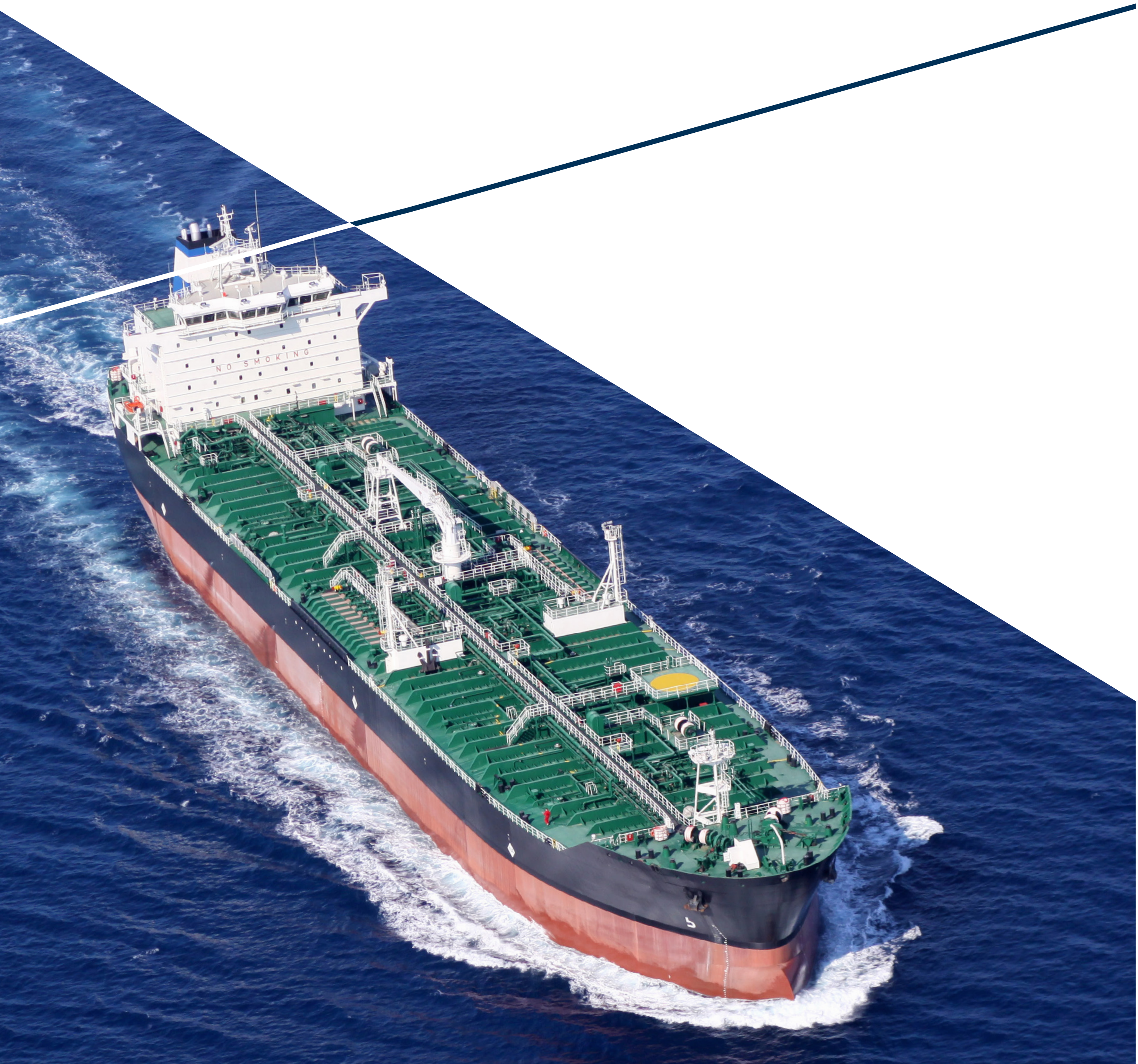
BLACKOUT AWARENESS AND PREVENTION ON SHIPS: TECHNICAL AND OPERATIONAL ADVISORY

June 2024



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INTRODUCTION

Over the last two decades, blackout incidents on ships have increased in proportion to the growth of the world marine fleet. Blackouts typically lead to loss of propulsion and loss of steering control. Figure 1 illustrates this increasing trend in the rate of reported blackouts in the world marine fleet from 2005 to 2024 according to the Lloyds List Casualty Database [1]. Most of these reported blackouts were experienced by general cargo and roll-on/roll-off passenger (ROPAX) vessels.

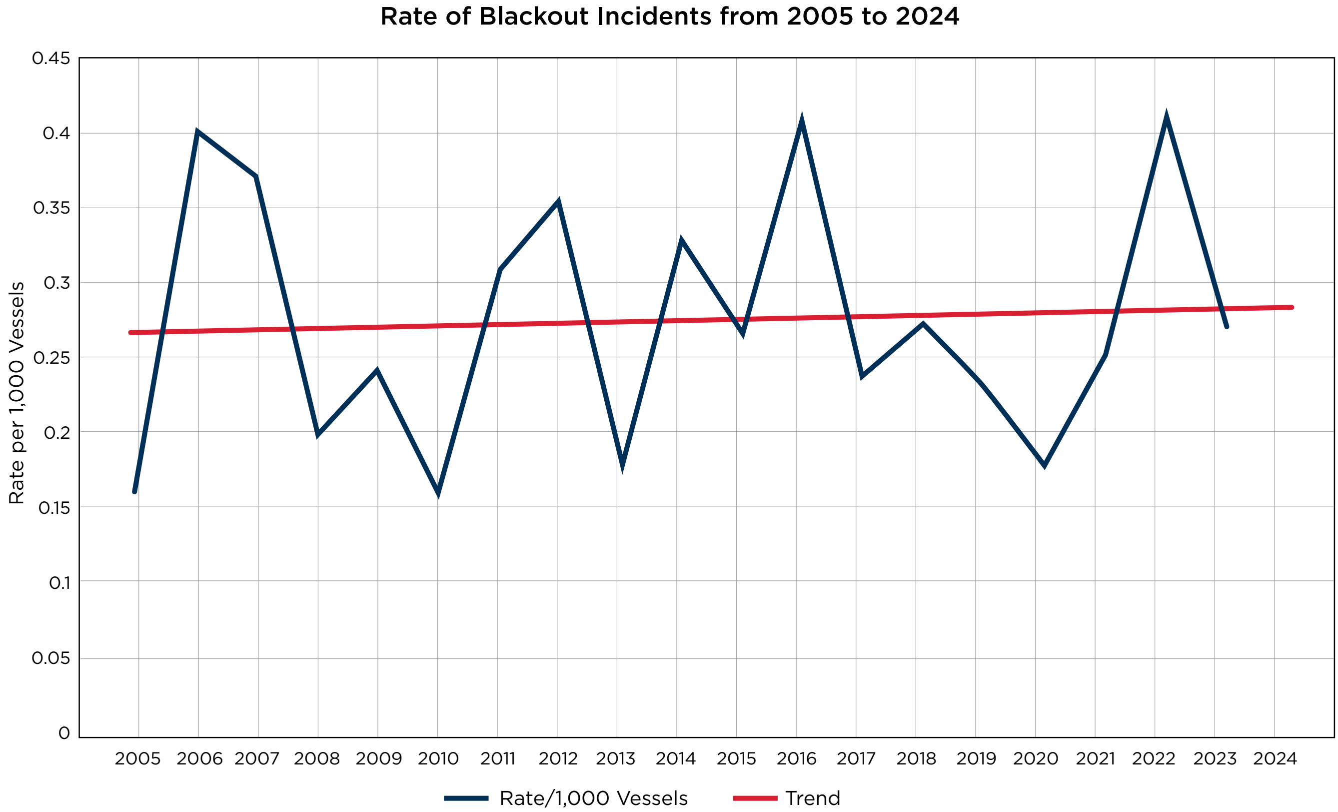


Figure 1: Rate of reported blackout incidents from 2005 – 2024

It is essential for seafarers and vessel owners to be aware of the risks of blackouts, and to implement measures to prevent or minimize their occurrence. Further, it is vital for ship crews to be fully proficient at recovering from a blackout situation.

SCOPE

The objective of this advisory is to raise awareness within the maritime industry of the causes and consequences of blackouts on ships, offer suggestions for prevention, and guidelines for recovering from blackouts. Loss of propulsion, loss of steering, and loss of essential services are addressed as consequences of blackouts. The guidelines provided in this advisory are directly applicable to conventional ships such as bulk carriers, tankers, container ships and general cargo ships fitted with conventional main propulsion and auxiliary machinery arrangements and covered by Class Requirements and International Maritime Organization (IMO) regulations.

Ships with electrically driven propulsion systems such as diesel electric, power take off (PTO)/power take in (PTI) systems with shaft generators, hybrid and all-electric propulsion systems and ships with Dynamic Positioning Systems are not covered in this Advisory, but parallels may be drawn where applicable.

MACHINERY ARRANGEMENT ON CONVENTIONAL SHIPS

Ships fitted with conventional propulsion systems are typically designed with traditional driveline arrangements, comprising main engine(s), drive shaft(s), propeller(s), steering gear, rudder(s), and in some cases reduction gear(s). An example of a direct drive arrangement is shown in Figure 2.

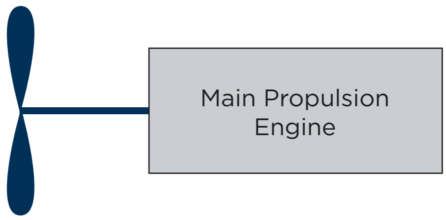


Figure 2: Traditional propulsion machinery arrangements

In addition, a power plant consisting of several engine-generator sets (gensets) typically form the main source of electrical power for the ship. These gensets provide power to the main switchboard and all essential and non-essential services are typically connected to the main switchboard. Essential services include auxiliaries necessary for starting and running the main propulsion engine, such as lube oil pumps and cooling water pumps. Figure 3 provides an example of the main source of power and main switchboard arrangement on a conventional ship.

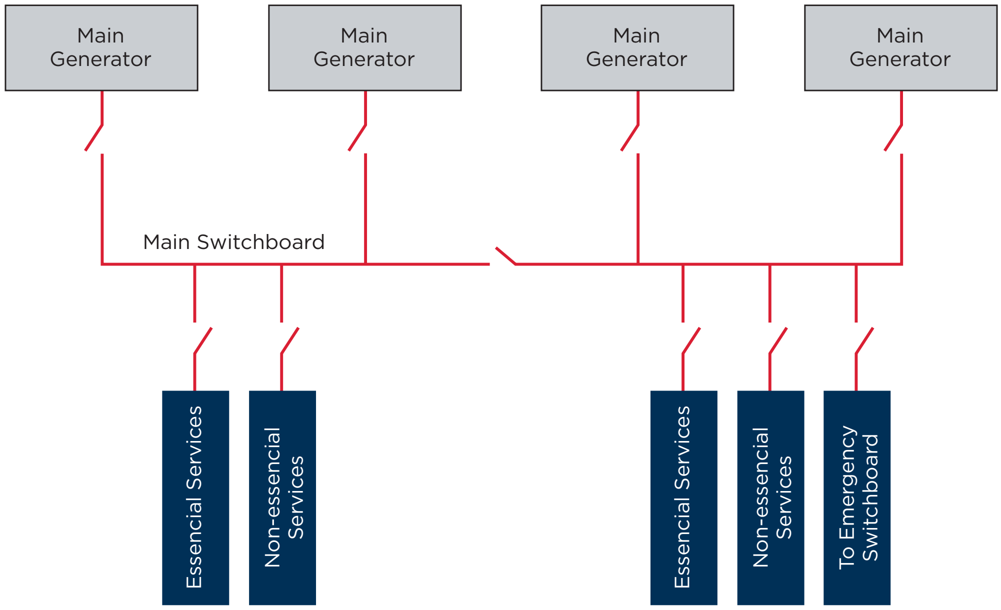


Figure 3: Main source of power and main switchboard arrangement

Conventional ships are also fitted with emergency generators. Emergency loads such as emergency lighting, navigation lights, communication, alarms, fire pumps, and steering gear are connected to the emergency switchboard. Refer to Table 1 in Section 4-8-2/5.5 of the ABS *Rules for Building and Classing Marine Vessels* for a detailed list of the services to be powered by an emergency source of power. During normal operation, the emergency switchboard is supplied from the main switchboard by an interconnecting feeder. Upon failure of the main source of electrical power, the interconnecting feeder automatically disconnects at the emergency switchboard, and the emergency generator provides power for the emergency services. Figure 4 illustrates a typical emergency generator and emergency switchboard arrangement on a conventional ship.

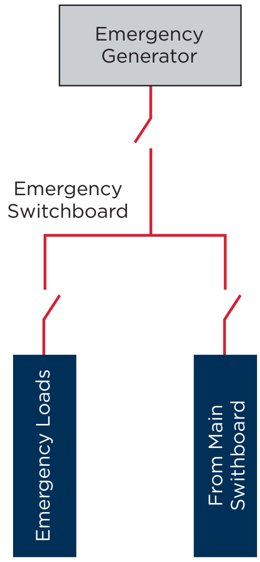


Figure 4: Emergency generator and emergency switchboard

WHAT IS A BLACKOUT CONDITION?

A blackout condition on a ship occurs when there is a loss of electrical power from the main switchboard. A blackout may be momentary or sustained.

A momentary blackout is a temporary condition during which power is not available from the main switchboard, until a main generator(s) is operational and connects to the main bus. The blackout begins the moment power is lost and ends when power is restored to the essential services.

During a sustained blackout, loss of power to essential equipment and systems is the main concern. Depending on the operating conditions of a ship, a sustained blackout can cause unsafe conditions or even a casualty incident. In the ABS *Rules for Building and Classing Marine Vessels* section 4-1-1/1.9.7, a blackout condition is defined as a situation where the main and auxiliary machinery installations, including the main power supply are out of operation, but the services for bringing them back into operation (e.g. compressed air, starting current from batteries, etc.) are available. The emergency generator is assumed to be available for operation at all times, including during blackout conditions.

Some typical blackout scenarios on a ship include but are not limited to:

- The main generators are shut down
- The main generators are running but power is not available from the main switchboard, possibly due to an electrical fault, operational error, automation fault, or other equipment/system failure

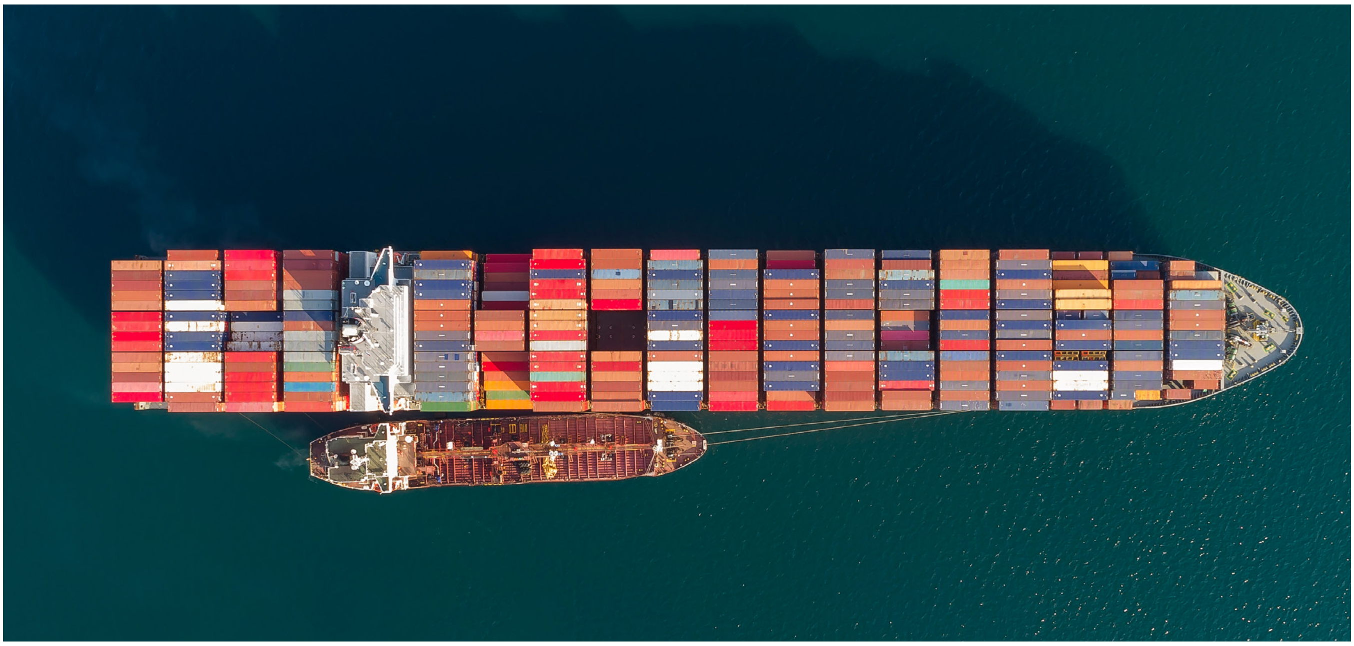
In summary, a blackout condition on a ship occurs when there is a loss of electrical power at the main switchboard, regardless of the status of the main generators, emergency generators, or emergency switchboard.

To further define “blackout” a distinction should be made between a blackout condition and a dead ship condition. The *ABS Rules for Building and Classing Marine Vessels* section 4-1-1/1.9.6 defines a dead ship condition as follows.

- The main propulsion plant, boilers and auxiliary machinery are not in operation due to the loss of the main source of electrical power
- In restoring propulsion, no stored energy for starting the propulsion plant, the main source of electrical power and other essential auxiliary machinery is assumed to be available

The difference between a blackout condition and a dead ship condition can be explained as follows:

- In a blackout condition, there is a loss of electrical power from the main switchboard. The two typical reasons for this loss of electrical power are the main generators are disconnected from the main switchboard, or not in operation. However, energy for restoring the main generators back into operation is available.
- In a dead ship condition, the main propulsion engine is not in operation due to a loss of electrical power. No stored energy for starting the main propulsion engine, main generators, and other essential auxiliaries is available.



REGULATORY AND CLASS REQUIREMENTS

The ABS *Rules for Building and Classing Marine Vessels* Section 4-8-2/3.11 address mitigation against interruption of essential services necessary for propulsion and steering by requiring redundancy in power system arrangements. Thus, ships are typically designed with multiple main generators. Depending upon the vessel, during the normal mode of operation, a single generator may be in operation, or multiple generators may operate in parallel.

SINGLE GENERATOR OPERATION

Where the electrical power is normally supplied by a single generator, provision is to be made upon loss of power for automatic starting and connecting to the main switchboard of a standby generator(s) preferably within 30 seconds after loss of the electrical power supply but in no case more than 45 seconds.

MULTIPLE GENERATOR OPERATION

Where the electrical power is normally supplied by more than one generator simultaneously in parallel operation, the system is to be so arranged that in the event of the loss of any one of the generators in service, the electrical supply to essential equipment necessary for propulsion and steering by the remaining generator(s) in service will be maintained for the safety of the vessel.

DEAD SHIP CONDITION

If there is no stored energy available for starting any of the ship's main generators and the ship's main propulsion engine(s), the vessel is in a dead ship condition. Arrangements for bringing the main and auxiliary machinery into operation are to have capacity such that the starting energy and any other power supplies for operation of the main propulsion engine(s) are available within 30 minutes from a dead ship condition.

EMERGENCY GENERATOR OPERATION

Per IMO Requirements and the ABS *Rules for Building and Classing Marine Vessels* Section 4-8-2/5.9, when power is not available from the main switchboard (i.e. blackout condition), the emergency generator is to supply power to the emergency services within 45 seconds automatically. The typical sequence of operations for transferring to emergency power is as follows:

- There is an automatic disconnection of the interconnecting feeder between the main switchboard and emergency switchboard, and the emergency generator automatically starts
- The emergency generator runs and connects to the emergency switchboard
- The emergency generator supplies power to the emergency loads

CONSEQUENCES OF BLACKOUTS

A blackout is serious and potentially dangerous. In a best-case scenario, a standby generator will be brought online to restore the main source of electrical power within 45 seconds. A sustained blackout can eventually lead to the following consequences:

- Loss of propulsion and steering
- Loss of other essential services
- A dead ship condition
- A casualty event

LOSS OF PROPULSION AND STEERING

A blackout will normally result in failure of the main propulsion engine control system and fuel delivery system, leading to loss of propulsion. In addition, a blackout will normally cause loss of steering. According to IMO and the ABS *Rules for Building and Classing Ships* Section 4-3-4/1.2.2, the steering system is to be provided with two sources of power; one from the main source of power and one from the emergency source of power. Thus, the steering system can be non-functional for up to 45 seconds, until it is supplied with power from the emergency generator. However, without propulsion, the effects of rudder input will most likely be limited.

Loss of propulsion and steering on ships can have enormous consequences. Port maneuvering, transiting confined or congested waterways, proximity to the shore, and weather conditions can significantly impact consequence severity. In the worst-case scenario, loss of propulsion or steering can result in a casualty event.

LOSS OF OTHER ESSENTIAL SERVICES

A blackout condition will normally result in the loss of other primary and secondary essential services in addition to the services necessary for propulsion and steering. These services typically include lighting, firefighting, cargo system control, ventilation and environmental controls, and any services associated with special notations. Refer to Section 4-8-1/7.3.3 of the ABS *Rules for Building and Classing Marine Vessels* for a detailed list of primary and secondary essential services.

DEAD SHIP CONDITION

When a marine vessel has experienced a sustained blackout and loss of propulsion, means for restoring propulsion are typically not available until electrical power is restored. Under those circumstances, the vessel is in a dead ship condition and at risk of drifting or a casualty due to loss of propulsion and steering.

CAUSES OF BLACKOUTS

This Advisory does not address all the possible causes that can lead to blackouts. However, to address general categories of blackouts, it is necessary to look at the equipment/components of a vessel's electrical power generation, distribution, and automation system.

ELECTRICAL FAULTS

Generator-sets (prime mover coupled with an alternator) which supply electric power on ships can be influenced by several kinds of electrical faults.

Generator electrical protection systems are implemented to protect generators from damage resulting from faults in the electrical system. Protection devices may act to isolate generators and other segments of the electrical system depending on the severity and duration of the fault. Generator faults are categorized below as faults associated with the fuel control system, the excitation control system, and overcurrent faults.

FAULTS ASSOCIATED WITH THE FUEL CONTROL SYSTEM

- **Over Frequency** – Occurs when the generator frequency exceeds a predetermined value due to an increase in engine speed
- **Under Frequency** – Occurs when the generator frequency is below a predetermined value due to a decrease in engine speed
- **Reverse Power** – Poor frequency control and/or voltage control can cause a faulty generator to absorb more than its share of electrical load. This condition can cause other running generators to trip on the required reverse power protection and the faulty generator can trip on overcurrent, thus causing a blackout.

FAULTS ASSOCIATED WITH THE EXCITATION CONTROL SYSTEM

- **Over Voltage** – Occurs when the generator voltage exceeds a predetermined value due to an increase in generator excitation
- **Under Voltage** – Occurs when the generator voltage is lower than a predetermined value due to a decrease in generator excitation
- **Loss of Excitation** – Occurs due to a loss of magnetism in a generator caused by a fault in the excitation system or the voltage regulator. Common causes include faulty excitor diodes and failed voltage regulators.

OVERCURRENT FAULTS

- **Overload** – Occurs when applied electrical load exceeds the rating of generators and other critical equipment in the power system. Overload faults generate heat which can damage equipment and cause injury to personnel.
- **Short Circuit** – Short circuits can occur within generator windings, within generator cables, or at the main switchboard. Short circuit faults can cause overheating, burns, fires, arc flash, and arc blast hazards. A system that does not isolate a short circuit fault quickly can experience a total blackout.

EXAMPLES OF OTHER TYPES OF ELECTRICAL FAULTS

- Poor synchronization of generators or switchboard buses can cause disturbances leading to blackouts
- Large electrical load steps (starting or stopping large motors) during which only minimal generators are running can cause voltage dips that lead to a blackout
- Faulty current interrupting devices such as circuit breakers, switches and fuses can cause loss of power to essential services
- Faulty electrical equipment such as transformers and motors causing short circuits
- Ground faults

PROTECTION COORDINATION

At the switchboard level of a ship's electrical system, incorrect protective device coordination can cause partial or full blackouts. The design and settings of circuit breakers and protective relays are specified to isolate any faults to the lowest level possible without causing a full blackout.

Figure 5 illustrates an example of a split bus configuration where a ship's electrical system is being operated with the bus-tie open. A fault is present within the port propulsion motor. The circuit breaker immediately upstream of the faulty motor should trip to isolate the faulty section of the system. However, due to uncoordinated current and time settings within the overcurrent protective devices, the two feeder breakers and the generator breaker upstream of the faulty motor trip instead, causing a loss of power to the port section of the ship.

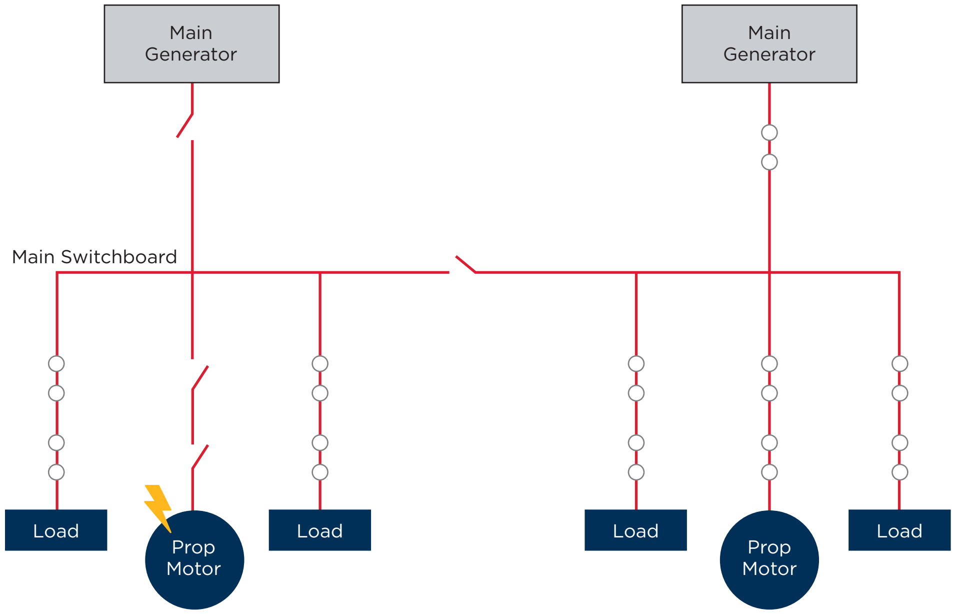


Figure 5: Poor coordination resulting in a partial blackout

In the example shown in Figure 6, only the breaker immediately upstream of the faulty motor trips because the overcurrent devices are correctly coordinated. In this instance the supply of power to the other loads connected to the port switchboard is not interrupted.

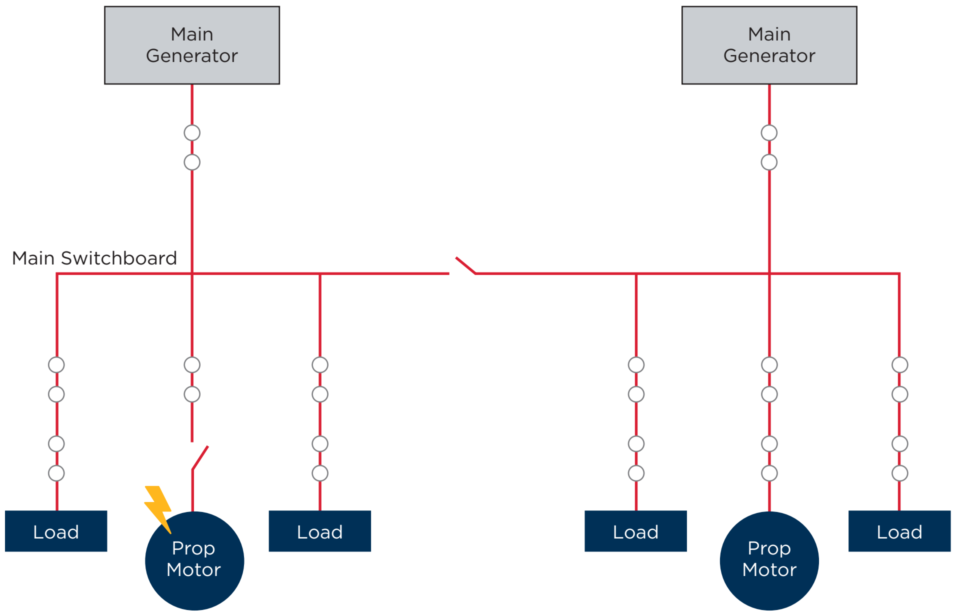


Figure 6: Good coordination: only the affected section is isolated

The list of electrical faults discussed is non-exhaustive and represents some of the common faults found in marine electrical systems. Depending on the severity and duration of a fault, system design, and protection coordination, electrical faults may lead to a blackout on a ship.

CONTROL AND AUTOMATION FAILURES

Generator and switchboard control and automation is another area with potential for failures. Loss of control power supply to metering, control, and protective devices can result in loss of monitoring and control of the power system.

SOFTWARE AND HUMAN MACHINE INTERACTION

Computer-based systems, software, and data networks are other potential sources of failures. Ship environments require Computer-based systems to be robust. The various software packages should be compatible, with development and testing conducted according to industry best practices. A ship is a System of Systems (SoS) with increasing levels of complexity. Although the intent of automatic controls is to ease the burden on the crew, the increased use of technology dependent upon sensors and software may put different demands on the crew. For example, by using automated controls on a ship's systems, the visibility of all the components of systems may not be so transparent to the crew. Furthermore, the crew may lack full mastery of the ship's automated systems design and automatic responses to critical events. The crew may inadvertently act in response to a situation that interferes with or even overrides the automatic system response. This highlights the need for the crew to fully understand the operational factors of the power generation plant and associated equipment and systems.

CYBERSECURITY

Control and automation networks can be susceptible to cyber vulnerabilities that may lead to power system failures. Causes of cyber related failures include human error and deliberate actions taken by individuals intending to cause harm. Without appropriate access control and monitoring, ship crews and owners may not be able mitigate against cyber-attacks that can compromise the ship's power system. In addition, lack of thorough computer-based system integration between suppliers, integrators and owners can lead to cyber vulnerabilities.

MECHANICAL FAILURES

Mechanical failures can also cause blackouts. In general, ship machinery is highly reliable, but mechanical failures do occasionally occur in engines, generators, pumps, and other machinery. Any of these can potentially lead to a blackout.

Performing regularly scheduled inspections and preventative maintenance at intervals recommended by the original equipment manufacturer will decrease the potential for material or component failures.

Some of the typical mechanical failures on auxiliary engines that may cause blackouts are:

- Governor failure causing engine overspeed and shutdown

- Lube oil pump failure causing engine shutdown
- Engine seizure causing heavy damage
- Worn or clogged fuel injector causing engine misfiring and shutdown
- Worn cylinder, piston, piston ring or cylinder cover valves causing compression defect and engine shutdown

OPERATIONS AND MAINTENANCE PRACTICES

Operational control and regular inspections and maintenance reduce the possibility of blackouts. Regularly scheduled inspections, preventative maintenance, testing, checking equipment operation and sustainable running parameters are key to preventing failures that can lead to momentary or sustained blackouts. Common causes of failures resulting from poor operations and maintenance practices include but are not limited to:

FUEL SYSTEM

- Clogged filters can cause auxiliary engine stoppages, reduction in capacity, or total shutdown
- Poor fuel management and contaminated fuel which has not been correctly purified and filtered can cause machinery breakdowns and total failures
- Switching over fuels to comply with statutory emissions requirements without the appropriate mitigation measures in place can result in failures
- Fuel piping and fuel pump failures can lead to a shutdown of auxiliary engines
- Inconsistent fuel injection valve operation can lead to incomplete combustion or high exhaust gas temperature
- Fuel supplied out of specification can cause auxiliary engines to malfunction

COOLING SYSTEM

- High cooling water temperature can lead to auxiliary engine shutdown
- Low cooling water pressure can cause the auxiliary engine to derate

LUBRICATION SYSTEM:

- Low lube oil pressure can lead to auxiliary engine shutdown
- High lube oil temperature can lead to auxiliary engine derate
- Crankcase oil mist detector or splash oil monitoring system failure can lead to auxiliary engine shutdown.
- High big end bearing and/or main bearing temperature due to lack of lubrication can cause auxiliary engines to shut down

OPERATIONS

- Repeated start and stop of main and/or auxiliary engines can deplete compressed starting air levels in the air receivers. Insufficient available starting air for auxiliary engines will lead to a blackout and inability to replenish the air receivers. Insufficient available starting air for the main engines will lead to a loss of propulsion incident.

HUMAN FACTORS

Understanding human capabilities and limitations is essential to overcome opportunities for human error. Human factors such as situational awareness, fatigue, training, decision-making, and communication impact the safety of maritime operations. A fatigued crew can become easily distracted and lose situational awareness. Lack of appropriate training and emergency preparedness can lead to unsafe actions.

It is of pivotal importance that crews are thoroughly trained, familiarized, and prepared for any emergency situation as required by the International Safety Management (ISM) code. Continual training, drills and exercises while onboard can strengthen competence and confidence to deal with any potential emergency such as a blackout.

Adequate rest is essential for avoiding poor judgement resulting from fatigue. Standards for training, certification and watchkeeping (STCW) and Maritime Labor Convention (MLC) requirements for hours of work and rest should be followed and compensatory rest given when exceptions or flexibility allowed by STCW/MLC is exercised in exceptional circumstances.

PREVENTION OF BLACKOUTS

Conditions and failures that lead to blackouts can occur due to a variety of reasons. To make a ship more resilient against blackouts, a single approach is not sufficient. Rather, a holistic approach to the ship and its systems is necessary.

DESIGN

ENHANCED POWER MANAGEMENT SYSTEM

To enhance the minimum design requirements for the electrical power system, upgrading the Power Management System (PMS) to incorporate Advanced Generator Protection can have a positive effect. A straightforward PMS may monitor the electrical loads on a ship's electrical system, then start and connect any available generators to the system as electrical loads increase and approach the limits of the running and connected generators. Also, a typical PMS can facilitate load shedding of non-essential services and electrical loads when the electrical load capacity of the generators is approached.

A more capable PMS incorporates Advanced Generator Protection where faulty generators can be detected earlier and disconnected from the electrical plant to remove electrical disturbances and prevent blackout situations. If available, another generator will be started and connected. Also, if necessary, non-essential services can be shed to facilitate the system status change. In addition, if the ship includes electrical thrusters, these can even be power-limited to reduce electrical load as necessary and applicable.

Automatic blackout recovery and testing of standby arrangements can be incorporated into the PMS and drills/exercise schedule of the vessel. Whether automatic or manual, regular testing of blackout recovery and standby arrangements is essential.

PROPULSION REDUNDANCY

Some conventional ships can be fitted with multiple propulsion machines and propulsors. ABS offers Propulsion Redundancy Notations which include requirements for and gives recognition to ships that are provided with redundancy for propulsion and steering. The intent is that after a single failure, as specified under each redundancy notation, propulsion and steering can continue or be restored in a short period of time, as specified in each notation. Figure 7 shows the four base Propulsion Redundancy notations: R1, R2, R1-S, and R2-S. For R1-S and R2-S notations,

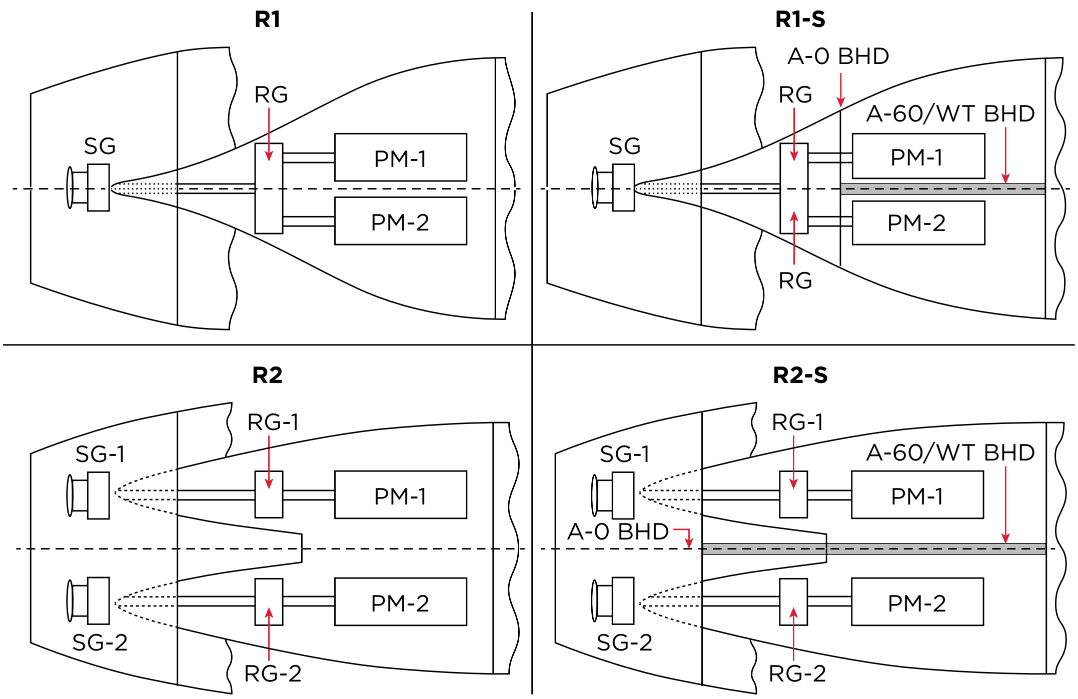


Figure 7: ABS Propulsion Redundancy Notation Arrangements

the main generators, their auxiliary systems, the switchboard sections and the power management systems are to be located in at least two machinery spaces separated by watertight bulkheads with an A-60 fire classification. Also, these notations can be enhanced with the "+" symbol to indicate that the vessel's propulsion capability is such that, upon a single failure, propulsive power can be maintained or immediately restored to the extent necessary to withstand adverse weather conditions without drifting.

COMPUTER-BASED SYSTEMS

ABS, in conjunction with the International Association of Classification Societies (IACS), recently updated the requirements for Computer-based Systems. The new requirements acknowledge complex systems concepts such as System of Systems (SoS).

The updated requirements provide improved transparency to the stakeholders by standardizing the information provided such as the Quality plan, System Description, Test Plans and Test Reports.

The updated requirements also include System of Systems Testing (SoST) onboard. This integration testing is performed to verify the functionality of the complete installation (SoS) including interfaces and inter-dependencies.

CYBER RESILIENCE/CYBERSECURITY

Also, in conjunction with IACS, ABS has introduced new mandatory requirements for Cyber Resilience of Ships and Cyber Resilience of Systems and Equipment to the Rules for new vessels. For new construction vessels contracted after January 1, 2024, Section 4-9-13 of the ABS Rules for Building and Classing Marine Vessels (IACS UR E26) is to be complied with. For existing vessels, ABS offers optional notations in the ABS *Guide for Cybersecurity Implementation for the Marine and Offshore Industries*. The new Cyber Resilience requirements recognize the distinct roles: Suppliers, Shipyards/Integrators, Owners, and Class.

For ships, the new Cyber Resilience requirements are divided into five sub-goals, or functional categories: Identify, Protect, Detect, Respond, and Recover. Like the updated Computer-based Systems requirements, transparency and awareness are improved. Other areas of focus include access controls, system segregation, network monitoring, incident response, and incident recovery.

The requirements for Cyber Resilience of Systems and Equipment are directly related to the system suppliers of Computer-based systems.

According to IMO Resolution MSC.428(98), safety management systems (SMS) should take into account cyber risk management in accordance with the objectives and functional requirements of the ISM Code and requires that the identified cyber risks are appropriately addressed. IMO Resolution MSC.428(98) references MSC-FAL.1/Circ.3 on the topic Guidelines on Maritime Cyber Risk Management.

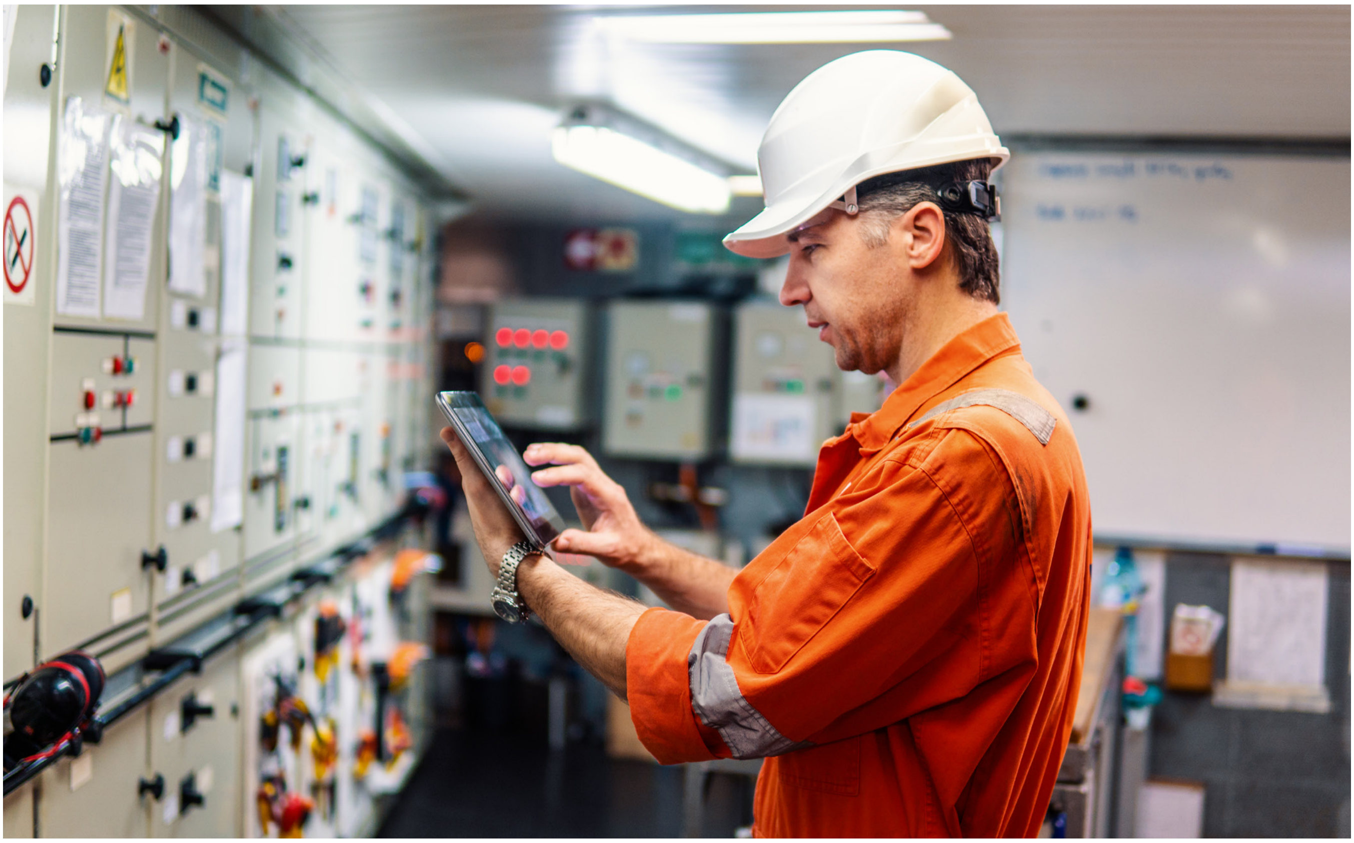
INDEPENDENT MAIN AND EMERGENCY POWER SUPPLIES

SOLAS regulations and the ABS *Rules for Building and Classing Marine Vessels* section 4-8-2/5.9.1 state that the main and emergency power supplies on ships should be mutually independent. Some of the subsystems that are impacted by this requirement include fuel supply, starting energy, and control power. Sufficient attention should be given to the design of ship electrical power systems to avoid common mode failures that can affect main and emergency power systems simultaneously.

IMPROVED OPERATIONS AND MAINTENANCE PROCEDURES

Planned maintenance activities and operational rigor are vital steps crews can take to avoid blackouts on ships. Operators must establish procedures, plans and instructions, including checklists for key shipboard operations and maintenance activities concerning the safety of personnel, ship and protection of the environment. Various tasks associated with ship operations and maintenance should be defined and assigned to qualified personnel.

In addition, operators should identify potential emergency shipboard situations and establish procedures to respond to them. A contingency planning mindset is essential where different modes of operation are considered, and systems are to be configured to respond to failures at any time.



As required by the ship's SMS, regular testing of main, auxiliary, emergency systems and other standby arrangements form a vital aspect of maintenance schedules that can help mitigate the risk of blackouts on ships and promote reliability of equipment or systems. Examples of tests and checks include but are not limited to:

- Confirming power system equipment and components are operating as designed in non-hazardous circumstances
- Confirm that equipment is operating within its design parameters
- Ensuring name plate ratings of power system equipment are visible and correct
- Regularly checking that shutdowns, safety devices, alarms and overrides allowed by class rules, statutory and regulatory requirements are functioning correctly
- Training and familiarization in the operation of existing and new equipment
- Familiarizing the crew with operational plans
- Regular testing in manual and automatic modes including standby arrangements and systems
- Regularly switching the plant over (e.g., port to starboard and/or unit number 1 to unit number 2, etc.) and ensuring all equipment gets equal operating time. Equipment that can be included in this exercise are generators, pumps, valves, circuit breakers, transformers, etc.
- Practicing blackout scenarios in controlled and safe circumstances so the crew knows how to respond in any emergency
- Keeping equipment properly lubricated in accordance with manufacturer's recommendations
- Maintaining lubrication systems regularly: purifying and/or filtering lubricants, cleaning purifiers, and changing filters at recommend intervals and when differential pressures increase
- Confirming that fuel is of the correct specification and quality
- Checking fuel system components such as valves and filters to confirm proper fuel delivery to engines
- Ensuring sufficient compressed air is available for starting main and auxiliary engines
- Ensuring starting battery chargers are in operation and batteries remain fully charged
- Confirming that all circuit breakers, switches and current interrupting devices are configured correctly for supplying power to essential services

Further insight on procedures to support safe operations can be gleaned from the IMO Resolution A.1138(31) Procedures for Port State Control, which lists several operational procedures that a Port State Control Officer (PSCO) may verify for marine vessels. Some of these procedures listed below if implemented effectively may help mitigate the risk of blackouts on ships.

- Procedures regarding the responsible ship's personnel familiarity with their duties related to operating essential machinery, such as:
  - Emergency and standby sources of electrical power
  - Auxiliary steering gear
  - Bilge and fire pumps
  - Any other equipment essential in emergency conditions

Specific procedures regarding the emergency and standby sources of electrical power:

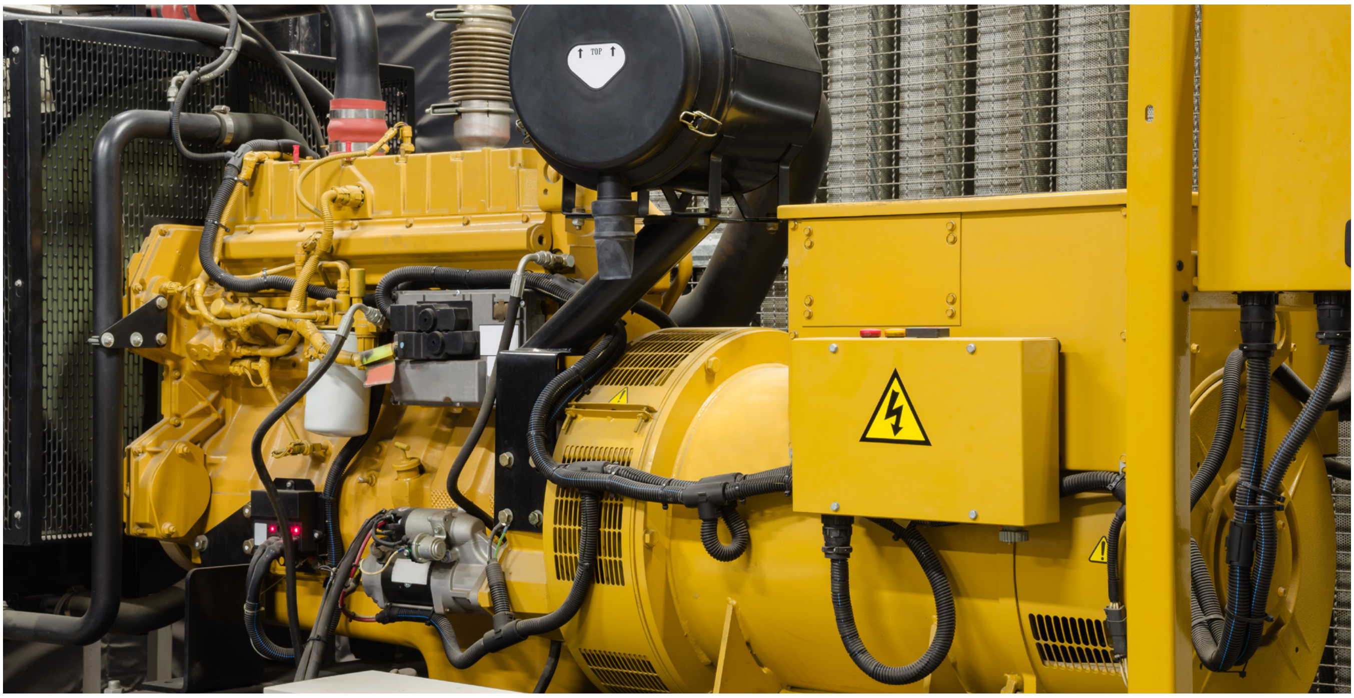
- Emergency generator
  - Actions which are necessary before the emergency generator can be started
  - Different possibilities to start the emergency generator in combination with the source of starting energy
  - Procedures when the first attempts to start the engine fail
- Standby generator
  - Possibilities to start the standby generator, automatically or by hand
  - Blackout procedures
  - Load sharing system

Most importantly, ship crews should follow the required protocols for the safe maneuvering and navigating of ships in pilotage waters. IMO Resolution A.960(23) requires shared responsibility between masters, pilots, and bridge officers for effective communication and understanding of each other's role. Factors that can impact maneuverability of ships such as vessel loading, weather conditions, currents, channel size, expected reaction to engine and/or steering commands, and power limitations should be discussed. In addition, limitations on the start and stop capability of main and auxiliary engines due to available starting air should be communicated. Special attention should be given to the expected power requirements of the vessel, equipment availability, and plans for recovering from a blackout condition.

In addition to the above, it is important for ship personnel to regularly undertake appropriate maintenance activities for power generation machinery, auxiliaries and any standby arrangements regularly and systematically in accordance with a ship's SMS.

Some critical items to consider for power generation machinery maintenance include:

- Emergency generator primary and secondary starting arrangements
- Emergency generator fluid levels



- Main and emergency generator insulation resistance
- Main and emergency generator automatic voltage regulators
- Main and emergency generator excitor diodes
- Generator, bus tie and feeder circuit breakers
- Engine control, monitoring, and safety systems
- Governors and speed control systems
- Synchronizing and load sharing controllers
- Power management system
- Software for all controllers involved in power generation

Ships contain several components and subsystems within the power generation and distribution system that require maintenance. The use of an appropriate computerized maintenance management system (CMMS) can help crews improve the effectiveness of their maintenance programs.

To further enhance maintenance, ABS offers guides and optional notations around Preventative Maintenance Programs (PMP) with varying levels up to Smart functionalities for monitoring and decision support for machinery systems and structures. PMP in its entirety is an aspect of blackout prevention, regardless of maintenance strategy, whether it is a calendar/counter based planned approach or a condition-based approach, using either traditional Condition Monitoring techniques or Smart Functionalities.

With the recent advances in connectivity, sensor technology, and data processing, analyzing vessel operational data at scale for a variety of purposes has entered the mainstream. Smart Functions are systems which can collect, transmit, manage, analyze, and report on insights from operational data at scale. Smart Functions related to Machinery Health Monitoring can often detect anomalies in data patterns that could be the precursors to incipient failures. Often these data patterns manifest themselves even before the point at which we can detect the onset of failure, as opposed to the more traditional Condition Based Monitoring approaches. As such, they are ideal for supporting a robust failure prevention strategy and for detecting the onset of equipment degradation, to prevent potential failures from occurring.

TRAINING

Due to the complexity of modern ships, crew members need to be well trained and familiarized to handle any emergency. Regular drills and emergency preparedness planning should be part of the SMS. It is imperative that crew members thoroughly understand the dynamics and various configurations of the ship's power system, what could go wrong, how to troubleshoot and how to resolve issues. Below is a list of some common operational scenarios which a ship's crew can expect to encounter and should be prepared for. This list is non-exhaustive.

- Adjusting the configuration of the power system as the operating mode of the vessel changes. For example, bringing additional generators online before navigating narrow channels.
- Being fully capable of operating the power plant manually in the event the power system automation fails
- Ensuring there is sufficient generation capacity online before starting large motors or energizing large transformers
- Detecting problems early by analyzing data from instrumentation, alarms, data logs
- Troubleshooting common problems encountered in a power plant
- Testing of all foreseeable scenarios and configurations of the power system in safe and controlled circumstances to prevent potential failures and to recover from blackouts quickly

In addition, pilots should be trained in bridge resource management in accordance with the requirements of IMO Resolution A.960(23). This training emphasizes situation assessment and information exchange between pilots and masters in routine and emergency situations. Emergency situations include loss of propulsion, loss of steering, and failures of vital systems, automation and radar, in a fairway or narrow channel.

RECOVERING FROM BLACKOUTS

Emergency response procedures should include blackout recovery in accordance with the SMS. Crews should be familiar with the blackout recovery procedures specific to their vessel. A vital aspect of the blackout recovery process is for the ship's crew to understand what caused the loss of power from the main switchboard. An example of a flow chart that crews can use for guidance in recovering from a blackout situation is provided in Figure 8.

First, the crew should confirm that the main bus has no electrical power. As soon as power is lost, the emergency generator should automatically start. If the emergency generator does not start, the crew should attempt to start it manually. Once the emergency generator has started, checks should be made to confirm that the emergency services are being supplied with power.

Once the emergency services are available, the main generators should be started and brought online. Attention should be paid to the configuration of the electrical network to ensure that the necessary interlocks are in place to avoid connecting two sources of power out of synchronism.

While power is being supplied by the emergency generator, the crew can begin to troubleshoot the cause of the blackout. A good starting point is to observe the alarms displayed on the alarm and monitoring system panel and determine whether the blackout was caused by the shutdown of generator(s) or tripping of breakers. If all alarms have been cleared and conditions are safe and healthy, the crew can attempt to start and/or connect the main generators to the main switchboard.

If there is an electrical fault in one bus section preventing a generator(s) from connecting to that bus section, the crew can attempt to connect available generators to healthy bus sections to provide power for the ship. If there is an electrical fault within one or more generators, the faulty generator(s) should be isolated and the healthy generator(s) should be brought online if conditions permit.

If no electrical fault is determined to be the cause of the blackout, the crew should move on to investigate other potential causes, such as human error, control failures or automation failures.

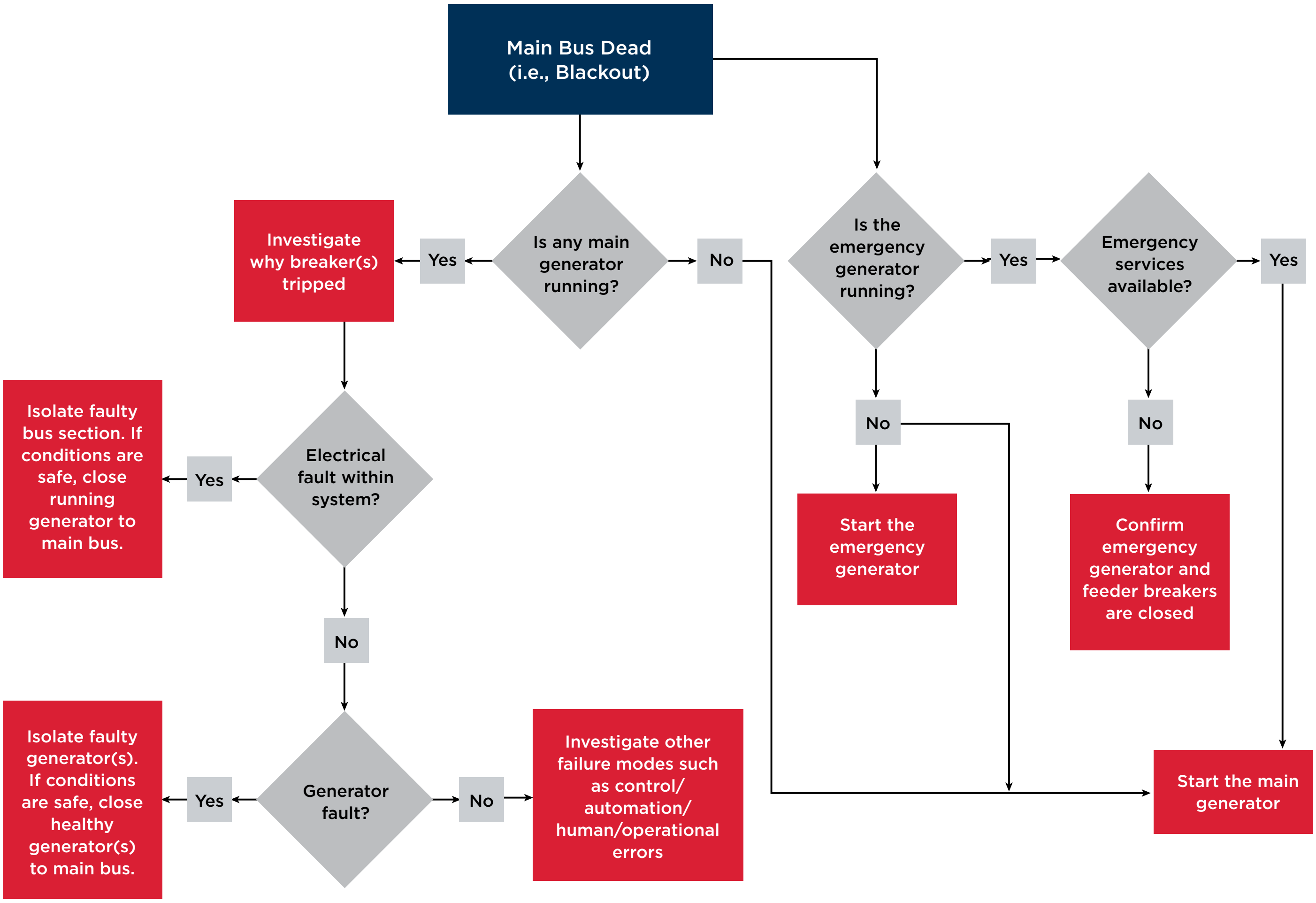


Figure 8: Recovering from a blackout condition

When recovering from a blackout condition, it is essential that power be restored as quickly as possible to restore propulsion and steering. In some instances, further steps need to be taken during blackout recovery procedures to avoid recurring blackouts. One common scenario is high inrush currents when starting large motors and magnetizing transformers. Motor starting currents can be multiple times the rated full load current of a motor, and these currents can cause generators to trip offline on overcurrent or under voltage protection, unless additional mitigation measures such as soft start controllers, adaptable protection settings, or sequential motor starting are used.

CONCLUSION

Blackouts continue to occur on ships leading to loss of propulsion and loss of steering incidents. Depending on the operating conditions of a ship, a blackout can result in a casualty. Multiple factors can cause blackouts, including various types of equipment and system failures and operational errors. Modern ships are a complex system of systems, and a holistic, multi-faceted approach is needed to minimize the occurrence of blackouts. Seafarers should be thoroughly trained in accordance with industry requirements and guidelines, and prepared to carry out their specific vessel's emergency plan, including recovering from a blackout situation as quickly as possible.

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LIST OF ACRONYMS AND ABBREVIATIONS

BHD	Bulkhead
CMMS	Computerized Maintenance Management System
IMO	International Maritime Organization
ISM	International Safety Management
MLC	Maritime Labor Convention
PM	Propulsion Machine
PMP	Preventative Maintenance Program
PMS	Power Management System
PSCO	Port State Control Officer
PTI	Power Take In
PTO	Power Take Off
RG	Reduction Gear
ROPAX	Roll-On/Roll-Off Passenger Vessel
SG	Steering Gear
SOLAS	The International Convention for the Safety of Life at Sea
SoS	System of Systems
SoST	System of Systems Testing
STCW	Standards for Training, Certification and Watchkeeping
WT	Watertight

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