New Zealand

Maritime School

ETO Course

Safe Use of Electrical Equipment

Module Assignment

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NEW ZEALAND
MARITIME SCHOOL

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1 Introduction

Brief

Research each of the FOUR Learning Outcomes and answer with your interpretation. You may work individually or as a team but you must name the team members. Use reading material provided on Canvas, library material or other suitable sources. Where possible provide reference to the sources. Email back to the tutor when complete.

Abstract

Background

This module addresses the importance of safety when working with electrical equipment, and the expected differences between voltages in maritime applications. It also discusses the different kinds of equipment, tools, provisions and signage relating to maritime safety.

Scope

This assignment contains a general overview of a typical electrical system on a ship, the dangers associated with it, and what to do to avoid those dangers, or how to act in the event of a disaster. Minimal detail is given on the specifics of this, in order to provide a more relevant document in a wide variety of maritime applications.

Aim

This assignment's aim is to provide a comprehensive document which may be referred to at sea for personal reference about a wide swath of topics relating to electrical safety. It also aims to reference highly vetted, accurate sources in order to provide a direction for further learning, and to convey as much accurate and relevant information as possible.

2 Learning Outcome 1

Learning Outcome 1: Follow safety instructions of electrical equipment and machinery

- Describe the generation and distribution of electrical power.
- Describe the use and purpose of implementation of a "three phase-three wire, insulated neutral system" for shipboard application.
- Demonstrate basic knowledge of structure of electrical switchboards.
- Identify safety precautions before commencing work or repair.

2.1 Generation and distribution

On the vast majority of ships active today, electrical power comes in two primary categories of voltages. These are low voltage electrical power (Anything less than 1000 Volts) and high voltage electrical power (Anything greater than 1000 Volts). Typically, these are 440V in low voltage systems, or in high voltage: 3.3kV, 6.6kV or 11kV. Generally speaking, azimuth thrusters demand higher voltages and it is therefore logical to assume 11kV systems will house them. The majority of ships active today rely on three-phase alternating current electrical power. In addition, it is N.A.T.O. (North Atlantic Treaty Organization) convention to use an alternating current frequency of 60 Hz. Interestingly, ships of the Soviet Union relied on a 50 Hz frequency, and were unmistakable by their unique radar patterns during the Cold War. It is this military origin, as well as the forerunner of the electrification of vessels, the United States, using 60 Hz on shore-based applications which solidified 60Hz as the standard by which all vessels infrequently deviate from.

Shipboard electrical systems transmit power from their main alternators onto large bus bars, connected to a primary switchboard. Depending on the size of the ship, and demand of the associated load, there may also be a secondary or tertiary bus bar and switchboard array connected to the primary switchboard via bus ties. Typically, these additional bus bars are connected to their own supplementary alternators, which have the ability to run in parallel with other alternators for fuel efficiency. With additional redundancy in generation, even in the event of a critical power failure in one alternator, the ship is still able to generate electrical power. These additional alternators usually supply enough electrical power for propulsion to function at a limited capacity. Furthermore, this system of redundancies allows micro-management of power generation, tailoring generated power to suit the requirements of the existing load. This allows for improved fuel efficiency, and reduced total running hours, potentially leading to less maintenance. To generate a stable and consisent 60Hz of power, alternators must run at very specific RPM; this is calcuated by the formula $N = \frac{120f}{P}$, where N is the RPM, f is the required frequency ($60Hz$) and P is the number of poles.

Governors determine the appropriate fuel intake for the engines, and voltage regulators work in harmony to ensure a clean sinusoidal $60Hz$. Unfortunately, this unchanging RPM means that alternators may have wasted power where the total load is less than the total generated electrical power. Battery backup arrays may assist in reducing total wasted power. It is therefore preferable to divide the load across one, or two alternators, bringing additional alternators on line as required to suit the demand of the load.

In addition to the primary alternators, under the S.O.L.A.S. (Safety Of Life At Sea) convention, vessels are required to house an emergency alternator. This is connected to a separate emergency switchboard. This emergency switchboard is connected to the primary switchboard via normally closed bus ties, and is responsible for critical loads associated with the passenger and crew safety. An example of a critical load is the shipboard lighting in areas like the engine room, or navigation lights. This emergency alternator is usually not capable of running in parallel with the other alternators, and is housed at the highest point possible aboard the ship, to ensure it is the last alternator to be submerged, if the ship is sinking, or flooding occurs below deck.

Lower voltage electrical power is transformed for specific applications. Smaller loads such as fans and lighting are connected to step-down transformers. Similarly, AC power can be provided in the form of sockets with which passengers can connect their devices from home, i.e. laptops, hairdryers. The majority of ships also include a battery array, for which the alternating current must be rectified by a series of diodes and capacitors into direct current, in order to charge the battery array. This battery array can be used for a number of systems, in some cases, it may even be used for the starter motor on the emergency generator.

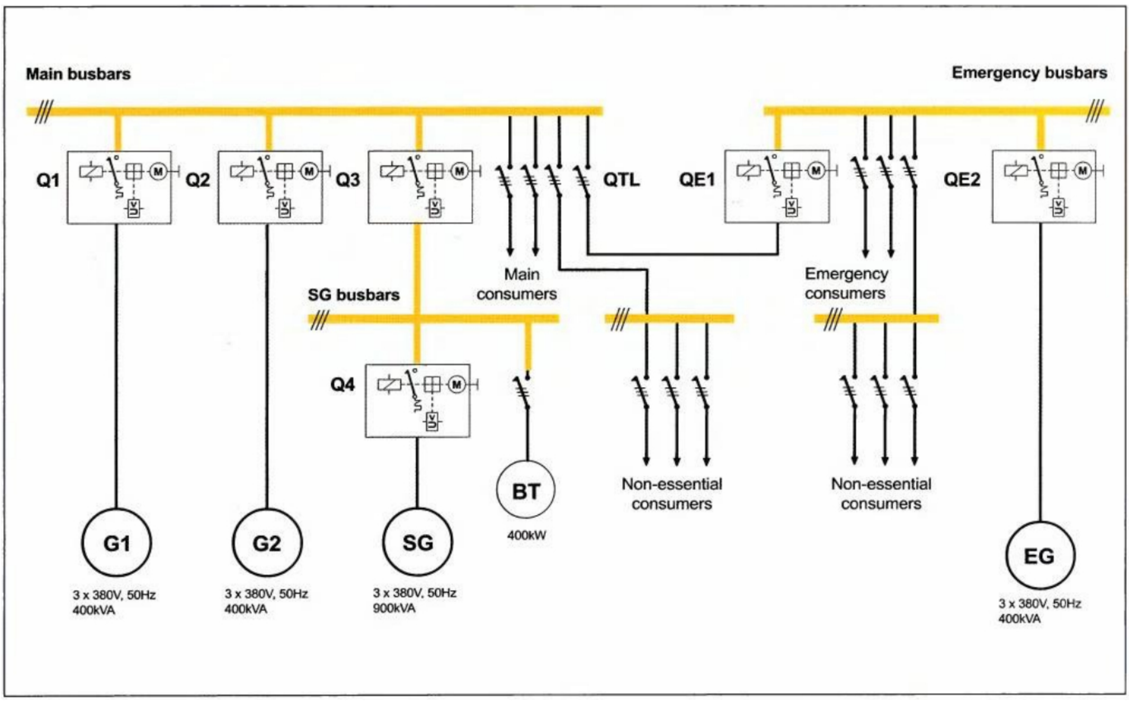


Figure 1: A typical configuration for a ship's electrical diagram.[1, p. 1]

2.2 Insulated Neutral Systems

In the vast majority of shipboard electrical systems, an insulated neutral system is used. This system is three-wire, three-phase alternating current. There are multiple advantages to a system of this nature. The primary advantage is redundancy. An accidental connection to earth, i.e. the ship's hull (otherwise known as an earth fault) is made by one wire being grounded, this does not effect systems, because there is no pathway between two or more phases. No circuit breaker will be tripped in this instance. If it was un-insulated, a single earth fault could potentially result in an unsafe situation (e.g. a lack of lighting, propulsion, or navigation). However, if a second earth fault occurs on another phase in the insulated system, a short circuit will occur and trip the circuit breaker, disconnecting the load. This turns an otherwise critical and urgent situation into a superficial routine task. A certified crew member will have ample opportunity to detect and repair any earth fault without systems being unexpectedly interrupted.

2.3 Circuit Breakers & Switchboards

Switchboards on ships are usually divided by their voltages. High voltage applications require significantly more protection in their circuit breakers. Usually these are vacuum-filled insulating cases. These ensure an arc does not expand as it ionizes the surrounding air. On lower voltages, a gas filled or simple air circuit breaker may be used, as the risk of arc is lowered.

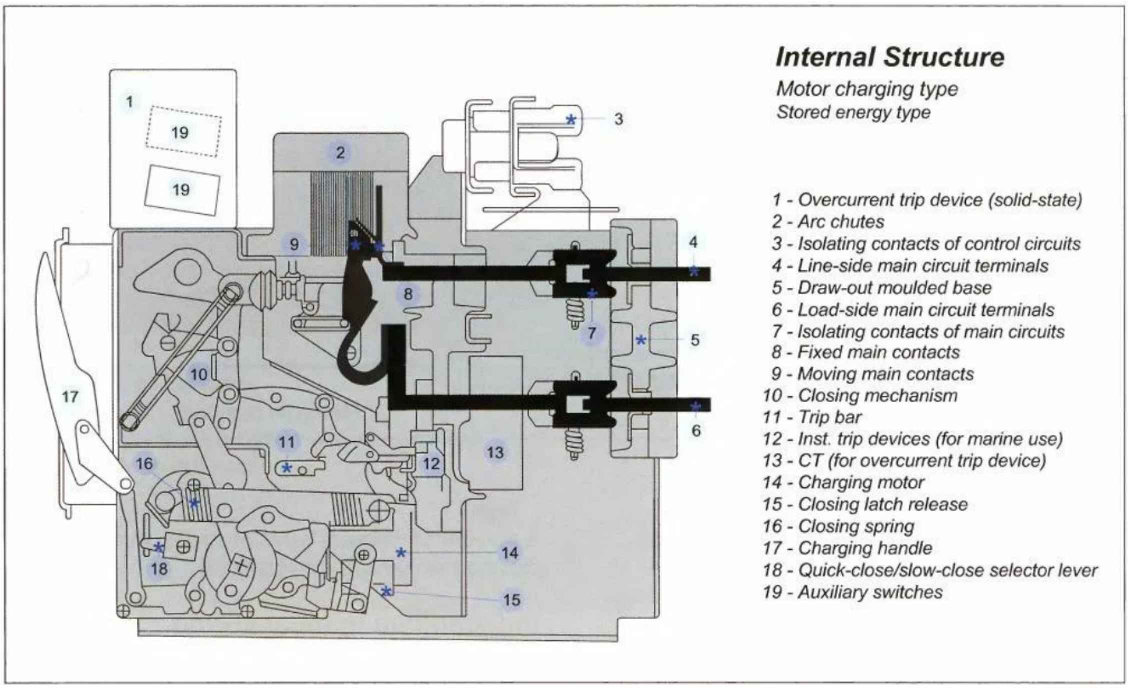


Figure 2: Cross-section of an air circuit breaker[1, p. 69]

On a typical switchboard arrangement, each alternator will have their own panel for monitoring the status of the alternator, and individual controls for starting/stopping the alternator. Between alternator panels, typically there will be a panel dedicated to synchronization. While power management generally automates the process of running alternators in parallel, it is good practice for crew to be well versed in the process of synchronization, to ensure readiness if power management fails.

Switchboards typically contain an interlock, preventing the panel of the switchboard being opened before it has been isolated. On the interior, there will be three main bus bars. Each bus bar is devoted to each phase of AC power. All consumers will be tethered to this bus bar, either directly, or through transformers. Usually, all switchboards will house a transformer regardless, to provide electrical power for indicator lights (white source lamp, and green running lamps), and for more sensitive electronics, such as PLCs or hour-running meters.

On generator switchboards, an ammeter will read the magnetic flux across a single phase from a rudimentary current transformer This may only be a small current of under 10 or so amps. The ammeter will extrapolate I_{phase} from the current transformer. In some systems, this may also be used to measure the sine wave of the alternator. Additional information may also be displayed on the switchboard panel, for instance, voltage, true power (watts), frequency and/or power factor (cos Φ)

Figure 3: Switchboard of the MPSV Havila Harmony[2]

2.4 Safety Precautions

The S.O.P. (Standard Operating Procedures) of any ship will be vigorously documented and should be adhered to strictly.

Before any work commences, ensuring the actions you plan to take are recorded and relayed to your supervisor is critical. In some situations, a Permit-to-Work may be necessary before any work may be carried out. All relevant circuit breakers have been opened, and your testing apparatus has been checked prior to *and* after any measurements are taken to confirm an accurate value. All phases should be checked, not only across each other (this will read V_{line}), but also from each phase to ground (this will read V_{phase}, or $\frac{V_{line}}{\sqrt{3}}$).

One of the most important and easily forgotten precaution is the necessity of P.P.E. (Personal Protection Equipment). P.P.E. is an umbrella term for all accoutrements which exist to provide the user with protection against various hazards. This may be as simple as eye protection, such as safety glasses, or an arc blast suit for working on high voltage systems. P.P.E. is the single most important line of defense against hazards, and routinely saves lives in entirely unpredictable ways.

Figure 4: An arc blast suit, for high voltage work.[3]

When working for extended periods of time it is important understand the potentially hazardous effects it may have on our bodies and our emotions. Stress, fatigue, emotional exhaustion and frustration can come as a result of work, or have accumulated in your home life, or off hours and extend into your work life. It is important to have a good feel for yourself and your emotions when working. Recognizing that you feel negative in a way which might impact your safety, or the safety of others, and communicating this may save lives. It is also just as important to move on from these emotions, and not let them dictate your performance or focus. We all suffer from these negative feelings in different ways, and nobody should ever perform delicate and dangerous work when they are unable to be entirely focused on it.

This also extends to intoxication, and working while under the influence. Generally, ships will be dry, meaning they have a zero tolerance for alcohol, and no ships allow illicit materials such as narcotics. There are some exceptions to the rule of alcohol, for example, in passenger ships it is not uncommon to be allowed a single drink when dining. This is, of course, after work has been completed, and you will not be expected to return to work until the following morning. If you are suffering from the effects of this, or any other effect which has not been authorized, it is absolutely critical that you communicate this to your superiors. It may cost you your job, but at least it won't cost you your life.

3 Learning Outcome 2

Learning Outcome 2: Recognise and report electrical hazards and unsafe equipment

- Recognise safety hazards which can be present when working on shipboard electrical equipment: electric shock, arc blast, transient over-voltage, and movable (rotating) parts, environmental factors like high temperature, humidity, water, fuel, steam leaks, rain, wind, and ship rolling or pitching.
- Follow isolation and emergency procedures.
- Explain Lockout/Tag out procedures.

3.1 Hazards

When working on electrical equipment, there are several hazards which one must be well prepared to recognize and safely avoid. On board a ship, there are a few unique hazards, as well.

3.1.1 Electric Shock

Electric Shock is often the greatest risk when working on electrical equipment. Electric Shock occurs when electromotive force is applied across a circuit, and accidental human interaction with exposed, live circuitry occurs. The path of shortest resistance to ground will be followed. In some instances, this may not be enough to stop a heart, but it may cause numbness, dizziness, fatigue or great pain. It is a risk never worth taking. The best defense against electric shock is following the isolation procedures correctly, and having an isolator switch locked out and tagged out to prevent re-energizing of the circuit. P.P.E. is also very important. On board ships, a defibrillator unit will also be located in the Engine Control Room (E.C.R.). In some ships, there may also be a defibrillator on the bridge, and possibly others elsewhere on the ship. Understanding where these units are on the ship, as well as the location of, and how to use a rescue hook to de-couple a victim of electric shock from the source are important things to be aware of.

3.1.2 Arc Blast

An arc blast (sometimes referred to as arc flash, or flash-over) is an umbrella term for the release of both light and heat energy resulting from an arc fault. A detonation or discharge occurs as a result of a low impedance connection to ground or a different phase across the aether. One of the most common causes of arc-flash injuries occurs when switching on electrical circuits, especially tripped circuit breakers. To avoid this, the fault must be isolated before energizing the circuit. An arc blast may also occur in energized circuits whilst testing and occur due to conductive debris being present. Arc blasts generally do not occur at voltages lower than 220 V, but their likelihood increases exponentially in proportion to the electromotive force in the circuit, as does the distance over the aether the arc fault may occur. The best defense against an arc blast is proper and thorough isolation of any circuit with which an arc fault occurs. Failing this, P.P.E. may be a technician's last line of defense. Arc Blast body suits are available and should be worn when working on any circuit of sufficiently high voltage (440V or greater) where there is risk of an arc blast.

3.1.3 Transient Over-voltage

"Over-voltage" is the term used to describe voltage in a circuit which exceeds the maximum voltage, or upper design limit for the particular circuit. Transient over-voltage is a short burst of energy which may occur naturally, especially from lightning, or man-made. These man-made spikes of over-voltage generally occur when inductive loads, such as electric motors or electromagnets. Transient over-voltages significantly degrade and damage electronic systems, and may result in a fire, or electric shock from a flash-over if insulation is worn down sufficiently. While generally most ships will have Surge Protection Devices (SPDs), these may need to be replaced if they suffer a great enough over-voltage. In addition, as the majority of motors on board ships are Direct On Line (D.O.L.) starters, over-voltage concerns are a regular occurance.

3.1.4 Electrolysis

Electrolysis is the process by which a chemical change is induced in a material by way of passing an electric current through it. Sometimes, this process of displacing electrons is known as oxidation. When an electron is displaced, it renders the material inert of charge, also known as neutral. At sea, we are able to combat electrolysis with sacrificial anodes. Seawater acts as an electrolyte and displaces electrons from the sacrificial anode, oxidizing and producing a protective layer. We apply this method to the ship's hull, the ballast tanks, heat exchangers, etc. Nearly any metal which is likely to encounter a significant amount of corrosion via electrolysis. We often use zinc as the primary metal in the sacrificial anode. Identifying and reporting corrosion to your immediate superior is incredibly important, and will prevent further damage from occurring.

3.2 Weather

3.2.1 Rain, Seawater, and Humidity

Rain, seawater and humidity are able to cause corrosion, and weaken the structural integrity of the ship, or cause systems to fail. They can also create hazards with which we must be aware of and prepare for. Heavy rains may cause visibility issues, making the important of correctly functioning lighting absolutely paramount. It will also cause surfaces to become slippery, and dangerous to tread on. Ensuring that you use the hand-railing provided is extremely important, as well. Rain may also cause moisture buildup inside sensitive electronics. In the case of induction motors, ensuring their heaters are functioning correctly and regularly maintained is also very important. In the case of lighting, water may pool at the bottom of the light fixture's enclosure. In this instance, regular maintenance and checking of seals will help. Additional moisture present on our bodies will also lower our internal resistance against electric current, which may greatly increase the amount of current which can pass through our bodies if we were to be electrocuted. Excessive water may also cause flooding aboard ship. When flooding occurs, it is paramount to isolate any effected circuits to prevent shorting and damage to equipment.

3.2.2 Temperature

As with the weather, temperatures may vary greatly at sea. It is important to understand the limitations of the electronics and machinery aboard ships. Many components have thermal protection units (TPUs) whose maximum safe operation temperatures may be within the realm of achievable in specific times and places throughout your voyage. It is important to understand that the temperature of a machine will always combine with the ambient temperature. For example, an engine who, at 0 degrees centigrade, has a thermal protection unit which trips at 100 degrees centigrade, and produces enough heat to operate between 50-70 degrees centigrade may actually reach a high enough temperature to trip the TPU on a hot 30-40 degrees centigrade day. It is important to treat every alarm with the severity of a fire until you are able to disprove it is not. On the other hand, during extremely cold seasons, systems may not be able to work at all. In this instance, keeping system heaters well maintained and working when the unit is not in use is absolutely critical to ensuring smooth operations and machine longevity. Temperature may also cause fatigue, heat stroke, or heat syncope in workers. Ensuring that regular breaks are taken, and all workers are sufficiently hydrated may save lives.

3.3 Other Hazards

3.3.1 Corrosion

A Sodium Chloride (salt, $NaCl$) and hydrogen hydroxide (water, H_2O) solution is electrically conductive. Salt ions are able to transport electrical charge, allowing galvanic corrosion to occur rapidly, and short circuiting to occur when live circuitry is submerged in it. At sea, it is inevitable that corrosion will occur. We have methods to reduce this corrosion, like sacrificial anodes, but it is a technician's duty to keep a rigorous schedule of preventative maintenance throughout the ship. Ensuring all seals do not allow the passage of water, as well as stopping any circuits exposed to salt water from being energized.

3.3.2 Movement of Ship

When working on a ship, it is important to understand the dynamics of being aboard a vessel capable of sudden, immediate movement on any axis. Rolling (rotational movement across the X axis) and pitching (rotational movement across the Z axis) may occur unexpectedly. It is important for technicians to ensure the appropriate level of P.P.E. for the job they are doing. In a situation where sudden movement causes the technician to lose balance, he may, consequently, fall into or onto live circuitry, or strike an object with considerable force. When working in compromising positions, e.g. atop a crane, that a harness is fitted at all times. Furthermore, understanding the degradation of electronics by repetitive kinetic motion is critical to quickly and effectively locating and repairing ground faults on the vessel. In addition, proper stowing of equipment and tools when work is completed is critical in ensuring that they are not misplaced or potentially create a hazard when left unattended.

3.3.3 Pipe Leakage

Depending on the fluid expelled, a pipe leakage may pose a hazard in a plethora of different ways. Wastewater pipes pose a biohazard and disease risk. Fuel pipes may be a biohazard and fire risk, and also have the potential to dissolve or greatly weaken insulation on any wires it may come in contact with, as well as potentially exposing aquatic life to harmful pollution. Steam pipes are a thermal risk and may endanger anyone near the pipe. If the temperature and pressure are great enough, steam pipes may also act as a powerful kinetic force, able to cut or seriously maim anyone it strikes. It is essential that the technician understand the location and operation of fire control units, as well as the control pumps for all pipes. Prior knowledge and understanding is your best defense against pipe leakages, as swift disabling of any existing flow is the most important step in damage control.

3.3.4 Gases & Fumes

Depending on the type of ship, it may be carrying hazardous cargo, such as on chemical or oil tankers. It is therefore critical to ensure that a breathing apparatus is affixed when working near these tanks. Short-term problems include dizziness, shortness of breath, unconsciousness, and, in severe cases, death. Long-term problems may include increased exposure to known carcinogens, respiratory irritation (nosebleeds, ulcers, and holes in the nasal septum in extreme cases), blood poisoning, metal fume fever, kidney and bone defects, nervous system disorders, and pulmonary edema (fluid in the lungs). In poorly ventilated areas, gases and fumes also displace oxygen. These may also be a skin irritant, and additional P.P.E. may be required.

3.4 Potentially Hazardous Energy

If the potential exists for the release of hazardous stored energy or for the re-accumulation of stored energy to a hazardous level, the technician must take steps to prevent injury from the release of said energy. Energy in any form becomes hazardous when it builds to a dangerous level or is released in any quantity that could injure a worker. Workers servicing or maintaining machines or equipment may be seriously injured or killed if hazardous energy is not properly controlled. Injuries resulting from the failure to control hazardous energy during maintenance activities can be serious or fatal. Injuries may include electrocution, burns, crushing, cutting, lacerating, amputating, or fracturing body parts, and others.

It's important to understand that electricity is not the only form of hazardous energy employees may encounter. Main energy sources that supply power to the entire machine or equipment may be electrical, but secondary energy sources such as pneumatic or mechanical energy may still be stored with the potential to cause injury.

- **Electrical**

  Exposed, or live circuitry or wires. Equipment not fully de-energized. Electrostatic charge.

- **Chemical**

  Liquids, such as diesel, acids, and caustics. Gases, such as natural gas. Solids, such as wet and dry cell batteries, and combustible dust.

- **Gravitational**

  Objects supported by a crane, and elevated platforms. Potential energy is converted to kinetic energy.

- **Hydraulic**

  Pressurized hydraulic systems, including hoses, pumps, valves, and actuators.

- **Mechanical**

  Sources such as a spring under compression. Extreme sound is also a hazardous mechanical energy.

- **Pneumatic**

  Pressurized air or gas systems, including pipes, pumps, valves, actuators, and air compressors, and tank and pipe purging systems.

- **Radiant**

  Energy that travels by waves or particles, particularly electromagnetic radiation such as heat or x-rays. Ionizing radiation includes alpha and beta particles, computed tomography (CT) and X-rays.

- **Thermal**

  Hot water, heated oil, steam, and equipment need time to cool, while liquefied gases, such as nitrogen, need time to warm to safe thermal levels.

- **Explosive**

  The rapid increase in the volume of energy with the generation of high temperatures and the release of gases. Supersonic explosions are called detonations. Subsonic explosions are called deflagration. A boiling liquid vapor expanding explosion is called "B.L.E.V.E."

- **Aural**

  Excessive sound or vibrations, especially those created by the primary engines of a ship, may cause sickness, syncope or permanent damage to hearing.

3.5 Safety Precautions & Lock Out Tag Out

When aiding a victim of electric shock, it is extremely important to avoid placing yourself at risk as well. Your ship will have a very specific S.O.P. to follow, but a general idea of the order of operations to assisting a victim is as follows:

1. **Approach**

   If a coworker or supervisor who is trained in electrical work is nearby, marshal their assistance immediately. The approach to where a coworker has succumbed to electrical shock should be made cautiously to help ensure the current that incapacitated the victim doesn't harm you too.

2. **Examine**

   A quick look at the accident scene will reveal whether the victim remains in contact with whatever shocked him. Avoid any nearby exposed conductors, and don't touch the victim until the electrical circuits that power the area have been de-energized.

3. **De-Energize**

   If the only source of power to the victim's locale is a power cord or extension cord to portable equipment, simply disconnecting it at the power source may be sufficient. However, a trip to the breaker box to open the circuit may be necessary

4. **Insulate**

   In the event that de-energization is impossible, you may have to remove the victim from a live conductor. While this is never desirable, hazards can be controlled by using something that won't conduct electricity to move the victim and donning insulating gloves and overshoes before attempting rescue if they are available, and exclusively retrieving them with a rescue hook.

5. **Rescue**

   Rescues are safest when the circuit is de-energized and you are standing on insulating material. Don't ever touch an electrocution victim unless you know the source of electricity that incapacitated them is powered down. If there is a risk of a neck injury or similar contingency, do not move the victim at all. Make sure the victim's airways are clear of obstruction. Next, check for breathing and a pulse, then provide CPR or defibrillation if necessary. A quick look at the accident scene will reveal whether the victim remains in contact with whatever shocked him. [4]

One major aspect of safety when working on circuits whose isolator switches have been opened is the L.O.T.O. (Lock On Tag On) convention. This essentially requires all technicians to lock a personalized padlock into a slot on an isolator switch or breaker, and tag the lock with a personal identifier card, as well as keeping rigorous paper logs about when, where and why systems have been disconnected. This ensures that the system where work is being performed cannot be made live, or the machinery activated in a situation which would otherwise place a technician in grave peril. Another aspect is the key of the locks of the L.O.T.O. cannot be cut into a copy, as it is illegal. Trapped key interlocking mechanisms may also be used. Essentially, a trapped key interlock only releases a key when a system has been isolated, and the entrance to the isolated system is only available with that very same key. Triple-trapped key interlock systems add an additional layer of protection by also releasing a key for the technician to carry with him, completely and totally preventing that specific isolator switch from being engaged and subsequently energized.

Figure 5: An example of a folding lockout hasp, with a tag and padlock.

In some S.O.Ps, the chief engineer may require all L.O.T.O. keys to be secure in a place only accessible by the chief engineer himself. This removes the potential for surprise or unexpected energizing of equipment. This also ensures that all technicians are accounted for. Routine communication when performing work should be made.

Figure 6: An example of a wall mounted group lockout box[5]

4 Learning Outcome 3

Learning Outcome 3: Understand safe voltages for hand-held equipment

- Recognise causes of electric shock and precautions to be observed to prevent shock.
- Describe relationships between shock voltage and shock current.
- Recognise the possibility of the electric shock by the electrostatic charge.
- Explain the influence of shock current on human body.
- Recognise meaning of warning signs.

4.1 Electric Shock

Work should never be done on a live circuit unless absolutely necessary. Always ensure that the relevant circuit is completely isolated, locked out and tagged out according to your company's S.O.P. Electric Shock is the greatest risk when working on electrical equipment; it is absolutely critical that all circuits be treated as live until thoroughly proven dead. Electric shock is caused by the flow of current through a person's body. This is frequently from hand-to-hand or from hand-to-foot. A shock current as low as 15 mA (AC or DC) can potentially be fatal. [1, p. 7]

Electric Shock may also occur because of subsystems being isolated separately. For instance, it is typical for all exterior electric motors are fitted with anti-condensation heaters to protect against moisture intake into the motor's winding. Moisture buildup is likely to occur if the motor is disconnected for any great length of time. Therefore, the heater circuit is energized whenever the primary circuit is not. This means that technicians working on that motor may need to de-energize the heater system as well, or perform their work adjacent to live heating elements, creating a great risk of shock or burn.

Some of the steps to reduce the likelihood of electric shock are as follows:

- **De-Energize**

  Always shut off the power to a circuit or device that you will be working on. This usually means turning off the appropriate breaker and ensuring it is locked out with a safety padlock, and attached is your personal I.D. Informing your supervisor or the chief engineer about what you're doing and how long you expect a system to be isolated is a good idea.

- **Test for Power**

Always test for power at the device or equipment after turning off the circuit breaker. Ensure you have confirmed your testing unit is working and reading accurately before and after taking measurements. Use a non-contact voltage tester (or another type of electrical tester) to check the circuit wiring and any electrical contacts before touching anything that may carry electricity.

- **Use Insulated tools**

  You never know when a tool might slip or drop and make an accidental electrical connection. Insulated tools have a minimal amount of exposed metal to prevent such catastrophes. It always makes sense to use insulated tools for electrical work.

- **Take Extra Care Around Capacitors**

  Capacitors store electricity, and can be extremely high voltages. They can deliver a deadly shock even when the circuit is isolated. Do not work on equipment that contains capacitors unless you have discharged the capacitors safely.

When talking about electric shock, we use the three primary aspects of Ohm's Law to describe the shock. Most important is the *voltage* in the circuit, otherwise known as electromotive force. Voltage is the primary factor in determining the severity of any electrical shock, as it determines the amount of *current* our bodies receive. Our bodies have internal *resistance*, which can be lowered by the moisture on our hands, and will also lower the greater the current that passes through it. A shock as low as $15mA$ may be fatal. While it is the current which ultimately harms us, the voltage of the shock must be sufficiently great enough to pass a shock through our internal resistance.

4.2 Electrostatic Charge

All materials (insulators and conductors) are sources of Electrostatic Discharge (E.S.D.). They are lumped together in what is known as "triboelectric" (a type of contact electrification on which certain materials become electrically charged after they are separated from a different material with which they were in contact). This defines the materials associated with positive or negative charges. Positive charges accumulate predominantly on human skin or animal fur. Negative charges are more common to synthetic materials such as Styrofoam or plastic. The amount of electrostatic charge that can accumulate on any item is dependent on its capacity to store a charge. For example, the human body can store a charge equal to 250 picofarads. This correlates into a stored charge that can be as high as 25,000V.[6] Using the formula $\Delta\phi = \frac{C}{F}$, or $25000V = \frac{6.25\mu C}{250pF}$ where C is the capacitance, measured in Farads (F), Q is electric charge, which is measured in coulombs (C), and $\Delta\phi$ is the potential difference, which is measured in volts (V). This is far above the level that damages circuits yet it may be below the human perception threshold.

Meaning that damage can be done to sensitive circuity, therefore it is preferable to wear an electrostatic wrist band when working on delicate electronics. However, this wristband will make you an extremely good earth, and will cause a larger current to flow through your body if you receive and electric shock on higher shock voltages. Another hazard posed by electrostatics is the interaction between an E.S.D. and a flammable material. For instance, an E.S.D. spark may ignite fuel, or cause a dust explosion. For this reason, when carrying cargo which is flammable or potentially dangerous, an inert gas is pumped into the storage tank. This inert gas displaces any oxygen within the storage tank, making ignition impossible without oxygen, even if an E.S.D. does occur.

4.3 The Influence of Shock on the Human Body

The minimum current a human can feel depends on the current type (AC or DC) and the frequency of current. A person can feel at least 1 mA of AC at 60 Hz, while at least 5 mA for DC. At around 10 milliamperes, AC current passing through the arm of a 68 kg (150 lb) human can cause powerful muscle contractions; the victim is unable to voluntarily control muscles and cannot release an electrified object. This is known as the "let go threshold" and is a criterion for shock hazard in electrical regulations. The current may, if it is high enough, cause tissue damage or fibrillation which leads to cardiac arrest; more than 30 mA of AC (rms, 60 Hz) or 300 – 500 mA of DC can cause fibrillation. A sustained electric shock from AC at 120 V, 60 Hz is an especially dangerous source of ventricular fibrillation because it usually exceeds the let-go threshold, while not delivering enough initial energy to propel the person away from the source. However, the potential seriousness of the shock depends on paths through the body that the currents take. If the voltage is less than 200 V, then the human skin, more precisely the stratum corneum, is the main contributor to the impedance of the body in the case of amacroshock—the passing of current between two contact points on the skin. The characteristics of the skin are non-linear however. If the voltage is above 450–600 V, thendielectric breakdown of the skin occurs. The protection offered by the skin is lowered by perspiration, and this is accelerated if electricity causes muscles to contract above the let-go threshold for a sustained period of time. If an electrical circuit is established by electrodes introduced in the body, bypassing the skin, then the potential for lethality is much higher if a circuit through the heart is established. This is known as a microshock. Currents of only 10 μA can be sufficient to cause fibrillation in this case.'

4.4 Warning Signs

Ships, like all industrial equipment, make liberal use of signage to inform all present of any potential hazards they may encounter in any given part of the ship. These signs will often be displayed near the entrances of different parts of the ship, and will illustrate in plain English what hazards are present. In addition or instead of the written messages, typically a pictograph demonstrating the hazard will be present.

Figure 7: An example of a common hazard pictographs

Warning signs are typically divided into five categories and separated by color. Ranked in order of importance, these are:

1. **Danger**

   DANGER signifies that serious injury or death is VERY LIKELY to occur. These signs should only be posted in areas where there is potentially deadly harm from dangerous equipment or other environmental hazards, such as radiation, high voltage, or hazardous fumes, among others. Danger signs must be red, black, and white, and include 'DANGER' printed in white lettering on a red, oval shaped background. OSHA requires that all employees be made aware that danger signs indicate immediate danger and extreme caution must be used in the area at all times.

2. **Warning**

WARNING signifies that serious injury or death MAY occur. 'WARNING' text must be printed in black letters on an orange background. These signs may also include a bright blue graphic depicting a safety precaution that should be taken in a specific area.

3. **Caution**

   CAUTION signifies that a minor or moderate injury may occur. These signs warn of potential physical injuries caused by slips or falls, harmful substances, or other unsafe practices. All caution signs must have a bright yellow background and yellow letters against a black panel.

4. **Safety Instructions**

   SAFETY INSTRUCTION SIGNS are used to relay general instructions and suggestions as they relate to safety measures. Safety instruction signs must include a green panel with white letters and a white background. All letters printed on the white background must be black.

5. **Notice**

   NOTICE SIGNS signify lower risk areas and can also promote safety in the workplace or other areas. These signs generally display rules such as 'please wash hands' or 'keep this area clean'. Notice signs also are used for distinguishing areas designated as 'employees only' and other low risk designations. Notice signs are blue and white.[7]

In addition to color, warning signs make use of shapes to convey information. The different shapes one might experience are as follows:

- Circle with Diagonal Bar (Prohibition Signs)

  A circle with a diagonal bar or "slash" indicates that a certain action is prohibited/not allowed in this area. For example, No Smoking. These are a red slash on a white background.

- Circle (Mandatory Action Signs)

  A mandatory action sign indicates that a certain action must be taken. For example, Wear Eye Protection. These are usually blue.

- Equilateral Triangle (Warning Signs)

  A warning sign indicates that there is a potential hazard you need to be aware of. For example, Flammable Material. These are usually yellow and black.

- Square or Rectangle (Safe Condition Signs or Fire Safety Signs)

  A square or rectangle sign can indicate multiple things. If Green, it may indicate the pathway to safety. For example, Exit signs. If they are red, they indicate important things to be aware of with regards to fire safety. For example, Extinguisher locations.

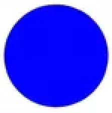
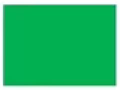
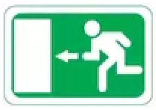
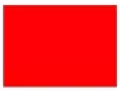
Shape	Meaning	Color	Examples
 Circle with diagonal bar	Prohibition	RED (contrast: white)	No smoking 
 Circle	Mandatory Action	BLUE (contrast: white)	Wear Eye protection 
 Equilateral Triangle	Warning	YELLOW (contrast: black)	Danger Flammable material 
 Square / Rectangle	Information about safe condition	GREEN (contrast: white)	Escape Route – Left 
 Square / Rectangle	Fire Safety	RED (contrast: white)	Fire Extinguisher 

Figure 8: A list of shapes and their corresponding message.

5 Learning Outcome 4

Learning Outcome 4: Understand risks associated with high-voltage equipment and on-board work

- Explain the different voltages on-board and their risks.
- Explain the difference of electric shock caused by low and high voltage.
- Explain the basic parameters of electric arc: the temperature, the energy etc.
- Demonstrate basic understanding of general High Voltage protection measures: housings, partitions, distances, insulation mats, insulation materials, access restrictions, markings and warnings, HV equipment access monitoring and locks.

5.1 High Voltage vs Low Voltage

We typically define voltages in two ways, in *high voltage* where voltage exceeds 1,000V, and *low voltage*, where it does not exceed 1,000V. The common low voltages we work with on ships are 440V, 220V, and a large variety of voltages under 100V, such as 24V, 12V, 5V.

Below 50V, the risk of electric shock is small. However, P.P.E. such as safety glasses should still be worn, as well as making use of insulated tools. While a deadly electric shock is improbable, it is possible under certain conditions. For example, when moisture or conductive dust is present on your bare fingers. Remember, it only takes as low as 15mA to kill. There is also a risk of fire at these voltages. Isolating these circuits before working on them is still important. At very low voltages (5V) you are also likely to do harm to the circuit itself.

At voltages between 50V and 1000V there are a multitude of new hazards present. Electric shocks at 220V and 440V are significantly more likely to cause a fatal electric shock. It is extremely important to isolate any circuits before working on them, as they pose risk of electrocution, and a fire hazard.

At voltages greater than 1000V, you are in great danger. Typically ships will use either 3,300V; 6,600V or 11,000V. As the voltage increases, so does the risk. However, at these extreme voltages, death by electrocution is unlikely. Rather, an explosive fireball caused by an arc blast is the most likely outcome. Obtain a permit-to-work before interacting with high voltage, ensure it is isolated and locked out/tagged out. Also ensure that your supervisor knows where you are and what you are doing at all times. If something goes wrong, it will only go wrong in the most catastrophic way possible.

5.2 What is an Arc?

An electric arc flash is one of the most serious electrical hazards. An electric arc (sometimes referred to as "flashover") is a continuous electric discharge of high current which flows through an air gap between conductors. This generates a very bright ultra-violet light as well as intensive heat. An arc flash is typically caused by a short circuit. This is sometimes due to a technical failure of electrical equipment (e.g. improper installation, dust, corrosion, surface impurities and sometimes simply due to normal wear and tear). However, in the majority of cases, short circuits are the result of a human error (e.g. caused by a worker touching a test probe to the wrong surface or from a slipped tool).[8]

5.2.1 What are the consequences of an Arc?

Depending on the severity of the arc flash, a function of arc current and the duration of the arc, and dependant on the distance from the arc, it can lead to:

- High heat of the electric arc up to 20,000 °C – causing burns to the skin and body of the worker
- Fire - causing potential injury to the worker as well as damage to the surrounding place of work
- An arc blast (electric arc explosion) with a blast pressure of up to 1000 kg /m2 which expels molten metal particles, remnants of destroyed equipment and related components at high speed - causing injury to the worker
- Sound blast (up to 140dB – as loud as a gun) - causing auditory damage to the worker
- Ultra-violet light from the blast – resulting in damage to the eyesight of the worker

The consequences for people working on or close to energized electric equipment will primarily depend on the amount of Incident Energy received at the body surface, which depends on its distance from the arc. The primary concern for the exposed person is skin burns.

5.3 H.V. Safety

While high voltage may be intimidating, risks associated with it can be managed with a modicum of common sense and with the proper tools. Furthermore, ships carrying high voltages will always have provisions to protect against disasters, including:

High Voltage windings in transformers typically have an epoxy/powdered quartz compound which is tropicalized, resistant to humidity and generally maintenance free. This reduces the risk of an arc event.

For cables, high voltage requires a more advanced insulation than low voltage, but the copper required is significantly less. In situations where the insulator is air, greater clearance is necessary to prevent creepage.[1, p. 167]

In circuit breakers, it is common to use vacuum sealed interrupter chambers. In this circuit breaker, the fixed and moving contact are enclosed within the vacuum. However, with no air molecules to ionize, the arc event is minimal.

Given the volatile nature of high voltage, specialized testing equipment should be utilized to prevent catastrophe. Before any work is done, the high voltage lines must be earthed to the hull. When testing a live line of high voltage, special insulated extension rods should be used.

As for personal protection, making use of an arc blast suit is very important, as it will provide the wearer with protection from electrocution via insulation, fire hazards, usually via asbestos inlets, as well as UV radiation with a polarized visor. These suits are the most advanced form of P.P.E. and their usefulness should never be downplayed.

When working on high voltage lines, according the Code of Safe Working Practices for Merchant Seafarers, the following steps must be taken:

- dead;
- isolated and all practicable steps have been taken to lock off live conductors, voltage transformers (except where the connections are bolted) and dead conductors that may become live;
- earthed at all points of disconnection of high-voltage supply and caution notices attached in English and any other working language of the vessel;

  and
- released for work by the issue of a permit to work or a sanction for test.

Also, the competent person designated to carry out the work should fully understand the nature and scope of the work to be carried out and have witnessed a demonstration that the equipment/installation is dead at the point of work. [9, p. 299]

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