TECHNICAL AND OPERATIONAL GUIDANCE (TECHOP)

TECHOP_ODP_02_(D)_(BLACKOUT RECOVERY)

SEPTEMBER 2012

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1 INTRODUCTION

1.1 PREAMBLE

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

- Classification Societies (DNV, ABS).
- United States Coast Guard (USCG).
- Marine Safety Forum (MSF).

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 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 in two categories:

- TECHOP_ODP.
- TECHOP_GEN.

1.2 TECHOP_ODP

1.2.1 Technical guidance Notes provided to address Guidance contained within the Operations, Design or DP Personnel

1.2.2 The TECHOP will be identified by the following:

TECHOP_ODP_SNO_CATEGORY (DESIGN (D) OPERATIONS (O) DP PERSONNEL (P).

- EG 1 TECHOP_ODP_01_(O)_(HIGH LEVEL PHILOSOPHY).
- EG 2 TECHOP_ODP_02_(D)_(BLACKOUT RECOVERY).

1.3 TECHOP_GEN

1.3.1 MTS DP TECHNICAL COMMITTEE intends to publish topical white papers. These topical white papers will be identified by the following:

TECHOP_GEN_SNO_DESCRIPTION.

- EG 1 TECHOP_GEN_00 (TECHOP GUIDANCE).
- EG 2 TECHOP_GEN_02-(POWER PLANT COMMON CAUSE FAILURES)

1.3.2 TECHOP as described in 1.2 and 1,3 above will be published as relevant and appropriate. These TECHOP will be written in a manner that will facilitate them to be used as standalone documents.

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

1.3.4 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.

1.4 MTS DP GUIDANCE REVISION METHODOLOGY

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2 SCOPE AND IMPACT OF THIS TECHOP

2.1 SCOPE

2.1.1 TECHOP_GEN_01_(BLACKOUT RECOVERY).

- The need for automatic blackout recovery.
- Design objectives.
- Desirable features.
- Undesirable features.
- Testing automatic blackout recovery.
- Preparation of specification for DP vessels.

2.2 IMPACT ON PUBLISHED GUIDANCE

2.2.1 This TECHOP impacts MTS DP Vessel Design Philosophy Guidelines Part I & 2 Section 11.

3 CASE FOR ACTION

3.1 DESIGN AND TESTING OF BLACKOUT RECOVERY SYSTEMS

3.1.1 This TECHOP-ODP was written to promote good practice in the design and testing of automatic blackout recovery systems for DP vessels.

3.1.2 Even though most DP Class notations do not specifically require automatic blackout recovery it is universally accepted as a risk reduction measure for all DP operations where the consequences of loss of position are unacceptable.

3.1.3 There have been a number of high profile DP incidents in which the automatic blackout recovery system failed to restore power and propulsion despite being routinely tested with satisfactory results. This guidance note seeks to alert system designers to potential design flaws and provide guidance on desirable features.

3.1.4 Most of the important features of Blackout Recovery systems are already discussed in the MTS DP Vessel Design Philosophy Guidelines in Section 11.15.3 to 11.15.7 but this Techop provides further expansion of these subjects.

3.2 RECOMMENDED ACTION

3.2.1 Vessel designers should carefully consider the design of blackout recovery systems to ensure they are effective and can be readily tested.

4 SUGGESTED IMPLEMENTATION METHODOLOGY

4.1 THE NEED FOR AUTOMATIC BLACKOUT RECOVERY

4.1.1 A rapid and robust automatic blackout recovery system is an essential risk reduction measure for any DP vessel carrying out operations where the consequences of loss of position are unacceptable.

4.1.2 The DP systems of vessels built to meet the requirements of DP equipment classes 2 and 3 are intended to be single fault tolerant. DP incident records confirm that a significant number of blackouts and other causes of loss of position have more complex causes including:

- Single failure combined with hidden failure.
- Configurations errors – System in non-redundant configuration.
- Internal and External common cause failure modes (fuel, combustion air contamination).
- Flaw in redundancy concept.

4.2 DESIGN OBJECTIVES

4.2.1 The blackout recovery system should be robust and secure.

4.2.2 **Robustness** – The blackout recovery system should be able to return to operational status as much of the power plant as can be make available following the incident and be able to do so regardless of the manner in which the power plant failed. The blackout recovery system should not be disabled by faults which have blackout as a consequence.

4.2.3 **Security** – The blackout recovery system should not operate spuriously in response to normal systems transient or single failures within the blackout detection and recovery system itself. Sufficient alarms and monitoring should be provided to have a high degree of confidence that the blackout recovery system is fully operational.

4.3 DESIRABLE FEATURES

4.3.1 **Speed of recovery** – Experience suggests there is a trade-off between speed of recovery and reliability of recovery. Rapid recovery is desirable but not at the expense of an unreliable system which fails or only recovers some of the available machinery. Blackout recovery systems typically need to be tuned and repeatedly tested at the commissioning phase to ensure they operate quickly and reliably. A single successfully test is unlikely to provide the necessary level of confidence. Recovery times of 60s from blackout detection to restoration of thrust should be achievable with modern methods. Significantly lower restart times can be achieved with certain engine thruster combinations but these may not be appropriate to all vessel designs.

4.3.2 Security of blackout detection – The design of the blackout detection system should ensure that blackouts are reliably detected and that failures that could prevent blackout detection are brought to the attention of operators and engineers by suitable alarms or periodic testing. The greatest risks from spurious detection of blackout comes from those systems that actively open generator circuit breakers as a precursor to blackout recovery. This is done in an attempt to ensure that a faulty generator is disconnected before the recovery process begins however any false detection of blackout will then initiate a real blackout (on at least one section of the switchboard). Such events can be as dangerous as the events they are intended to avoid. Designers should consider the relative merit of such designs and consider where the greatest risks and benefits lie. It may be preferable to rely on the protective functions within the switchboards to open generators circuit breakers and busties. If a generator circuit breaker cannot be opened by the protection device in the switchboards there is a good chance it cannot be opened by any system including the PMS therefore actively sending an open signal may not provide much additional security. It does however increase the risk of initiation an unnecessary blackout.

4.3.3 Blackouts are typically detected by using more than one measurement. Typically three 'blackout relays' are arranged to measure the system line voltages. These can be simple dry contact relays or they may be more sophisticated under-voltage relays which take a control power supply and can be programmed to operate after a defined delay and at a defined voltage. This provides some defence against spurious detection caused by voltage dips. Whatever method is employed it is useful to create some cross checking to ensure that one of the three relays has not changed state due to failure or wire break. Where dry contact relays are used blackout is typically detected using normally energised contacts. The contacts for each of the three phases are wired in series to a single digital I/O input on the PMS (one input for each section of bus bar). Clearly such an arrangement can falsely indicate blackout if a relay fails or a wire breaks in the series circuit but the consequences of this are not severe provided the PMS only attempts to restart machinery that has stopped, as in this case, no machinery should have stopped. To provide additional security it is common to cross check the blackout relays against the voltage transducers and only initiate blackout recovery if these agree. Care must be taken not to rely too heavily on this cross check if the blackout relays and the voltage transducers use the same bus VT as the signal source, as Bus VT failure may cause both the detection methods to indicate falsely. Having said this, the Bus VT single may also indicate to the feeder protection relays that the bus is dead causing them to drop out. If this is the case the generators on that bus section should stay on line but all the service and feeder transformers will trip.

4.3.4 The severity of this failure effect should not exceed the worst case failure design intent. Additional security in 'dead bus' detection (for any purpose) can be achieved by using a spare set of normally open and normally closed contacts on each of the dead bus relays. If all the normally open contacts are a wired in series and all the normally closed contacts are wired in series and then these two sets wired in parallel with each other there should always be a path for current through this circuit which can be detected by a digital I/O in the PMS. If any relay fails when the bus bar is live the circuit will be interrupted. If any relays sticks in the closed position it should be detected next time the bus bar is de-energised. This does not prevent a false indication but can detect hidden failures which reduce reliability.

4.3.5 Some designs include a second set of blackout relays arranged to measure the line voltages on a transformers that is normally connected to the bus such as a grounding transformers or a pre-mag transformer – this can provide additional security of detection.

4.3.6 Although the focus is often on ensuring that a false indication of blackout is not detected it is equally important that the detection function be reliable. Periodic testing is generally accepted as providing the necessary level of confidence.

4.3.7 **Minimise consequences of spurious operation** – It may not be possible to reduce the risk of false detection completely so another approach is to carefully consider what action the PMS should take on detection of blackout. If all the PMS attempts to do is restart stopped machinery then the impact of a false indication of blackout may relatively minor – for example it start standby generators. This may be inconvenient but it should not lead to a critical situation. Provided the PMS does not attempt to 'reset' running equipment before the restart the effects of a false indication of blackout should be relatively benign.

4.3.8 **Autonomy in machinery control** – One way to minimise the risk of blackout recovery failing because a centralised blackout recovery system has malfunctioned due to a hidden failure is to distribute the blackout recovery function to the control system of the major machinery such as thruster and generators such that each unit is responsible for detecting blackout and making itself ready for reconnection. This approach required the majority machinery items to have control over all the auxiliary systems and support functions they require if it is to be fully effective therefore it has to be considered and adopted at design inception. It may also require that major items of machinery such as thrusters and their control systems have significantly larger reserves of stored energy in the form of UPSs or battery banks so that they can make themselves ready for connection in parallel with generators restart thus reducing the time taken to restore thrust.

4.3.9 **Minimise use of permissive and interlocks** - Poorly designed blackout recovery systems often fail to recover major items of plant because a start sequence failed on some permissive or interlock. It may be beneficial in such circumstances to have a different set of starting criteria for blackout recovery than that used in the normal starting sequence. It is quite normal for engine manufacturers to offer an emergency load up sequence for engines that is much shorter during blackout. However this philosophy can also be applied to other systems. For example, it may be normal for a thruster start sequences to include a permissive indicating that a cooling pump is running. During an emergency start it might be better to start the thruster anyway whether the cooling pump indicates as running or not and rely on the over temperature shutdown if the thruster does develop a problem. Depending, on the nature of the thruster installation it could be several tens of minutes before the thruster overheats and that could be more than enough time to bring the vessel under control. It could allow the drift of to be halted more quickly even if the thruster is subsequently lost. This example is only intended to illustrate the possibilities that could be considered to improve the reliability of blackout recovery. In each case the advantages and disadvantages of each protective function and interlock should be carefully evaluated to determine where maximum benefit lies.

4.3.10 **Low stress connection strategies -** Reliability of blackout recovery can be further enhanced by reducing the risk of a second blackout during the recovery process. Restoring the power plant as several islands helps to avoid the risk that the fault was not properly cleared by the protection functions and avoids the severe current and voltage transient associated with reclosing a bustie circuit breaker onto a fault. This approach has to be balanced against the advantages of connecting the switchboards together so that it is possible to establish surge sway and yaw forces as quickly as possible depending on which thruster and generating sets reconnect. The decision to choose one option or the other could be based on the efficacy of the protection scheme and its immunity to hidden failures.

4.3.11 Reconnection of service transformers and drive transformers can create very significant current and voltage transients sufficient to trip a generator offline. Traditionally this problem has been overcome by using the PMS to prevent connection of transforms and other consumers until sufficient generating capacity is connected to switchboards. This can introduce undesirable delays which would not be necessary if there were no restriction on connecting loads to a single generator. The use of premagnetisation for transformers and other 'soft start' strategies allows a thruster to be connected as soon as the first generator is available and effective blackout protection functions in the thruster drives can be used to ensure the thruster can safely use what power is available for thrust to start slowing the drift off.

4.3.12 Precharging of the DC links in drives from stored energy sources allows thrusters to be made ready for connection independently of the generators. Stored energy in the form of battery banks or super capacitors can also be used to drive small cooling water pumps for power electronics which are very sensitive to loss of cooling.

4.3.13 An alternative strategy for making generators and thrusters ready simultaneously involves connecting generators and thruster drive transformers to a dead bus in their de-energised state and ramping up the excitation in the generators after connection this effectively 'soft starts' the whole power plant.

4.3.14 **Start all generators -** When considering systems which need to be optimised for blackout recovery it is important to remember that the starting air systems should be dimensioned to allow simultaneous starting of all available diesels engines. This may not require significantly increased capacity in air receivers but could require larger bore pipework to allow for pressure drops. Sequentially starting engines appears to have few advantages for blackout recovery. Supervision of dead bus connection requires special attention when so many generators may be ready for connection at the same time.

4.3.15 **Reducing engine stating times** – A very large part of the time taken to recover a diesel electric power plant is associated with starting the diesels engines. Engine starting times should be one of the considerations when choosing engines for a DP vessel. Some engines have characteristics which can impose additional starting delays such as slow turning when starting from cold. These features should be avoided or carefully managed by the automation system. Smaller engines with air or electric starter motors are often faster to start and connect than large medium speed diesels using distributor type starting systems. Starting performance can often be improved by approaching the manufacturers see what options are available. Fitting additional starter motors to accelerate the mass of the engine and generator rotor to self-sustaining speeds has been effective in improving starting times.

4.3.16 **Ability to recover from all types of blackout initiators** – when designing a blackout recovery system it is important to remember that a power plant may pass through a period of very abnormal operation in the process of blacking out and voltage and frequency may be well outside normal partners. It is important that all healthy machinery is able to restart after being exposed to these abnormal conditions and not locked out by protective functions triggered by these abnormal conditions.

4.3.17 A power plant may also blackout out in such a way that the engines stop such as fuel or combustion air problems. Alternatively the power plant may blackout with the engines running offline due to an electrical fault. The blackout recovery system needs to be designed and tested to cope will all manners of blackout.

4.3.18 **Limit the number of protective functions leading to thruster, transformer and generator lockout.** In the process of designing a power plant for a DP vessel, a great deal of consideration is given to limiting equipment damage and ensuring the safety of personnel. These are extremely important considerations but do not overrule the need to ensure station keeping integrity particularly where the consequences of loss of position include risk to life, property and the environment. Thus it is necessary to carefully consider the benefits that each protective functions brings and whether or not machinery should be locked out from reconnection solely because it has been tripped by a particular protective function. For example if a generator has been tripped by the differential protection for the generators windings it is reasonable to assume that the generators itself is faulty. However, if the generator is tripped on overcurrent or over/under voltage or over/under frequency there is a possibility the fault lies external to the generators particularly if operating in parallel with a number of other sets. Thus it may be appropriate to lock out a generator on ESD, and differential protection trips but not on other functions as to do so could make the generator unavailable for reconnection after a blackout even though it is perfectly healthy. If the decision is taken not to have a lockout function associated with a particular protection trip there is still a degree of protection in function associated with synchronising the generators. For example, a generator which is significantly off frequency or voltage will not be able to connect with others. One situation to avoid however is dead bus connecting a faulty generator such that other generators cannot synchronise with it. Making under/over voltage/frequency protection active just prior to connection can help to avoid this condition.

4.3.19 Similarly there are many protective functions in variable speed drives used for thruster and other functions which will trip a thruster and lock it out. Such trips such as DC link over/under voltage may be absolute necessary to ensure the thruster is available for reconnection but the need to lock out the thruster from restart should be carefully considered in each case. These protective functions in drives also need careful coordination with other protective functions to ensure that drives are able to ride through the frequency and voltage excursion associated with protection system clearing faulty generators from the bus and isolating faulty circuits. In general, the protection study for a diesel electric DP vessel needs to consider every protective function affecting the operations of generators thrusters and other essential electrical consumers and not just the overcurrent protection designed to isolate short circuits and earth faults as has been traditional in some designs.

When considering recovery from partial blackout it is equally important to remember that dual fed consumers such as transferable thrusters may be expected to transfer to their alternative power source even though they may have experienced very abnormal operating conditions on their main supply. Classifications society rules for various DP notations differ on whether transferable thrusters can be considered as contributing to redundancy but where this is the case it is vitally important to confirm (by testing where practical) that the transfer process is not rendered ineffective by the conditions prior to blackout.

4.3.20 Maximise the use of auto reset – remove the need for local reset. Thruster drives and other machinery often have a certain amount of protective functions that will lock out the drive from reconnection. Although these functions may be absolutely necessary to prevent damage they need to be promptly coordinated with other protective function to ensure they do not operate in a manner that defeats the redundancy concept. However in the event that they do it is preferable to have an auto reset function that will make the drive available when the conditions that initiated the trip no longer exist. If this is not possible then a remote manual reset is preferable to a local reset as in an emergency situation it can take a very long time for engineers to attend each piece of machinery that needs such a reset. It can be argued that the reason for having a local reset is to ensure that the condition of the drive is inspected before it is reenergised. If this is the case then consideration should be given to augmenting monitoring and CCTV to allow this to be done remotely.

4.3.21 T**hrusters automatically recovered to DP system control** – It is generally accepted that there are significant advantages to having thrust automatically restarted and recovered to full DP control following a blackout – DPOs should only need to supervise the system as it recovers control. There is always a risk that reconnecting a faulty item of machinery will cause the blackout to occur again but this risk should be mitigated by the use of effective protective functions so that automatic reconnections can be made with confidence.

4.3.22 **Avoid reliance on single non redundant elements such as the emergency generator**. Blackout recovery system designs that introduce significant commonality into the redundancy concept are to be avoided for several reasons

- They may introduce fault propagation paths between otherwise separate and redundant systems.
- They may reduce the reliability of the blackout recovery system by creating a potential single point failure that may render it ineffective.

4.3.23 Such a common point is sometimes created in systems where the emergency generator forms part of the blackout recovery systems. The emergency generator and switchboard are sometimes used in blackout recovery systems to provide power to engine support systems that must be operational before an engine can start. Prelubrication is one such example as some engines will not start without lubricating oil pressure. Other functions may include fuel oil booster pumps. Some classification societies expressly forbid the use of the emergency switchboard for such functions and in the case of vessel's built to the rules these problems should not arise. Even when the power of the emergency generator is not used directly it is sometimes the case that the stored energy systems associated with the emergency generator are used in some way. For example the 24Vdc control power supply for the emergency generator may be used to power control logic associated with blackout recovery and this can introduce a single point failure leading to failure to recover from a blackout.

4.3.24 **Recovery from ESD 0.**

4.3.25 One blackout initiator that is sometimes overlooked is the emergency shutdown system. Because it is assumed that this will always be operated in an emergency situation and that neither the main power plant nor the emergency generator should start in such circumstances it is assumed that there will be no role for blackout recovery in this scenario. However, it can be important to be able to recover from inadvertent operation of the ESD systems or where the ESD system has operated because if an internal fault. Thus it is important to consider how the blackout recovery system interfaces with the ESD systems and how automatic blackout recovery can be initiated after the ESD is reset or removed.

4.4 UNDESIRABLE FEATURES

4.4.1 Most of the undesirable features have been discussed in the course of discussing desirable design features above but they are repeated here for ease of reference.

- Dependence on single non redundant items such as emergency generator and/or switchboard – This is expressly forbidden by some classification societies.
- Protective functions that lock out healthy equipment from reconnection.
- Unreliable blackout detection unable to distinguish between real blackout and normal system transients.
- Tripping of online generators in response to blackout indication.
- Using a single source for blackout detection.
- Sequential start of generators in response to blackout.
- Power systems designs which have transients associated with transformer connection (use of multiple generators and delays in thruster restart to compensate for such demands for surge current).
- Overuse of unnecessary permissives for generator and thruster connection.
- Unnecessary use of local reset functions.
- Engines and thrusters with long connection times.

4.5 TESTING AUTOMATIC BLACKOUT RECOVERY

4.5.1 Blackout recovery systems are a risk reduction measure intended to recover the vessel to DP control in the event at the redundancy concept is defeated for any reason. It is important to test the blackout recovery system in each of the power plant configurations used to carry out DP operations at or below the assigned equipment class. In this respect it is important to consider that even vessels operating with independent power systems have blacked out and thus operating in split bus configuration is not generally considered as sufficient reason for not periodically testing blackout recovery from this configuration.

4.5.2 Blackout recovery system needs to be carefully commissioned, tuned and tested to ensure reliable operation when needed. It is import to test the response of the blackout recovery system to a comprehensive range of blackout scenarios. It may not be the case that the blackout recovery system is deficient in any way but other systems in generators and thruster drives may react badly to the electrical conditions experienced prior to blackout. These may not be adequately simulated by simply stopping generators to create the blackout for test purposes.

4.5.3 Unless there are justifiable reasons why such simulations are unnecessary, test protocols should include tests demonstrating satisfactory recovery from blackout caused by the following conditions:

- Over / under voltage.
- Over / under frequency.
- Blackout leading to engines stopping.
- Blackout leading to engines running offline.
- Recovery from ESD 0 reset – where appropriate.

4.5.4 A comprehensive protection coordination study considering all the protective functions that can trip an item of DP essential equipment should be developed. This analysis should demonstrate that protection functions intended for personnel safety and limiting equipment damage do not operate spuriously in response to common mode failures, causing effects exceeding WCFDI and that they do not prevent the reconnection of healthy equipment.

4.5.5 In the case of a MODU, there may be limited opportunities to test full blackout recovery functions until there is a break in operations. However, consideration can be given to creating a more limited test function which is able to confirm the health of important elements of the blackout recovery systems without actually causing any disruption to the power plant.

4.5.6 A complete test of the blackout recovery systems is necessary in order to have a sufficiently high level of confidence that it will operate satisfactorily on demand,

4.6 PREPARATION OF SPECIFICATIONS FOR DP VESSELS

4.6.1 As automatic blackout recovery is not a requirements of traditional DP class notations is it is important that the vessel owner's requirements for this system are very well described in the specification for the vessel that forms part of the contract with the shipyard. Including requirements for commissioning and testing the blackout recovery systems to prove its effectiveness. Reliance upon compliance with classification society rules may not be sufficient to ensure an effective blackout recovery system is delivered.

4.6.2 It is recommended that a detailed specification for the blackout recovery system forms part of the redundancy concept documents included in the vessel specification. In particular, this specification should consider the functions and features present in the redundancy concept and the restrictions placed upon it by the choice of main machinery or particular system vendors.

5 MISCELLANEOUS

Stakeholders	Impacted	Remarks
MTS DP Committee	✓	To track and incorporate in next rev of MTS DP Operations Guidance Document Part 2 Appendix 1. Communicate to DNV, USCG, Upload in MTS website part
USCG	✓	MTS to communicate- FR notice impacted when Rev is available
DNV	X	MTS to Communicate- DNV RP E 307 impacted
Equipment vendor community	✓	MTS to engage with protection suppliers
Consultant community	✓	MTS members to cascade/ promulgate
Training institutions	X	MTS members to cascade/ promulgate
Vessel Owners/Operators	✓	Establish effective means to disseminate information to Vessel Management and Vessel Operational Teams
Vessel Management/Operational teams	✓	Establish effective means to disseminate information to Vessel Operational Teams