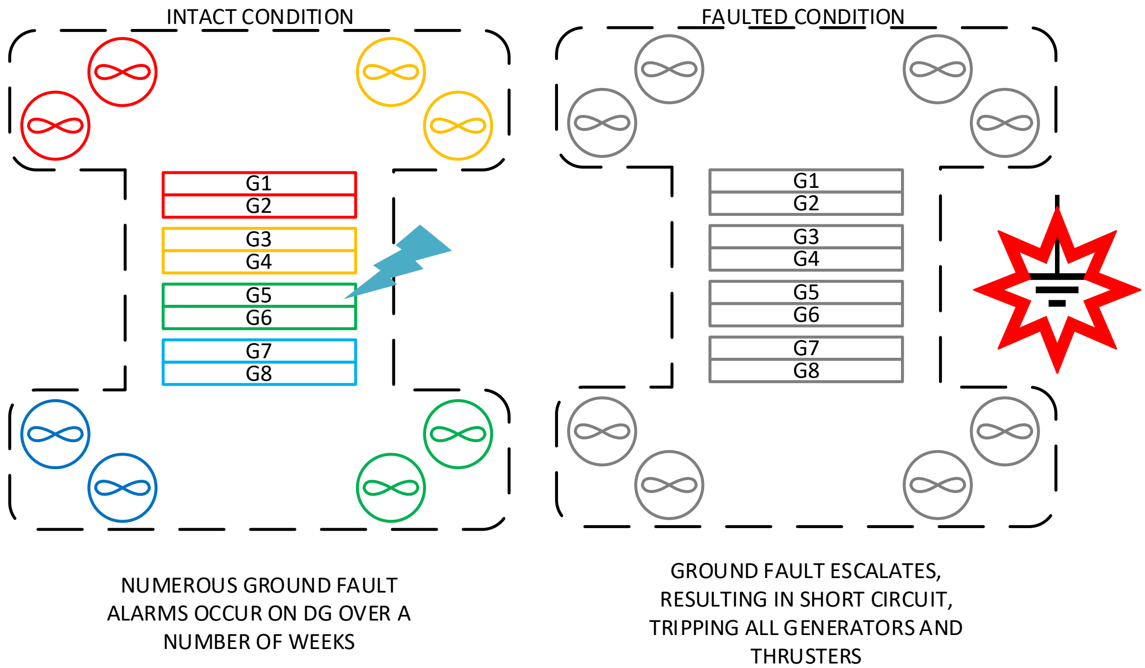

Figure 3-5 **Intermittent Ground Fault**

3.5.4 **Example 4 –** A DP Class 3 MODU operating with its busties open experienced multiple loss of generators and thrusters due to overheating of cooling systems in elevated environmental conditions as show in Figure 3-6. Frequent high temperature alarms had been experienced on individual units at different times prior to the incident but the possibility of losing several units together, when the power plant was highly loaded (as shown in Figure 3-7), was not considered. The cooling systems were found to be in poor condition.

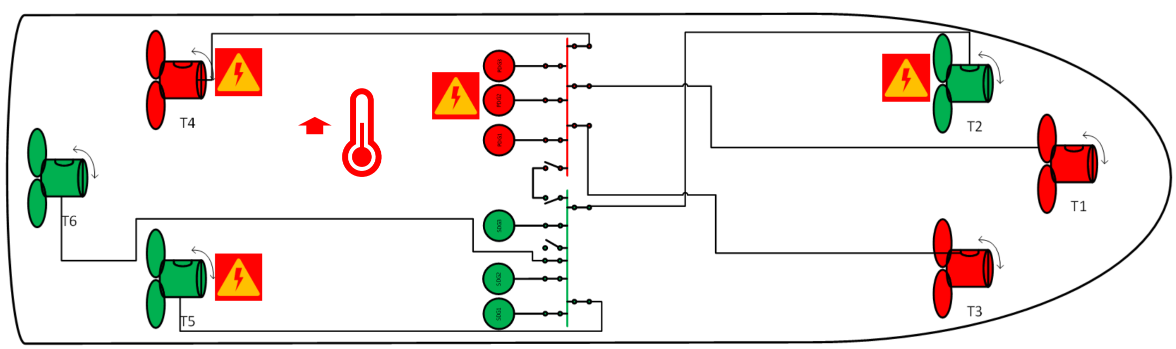

Figure 3-6 **Intermittent High Temperature Alarms**

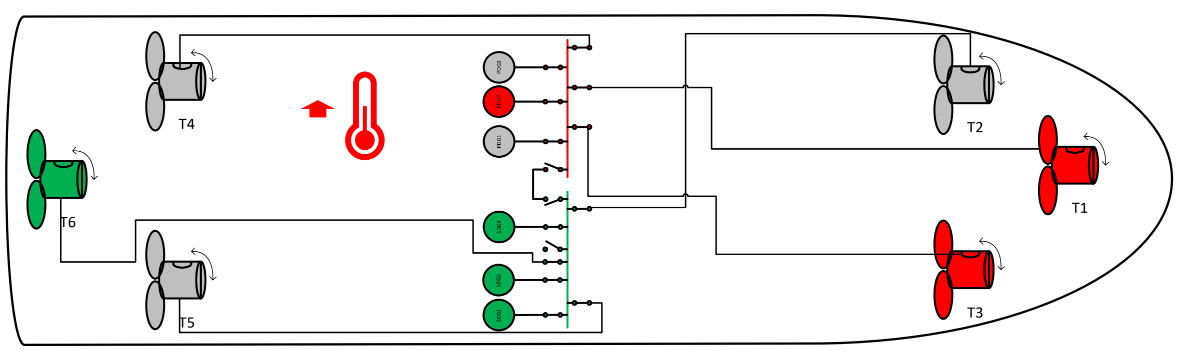

Figure 3-7 **Shutdown of Multiple Engines and Thrusters in Elevated Environment**

3.5.5 **Example 5 –** In the example shown in Figure 3-8, a DP Class 2 platform supply vessel operating with its busties closed had been experiencing intermittent thruster prediction errors alarms on several thrusters, hours prior to collision with a fixed platform. These alarms were triggered by the deterioration of network communications, eventually leading to a network storm in the power management system which developed to the point that the stern thrusters phased back and eventually tripped. Intermittent phase back was the cause of the earlier prediction error alarms.

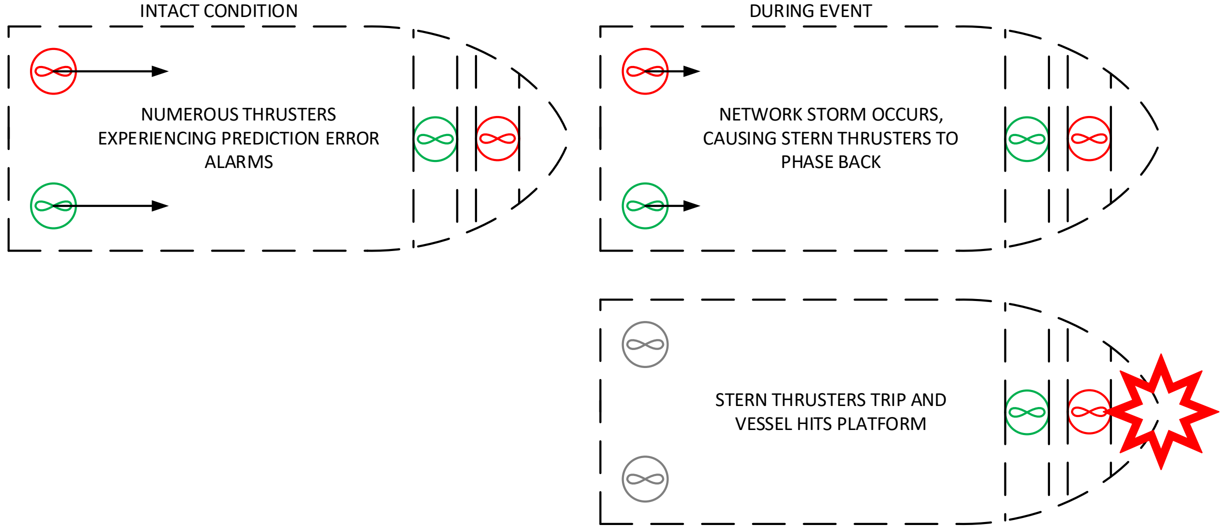

Figure 3-8 Recurrent Spurious Stern Thruster Phase Back

3.5.6 **Example 6** – A DP class 3 diving vessel was periodically experiencing difficulty retracting one if its azimuth thrusters as shown in Figure 3-9. It was found to be pointing in the wrong direction, resetting the azimuth control system temporarily restored correct operation but no cause could be found for the anomalous behaviours and operations continued (the thruster was installed and commissioned correctly). During one DP operation the azimuth thruster turned through 180° causing position instability with large position excursions. The entire azimuth control system was replaced but no cause was ever positively identified.

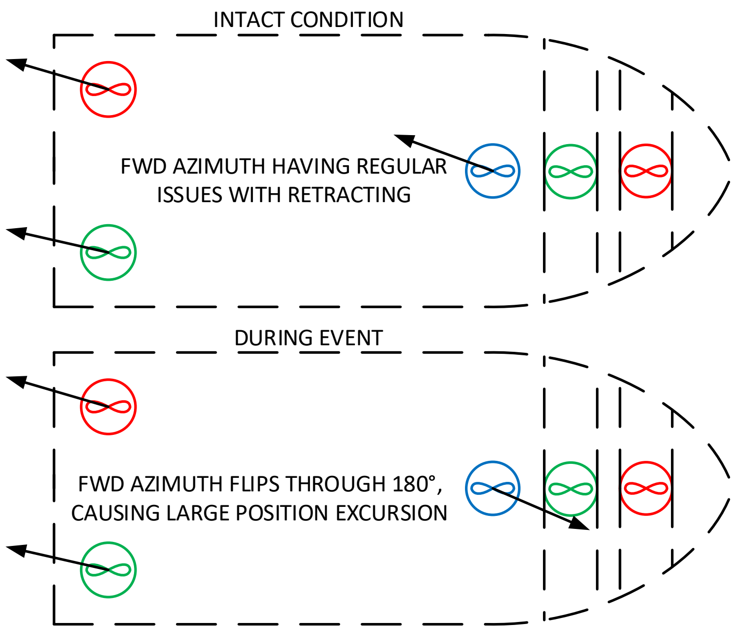

Figure 3-9 Recurrent Unexplained Thruster Azimuth Offset

3.5.7 **Example 7** – The DP class 3 MODU operating with its busties open (See Figure 3-10) suffered a partial blackout when an incoming standby generator connected and tripped all the other generators on the same bus on reverse reactive power protection (See Figure 3-11). The disturbance was coupled to the other redundant groups through incorrectly grounded network shields leading to a complete blackout as shown in Figure 3-12. It was found that the excitation systems of two generators had been incorrectly connected since delivery and the vessel had a history of this type of protection trip which had not been resolved. During pervious occurrences, the complex and variable nature of the fault propagation path had limited the severity of the failure effect to within that defined by the worst-case failure design intent

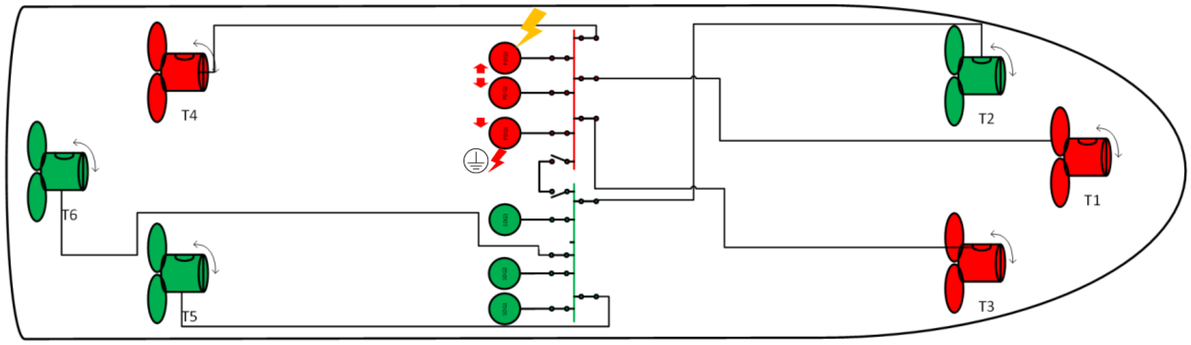

Figure 3-10 Recurrent Loss of Generators – Initial Failure Effect

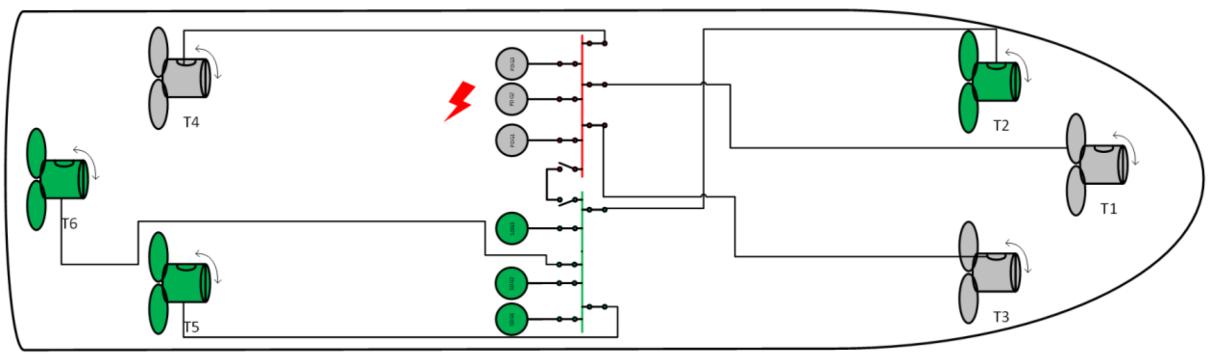

Figure 3-11 Recurrent Loss of Generators – Partial Blackout and Coupled Effect

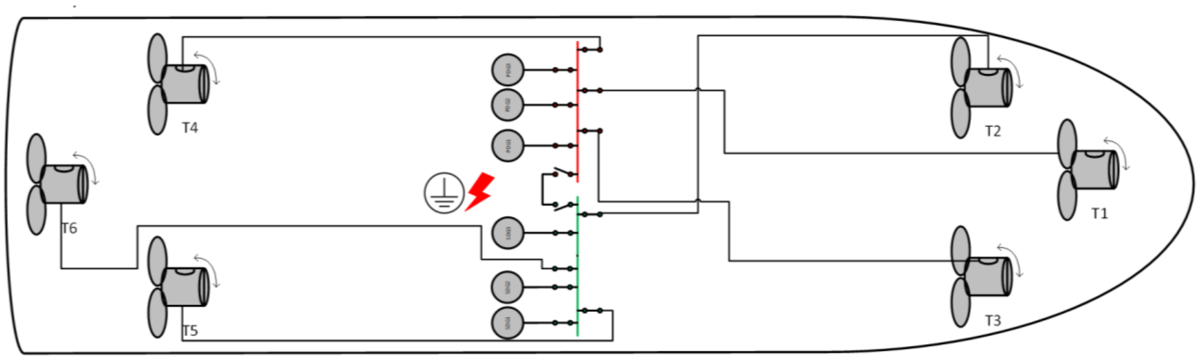

Figure 3-12 Recurrent Loss of Generators – End Effect – Complete Blackout

Note: *In the incidents described above, flaws in the vessel's DP redundancy concept were a contributory factor for some but not for others. However, in all cases, the safety, commercial and reputational consequences of the DP incidents could have been avoided if appropriate action had been taken when the fault was still intermittent and before it escalated into something more serious.*

4 MANAGEMENT OF INTERMITTENT FAULTS

4.1 IDENTIFICATION

4.1.1 Intermittent faults can be some of the most challenging to identify and troubleshoot. A DP system is a complex system of subsystems, created from tens of thousands of components, some of which will be in a failed state at some point in time. It would be very unusual for every system and component on a DP vessel to be fully operational all the time. It is often for this reason that noncritical redundancy is applied to the design to improve the overall reliability and availability of the vessel so that DP operations can continue without interruption after the first failure using the non-critical redundancy (which becomes critical). When critical redundancy fails, the remaining equipment is used to safely suspended if:

- The redundancy concept is compromised (by lack of redundancy or loss of single fault tolerance)

  or

- The post failure DP capability is reduced below the required levels by deterioration in performance.

4.1.2 The important point is therefore that the vessel crew should be able to identify which alarms, indications and abnormal behaviours are critical and those that are not. In general, a fault on any piece of equipment that reduces the DP system's post failure DP capability, or that removes or reduces its single fault tolerance is critical. Alarms should not be ignored but understanding their criticality allows appropriate action to be take in response. Appropriate technical support should be engaged when there is doubt as to the criticality of particular alarms or events.

Note: *DP FMEA providers are well placed to assess the capability and criticality of alarms and can provide information to develop a catalogue of critical alarms and their consequences.* It is emphasized that vessel's operational documentation and familiarization processes should clearly identify critical alarms and their respective response strategies.

4.1.3 The fundamental point is that critical redundancy in the DP system cannot be relied upon in mitigation of an intermittent fault in another part of the DP system. All redundant groups have to be healthy to operate. In other words, critical redundancy does not offset the threat to station keeping integrity posed by an intermittent fault somewhere else in the system.

4.1.4 Manual or automatic methods for detecting recurrent alarms may play a part in the management of this type of fault and methods are suggested in [1][3]. This may be particularly useful in the early stages where the frequency of recurrence may be low, and the effects present for only a brief period of time. Fundamental to this process is the ability to understand the criticality of alarms even if only one has been detected.

4.1.5 There may be occasions where a hidden failure compounds the effects of a subsequent failure thereby defeating the redundancy concept. This possibility is reduced by monitoring, and maintenance activities in conjunction with, annual DP and field arrival trials etc. However, this is not the same as continuing to carry out DP operations with a known, uncorrected defect in some part of the DP system even if it appears to have resolved itself for the time being. Very few faults are self-healing and if it has occurred once it is very likely to occur again, possibly at the worst possible time when some other part of the DP system has failed and position and/or heading now relies on a faulty piece of equipment with an intermittent fault.

4.1.6 It may not always be obvious to the DP vessel crew that there is an intermittent fault in the system, particularly if the frequency of recurrence is of the order of weeks. Repairs to consequential damage may lead a crew to believe that a hard fault has been repaired when in fact only the consequential damage has been addressed. The recurrence of the fault may take place when a different crew is onboard requiring careful documentations and hand over to avoid extended periods of time passing before the nature of the fault is recognised.

4.2 FIRST FAULT – HARD OR INTERMITTENT?

4.2.1 Example - A DP vessel experiences a fault that causes a critical part of the DP system to cease operation. A defective component is identified and replaced, and normal equipment operation can be restored. The decision to return to work is based on the assumption that the repair has addressed the root cause and the DP system is once again single fault tolerant. However, it is the nature of intermittent faults that they may cause secondary or consequential damage which is not related to the root cause.

4.2.2 What measures can be used to determine (without simply waiting to see if it happens again) whether the fault that has been experienced and repaired is:

- a hard fault

  or

- the first manifestation of an intermittent fault which will recur?

4.2.3 Measures which can assist in answering this question include:

- Create test conditions which reproduce those that were prevalent at the time fault occurred.
- Review all supporting and substantiating data sources. – Does the information available point to the repaired equipment being a credible root cause or is it more likely to be consequential damage?
- Carry out confidence building tests to prove the robustness of the equipment which will include soak and stress tests.
- Document the categorisation process so that it may be subjected to external review.

4.3 OTHER EFFECTS

4.3.1 Intermittent faults can have effects other than the local effect on the faulty equipment.

- When intermittent faults recur frequently, they may generate avalanches of alarms that are distracting to the crew.
- This may reduce the effectiveness of watchkeeping activities.
- There may be temptation to disable what are assumed to be spurious alarms.
- Avalanches of alarms may create enough volume of network traffic to reduce the performance of processors.
- Alarms may divert the attention of technical and operational personnel away from the real cause of the fault. The alarm or failure experienced is a consequence of the real fault on another part of the system. It is quite likely that the device or system that is actually faulty is not monitored and thus will not generate an alarm.

4.4 COMMUNICATION

4.4.1 Effective communication should be used to escalate issues associated with intermittent faults to the shore-based management team and engage OEM support to assist. For more complex equipment such as drives and control systems, OEMs may have easier access to any data stored in the drive about the fault. There may also be fault codes that will point the investigation in the direction of a particular cause. Protection relays and drives may store high resolution snap-shot data of power and propulsion system faults (it is important not to accidentally erase this when the investigation starts by cycling the control power to the relay for example). Data should be carefully extracted and forwarded to the investigation team onboard and/or ashore. The crew should be alert to the risk of data loss from storage buffers that are continuously overwritten in DP and vessel control systems. Data may be lost if not extracted and saved before the buffer is overwritten with new data.

4.5 CAUSES

4.5.1 Intermittent faults occur for a variety of reasons including:

- Loose connections in circuits, vibration, wear and tear.
- Slow leaks in pneumatic and hydraulic systems.
- Deteriorating / failing / marginal component performance (maintenance related issues).
- Environmental conditions, temperature, humidity, surface contamination.
- Commissioning and installation errors.

4.5.2 Intermittent faults can also occur because of poor design. In this case, apparently abnormal behaviour may occur when conditions cause a hardware or software-based system to become unstable only when certain conditions or combination of conditions are experienced. Strictly speaking these are designs flaws rather than faults but the effects are the same.

4.6 REMEDIATION

4.6.1 Repairing intermittent faults can be extremely challenging. There are several approaches which vary depending on the availability of diagnostic tools.

4.6.2 By their nature, intermittent faults may not manifest themselves when troubleshooting is ongoing. In this case, any alarms, observations and data captured at the time the fault was active form the starting point.

4.6.3 Troubleshooting may be able to identify some weakness or abnormal behaviour that leads to identification of the issues but in the worst case, the equipment appears to operate normally and within specification.

Note: *Being able to recreate the faulty behaviour gives the highest levels of confidence that an intermittent fault has been eliminated but this may not recur at a convenient time or on demand*.

4.6.4 In such cases it may be possible to provoke a recurrence through a combination of stress tests and soak tests. This can be particularly helpful if it recreates the conditions the equipment was experiencing at the time the fault occurred.

4.6.5 When attempting to recreate the failure effects, it may be beneficial to involve those that witnessed the intermittent fault. As the crew are part of the environment that influences the system, their actions may be required to recreate the circumstances in which an intermittent fault occurs.

4.6.6 High speed data loggers and digital oscilloscopes can be fitted to gather a wider range of data than is sometimes available from the internal data logger in the equipment itself, in the hope that the fault will recur and provided more data about its cause before troubleshooting options are exhausted.

4.6.7 If none of this intensive diagnostic work returns any information on the cause and resolution, the traditional route to follow is to replace parts of the equipment most likely to contain the fault (this replacement must be subject to validation testing even if a like-for-like replacement). Special attention may be given to the wiring harness and connectors. At this point there is a temptation to return the equipment to service and continue with DP operations. This should not be done without the participation and concurrence of all stakeholders so the risks can be fully understood, and additional barriers and compensating put in place. ASOGs / WSOGs and return to work protocols of charterers will likely consider an intermittent fault on a critically redundant element of the DP system in the same way as any other more permanent fault and initiate a Yellow condition (A change to yellow status in an ASOG or WSOG requires a cessation of DP operations).

4.6.8 It may be acceptable to use the '*replace and wait'* method to build confidence that the intermittent fault has gone only when there are insurmountable constraints to establish confidence by executing any of the other processes or combination of processes. It is essential that additional efforts are expended to establish and/or augment barriers such as operational controls and restrictions (for example operating the vessel in a blow-off condition).

4.6.9 Subject to the risk profile and consequences of a loss of position and/or heading, a replacement vessel with the capability and validated confidence to undertake the industrial mission may be an option for consideration, if it is not possible to establish an acceptable level of confidence that intermittent faults have been addressed or effectively mitigated with compensating provisions/mitigating measures.

5 SUGGESTED IMPLEMENTATION STRATEGY

5.1 CATEGORISATION

5.1.1 Intermittent faults should be evaluated for their effect on post failure DP capability.

5.1.2 Intermittent faults should not be ignored, even if they appear to have resolved themselves, as they can recur following failure of some other part of the DP system (as per the examples in the case for action) leading to failure effects with a severity exceeding that of the worst-case failure design intent. The consequences of the ensuing loss of position and/or heading will depend on the nature of the vessel's industrial mission.

5.1.3 Intermittent faults may recur following the occurrence of a (new) single fault elsewhere in the DP system. This can happen because the equipment with the intermittent fault is placed under greater stress when called upon to compensate for the loss of other equipment associated with the new fault. This situation can lead to a loss of position and / or heading when the new fault and the pre-existing intermittent fault are in different redundant DP equipment groups.

5.2 DETECTION & REMEDIATION

5.2.1 Routine reset and restart of faulted DP related equipment should not be accepted as a means of restoring a DP vessel's single fault tolerance.

5.2.2 Data logging (manual or automatic) may help to indicate the presence of certain types of recurrent faults and may prompt a change in configuration from closed bus to open bus as an additional barrier. Until such time as the potential maximum effects are understood, the vessel should no longer be considered single fault tolerant.

5.2.3 The preferred pathway to resolution is for intermittent faults to be recreated physically, diagnosed analytically and remediations proven by appropriate validation testing.

5.2.4 A '*replace and wait'* strategy should not be used as the basis for a return to work (recommencement of DP operations) without concurrence from all stakeholders in full possession of the facts and knowledge of the risks.

5.2.5 Communication and return to work protocols should ensure all necessary stakeholders are kept abreast of developments so that appropriate mitigating measures and operational barriers can be established if the vessel must resume DP operations before the cause has been positively identified and mitigated.

5.3 HUMAN PERFORMANCE

5.3.1 It should not be assumed that the concept of single fault tolerance and principles of post failure DP capability are well understood by all the relevant stakeholders, including on board vessel operational teams.

5.3.2 It is imperative that every opportunity is leveraged to reinforce the significance of the redundancy concept, the post failure capability of the vessel and the impacts of faults (hard and intermittent) on the same, and the role stakeholders play in defending the redundancy concept and operating the vessel within its validated post failure capability.

6 MISCELLANEOUS

Stakeholders	Impacted	Remarks
MTS DP Committee	✓	
USCG	✓	
ABS	✓	
DNV	✓	
Equipment vendor community	✓	This topic has not previously had this level of focus in previous guidance
Consultant community	✓	
Training institutions	✓	
Vessel Owners/Operators	✓	
Vessel Management/Operational teams	✓	