High Voltage Safety Training

Management and Operational Levels

Course Material 942.617

Training Manual

STCW 2010 Manila Amendments - **Engineering Certificate of Competency Revalidation, High Voltage (HV) requirements**

Chief/Second/ Engineer Officer CoC Reg. III/2 and III/3 (Management Level)

EOOW CoC Reg. III/1 (Operational Level)

Attendees: Chief /Second, EOOW Engineer Officers and Electro-technical Officers

Presented by;

John Lamb
Senior Tutor
NZ Maritime School

Email – jlamb@manukau.ac.nz for all correspondence

V2.1 2017

This “High-Voltage Safety Training Course” is offered to Marine Engineers and Electrical Officers.

The Course includes both theoretical delivery and practical hands-on exercises, familiarising the participants with High-Voltage systems/equipment and the various “best practice” safety procedures for managing and operating HV generation / distribution systems at sea.

The course contents address all the guidelines as mentioned in Section B-III/2 of the STCW Code 2010 (Manila Amendments).

Course Objectives:

Enable all course attendees to :-

Understand the working of the various specialised components & equipment used in High Voltage marine installations.

Learn to operate, maintain & troubleshoot High Voltage marine installations safely & efficiently.

Become confident through practical “hands on” activities on the correct procedures when carrying out High Voltage testing and inspections.

Learn through properly conducted classroom discussions and the sharing of experience amongst participants.

Contents

Review marine electrical generating and distribution systems and commonly used voltages – 220/230V, 380/400V, 440V, 690V, 3.3kV, 6.6kV and 11kV frequency 50 or 60 Hz

Introduce the principles of marine High Voltage installations (installations exceeding 1000V), how and why HV installations are used on-board ships, HV bow thruster in LV vessels and full HV vessels

Calculations for solving fault currents

Legislative requirements for ships operating with HV systems Classification-minimum physical requirements, ISM-“Permit to work”, SOLAS-minimum shipboard systems, IACS rules as applicable

HV Generators, switchboards and transformers – dry and oil filled, HV cable construction and characteristics, distribution/switchboard layouts HV switchgear-circuit breakers, Vacuum, Gas (Sulphur Hexafluoride SF6)- number of switching operations (typically count value of approx 10,000) Current injection, long-term and short-term delay tests

Special characteristics and features of HV installations compared to LV

Compare “earthed” and “insulated” electrical systems used on-board ships

HV protection devices, prospective short circuit currents with limits

Principle operation of HV (HRC) fuses and HV circuit breakers

Engine room staff safety working in HV equipment areas.

Engine room staff to understand HV electrical hazards and the precautions necessary to work safely – work to be done by competent qualified personnel, following recognised safe protocols

Safe working procedures to eliminate risk when working on HV systems

Effects of electric shock to the human body

PPE clothing and equipment, temporary barriers and signage warnings

Rubber matting (manufacturers certification ID, for traceability, voltage rating)

HV arc and blast damage to ship equipment and personal injury – first response procedures

Overview of HV switchboard cabinet and cubicle construction – fault energy and arc flash containment, shock-wave, duct vents

Arc-flash detector protection systems

Switching strategy for safe HV Isolation procedures, earthing down – mechanical switches and portable earth down cables, “key safe” methods and “trapped key” interlocks, other physical interlocks used when racking out HV circuit breakers, for safety of all personnel when testing/maintenance is required on HV equipment/installations

Switching and isolation procedures on a marine HV system, safety documentation

Lock out Tag out “permits to work”, risk assessment, job hazard analysis (JHA) - minimum number of staff required when working on HV equipment

Actions necessary to remedy faults in a HV system-limited by the severity of the fault, VCB swapping out

Prevention of HV accidents through the strict observation of safety precautions

HV measuring instruments – correct use and instrument calibration requirements and compliance records

The role and purpose of protective systems, fuses and circuit breakers- Discrimination/selectivity

Transformer protection – oil and dry types

HV cable insulation failure, fault finding

HV Motor protection, insulation tests of generators

Indication of earth faults in HV installations with earthed neutral

HV Generator protection – NER star point resistor to ship frame.

Remote operation of equipment in HV installations and safe clearance distances maintained

HV Testing of generators, motors and transformers

Insulation resistance testing over time period

Performance of insulation resistance / PI-Polarization Index

H.V. Practices – PRACTICAL SECTION

Students to carry out practical “hands on” HV testing – the actual wearing of all appropriate PPE clothing

Using approved test instruments/equipment (5kV Insulation Resistance testing) HV voltage measuring using proximity HV detector

IR tests

VCB - prove - test – prove

- PPE gear worn/student
- Earth down VCB
- Rack out
- Test contacts
    - Open M ohms
    - Closed ohms
- Examine mechanism for wear

All to include management procedures

- JSA
- Switch schedule
- Permit to work
- Sanction to test
- Castel (captive) lock system

Oil filled and dry type transformers

PT and CT H.V. instruments

Circuit breaker control drawings

Thermography practices

Documentation methods/recording and storage of test results

Fire protection systems for ship HV areas and switchgear rooms
Inergen, Novec 1230.

HV Shore power

Overview of HV shore power systems – shore power authorities and ship staff responsibilities when connections are made and removed

HV DC grid – case study

Azipod entry procedures – rescue technique from HV pod space

HV propulsion systems, Electric PM and Thruster Pods

HV propulsion motor speed control, 3ph Synchronous and Induction motors-Synchro-converters, Cyclo-converters and PWM

Written Assessment for each level of participant

(Finish of course)

Engineering Certificate of Competency Revalidation, High Voltage (HV) requirements

The 2010 Manila Amendments to the STCW Code bring in the requirement for engineers to undergo education and training in High Voltage systems, at both the operational and management levels.

This requirement comes into force on the 1 January 2017 but will affect the revalidation of Engineering Certificates of Competency (CoC) from 1 January 2012.

There is no requirement for additional training to be undertaken by all existing Engineer Officers, whether or not they intend to work on ships having High Voltage systems. However, High Voltage training requirements will be incorporated in the future training programmes of Engineer Officers at both the operational and management levels.

No additional action is required for Engineer Officers who do not work on and do not intend to work on ships with High Voltage systems. These Engineer Officers will receive the following CoC limitation:

“From 1 January 2017 this certificate is not valid for service on ships fitted with High Voltage (over 1000V) systems”. Engineer Officers who do not want this limitation placed on their CoC should read the following section applicable to their Certificate.

Note: A High Voltage (over 1000V) system is where voltage is generated and distributed at high voltage or transformed to and distributed at high voltage. It does not include systems where high voltage is utilised locally e.g. ignition systems, radio transmission, Radar and other navigational equipment.

EOOW CoC Reg. III/1 (Operational Level)

To avoid having the High Voltage limitation, Engineer Officers of the Watch will need to show compliance with the 2010 Manila Amendments. In addition to the current revalidation requirements, they will have to provide documentary evidence of:

• completion of High Voltage (HV) course(*); or

• completion of the following sea service in the engine room on vessels fitted with HV systems;

• six months in the preceding five years; or

• three months sea service during the last twelve months.

Sea service evidence can be provided in the form of a company letter signed by an authorised official within the company.

Second/Chief Engineer Officer CoC Reg. III/2 and III/3 (Management Level)

To avoid having the High Voltage limitation, Senior Engineer Officers will need to show compliance with 2010 Manila Amendments. In addition to the current revalidation requirements, they will have to provide documentary evidence of completion of High Voltage (HV) course (*).*

High Voltage Courses

Courses previously undertaken prior to 1 July 2013 do not need to be MCA approved but you must provide documentary evidence confirming the course covers at least the following topics:

At the Operational level

• The hazards associated with High Voltage systems;

• The functional, operational and safety requirements for a marine high-voltage system;

• Basic arrangement of High Voltage systems and their protective devices;

• Safety procedures related to High Voltage systems;

• Immediate actions to be taken under fault conditions.

At the Management level

• The functional, operational and safety requirements for a marine high-voltage system;

• Assignment of suitably qualified personnel to carry out maintenance and repair of high-voltage switchgear of various types;

• Taking remedial action necessary during faults in a high-voltage system;

• Producing a switching strategy for isolating components of a high-voltage system;

• Selecting suitable apparatus for isolation and testing of high-voltage equipment;

• Carrying out a switching and isolation procedure on a marine high-voltage system, complete with safety documentation;

• ***Performing tests of insulation resistance and polarization index on high-voltage equipment. (Otara Engine room)***

The original certificate and course syllabus must be submitted with the application.

Engineer Officers may subsequently request the removal of the High Voltage limitation by providing documentary evidence of a High Voltage training course that includes the required topics.

Note:-The material delivered in this short course is common to both Management and Operational levels attendees – the written assessment criteria differs for each level.

Chapter one

Section 1

Electrical principles reviewed – introduction to High Voltage marine installations

Electricity

In some materials, particularly metals, the electrons farthest from the nucleus are not bound to a particular atom - they can move freely from one atom to another. Electricity is the flow of these free electrons in a conductor:

Alternating current

In alternating current AC, the flow of electric charge periodically reverses direction.

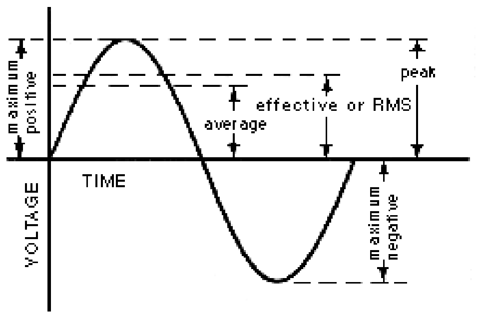
AC is the form in which electric power is delivered to businesses and residences. The usual waveform of an AC power circuit is a sine wave. In certain applications, different waveforms are used, such as triangular or square waves.

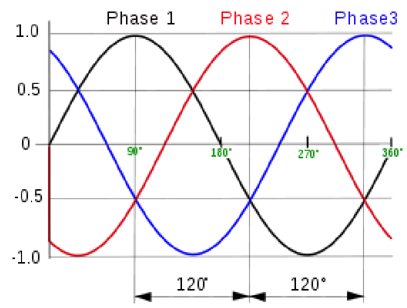
In *alternating current*, the electrons don't move in only one direction. Instead, they hop from atom to atom in one direction for a while, and then turn around and hop from atom to atom in the opposite direction. Every so often, the electrons change direction. In alternating current, the electrons don’t move steadily forward. Instead, they just move back and forth.

When the electrons in alternating current switch direction, the direction of current and the voltage of the circuit reverses itself. The voltage reverses itself 60 times per second. In some ships, the voltage reverses itself 50 times per second.

The rate at which alternating current reverses direction is called its *frequency*, expressed in hertz.

In an alternating current circuit, the voltage, and therefore the current, is always changing. However, the voltage doesn't instantly reverse polarity. Instead, the voltage steadily increases from zero until it reaches a maximum voltage, which is called the *peak voltage*.Then, the voltage begins to decrease again back to zero. The voltage then reverses polarity and drops below zero, again heading for the peak voltage but negative polarity. When it reaches the peak negative voltage, it begins climbing back again until it gets to zero. Then the cycle repeats.





In producing AC, physical movement is not necessary to create this effect. If the conductor stays in a fixed position but then intensity of the magnetic field increases or decreases (that is, if the magnetic field expands or contracts), a current is induced in the conductor the same as if the magnetic field were fixed and the conductor was physically moving across the field.

Because the voltage in an alternating current is always either increasing or decreasing as the polarity swings from positive to negative and back again, the magnetic field that surrounds the current is always either collapsing or expanding. So, if you place a conductor within this expanding and collapsing magnetic field, alternating current will be induced in the conductor.

With alternating current, it is possible for current in one wire to induce current in an adjacent wire, even though there is no physical contact between the wires.

Alternating current can be used to create a changing magnetic field, and changing magnetic fields can be used to create alternating current. This relationship between alternating current and magnetic fields makes three important devices possible:

An alternator generates alternating current from a source of rotating motion, such as a turbine powered by steam or fuel. Alternators work by using the rotating motion to spin a magnet that's placed within a coil of wire. As the magnet rotates, its magnetic field moves, which induces an alternating current in the coiled wire. *(Faradays Law)*

A motor converts alternating current to rotating motion. In its simplest form, a motor is simply an alternator that's connected backward. A magnet is mounted on a shaft that can rotate; the magnet is placed within the turns of a coil of wire.

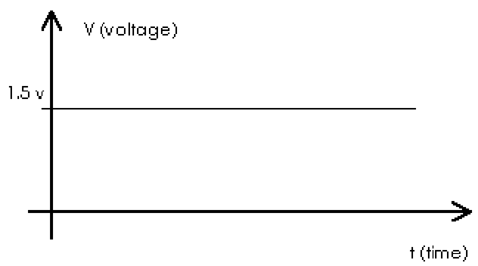
When alternating current is applied to the coil, the rising and falling magnetic field created by the current causes the magnet to spin, which turns the shaft.

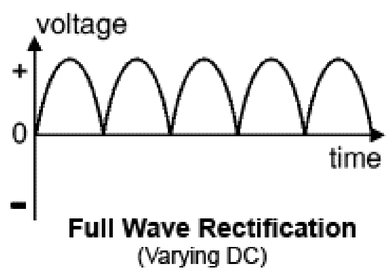
A transformer consists of two coils of wire placed within close proximity. If an alternating current is placed on one of the coils, the collapsing and expanding magnetic field will induce an alternating current in the other coil. Transformers are either "dry-type" or "oil filled" in construction for marine installations.

Direct current

DC, the unidirectional (single direction) flow of electric charge. Direct current is produced by sources such as batteries, thermocouples, solar cells, and commutated-type electric machines of the dynamo type.

Direct current may flow in a conductor such as a wire, but can also flow through semiconductors, or even through a vacuum as in electron or ion beams. The electric current flows in a constant direction.

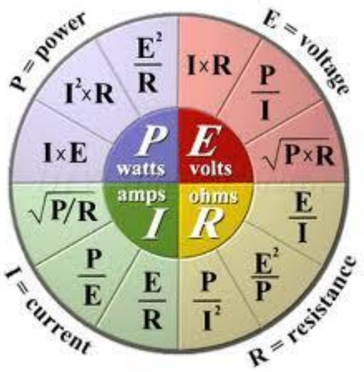




Direct current may be obtained from an alternating current supply by use of a current-switching arrangement called a rectifier, which contains electronic elements (usually) or electromechanical elements (historically) that allow current to flow only in one direction. Direct current may be made into alternating current with an inverter or a motor-generator set.

Ohms Law

Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship:



V=IR or **E=IR** where *I* is the current through the conductor in units of amperes, *V* is the potential difference measured *across* the conductor in units of volts- E = EMF, and *R* is the resistance of the conductor in units of ohms.

More specifically, Ohm's law states that the *R* in this relation is constant, independent of the current.

Insulation

An **electrical insulator** is a material whose internal electric charges do not flow freely, and therefore does not conduct an electric current under the influence of an electric field. A perfect insulator does not exist, but some materials such as glass, paper and Teflon, which have high resistivity, are very good electrical insulators.

A much larger class of materials, even though they may have lower bulk resistivity, are still good enough to insulate electrical wiring and cables. Examples include rubber-like polymers and most plastics. Such materials can serve as practical and safe insulators for low to moderate voltages (hundreds, or even thousands, of volts).

Insulators are used in electrical equipment to support and separate electrical conductors without allowing current through themselves. An insulating material used in bulk to wrap electrical cables or other equipment is called *insulation*.

High Voltage (HV) Insulation Requirements

The winding arrangements for marine HV generators and motors are similar to those at LV **<u>except</u>** for the need for higher level insulating materials such as *Micalastic (MICALASTIC is the registered trademark for Siemens insulation systems for high-voltage windings of rotating electrical machines. These systems use mica, a material capable of withstanding high electrical and thermal loads, together with curable, elastic epoxy resins as bonding material or similar*).

The windings of HV **dry-type** transformers are usually insulated with an epoxy resin and quartz powder compound. This is a non-hazardous material which is maintenance free, humidity resistant and tropicalised. Insulation for the HV conductors requires a more complicated design than is necessary for LV cables. But HV cables provide a significant saving in weight and space, leading to easier installation and a more compact result.

Where air is being used as the insulating medium between bare copper busbars and terminals, the creepage and clearance distances between live parts and earth are greater on HV systems.

Reasons for Using High Voltage Systems On board Ships

The voltage used on board a ship, is usually a three phase, 60Hz, 440 Volts supply being generated and distributed on board. Owners and designers aim for bigger ships for more profitability. As the ship size increases, there is a need to install more powerful engines and other machinery.
This increase in size of machinery and other equipment demands more electrical power and it is required to use higher voltages on board a ship.

Any Voltage used on board a ship if less than 1kV (1000 V) then it is called as LV (Low Voltage) system and any voltage above 1kV is termed as High Voltage.

Typical marine HV systems operate usually at 3.3kV or 6.6kV. Newer passenger ships operate at 11.1kV, with higher voltages planned in future builds.

A ship generating 8MW of power at 440V, from 4 diesel generating sets of 2MW, 0.8 power factor each.

Each generator feeder cable and circuit breaker has to handle a I_{FL} = full-load current of: **Approximately 3300 Amps.**

The protection devices like circuit breaker should be rated at approximately **130kA** for each feeder cable.

Calculate the same if the generated voltage is 6600Volts. **Approximately 220 Amps**.

The protection devices can be rated as low as **8800 Amps.** Also Power Loss = $I^2 \times R$. Where I is the current carried by the conductor, R is the resistance of the conductor.

The power loss varies square of the current carried by the conductor. The power loss is reduced by a greater extent if the voltage is stepped up. It is always efficient to transmit power at a higher voltage.
Conversely, the power loss can be reduced by reducing the resistance of the conductor.
By increasing the cross-sectional area of the conductor (diameter), the resistance of the conductor can be reduced and thus the power loss. But this involves huge increase in cost and heavy cables with supports.
Also a motor (let us assume a bow thruster), may be of a smaller size if it designed to operate on 6600 Volts.
For the same power, the motor would be of a smaller size if it is designed for 6600Volts when compared to 440Volts.

Note – as a rule of thumb
IFL = KVA/ ($\sqrt{3}$ VL pf)   Isc= approx 10 times IFL
Imax for circuit breaker closing on fault *(this is higher when closing than when opening on a fault)* = 4 times Isc

Review of ships electrical generating and distribution systems

Power Distribution

The function of a ship's electrical distribution system is to safely convey electrical power to every item of equipment connected to it. The most obvious element in the system is the main switchboard. The main board supplies bulk power to motor starter groups (often part of the main board), section boards and distribution boards. Transformers interconnect the HV and LV distribution sections of the system.
Circuit breakers and fuses strategically placed throughout the system automatically disconnects a faulty circuit within the network. The main switchboard is placed in the engine control room and from there engine room staff monitor and control the generation and distribution of electrical power. It is very important that every engineer has a profound knowledge of the electrical distribution of the ship's power. The only way to acquire this knowledge is to study the ship's power diagrams.
Almost all oceangoing ships have an A.C. distribution system in preference to a direct current D.C. system. Usually a ship's electrical distribution scheme follows shore practice. This allows normal industrial equipment to be used after being adapted and certified where and if necessary, so it can withstand the conditions on board of a ship (e.g. vibration, freezing and tropical temperatures, humidity, the salty atmosphere, etc. encountered in various parts of the ship). Most ships have a 3-phase A.C., 3-wire, 440V insulated-neutral system.

This means that the neutral point of star connected-generators is not directly earthed (NER) to the ship's hull. Ship's with very large electrical loads have generators operating at high voltages (HV) of 3.3KV, 6.6KV, and even 11KV.
By using these high voltages we can reduce the size of cables and equipment. High voltage systems are becoming more common as ship size and complexity increase.

The frequency of an A.C. power system can be 50Hz or 60Hz. The most common power frequency adopted for use on board ships is 60Hz. This higher frequency means that generators and motors run at higher speeds with a consequent reduction in size for a given power rating. Lighting and low power single-phase supplies usually operate at 220V. This voltage is derived from a step down transformer connected to the 440V system.

Three Phase Ships Generators

In marine applications generators are always synchronous machines. Synchronous machines are excited by direct current. In all but very small generators the rotor is the exciter of the generator. The direct current can be supplied to the rotor via a small AC generator and rectifier on the rotor shaft (brushless excitation).
An automatic voltage regulator (AVR) controls the exciting current. The AVR keeps the generators voltage in the set value, regardless of changes in load.

$$N = \frac{120\,f}{P}$$

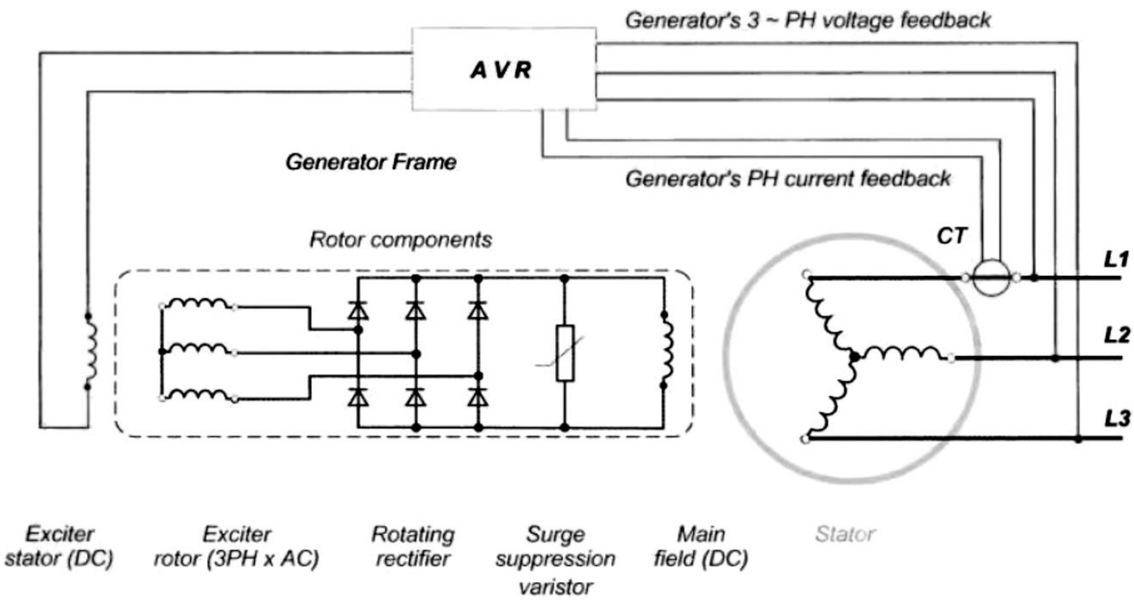
Where N = Synchronous speed

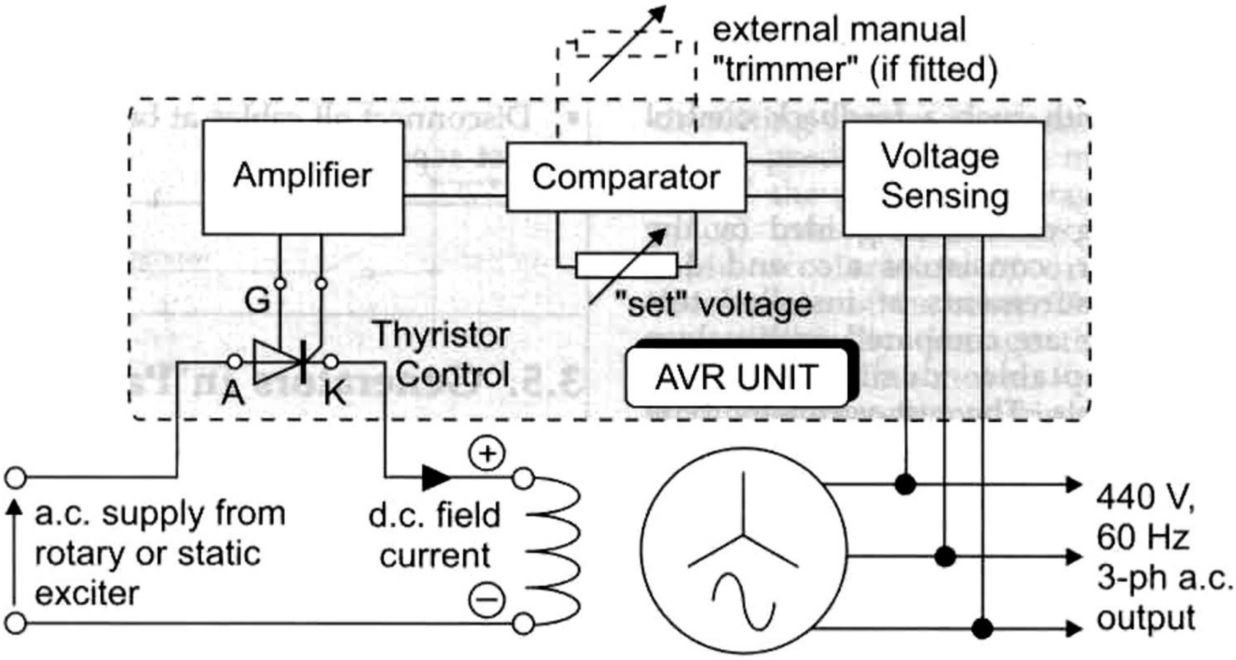
f = Frequency

P = Number of poles

No. of poles	Sync. speed (at 60 Hz)	Sync. speed (at 50 Hz)
2	3600	3000
4	1800	1500
6	1200	1000
8	900	750
10	720	600
12	600	500

Table 3-1. Motor synchronous speeds vs. number of poles





Electric motors

The most widely used electric motors in marine applications are 3-phase alternating current Asynchronous motors with a squirrel cage rotor. Synchronous – brushless excited motors are typically used for propulsion.

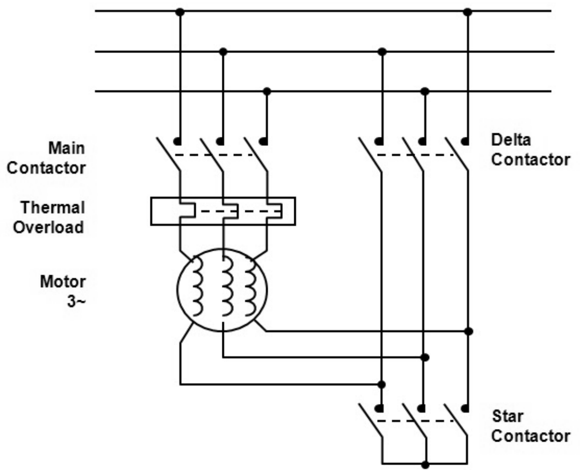
Three Phase Motor starters

A motor starting device is the general term for a piece of equipment that allows the connection of a motor to its main power supply. Starters can also be used to limit inrush current of a motor to an acceptable value.
An acceptable value is one that does not disturb the proper functioning of the power supply as this would also disturb other consumers on this supply.
Limiting the starting current will also limit the starting torque of an electric motor. This may be necessary to protect for instance a gear box or other mechanical devices.

Direct-on-line starters (DOL)
The simplest and cheapest way of starting an electric load is Direct-On-Line starting. The starting time will be minimal, the starting torque will be maximum but the voltage drop while starting will be maximal also for the other consumers. In general, a generator is able to supply a sudden overload of 50 percent of its KVA rating, resulting in a voltage drop at the generator terminals of less than 15 percent. This allows for another 5 percent voltage drop in the distribution network, in order to stay under the maximum allowed voltage drop of 20 percent during starting of a large consumer.
The voltage drop is mostly a result of the capabilities of the generator (and AVR) as the power factor of a starting motor is almost always less then 0.4.
A diesel engine should be capable of handling a load step of 20 percent or more without a frequency dip of more than 10 percent, which should be recovered within 15 seconds.

Reduced voltage starting
In some applications a motor cannot be directly connected to the line because the starting current is too high. In these cases we have to reduce the voltage applied to the motor.

Star-delta starters
Star-delta starting is a way of reduced voltage starting. This starting method gives the same results as an autotransformer starter having a 58 percent tap. The reason is that the voltage across each star-connected winding is only 1 p3 = 0; 58 of its rated value. Starting current will be reduced to 58 percent starting torque will be reduced to 0; 582 = 0; 33 or only 33 percent.



Star-Delta

- The motor is initially connected in **star** configuration and then, after a preset time, the motor is disconnected from the supply and reconnected in **delta** configuration.
- The current and torque in the star configuration are **one third of the full voltage** current and torque when the motor is connected in delta.

Electronic Soft Starters
Electrical soft starters can use solid state devices to control the current flow and therefore the voltage applied to the motor. They can be connected in series with the line voltage applied to the motor, or can be connected inside the delta loop of a delta-connected motor, controlling the voltage applied to each winding. Solid state soft starters can control one or more phases of the voltage applied to the induction motor with the best results achieved by three-phase control. Typically, the voltage is controlled by reverse-parallel-connected silicon-controlled rectifiers (thyristors), but in some circumstances with three-phase control, the control elements can be a reverse-parallel-connected SCR and diode.

A soft starter continuously controls the three-phase motors voltage supply during the start-up phase. This way, the motor is adjusted to the machines load behaviour.

Mechanical operating equipment is accelerated in a controlled manner. Fig12.

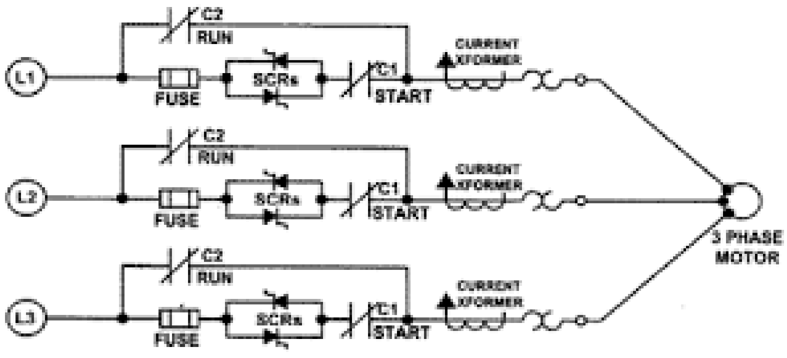
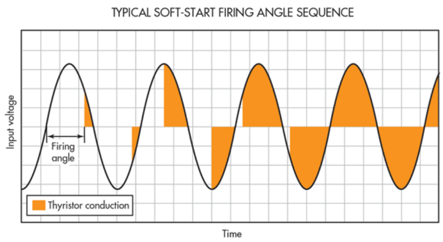
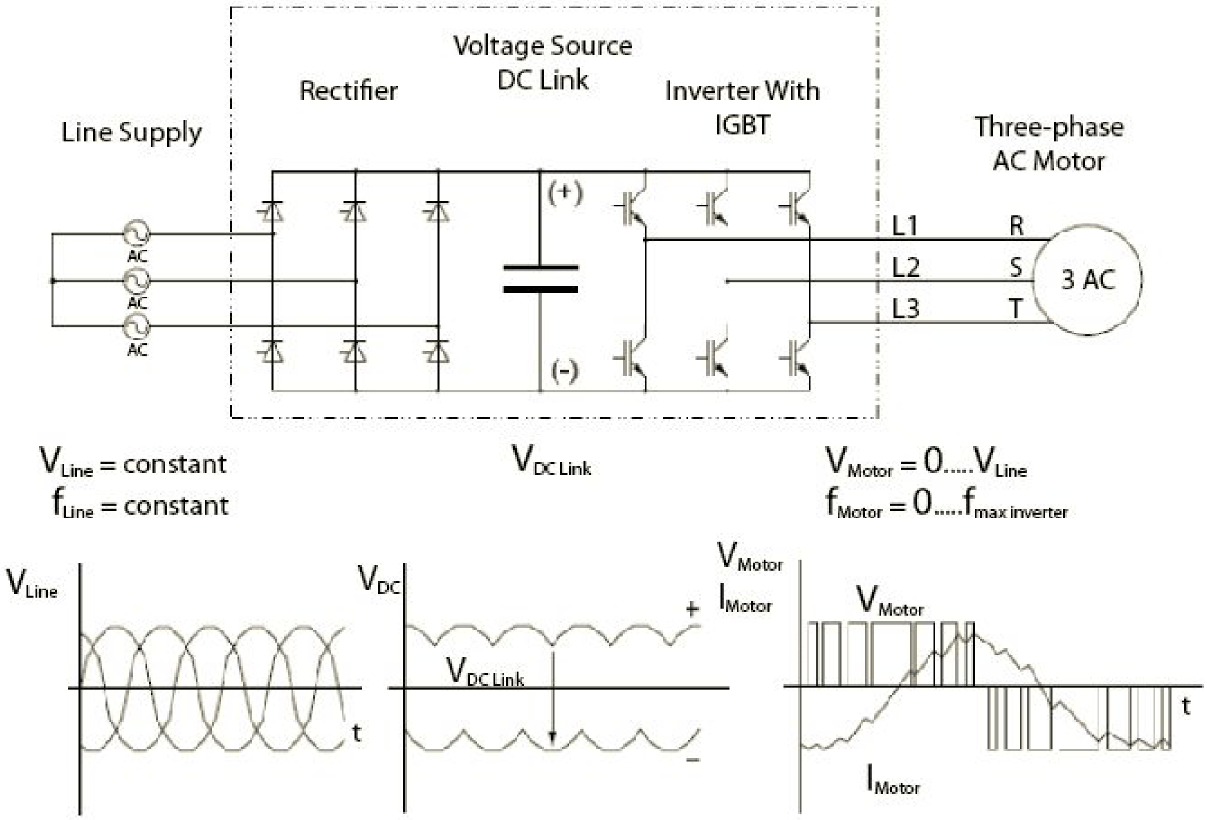


FIGURE 12. SOLID STATE REDUCED VOLTAGE STARTER
(SHOWN HERE WITH REVERSE PARALLEL WIRING TO ALLOW FOR MAXIMUM CONTROL)



Variable Frequency Drives

A variable-frequency drive (**VFD** typically meaning both synchro or cycloconverter) (also termed, *variable-speed drive*, *AC drive*, or *inverter drive*) is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage.

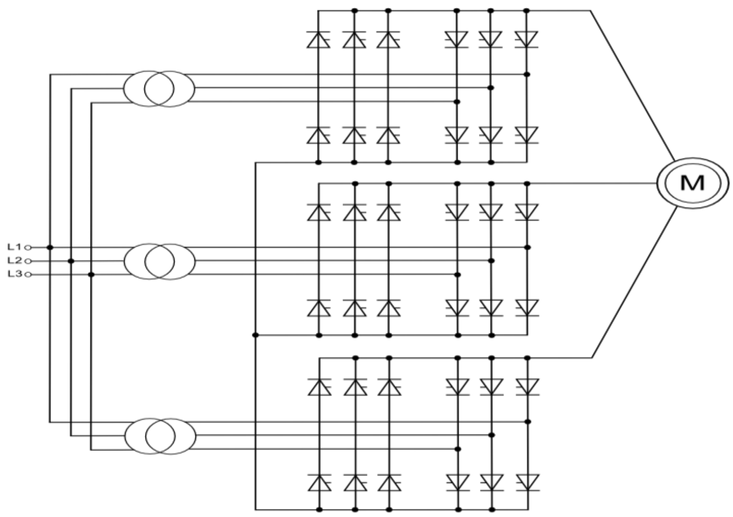


Three Phase Synchroconverter

VFDs on board ships controlling speeds typically larger kW 3ph motors for propulsion systems also driving pumps, mooring winches, cargo handling machinery, compressors, fans and other loads requiring variable speeds. – now are common place on modern vessels, these drives allow for significant energy efficiency improvement.

VFD drives, control thruster motor speed requirements for a vessel, manoeuvring and dynamic positioning systems, with 3ph synchronous or asynchronous motors, typically HV.

Three Phase Thyristor Silicon Controlled Rectifier (SCRs) Cycloconverter AC to AC



Comparisons of HV to LV

Major features of a HV system compared to a LV system

HV systems have more extensive and complex networks and connections.

Access to HV areas is strictly limited and securely controlled.

Isolation procedures are more involved and switching strategies have to be formulated and recorded.

Isolated equipment must be earthed down.

Appropriate test probes and instruments should be used ***(never use a multimeter)***.

Diagnostic insulation resistance testing is necessary.

HV systems may sometimes be earthed neutral and use current limiting resistors.

Special HV circuit breakers should be installed.

Current magnitude and time is used for discrimination in protection/monitoring devices.

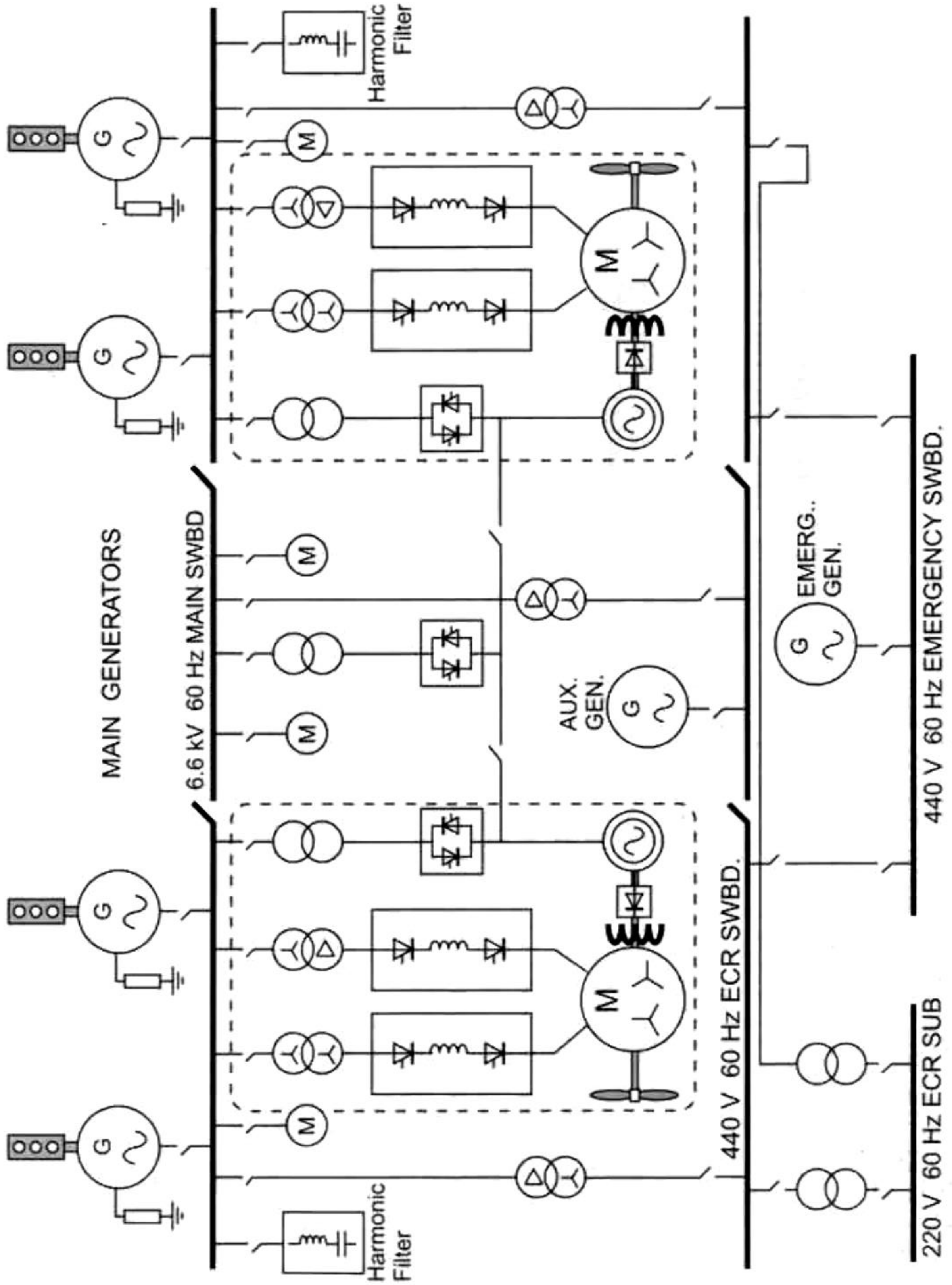

MAIN GENERATORS
6.6 kV 60 Hz MAIN SWBD
Harmonic Filter
Harmonic Filter
G
M
AUX. GEN.
EMERG.. GEN.
440 V 60 Hz ECR SWBD.
440 V 60 Hz EMERGENCY SWBD.
220 V 60 Hz ECR SUB

Illustration 2.13.1a Main Electrical Network

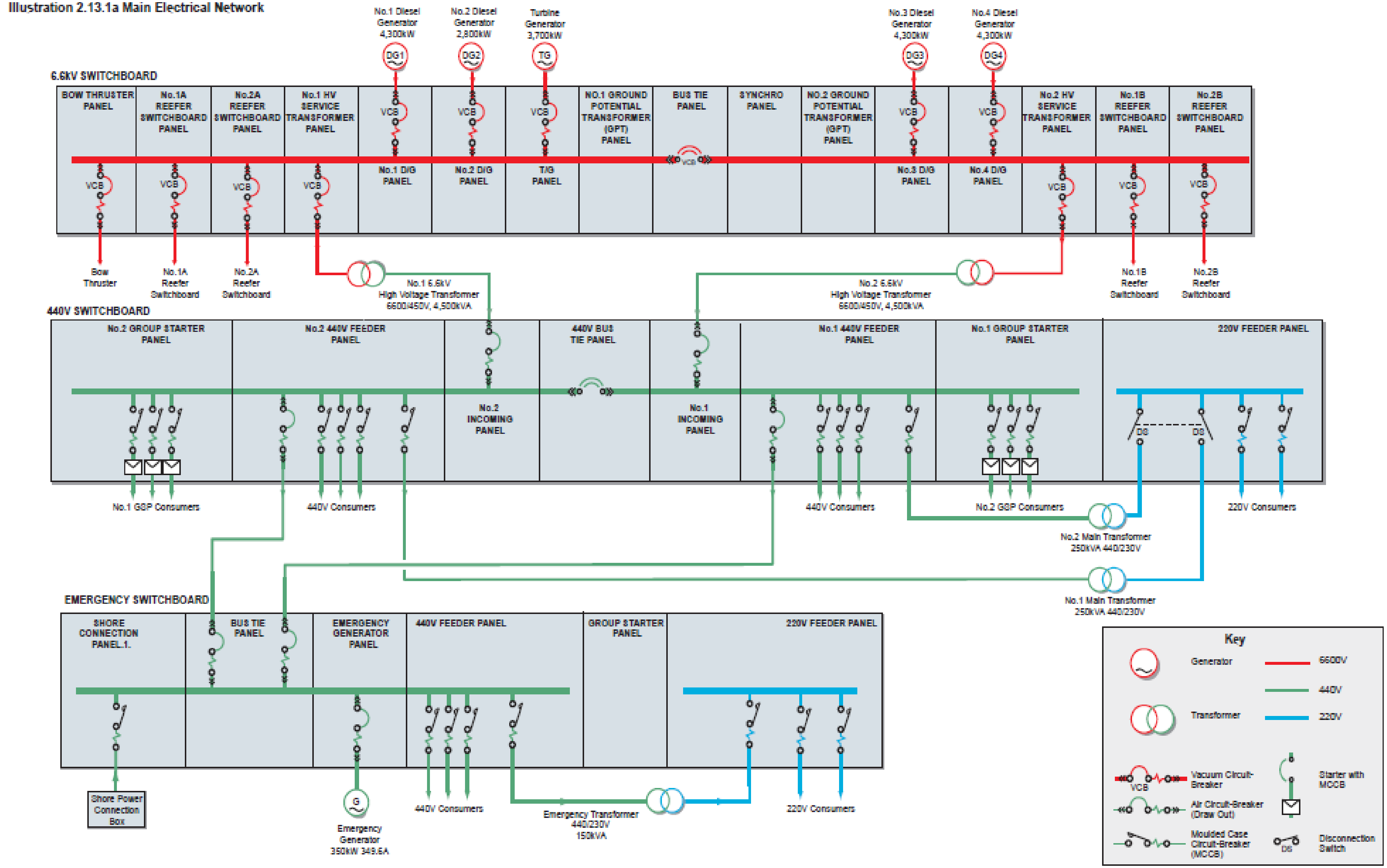
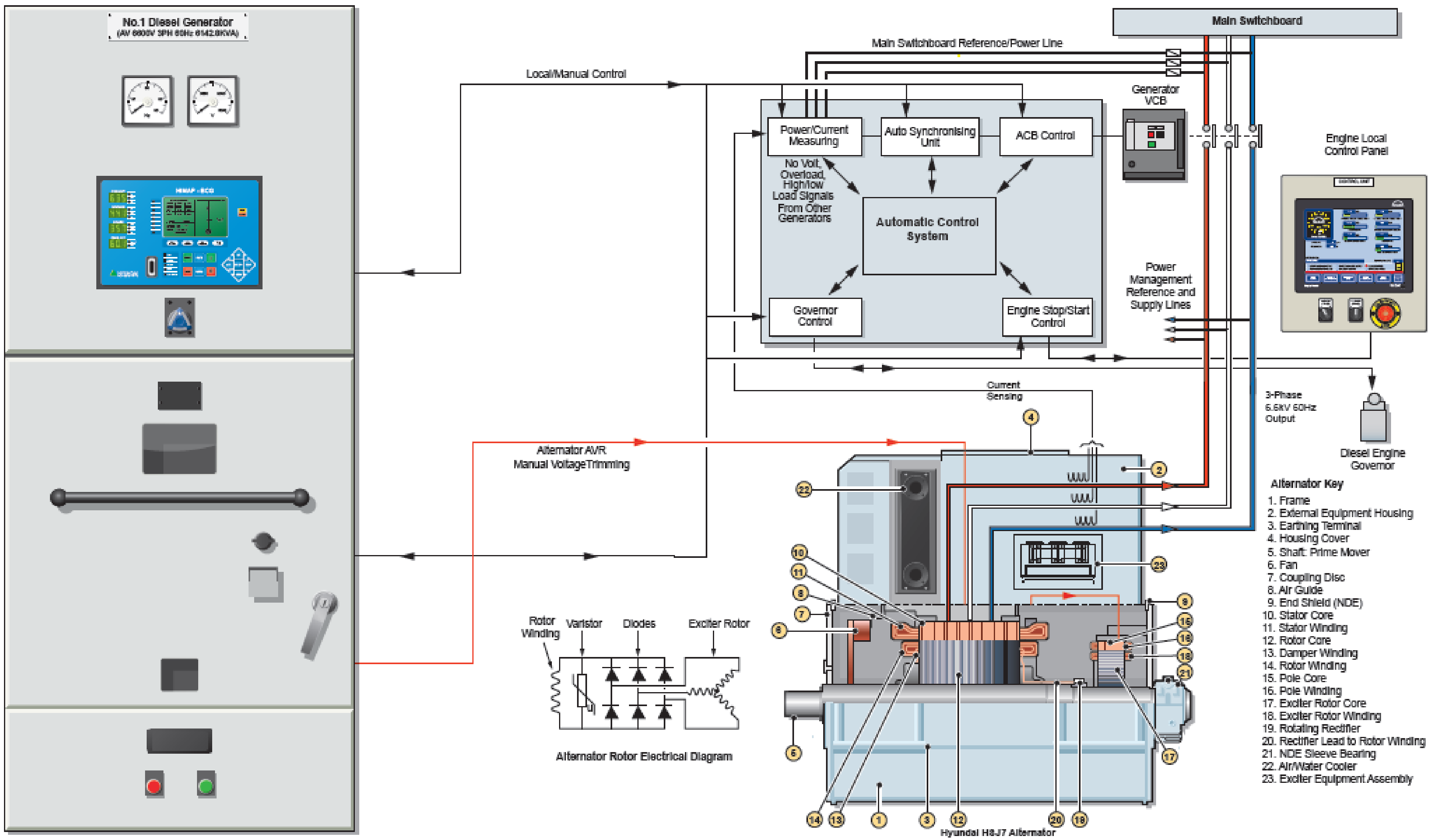
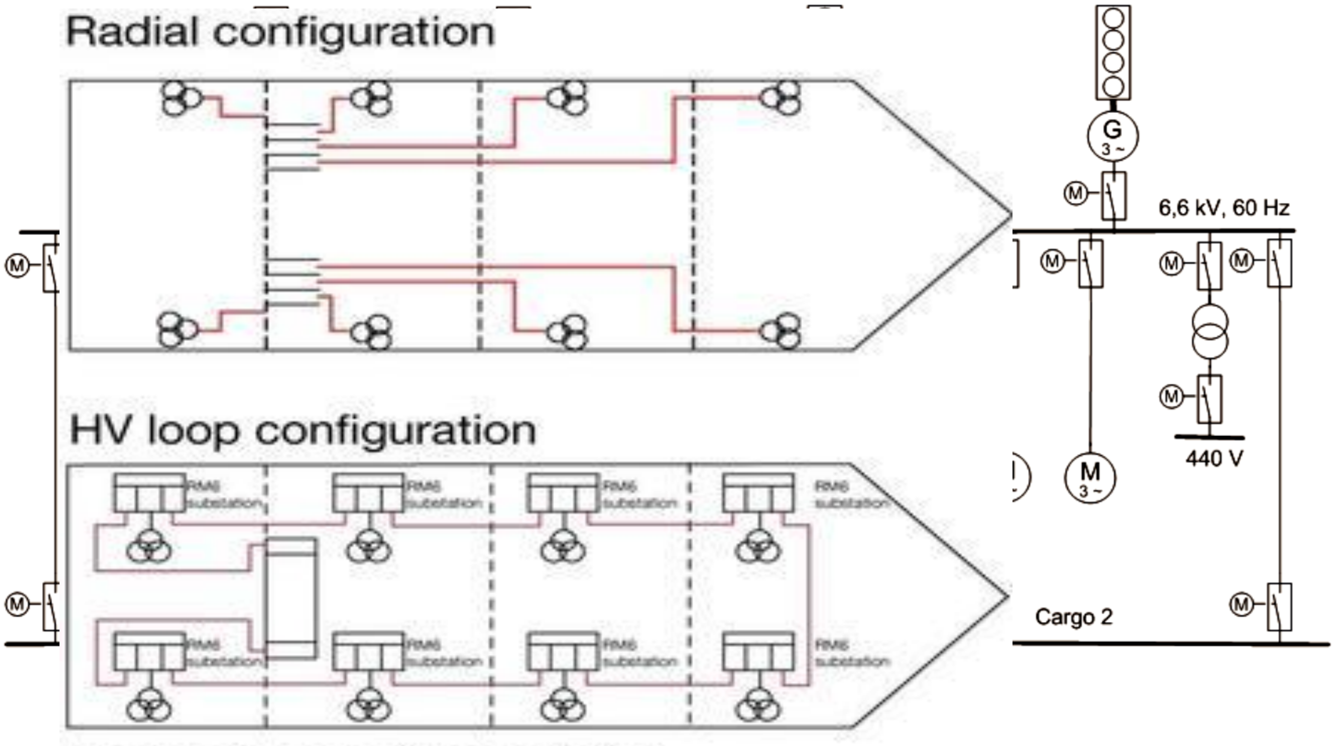


Illustration 2.13.6a Main Alternators



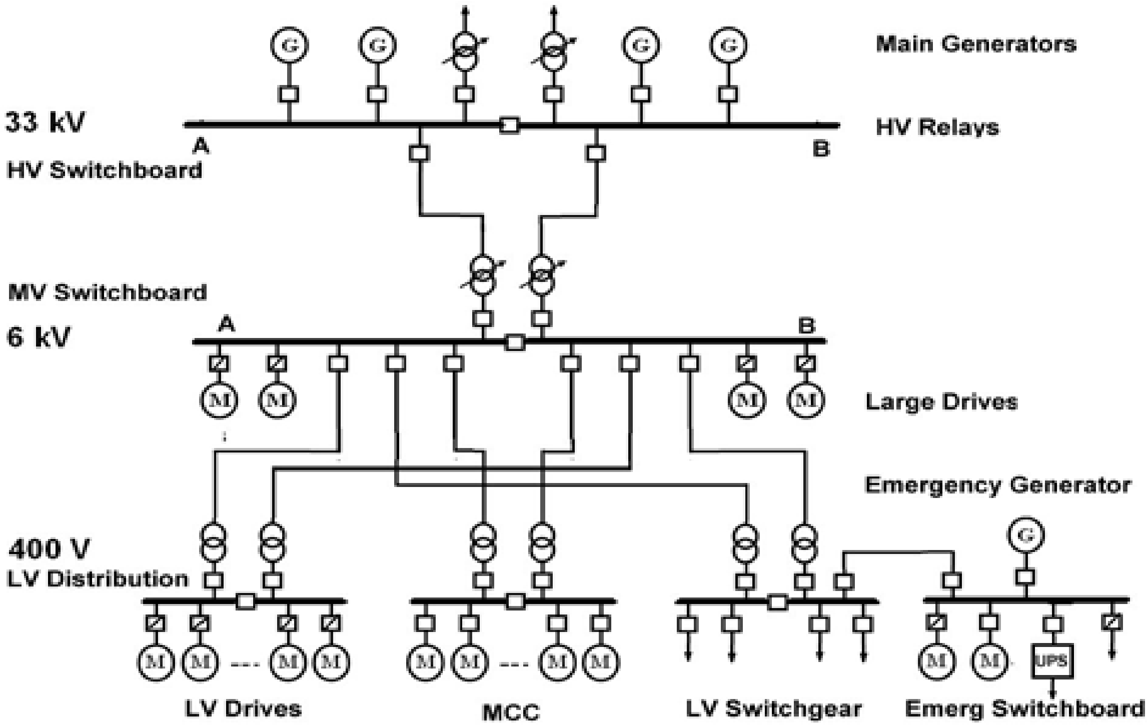
HV 6.6kV - LNG Carrier



Example of a cruise liner architecture

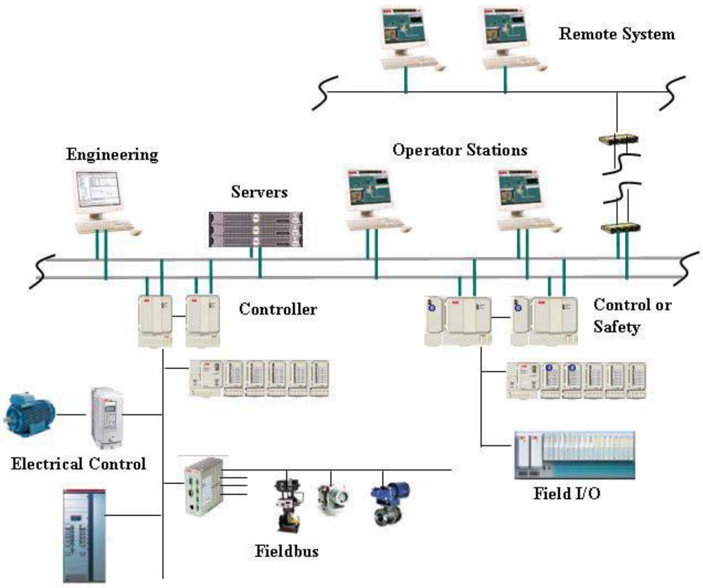
Distribution layouts:

HV example typical of an "offshore" oil handling platform



A separate emergency power switchboard provides power for critical equipment. It can be powered from a local emergency generator if main power is lost. Computer systems are fed from an uninterruptible power system (UPS) with batteries, connected to the main or emergency switchboard.

A power management system is used for control of electrical switchgear and equipment. Its function is to optimize electricity generation and usage and to prevent major disturbances and plant outages (blackouts). The power management system includes HV, MV and LV low voltage switchgear plus MCCs and emergency generator sets. Functions include prioritization of loads, emergency load shedding (closing down of nonessential equipment) and prestart of generator sets (e.g., when additional power to start a big crude pump is required).



The dangers of high voltage electrical systems on ships

HV systems are increasingly being used and present real dangers and hazards to personnel who are not trained or aware of the dangers. Those personnel using high voltage systems on ships should be trained in the additional safety procedures required before using or maintaining high voltage systems. The dangers of high voltage systems should not be underestimated, and untrained personnel could be at great risk.

The demand for electrical power has increased on many ships, especially those with diesel-electric propulsion where the supply current becomes too high. The supply current becomes far too high and it is not efficient or practical to use the common shipboard voltage supply of 440V.

Modern ships, particularly container, passenger and specialist offshore ships are built now with high voltage generating plant; however, the engineer officers will normally only have been trained on low voltage systems. Also not every ship has an electrician and the engineers often have to do the electrician's work when things go wrong.

Neutral Earth Resistor (NER) on vessels 3.3kV to 13.8kV

High voltage generators typically have a connection from the Star point of the three stator windings to the ship's hull via a medium to low ohms value resistor (NER) the purpose of this resistor is to limit generator earth fault currents.

An earth fault of 0Ω impedance is a short circuit across a generator stator winding.

Example- fault current Ifault = Vph/R (NER), on a 6.6kV system with a 200Ω NER

Vph = 6600/√3 = 3810 Volts (must use Phase voltage not Line voltage)

The maximum Earth Fault current = 3810/200 = 19 Amps

(Note: HAL MV Oosterdam NER is 2100 Ω = 3 Amps)

This potential fault current is considerably lower for high voltage supplies, the protective tripping devices are matched to alarm or trip at these low currents.

Grounded High impedance Vs Ungrounded
In LV shipboard installations ungrounded earthing is selected because it ensures continuous power supply in the event of one earth fault.
However, the LV network is actually earthed via the high impedance capacitances of all the equipment installed onboard. Therefore, the 'ungrounded' earthing type of shipboard installations has to be treated as 'grounded' via capacitive elements.

Stray capacitances.
These capacitances consist of all stray leakage capacitive elements of:

- cablings (due to proximity of insulated conductors)
- static and rotary machinery windings
- circuit breakers and surge suppressing devices

Considering that inmost new builds with electric propulsion or even in All Electric Ships (AES), high voltage (in the range of 1kV up to15kV) is integrated, it can be deduced that special attention has to be paid to applying ungrounded earthing**, especially considering that stray capacitances are to increase by an order of magnitude due to the corresponding high insulation requirements of an HV installation of generation and distribution.**
(Xc=1/(2π f c) at for example a capacitance to the hull of 300μF Xc = 8.84Ω at 11kV I to hull could be Vph 6.350kV / 8.84Ω = 718 A
This can easily reach a few thousand Amps as capacitance increases Xc decreases)
Grounded High impedance compared to an Ungrounded ship generator star point

In LV shipboard installations ungrounded earthing is selected because it ensures continuous power supply in the event of one earth fault.

However, the LV unearthed network is not actually an infinite impedance, it is determined by all the **stray capacitances** of all the equipment installed onboard and therefore it is **"capacitively earthed"** via all of the high impedance (Ω) capacitances.

Therefore, the 'ungrounded' earthing type of shipboard installations has to be treated as 'grounded / earthed' via all capacitive elements allowing a capacitive current to flow to earth (ships hull). This capacitive current is high enough on contact to cause death due to electrocution.

Stray capacitances.
These capacitances consist of all stray leakage capacitive elements of:
- cablings (due to proximity of insulated conductors and steel-work)
- static and rotary machinery windings
- circuit breakers and surge suppressing devices

Stray capacitances increase due to the corresponding high voltage insulation requirements of an HV installation of generation and distribution/cables/machines.

Example #1 XC=1/(2π f C) at a capacitance to the hull of 60μF XC = 44.2Ω at 11kV 60Hz I to hull could be Vph 6.350kV / 44.2Ω = 143 Amps

Example #2 XC=1/(2π f C) at a capacitance to the hull of 120μF XC = 22.1Ω at 11kV 60Hz I to hull could be Vph 6,350V / 22.1Ω = 287 Amps

The cumulative capacitance can be high in value (micro-farads) resulting in large capacitive currents, as an increase in capacitance will decrease the AC reactance in ohms XC Ω (I=V/XC) Considering that in most new builds with diesel electric propulsion high voltage (in the range of 6.6kV up to11kV) is integrated, special attention has to be paid to applying earthing to limit any earth fault currents to low values, therefore "ungrounded" systems are not used on HV vessels.

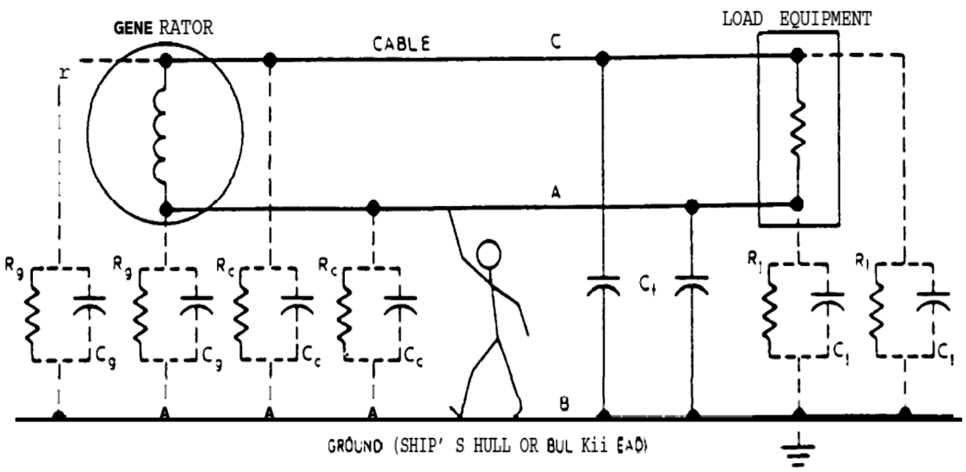


Figure 3-2. Typical Shipboard "Real" Ungrounded System

Low voltage electrocution hazard exists at 220 Volts, with a shock voltage to the ship's hull of approximately 110 V, if the capacitance earthing that provides a path for current through the victim was only 10 μF and the ship is 60Hz.

XC=1/(2π f C) at a capacitance to the hull of 10μF XC = 265.25Ω at 110V 60Hz I to hull could be 110V / 265.25Ω = 0.4 Amps (400mA) enough to cause a fatal electric shock.

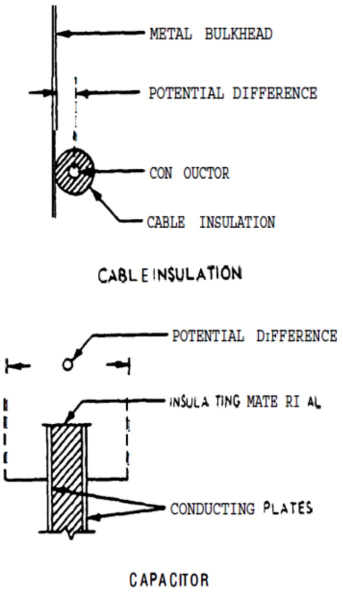
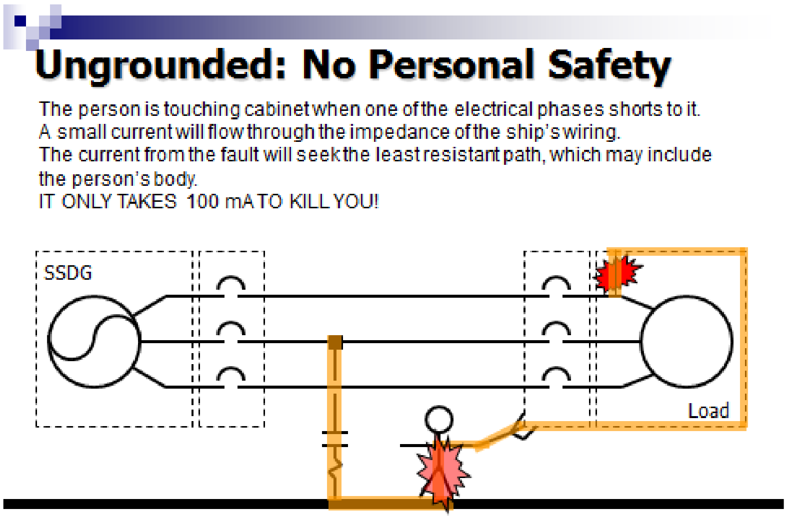
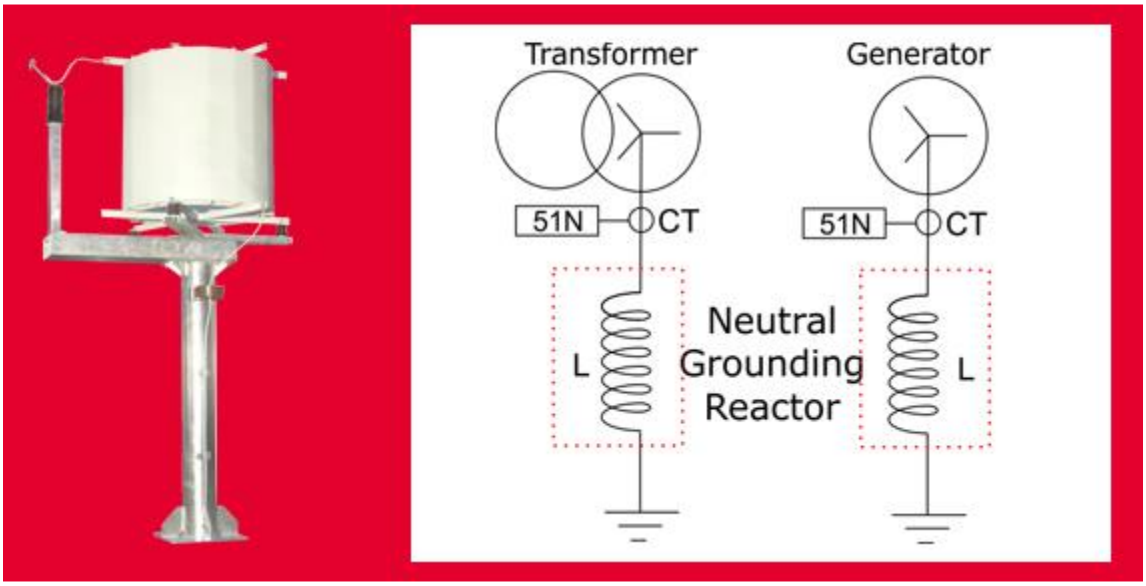


Figure 3-3. Capacitance of Cables



Resistance grounding systems (NER) on HV systems have advantages over solidly grounded systems, including arc-flash hazard reduction, limiting mechanical and thermal damage associated with high level fault currents, and controlling transient over-voltages.

Some vessels use neutral earthing reactors.



An **arc flash** (also called a **flashover**), is distinctly different from the **arc blast**.
An arc flash is the light and heat produced from an electric arc supplied with sufficient electrical energy to cause substantial damage, harm, fire, or injury, it typically occurs suddenly and without warning - but not without a cause. Many arc flashes are caused by human error. The arc flash could have been avoided and the seriousness of arc flash injuries could have been reduced by those involved having followed proper procedures. Electrical arcs experience negative incremental resistance, which causes the electrical resistance to decrease as the arc temperature increases.
Therefore, as the arc develops and gets hotter the resistance drops, drawing more and more current (runaway) until some part of the system melts, trips, or evaporates, providing enough distance to break the circuit and extinguishing the arc.
When an uncontrolled arc forms at high voltages, arc flashes can produce deafening noises, supersonic concussive-forces, super-heated shrapnel, temperatures far greater than the Sun's surface, and intense, high-energy radiation capable of vaporizing nearby materials.
Arc flash temperatures can reach or exceed 35,000 °F (19,400 °C) at the arc terminals. The massive energy released in the fault rapidly vaporizes the metal conductors involved, blasting molten metal and expanding plasma outward with extraordinary force. The result of the violent event can cause destruction of equipment involved, fire, and injury not only to an electrical worker but also to bystanders.
During the arc flash, electrical energy vaporizes the metal, which changes from solid state to gas vapor, expanding it with explosive force **(**the **arc blast)**. For example, when copper vaporizes it suddenly expands by a factor of 67,000 times in volume.
In addition to the explosive blast, called the **arc blast** of such a fault, destruction also arises from the intense radiant heat produced by the arc. The metal plasma arc produces tremendous amounts of light energy from far infrared to ultraviolet. Surfaces of nearby objects, including people, absorb this energy and are instantly heated to vaporizing temperatures. The effects of this can be seen on adjacent walls and equipment - they are often ablated and eroded from the radiant effects.
One of the most common causes of **arc flash** injuries happens when switching on electrical circuits and, especially, tripped circuit breakers. A tripped circuit breaker often indicates a fault has occurred somewhere down the line from the panel. The fault must usually be isolated before switching the power on, or an arc flash can easily be generated. Small arcs usually form in switches when the contacts first touch, and can provide a place for an arc flash to develop. If the voltage is high enough, and the wires leading to the fault are large enough to allow a substantial amount of current, an arc flash can form within the panel when the breaker is turned on.
Generally, either an electric motor with shorted windings or a shorted power transformer are the culprits, being capable of drawing the energy needed to sustain a dangerous arc flash.
Circuit breakers are often the primary defence against current runaway, especially if there are no secondary fuses, so if an arc flash develops in a breaker there may be nothing to stop a flash from going out of control.
Once an arc flash begins in a breaker, it can quickly migrate from a single circuit to the busbars of the panel itself, allowing very high energies to flow. Precautions must usually be used when switching circuit breakers, such as standing off to the side while switching to keep the body out of the way, wearing protective clothing, or turning off equipment, circuits and panels down-line prior to switching. 27

HV switchgear is able to handle very high energies and many places require the use of full protective equipment before switching.
In addition to the heat, light and concussive forces, an arc flash also produces a cloud of plasma and ionized particles.
When inhaled, this ionized gas can cause severe burns to the airways and lungs. The charged plasma may also be attracted to metallic objects worn by people in the vicinity, such as ear rings, belt buckles, keys, body jewellery, or the frames of glasses, causing severe, localised burns. Care should usually be taken when switching circuits to remove any metals from a person's body, to hold their breath and close their eyes. An arc flash is more likely to form in a switch that is closed slowly, by allowing time for an arc to form between the contacts.
As an example of the energy released in an arc flash incident, a single phase-to-phase fault on a 480 V system with 20,000 amps of fault current. The resulting power is 9.6 MW. If the fault lasts for 10 cycles at 60 Hz, the resulting energy would be 1600 kilojoules (energy=power x time).
The character of an arc flash blast is quite different from a chemical explosion (more heat and light, less mechanical shock), but the resulting devastation is comparable. The rapidly expanding superheated vapour produced by the arc can cause serious injury or damage, and the intense UV, visible, and IR light produced by the arc can temporarily and sometimes even permanently blind or cause eye damage to people.
There are four different arc flash type events to be assessed

- Open Air Arc Flashes
- Ejected Arc Flashes
- Equipment Focused Arc Flashes (Arc-in-a-box)
- Tracking Arc Flashes

Protecting personnel
There are many methods of protecting personnel from arc flash hazards. This can include personnel wearing arc flash personal protective equipment (PPE) or modifying the design and configuration of electrical equipment. The best way to remove the hazards of an arc flash is to de-energize electrical equipment when interacting with it, however de-energizing electrical equipment is in and of itself an arc flash hazard. In this case, one of the newest solutions is to allow the operator to stand far back from the electrical equipment by operating equipment remotely, this is called remote racking.
Arc flash protection equipment
Any amount of heat delivered within a long enough time interval will have no impact on the fabrics' integrity while a limited amount of heat delivered within short enough time interval may ignite or melt the fabric. With recent increased awareness of the dangers of arc flash, there have been many companies that offer arc flash personal protective equipment (PPE). The materials are tested for their arc rating. The arc rating is the maximum incident energy resistance demonstrated by a material prior to break-open (a hole in the material) or necessary to pass through and cause with 50% probability a second or third degree burn. Arc rating is normally expressed in cal/cm² (or small calories of heat energy per square centi-meter). The tests for determining arc rating are defined in ASTM F1506 *Standard Performance Specification for Flame Resistant Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards*. 28
The minimum rating of PPE necessary for any category is the maximum available energy for that category. For example, a Category 3 arc flash hazard requires PPE rated for no less than 25 cal/cm² (1.05 MJ/m²).
The second method of selecting PPE is to perform an arc flash hazard calculation to determine the available incident arc energy. IEEE 1584 provides a guide to perform these calculations given that the maximum fault current, duration of faults, and other general equipment information is known. Once the incident energy is calculated the appropriate ensemble of PPE that offers protection greater than the energy available can be selected.
PPE provides protection after an arc flash incident has occurred and should be viewed as the last line of protection.

Reducing hazard by design
Three key factors determine the intensity of an arc flash on personnel.
1- Fault current
Fault current can be limited by using current limiting devices such as grounding resistors or fuses. If the fault current is limited to 5 amperes or less, then many ground faults self-extinguish and do not propagate into phase-to-phase faults.
2- Arcing time
Arcing time can significantly be reduced by protection based on **arc flash light**. Optical detection is often combined with overcurrent information. Light and current based protection can be set up with dedicated arc flash detector protective relays, or by using normal protective relays equipped with an add-on arc-flash option.
3- Distance
The radiant energy released by an electric arc is capable of permanently injuring or killing a human being at distances of up to 20 feet (6.1 m). The distance from an arc flash source within which an unprotected person has a 50% chance of receiving a second degree burn is referred to as the "flash protection boundary". The incident energy of 1.2 cal/cm^2 on a bare skin was selected in solving the equation for the arc flash boundary in IEEE 1584. The IEEE 1584 arc flash boundary equations can also be used to calculate the arc flash boundaries with boundary energy other than 1.2 cal/cm^2 such as onset to 2nd degree burn energy. Those conducting flash hazard analyses must consider this boundary, and then must determine what PPE should be worn within the flash protection boundary. Remote operators or robots can be used to perform activities that have a high risk for arc flash incidents, such as inserting draw-out circuit breakers on a live electrical bus. Remote racking systems are available which keep the operator outside the arc flash hazard zone. Selection of appropriate PPE, given a certain task to be performed, is normally handled in one of two possible ways. The first method is to consult a hazard category classification table, like that found in NFPA 70E. Table 130.7(C)(15)(a) lists a number of typical electrical tasks by various voltage levels and recommends the category of PPE that should be worn. For example when working on 600 V switchgear and performing a removal of bolted covers to expose bare, energized parts, the table recommends a Category 3 Protective Clothing System. This Category 3 system corresponds to an ensemble of PPE that together offers protection up to 25 cal/cm² (105 J/cm² or 1.05 MJ/m²).

Classification as High Voltage

In marine practice, voltages below 1,000Vac (1kV) are considered low voltage, and high voltage is any voltage above 1kV. Typical marine high voltage system voltages are 3.3kV, 6.6kV and 11.1kV. *(although it should be notes that some vessels or “offshore” installations may list these HV voltages as medium voltage MV)*

High voltage equipment
A typical high voltage installation will incorporate only high voltage rated equipment on the following:

- HV generating sets
- High voltage switchboards with associated switchgear, protection devices and instrumentation
- High voltage cables
- High voltage/low voltage step-down transformers to service low voltage loads
- High voltage/high voltage (typically 11kV or 6.6kV to 2kV) step-down transformers supplying propulsion converters and motors
- High voltage motors for propulsion, thrusters, HVAC air conditioning and compressors step-down transformer, high voltage system safety requirements

Certifications
Lloyds Register (LR)
Registro Italiano Navale (RINA)
Det Norske Veritas (DNV) DNV GL (Germanischer Lloyd- formally)
Bureau Veritas (BV)

HV Legislative requirements

The **International Association of Classification Societies** (**IACS**) is a technically based organization consisting of thirteen marine classification societies headquartered in London.

Marine classification is a system for promoting the safety of life, property and the environment primarily through the establishment and verification of compliance with technical and engineering standards for the design, construction and life-cycle maintenance of ships, offshore units and other marine-related facilities. These standards are contained in rules established by each Society. IACS provides a forum within which the member societies can discuss, research and adopt technical criteria that enhance maritime safety.

Note: the following Legislation pages are extracted verbatim **–** *www reference*

http://www.iacs.org.uk/document/public/Publications/Unified_requirements/PDF/UR_E_pdf150.PDF

INTERNATIONAL ASSOCIATION OF CLASSIFICATION SOCIETIES
Concerning ELECTRICAL INSTALLATIONS

E11 1991 (Rev. 1May2001) (Rev.2July2003)

E11 1-7 **IACS Req. 1991/Rev. 2, 2003**

Unified requirements for systems with voltages above 1 kV up to 15 kV

1. General
1.1 Field of application
The following requirements apply to AC three-phase systems with nominal voltage exceeding 1kV, the nominal voltage is the voltage between phases. If not otherwise stated herein, construction and installation applicable to low voltage equipment generally apply to high voltage equipment.
1.2 Nominal system voltage
The nominal system voltage is not to exceed 15 kV.
1.3 High-voltage, low-voltage segregation Equipment with voltage above about 1 kV is not to be installed in the same enclosure as low voltage equipment, unless segregation or other suitable measures are taken to ensure that access to low voltage equipment is obtained without danger.

2 System Design
2.1 Distribution
2.1.1 Network configuration for continuity of ship services It is to be possible to split the main switchboard into at least two independent sections, by means of at least one circuit breaker or other suitable disconnecting devices, each supplied by at least one generator. If two separate switchboards are provided and interconnected with cables, a circuit breaker is to be provided at each end of the cable. Services which are duplicated are to be divided between the sections.

2.1.2 Earthed neutral systems
In case of earth fault, the current is not to be greater than full load current of the largest generator on the switchboard or relevant switchboard section and not less than three times the minimum current required to operate any device against earth fault. It is to be assured that at least one source neutral to ground connection is available whenever the system is in the energised mode.
Electrical equipment in directly earthed neutral or other neutral earthed systems is to withstand the current due to a single phase fault against earth for
the time necessary to trip the protection device.
2.1.3 Neutral disconnection
Means of disconnection are to be fitted in the neutral earthing connection of each generator so that the generator may be disconnected for maintenance and for insulation resistance measurement. *The NER earthing switch is opened from the generator star point.*
2.1. 4 Hull connection of earthing impedance
All earthing impedances are to be connected to the hull. The connection to the hull is to be so arranged that any circulating currents in the earth connections do not interfere with radio, radar, communication and control equipment circuits.
2.1. 5 Divided systems
In the systems with neutral earthed, connection of the neutral to the hull is to be provided for each section.
2.2 Degrees of protection
2.2.1 General
Each part of the electrical installation is to be provided with a degree of protection appropriate to the location, as a minimum the requirements of IEC Publication 60092-201.
2.2.2 Rotating machines
The degree of protection of enclosures of rotating electrical machines is to be at least IP 23.
The degree of protection of terminals is to be at least IP44.
For motors installed in spaces accessible to unqualified personnel, a degree of protection against approaching or contact with live or moving parts of at least IP4X is required.
2.2.3 Transformers
The degree of protection of enclosures of transformers is to be at least IP23
For transformers installed in spaces accessible to unqualified personnel a degree of protection of at least IP4X is required.
For transformers not contained in enclosures, *see* para 7.1.
2.2.4 Switchgear, control gear assemblies and converters
The degree of protection of metal enclosed switchgear, control gear assemblies and static convertors is to be at least IP32. For switchgear, control gear assemblies and static converters installed in spaces accessible to unqualified personnel, a degree of protection of at least IP4X is required.
2.3 Insulation
2.3.1 Air clearance
In general, for Non Type Tested equipment phase-to-phase air clearances and phase to-earth air clearances between non-insulated parts are to be not less than those specified

Nominal Voltage kV Minimum Air Clearance mm
3 - 3.3kV 55 mm
6 - 6.6 kV 90 mm
10 - 11 kV 120 mm

2.3.2 Creepage distances
Creepage distances between live parts and between live parts and earthed metal parts for standard components are to be in accordance with relevant IEC Publications for the nominal voltage of the system, the nature of the insulation material and the transient overvoltage developed by switch and fault conditions.
For non-standardised parts within the busbar section of a switchgear assembly, the minimum creepage distance is to be at least 25 mm/kV and behind current limiting devices, 16mm/kV.

2.4 Protection
2.4.1 Faults on the generator side of circuit breaker
Protective devices are to be provided against phase-to-phase faults in the cables connecting the generators to the main switchboard and against inter winding faults within the generators.
The protective devices are to trip the generator circuit breaker and to automatically de-excite the generator.
In distribution systems with a neutral earthed, phase to earth faults are also to be treated as above.

2.4.2 Faults to earth
Any earth fault in the system is to be indicated by means of a visual and audible alarm.
In low impedance or direct earthed systems provision is to be made to automatic disconnect the faulty circuits. In high impedance earthed systems, where outgoing feeders will not be isolated in case of an earth fault, the insulation of the equipment is to be designed for the phase to phase voltage.
Note: Earthing factor is defined as the ratio between the phase to earth voltage of the health phase and the phase to phase voltage. This factor may vary between (1/sqrt 3) and 1.
A system is defined effectively earthed (low impedance) when this factor is lower than 0.8. A system is defined non-effectively earthed (high impedance) when this factor is higher than 0.8.

Qualified persons

A qualified person (ETO or Engineering officer) is appropriately trained and has sufficient technical knowledge or HV vessel experience to enable him to avoid danger. It is the duty of the authorised person (Chief Engineer or Chief ETO) issuing a permit to work to satisfy himself that the persons are competent to carry out the work involved.

All the installation, putting into service, running and maintenance operations must be carried out by suitably qualified personnel with in-depth knowledge of the apparatus.

Make sure that the personnel working on the apparatus have this manual to hand and all the information required for correct intervention.

Carefully reads the instruction manual all the way through. Has in-depth knowledge of the HV installation on board, service of the apparatus and knows about the risks connected with any interventions.

Is qualified and authorised to energise, de-energise, earth and identify the circuits according to the safety procedures.

Is qualified and authorised to put this apparatus into service, and to carry out maintenance and repair operations on it.

Is trained in correct use of **PPE** protective equipment, such as rubber gloves, hard hats, protective goggles, face shields, flameproof clothing, etc. according to the safety procedures of the IMO and company best safe practices.

A qualified person is trained in first-aid procedures.

Persons involved in carrying out work should have the self - discipline to recognise their own limitations and to seek assistance with work that may be outside their area of competence.

Selecting suitable apparatus for isolation and testing of high-voltage equipment

The principal items of a high voltage electrical system would be:

The main generating sets.

The main and auxiliary HV switchboards with associated switchgear, protective devices and instrumentation.

High voltage cables.

HV to LV transformers.

HV to HV transformers typically step down or isolating transformers supplying propulsion converters and motors.

HV motors for propulsion, thrusters, ballast-pumps, cargo-pumps and compressors.

Correct identification of the HV equipment, it is vital that no work is commenced before the absolute correct identification of all HV circuits, fuses, circuit breakers and equipment has been satisfied by all persons involved in the work to be done.

This will be by way of written permits and a meeting "Chief Engineer/Chief Electrician (ETO)" to ensure that all persons are communicating on the nature of the work to be done – all risks identified- all procedures are understood.

HV circuits and equipment require labelling, but it should never be assumed that labelling is correct and that work can be started without having first proved that the equipment or circuit is in fact the actual equipment that is intended to be worked on – there MUST be no doubt.

Secure isolation and Proving HV equipment is de-energised

Take special care on a moving vessel as the ship may be suddenly start rolling.

If, for some reason the HV equipment must be worked on – after all procedures of meetings and permits to work have been completed including the wearing of full PPE. Then the following "best practices" procedure must be followed before working on any HV equipment to ensure it is not energised.

The company procedures Must also be fully adhered to – with clear understanding through-out all communications, both written and spoken (repeating back is a recognised form of ensuring the correct message is communicated) .

When proving the installation is not energised, the **"Prove Test Prove**" method is recognised as being a "best practice" procedure to follow.

The testing of HV equipment for being energised (alive), **Must** only be carried out using approved test instruments and apparatus – and always must include the correct wearing of PPE clothing.

HV test probe

Inspect all test instruments before use – check the condition for damage or wear, inspection dates, be familiar with the correct use of the instruments.

Prove: Before any HV testing is carried out, FIRST - Test the instrument for proper functioning, the HV test probe is inserted into its test pod to verify it is operating correctly.

Test: Then verify with the HV test probe instrument that the installation is not energised.

Prove: Recheck the test instrument is still operating correctly.

<u>ONLY</u> then, you are absolutely **certain** your installation is de-energised.

To summarise this testing procedure - you prove the test instrument before doing a test because if you do not, you will not know if the tester is giving a true reading --- you need to avoid a false negative reading so as to avoid getting shocked or burnt. If you do not prove the test instrument before using it, and it shows that the circuit is "live", the circuit is "live" but if is shows that the circuit is "dead", the circuit might be "live".

You prove the test instrument after doing a test because if you do not, you will not know if the test instrument failed during the testing of the circuit. Like any electrical equipment, a test instrument can be in perfect working order, one moment, and be useless within a micro-second.
The "prove-test-prove" rule has dramatically reduced the number of cases of workers touching "live" parts. **<u>Never take any short-cuts when testing</u>.**

The trapped key system for circuit breaker isolation, cubical doors, earthing down switches and LOTO further ensures safe access to the HV equipment to be worked on, barriers and danger tape or other suitable materials should be used.

Carrying out “earthing down” short circuiting all three lines to earth (the ships hull), earthing makes the installation free of residual charges and short-circuits the system in case of a fault current or the circuit being re-energised. Use only equipment designed for this purpose.

Note this usually involves a trapped key sequence to be followed (e.g. the Castel captive key system) this system determines a set sequence procedure that can’t be by-passed.

To ensure adequate isolation, having isolated the circuit or equipment, disconnecting device should have an isolating check at the point of work that the parts to be gap sufficient for the voltage levels present or worked on or near really are de-energised, it is not necessary to touch live voltage parts to suffer a shock or burns.

Where air is being used as the insulating medium between bare copper busbars and terminals, the creepage and clearance distances between live parts and earth are greater on HV systems.

If a fuse is removed, make sure that it or a similar one cannot be reinserted by taking it away or by locking the box or enclosure until work is completed.

A permit-to-work should be issued by only a designated competent person who is deemed to be so by means of technical knowledge and/or experience and who is familiar with the system and equipment. The person should be authorised, in writing, by the employer to issue permits relating to specified equipment or systems. Before issuing the permit, this person should work out, in detail and in writing, what the various steps are to disconnect, isolate, prove dead, lock OFF and earth the equipment, post warning notices and identify the equipment to be worked on and adjacent equipment which will still be live.

Similar procedures may also be necessary if high-voltage apparatus is to be tested. In every case, the objective is to prevent anyone coming near to live, high-voltage conductors and the procedure should reflect this. An electrical permit-to-work is primarily a statement that a circuit or item of equipment is safe to work on. A permit should never be issued on equipment that is still live.
The information given in the permit should be precise, detailed and accurate. It should state which equipment has been made safe, the steps by which this safety has been achieved and exactly what work is to be done.
Accompaniment, especially if an accompanying person can substantially contribute towards the implementation of safe working practice. If the risk is one of electric shock, evidence shows that prompt first aid is a significant factor in survival.

The accompanying person should be trained to recognise danger, how to switch off and, if necessary, to give assistance in the event of an emergency. Help can also be given in restricting access to non-authorised personnel. In addition, a less experienced.

This is often necessary for working live, worker may need to be supervised to enable
the work to be carried out safely.

Limitation of access (LOA)

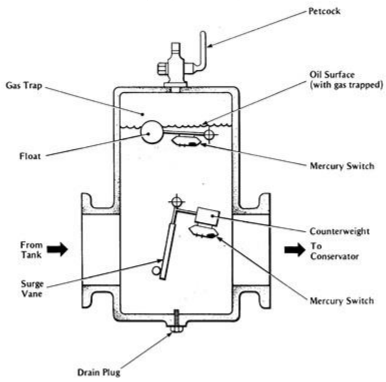
Identify the right work location and mark it clearly. The work location should have appropriate access and lighting.

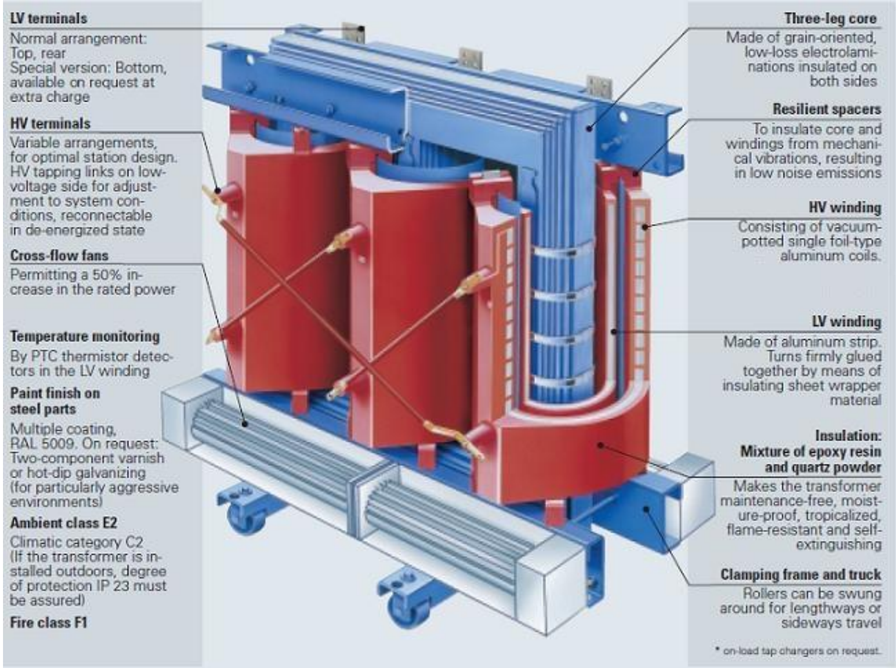
Non-authorised persons shall be restricted from entering the work location.

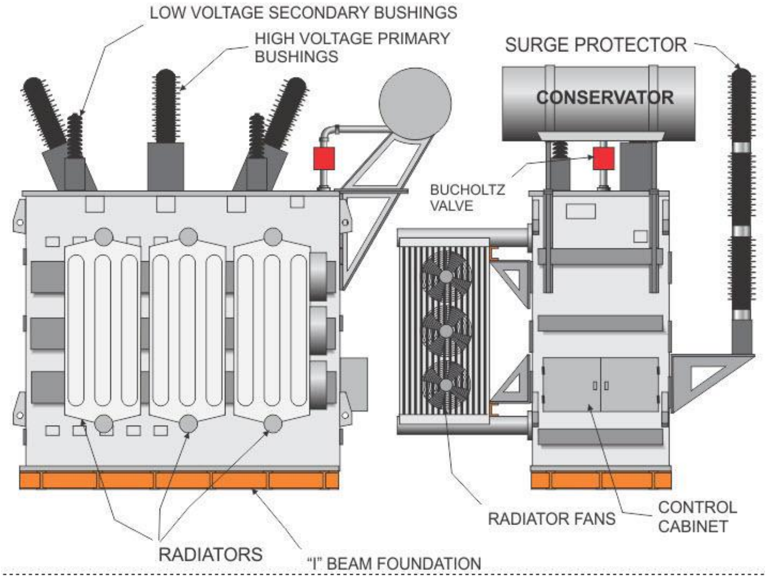
A form issued by an authorised person to a competent person, the limits of the work to be carried out in the vicinity of, but not on, high voltage electrical apparatus.

HV Power transformers

Buchholz relay (valve) oil filled transformers







HV Power transformers – dry-type resin insulated are common in marine installations, with some vessels using oil filled types, they are provided with overload and short circuit protection. When transformers are connected in parallel, tripping of the protective devices at the primary side has to automatically trip the switch connected at the secondary side.

C. High Voltage Cables
Construction of high voltage cables
a) Types of cables and insulated conductors shall comply with the requirements for cable construction in (b).
b) The construction and testing of cables for permanent installations shall normally comply with the recommendations of IEC 60092-354, "Electrical installations in ships.

Part 354: Single- and three-core power cables with extruded solid insulation", with the following additional requirements:
as insulating materials only cross linked polyethylene (XLPE) or ethylene propylene rubber (EPR) shall be used as listed in IEC 60092-351 — conductor screening is required for all cables with XLPE insulation, and for EPR-insulated cables with rated voltage U0/U above 3,6/6 kV. Conductor screening shall be non-metallic and consist of either semiconducting tape or a layer of extruded semi-conducting compound, or a combination of the two insulation screening is required for all cable and shall consist of a non-metallic semi-conducting part in contact with a metallic part (see further IEC 60092-354) as sheath materials one of the types specified in IEC 60092-359 shall be used wire braid and armour shall comply with the requirements in D300.

High Voltage Safety.

4.1 introduction
As the demand for electrical power increases on vessels the supply current ratings becomes too high at the usual 3phase 440 V.
To reduce the size of both steady state and fault current levels it is necessary to specify a higher power system voltage at the higher power ratings.
In marine practice voltages below 1000 V are considered LV (low voltage).
HV (high voltage) is any voltage above 1 KV.

Typical marine HV system voltages are 3.3 KV and 6.6 KV. 11 KV Systems are emerging with the still increasing power demands. By generating electrical power at 6.6 KV instead of 440 V the distribution and switching of power levels above about 6 MW becomes more practicable and manageable.

By generating electrical power at **440V** from 3 x1 megawatt, 0.8 power factor diesel generator sets, each generator main cable and circuit breaker has to handle a full load current of:
1640 Amps

If a short circuit fault occurs on one of the outgoing feeder cables from the main switchboard the feeder circuit breaker would need to be rated to break a prospective fault current of about 65 KA.
For the same system at **6.6 KV** the full-load current of each generator is: **109 Amps**

Also, the fault level at the main board would be as low as 4.5 KA.
In addition to the above, the power loss in an HV installation may be calculated by:
P = I squared x R

Power loss is reduced if the voltage is stepped up and thus it is always efficient to transmit power at a higher voltage.

4.2 Training
The 2010 Manila Amendments to the International Convention on Standards of Training, Certification and Watch-keeping for Seafarers (STCW) introduced revised competence standards for the engine department, including a new additional requirement for engine personnel to have undergone training and education in HV systems.

The Manila Amendments entered into force on 1 January 2012. Seafarers who started their training before 1 July 2013 may continue to meet the previous training requirements until January 2017. However, from 1 January 2017, engineering personnel will have to demonstrate that they meet the new HV requirements.

4.3 Definitions

4.3.1 Additional earth
An earth connection applied to apparatus after application of a CME, normally applied at the point of work if not already fitted with CME.
4.3.2 Approved
A type of form sanctioned for use by the DPA/superintendent/senior electrical engineer.

4.3.3 Authorised person (AP)
An authorised person is appropriately trained and appointed in writing by the superintendent/electrical engineer to carry out work as permitted by these rules.
4.3.4 Caution notice
A notice conveying a warning against interference with the apparatus to which it is attached.
4.3.5 Chief engineer
Senior engineer on board the vessel responsible for all vessel technical operations and maintenance.
4.3.6 Circuit main earth (CME)
An earth connection applied for the purpose of making apparatus safe to work on before a permit to work or sanction for test is issued and which is nominated on the document.
4.3.7 Competent person
A competent person is appropriately trained and has sufficient technical knowledge or experience to enable him to avoid danger. It is the duty of the authorised person issuing a permit to work to satisfy himself that the persons are competent to carry out the work involved.
4.3.8 Danger notice
A notice calling attention to the danger of approach or interference with the apparatus to which it is attached.
4.3.9 Dead
At or about zero voltage and disconnected from all sources of electrical energy.
4.3.10 Earthed
Connected to the general mass of earth in such a manner as will ensure at all times an immediate discharge of electrical energy without danger.
4.3.11 High voltage (HV)
All voltage exceeding 1000 V ac.
4.3.12 High voltage apparatus
Any apparatus, equipment or conductors normally operated at a voltage higher than 1000 V ac.
4.3.13 Isolated
The disconnection and separation of the electrical equipment from every source of electrical energy in such a way that this separation and disconnection is secure.
4.3.14 Key safe
A device for the safe retention of keys used to lock means of isolation, earthing or other safety devices.
4.3.15 **Limitation of access (LOA)**
A form issued by an authorised person to a competent person, defining the limits of the work to be carried out in the vicinity of, but not on, high voltage electrical apparatus.

4.3.16 Live
Electrically charged from a supply of electricity.
4.3.17 Permit to work (PTW)
A form of declaration signed and given by an authorised person to a competent person in charge of the work to be carried out on or in close proximity to high voltage apparatus, making known to him the extend (in time and space) of the work, exactly what apparatus is dead, is isolated from all live conductors, has been discharged and earthed and, insofar as electric hazards are concerned, on which it is safe to work.

4.3.18 Safety lock
A lock used to secure points of isolation, safety devices and earth circuits, being unique from other locks used on the system.

4.3.19 Sanction for test (SFT)
A form of declaration, signed and given by an authorised person to another authorised person in charge of testing high voltage apparatus making known to the recipient what apparatus is to be tested and the conditions under which the testing is to be carried out.
4.3.20 Designated person ashore (DPA)
A senior electrical/mechanical engineer suitably qualified and appointed in writing by the company to be responsible for compilation and administration of procedures for high voltage installations and operations.

4.4 What is classed high voltage on board a vessel in marine practice, voltages below 1000V ac are considered LV (low voltage).
HV (high voltage) is any voltage above 1000V. Typical marine HV systems are 3.3KV, 6.6KV and 11KV.

4.5 HV Equipment
The principal items of a high voltage electrical system would be:
The main generating sets.
The main and auxiliary HV switchboards with associated switchgear, protective devices and instrumentation.
High voltage cables.
HV to LV transformers.
HV to HV transformers typically step down or isolating transformers supplying propulsion converters and motors.
HV motors for propulsion, thrusters, ballast-pumps, cargo-pumps and compressors.

4.5.1 HV Insulation Requirements
The winding arrangements for marine HV generators and motors are similar to those at LV except for the need for much better insulating materials such as Micalastic or similar.
The windings of HV transformers are usually insulated with an epoxy resin and quartz powder compound. This is a non-hazardous material which is maintenance free, humidity resistant and tropicalised. Insulation for the HV conductors requires a more complicated design than is necessary for LV cables. HV cables provide a significant saving in weight and space,
leading to easier installation and a more compact result. Where air is being used as the insulating medium between bare copper busbars and terminals, the creepage and clearance distances between live parts and earth are greater on HV systems.
4.6 Major features of a HV system compared to a LV system
HV systems have more extensive and complex networks and connections.
Access to HV areas is strictly limited and securely controlled.
Isolation procedures are more involved and switching strategies have to be formulated and recorded.
Isolated equipment must be earthed down.
Appropriate test probes and instruments should be used.
Diagnostic insulation resistance testing is necessary.
HV systems may sometimes be earthed neutral and use current limiting resistors.
Special HV circuit breakers should be installed.
Current magnitude and time is used for discrimination in protection/monitoring devices.
4.7 Dangers when working on HV equipment

4.7.1 Electric shock
Making personal contact with any electric voltage is potentially dangerous.
At high voltage levels the electric shock potential is lethal. Body resistance decreases with increased voltage level which enhances the current flow. Remember that an electric current shock of as low as 15mA can be fatal. The risk to people working in HV areas can be greatly minimized by the diligent application of sensible general and company regulations and procedures.

Factors likely to increase the risk of receiving an electric shock include the following.
HV work on board due to limited space may be carried out in close proximity to a person(s) not familiar with HV hazards. Therefore the area must be properly cordoned off from surrounding work that may be going on and danger notices well posted.

There will be large areas of earthed metal that can be easily touched, increasing the possibility of electrical shock from an HV conductor.
High voltage isolation testing can be particularly hazardous when several parts of the equipment are energised for a period of time.
Some equipment could be using water in its operation which can lead to an increased risk of injury. In general, water conducts electricity and reduces the resistance of the skin.
The use of instruments when taking measurements of high voltages can increase the risk of injury if they are inadvertently used without the earth (protective) conductor connected. This can result in the enclosure of the instrument becoming live at high voltages.
High voltage equipment will store energy after disconnection. For example, on a 6.6KV switchboard a fatal charge may still be present on the equipment hours or even days later.
If during maintenance an HV circuit main earth (CME) is removed from the system, it must not be worked on, as the HV cabling can recharge itself to a high voltage from induced voltages from nearby live HV cabling.

4.7.2 Arc
An arc is a discharge of electrical current across a gap.
An arc fault is a high power discharge of electricity between two or more conductors.
The radiation of heat in an arc is very high and it can very easily set a persons clothes on fire.
4.7.3 Arc Blast
Arc blast pressure derives from two things. First, the expansion of metal in a boiling, vaporising state, and second the heating of ambient air by passage of the arc.
The mixture of vaporised water and metal in air near the arc generates a rapidly expanding plasma of ionized vapour, which can lead to extensive injuries.

4.8 Electrical Permit Work System
The access procedure to HV switchboards and equipment must be strictly controlled by using a Electrical-Permit-Work-System (PTW), isolation procedure involving a safety key system, and Earthing down.
The format of a permit will vary for different companies and organisations.
Before work is commenced on HV equipment a PTW must be issued. This permit is usually the last stage of a planned maintenance task organised and approved by the authorising officer to be carried out by the responsible person.

4.9 Additional procedures to be implemented for HV systems
For HV systems, additional procedures and precautions should be taken.

These are as follows:
4.9.1 Sanction-to-test system
Usually testing on an HV system can only be carried out after the circuit main earth (CME) has been removed. An example of this can be insulation testing as it involves the system being checked for insulation to earth.
A sanction-to-test should be issued in a similar manner to a permit-to-work.

A sanction-to-test should never be issued on an apparatus on which a permit-to-work is still in force, or on which another sanction-to-test is in force.
Note: Maintenance and repair cannot be carried out under a sanction-to-test.

4.9.2 Limitation of access form
When carrying out HV maintenance, it may be dangerous to allow unrestricted work be carried out nearby. Workers carrying out maintenance nearby may not have HV training and may not be familiar with the risks involved when working on or near HV equipment. Due to these risks the Limitation of access form should be used. This form states the type of work that is allowed to be carried out nearby the HV work, the limitations imposed (space and time) and the safety precautions taken.
The form is to be issued and signed by the authorised person (AP) and a confirmation of receipt signature by the person carrying out the work. The form should include a sign off and a cancellation section.

4.9.3 Earthing Down
Earthing down is required to ensure that any stored electrical energy in the inherent capacitance of the equipment insulation after isolation is safely discharged to earth. The higher values of insulation resistance required on HV cabling leads to a high value of insulation capacitance (C) this coupled with the high voltage means the energy stored (W) in HV equipment is far greater than that in LV systems.

Energy stored (W) Joules = (Capacitance x Voltage²) / 2

Earthing Down also ensures that isolated equipment remains at a safe potential during work procedures.

Earthing Down at a HV switchboard is of two types.

1-Circuit Earthing:
An incoming ore outgoing feeder cable is connected by a heavy earth connection from earth to all three conductors after the circuit breaker has been racked out, this is done at the circuit breaker using a special key. The key is then locked in the key safe. The circuit breaker cannot be racked in until the circuit's earth connection has been removed.

2-Busbar Earthing:
When it is necessary to work on a section of busbars they must be completely isolated from all possible electrical sources. This will include generator incomers, section or bus-tie breakers and transformers on that bus-bar section.
The busbars are connected together and earthed down using portable leads (spider) which give visible confirmation of the earthing arrangement.

Earthing down
Earthing down is a very important concept to understand when working with high voltage systems. It is important to ensure that any stored electrical energy in equipment insulation after isolation is safely discharged to earth.
The higher levels of insulation resistance required on high voltage cabling leads to higher values of insulation capacitance (C) and greater stored energy (W).

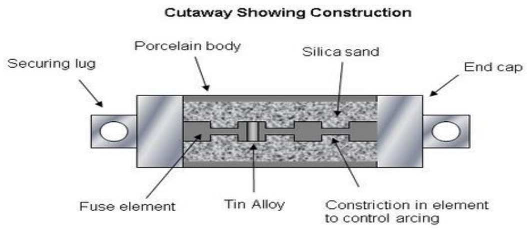
This is demonstrated by the electrical formula:
Energy stored (W) Joules = (Capacitance x Voltage²) / 2
Earthing down ensures that isolated equipment remains safe.
Even if the system is isolated, you can still receive a fatal shock caused by the stored energy.
The system must be earthed and proven dead before work commences.

Protection from current overload and short circuits

HV Fuses - High Rupturing Capacity **(HRC)**

The HRC fuse is a fully enclosed cartridge type fuse that has a high rupturing capacity. It is able to withstand and interrupt high current, short circuit faults safely.

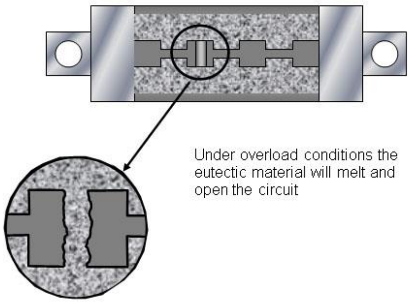
A cutaway of the construction of the HRC is shown below.



The fusing element is enclosed in a porcelain body surrounded by silica sand. The end caps have securing lugs. The element has constrictions and a tin alloy section.

HRC fuse operation

Under normal operating conditions the current flowing through the fuse element does not provide enough energy to melt the element. The heat produced is absorbed by the surrounding silica sand. If a large current flows the energy produced melts and vaporises the element.



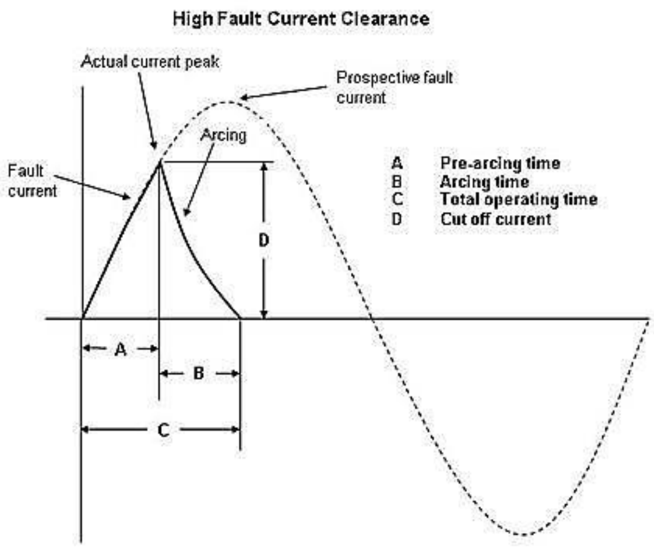
The time taken to reach this point is known as the pre arcing time. The high prospective fault current is 'cut off' although an arc will still be formed. The heat produced by the arc causes the fuse element to fuse with the silica sand and for the silica sand to absorb the energy.

This has the effect of extinguishing the arc and stopping further current flow. The time taken to reach this point is known as the total clearance time.

Overload Condition

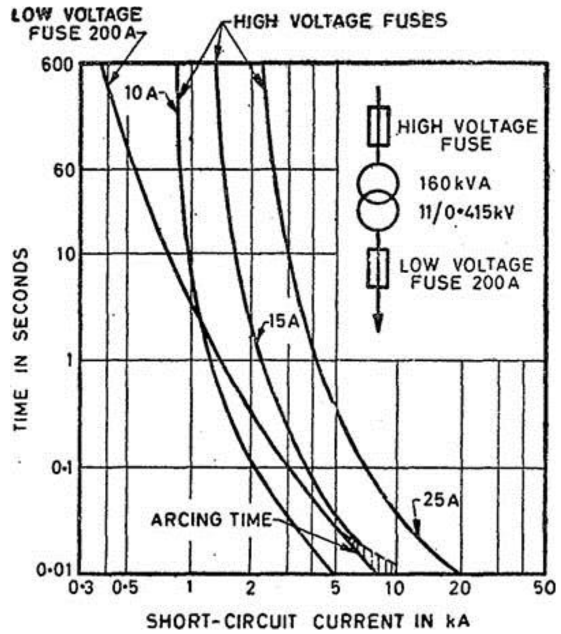
HRC fuse elements incorporate a tin alloy section. This is known as a eutectic material. It is used to give the fuse specific operating characteristics. Under overload conditions the material heats up and if the overload is prolonged, it will melt and break the fuse element.
Short Circuit Condition

Under high current short circuit conditions the smaller area constricted parts of the element will melt rapidly and vaporise. These will break before the eutectic material.
The quartz silica sand surrounding the element is also heated and changes into a glass material called fugurite. This quenches the arc and prevents any re-striking across the element gaps.



With reference to graph – the pre-arcing time (shown by A) is the time given by fuse characteristic charts. The figures given by the graphs are reliable for all conditions. This is the time taken for the fault current to melt and break the element. However it is at this time that an arc will form and the current will continue to flow. The quenching qualities of the silica sand will extinguish the arc and stop the current flow.

The time taken for this is less predictable (shown by B) as there are many factors to vary its duration.
The total operating time (or clearance time) is the combination of the two and is shown by C. The cut off current is shown by D and indicates the maximum fault current flowing in the circuit. Quick clearance of the fault ensures that the cut off current does not reach prospective fault current level.



Advantages of the HRC Fuse

The HRC fuse has many advantages. These include:

- The ability to safely interrupt short circuit currents of much higher values (higher rupturing capacity). They are specifically designed to operate under these short circuit conditions.
- The elimination of arcing because the fuse element is sealed
- It is obtainable in a range of fusing factors
- The current rating is clearly marked
- It has a reliable operation
- It can be used to provide good discrimination because it provides close protection and operates at a 'known' value.
- It has constant fusing characteristics
- It operates 'fast'
- Doesn't deteriorate over time

Replacing a HRC Fuse

When replacing a HRC fuse the replacement fuse must have the same characteristics as the original. More specifically it must have the same:

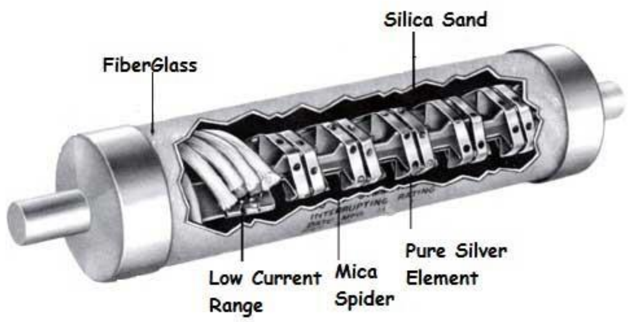
- Current rating
- Voltage Rating
- Category of Duty (Rupturing capacity)
- Utilisation category (fusing factor)

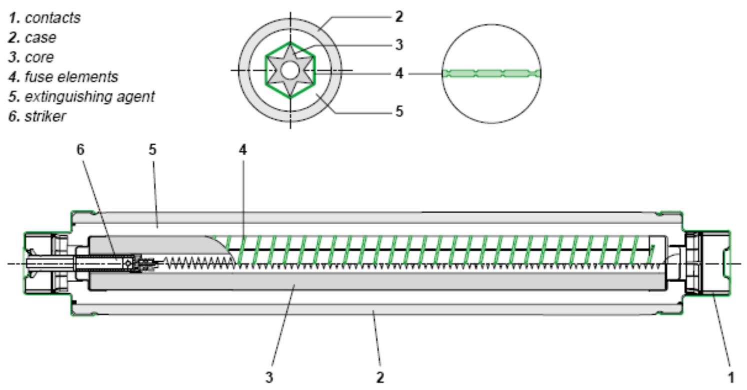
If the current rating of the replaced fuse is too low the circuit could blow (break) for no apparent reason well below the circuit full load. For example if a 5A fuse is put in a circuit designed for a 10A load the 5A is going to blow even under normal load conditions.
If the current rating is too large for the circuit and a fault occurs, the circuit current could increase to a high level causing damage, before the fuse operates. For instance if a 20A fuse was used to replace a blown 5A fuse and a fault in the circuit caused 15A to flow (which would 'blow' the normal 5A fuse) it would not operate the incorrect 20A fuse.

Cartridge type HV HRC Fuse

This is a kind of high voltage fuse have high rupturing capacity and its body is like a cartridge. Outer portion of the fuse is made up of some ceramic materials so as to increase its mechanical strength. Fuse element which is the most important part lies inside the cartridge body. Metals caps are provided on the two outer sides of the fuse element. High voltage fuse is similar in construction with that of a low voltage (LV) fuse. In high voltage fuses, fuse elements are made with special designs. At higher voltage corona is a major problem. To overcome this sometimes fuse elements are wound in the shape of a helix which resembles the DNA shape we have all studied in biology. Fuse wires are made up of cooper, silver or tin in HV fuses. More than one fuse elements are also employed in some of the high voltage fuses**.** Two fuse elements are connected in parallel and they are of different nature.

One of them has low resistance like silver wire and the other is of high resistance (like tungsten wire). Low resistance wire carries normal current under normal operating condition. But when fault occurs, low resistance wire blows off at first and high resistance path reduces the short circuit current. Finally the circuit breaks. High voltage fuses are rated with 200A at 6.6kV and 11kV, 50A at 33kV. These fuses have rupturing capacity as high as 8760 Amperes and they are rated up to 33kV.





The fuse is a self - sacrificial device used to interrupt a circuit under short circuit, excessive overload or over current conditions by melting the fuse element.

Fuse element

The part of the fuse that melts when an excessive current flows in the circuit is known as the fuse element.

Current rating-

The RMS value of current that the fuse wire can carry without being deteriorated, within specified temperature limits is known as the current rating. Current rating is specified by the manufacturer.

Fusing current-

Fusing current is defined as the minimum value of current at which the fusing element melts.

Fusing factor-

Fusing factor is the ratio of minimum fusing current and the current rating of the fuse element.

Fusing factor = Minimum fusing current / Current rating of the fuse element

Voltage rating-

The voltage rating of fuse must be greater than or equal to the open circuit voltage.

Breaking capacity-

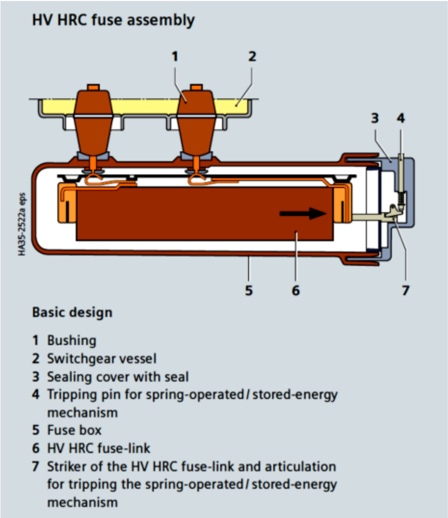
Breaking capacity of a fuse is the rating corresponding to the RMS value of ac component of maximum prospective current.

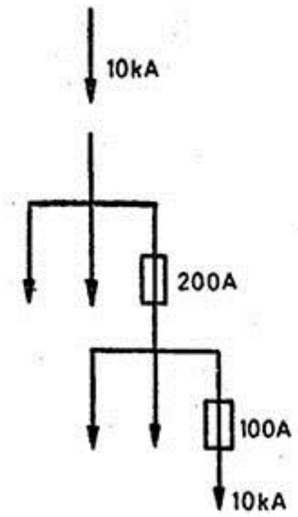
Prospective current

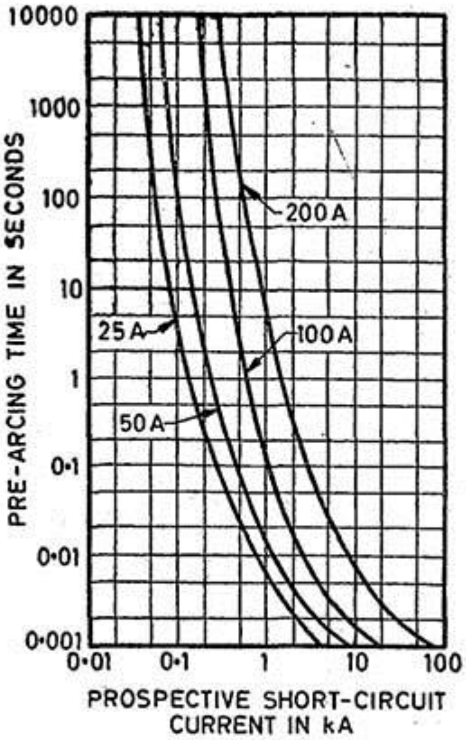
The current that would flow in the circuit under fault condition when the fuse is replaced by a link of negligible impedance is called prospective current. The prospective short circuit current (PSCC) or available fault current or short circuit making current is the highest electric current which can exist in a particular electrical system under short-circuit conditions.

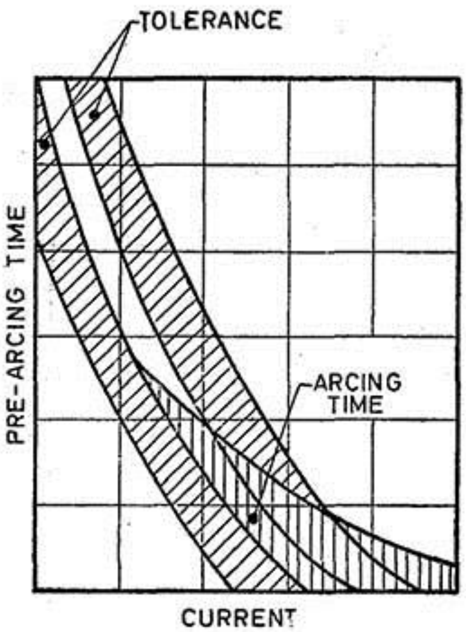
It is determined by the voltage and impedance of the supply system. Can be as high as hundreds of thousands of amps.

Protective devices such as circuit breakers and fuses must be selected with an interrupting rating that exceeds the prospective short circuit current, if they are to safely protect the circuit from a fault. When a large electric current is interrupted an arc forms, and if the breaking capacity of a fuse or circuit breaker is exceeded, it will not extinguish the arc. Current will continue, resulting in damage to equipment, fire or explosion.









9A **Radial Feeders Protected by Fuses**

9B **Typical Characteristic Curves of Cartridge Fuses of Different Ratings**

9C **Discriminate Operation Offered by Two Fuses in Series**

Co-ordination between two fuses in series—It is a good practice to provide fuses at the point where the cross-section of the cables decreases. There may, therefore, be three and four fuses behind one another in a radial feeder without any other protective device in between (*see* Fig. 9A). Proper selectivity is, therefore, necessary so that in the event of a fault, only the fuse nearest to the fault operates and the others remain intact.

Since in a radial feeder, almost the same value of the fault current flows through all the fuses in series, it is clear that all such fuses should not have the same rating. Fig. 9B shows the typical characteristic curves of the cartridge fuses. These curves are drawn between the pre-arcing time and the prospective short-circuit current.

There is a considerable difference between the pre-arcing time of two consecutive fuses at lower prospective short-circuit currents. For close discrimination in overload range, it is generally sufficient. When the two fuses have a difference of 25 percent between their pre-arcing time. In the range of higher prospective short-circuit currents, if the pre-arcing time of the minor fuses is less than 0.02 second, two fuses connected, in series would offer discriminate operation only if the total I^2_t value of the minor fuse is less than the pre-arcing I^2_t of the major fuse [*see* Fig. 9C]. It should be further borne in mind that:

a. due to the manufacturing tolerances, the pre-arcing time of the fuse is not an exact value, but varies to some extent; and

b. as soon as the arcing takes place in the minor fuses the current in the circuit reduces very sharply due to the arc resistance and thus the major fuses are not affected to the same extent during the pre-arcing time of the minor fuse.

The manufacturers should therefore be consulted for the proper rating of the fuses which would offer discriminate operation between one another for the prospective short-circuit currents expected at the point of installation. As a rough guide, a ratio of 1.5 between the rating of the major and minor fuses may be expected to give discriminate operation for fault levels up to 40 kA.

Co-ordination between a circuit-breaker and a fuse on the incoming side—when fuses are used for the back-up protection of circuit-breakers, link-type fuses are normally used for this purpose. The circuit-breakers are usually provided with overload and short-circuit releases and their operating times are so co-ordinated by the supplier that no damage is caused to the circuit-breaker for the duration of short-circuit current according to their tripping time. For the co-ordinated selection of the fuse, the following requirements should therefore be fulfilled:

a. For normal overloads, the circuit-breaker should be tripped by its own overload relay and the fuse should not operate;
b. Short-circuit release should trip the circuit-breaker for all short-circuit currents within its breaking capacity and the fuse should not operate; and
c. For all short-circuit currents in excess of breaking capacity, the fuse should operate sufficiently early so as to prevent opening of the circuit breaker on currents in excess of its breaking capacity and damage due to the thermal and dynamic effects.

HV Circuit Breakers

Most common are two types of HV circuit breakers. One uses SF6 gas as the quenching media and the other uses a Vacuum.

The Vacuum Circuit Breaker VCBs *(in common use on HV Ships)*

In a Vacuum Circuit Breaker, the load and fault currents are broken with vacuum interrupters. When the contacts in the vacuum interrupters separate, the overloaded current initiates the discharge of a metal vapour arc which flows through the plasma.

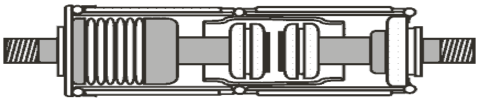
Within micro seconds, the arc is extinguished and the conductive metal vapour condenses. This results in the dielectric strength in the breaker to build up.

The vacuum circuit breaker depends largely on the materials and the forms of the contacts, the best material to use in the vacuum high voltage circuit breaker was chromium alloy copper. In this alloy, chromium is distributed through copper in the form of fine grains. This material combines good arc extinguishing characteristic with a reduced tendency to contact welding.

Operation of Vacuum Circuit Breaker

The main aim of any circuit breaker is to quench arc during current zero crossing, by establishing high dielectric strength in between the contacts so that reestablishment of arc after current zero becomes impossible. The dielectric strength of vacuum is eight times greater than that of air and four times greater than that of SF_6 gas.

This high dielectric strength makes it possible to quench a vacuum arc within very small contact gap. For short contact gap, low contact mass and no compression of medium the drive energy required in vacuum circuit breaker is minimum. When two face to face contact areas are just being separated to each other, they do not be separated instantly, contact area on the contact face is being reduced and ultimately comes to a point and then they are finally de-touched. Although this happens in a fraction of micro second but it is the fact. At this instant of de-touching of contacts in a vacuum, the current through the contacts concentrated on that last contact point on the contact surface and makes a hot spot. As it is vacuum, the metal on the contact surface is easily vaporized due to that hot spot and create a conducting media for arc path. Then the arc will be initiated and continued until the next current zero.

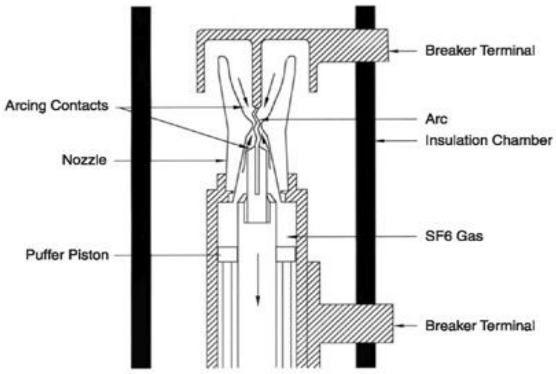


Cross section of Vacuum Interrupter

At current zero this vacuum arc is extinguished and the conducting metal vapor is re-condensed on the contact surface. At this point, the contacts are already separated hence there is no question of re-vaporization of contact surface, for next cycle of current. That means, the arc cannot be re-established again. In this way vacuum circuit breaker prevents the reestablishment of arc by producing high dielectric strength in the contact gap after current zero.

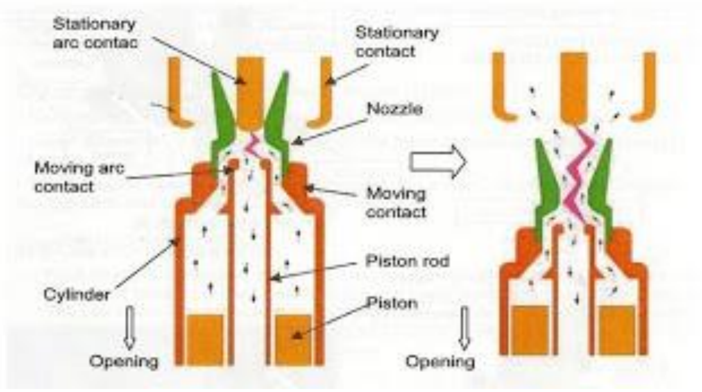
There are two types of arc shapes. For interrupting current up to 10 kA, the arc remains diffused and the form of vapour discharge and covers the entire contact surface. Above 10 kA the diffused arc is constricted considerably by its own magnetic field and it contracts. Specially designed contact shape of vacuum circuit breaker make the constricted stationary arc travel along the surface of the contacts, thereby causing minimum and uniform contact erosion.

The SF6 Gas Circuit Breaker *(along with VCB these are in use on HV Ships)*



A circuit breaker in which the current carrying contacts operate in **Sulphur Hexafluoride** or SF6 gas is known as an SF6 Circuit Breaker.

Gas Circuit Breaker (GCB)



Current interruption in a high-voltage circuit-breaker is obtained by separating two contacts in a medium, such as SF6, having excellent dielectric and arc quenching properties. After contact separation, current is carried through an arc and is interrupted when this arc is cooled by a gas blast of sufficient intensity. Gas blast applied on the arc must be able to cool it rapidly so that gas temperature between the contacts is reduced from 20,000 K to less than 2000 K in a few hundred microseconds, so that it is able to withstand the transient recovery voltage that is applied across the contacts after current interruption. SF6 is generally used in present high-voltage circuit-breakers.

Interrupting sequence

- SF6 gas in the cylinder is compressed by the downward movement
- Gas is forced into the nozzle where the arc is drawn
- In early stages pressure inside the cylinder is raised
- Nozzle concentrates the gas flow to the area of the arc

SF6 has excellent insulating property. SF6 has high electro-negativity. That means it has high affinity of absorbing free electron. Whenever a free electron collides with the SF6 gas molecule, it is absorbed by that gas molecule and forms a negative ion.

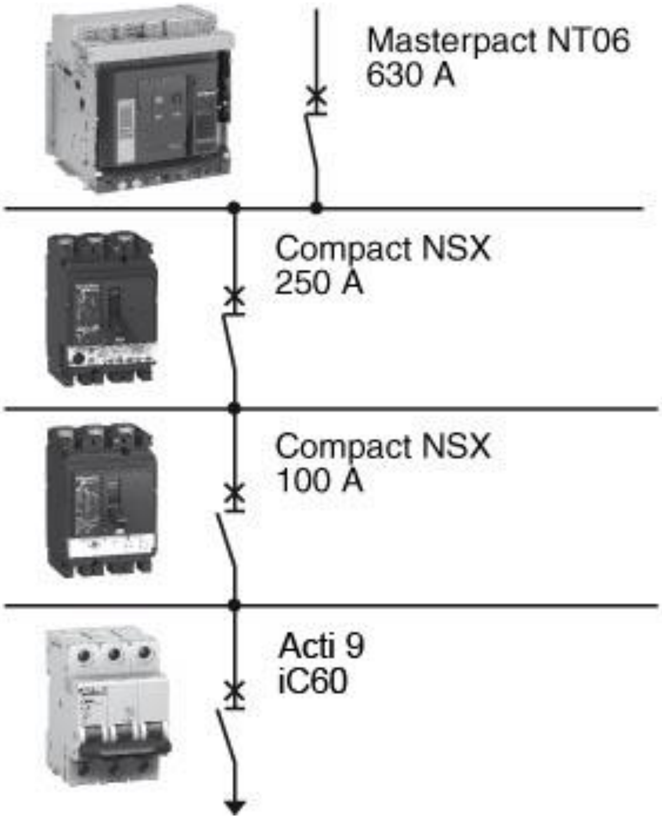
The gas has a good dielectric strength but also it has the unique property of fast recombination after the source energizing the spark is removed. The gas has also very good heat transfer property.

Typical conditions for HV circuit breaker operation

- Over current (Inst.)
- Over current (I/t)
- Under voltage
- Unbalanced load
- Reverse power
- Earth leakage)
- Over frequency
- Under frequency

Discrimination

Discrimination, also called selectivity, is considered to be achieved when, under fault conditions the circuit breaker nearest the fault operates rather than any of the circuit breakers upstream of it.



The discrimination of circuit breakers can be based on either magnitude of fault (current discrimination) or the duration of the time during which the circuit breaker “sees” the fault current (time discrimination).

Current Discrimination in a distribution system requires a circuit breaker to have a lower continuous current rating and a lower instantaneous pick-up value than the next upstream circuit breaker.
Current discrimination increases as the difference between continuous current ratings increases and as pick-up settings increase between the upstream and downstream breakers.

Time Discrimination in a distribution system requires the use, upstream, of circuit breakers with adjustable time delay settings.
The upstream breakers must be capable of withstanding the thermal and electro-dynamic effects of the full prospective fault current during the time delay.

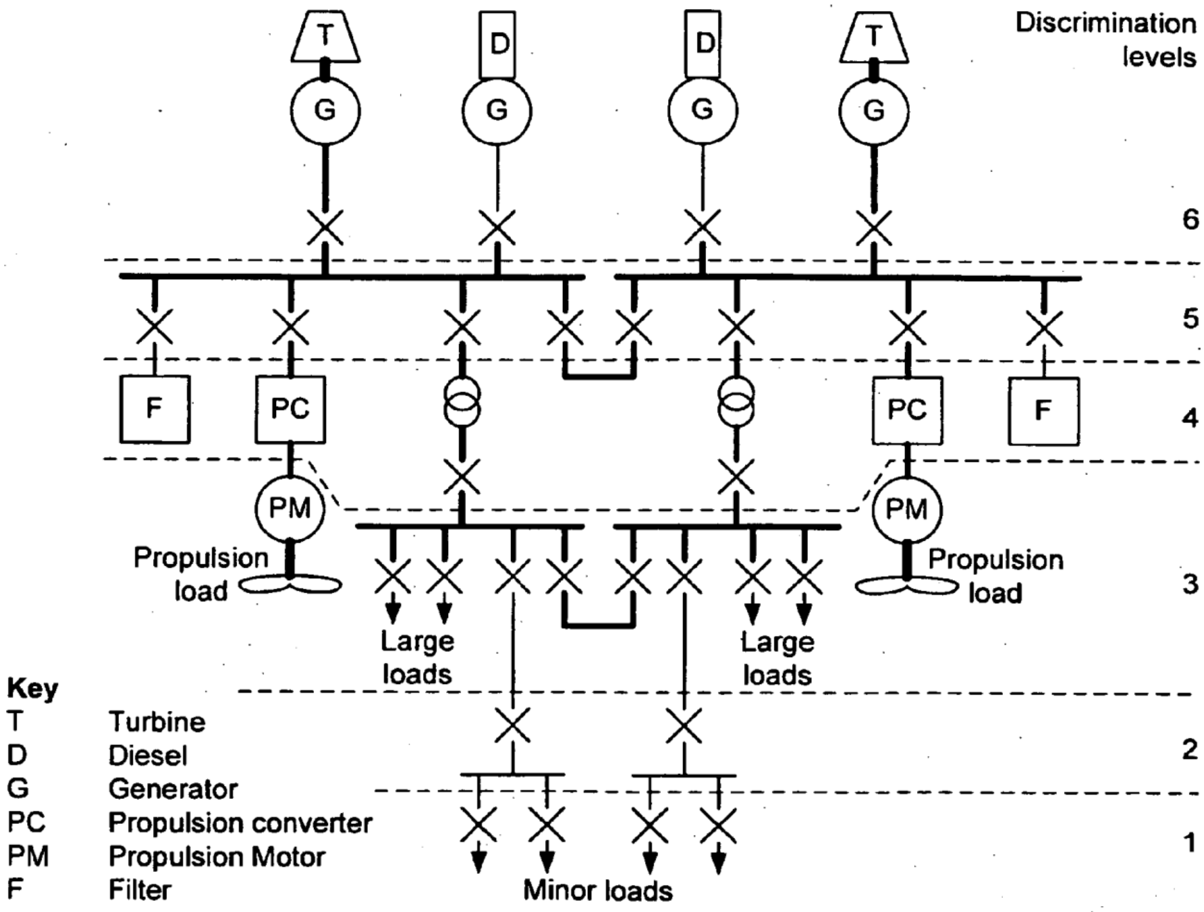
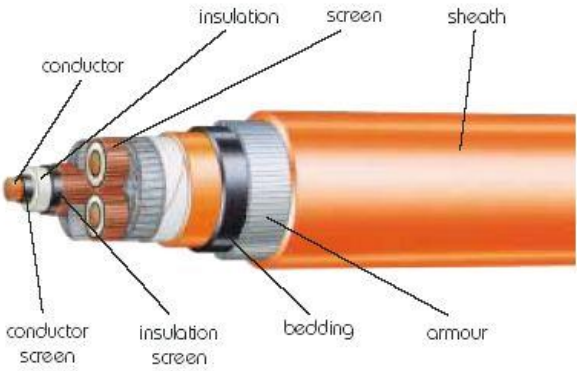
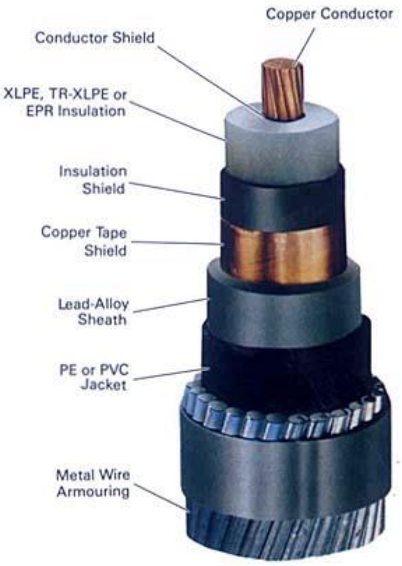
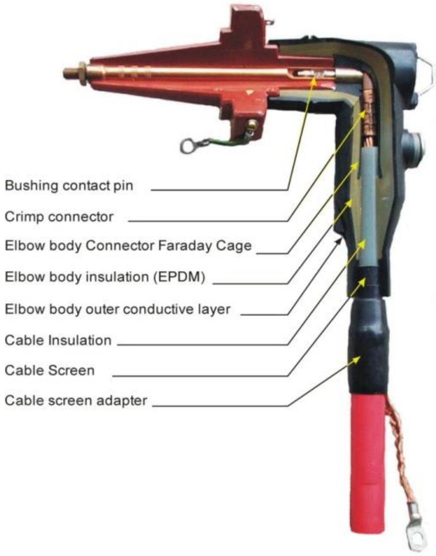

Discrimination levels
T
D
D
T
G
G
G
G
6
5
F
PC
PC
F
4
PM
PM
Propulsion load
Propulsion load
3
Large loads
Large loads
Key
T Turbine
D Diesel
G Generator
PC Propulsion converter
PM Propulsion Motor
F Filter
2
1
Minor loads

Figure 1

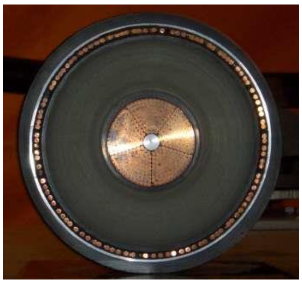
High Voltage cable construction

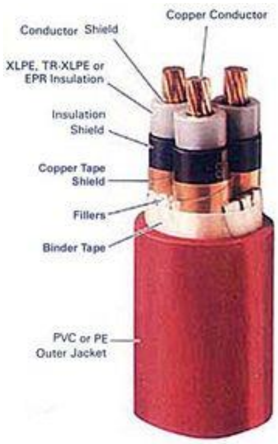




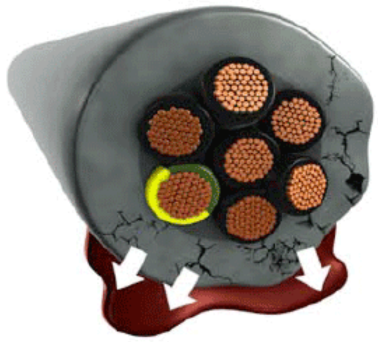


A semi-conducting tape to maintain a uniform electric field and minimise electrostatic stresses





Cable Failure



A cable failure almost always exhibits itself as either an open circuit or a short circuit. Open circuits are more common in low voltage cables than at medium or high voltage. Open circuits are usually the result of failed connectors, or broken and/or corroded conductors. The reason that open circuit failures are rare in higher voltage systems is that arcing will occur in the conduction path, leading to overheating, failure of the insulation and a short circuit. Short circuit failures will most often cause the protection system to operate and interrupt the current flow to the load. There are times when the flash over at the fault may result in more serious consequences like fire or even explosion.

Root Cause Failure Analysis

Root cause failure analysis is the process of examining a failed sample, along with the operating and environmental information, to determine the fundamental cause of the failure. During the failure analysis, various tests may be conducted on the failed sample, on pieces of nearby non faulted cable, or on accessories removed from adjacent un-failed phases. Each bit of evidence is looked at as an effect, which had a cause. Then each cause is looked at in turn as the possible effect of a previous cause. This cause/effect trail is followed to the fundamental or root cause. The amount of evidence that can be gathered will depend on the condition of the sample, what has happened to the sample since the failure, and the availability of information about the failure and previous conditions that the cable or accessory has undergone. Often direct evidence at the failure site is destroyed by the fault. An important factor in failure analysis is of course the amount of time and money one can spend on the analysis.

Two important things that must be done in any failure analysis are a close visual examination of the sample at and near the failure site, and talking to or reading accounts of the failure from the personnel involved. Depending on the circumstances more investigations or tests may be required, or more information may be requested from the cable user.

If the failure occurred in a polymeric cable, other work may include:

- More detailed examination of the conductor including possible metallurgical examination
- Dissecting the insulation close to the failure and cutting wafers
- Measuring insulation resistance
- Performing ac breakdown level tests on a long sample near the failure site
- Performing chemical tests on the insulation
- Measuring semicon resistivity at elevated temperature near the failure site
- Performing metallurgical tests on the shield or sheath if present
- Performing chemical tests on the jacket if present

Cracking of embrittled insulation

During the examination, look for signs of overheating. These may include discolored metal, or cracked and distorted polymers. **Figure 1** shows an embrittled and cracked polyethylene wafer caused by overheating.

Remember to look at samples sufficiently far from the fault site to be sure they were not damaged by the arcing fault. Overheating may indicate a possible root cause of failure of the system protection, incorrect determination of the system ampacity, thermal runaway, or lack of thermal backfill.

Signs of over heating may warrant further chemical or metallurgical tests to determine the maximum temperature reached. Further investigation into system operations may be necessary to determine the true root cause of this type of failure. Examples of root causes of over heating may be poor initial ampacity calculations, improper breaker settings, removal of proper backfill, or change in ambient conditions like the adding of a steam pipe.

Cable wafer with extensive voids

Voids or inclusions in the insulation, or protrusions from the semicon may be seen in the wafer examination. **Figure 2** shows a cable wafer with extensive voids. Voids are simply bubbles in the insulation, while inclusions are foreign matter. Protrusions are sharp points extending into the insulation from the semicon. These are all forms of cable manufacturing defects. All cause high local electrical fields, which may lead to partial discharge at the site or rapid growth of water or electrical trees near the defect. Any of these observations indicate a manufacturing defect as the cause of failure. Unfortunately the defect, which may have caused the failure, is usually destroyed by the fault, but the presence of nearby defects may give sufficient evidence of poor manufacturing. Since modern cables can be produced with super-clean insulation and semicons, and very few defects, one might conclude that the root cause of these types of failures occurring in newly purchased cables is poor specifications or acceptance testing.

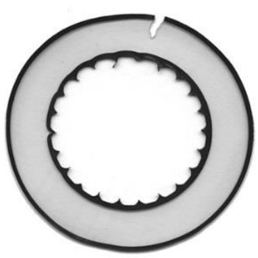


Figure 1. Cracking of embrittled insulation

Figure 2. Cable wafer with extensive voids

Large vented water tree at a fault site

Water trees can grow in both polyethylene and EPR insulation. **Figure 3** shows a large vented water tree growing from the insulation shield. This water tree has a fault through it. If newer TR-XLPE has extensive water treeing, a manufacturing problem may be the cause. If the cable is supposed to have strand blocking, water absorbing tape, or a hermetically sealed LC shield, and develops extensive water treeing in a short time, investigate the possible root cause as a manufacturing problem, mechanical damage or shield corrosion.

Cable failing from the outside jacket to inside

Another type of failure is evidenced by signs of burning or arcing on the surface of the semicon. If the burning or arcing becomes extensive, the cable can fail from the outside in.

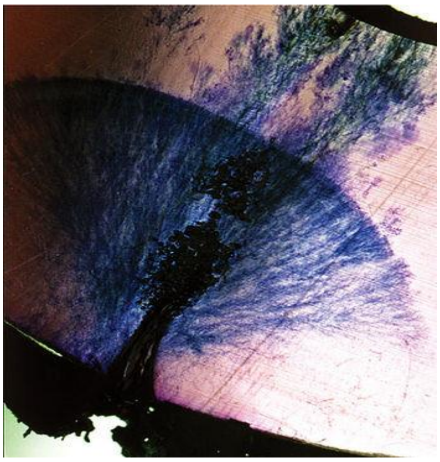


Figure 3. Large vented water tree at a fault site

Other sources
To investigate a failure in an accessory, in addition to the usual visual examination and gathering of environmental and operating information, other work specific to accessory failure analysis may include:

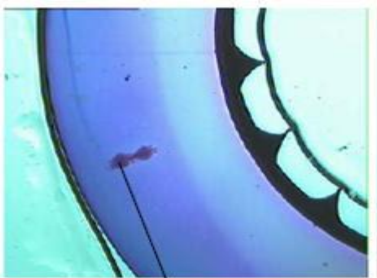
- Comparing the failed accessory with undamaged accessories in adjacent phases
- Measuring contact resistance in connectors
- Careful dissection of the accessory comparing dimensions with assembly drawings
- Looking for signs of poor workmanship
- Looking for signs of surface tracking
- Looking for electrically floating metal electrodes.

Water Tree in XLPE Cable.

Water tree degradation is a major problem for medium voltage XLPE cables. One the Most important degradation process of the polymeric insulation that contributes to the failure of the cable

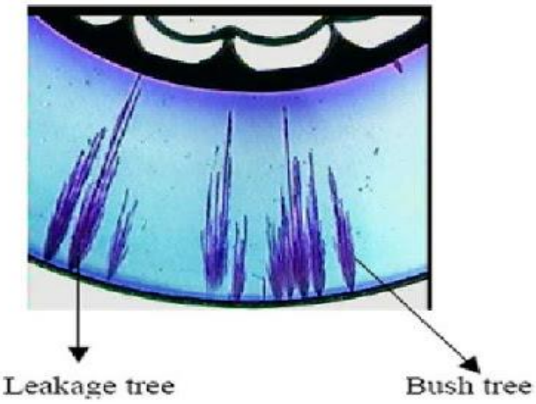
Water Trees are a diffuse structure in the polymer resembling the shape of a tree or bush. Water Tree are formed and grow in the presence of moisture, impurities or contamination@ and electric field over time.

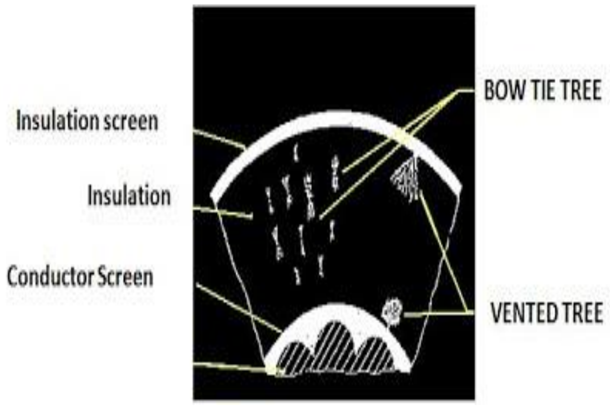
There are generally two types of water trees, namely;
Bow-Tie Tree



Bow-tie tree

Vented Trees





Water Treeing - Bow-Tie tree

Bow-Tie trees are water trees that grows from the insulation outwards towards the surfaces of the insulation.

These trees grow in the direction of the electric field in both directions, towards the two electrodes.

Bow-Tie trees have faster initial growth rate as compared to vented trees.

Bow-Tie trees are however, not capable to growing to large sizes and usually do not grow to a size significant enough to cause failure of the insulation.

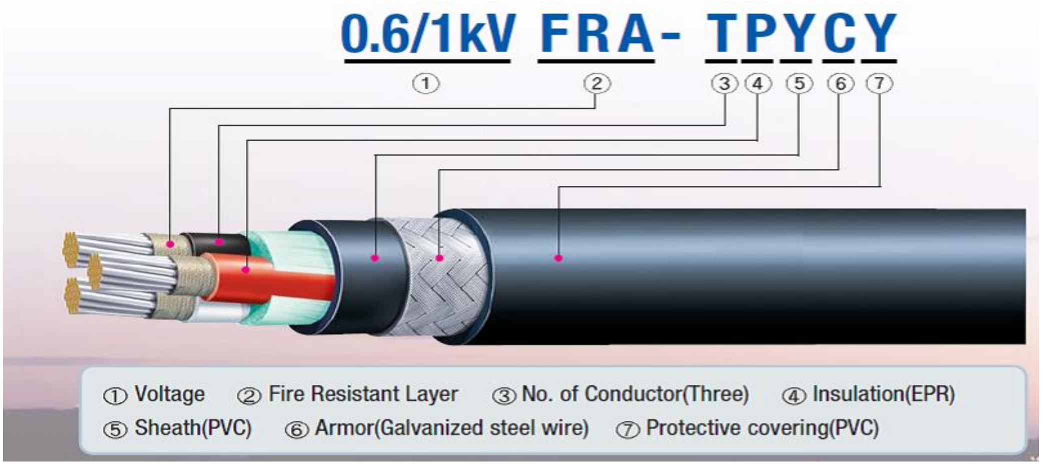
Water Treeing – Vented tree

Vented Tree are water trees that grows from the surface of the polymer inwards into the insulation system. These trees will grow in the direction of the electric field. Vented trees have lower initial growth rate as compared to bow-tie tree. Vented trees are capable of growing right through the entire insulation thickness. This is the more venomous of the two trees as these trees as it is of bridging the insulation system across two electrodes.

Electrical cables installed in ships – LV and HV

Symbols of number of core and main use;

FA- Flame retardant (IEC 60332-3 Cat A)
T Three core for power and lighting
FR- Fire resistance (IEC 60331)
F Four core for power and lighting
FRA Flame retardant & Fire resistant (IEC 60332-3 Cat A & IEC 60331)
M Multi core for control and signal
S Single core for power and lighting
TT Telephone and instrumentation
D Double core for power and lighting
P Portable or flexible



Voltage rating : 600 / 1000 volts
Conductor: Tinned annealed copper conductors
Insulation: Ethylene Propylene Rubber (EPR)
Sheath: Chlorosulphonated Polyethylene (CSP)

Outer Sheath (in accordance with IEC 60092-359)
Polyolefine Material (IEC type SHF-1)

- -Fire Properties:
- -Halogen-Free (IEC 60754-1)
- -Flame Retardant (IEC 60332-1, IEC 60332-3-22 Cat. A)
- -Low Smoke (IEC 61034)
- -No Toxic flame-inhibitors
- -Chemical Properties
- -Good resistance to oils & - Mechanical Properties
- -Excellent abrasion resistance
- -Wide temperature range (installation:-20 +70; use -40 +70)

HV cables failure

Figure 4: White powder/dust residue formed on 13kV power cables that are tie-wrapped together, forming tight air spaces between each other; ideal locations for corona to form.

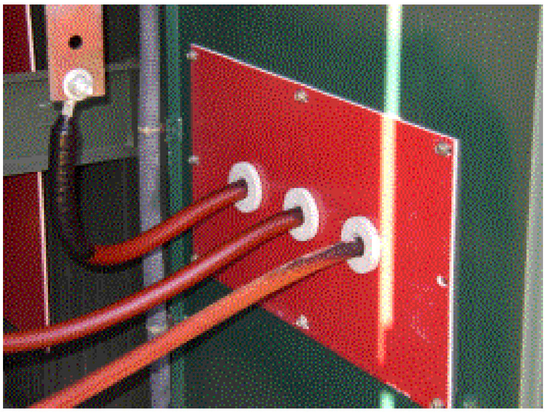
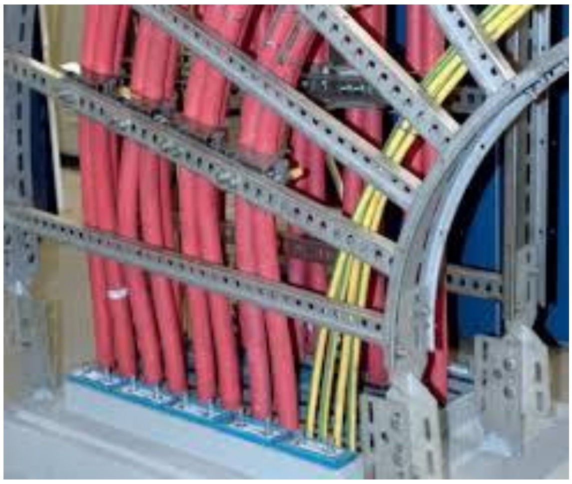


Figure 5: Non-shielded 23kV cables in contact with grounded porcelain collars produce corona conditions. Note discoloration of cable in foreground.

Sealing solutions for marine installations – cable transits



The Roxtec *(brand-name)* sealing system is used to seal all types of penetrating cables and pipes, passing through decks and bulkheads on rigs and other offshore units.

Roxtec modular-based cable transits. The system has been developed and designed to withstand very tough conditions. Roxtec seals ensure protection against fire, jet-fire, water, and gas pressure and explosions, as well as electromagnetic interference. They can also provide solutions for bonding and grounding.

The seals are used between different sections, such as machine and equipment areas, storage rooms, and living compartments. They are also used in various types of control cabinets and junction boxes.

HV Testing – test for energised (live) equipment

HVPA (High Voltage Personal Alert)

• ALL people (skilled AND unskilled) can now SEE whether electrical equipment is live or dead
• Use on any voltage from 110Vac to 760kVac (see graph operating distance 11kV)
• The Personal Alert is worn on your wrist like a watch, fastened with Velcro straps, OR mounted on telescopic link stick with standard crown adapter
• No user controls, automatically switches ON or OFF, entering or leaving HV electric field
• Buzzers beep and ultra bright LED flashes at a rate that increases from 0.7Hz when approaching live equipment, to 20Hz near live conductor
• Filters for corona, partial discharge and electrical noise make the HV/PA stable under wide range of electrical noise

HV fully insulated tools

HV Testing for Insulation Resistance (IR)

The measurement of insulation resistance is a common routine test performed on all types of electrical wires and cables. As a production test, this test is often used as a customer acceptance test, with minimum insulation resistance per unit length often specified by the customer. The results obtained from Insulation Resistance Testing are not intended to be useful in finding localized defects in the insulation as in a true **HIPOT** test, but rather give information on the quality of the bulk material used as the insulation.

Hipot Test is short name of high potential (high voltage) Test and it is also known as Dielectric Withstand Test. A hipot test checks for "*good isolation*."

Hipot test makes surety of ***no current*** will flow from one point to another point.

Hipot test is the opposite of a continuity test. 

Continuity Test checks surety of current flows easily from one point to another point while Hipot Test checks surety of current would not flow from one point to another point (and turn up the voltage really high just to make sure no current will flow).

Importance of HIPOT Testing

The hipot test is a nondestructive test that determines the adequacy of electrical insulation for the normally occurring over voltage transient. This is a high-voltage test that is applied to all devices for a specific time in order to ensure that the insulation is not marginal.

Hipot tests are helpful in finding nicked or crushed insulation, stray wire strands or braided shielding, conductive or corrosive contaminants around the conductors, terminal spacing problems, and tolerance errors in cables. Inadequate creepage and clearance distances introduced during the manufacturing process.

The production-line hipot test, however, is a test of the manufacturing process to determine whether the construction of a production unit is about the same as the construction of the unit that was subjected to type testing. Some of the process failures that can be detected by a production-line hipot test include, for example, a transformer wound in such a way that creepage and clearance have been reduced.

HIPOT test is applied after tests such as fault condition, humidity, and vibration to determine whether any degradation has taken place.

As per IEC 60950, The Basic test Voltage for Hipot test is the **2X (Operating Voltage) + 1000 V** The reason for using 1000 V as part of the basic formula is that the insulation in any product can be subjected to normal day-to-day transient over voltages.

Selection of Insulation Resistance (IR) Testers (The Megger brand **Meggers**)

Insulation testers with test voltage of 500, 1000, 2500 and 5000 V and above.
The recommended ratings of the insulation testers are given below:

Voltage Level	**IR Tester**
650V	500V DC
1.1KV	1KV DC
3.3KV	2.5KV DC
6.6Kv and Above	5KV DC

Measurement Range of Megger

Test voltage	**Measurement Range**
250V DC	0MΩ to 250GΩ
500V DC	0MΩ to 500GΩ
1KV DC	0MΩ to 1TΩ
2.5KV DC	0MΩ to 2.5TΩ
5KV DC	0MΩ to 5TΩ

Precaution while Meggering

Before Meggering

Make sure that all connections in the test circuit are tight.

Test the megger before use, whether it gives **INFINITY** value when not connected, and **ZERO** when the two terminals are connected together and the handle is rotated.

During Meggering

Make sure when testing for earth, that the far end of the conductor is not touching, otherwise the test will show faulty insulation when such is not actually the case.

Make sure that the earth used when testing for earth and open circuits is a good one otherwise the test will give wrong information.

Spare conductors should not be meggered when other working conductors of the same cable are connected to the respective circuits.

Safety Requirements for Meggering

All equipment under test **MUST** be disconnected and isolated.
Equipment should be discharged (shunted or shorted out) for at least as long as the test voltage was applied in order to be absolutely safe for the person conducting the test.
Never use Megger in an explosive atmosphere.
Make sure all switches are blocked out and cable ends marked properly for safety.
Cable ends to be isolated shall be disconnected from the supply and protected from contact to supply, or ground, or accidental contact.
Erection of safety barriers with warning signs, and an open communication channel between testing personnel.

Do not megger when humidity is more than 70 %.
Good Insulation: Megger reading increases first then remain constant.
Bad Insulation: Megger reading increases first and then decreases.
Expected IR value gets on Temp. 20 to 30 degree centigrade.

If above temperature reduces by 10 degree centigrade, IR values will increased by two times.
If above temperature increased by 70 degree centigrade IR values decreases by 700 times.

After completion of cable Meggering

Ensure that all conductors have been reconnected properly.
Test the functions of Points, Tracks & Signals connected through the cable for their correct response.
In case of signals, aspect should be verified personally.
In case of points, verify positions at site. Check whether any polarity of any feed taken through the cable has got earthed inadvertently.

Insulation resistance (IR) test

EXTRA NOTES – Suit HV Course and Practical Maritime Courses.

The insulation resistance (IR) test (also commonly known as a Megger) is a spot insulation test which uses an applied DC voltage (typically either 250Vdc, 500Vdc or 1,000Vdc for low voltage equipment <600V and 2,500Vdc and 5,000Vdc for high voltage equipment) to measure insulation resistance in either kΩ, MΩ or GΩ.

The measured resistance is intended to indicate the condition of the insulation or dieletric between two conductive parts, where the higher the resistance, the better the condition of the insulation. Ideally, the insulation resistance would be infinite, but as no insulators are perfect, leakage currents through the dielectric will ensure that a finite (though high) resistance value is measured.

Note that when applying an IR test to earth, it is good practice to connect the **positive pole of the IR tester to earth** in order to avoid any polarisation effects on the earth.

Once connected, the IR tester is energised for a typical test duration of 1 minute. The IR test measurements are recorded after 1 minute.

When the IR test is finished, discharge capacitances again for a period of 4-5 times the test duration.

Factors Affecting Test Results

Temperature

Electrical resistance has an inverse exponential relationship with temperature, i.e. as temperature increases, resistance will decrease and vice versa. Since the minimum acceptable IR test values are based on a fixed reference temperature (usually 20ºC), the measured IR test values must be corrected to the reference temperature in order to make sense of them.

As a rule of thumb, **the resistance halves for every 10ºC increase** in temperature (and vice versa). So if the measured IR test value was 2MΩ at 20ºC, then it would be 1MΩ at 30ºC or 4MΩ at 10ºC.

ANSI/NETA ATS-2009 Table 100.14 provides correction factors for IR test measurements taken at temperatures other than 20ºC or 40ºC, which were in turn based on the correction factors in the freely available Megger book "A stitch in time..." [4].

Humidity

The presence (or lack) of moisture can also affect the IR test measurements, **the higher the moisture content in the air, the lower the IR test reading**.

If possible, IR tests should **not** be carried out in very humid atmospheres (below the dew point). While there are no standard correction factors or guidance for humid conditions, it is good practice to record the relative humidity of each IR test so that they can be used for baseline comparisons in future tests. For example, having past data on the IR test values for dry and humid days will give you a foundation for evaluating future test values.

Red +ve on ground, black –ve on conductor is the correct set up if you suspect moisture in insulation is a good way to verify it, then you know if baking (heating up) will be effective.

From IEEE 43: *"Insulation resistance tests are usually conducted at constant direct voltages of 500–10 000 V having negative polarity. Negative polarity is preferred to accommodate the phenomenon of electroendosmosis." You can also refer to a publication from megger called A GUIDE TO DIAGNOSTIC INSULATION TESTING ABOVE 1 KV that states : "With modern insulating materials there is little, if any, difference in the reading obtained, regardless of which way the terminals are connected. However, on older insulation, a little known phenomenon called electroendosmosis causes the lower reading to be obtained with the positive terminal connected to the grounded side of the insulation being tested."*

How to use a Megger (insulation resistance tester)

Meggers are equipped with three connection Line Terminal (L), Earth Terminal (E) and Guard Terminal (G).

Resistance is measured between the Line and Earth terminals, where current will travel through coil 1. **The "Guard" terminal is provided for special testing situations where one resistance must be isolated from another.** Let's us check one situation where the insulation resistance is to be tested in a two-wire cable.

To measure insulation resistance from a conductor to the outside of the cable, we need to connect the "Line" lead of the megger to one of the conductors and connect the "Earth" lead of the megger to a wire wrapped around the sheath of the cable.

Megger BM 25

In this configuration the Megger should read the resistance between one conductor and the outside sheath.

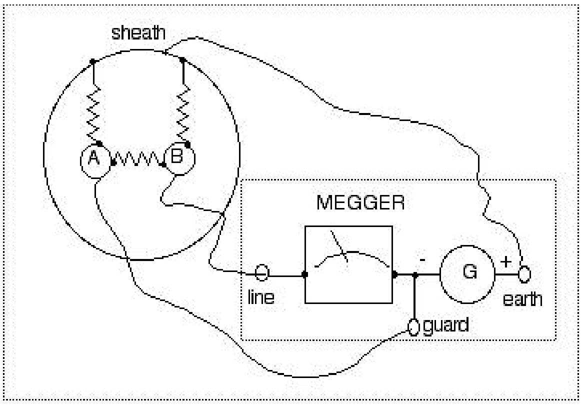
We want to measure Resistance between Conductor- 2To Sheaths but Actually Megger measure resistance in parallel with the series combination of conductor-to-conductor resistance (R_{c1-c2}) and the first conductor to the sheath (R_{c1-s}).

If we desire to measure *only* the resistance between the second conductor and the sheath (R_{c2-s}), then we need to use the megger's "Guard" terminal.

Connecting the "Guard" terminal to the first conductor places the two conductors at almost equal potential.

With little or no voltage between them, the insulation resistance is nearly infinite, and thus there will be no current *between* the two conductors. Consequently, the Megger's resistance indication will be based exclusively on the current through the second conductor's insulation, through the cable sheath, and to the wire wrapped around, not the current leaking through the first conductor's insulation.

The guard terminal (if fitted) acts as a shunt to remove the connected element from the measurement. In other words, it allows you to be selective in evaluating certain specific components in a large piece of electrical equipment. For example consider a two core cable with a sheath. As the diagram below shows there are three resistances to be considered.



Insulation Resistance test on a HV cable

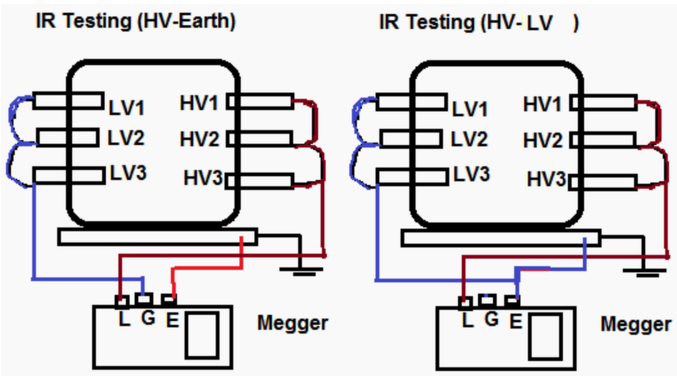
If we measure between core B and sheath without a connection to the guard terminal some current will pass from B to A and from A to the sheath. Our measurement would be low. By connecting the guard terminal to A the two cable cores will be at very nearly the same potential and thus the shunting effect is eliminated.

Insulation Resistance Values for a HV Transformer

Insulation resistance tests are made to determine insulation resistance from individual windings to ground or between individual windings. Insulation resistance tests are commonly measured directly in Meg-Ohms or may be calculated from measurements of applied voltage and leakage current.

The recommended practice in measuring insulation resistance is to always ground the tank (and the core). Short circuit each winding of the transformer at the bushing terminals. Resistance measurements are then made between each winding and all other windings grounded.

HV Transformer



Windings are never left floating for insulation resistance measurements. Solidly grounded winding must have the ground removed in order to measure the insulation resistance of the winding grounded.

If the ground cannot be removed, as in the case of some windings with solidly grounded neutrals, the insulation resistance of the winding cannot be measured. Treat it as part of the grounded section of the circuit.

We need to test winding to winding and winding to ground (E).For three phase transformers, We need to test winding (L1,L2,L3) with substitute Earthing for Delta transformer or winding (L1,L2,L3) with earthing (E) and neutral (N) for wye transformers.

Insulation resistance tests 5kV max

Spot or Short time IR test < 1min

Timed IR test minimum of 1min

Step Voltage Test

Ramp voltage test

PI test

DAR

DD

PI test (polarisation index) 10min/1min

Tested equipment condition

< 1 dangerous

1.0-1.1 poor

1.1-1.25 questionable

1.25-2.0 fair

> 2 good

>4 very good

DAR, Dielectric Absorption Ratio (Reading @ 60 sec / Reading @ 30 sec)

Tested equipment condition

< 1 Poor

1 – 1.4 Acceptable

1.4 – 1.6 Excellent

DD, Dielectric Discharge (meter calculates while discharging, typically after a 30min test)

Tested equipment condition

7 dangerous

4-7 poor

2-4 questionable

<2 good

Temperature effect on IR values

Up by 10C halve the IR value

Down by 10C double the IR value

All tests will be done +ve lead of the Megger MUST ALWAYS CONNECT TO EARTH !!

Guard lead to be attached to the insulating bushes with soft wire (for any surface leakage)

Steps for measuring the IR of Transformer:

Shut down the transformer and disconnect any jumpers.
Discharge the winding capacitance.
Thoroughly clean all bushings
Short circuit the windings.
Guard the terminals to eliminate surface leakage over terminal bushings.
Record the temperature.
Connect the test leads (avoid joints).
Apply the test voltage and note the reading. The IR value at 60 seconds after application of the test voltage is referred to as the Insulation Resistance of the transformer at the test temperature.
The transformer Neutral bushing is to be disconnected from earth during the test.
All LV surge diverter earth connections are to be disconnected during the test.
Due to the inductive characteristics of transformers, the insulation resistance reading shall not be taken until the test current stabilizes.

Factors affecting on IR value of Transformer

The IR value of transformers are influenced by

- Surface condition of the terminal bushing
- Quality of oil
- Quality of winding insulation
- Temperature of oil
- Duration of application and value of test voltage

Insulation resistance measured shall not be less than:

- HV – Earth 200 M Ω
- LV – Earth 100 M Ω
- HV – LV 200 M Ω

Tests for Dielectric Absorption

DAR, Dielectric Absorption Ratio (Reading @ 60 sec / Reading @ 30 sec)

PI, Polarization Index (Reading @ 10min / Reading @ 1min)

DD, Dielectric Discharge. Used more for multilayer insulated equipment and cables, test measures the discharge currents 1 minute after an insulation test has been completed. At this time the capacitive current has usually become insignificant compared with the reabsorption current.
The level of reabsorption after this time shows the state of the insulation material, providing the insulation has been fully charged for full absorption to take place (typically 10 to 30 minutes). A high reabsorption current shows that the insulation has been contaminated, usually by moisture. A low current usually shows that the insulation is clean and has not absorbed much water.

DD Test Result Analysis
A low DD value shows that the reabsorption current is decaying quickly and the time constant of each layer of insulation is similar. A high value of DD shows that the reabsorption current exhibits long relaxation times which may point to a problem with the insulation.

Typical conditions from practical research, primarily carried out on generators by a major utility, arrived at the figures of merit in the table below. This technique was developed for HV Generators.

DD Test Result Analysis / Multi-layer Insulation.

Insulation in high voltage equipment often consists of layers, each having its own capacitance and associated leakage resistance. When insulation is built up in this way, the aim is to make each layer such that the voltage stress is shared equally between layers. When the insulator is discharged each layer's charge will decrease equally until there is no voltage remaining.
The DD test result can also show how similar the layers of insulation are. In the case of insulation failure in a single layer of insulation the leakage resistance will decrease but the capacitance is likely to remain the same. This type of fault is not possible to detect from a standard insulation test because the overall resistance will remain high due to the other, high resistance, layers.

Step Voltage Test
The SV test is a controlled overvoltage test that can be applied to stator and rotor windings on synchronous and asynchronous AC motors

Ramp voltage test
The ramp voltage test is an overvoltage test similar to the SV test but with improved control and warning of potential
insulation failure.

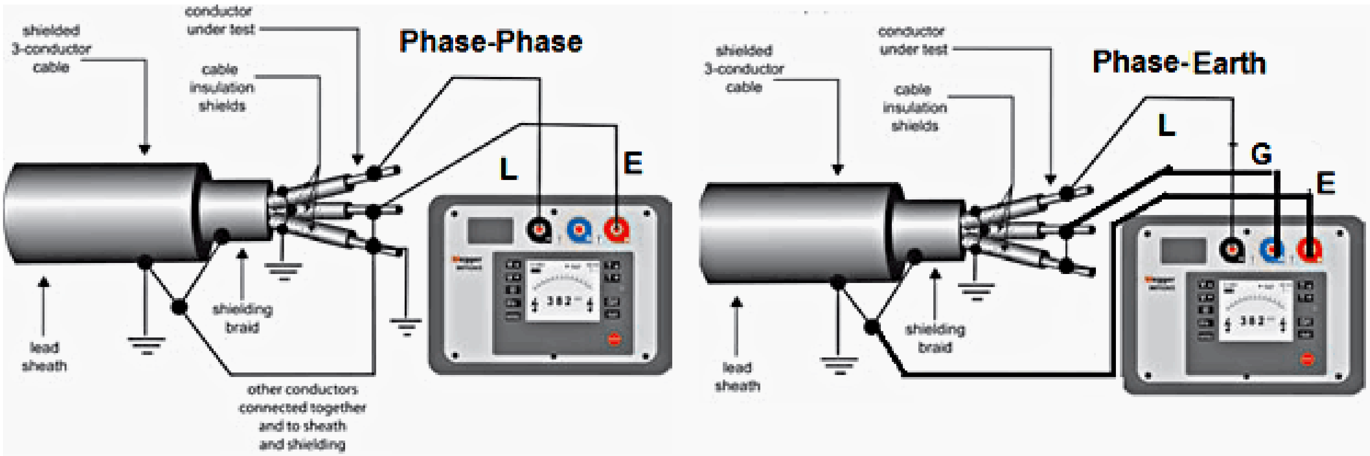
The slow continuous voltage ramp is less likely to result in unpredictable damage to the insulation than the rapid step increases employed in SV test.

The typical voltage ramp
(dV/dt) is 1 kV/min

Settings on the BM25 Megger

Breakdown mode / burn mode
The insulation resistance ‘IR’ test operates
in either ‘Breakdown’ or ‘Burn’ mode.
Default mode is *breakdown*.
Left and right arrow buttons toggle between
burn and breakdown mode when a voltage
range is selected. Press and hold left
arrow/burn to activate burn mode.
In breakdown mode the test will automatically terminate on
detection of a breakdown to prevent damage to the insulation.

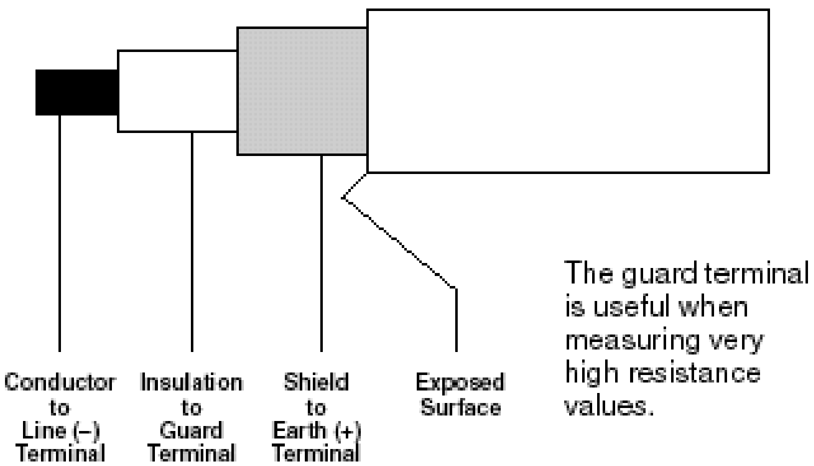
Burn mode disables the normal breakdown detection and test voltage continues after breakdown of the insulation. This enables the location of the failure to be seen and detected acoustically but it is a destructive test.
Due to the potential damage that could occur, the unit
produces two long beeps when starting a test with burn mode activated.



IR Value for Electrical cable and wiring

HV test on new XLPE cable

Application	**Test Voltage**	**Min IR Value**
New cables – Sheath	1KV DC	100 MΩ
New cables – Insulation	10KV DC	1000 MΩ
After repairs – Sheath	1KV DC	10 MΩ
After repairs – Insulation	5KV DC	1000MΩ



HV Cables, 11 KV XLPE

Outer Sheath Insulation Resistance (Screen wire test)

The purpose of the test is to determine soundness of the outer polyethylene sheath against water ingress, mechanical damage and termite attack.
Values below 0.5 meg-ohms (500 kΩ) can indicate sheath damage. Values between 1.0 and 10 meg-ohms may not indicate damage in a single location. Fault finding can often be very difficult. In new cables, values of greater than 100 mega ohms are required.
The integrity of the outer sheath shall be checked after cables have been installed, by an insulation tester (Megger) at 1000 Volts.
The test shall be conducted for 1 minute between each wire screen and earth after the cable terminations installed.
For cables after repairs, the resistance must not be less than 10 meg-ohms.

Insulation Resistance Test and Polarization Index Test

Both **Insulation Resistance Test** (IR Value Test) and **Polarization Index Test** (PI Value Test) are conducted on HV machines to determine service condition of the insulation. In HV machines and winding are likely to be affected by moisture and contamination. IP test is conducted specially to determine the dryness and cleanliness of winding insulation.

In insulation resistance test, a high DC voltage is applied across, conductor and ground more specifically. The voltage is applied across the insulator.

Due to this applied high DC voltage there will be a electric current through the electrical insulator. Big dividing the applied voltage by this electric current we get the actual resistive value of the insulator.

This test is generally done by means of a megger.
Megger gives required direct (dc) voltage across the insulator an it also shows the resistive value of insulator directly in Mohm range.
The megger are generally of 500 V, 2.5 KV an 5 KV.
500 V megger are used for insulation test up to 1.1 KV rated insulation.
For high voltage transformer, other HV equipment and machines, 2.5 or 5 KV megger are used.
As all insulators are dielectric in nature they have always a capacitive property. Due to that, during application of voltage across the electrical insulator, initially there will be a charging current. But after some time when the insulator is totally charged, the capacitive changing electric current becomes zero and then only resistive conductive electric current presents in the insulator. That is why it is always recommended to do insulation resistance test at least for 1 minute as it is proved that charging electric current totally becomes zero after 1 minute.
Only measuring insulation resistance by megger for 1 minute does not always give reliable result. As the resistive value of an electrical insulator also varies with temperature.
This difficulty is partially solved by introducing polarity index test or in short PI value test. The philosophy behind PI test is discussed below.

When a voltage is applied across an insulator there will be a leakage electric current from line to ground.

Although this leakage electric current is very small is in millampere or sometimes in micro ampere range, but it has mainly four components.

1) Capacitive component.
2) Resistive or conductive component.
3) Surface leakage component.
4) Polarization component.

Capacitive Component

When a DC voltage is applied across in insulator, because of its dielectric nature there will be an initial high charging electric current through the insulator from line to ground. Although this electric current decays exponentially and becomes zero.

Generally this electric current exists for initial 10 seconds of the test. But it takes nearly 60 seconds to decay totally.

Resistive or Conductive Component

This electric current is purely conductive in nature flows through the insulator as if the insulator is purely resistive. This is direct flow of electrons. Every insulator should have this component of electric current. Since in practice every material in this universe persists some sensitive nature.

The resistive or conductive component of insulator leakage electric current remains constant throughout the test.

Surface Leakage Component

Due to dust, moisture and other contaminants on the surface of the insulator, there is one small component of leakage electric current through the outer surface of the insulator.

Polarization Component

Every insulator is hygroscopic in nature. Some contaminant molecules and mainly moisture in insulator are very polar. When an electric field is applied across insulator the polar molecules align themselves along the direction of electric field. The energy required for this alignment of polar molecules, comes from voltage source in form of electric current. This electric current is called polarization current. It continues until all the polar molecules allied themselves along the direction of electric field.

It takes around 10 minutes to align the polar molecules along electric field and that is why if we take megger result for 10 minutes, there would be no effect of polarizing in megger result. So when we take megger value of an insulator for 1 minute, the results reflects, the IR value which is free from effect of capacitive component of leakage current.

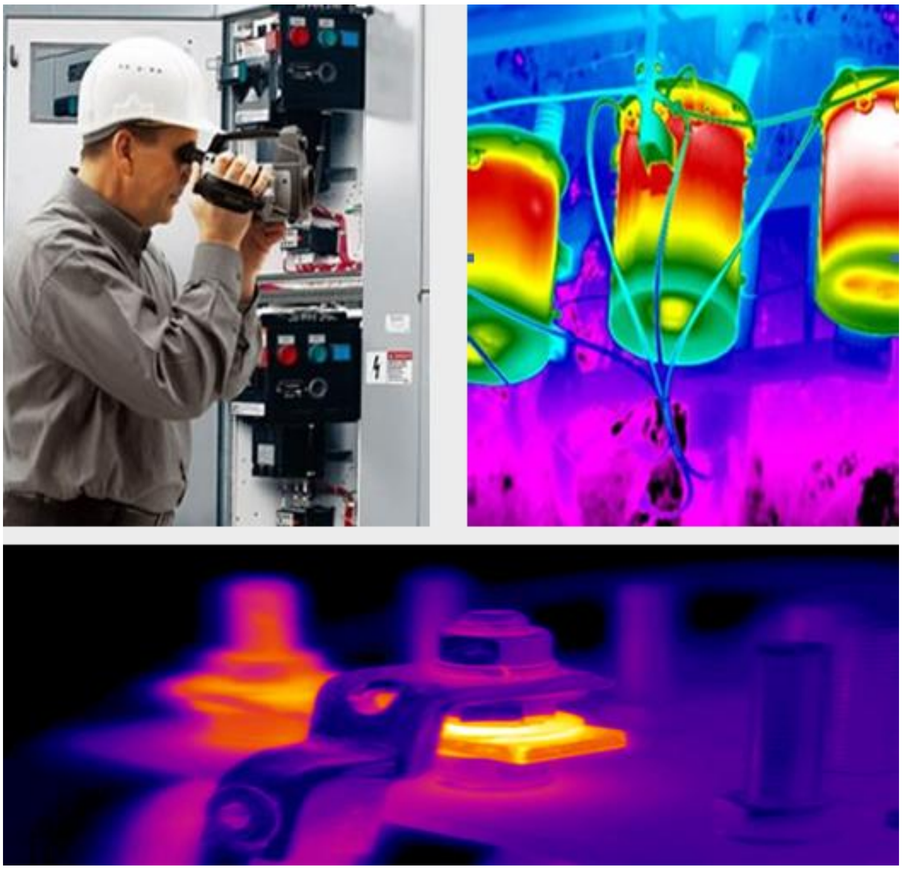
Again when we take megger value of an insulator for 10 minutes, the megger result shows the IR value, free from affects of both capacitive component and polarization component of leakage current.

Polarization index is the ratio of megger value taken for 10 minutes to the megger value taken for 1 minute.

It is always desired to have polarization index of an electrical insulator more than 2. It is hazardous to have polarization index less than 1.0.

Thermography testing of HV equipment

By detecting potential HV electrical equipment failure areas with an infrared camera, you can prevent equipment shutdowns or “black-outs” by identifying potential electrical problems before they lead to higher maintenance bills and possibly devastating electrical fires.



It has been standard practice to arrange scheduled shut downs of main switchboards and equipment to inspect the boards and their respective componentry, while in a de- energized state in order to manually check electrical connections for tightness and identify signs of deterioration, this is an effective method to identify obvious potential problems, but this is not a full proof method of ensuring all equipment is operating correctly.

The only way of identifying such potential issues during a total maintenance shut down has been through obvious evidence of overheating through burnt terminals and wiring etc. If no visible signs of such are evident, the potential fault could go unnoticed resulting in failure in the future when the equipment is again in service.

Apart from the obvious downtime and lengthy costs associated, sometimes days on an annual basis, there are other risks involved with conducting switchboard maintenance in such a manner, as like the continued and repetitive tightening of terminals and studs can lead to failure through over tightening.

Thermal Imaging is non-contact and non-destructive, therefore there is no need to interrupt the supply to the switchgear.

Ensuring the safety of all engine-room staff

Earthing-Down, to ensure that the risk to personnel is minimised, even if the above precautions fail, it is preferable that all the conductors are earthed using properly designed earthing devices or earthing leads, usually applied to all points where the circuit or equipment is isolated from the supply.

Additional local earths at the point of work may also be necessary if this is remote from the point of isolation, but these should be applied only after proving dead at the point of work.
This procedure is essential for high voltage apparatus and stored energy equipment (eg capacitors).

The earthing conductors and their connections should be suitable for the energy that may flow in the event of a failure of the above precautions. Earthing low-voltage equipment is particularly desirable if there is a risk of re-energisation.

Posting of notices, put a notice or label at the place of disconnection so everyone else knows that work is being done.
A good system is to use a ‘caution’ notice to indicate that someone is working on the apparatus and may be injured if it is re-energised. This should be supplemented by ‘danger’ notices adjacent to the place of work indicating nearby apparatus that is still energised.
Notices or labels should be easily understandable to anyone in the area.

It is also important to remove labels or notices when they no longer apply so that the system does not fall into disrepute.
It is often useful for the ‘caution’ and ‘danger’ notices to have a space for the name of the person working or in charge and for the date. All keys should be retained in a secure place.

Adjacent parts, worked on has been made dead or where the work is non-electrical, it may still be necessary to protect against inadvertent contact.

When the circuit or equipment to be live parts nearby. This should preferably be done by erecting physical barriers and/or the use of temporary insulation.

HV work on board may have limited space and may be carried out in close proximity to a person(s) not familiar with HV hazards. Therefore the area must be properly cordoned off from surrounding work that may be going on and danger notices well posted, even post a watch person e.g. passenger areas.

Regarding adequate working space, access and lighting should also be met.

The use of instruments when taking measurements of high voltages can increase the risk of injury if they are inadvertently used without the earth (protective) conductor connected. This can result in the enclosure of the instrument becoming live at high voltages.

High voltage equipment will store energy after disconnection. For example, on a 6.6KV switchboard a fatal charge may still be present on the equipment hours or even days later.

If during maintenance an HV circuit main earth (CME) (eg portable earth leads) is removed from the system, it must not be worked on, as the HV cabling can recharge itself to a high voltage from induced voltages from nearby live cables.

Limitation of access forms
When carrying out HV maintenance, it is dangerous to allow unrestricted work be carried out nearby.
Workers carrying out maintenance nearby may not have HV training and may not be familiar with the risks involved when working on or near HV equipment. Due to these risks the Limitation of access form should be used. This form states the type of work
that is allowed to be carried out nearby the HV work, the limitations imposed (space and time) and the safety precautions taken. The form is to be issued and signed by the authorised person (AP) and a confirmation of receipt signature by the person carrying out the work.
The form should include a sign off and a cancellation section.

HV Equipment
The principal items of a high voltage electrical system would be:
The main generating sets.
The main and auxiliary HV switchboards with associated switchgear, protective devices and instrumentation.
High voltage cables.
HV to LV transformers.
HV to HV transformers typically step down or isolating transformers supplying propulsion converters and motors.
HV motors for propulsion, thrusters, ballast-pumps, cargo-pumps and compressors.

Dangers when working on HV equipment
4.7.1 Electric shock
Making personal contact with any electric voltage is potentially dangerous.
At high voltage levels the electric shock potential is lethal. Body resistance decreases with increased voltage level which enhances the current flow. Remember that an electric current shock of as low as 15mA can be fatal. The risk to people working in HV areas can be greatly minimized by the diligent application of sensible general and company regulations and procedures.
Factors likely to increase the risk of receiving an electric shock include the following. HV work on board due to limited space may be carried out in close proximity to a person(s) not familiar with HV hazards. Therefore the area must be properly cordoned off from surrounding work that may be going on and danger notices well posted.

There will be large areas of earthed metal that can be easily touched, increasing the possibility of electrical shock from an HV conductor.
High voltage isolation testing can be particularly hazardous when several parts of the equipment are energised for a period of time.
Some equipment could be using water in its operation which can lead to an increased risk of injury. In general, water conducts electricity and reduces the resistance of the skin.

The use of instruments when taking measurements of high voltages can increase the risk of injury if they are inadvertently used without the earth (protective) conductor connected. This can result in the enclosure of the instrument becoming live at high voltages.
High voltage equipment will store energy after disconnection.
For example, on a 6.6KV switchboard a fatal charge may still be present on the equipment hours or even days later.
If during maintenance an HV circuit main earth (CME) is removed from the system, it must not be worked on, as the HV cabling can recharge itself to a high voltage from induced voltages from nearby live HV cabling.

Electrical switchboards and connections
On most vessels, there is a range of control boxes, switches and sockets in areas exposed to physical damage.
Ensure the flame-proof and water-proof enclosures are kept in excellent physical condition.
Regularly check that contacts and connections inside are still tight. Remember a vessel is continually vibrating, so connections do come loose, which can create a hot spot.

Electric motors and generators
These are often in areas where they are exposed to fumes and dust. The fumes and dust can get into the vents of the machine. Sparks from the electrics can ignite fumes or dust.
Have a qualified person regularly check the vents and remove grills to make sure the internals of the machine are clean. At the same time check that all connections inside are still tight.

Portable electric power tools
Ensure tools (including leads and extension leads) are kept in excellent condition.
Turn power off after use.
Do not run leads across deck.

Risk of electric shock, death or fire due to unauthorised access to switchboards and cabinets, overloading of sockets, corrosion of wires exposed to salt water or equipment unsuitable for the work environment.

Arc
An arc is a discharge of electrical current across a gap.
An arc fault is a high power discharge of electricity between two or more conductors.
The radiation of heat in an arc is very high and it can very easily set a persons clothes on fire.

Arc Blast
Arc blast pressure derives from two things. First, the expansion of metal in a boiling, vaporising state, and second the heating of ambient air by passage of the arc. The mixture of vaporised water and metal in air near the arc generates a rapidly expanding plasma of ionized vapour, which can lead to extensive injuries.

Electrocution
Three primary factors affect the severity of the shock a person receives when he or she is a part of an electrical circuit:

Amount of current flowing through the body (measured in *amperes*).
Path of the current through the body.
Length of time the body is in the circuit.

Other factors that may affect the severity of the shock are:

The voltage of the current.
The presence of moisture in the environment.
The phase of the heart cycle when the shock occurs.
The general health of the person prior to the shock.

Effects can range from a barely perceptible tingle to severe burns and immediate cardiac arrest. Although it is not known the exact injuries that result from any given amperage, the following table demonstrates this general relationship for a 60-cycle, hand-to-foot shock of one second's duration:

Current level (Milliamperes)	**Probable Effect on Human Body**
1 mA	Perception level. Slight tingling sensation. Still dangerous under certain conditions.
5mA	Slight shock felt; not painful but disturbing. Average individual can let go. However, strong involuntary reactions to shocks in this range may lead to injuries.
6mA - 16mA	Painful shock, begin to lose muscular control. Commonly referred to as the freezing current or "let-go" range.
17mA - 99mA	Extreme pain, respiratory arrest, severe muscular contractions. Individual cannot let go. Death is possible.
100mA - 2000mA	Ventricular fibrillation (uneven, uncoordinated pumping of the heart.) Muscular contraction and nerve damage begins to occur. Death is likely.
> 2000mA (2 Amps)	Cardiac arrest, internal organ damage, and severe burns. Death is probable.

Wet conditions are common during low-voltage electrocutions. Under dry conditions, human skin is very resistant. Wet skin dramatically drops the body's resistance.

Dry Conditions: Current = Volts/Ohms = 120/100,000 = 1mA
a barely perceptible level of current
Wet conditions: Current = Volts/Ohms = 120/1,000 = 120mA
sufficient current to cause ventricular fibrillation

High voltage electrical energy greatly reduces the body's resistance by quickly breaking down human skin. Once the skin is punctured, the lowered resistance results in massive current flow.

Ohm's law is used to demonstrate the action.
At 1,000 volts, Current = Volts/Ohms = 1,000/500 = 2 Amps
which can cause cardiac arrest and serious damage to internal organs.

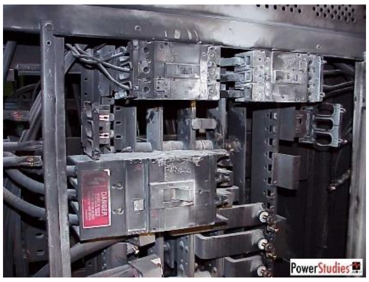
Electric current through the human body may produce injury or death by affecting muscles and nerves, initiating abnormal electrical rhythms in the heart and brain, or producing internal and external electrical burns.

Alternating current (AC) may produce ventricular fibrillation of the heart if the path of the current involves a passage through the chest cavity. This may occur when the current flows from arm to arm, arm to leg, or head to arm or leg.

The risk of electrocution depends on the conductivity of the area of human skin in contact with the voltage source. If skin is wet, or if there are wounds, or if the live conductor penetrates the outer skin layers, then even voltage sources below 40 V can be highly dangerous if contacted.

The exact effects of electricity flowing through the human body vary from a tingling sensation at a current of 1-2 mA, through pain at 5 - 6 mA, to muscle spasms above 20 mA, and as the voltages increase so do the risks of serious injury.

An incident at 440V - Entered an energized 440V electrical control cabinet to replace a fuse. He wasn't wearing proper PPE, nor was the system de-energized prior to his entry. On top of that, he was not qualified or trained to perform the fuse replacement. An arc blast occurred when inserting the fuse onto a short circuit, he suffered 2nd and 3rd degree burns to his face, hands, and arms.



Section 3

Personal Protective Equipment for High Voltage Environments (PPE)

An electric arc flash event consists of a complicated series of hazards primarily originating from the nearly instantaneous generation of an atmospheric plasma. These hazards include a radiant heat exposure, a pressure or "shock" wave, an excessive noise exposure, molten metal splatter (from the plasma erosion of the conductors and nearby materials), and ejection of projectiles or bits of "shrapnel" accelerated by the explosive force of the plasma formation.

Personal protective equipment (PPE) has been developed to protect workers from the intense heat energy of an electric arc flash event. Oberon arc flash suits including hoods and hood shield windows are available with heat protection levels up to 100 cal/cm2. However, there is increasing concern among some members of the NFPA 70E Technical Committee regarding potential hazards other than heat exposure that are also part of an electric arc event, e.g. shrapnel, pressure waves and high sound levels. The NFPA 70E Technical Committee elected to limit its Hazard/Risk Category exposure levels to 40 cal/cm2 in the proposed 2004 edition until a better understanding of these additional arc flash hazards is achieved. Oberon and DuPont have conducted limited ballistic testing for the better understand the performance of Oberon arc flash product performance against shrapnel hazards.

Knowing the voltage is only one piece of determining Arc Flash PPE. The available fault current (amps), the working distance between the worker and the equipment, the clearing time of the circuit protection device, the spacing between conductors or from a conductor to ground, the number of phases, whether the conductors are in an enclosure, and the equipment configuration are also needed to determining the potential Arc Flash exposure level and the required PPE.

In order to select the proper PPE, incident energy must be known at every point where workers may be required to perform work on energized equipment. These calculations need to be performed by a qualified person such as an electrical engineer. All parts of the body that may be exposed to the arc flash need to be covered by the appropriate type and quality of PPE. Proper PPE can include Flame Resistant clothing, helmet or headgear, face shield, safety glasses, gloves, shoes, etc. depending upon the magnitude of the arc energy.

Arc flash protection, what is the risk to being exposed to arc flash? The exposure to arc flash can depend on the following:

- Number of times the workers perform a task involving live electrical equipment
- Complexity of the task performed, need to use force, available space, safety margins, reach, etc.
- Training, skills, mental and physical agility, coordination with helper
- Tools used
- Condition of equipment

Exposure to an arc flash frequently results in a variety of serious injuries and in some cases death. Workers have been injured even though they were 3 mtrs or more away from the arc center. Worker injuries can include damaged hearing, eyesight, and severe burns.

Flash Protection Boundary
For systems that are 600 volts or less, the Flash Protection Boundary shall be 4.0 ft (1.5m approx), based on the product of clearing times of 6 cycles (0.1 second) and the available bolted fault current of 50kA or any combination not exceeding 300 kA cycles (5000 ampere seconds).
For clearing times and bolted fault currents other than 300 kA cycles.

The Flash Protection Boundary shall alternatively be permitted to be calculated in accordance with the following general formula:

D, = [53 x MVA x t]"

Where:

D, = distance in feet from an arc source for a second-degree burn
MVA = capacity rating of transformer (mega volt-amps). For transformers with MVA ratings below 0.75 MVA, multiply the transformer MVA rating by 1.25
t = time of arc exposure (in seconds)

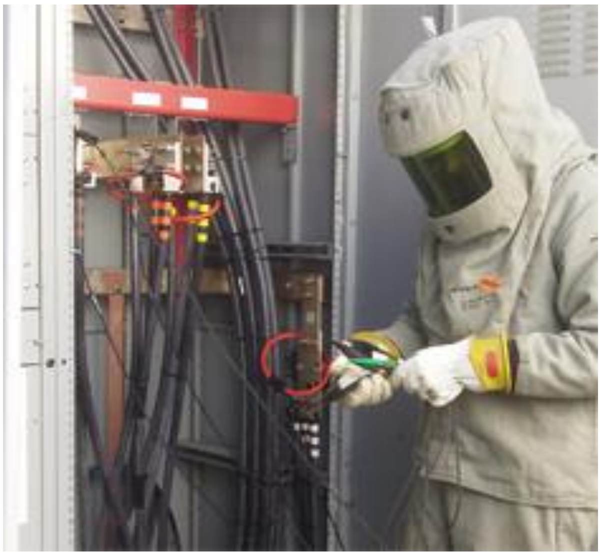
At voltage levels above 600 volts, the Flash Protection Boundary is the distance at which the incident energy equals 5 ~l cm~(1c.a2l/ cm2), For situations where fault clearing time is 0.1 seconds (or faster), the Flash Protection Boundary is the distance at which the incident energy level equals 6.24 ~/cm*(1.5c al/cm2).

Protective Clothing and Personal Protective Equipment for Application with a Flash Hazard Analysis.

Where it has been determined that work will be performed within the Flash Protection Boundary, the flash hazard analysis shall determine, the employer shall document, the incident energy exposure of the worker (in calories per square centimetre).
The incident energy exposure level shall be based on the working distance of the employee's face and chest areas from a prospective arc source for the specific task to be performed. Flame-resistant (FR) clothing and personal protective equipment (PPE) shall be used by the employee based on the incident energy exposure associated with the specific task.

Recognising that incident energy increases as the distance from the arc flash decreases, additional PPE shall be used for any parts of the body that are closer than the distance at which the incident energy was determined as an alternative, the PPE requirements of 130.7(C) shall be permitted to be used in lieu of the detailed flash hazard analysis approach.


ELECTRICAL
ENGINEERING



PPE options

As with all tasks, the hierarchy of risk reduction always starts with trying to do the work in a different way that either removes or reduces the hazard to an acceptable level. For instance, the risk of shock can be removed if it is possible to work on the equipment with the supply disconnected, locked off and earthed.

If the equipment cannot be made safe or the job done in a different way, however, the use of Personal Protective Equipment (PPE), such as protective gloves which have been tested and approved as providing an acceptable level of protection against contact with a high voltages, will be required.

In order to prevent dangerous levels of current through the wearer's body, a layer of electrically insulating material needs to be introduced to break any possible circuit. A number of items of PPE are available to provide protection against electric shock, so in addition to products such as gloves and mitts used in the electrical industry for live working applications, there are helmets such as those used by firefighters, and sleeves.

One regularly used protective mechanism against such electrical hazards is footwear with a very high electrical resistance. This is required to protect the wearer when there is the possibility of a large potential difference (voltage) between the wearer's hand or body and the ground that he or she is standing on. Insulating footwear is available that has good insulating properties when subjected to high voltages.

While standard gloves produced from rubber or polymeric compounds not containing any conductive impurities may offer some degree of protection against low voltages, specially designed gloves are necessary to ensure reliable protection in such applications. Higher voltages of, say, up to 1,000 V, while still generally referred to in the electrical industry as low voltages, require gloves which meet specialised designs and testing requirements.

The most common type of product is likely to be an all-rubber or all-polymeric glove. Test methods for products usually involve measuring leakage currents through the full thickness of the glove's construction when high voltages, such as up to 50,000 V, are applied between the inner and outer surfaces.

Inspecting High Voltage Rubber Gloves & Sleeves

Cracking and Cutting

Shown above is the damage caused by prolonged folding or compressing.

Chemical Attack

This photo shows swelling caused by oils and other petroleum compounds.

Snags

Damage shown here is due to wood and metal splinters and other sharp objects.

UV Checking

Storing in areas exposed to prolonged sunlight causes UV checking.

Avoid Folding Gloves

The strain on rubber at a folded point is equal to stretching the glove to twice its length.

Avoid Storing Inside Out

Gloves should never be stored inside out. Storing gloves reversed strains the rubber severely and causes ozone cutting.

Rubber Insulating Gloves

Made from 100% natural rubber, Rubber Glove, Leather Protector Glove.

- Class 00 (500 Volts)
- Class 0 (1000 Volts)
- Class 1 (7500 Volts)
- Class 2 (17000 Volts)

Testing HV Gloves

A reliable means of inspecting high voltage gloves in the field, stretch the glove cuff over the grooved housing and secure it with either the rubber O-ring or Velcro strap included, then inflate and check for leaks.

When working on live electrical equipment with exposed parts that may be electrically live, however, it is important that the wearer does not introduce a conductive path – either through the body and footwear to ground, or from one hand to another part of the body (such as the other hand) that may be touching another part of the equipment that is at a different potential.

Many test specifications, such as those applied to gloves, include a wet test to ensure that all parts of the item meet the minimum required performance characteristics. For this, the glove is placed in a tank and both the sample and the tank are filled with water.
Care is taken to exclude any air pockets or bubbles, which therefore ensures continuous contact inside and outside the product under test.
One probe is placed inside the glove and the other outside in the tank, and the test voltage applied in the normal way. Similar test methodology is applied to insulating footwear.

Switchboard Matting is placed permanently in front of switchgear, motor control centers and other high voltage apparatus to provide an additional level of protection for electrical workers. Made from high quality Type II material, 1/4" (6.4mm) thick and tested to 20kV to comply with ASTM D178, Class 2 specifications. The corrugated surface acts as a safety tread while reducing the possibility of metal particles becoming embedded.

Class 2 Maximum Use Voltage: 17,000 VAC
Class 4 Maximum Use Voltage: 36,000 VAC

PPE Clothing

Anti-static properties

Garments rated as anti-static have the ability to discharge any build-up of electricity instantly; they do not in affect hold an electrical charge. This charge can come from different synthetic fabrics rubbing against each other, badly earthed electrical products and numerous other sources. The main reasons certain industries insist on anti-static gear are firstly that a spark would readily ignite any petro-chemical vapours, causing an explosion, and secondly, some equipment such as computer memory chips and components are able to be rendered useless by static electricity. Natural fibres such as cotton are naturally good at preventing static charge build-up above freezing point, and therefore would be of benefit to someone looking for limited protection against these risks. For a more guaranteed protection against static discharge, it is necessary to either chemically coat the material (which washes out after 12 to 15 washes), or to weave conductive thread into the garment, like we have done with the Arcguard® garments and the Bison® Rigour rainwear.

EN50534 / NFPA 70E Electrical arc flash protection

These standards include specifications on Garment Design and Protection Factor in the event of high voltage arc strike. According to the North American association, the National Fire Protection Association (NFPA) 70E Hazard Risk levels (HRC levels), the minimum requirements for HRC 2 are 8.0 cal/cm².

All of our ArcGuard textiles® garments exceed the 8.0 cal/cm² minimum requirements for HRC 2. These garments range from our top quality FEPVC overall, FTPVC trouser and FJPVC jacket which have an arc rating of 9.6 cal/cm² ATPV+, to our lightweight FTPCN overall which has an arc rating of 8.4 cal/cm² ATPV+.

Arc Thermal Protection Value Rating (ATPV Rating)

This rating is stated where a fabric gives the wearer protection against the heat generated by an electrical arc from high voltage equipment. The surface temperature at the point of contact of such an arc can reach temperatures greater than 10,000oC, and obviously cause severe if not fatal burns without some protection against this. Our Arcguard® garments have a rating exceeding the minimum requirements of NZ companies for protection against 2nd degree burns. The rating of the materials used are based on the period of time it takes for the required test voltage arc to cause 2nd degree burns to the wearer.

The fabric helps prevent serious burns by turning into a fluffy carbonized deposit that sits against the wearer and reduces the heat transmitted directly to the wearer. To meet higher required ratings (where voltages worked around are considerably higher) the wearer of the garment must either use a specialized suit which may include a full hood, or layer other such ATPV rated garments underneath to provide further layers of protective “fluff” in the event of an arc flash.

This is similar to comparing thin and thick Pink Bats - the thicker the insulation, the less heat escapes, or in this case, the less the heat penetrates.

Should PPE be worn for Operating Breakers?

Operating breakers – opened/closed considered an arc flash exposure even if the hinged cover is on?

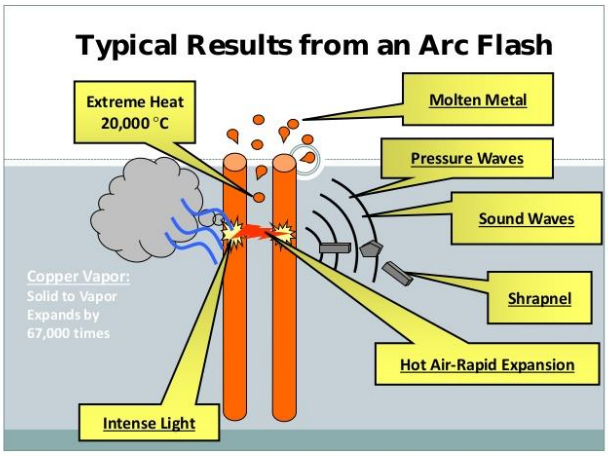
An arc flash hazard may exist when energized electrical conductors or circuit parts are exposed. When they are within equipment in a guarded or enclosed condition, provided a person is interacting with the equipment in such a manner that could cause an electric arc.

Under normal operating conditions, enclosed energized equipment that has been properly installed and maintained is not likely to pose an arc flash hazard.

1. Whenever a person interacts with electrical equipment, such as an opening/closing operation, even though the door is closed or the cover is on, an arc flash hazard may exist.

2. If the equipment has been properly installed, and properly maintained, an arc flash hazard is not likely to occur.
A person needs to take into account the age of the equipment, the design of the equipment, as well as its installed and maintained condition in order to determine if there is an arc flash hazard when open or closing a circuit breaker.

The doors may not withstand the pressure wave from an arc, and so may be just as hazardous as or more hazardous than doors open.



Incident energy caused by arc flash

Arc flash in switchboard

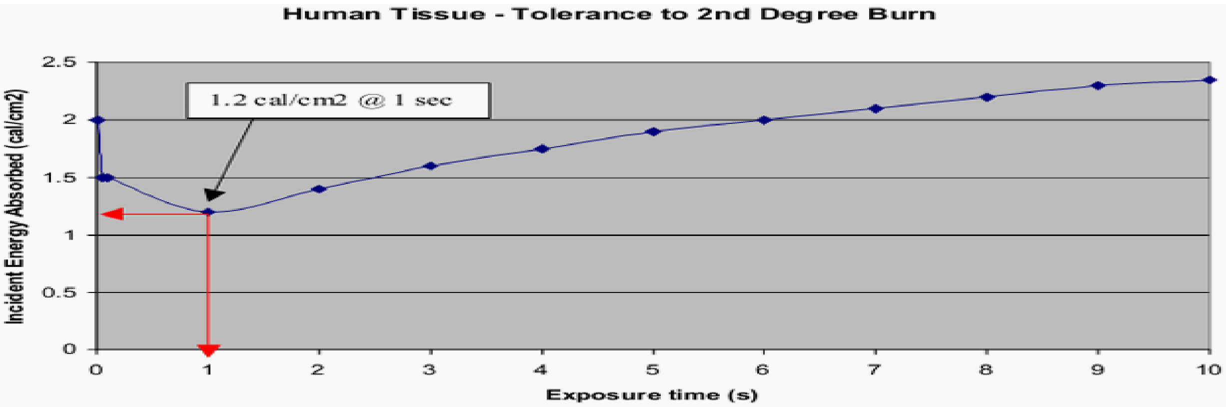
Incident energy is the energy per unit area received on a surface located a working distance away from the arc flash location. The working distance is the distance from where the worker to the flash location.

This is basically an arm length away or approximately 18 inches for low voltage panel boards, smaller equipment, and 24 inches for Switchgear. The distance is longer as the voltage increases.

The unit of incident energy is cal/cm^2. The threshold value of incident energy for 2nd degree burn of the human skin is about 1.2 cal/cm2. One cal/cm^2 is equivalent to the amount of energy produced by a cigarette lighter in one second. It is the incident energy that causes burns to the human skin.

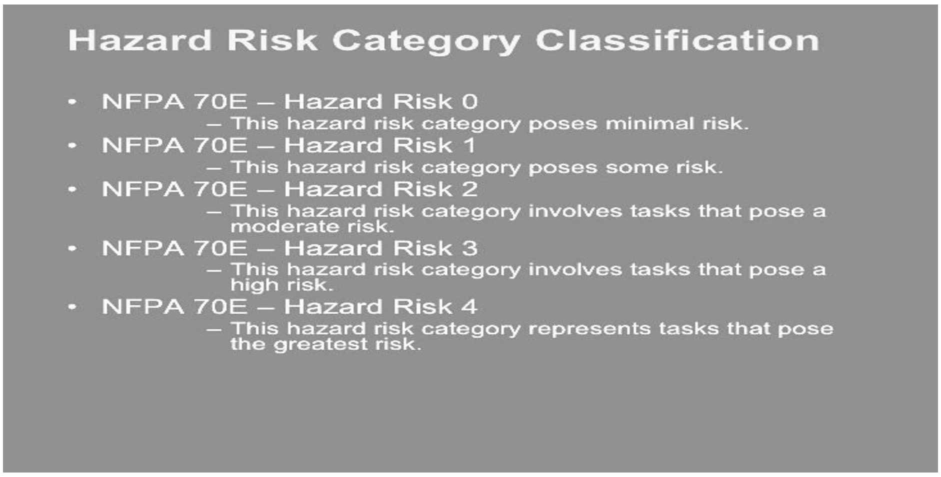
Incident Energy (cal/cm^2)	**Degree burn**
1.2	2nd degree burn to bare skin
4	Ignite a cotton shirt
8	3rd degree burn to bare skin

Incident energy is both radiant and convective. It is inversely proportional to the working distance squared. It is directly proportional to the time duration of the arc and to the available bolted fault current. It should be noted that time has a greater effect on the incident energy than the available bolted fault current.



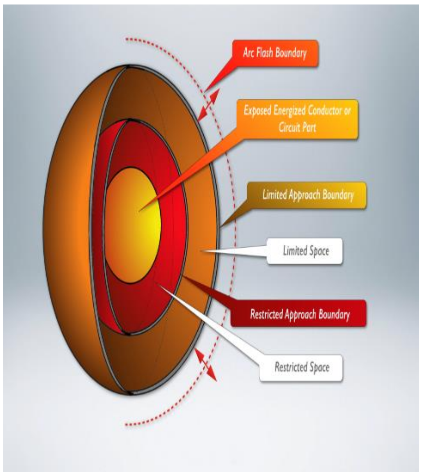
Human Tissue – Tolerance to 2nd Degree Burn

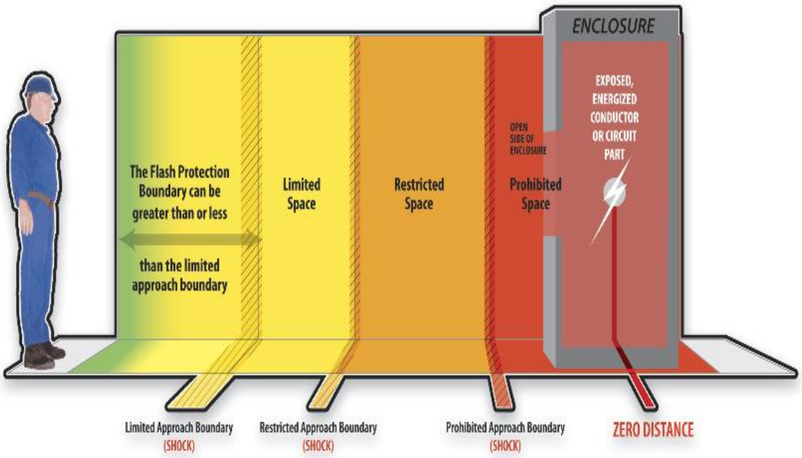
Both the NFPA-70E and IEEE Standard 1584 uses the assumption that an arc flash generating 1.2 calorie/cm^2 (1.2 calorie/cm^2 = 5.02 Joules/cm^2 = 5.02 Watt-sec/cm^2) for 0.1 second will result in a second-degree burn. It is also assumed that a second-degree burn will be curable and will not result in death.



HAZARD RISK CATEGORY	CLOTHING DESCRIPTION (number of clothing layers is given in parentheses)	Required Minimum ARC RATING OF PPE cal/cm2
0	Non-melting, flammable materials (i.e., untreated cotton, N/A wool, rayon, silk, or blends of these materials) with a fabric weight of at least 4.5 oz/yd2 (1)	N/A
HRC1	FR Shirt and FR pants or FR coveralls (1)	4
HRC2	Cotton underwear - short sleeve and brief/shorts, plus FR shirt and FR pants (1 or 2)	8
HRC3	Cotton underwear plus FR shirt and FR pants plus FR coverall, or cotton underwear plus two FR coveralls (2 or 3)	25
HRC4	Cotton underwear plus FR shirt and FR pants plus multilayer flash suit (3 or more)	40

Hazard Risk Category Chart based on NFPA 2112 and 70E






Facility Results™

Electrical System Reliability & Safety Solutions

FlashTrack™ Change Management Compliance Tool

QUALIFIED70E.com

Gloves on Hand

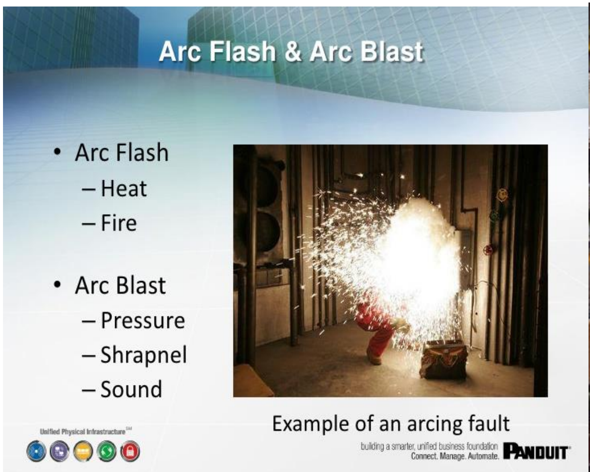
NFPA 70E 2012 EDITION

Table 130.7 (C)(16) Protective Clothing and Personal Protective Equipment (PPE)

*For More Detailed Information or Other Options Refer to NFPA 70E 2012 Edition, Table 130.7 (C)(16)

Hazard/Risk Category **0**	Untreated natural fiber Shirt (long sleeve) Pants (long) Safety glasses Hearing protection Leather gloves (as needed)	
Hazard/Risk Category **1** cal/cm² 4	Arc-rated long-sleeve shirt Arc-rated pants or coverall Arc-rated face shield with hard hat Safety glasses Hearing protection Leather & voltage rated gloves (as needed)	
Hazard/Risk Category **2** cal/cm² 8	Arc-rated long-sleeve shirt Arc-rated pants or coverall (New 2012) Arc-rated face shield & balaclava or arc flash suite hood Safety glasses Hearing protection Leather & voltage rated gloves (as needed)	
Hazard/Risk Category **3** cal/cm² 25	Arc-rated long-sleeve shirt Arc-rated pants or coverall Arc-rated flash hood Safety glasses Hearing protection Leather & voltage rated gloves (as needed)	
Hazard/Risk Category **4** cal/cm² 40	Arc-rated long-sleeve shirt Arc-rated pants or coverall Arc-rated flash hood Safety glasses Hearing protection Leather & voltage rated gloves (as needed)	

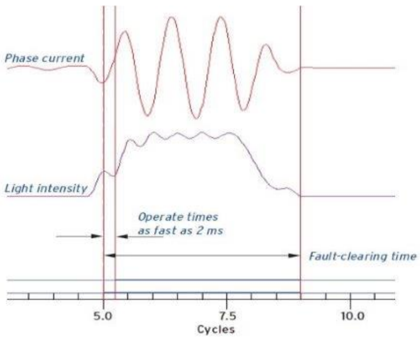
FacilityResults.com Sales@FacilityResults.com (888) 762-0090 © Rupert LLC © 2012

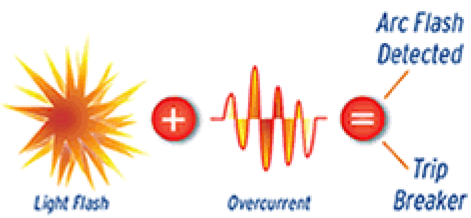


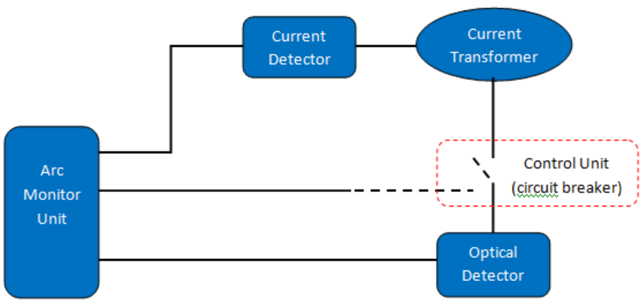
HV Electrical Safety Mats, these are manufactured using materials with high di-electric strength & can withstands Voltages up to 65kV AC & 240V DC.
These mats are laid on floors in close vicinity to Electrical apparatus, LV & HV Control Panels, Switchboards, Fuse Boxes, Switch-gear. Insulation mats are installed for safety of the engineers when operating switchgear and apparatus.

- Type II, Class 2 meets additional testing for Flame, Oil and Ozone resistance
- Protects workers from electrical shock by insulating against high voltage
- Diamond Plate matting conforms to ASTM testing D-178-01
- Tested dielectric strength 30,000 volts
- Maximum use voltage is 17,000 volts

Arc Flash detector
Dedicated Arc Flash Protection, arc flash protection is specifically designed to detect and trip for an arc flash event. Arcing time is a critical factor in limiting the damage and risk of personal injury resulting from an arc flash and possibly an arc blast.
Optical sensors detect the sudden increase in light intensity. Instantaneous over-current elements are used as fault detectors to supervise the optical system for security. Only source-connected current transformers (typically at the main breakers) need to be connected. Tripping occurs **only** if both light and fault current are simultaneously detected. For additional speed, these relays are equipped with high-speed solid state tripping outputs. Total operating time is typically less than 2.5 ms *(at 60Hz 1 cycle of AC is 16.667ms)*.







Case study :- Two engineers were working a 6.6 kV breaker that had been withdrawn to its test position.
Unfortunately, they forgot that the breaker was closed as they tried to push it into the operation position. The mechanical interlocks were bypassed as they forced the breaker into position. This, in turn, initiated an arc that could have caused extremely serious consequences.
Fortunately, the switchgear was equipped with dedicated arc flash relays utilizing long-fiber sensor technology, disconnection to cubical achieved and a major catastrophe was averted, due to the fast reaction time of the arc detection system, both workers escaped injury and possible death.


Electro-Magnetic fields

The hazards of exposure to electric and magnetic fields from high voltage power lines are well known ashore. With increasing application of high voltage power generation, distribution and propulsion systems on board merchant ships, ships' crews risk prolonged exposure to energy emissions when working at very close proximity to such equipment. It is suggested that more scientific studies are commissioned on this issue and ILO's system of certification of working and living spaces be expanded to include the independent measurement and evaluation of radiation from all shipboard sources (including communication system antennas), so that equipment makers and shipbuilders take all necessary measures to effectively protect ships' crews from harm.

Failure mode and effects Analysis (FMEA)

HV systems are complex, to ensure reliability and stability of these systems at sea, where they are typically also supplying propulsion and positioning thrusters. FMEA is a tool used when designing these systems to be robust under adverse situations.

An FMEA is often the first step of a system reliability study. It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects. For each component, the failure modes and their resulting effects on the rest of the system are recorded in a specific FMEA worksheet. There are numerous variations of such worksheets. An FMEA is mainly a qualitative analysis.

A few different types of FMEA analyses exist, such as

- Functional,
- Design, and
- Process FMEA

Fire protection systems for HV equipment and switchboards

Fire Fighting Systems, Inergen and Novec™ 1230 Gaseous inert gases.

Inergen is a mixture of nitrogen, argon and carbon dioxide gases and has been specially developed to provide fire protection as a Halon 1301 replacement.

It extinguishes fire by reducing the oxygen level in a room to below 15%, the point at which most combustibles will no longer burn.

Simultaneously the carbon dioxide in inergen stimulates the uptake of oxygen by the human body, so protecting anyone who might be trapped in the fire area from the effects of the lowered oxygen levels.

Inergen has been medically evaluated and approved by leading authorities around the world. All of them have accepted Inergen as being safe for use in “normally occupied areas”. Inergen is the first Halon replacement to have been fully tested on humans.

Inergen is stored in gaseous form. It therefore does not produce fog when the gas is released into the room.

Because Inergen is a mixture of naturally occurring gases, it does not form decomposition products in a fire.

One of the greatest failings of Halon systems is the speed with which the Halon gas escapes from the room after discharge.

The mixture specification of Inergen overcomes this problem by bringing the relative density of Inergen close to that of air. The result is outstanding hold time performance for Inergen.

Inergen does not chemically interfere with the fire and hence does not form any corrosive decomposition products in the fire.

Features:

- No ozone depletion potential
- No Global Warming Potential
- No Atmospheric Live
- Safe for occupied areas

- No decomposition products
- Fully tested on humans
- No fogging when discharged
- Remote Storage of Agent
- Directional Valve Systems
- Escape routes are not obscured.
- No toxic decomposition products.
- Excellent retention time within the room.
- No corrosive decomposition products

Novec 1230 , 3M™ Novec™ 1230 Fire Protection Fluid is engineered to provide clean, fast, people-safe protection for applications requiring a "green" solution to fire suppression. The system includes detectors, a control unit, agent storage cylinders, piping and discharge nozzles. The system is computer calculated to provide system discharge within 10 seconds.

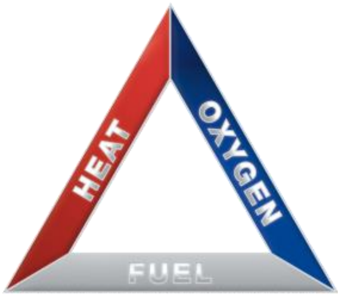
ʼre-engineered marine fire suppression systems are fixed installations. The system protects a given volume of an enclosure incorporating various discharge modes such as automatic heat activation or manual release by way of a mechanical pull cable. Is non-corrosive and electrically non-conductive, so it will not harm delicate electronics, radar, navigation and other equipment. Evaporates quickly and completely. Leaves no residue.
Can be safely used on energized equipment, helping to ensure continuity of operations during a fire emergency a highly effective fire extinguishant, designed to knock down fires quickly.

HPWM (high pressure water mist) HI-FOG®, the discharge is qualified as 'dry' mist because it has a lower water volume, making the HI-FOG® DAU ideal for sub-floor spaces with high voltage or electronic equipment.

"High Fog" raises the issue that current ships fire fighting techniques are old fashioned and slow to act failing initial first aid fire fighting efforts.
If ships' crews are to be reduced on future vessels, attention will need to be paid to developing a holistic and intelligent fire fighting system that can remove the 'man with an extinguisher' as far as possible.

HPWM is an excellent solution for providing comprehensive cover across a surface ship. It allows for an instant response to a fire situation, in that it is non-toxic, does not require spaces to be sealed and ***can be deployed in HV and machinery spaces.*** The mist acts in several ways to fight fire but can also be used to prevent flashovers and pre-emptively cool compartments.

Water mist has also been found to offer blast mitigation. In order to provide comprehensive cover however, the entire ship needs to be covered by high pressure sprinkler nozzles that can either be triggered locally by rising temperatures or on command from a control system. It is this 'total coverage' element that means personnel are not required in the large numbers in firefighting. Installing and supplying such a large system presents its own complexities. Possible savings could be made if certain areas of a platform were prioritised for HPWM cover. This could be limited to high risk areas or priority escape routes and passageways for personnel.
Water would need to be provided from a fresh water source and would not initially be supplemented from the Sea Water Main supply pumps.



HI-FOG® is an exceptionally efficient fire safety technology, as it uses significantly less water than traditional sprinkler systems, while achieving a similar or better level of performance, and minimizes both fire and water damage.
HI-FOG® performance is based on fast evaporation of water that cools down the flame and surrounding gases as well as locally displaces oxygen. The very small droplets as such effectively block radiant heat. The HI-FOG® micro-droplets, represent water in its most effective fire fighting form.
The high pressure enables the water mist to penetrate into a fire in liquid form and result in evaporation in locations where it is of most use. High pressure water mist also effectively fills up the protected space and provides superior cooling, hence protecting surrounding equipment and structures. The strong downward throw of the water mist sprays also entrain surrounding hot smoke restricting its spread and reducing the number of unnecessary sprinkler activations further away from the actual fire. This property further contributes in minimising water related damage as compared to traditional sprinkler systems.

The benefits of the HI-FOG® Water Mist System stem from safer, simpler and easier fire protection.
While gas suppression has proven to be an effective fire protection method, there are a number of pitfalls to using this type of system. Indeed, when compared to the effectiveness and cost-saving features of HI-FOG®, the gulf becomes remarkably apparent.

Gaseous systems place high demands on the construction and maintenance of the facility, and may also lead to facility- and equipment-damaging issues. The common challenges associated with these systems often revolve around the fact that only the purchase costs are analysed, with other construction and maintenance costs forgotten or neglected.

The room or the enclosure needs to be 'air tight' with gas suppression systems in order to contain the agent long enough to extinguish a fire. This requires the complete sealing of all walls, floors and ceiling slabs including doorways and openings. Full discharge test or an enclosure integrity test (also known as a door fan test) is needed as part of the system acceptance process in order to prove the system functionality. That is not the case with HI-FOG®, which fire fighting performance has been proven in number of full scale fire tests. HI-FOG® can be activated at any point in time without delay – thus increasing the safety of the facility and its personnel.

HI-FOG®: Saving Time, Costs and Productivity
As well as the logistical issues, gas suppression, particularly when measured against the HI-FOG® water mist fire suppression system, can be costly.
Regardless of whether there is a large or small fire, or if there is simply false alarm activation, all the gas within the system is discharged. Refilling the system can cost a great deal of money, while waiting for the system to be operational once again often hinders business continuity.
Conversely, the type-approved HI-FOG® system is easily reset via a pump unit, allowing the system to be instantaneously ready to serve its purpose: fire protection.

Electrical fires are fires involving potentially energized electrical equipment. The US system designates these "Class C"; the Australian system designates them "Class E". This sort of fire may be caused by short-circuiting machinery or overloaded electrical cables. These fires can be a severe hazard to firefighters using water or other conductive agents.

Electricity may be conducted from the fire, through water, to the firefighter's body, and then hull.

Electrical fire may be fought in the same way as an ordinary combustible fire, but water, foam, and other conductive agents are not to be used.

While the fire is or possibly could be electrically energized, it can be fought with any extinguishing agent rated for electrical fire. Carbon dioxide CO_2, FM-200 and dry chemical powder extinguishers such as PKP and even baking soda are especially suited to extinguishing this sort of fire. PKP should be a last resort solution to extinguishing the fire due to its corrosive tendencies.

Once electricity is shut off to the equipment involved, it will generally become an ordinary combustible fire. In Europe "Electrical Fires" are no longer a class of fire as electricity can not burn. The items around the electrical sources may burn.

By turning the electrical source off, the fire can be fought by one of the other class of fire extinguishers.

Class C (E for Australian Standards) - Electrical Equipment

Class C fires take place in live electrical equipment - motors, generators, switches, and appliances. Non-conducting extinguishing agents such as dry chemicals, or carbon dioxide are required to extinguish them.

Carbon Dioxide
(red, now red with a black band or label) Carbon Dioxide or CO2 is suitable for use on Class B and E fires. Its major advantage is that it is a naturally occurring gas that does not require Carbon dioxide can be used on electrical fires because, being a gas, it does not leave residues which might further harm the damaged equipment, cleaning up after use.

Similarly, water sprayed on an electrical fire (UK: Class E, US: Class C) increases the likelihood that the operator will receive an electric shock. However, if the power can be reliably disconnected and a carbon dioxide or halon extinguisher is not available, clean water actually causes less damage to electrical equipment than will either foam or dry powders.

Maintaining a “Fire Folder” - a good practice is to have a folder containing all information on the ships fire fighting systems available in the various locations on board, hazards to be aware of when isolating electrical equipment, location of isolators.

Chapter 2

Section 1

Trapped key interlocking systems

This method utilizes locks and keys for sequential control of equipment and machinery to ensure safe operation. Trapped key interlocks are widely used to ensure safe access to potentially live or dangerous plant or equipment in an industrial setting.

A safe sequence of operations is enabled through transfer of keys that are either trapped or released in a predetermined order. For example, a key is used to isolate a power source (circuit breaker or supply valve), this key is then released and can then be used to gain access through a gate or door to a high risk area by inserting it into an access lock. The key will then remain trapped until the gate or door is closed. A personnel or safety key can be released from the access lock, this ensures that the gate or door cannot be closed and the initial key released until this personnel or safety key is returned. This provides increased operator safety.

Trapped Key Interlocks are mechanical or electro-mechanical devices used to ensure the safe operation of plant and equipment in a predetermined fashion.

Switchgear interlocking and HV switching, prevents switching and isolation risks in complicated distribution systems.

A good safety system is a comprehensive risk assessment and understanding of the maintenance requirements. Trapped key technology will enforce these procedures.

Key Interlocks

Unlike padlocks, key interlocks are permanently fitted to switchgear and only allow the release of a key when the switchgear is locked in a safe open/isolating position. The released key can then be used to operate the next step in the controlled system, such as:

Operate/close another switchgear device controlling an alternative supply
Operate a door lock to provide access to the switchgear enclosure for arc flash protection
Operate an access/door lock for entry into a once hazardous area/machine.

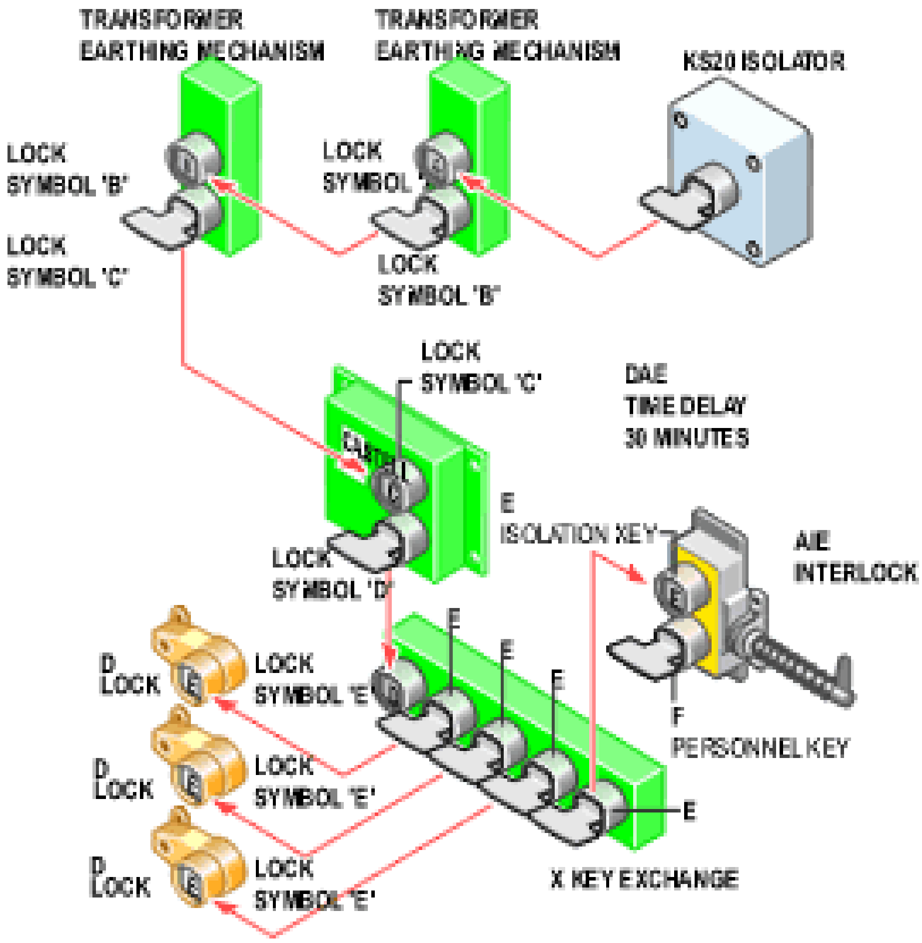
Key interlocks coded with the same key code can be installed on all incomer switchgear. With only one key to allow closure/operation of switchgear, it ensures that only one source can be active at any time. Only the switchgear in which the key is placed can be closed and turned on.

Key interlocks force lockout via a permanent keyed sequence of operations and eliminate procedures, inspections and human errors that are required or present with simple unenforced padlock methods.

Trapped Key Interlock - Example 1

Ensure that transformers are isolated and earthed prior to access being gained to the transformer enclosures.

Condition 1
Transformer is locked on with the earth switch locked off and access cabinets locked closed.

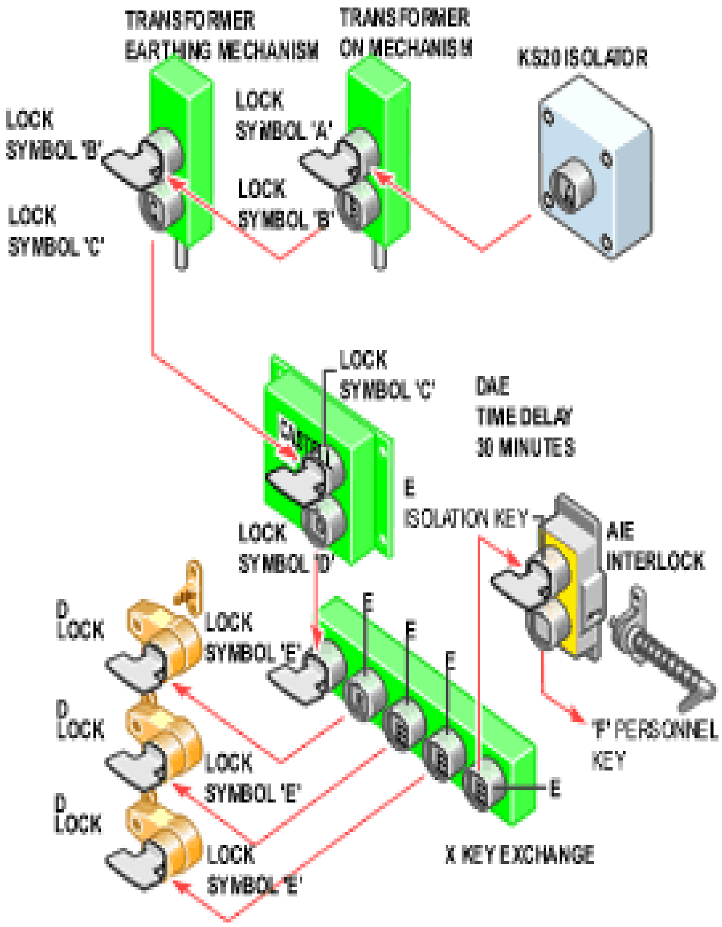


Condition 2

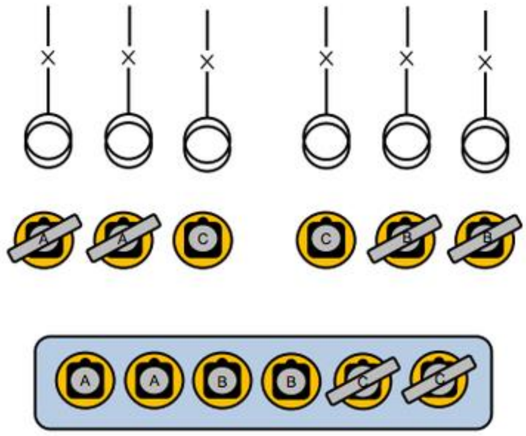
Power to the transformer is isolated via an isolator, this releases key ‘A’. Key ‘A’ is taken to the ‘KL’ lock fitted to the transformer ‘ON’ mechanism. The mechanism is switched to the ‘OFF’ position and the key ‘A’ inserted which allows the extension of the ‘KL’ locking bolt and the release of key ‘B’. The transformer is now locked off. Key ‘B’ is taken to the transformer earth mechanism which is moved to the earthed ‘ON’ position and inserted which allows the extension of the ‘KL’ locking bolt and the release of key ‘C’. The earth is now locked on. Key ‘C’ is inserted into the time delay unit ‘D’ and the time delay initiated. The time delay is required to ensure that the capacitors are discharged prior to access. On completion of the delay key ‘D’ becomes available. Key ‘D’ is inserted into the key exchange box ‘X’ to release the access keys ‘E’. Access can now be gained to the enclosures via the access locks ‘D’ and ‘AIE’.

KL=key lock, X=exchange box, AIE **A**ccess **I**nterlock **E**xchange (dual key access interlock)

Condition 2 contin… *(below is the state with the AIE access interlock bolt lock open allowing access to the transformer enclosures)*



Trapped Key Interlock - Example 2 Feeders incomer interlocking;



This system will require six locks depending on the breakers. One key exchange box and six keys.

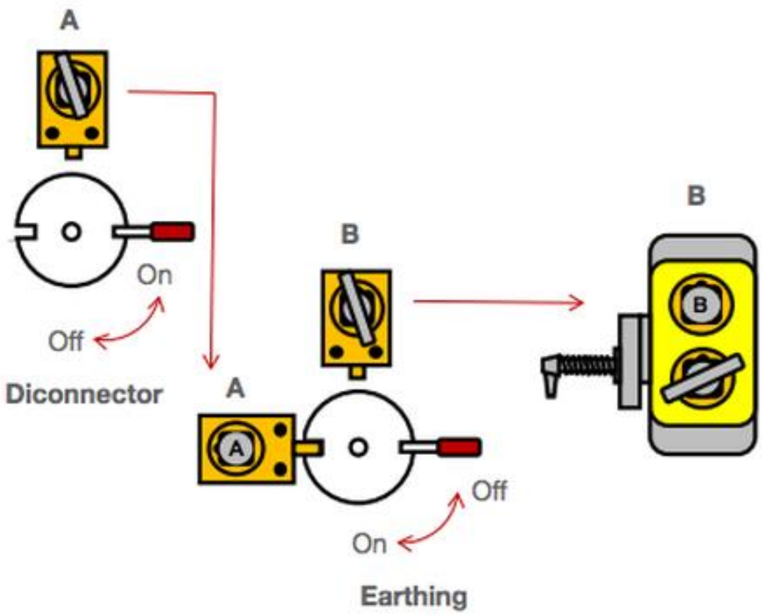
Breakers A and B are closed and the keys are trapped. Keys A and B are removed from the breakers when they are opened and inserted into the key exchange box releasing the C keys.

The C keys are then inserted in the C locks, closing breakers C.

The symbols used here are A, B and C for the incomers.

All locks can be individually fitted to suit the switchgear.

Trapped Key Interlock - Example 3   Transformer Interlocking;



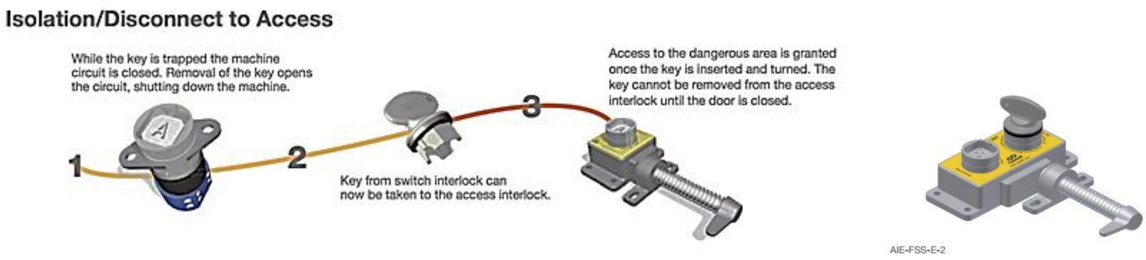
The disconnector is on the A key cannot be removed. Switching the disconnector to the off position will allow the A key to be removed from the K Lock.

This A key can then be inserted into the K Lock which will retract the bolt and allow the earthing to be switched on.

This will in turn allow the key B to be removed extending the bolt and locking the earthing in to the on position.

The B key can now we used to gain access through AIE. A personnel key will be released to ensure that the operation cannot be reversed whilst personnel are in the transformer housing.

The symbols used here are A for the disconnector and earthing and B for the earthing and the access lock.



Lock Out Tag Out (LOTO)

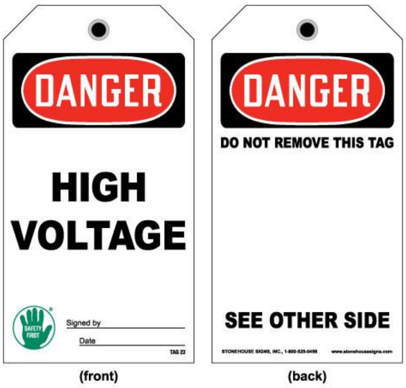
Lockout is the process of blocking the flow of energy (electrical, pneumatic, hydraulic, gravitational, energy stored in springs, etc.) to a piece of equipment and keeping it blocked out. A lockout device is a lock, block or chain that keeps a switch, valve or lever in the off position.

Tags are used to support the lockout and are part of the complete process. The tag records who made the energy isolation (lock out) and when. The tag acts as a warning not to restore energy to or restart the piece of equipment under lockout. Tags must clearly state: **DO NOT OPERATE** and it must be applied by hand.

Lockout tagout is a safety procedure which is used in industry to isolate hazards such as electrical power by locking off breakers or other switchgear in their isolating position and therefore rendered inoperative until the lock is removed.

Lockout devices are devices that can be used to positively lock energy isolating devices in the open/isolating position. The most common lockout tagout device is a padlock. Padlocks ensure positive lockout by locking the energy isolating device in the open/isolating position.

Note - while padlocks are a common solution, they are not considered the safest form of lockout, this is because there is no enforcing control, i.e. there is no way to ensure a padlock is actually applied and used.



When maintenance is needed on any electrical powered line, motor, equipment or fuel-powered engines, you should protect yourself and others from accidental turn-on. Accidents and deaths can occur when someone "thought" the machine or electricity was safely turned **OFF**.

1) The person in charge should identify all parts that are to be shut down and which switches, equipment and people will be involved in maintenance, repairs or installation. At this time, the restarting procedures are planned with details written down for who starts it, when it happens and how it is carried out.
2) Advise everyone involved that a lockout/tag out procedure will take place.
3) Identify all power sources for the project. What makes it work? This includes identifying all hydraulic and pneumatic systems, spring, compressed air, gravity systems and all electrical circuits.
4) Every power source has its own procedures for lockout which may be accomplished by pulling a plug, opening a disconnect switch, removing a fuse, closing a valve, bleeding the line or placing a block in the equipment.
5) Each worker involved should have his own lock keyed differently from anyone else's lock. It should be identified with the owner's name, an assigned number or color code and the name of their department or company. Clips, chains and lockout boxes, which are available from locksmiths, electrical supply companies or through your company Health, Safety and

Environment (HSE) or Purchasing Department may also be used. These lockout devices may only be removed by the individual placing the lock.

6) Tag out all the power sources and machines. Tags should indicate that the machine or circuit is out of order, the reasons for the lockout, time and date of lockout, your name, the phone number at which you can be reached and the time of tagging. Tagging should be done by the person in charge and removed only after everyone's lock has been removed, the system tested and restart approved.
7) When locks and tags are in place, and before any work takes place, verify that there is an absence of energy in the system (zero energy state).
8) The person in charge should clear the area. Double check all the steps listed above. Remove locks, turn on power sources and operate any valves to prepare to test the system. With all workers safe and the equipment ready, remove the "out of order" tab before turning the power on.
9) Supervisors or persons in charge should ensure that they have received "Permit to Work" training as applied to that particular location and people working for them have received adequate instruction in the system.
10) Adequate time should be allowed during shift changes to ensure effective transfer of information on outstanding permits.

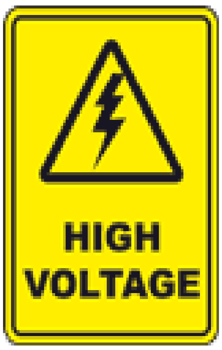
Permits to Work (PTW) are designed to ensure that safe methods of working are adopted in circumstances where there is a potential hazard to those carrying out the work. Appropriate Permits to Work (PTW) are to be obtained from the Authorised Persons prior to commencing work of this nature and these must be signed off once the work has been completed.

Once issued the conditions of the permit must be strictly adhered to at all times.

High Voltage Signs

High voltage areas can be very dangerous for people because of the electrical hazards there that are often invisible. Unless notified with properly placed high voltage signs, people won't be alerted of the hazards there, and entry to these areas could result in fatalities or serious injuries. Warning people to keep out with high voltage signs is essential for their safety.

Safety signs for stating “Danger High Voltage” to warn people of dangerous electrical areas. Signs can help ensure the safety of everyone in high voltage areas and are available in multiple sizes.



International safety symbol "Caution, risk of electric shock" (ISO 3864), also known as *high voltage symbol.* Signs are a constant reminder to warn and raise levels of conscience.

Risk assessment – Job Safety Analysis (JSA)

The access to high voltage switchboards and equipment must be strictly controlled by using a risk assessment and a permit to work system. Isolation procedures must involve a safety key system and earthing down procedures.

Safety acronym:
- **D**isconnect
- **I**solate
- **E**arth

To help identify high voltage system work precautions, a risk assessment must be completed by the Chief Engineer or Chief Electrical officer before work begins, and this should consider:
- how familiar are the personnel with the high voltage system and equipment?
- can the work be done with the equipment dead?
- is it necessary for someone to work on or near live high voltage equipment?
- what precautions have been taken to avoid danger and prevent injury?
- is the person(s) carrying out the work competent or adequately supervised?

(Documentation forms- examples in Appendix 1**)**

Permit to work system for high voltage system work

The company safety management system (SMS) should include a permit to work system for electrical equipment under 1,000V. A similar high voltage permit should also be included in the SMS.
Samples of electrical permits for low voltage and high voltage installations can be found in the Code of Safe Working Practices for Merchant Seaman (COSWP) 2010 edition.

https://www.gov.uk/government/publications/code-of-safe-working-practices-for-merchant-seamen-coswp

LOW VOLTAGE SYSTEM PERMITS TO WORK ARE NOT APPROPRIATE FOR WORKING WITH HIGH VOLTAGE SYSTEMS.

Dangers working with high voltage equipment

A high voltage electrical shock is a significant danger to any person carrying out electrical work. Any simultaneous contact with a part of the body and a live conductor will probably result in a fatal electric shock.
There is also a risk of severe burn injuries from arcing if conductors are accidentally short-circuited.
A high voltage electric shock will almost certainly lead to severe injury or a fatality.
Factors that could increase the risk of receiving an electric shock:
- high voltage work may be carried out close to a person that is not familiar with high voltage hazards. Therefore, the area must be secured from the surrounding non-electrical work and danger notices posted
- areas of earthed metal that can be easily touched increase the possibility of electric shock from a high voltage conductor

• high voltage insulation testing (flash testing) can be particularly hazardous when several parts of the equipment are energised for a period of time
• equipment using water as part of the high voltage plant can lead to an increased risk of injury
• using test instruments when taking high voltage measurements can increase the risk of injury if the protective earth conductor is not connected. This can result in the enclosure of the instrument becoming live at dangerous voltages
• high voltage equipment will store energy after disconnection. For example, on a 6.6kV switchboard, a fatal residual capacitive charge may still be present hours or even days later
• if, during maintenance, a high voltage circuit main earth (CME) is removed from the system, it must not be worked on as the high voltage cabling can recharge itself to a high voltage (3–5kV) from induced voltages from nearby live high voltage cabling.

Personnel should not work on high voltage equipment unless it is dead, isolated and earthed at all high voltage disconnection points.

The area should be secured, permits to work or sanction for test notices issued, access should be limited and only competent personnel should witness the testing to prove isolation.
Safety Management Systems should also address the additional requirements of high voltage systems.

Additional procedures needed for high voltage systems

These additional procedures are freely available from the MCA Code of Safe Working Practices for Merchant Seaman
(COSWP) 2010 edition, which could be used as reference.

Sanction-for-test System
Following work on a high voltage system, it is often necessary to perform various tests. Testing should only be carried out after the circuit main earth (CME) has been removed.
A sanction-for-test declaration should be issued in an identical manner to a permit to work provided and it should not be issued on any apparatus where a permit to work or where another sanction-for test is in force.

Note: A sanction-for-test is NOT a permit to work.
An example of a sanction-for-test declaration is shown in the Code of
Safe Working Practices (COSWP) 2010 edition Annex 16.2.1.

Limitation of access form
When carrying out high voltage maintenance, it may be dangerous to allow anyone to work adjacent to high voltage equipment, as workers may not be familiar with the risks involved when working on or nearby high voltage equipment. The limitation of access form states the type of work that is allowed near high voltage equipment and safety precautions. The form is issued and signed by the Chief Engineer or Chief Electrical officer, and countersigned by the person carrying out the work.

Voltages greater than 50 V applied across dry unbroken human skin can cause heart fibrillation if they produce electric currents in body tissues that happen to pass through the chest area. The voltage at which there is the danger of electrocution depends on the electrical conductivity of dry human skin. Living human tissue can be protected from damage by the insulating characteristics of dry skin up to around 50 volts. If the same skin becomes wet, if there are wounds, or if the voltage is applied to electrodes that penetrate the skin, then even voltage sources below 40 V can be lethal.

Accidental contact with high voltage supplying sufficient energy may result in severe injury or death. This can occur as a person's body provides a path for current flow, causing tissue damage and heart failure. Other injuries can include burns from the arc generated by the accidental contact. These burns can be especially dangerous if the victim's airways are affected. Injuries may also be suffered as a result of the physical forces experienced by people who fall from a great height or are thrown a considerable distance.

Low-energy exposure to high voltage may be harmless, such as the spark produced in a dry climate when touching a doorknob after walking across a carpeted floor. The voltage can be in the thousand-volt range, but the amperage (the number of electrons involved) is low.

Safety equipment used by electrical workers includes insulated rubber gloves and mats. These protect the user from electric shock. Safety equipment is tested regularly to ensure it is still protecting the user.

While lower voltages don't, in general, jump a gap that is present before the voltage is applied, interrupting an existing current flow often produces a low-voltage spark or arc. As the contacts are separated, a few small points of contact become the last to separate. The current becomes constricted to these small *hot spots*, causing them to become incandescent, so that they emit electrons (through thermionic emission). Even a small 9 V battery can spark noticeably by this mechanism in a darkened room. The ionized air and metal vapour (from the contacts) form plasma, which temporarily bridges the widening gap.

If the power supply and load allow sufficient current to flow, a self-sustaining arc may form. Once formed, an arc may be extended to a significant length before breaking the circuit. Attempting to open an inductive circuit often forms an arc, since the inductance provides a high-voltage pulse whenever the current is interrupted. AC systems make sustained arcing somewhat less likely, since the current returns to zero twice per cycle. The arc is extinguished every time the current goes through a zero crossing, and must reignite during the next half-cycle to maintain the arc.

Unlike an ohmic conductor, the resistance of an arc decreases as the current increases. This makes unintentional arcs in an electrical apparatus dangerous since even a small arc can grow large enough to damage equipment and start fires if sufficient current is available. Intentionally produced arcs, such as used in lighting or welding, require some element in the circuit to stabilize the arc's current/voltage characteristics.

Arc flash hazard

Depending on the prospective short circuit current available at a switchgear line-up, a hazard is presented to maintenance and operating personnel due to the possibility of a high-intensity electric arc. Maximum temperature of an arc can exceed 10,000 kelvin, and the radiant heat, expanding hot air, and explosive vaporization of metal and insulation material can cause severe injury to unprotected workers. Such switchgear line-ups and high-energy arc sources are commonly present in electric power utility substations and generating stations, industrial plants and large commercial buildings. In the United States, the National Fire Protection Association, has published a guideline standard NFPA 70E for evaluating and calculating *arc flash hazard*, and provides standards for the protective clothing required for electrical workers exposed to such hazards in the workplace.

Explosion hazard

Electrical equipment in hazardous areas

Even voltages insufficient to break down air can be associated with enough energy to ignite atmospheres containing flammable gases or vapours, or suspended dust. For example, hydrogen gas, natural gas, or petrol/gasoline vapour mixed with air can be ignited by sparks produced by electrical apparatus.

Measures taken to prevent such explosions include:

- Intrinsic safety by the use of apparatus designed not to accumulate enough stored electrical energy to trigger an explosion
- Increased safety, which applies to devices using measures such as oil-filled enclosures to prevent sparks
- Explosion-proof (flame-proof) enclosures, which are designed so that an explosion within the enclosure cannot escape and ignite a surrounding explosive atmosphere (this designation does not imply that the apparatus can survive an internal or external explosion)
- Bonding GRP ladder support systems to prevent electrostatic discharge ignition

In recent years, standards for explosion hazard protection have become more uniform between European and North American practice. The "zone" system of classification is now used in modified form in U.S. National Electrical Code and in the Canadian Electrical Code. Intrinsic safety apparatus is now approved for use in North American applications, though the explosion-proof (flame-proof) enclosures used in North America are still uncommon in Europe.

Section 2

High Voltage measuring instruments connections

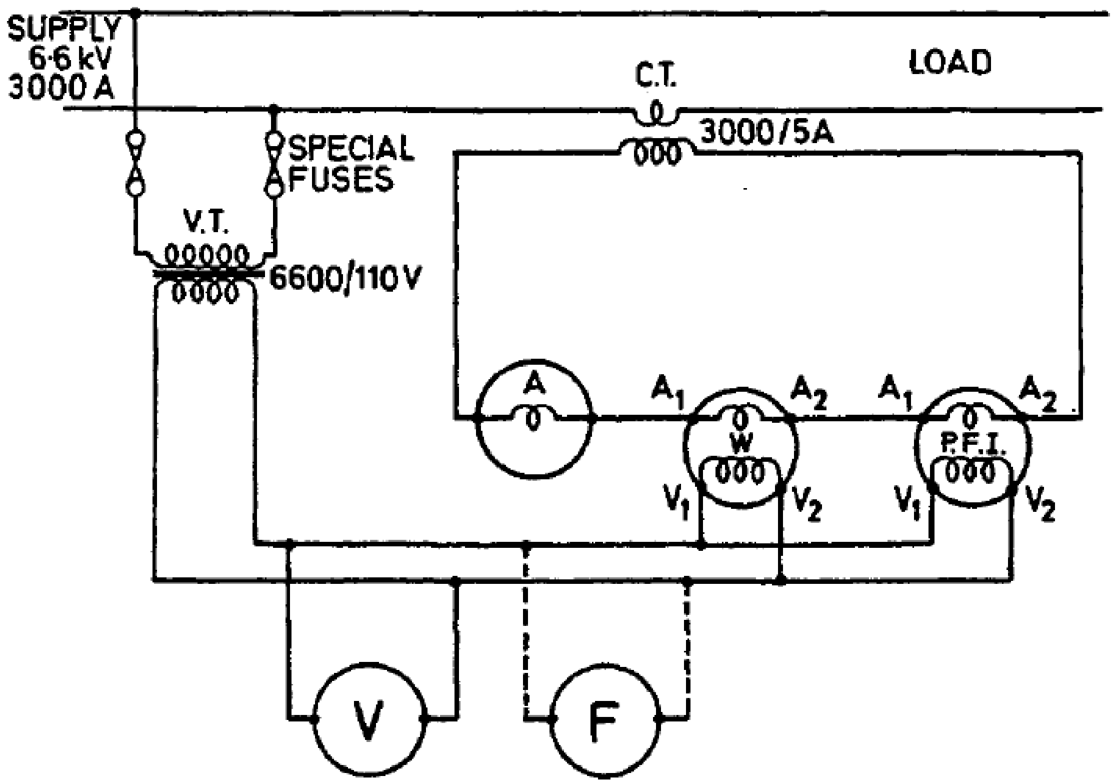
Current Transformer

Voltage Transformer

High Voltage VT or PT (potential) instrument transformer– VP=3000-15000V, VS=110V. This transformer is used in measuring instruments and protection systems.

High Voltage current transformer CT, are used for current metering and protection in high voltage systems. They transform the high current on the high voltage side into low current (1 or 5 A) adequate to be processed in measuring and protection instruments). A current transformer also isolates the measuring instruments from the high voltage of the monitored circuit.

PT and CT transform currents or voltages from a usually high value to a value easy to handle for protection relays and measurement instruments.
Used to insulate the metering circuit from the primary high voltage system, standardising the instruments and relays to a few rated currents and voltages.



HV Neutral Earthing Resistor (NER)

High voltage systems (3.3kV and above) on board ship are normally earthed.

HV systems are usually earthed via a NER resistor connecting the main generator neutrals to earth as shown in fig 2.6

The ohmic value of each earthing resistor is usually chosen so as to limit the maximum earth fault current to not more than the generator full load current. Such a Neutral Earthing Resistor (NER) is usually assembled from metallic plates. The use of such an earthed HV system means that a single earth fault will cause current to flow in the neutral connection wire. This is monitored by an earth fault (E/F) relay to create alarm and trip functions.

The Neutral Earthing Resistor is limiting the fault current on a High Voltage Ship installation to a low value, compared with a 440 Volt system where the PSC currents can be extreemly high as the only limiting factor is the impedance that is typically very low.

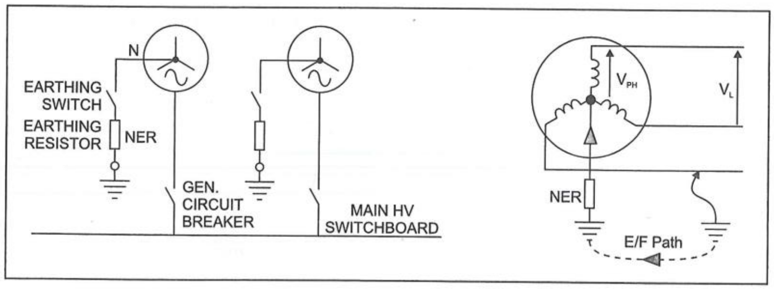


Fig. 2.6 Neutral earthing in HV system.

To calculate what would be the ohmic value of an NER, to limit the earth fault current to the full load rating of a 2MW (2,000000W), 0.8 pf, 3.3kV, 3 phase AC generator?

Solution, in a 3 phase system; $P=\sqrt{3}.VL.IL.\ Cos\theta$

where VL is the line voltage 3.3kV, IL is the line current and Cosθ is the power factor

The generator full load current is:

$$IL = \frac{2{,}000000\text{W}}{\sqrt{3}\ \text{x}\ 3{,}300\text{V x } 0.8\text{pf}}$$

= 437 Amp

Under E/F conditions a phase voltage of $VPH = \frac{3{,}300}{\sqrt{3}}$ = V phase = 1905V

$NER = \frac{1905\ \text{V}}{437\ \text{A}}$ = 4.4 Ω therefore a 4.4 Ω NER resistor will limit the maximum earth fault current to approximately 400 Amps

The HV system is normally not an insulated system as found typically on LV systems on board ships, the NER resistance can designed as a high impedance on some vessels or as a medium or low impedance on other vessels the value of the NER will directly relate to the protection systems, eg:- High impedance NER value will result lower earth fault currents and protection relays will be calibrated to trip on lower currents.

The NER has no effect on limiting a Line to Line short circuit (possible cable fault between the generator and the main switchboard), in this fault condition the current is limited only by the total impedance in the fault path, again typically very low and with a HV system the fault current is likely to be extremely high eg:- at 6.6kV ÷ 0.025Ω (typical impedance at the live side of a main circuit breaker) I_f = 264,000 Amps

An HV system (1kV – 11kV) is usually earthed at the main generators neutral point via a neutral earthing resistor (NER). This arrangement (fig 2.9) allows the neutral (earth fault) current to be monitored for the alarm/trip by a current transformer (CT) and earth fault (E/F) relay.

(Note: HAL MV Oosterdam NER is 2100 Ω = 3 Amps)

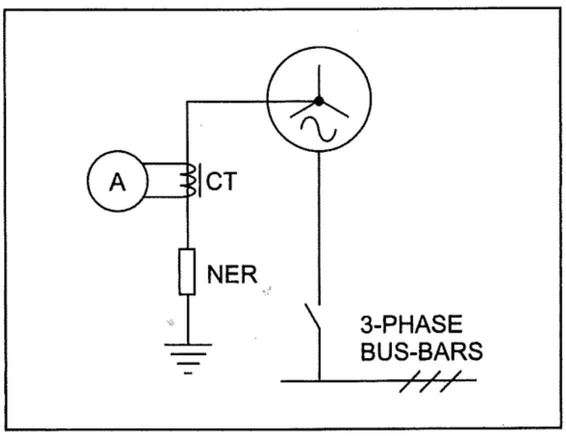
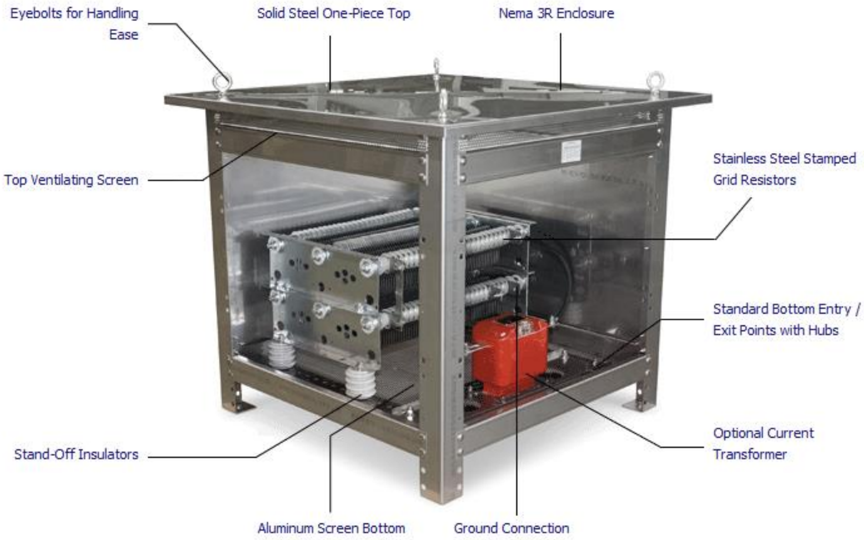


Fig. 2.9 NER circuit.



Prospective short-circuit current (I PSC) fault current

The current which is likely to flow in a circuit if line and neutral cables are short circuited is called the prospective short circuit current (PSC). It is the largest current which can flow in the system.

Protective devices must be capable of breaking it safely. The breaking capacity of a fuse or of a circuit breaker is one of the factors which need to be considered in its selection.

The effective breaking capacity of overcurrent devices varies widely with their construction.

Cartridge fuses to BS 1361 will safely break at 16.5 kA for type 1 or 33 kA for type II. BS 88 fuses are capable of breaking any possible short-circuit current.

Miniature circuit breakers to BS EN60898 have their rated breaking capacity marked on their cases in amperes (not kA) although above 10000 A the MCB may be damaged and lower breaking currents (75% for 10000 A and 50% above that level) must be used for design purposes.

Prospective short circuit current is driven by the e.m.f. of the secondary winding of the supply transformer through an impedance made up of the secondary winding and the cables from the transformer to the fault Fig 3.21.

The impedance of the cables will depend on their size and length, so the PSC value will vary throughout the installation, becoming smaller as the distance from the intake position increases.

If the impedance of the supply system can be found, a straightforward calculation using the formula of Fig 3.21 can be used.

$$\text{Prospective Short Circuit current} \quad I\,PSC = \frac{\text{Supply Volts}}{Z_1+Z_2+Z_3\ldots}$$

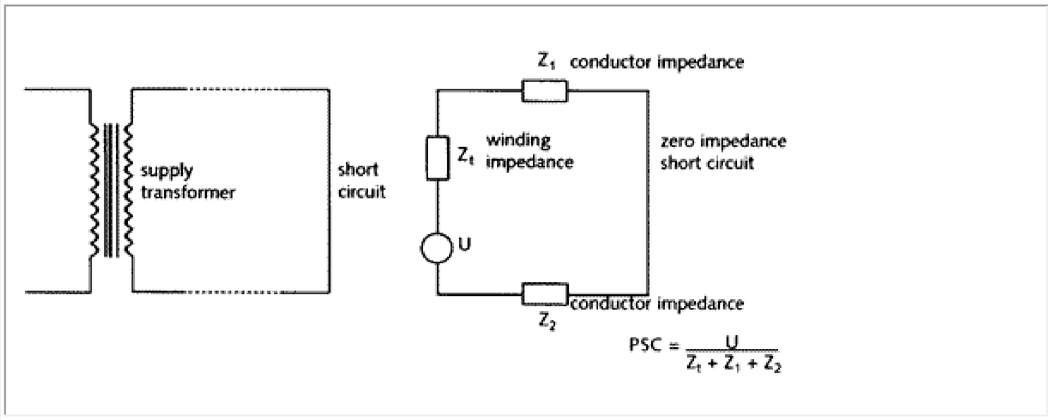
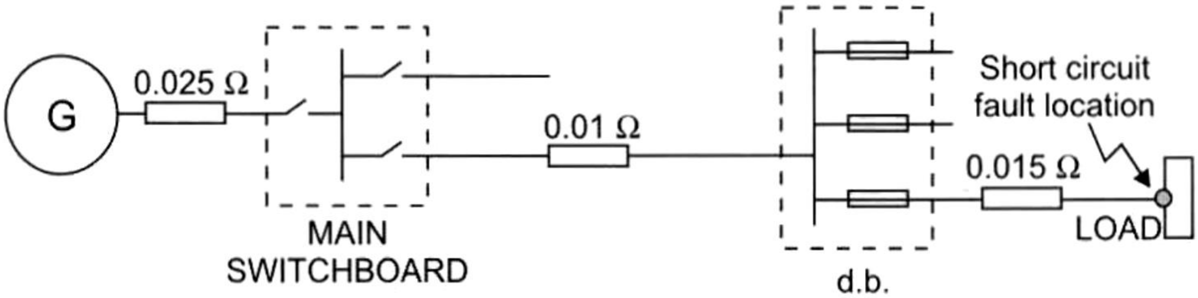


Fig 3.21 Prospective short circuit current (PSC)



When a short circuit fault occurs at the load terminals, as the total impedance (Z) from the generator to fault is Z fault = 0.025 + 0.01 + 0.015 = 0.05Ω

Therefore the prospective fault current = 440V/0.05Ω = 8800 Amps, that the protective devices have to clear.

A short circuit fault occurring at the main switchboard Z fault =0.025Ω and the prospective fault current is 440V/0.025Ω = 17600 Amps that the generator main circuit-breaker must clear.

Fault finding and trouble-shooting HV systems

It is essential to have a good understanding of the operation of the particular equipment and general insight into some of the diagnostic skills used to solve the problem.

Planning; A good fault-finder has a mentally planned strategy. The evidence is carefully considered before deciding what action to take.
A good diagnostician will use most of the following mental abilities
Memory, Logical thinking, Perception, Spatial/mechanical ability, Social skills, Persistence

Background (underpinning) knowledge; Knowledge and experience are essential, this must be wide ranging and includes knowledge of components, methods and systems together with operational characteristics. The combination of knowledge and direct practical experience with the equipment is a powerful aid to fault finding.

Fault charts; A list of typical symptoms and faults for a particular equipment plus remedies, these lists should be updated according to experience to show the most probable faults.

Search strategy; Once the diagnostician can visualise the circuit or machine as a series of functions, as search strategy can be applied to locate the fault in the minimum time.

A six step approach

1 Collect evidence (stop and think)

2 Analyse the evidence (check assumptions)

3 Locate the fault (inspect and test)

4 Determine and remove cause

5 Rectify fault

6 Check system

HV Faults

Cable faults – damaged cabling (fire, mechanical, flooding of space) insulation failures, corrosive environmental effects

HV machines faults – insulation failures, flooding of space, mechanical failures

HV Circuit Breaker failures – vibration – mechanical / electronic, the unsafe practice of installing non OEM replacement parts, exceeding the manufacturers recommended operations count value

HV Bus Bar failures-vibration- insulation failures-foreign objects ingress to space, overheating

Failed connections or terminations and cable joints

Humidity, salty residues, environmental issues, dust causing tracking
Mechanical failures affecting HV equipment

Improper operation (operator error) of HV switching/equipment

FACERAP (mnemonic) – key steps to fault finding

F- fault - name and classification of the fault

A- appearance- the description of the fault or its related symptom

C- cause - the operational reason for the fault

E- effect – the consequential effect of the fault

R- responsibility – the correct person to take remedial action

A- action – the standard procedure adopted to rectify the fault

P- prevention – the procedure to avoid repetition of the fault

Systematic Approach to Trouble shooting and Electrical Fault Finding

To expertly troubleshoot electrical equipment, problems must be solved by replacing only defective equipment or components in the least amount of time. One of the most important factors in doing this, is the approach used. An expert trouble-shooter uses a system or approach that allows them to logically and systematically analyse a circuit and determine exactly what is wrong.

The approach described here is a logical, systematic approach called the 5 Step Troubleshooting Approach. It is a proven process that is highly effective and reliable in helping to solve electrical problems.

This approach differs from troubleshooting procedures in that it does not tell you step by step how to troubleshoot a particular kind of circuit. It is more of a thinking process that is used to analyse a circuit's behaviour and determine what component or components are responsible for the faulty operation. This approach is general in nature allowing it to be used on any type of electrical circuit.

In fact, the principles covered in this approach can be applied to many other types of problem solving scenarios, not just electrical circuits.

Electrical Troubleshooting Approach

The 5 Step Troubleshooting Approach consists of the following:

- Preparation Step 1
- Observation Step 2
- Define Problem Area Step 3
- Identify Possible Causes Step 4
- Determine Most Probable Cause Step
- 5 Test and Repair (then follow up)

Preparation

Before you begin to troubleshoot any piece of equipment, you must be familiar with your organization's safety rules and procedures for working on electrical equipment.

These rules and procedures govern the methods you can use to troubleshoot electrical equipment (including your lockout/tagout procedures, testing procedures etc.) and must be followed while troubleshooting.

Next, you need to gather information regarding the equipment and the problem. Be sure you understand how the equipment is designed to operate. It is much easier to analyze faulty operation when you know how it should operate. Operation or equipment manuals and drawings are great sources of information and are helpful to have available. If there are equipment history records, you should review them to see if there are any recurring problems. You should also have on-hand any documentation describing the problem. (i.e., a work order, trouble report, or even your notes taken from a discussion with a customer.)

Step 1 – Observe

Most faults provide obvious clues as to their cause. Through careful observation and a little bit of reasoning, most faults can be identified as to the actual component with very little testing. When observing malfunctioning equipment, look for visual signs of mechanical damage such as indications of impact, chafed wires, loose components or parts laying in the bottom of the cabinet. Look for signs of overheating, especially on wiring, relay coils, and printed circuit boards.

Don't forget to use your other senses when inspecting equipment. The smell of burnt insulation is something you won't miss. Listening to the sound of the equipment operating may give you a clue to where the problem is located. Checking the temperature of components can also help find problems but be careful while doing this, some components may be alive or hot enough to burn you.

Pay particular attention to areas that were identified either by past history or by the person that reported the problem. A note of caution here! Do not let these mislead you, past problems are just that – past problems, they are not necessarily the problem you are looking for now. Also, do not take reported problems as fact, always check for yourself if possible. The person reporting the problem may not have described it properly or may have made their own incorrect assumptions.

When faced with equipment which is not functioning properly you should:

- Be sure you understand how the equipment is designed to operate. It makes it much easier to analyse faulty operation when you know how it should operate;
- Note the condition of the equipment as found. You should look at the state of the relays (energized or not), which lamps are lit, which auxiliary equipment is energized or running etc. This is the best time to give the equipment a thorough inspection (using all your senses). Look for signs of mechanical damage, overheating, unusual sounds, smells etc.
- Test the operation of the equipment including all of its features. Make note of any feature that is not operating properly. Make sure you observe these operations very carefully. This can give you a lot of valuable information regarding all parts of the equipment.

Step 2 – Define Problem Area
It is at this stage that you apply logic and reasoning to your observations to determine the problem area of the malfunctioning equipment. Often times when equipment malfunctions, certain parts of the equipment will work properly while others not.

The key is to use your observations (from step 1) to rule out parts of the equipment or circuitry that are operating properly and not contributing to the cause of the malfunction.

You should continue to do this until you are left with only the part(s) that if faulty, could cause the symptoms that the equipment is experiencing.

To help you define the problem area you should have a schematic diagram of the circuit in addition to your noted observations.

Starting with the whole circuit as the problem area, take each noted observation and ask yourself "what does this tell me about the circuit operation?" If an observation indicates that a section of the circuit appears to be operating properly, you can then eliminate it from the problem area. As you eliminate each part of the circuit from the problem area, make sure to identify them on your schematic. This will help you keep track of all your information.

Step 3 – Identify Possible Causes
Once the problem area(s) have been defined, it is necessary to identify all the possible causes of the malfunction. This typically involves every component in the problem area(s). It is necessary to list (actually write down) every fault which could cause the problem no matter how remote the possibility of it occurring. Use your initial observations to help you do this. During the next step you will eliminate those which are not likely to happen.

Step 4 – Determine Most Probable Cause
Once the list of possible causes has been made, it is then necessary to prioritize each item as to the probability of it being the cause of the malfunction. The following are some rules of thumb when prioritizing possible causes.

Although it could be possible for two components to fail at the same time, it is not very likely. Start by looking for one faulty component as the culprit. The following list shows the order in which you should check components based on the probability of them being defective:

- First look for components which burn out or have a tendency to wear out, i.e. mechanical switches, fuses, relay contacts, or light bulbs. (Remember, that in the case of fuses, they burn out for a reason. You should find out why before replacing them.)
- The next most likely cause of failure are coils, motors, transformers and other devices with windings. These usually generate heat and, with time, can malfunction.
- Connections should be your third choice, especially screw type or bolted type. Over time these can loosen and cause a high resistance. In some cases this resistance will cause overheating and eventually will burn open. Connections on equipment that is subject to vibration are especially prone to coming loose.
- Finally, you should look for is defective wiring. Pay particular attention to areas where the wire insulation could be damaged causing short circuits. Don't rule out incorrect wiring, especially on a new piece of equipment.

Step 5 – Test and Repair

Testing electrical equipment can be hazardous. The electrical energy contained in many circuits can be enough to injure or kill. Make sure you follow all your companies safety precautions, rules and procedures while troubleshooting.

Once you have determined the most probable cause, you must either prove it to be the problem or rule it out. This can sometimes be done by careful inspection however, in many cases the fault will be such that you cannot identify the problem component by observation and analysis alone. In these circumstances, test instruments can be used to help narrow the problem area and identify the problem component.

There are many types of test instruments used for troubleshooting. Some are specialised instruments designed to measure various behaviours of specific equipment, while others like the multimeters are more general in nature and can be used on most electrical equipment. A typical multimeter can measure AC and DC Voltages, Resistance, and Current.

A very important rule when taking meter readings is to predict what the meter will read before taking the reading. Use the circuit schematic to determine what the meter will read if the circuit is operating normally. If the reading is anything other than your predicted value, you know that this part of the circuit is being affected by the fault.

Depending on the circuit and type of fault, the problem area as defined by your observations, can include a large area of the circuit creating a very large list of possible and probable causes. Under such circumstances, you could use a “divide and eliminate” testing approach to eliminate parts of the circuit from the problem area. The results of each test provides information to help you reduce the size of the problem area until the defective component is identified.

Once you have determined the cause of the faulty operation of the circuit you can proceed to replace the defective component. Be sure the circuit is locked out and you follow all safety procedures before disconnecting the component or any wires.

After replacing the component, you must test operate all features of the circuit to be sure you have replaced the proper component and that there are no other faults in the circuit. It can be very embarrassing to tell the customer that you have repaired the problem only to have him find another problem with the equipment just after you leave.

Please note, Testing is a large topic and this article has only touched on the highlights.

Follow up
Although this is not an official step of the troubleshooting process it nevertheless should be done once the equipment has been repaired and put back in service. You should try to determine the reason for the malfunction.

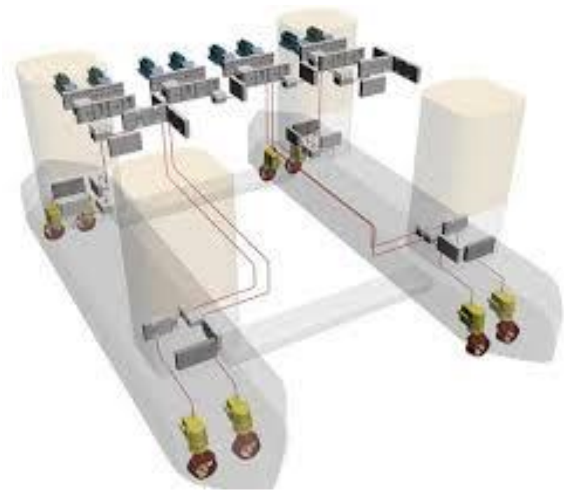
- Did the component fail due to age?
- Did the environment the equipment operates in cause excessive corrosion?
- Are there wear points that caused the wiring to short out?
- Did it fail due to improper use?
- Is there a design flaw that causes the same component to fail repeatedly?

Through this process further failures can be minimized. Many organizations have their own follow-up documentation and processes.

Make sure you check your organisation's procedures. Adopting a logical and systematic approach such as the 5 Step Troubleshooting Approach can help you to troubleshoot faults.

HV Propulsion and positioning systems – overview of typical systems

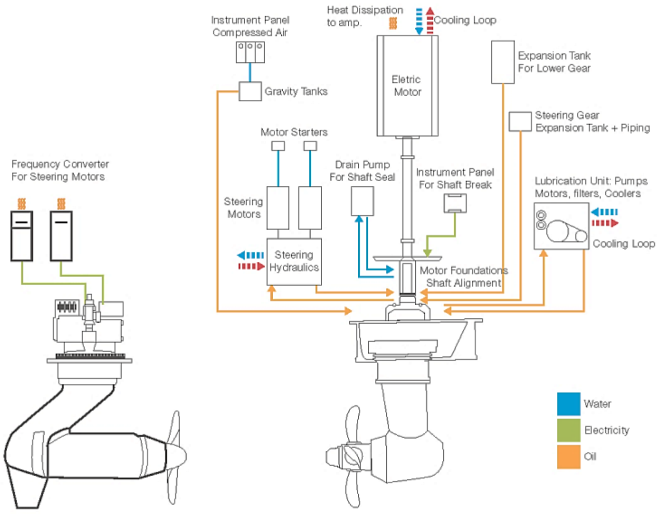
Thrusters and drive systems (Pods and conventional PEM)

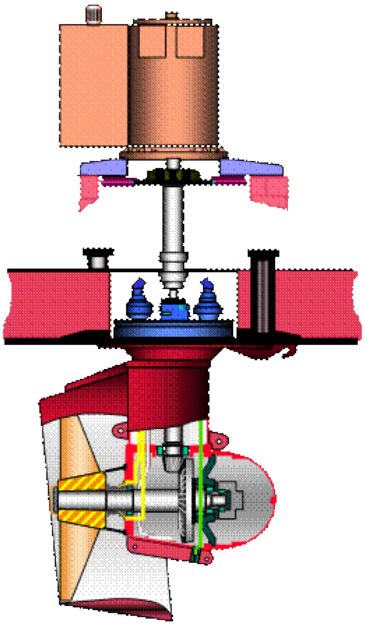


Dynamic positions HV thrusters as used on Drill Ships and Semi-submersible drill rigs

(Note: HAL MV Oosterdam Azipods 18MW each – 3000Amps at 1500V 24-28Hz max power)

Bow and stern thrusters





HV bow or stern thrusters on HV ships are controlled usually by Direct on Line Starting through a HV circuit breaker with controls on the bridge and in ECR.

HV bow or stern thrusters installed on LV ships will be fed from a step-up transformer (oil or dry type) eg:- 440V to 3.3kV or greater. The transformer supplies a HV circuit breaker for each thruster with controls on the bridge and in ECR.

The thruster motor is commonly an asynchronous induction motor with CPP propeller.

Asynchronous motors with squirrel-cage rotor HV Thruster motors 500- 5,000 kW

Voltage range: 400 V – 11,000 V, Frequency: 50/60 Hz or converter operation, Number of poles: 4-, 6- or 8-poles.

Typical dynamic positioning control system, HV thrusters are controlling the rig position over the drill hole.

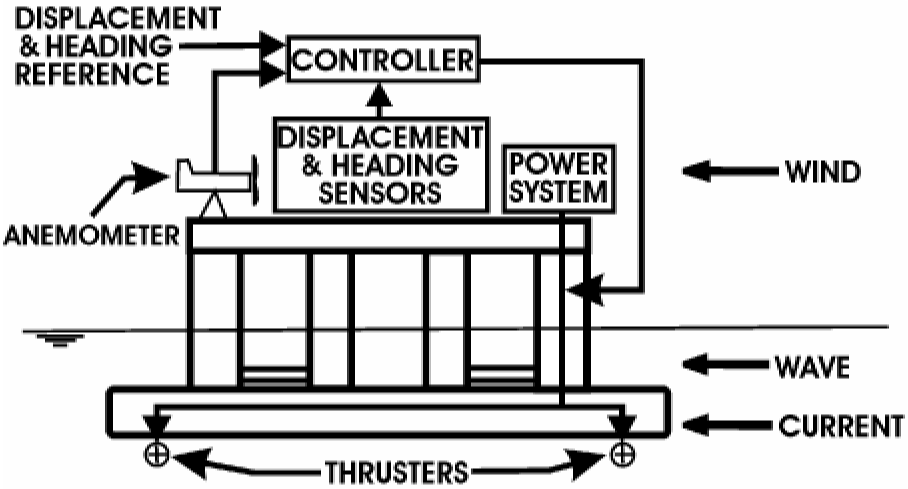
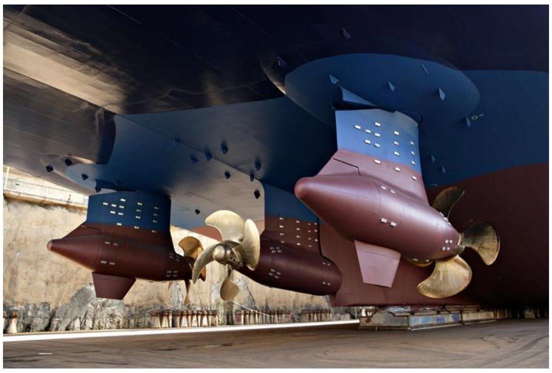


Figure 1. An example of DPS.

Propulsion Electric Motor (PEM)
HV propulsion motor speed control,
Synchroconverters, Cycloconverters

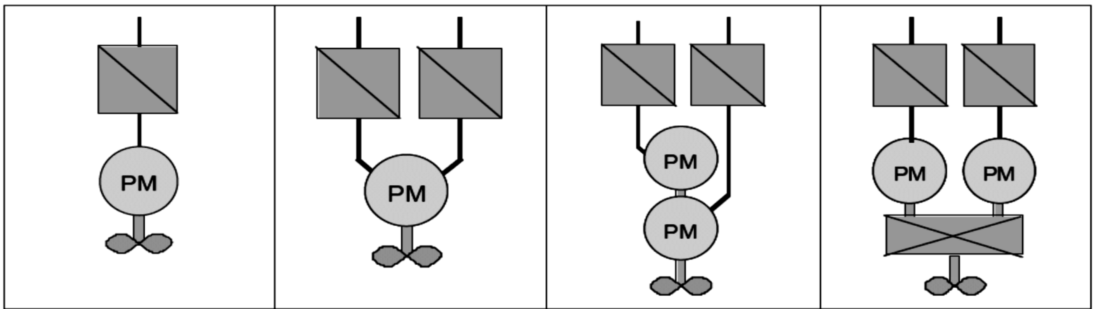

Ship Electric Propulsion Systems
Usually electric propulsion system consists of **one** or **two** electric motors that are connected directly (or by gear box) to the propeller of the ship. Required electric power of this motors are provided by the ship's diesel generators.

HV Synchronous Motors. Synchronous electric motor is an AC motor, which rotations speed of the motor's shaft is proportion to the applied stator frequency and the number of poles. Constant rotor speed with high power of motor is the advantages and reasons for using them in huge ships such as icebreaker ships. These engines also have high depreciation somewhat like direct current motors.

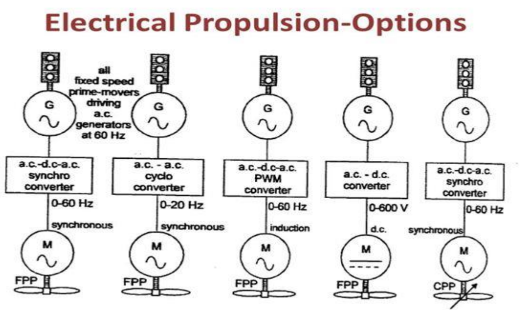
HV Induction Motors. Induction motors due to simple structure, high starting torque (along with the appropriate drive), long life and high reliability and other benefits.

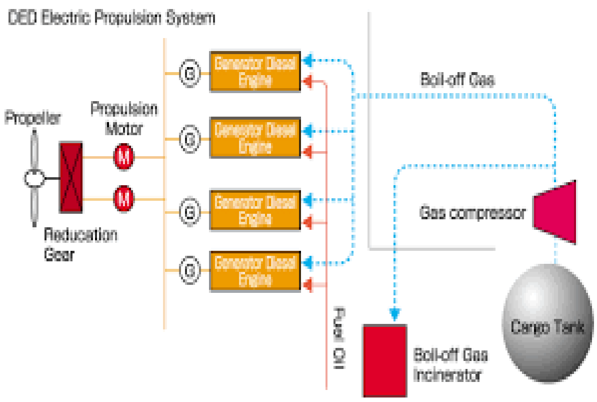
Advantages of Diesel Electric propulsion

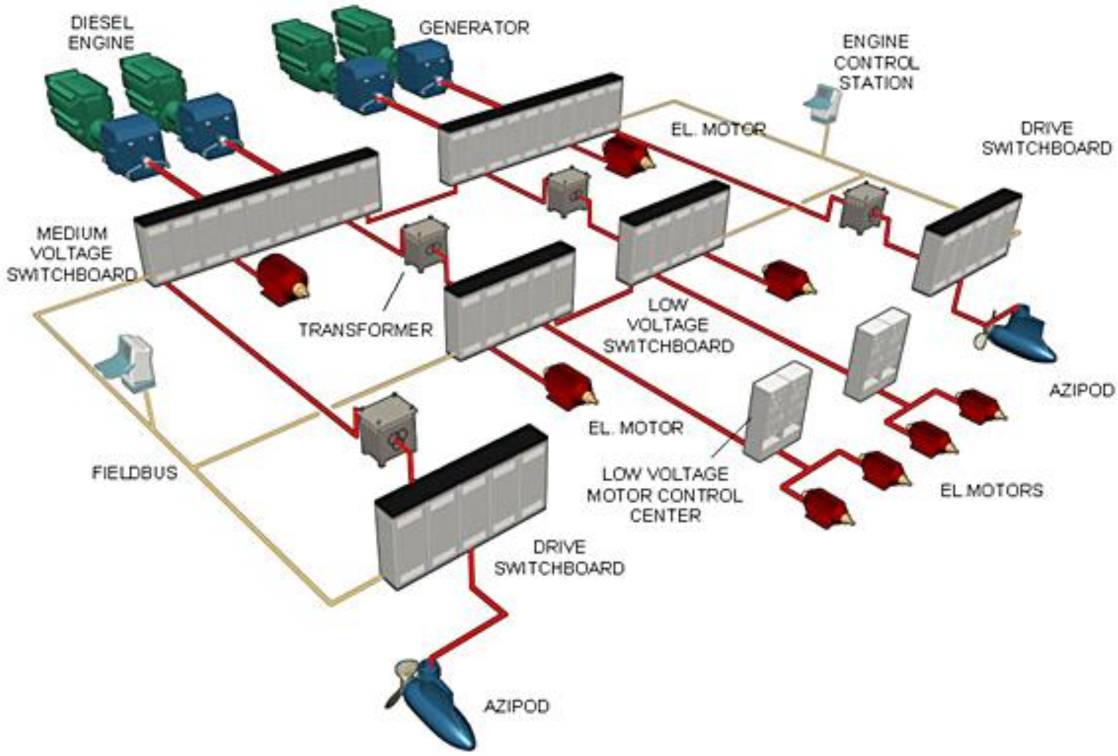
- Flexible operation profile
- Best adaptability, modular design, great design freedom
- Smaller overall installed power (common network for drive and consumers)
- High efficiency of generation of electrical energy
- Highest efficiency at all speeds, high redundancy and reliability.
- Redundant design ensures high availability of the drive
- Maintenance-friendly
- Longer service intervals reduced maintenance costs and downtimes.
- Reduced emission of the diesel engines through optimal speed / load operation
- Arrangement of equipment can be designed freely and a wide cargo space can be kept.
- Ship manoeuvrability is improved by high torque at low speed navigation.
- Comfortableness is improved due to low vibration, low noise.



Single motor drive	Two-winding motor with redundant converters	Tandem motor with redundant converters	Geared, dual shaft propulsion

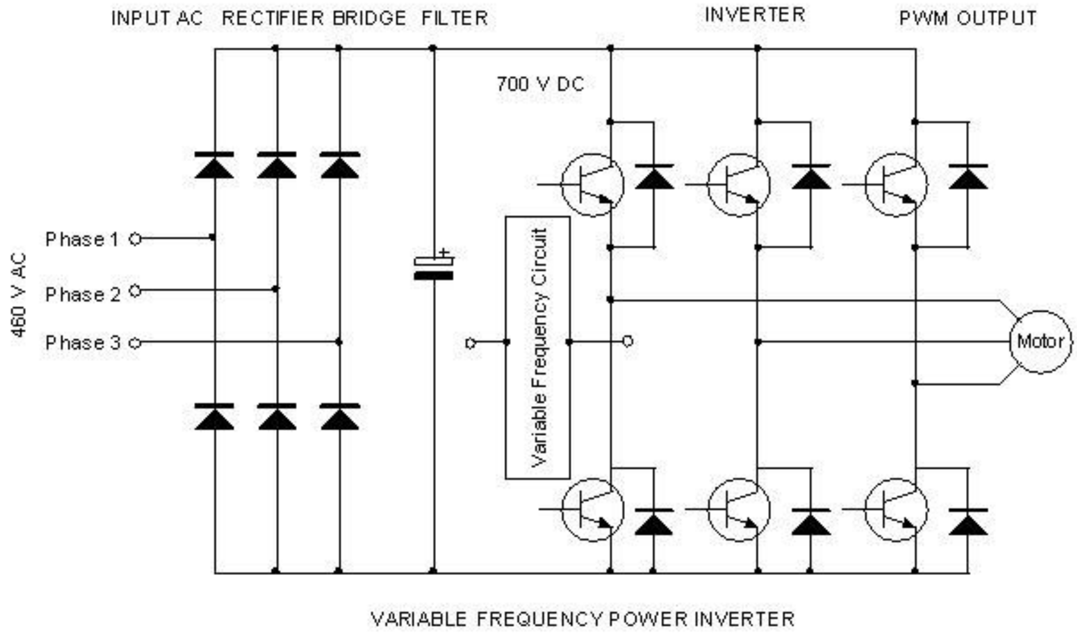






Typical Azipod spaces

SYNCHROCONVERTER - CURRENT SOURCE VARIABLE SPEED DRIVES
(Load Commutated Inverter – LCI, Current Source Inverter - CSI)
Output frequency can exceed 60Hz AC supply Frequency, eg 80Hz



The introduction of power electronic devices in the propulsion motor driving systems generates voltage and harmonic distortion to the ship electric network, however, the application of sophisticated driving schemes like SPWM and in particular cycloconverters reduces the problem considerably.

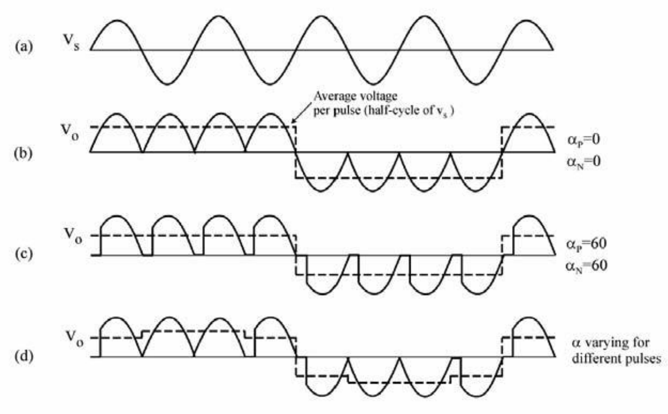
Sinusoidal Pulse Width Modulators (SPWM) or PWM: the widely known converter consisting of an uncontrolled rectifier in series to an SPWM-driven inverter. They are used in high speed propulsion applications (often in combination with a reduction gear) and in particular in low rated power motor cases (below 5 MW).

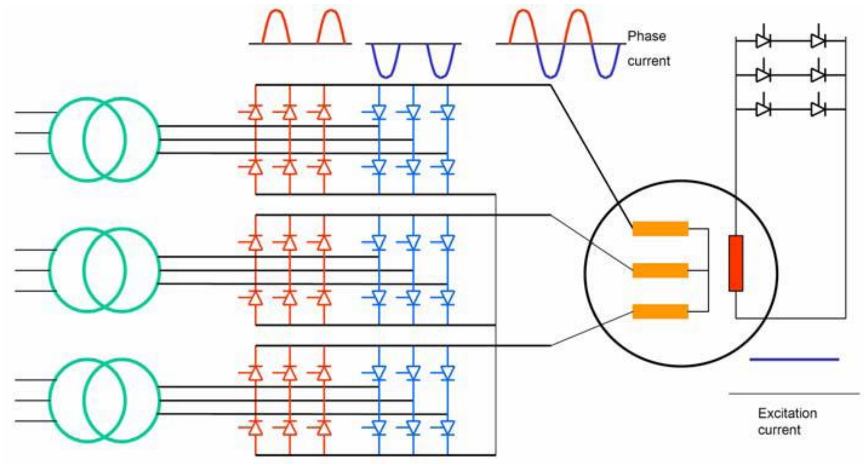
CYCLOCONVERTER VARIABLE SPEED DRIVES

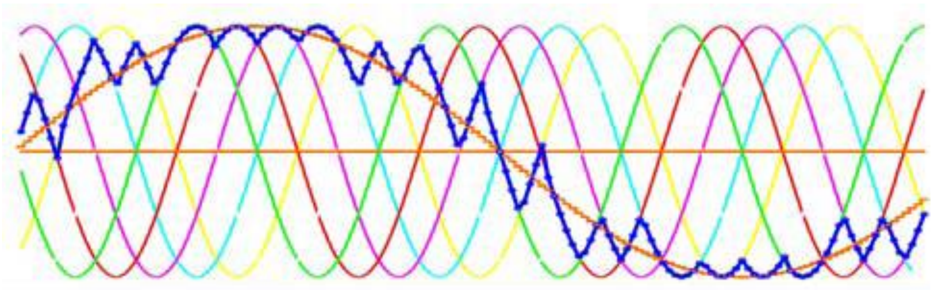
The cycloconverter is an SCR Converter System which converts a fixed frequency, fixed voltage input into a variable frequency, variable voltage output in a single stage without the need for a DC link and may be used to power either synchronous or asynchronous motor.
In marine applications, only synchronous motors (AC motor with DC excitation) have been used with cycloconvertors. Synchronous machines are preferred to cage induction motors (asynchronous machines) due to their large air gap giving them a higher degree of robustness.
Motor nominal voltage 1500V or 1800V

The Cycloconverter and Current Source drives (Synchro, CSI, LSI) are direct descendants of DC drive technology and use the same basic naturally commutated thyristor converters
Its major advantage is high torque at low speeds with low torque pulsations and excellent dynamic response performance:
applied as direct propeller drives on modern icebreakers (possible to free a propeller frozen in ice or to cut a block of ice without stalling the motor)
in dynamic positioning and passenger vessel applications (not necessary) where low speed / manoeuvring performance is essential.

• Can inherently reverse and regenerate
• Can easily provide large overloads (e.g. 250% and field weakening)
• Multiple bridges give high power ratings
• Ratings typically up to 30MW pre drive motor, 500 RPM



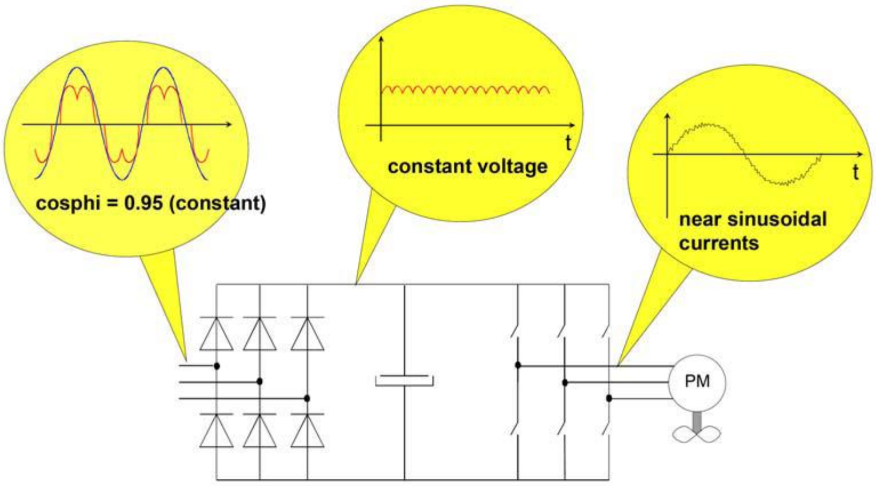


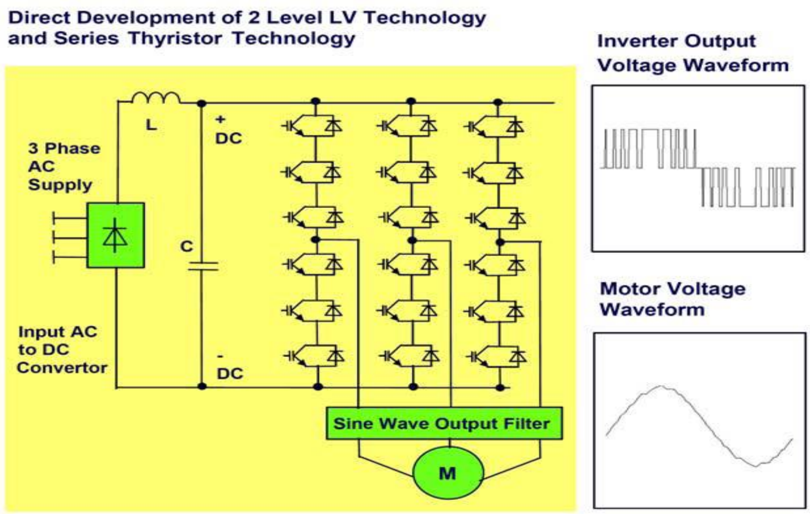


6-pulse cycloconverter - ACS6000c – ABB

- Direct AC to AC converter
- SCR Thyristor
- Synchronous motor (AC motor with DC excitation)
- High power at low speed

The **PWM (Pulse Width Modulated)** drive, often also referred to as **VSI (Voltage Source Inverter)** is characterized by its DC voltage link which is fed from the power system by a diode rectifier. A capacitor bank C is used to smooth the DC link voltage and to minimize the effect of harmonic distortion from the output (inverter) stage on the supply.





Due to **power plant limitations** – There is no available power on network in such short time. Power management system (PMS) usually takes up to 5 to 10 seconds to allocate necessary power. Diesel engine driven generators need about 10 to 20 seconds to take the full load from 0 to 100%. Moreover, if PMS should start new generator, due to low available power on network, it will take more than 20 seconds until next generator start to share the load and more 10 to 20 seconds until be fully loaded.

High Voltage DC electric circuit on ships – The HV DC Grid (ABB)

Ships with diesel electric drive, until now they were powered mostly with alternating current but the drives for the propeller or the bow thruster can be based internally on direct current supply.

A DC on-board system developed by ABB distributes the energy via DC circuits, eliminating the need for transformers in particular and also for switches in some cases.

Space requirements and the weight of electrical components are decreased by up to 30 percent.

This direct current technology uses ten to twenty percent less energy for power distribution than a conventional AC supply. It also requires less space, thus reducing the costs of equipment, installation, maintenance and space.

DC power system in ship applications is an emerging technology, which provides new opportunities for reducing fuel consumption and emission.

With direct current, they flow across the entire cross section of the conductor. That is why more current can be transported for a given wire diameter with direct current and why AC cable conductors have to be produced with a special substructure not required to the same extent for DC cables.

With power semiconductors, each of the two types of current can be converted into the other with great efficiency at converter stations. The efficiency of an individual converter station can be as high as 99 percent.

An ABB DC grid comes at the same price as a traditional power grid for ships, but with 20 percent energy savings.

ABB recently announced an order for the first DC power grid aboard a ship. The new power system allows for the ship’s propulsion system to run at a variable speed and maximize efficiency.

In the traditional design of propulsion systems, the DC power is converted through an AC switchboard and then fed to the thrusters and propulsion drives. In the new onboard DC grid, ABB removes the switchboard completely and routes the power through a single DC circuit, which can cut the power use by about 20 percent. Some of the increased efficiency comes from fewer conversions, which means less lost power.

The challenge is to ensure that the equipment is protected and the system is stable if the power is not converted from DC to AC. The solution didn’t require new equipment, however, just a redesign on how traditional components are put together.

The first order will be for a new offshore platform support vessel, but the DC microgrid could be installed as a retrofit on any ship with low-voltage onboard circuits, including tugboats, ferries, offshore support vessels and yachts.

ABB announced the concept for a DC grid for ships in 2011, but this is the first order, delivered in the first quarter of 2013. Although ABB could retrofit ships with this solution, the focus will be on new orders to bring the offering to market.

Because the components are essentially the same as what are on ships today, cost is comparable to systems available today, though the system's improved efficiency makes it a much better investment.

The savings might also go far beyond 20 percent. If ship owners want to incorporate alternative energy sources, such as fuel cells, solar or storage like battery packs, they can plug directly into the DC grid and achieve even greater energy efficiency.

There are also advantages beyond energy. The grid is up to 30 percent smaller and lighter, which means more space for cargo or passengers.

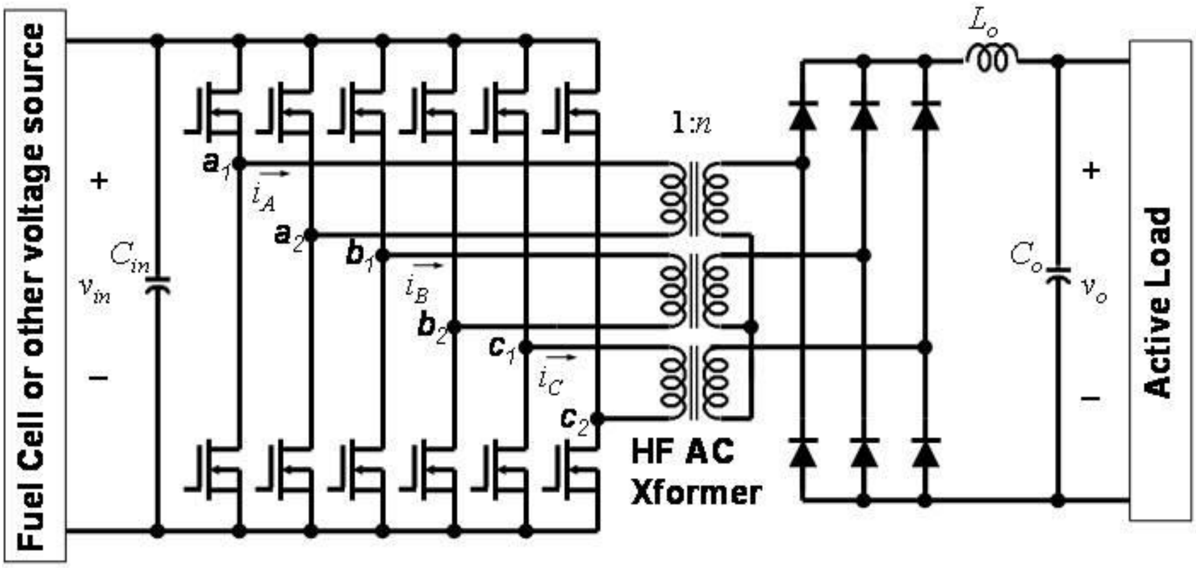
ABB, like its competitors, is supporting the DC renaissance in various industries. Making some ships more efficient is part of a larger trend in cleaning up the marine industry, from the growth of shore power for cruise ships to increased standards for some of the largest ports.

ABB is expecting that its new ***DC grid*** for ships will become a popular standby among its offerings.

In addition to reducing the amount of power lost to conversions, there were also fewer transient and harmonics issues with DC systems.

The future of industrial power could be found at sea. One of the newest developments in the shipping industry is the introduction of DC propulsion systems to increase energy efficiency.

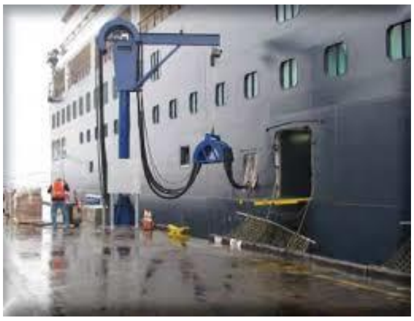
This not only allows engineers to shrink the overall size of the propulsion machinery, equipment and cables that power the propellers, it also leaves more space for cargo.



The advantage of running an electrical system at 400 Hz rather than 60 Hz is that the power supplies are smaller and lighter. This benefit is important aboard since space can be limited, and it is imperative to minimize weight in order to maximize performance.

Section 3

HV Shore Power

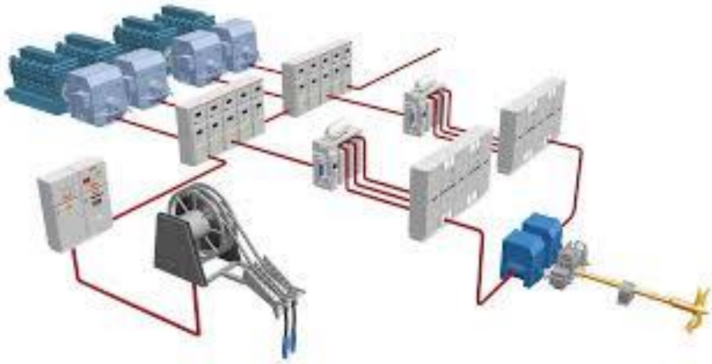


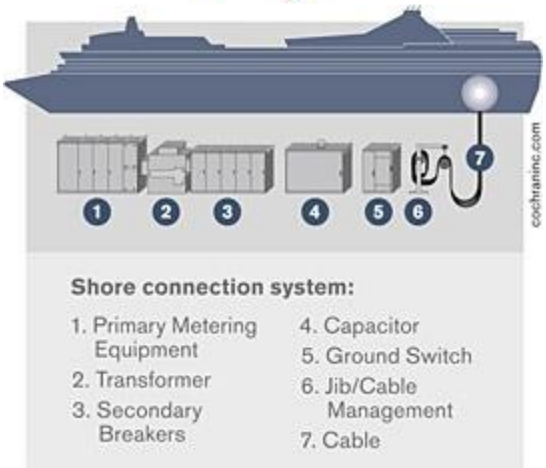
High Voltage Shore Connection: (HVSC)

It is envisaged that the effect of increasingly stricter air emissions legislation implemented through mainly local air quality controls will see an increasing number of vessels installing high voltage shore connection (HVSC) in the near future.

Shore power supply facilities have adopted high voltage rather than low voltage by necessity in order to keep the physical size of related electrical equipment such as shore connection cables manageable.
Inevitably high voltage would otherwise introduce new risks to ship's crew and the shipboard installations if necessary safety features were not built into the HVSC system or safe operating procedures were not put in place.

Those on board systems that are designed to accept high voltage shore power, typically involving incoming power receptacles, shore connection switchgear, step-down transformer or isolation transformer, fixed power cables, incoming switchgear at the main switchboard and associated instrumentation.





When a ship connects to shore-side power, it does not use its diesel engines to power the ship, but rather connects to the city's electrical grid to run its onboard systems.

After a ship docks, it's hooked up to the grid by what is essentially a large power plug; this takes roughly 30 to 40 minutes. Once connected, the ship's engines are then shut down until roughly a half-hour prior to departure, when the engines are restarted to prepare for departure. While the ship is plugged in, it releases hardly any fuel emissions.

Tighter emission control

The IMO (International Maritime Organization), the UN agency with special responsibility for the safety and security of shipping and the prevention of marine pollution by ships, has introduced international limits to the maximum sulphur content in bunker fuel in Annex VI of its International Convention for the Prevention of Pollution from Ships (MARPOL). This fixes limits on SO_2 and NO_2 emissions from ship exhausts. The maximum sulphur content of bunker fuel was set at 3,5% from 1 January 2012 until January 2020, with lower levels to be introduced later.

Some regions (Baltic, North Sea, North America, Caribbean Sea area) have introduced tighter limits in so-called Emission Control Areas (ECAs).

Cutting emission and noise in ports

If ships auxiliary generators used to provide electric power to docked ships do not burn bunker fuel but cleaner fuels, SO_2, NO_2 and PM are still emitted. During a 10-hour stay in port, the diesel engines of a single cruise ship burn around 20 tonnes of fuel, producing some 60 tonnes of CO_2.

On average, ships spend 100 days a year in port, using several tonnes of fuel a day to power ancillary systems. Ports are often located in densely populated cities and the environmental impact on the local population may be severe.

Cutting noxious emissions in ports has become a priority worldwide and has led to the introduction of OPS (onshore power supplies), which allow ships to shut down their diesel engines and connect to the land-based grid while they are docked.

Another advantage of HVSC is that it reduces noise and vibration from ships. Crews, dockside workers and nearby residents all benefit from this reduction.

Providing electric power from shore to ships at berth is not a recent development; in fact the term commonly used to describe it, "cold ironing", dates back to the time when ships had coal-fired engines that were allowed to go completely cold when in port, as power was supplied from shore.

Tighter environmental regulations incite more and more ports to put in HVSC systems. In addition to the more than 20 ports in Europe and North America that currently have operational HSVC systems, others are starting or planning to install them. The new IEC/ISO/IEEE International Standard should help drive that wider adoption.

Electrical System Grounding Philosophy: The manner in which electrical system is grounded (e.g., ungrounded system, solid neutral grounding system, low impedance neutral grounding system, or high impedance neutral grounding system), Circuit protection strategy is built around the selected method of system grounding in terms of over voltage prevention, over current prevention or continued operability under single phase grounded condition.

Cable Management System: The cable management system is the ship’s interface point with the shore power system. The cable management system is typically composed of flexible HV cables with the plug that extends to the shore power receptacle, cable reel, automatic tension control system with associated control gears, and instrumentation. Shore power is fed to the shore connection switchboard via the cable management system.

Shore Connection Switchboard:
Where no cable management system is provided on board, the shore connection switchboard is normally the ship's interface point with the shore power system. HV shore power is connected to this shore connection switchboard by means of an HV plug and socket arrangement.
The shore connection switchboard is provided with a shore power connecting circuit breaker with circuit protection devices.

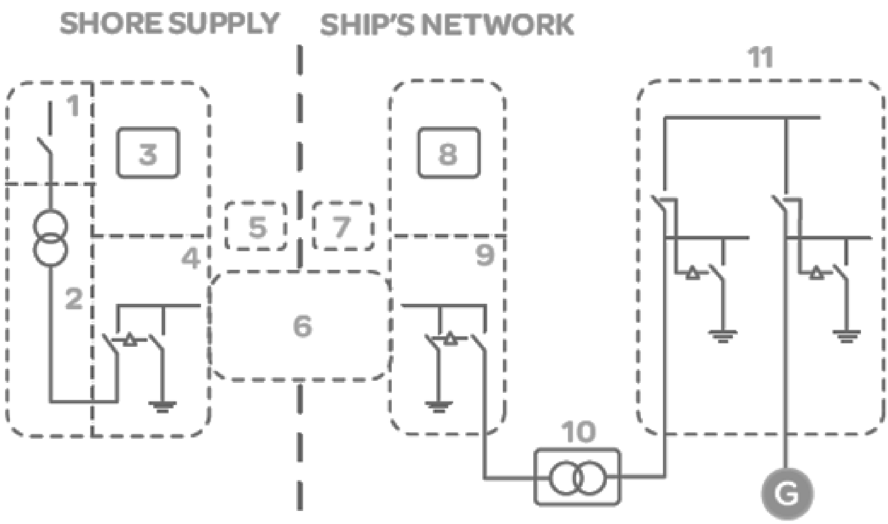
On board Receiving Switchboard: The receiving switchboard is normally a part of the ship's main switchboard to which the shore power is fed from the shore connection switchboard.

System Grounding Compatibility
Arrangements are to be provided so that when the shore connection is established, the resulting system grounding on board is to be compatible with the vessel's original electrical system grounding philosophy (for instance, the shipboard ungrounded power distribution system is to remain ungrounded, or the shipboard high impedance grounding system is to remain high impedance grounded within the design grounding impedance values). Ground fault detection and protection is to remain available after the shore connection has been established.

Equipotential Bonding

Equipotential bonding between the ship and the shore is to be provided. An interlock is provided such that the HV shore connection cannot be established until the equipotential bonding has been established. The bonding cable may be integrated into the HV shore power cable. If the equipotential bonding cable is intended to carry the shipboard ground fault current, the cable size is to be sufficient to carry the design maximum ground fault current.

The typical shore connection architecture set out in standard IEC/ISO/IEEE 80005 1 looks like this:



1. Connection to the MV Port's internal network or to local grid
2. Shore-side isolation transformer: mandatory to prevent circulation of earth fault current between several ships
3. Shore-side protection relays and interlocking system
4. Shore CB and earthing switch
5. Shore-to-ship connection, including: HV cables and cable reels, HV plug/socket-outlets with handling facilities, communication and control wires, equipotential bonding cable, etc.

6. Same as 5.
7. Same as 5.
8. Shipside protection relays and interlocking system
9. Shipside CB and earthing switch
10. Where applicable (ship voltage different from shore connection voltage), an onboard transformer is needed to adapt the high voltage supply to the ship's main switchboard voltage; this transformer is preferably located near the main switchboard in a dedicated room
11. Onboard receiving switchboard

PERMIT-TO-WORK –
ELECTRICAL HIGH VOLTAGE (OVER 1000 VOLTS)

Note (i): The Authorising Officer should indicate the sections applicable by ticks in the lefthand boxes next to headings, deleting any subheading not applicable.

Note (ii): The Authorising Officer should insert the appropriate details when the Sections for Other Work or Additional precautions are used.

Note (iii): The Authorised Person should tick each applicable righthand box as they make their check.

Note (iv): This Permit-to-Work contains 6 sections.

SECTION A – Scope of Work

Location (designation of space) ....

....

Plant Apparatus /Identification

(designation of machinery / equipment) ....

....

....

Work to be done (description) ....

....

....

Permit issued to (name of person carrying out work or in charge of the work party) ....

Section B – Check List / Isolation Data

Has a risk assessment of the proposed work been carried out?

The above apparatus is dead and has been isolated from the system at the following points (Description) ....

....

....

Circuit Main Earths have been applied to the equipment at the following points. (Description) ....

....

....

Safety Locks

(Detail location fitted and identify lock set) ....

....

Additional Precautions to avoid danger have been taken by

(Description) ....

....

Caution/Danger notices have been applied at all points of isolation, and Safety Signs appropriately positioned.

TREAT ALL OTHER APPARATUS AND AREAS AS DANGEROUS

....

....

....

....

....

SECTION C – Authorising of permit

Period of validity of permit (should not exceed 24 hours) .... hours
I hereby declare that the above equipment is dead and isolated from all live conductors.

Authorising person

(Name) .... (Signature) ....

(Time) .... (Date) ....

SECTION D – Receipt of Permit

I accept responsibility for carrying out the work on the apparatus detailed on this permit to work and no attempt will be made by me or people under my charge to work on any other apparatus or in any other area.
I am satisfied that all precautions have been taken and that safety arrangements will be maintained for the duration of the work.

Safety Key No .... Received* /Applied*

Competent person

(Name) .... (Signature) ....

(Time) .... (Date) ....

Note: After signing the receipt, this permit to work should be retained by

SECTION E – Clearance of Permit

The work for which this permit to work was issued is now suspended* / completed* and all people under my charge have been withdrawn and warned that it is no longer safe to work on the apparatus detailed in this permit to work.

All work equipment, tools, test instruments etc have been removed.

Competent person

(Name) .... (Signature) ....

(Time) .... (Date) ....

Safety Key No .... Received* /Applied*

SECTION F – Cancellation of Permit

This Permit to work is cancelled.

Authorising Person

(Name) .... (Signature) ....

(Time) .... (Date) ....

Safety Key No .... Received* /Applied*

* Delete words not applicable and where appropriate state:

The work is complete* / incomplete* as follows: (description)

....

....

....

....

....

....

....

....

....

....

Appendix A Sample form for Job Safety Analysis (JSA)

JOB SAFETY ANALYSIS WORKSHEET

JOB: ____________________

Analysed by: ____________________ Date: ____________

Reviewed by: ____________________ Date: ____________

Approved by: ____________________ Date: ____________

Sequence of Tasks	Potential Hazards	Preventive Measures

Appendix B Step-by-step Instructions for Job Safety Analysis (JSA)

Step 1

Select a job for JSA.

Step 2

Break the job into ten basic tasks or less.

Step 3

Analyse each task by one of the following methods.

Method 1

A) Find the most important job parameter for each task.

B) Find potential hazards by asking questions that begin by "What if".

Guide words	Parameters
No or not	Colour, shape, height
More	Sound, odour, light, pressure
Less	Motion, sequence, pace
As well as	Power, energy, temperature
Part of	Protective devices
Reverse	Substance, component, ensemble
Other than	Location, environment, etc.

Method 2

A) Determine the type of energy involved in each task.

B) Determine the potential risk of contact between energy and employee.

Type of energy	Type of contact
Gravitational	Contact with objects or equipment
Kinetic	Falls
Thermal	Bodily reaction and exertion
Biological	Exposure to substances
Chemical	Transportation accidents
Hydraulic	Fires and explosions
Electrical	Assaults and violent acts
Radiation	
Animal	
Stored potential energy	
Noise	

Step 4

Determine preventive measure(s) using hazard control strategies or the energy-barrier approach.

Control strategy	Energy barrier
Eliminate the hazard	Limit energy
Substitute the hazard	Substitute safer energy form
Mitigate the risk:	Prevent build-up
- adopt safe work practices;	Prevent the release of energy
- comply with acts and regulations;	Provide slow release of energy
- develop organizational rules;	Channel the release of energy
- reduce exposure source.	Apply energy barrier on the source
Have an emergency plan	Barrier between source and target
Repair damages	Barrier on person or object
	Raise damage threshold
	Limit damage evolution
	Rehabilitate

Step 5

Communicate the information to every person concerned in a narrative-style format.

Appendix C Practical Tips for Performing Job Safety analysis (JSA) and its Implementation

INVOLVE employees in the development, implementation and review of JSA.

KEEP written JSA short and simple, preferably one page long.

ILLUSTRATE safe practices and the use of personal protective equipment with the help of pictures and drawings.

ASSIGN responsibility of JSA and its implementation to supervisors.

TRAIN all employees and supervisors on the benefits of implementing recommendations of JSA.

INCLUDE relevant JSA in the new and transferred employee orientation kit.

EXPLAIN the use of JSA to employees before they start their new or modified job.

IMPLEMENT safe work practices recommended in the JSA as a part of the overall health and safety program.

POST relevant JSA close to the workstation to provide easy access to workers.

MAINTAIN a binder of all JSAs and make it accessible to all employees at all times.

REVIEW JSA when equipment or process changes or new information becomes available regarding potential hazards associated with the job.

INCLUDE implementation of JSA as a measure of the job performance of employees at all levels.

ENCOURAGE the use of JSA in work place inspection and accident/incident investigation.

			Potential Consequences				
			L6	L5	L4	L3	L2
			Minor injuries or discomfort. No medical treatment or measureable physical effects.	Injuries or illness requiring medical treatment. Temporary impairment.	Injuries or illness requiring hospital admission.	Injury or illness resulting in permanent impairment.	Fatality
			Not Significant	**Minor**	**Moderate**	**Major**	**Severe**
Likelihood	Expected to occur regularly under normal circumstances	**Almost Certain**	Medium	High	Very High	Very High	Very High
	Expected to occur at some time	**Likely**	Medium	High	High	Very High	Very High
	May occur at some time	**Possible**	Low	Medium	High	High	Very High
	Not likely to occur in normal circumstances	**Unlikely**	Low	Low	Medium	Medium	High
	Could happen, but probably never will	**Rare**	Low	Low	Low	Low	Medium

Job Safety Analysis (JSA) Work Sheet

Date:	Division:	Reference No:
Location:	Procedure/Task/Plant/Event Assessed:	
Functional/Operational Unit:	JSA Team Members	

Task Step	Hazard	Current control	Current control effective? Y/N	Risk Level	Proposed control
JSA Reported to:			Date Reported:		

To be Completed by Manager/Supervisor

Control proposed by JSA Team approved for implementation	Signature	Date / /
JSA registered for a formal risk assessment	Signature	Date / /

JOB SAFETY ANALYSIS WORKSHEET

JSA No.:

	A	B	C	D	E
1	H	H	H	S	S
2	H	H	S	S	M
3	H	H	S	M	L
4	H	S	M	L	L
5	S	S	M	L	L

H = High S= Significant M = Medium L = Low

Probability
A – common or repeating occurrence
B – known to occur or "It has happened"
C – could occur, "I've heard of it happening"
D – not likely to occur
E – practically impossible

Consequences
People
1 – fatality or permanent disability
2 – lost time injury or illness
3 – medical treatment
4 – first aid treatment
5 – incident report only

Environment
1 – toxic release off site with detrimental effect
2 – off site release with no detrimental effect
3 – off site release contained with outside assistance
4 – on site release immediately contained
5 – no environmental impact

STEP NO.	JOB STEP List the steps required to perform the task in the sequence they are carried out.	POTENTIAL HAZARD Against each step list the potential / risk hazards that could cause injury / damage when the task step is performed.	Probability	Consequence	Risk Rank L S M H	REQUIRED HAZARD CONTROL For each hazard identified list the control measures required to eliminate or minimise the risk of injury.	RESPONSIBILITY Nominate the person who will be required to action the control measures.
1.							

HV Switching schedule (plan) example #1

SKYCITY SWITCHING SCHEDULE

SKYCITY AUCKLAND

Work for which switching is required;

Reason: MSB4 Transformer Isolation for Tx Room Fireproofing

Requested By:	Barry J	**Date Requested:**	3rd March 2014
Switching Date:	6th March 2014	**Start Time:**	07-30 am
Schedule By:	Barry J	(Name of Authorised Person)	
Checked By:		(Name of Authorised Person)	

PPE

x	Overalls	x	Safety Footwear	x	Safety Glasses	x	HV Gloves
x	Hard Hat (with visor)		Hard Hat				

Equipment

X	HV Tester		Out of Service Tags	x	Do Not Operate Tags	X	Hand Earths
	Castel Interlock Keys	X	Padlocks (small)	x	Padlocks (large)		Clamp Meter

SWITCH	OPERATION	SCHED TIME	ACT TIME	OK √	CARRIED OUT BY
MSB4 Monitor Link Cable Load is below 800A during operation		07-30			
MSB4 Main ACB Man/Auto switch	Switch to Manual. Tag for reference	07-30			
Link Cable MSB4 to MSB3	Close at both ends. Check link cable is carrying current	07-40			
MSB4 400V Main ACB	Open, Rack out, Lock Tag	07-55			
MSB4 RMU 11kV Fuse Switch feeding TX4	OPEN, Lock and Tag. Observe Neon indicators for Tx are extinguished	08-00			
MSB4 RMU 11kV Fuse Switch feeding TX4	CLOSE in Earth Position	08-10			
11kV MSB4 transformer terminals	Prove Test Prove for isolation.	08-20			
11kV MSB4 transformer terminals	Apply hand earths to Tx Primary and Secondary	08-30			

HV Switching schedule (plan) example #2

SUBSTATION "B"	MWA NO:
ISOLATION PROCEDURE	
FOR: Maintenance Of Transformer No. 3, HV and LV Circuit Breaker Including Protection Relays	
EQUIPMENT IDENTIFICATION AND ISOLATION POINTS	
High Voltage Switchboard CB	02502
Low Voltage Switchboard CB	Q13 02471
Pre-arranged Notification Required Before Isolating	
Manager:	Building No:

Before Entry Into Substation Follow – Substation Entry Procedure Form

Isolation Sequence		
1	Check all Transformers, HV and LV Circuit Breakers are closed	
2	Check combined loads of Transformers 1, 2 and 3 at LV Switchboard < 2000amps	
3	Ensure LV Bustie "Q7" 2 – 1 is closed 02467	
4	Ensure LV Bustie "Q12" 3-2 is closed 02468	
5	Check all loads are equal HV and LV (Current Meters)	
6	Trip HV C/B 02500 TX3	
7	Confimr L.V. C/B 02471 is open and has tripped on intertrip	
8	Check load has transferred to No. 1 and No. 2 Transformer	
9	Confirm no load on No. 3 Transformer	
10	Rack out HV CB 02502 TX3	
11	Apply Danger Tag and lock to Bus Bar shutter mechanism	
12	Rack out LV "Q13" 02471	
13	Utilise lock box, issue High Voltage "Access Permit" for work on isolated switchgear and relays only	
14	Tape Live Equipment	

Note: A HV switching schedule (plan) (sheet) is required to be produced for each new isolation job and also a separate HV switching schedule is required to be produced to reinstate all system circuits after the PTW has been cancelled.

Action Plan: Reactivation transformer T2

#	Operation time: Hours	minutes	Actions	
1	10	4	Check the operating conditions	
2	0	0	Inspection of the operating area	✓
3	0	0	Check disconnectivity of portables grounds in the area	✓
4	0	0	Open disconnector T2G120 and check opened 3	✓
5	0	0	Open disconnector T2G25 and check opened 3	✓
6	0	0	Turn on gas / temp. protection T2	✓
7	0	0	Turn off the service restorers Rs (T1,T2)	✓
8	0	0	Turn on local control circuit breakers 120-4, 25-02 and discon. T2B12	✓
9	0	0	Check circuit breaker 120-4 closed on control panel	✓
10	0	0	Check circuit breaker 25-02 opened on control panel	✓
11	0	0	Check circuit breaker 25-02 opened on semaphore	✓
12	0	0	Activating disconnector T2B12	✓
13	0	0	Close disconnector T2B12 and check closed 3 phases (T2 under power)	✓
14	0	0	Close disconnector 02B2 and check closed 3 phases	✓

HIGH VOLTAGE ELECTRICAL SANCTION-FOR TEST	Serial No.

1) **Issue**
To..Employed By...

2) **I hereby declare that:-**
(I) It is safe to Test the following apparatus..
which is Dead, Isolated from all points of Supply,
connected to Earth and Caution Notices posted...
ALL OTHER PARTS ARE DANGEROUS

(II) The apparatus is **Isolated** at the following points..
....
(III) The apparatus is efficiently **Earthed** at the following points. (These Earths maybe removed and replaced without reference to the Issuer) ....
....
(IV) Caution Notices have been posted at the following points ....
....
(V) The following is the testing to be carried out on the apparatus ....
....

Signed..Time...............................Date.....................
Being authorised to issue this Sanction-for-Test.

3) **Receipt**
I hereby declare that I accept responsibility for carrying out the Testing detailed on this Sanction and that no attempt will be made by me or men under my supervision to carryout work or Tests on any other apparatus.

Signed..Time...............................Date.....................
Being the Authorised person in charge of the Testing.

4) **Clearance.**
I hereby declare that the Testing for which this Sanction was issued is now suspended/completed that all men under my supervision have been withdrawn and warned that this Sanction-for-Test is no longer valid and that the apparatus, with the exception of the Earths detailed above and the remarks noted below is ready/not ready for service.

Signed..Time...............................Date.....................
Being the Authorised person in charge of the Testing.

5) **Cancellation.**
This Sanction-To-Test and all copies of it are hereby cancelled.

Signed..Time...............................Date.....................
Being authorised to cancel this Sanction-for-Test.

Forms Links

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/282659/coswp2010.pdf
http://www.hseni.gov.uk/hsg85_electricity_at_work_-_safe_working_practices.pdf
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/153613/HTM_06-03.pdf

Appendix 2

CASE STUDIES

Recent High Voltage incidents and fires at sea

Note:- Full PDF files printed and given to students – each HV incident will be discussed in class.

HV incident #1-Fire on the ***RMS Queen Mary 2***, 23 September 2010

Report on the investigation of the catastrophic failure of a capacitor in the aft harmonic filter room on board while approaching Barcelona

The failure of all four propulsion motors, due to an explosion and failure of a High Frequency (HF) Capacitor in the high voltage room.

Total power outage due to catastrophic engine room explosion on *QM2*
Early in the morning on 23 September 2010 at 0426 hours, the passenger ship RMS Queen Mary 2 was approaching Barcelona when one out of 12 capacitors in a harmonic filter failed. Leaking oil was sprayed onto high voltage bars, causing a major arc flash event, in other words – a heavy

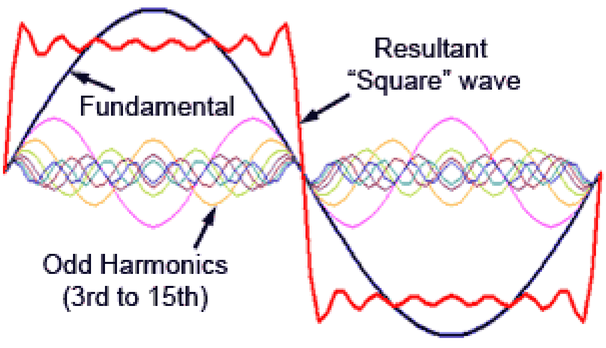
explosion near one of QM2 's main electric switchboard rooms. The harmonic filter* was located in a compartment within the aft main switchboard room.

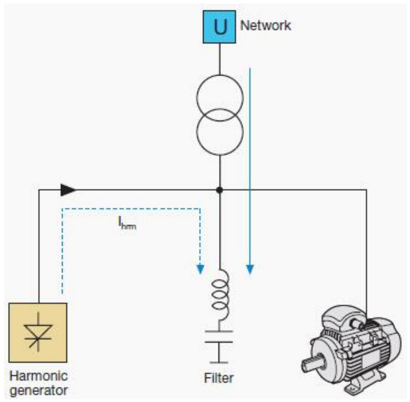
The explosion resulted in extensive damage to the surrounding electric panels and caused the 031 – Queen Mary 2 catastrophic explosion causes total power outage.

Alternating current (AC) motors for electric propulsion operate on variable frequency and voltage. Thyristors used in power converters result in voltage distortion. Passive harmonic filters, when applied correctly, are designed to attenuate the harmonic currents which vessel to black out. The Queen Mary 2 was drifting off the coast of Barcelona with no power! After approximately one hour the ship slowly started to move and limping towards port.

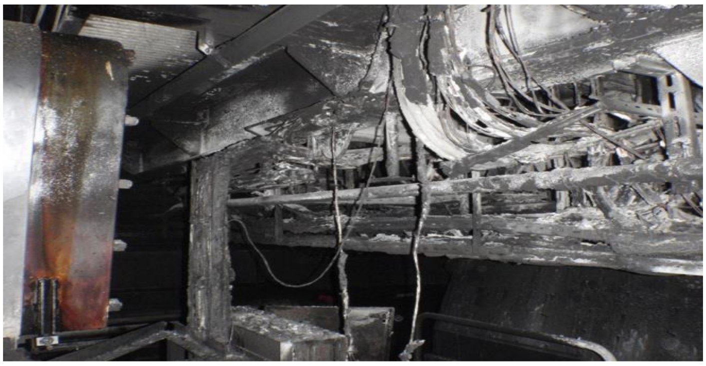
If things were designed properly, all the power shouldn't have gone out!
According to the MAIB Marine Accident Investigation Branch report, the situation was more serious than passengers knew. The report goes on to say that the explosion was forceful enough to damage steel doors and casings and buckle stiffeners on the
bulkhead of a compartment within the aft main switchboard room. He steel cover plate on a cross-flooding duct was blown out into the main switchboard room. The MAIB's investigation revealed that the capacitor had "deteriorated gradually", yet monitoring devices did not detect the problem. Therefore the MAIB issued strong recommendations to cruise lines and other ship owners to prevent similar events from taking place.
The recommendations include inspecting the capacitors for signs of physical distortion, ensuring that cooling and ventilation systems are operating normally, testing monitoring devices and checking for cleanliness of exposed conductors and chaffing damage on high voltage cables.
The MAIB reporting of this incident raises the issues of safety, predictive, preventive and planned maintenance as well as the use of original equipment manufacturers' components, reduction of operating costs and the liability of classification societies.

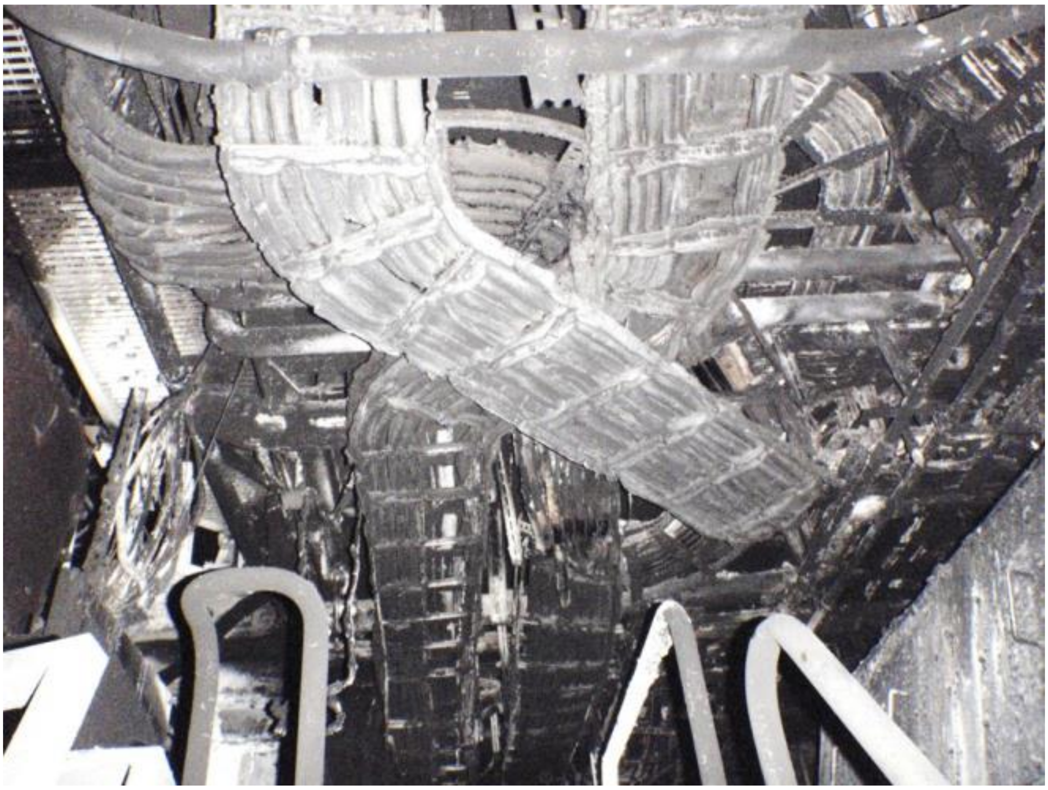
IFEP Integrated Full Electric Propulsion will have to be abandoned and there will be a strict physical separation between main and auxiliary (emergency) power supply.
Proactive retrograde steps toward minimum one direct drive for emergency operation controlled via a conventional (simple) switchboard will have to be taken.





HV incident #2 -Report of Investigation into the Fire On board the CARNIVAL SPLENDOR which occurred in the Pacific Ocean off the Coast of Mexico on November 8, 2010, which resulted in Complete Loss of Power





HV incident #3 Switchboard fire on High Voltage Holland America Line passenger vessel *Statendam,* the main 6.6kV HV SF6 gas circuit breaker for one of the diesel generators suffered a catastrophic failure. This started fires in the main switchboard room and the adjacent engine control room. The arc shattered the epoxy-resin case and the accompanying flash, aided by the sudden release of pressurized SF6 gas, carried the generated thermal energy ahead of it and in all directions.

CAUSES AND CONTRIBUTING FACTORS OF OIL RIG EXPLOSIONS OR FIRES

CAUSES AND CONTRIBUTING FACTORS OF OIL RIG EXPLOSIONS OR FIRES

As evidenced by the recent (November 2014) deadly explosion on the Black Elk Energy oil platform in West Delta 32 that took 3 lives, the 2012 Chevron oil rig K.S. Endeavor, which caught fire while operating off the coast of Nigeria, and the 2010 BP Deepwater Horizon mammoth disaster in the Gulf of Mexico, oil rig explosions have the potential to have serious consequences.

Multiple workers may be at risk of serious harm or may lose their lives.

Causes and Contributing Factors of Oil Rig Explosions or Fires

The various causes of an explosion or fire on an oil rig are virtually innumerable. An offshore oil platform is a hazardous place. Workers are required to operate or work in close proximity to heavy machinery and combustible substances. Rough seas and heavy weather can make the environment unpredictable at best. All it takes is a single mistake, defect in a piece of equipment or freak accident to cause a fire or explosion that leads to the injury or death of numerous workers and even the sinking of an entire platform.

Some examples of potential hazards that may cause oil rig explosions include:

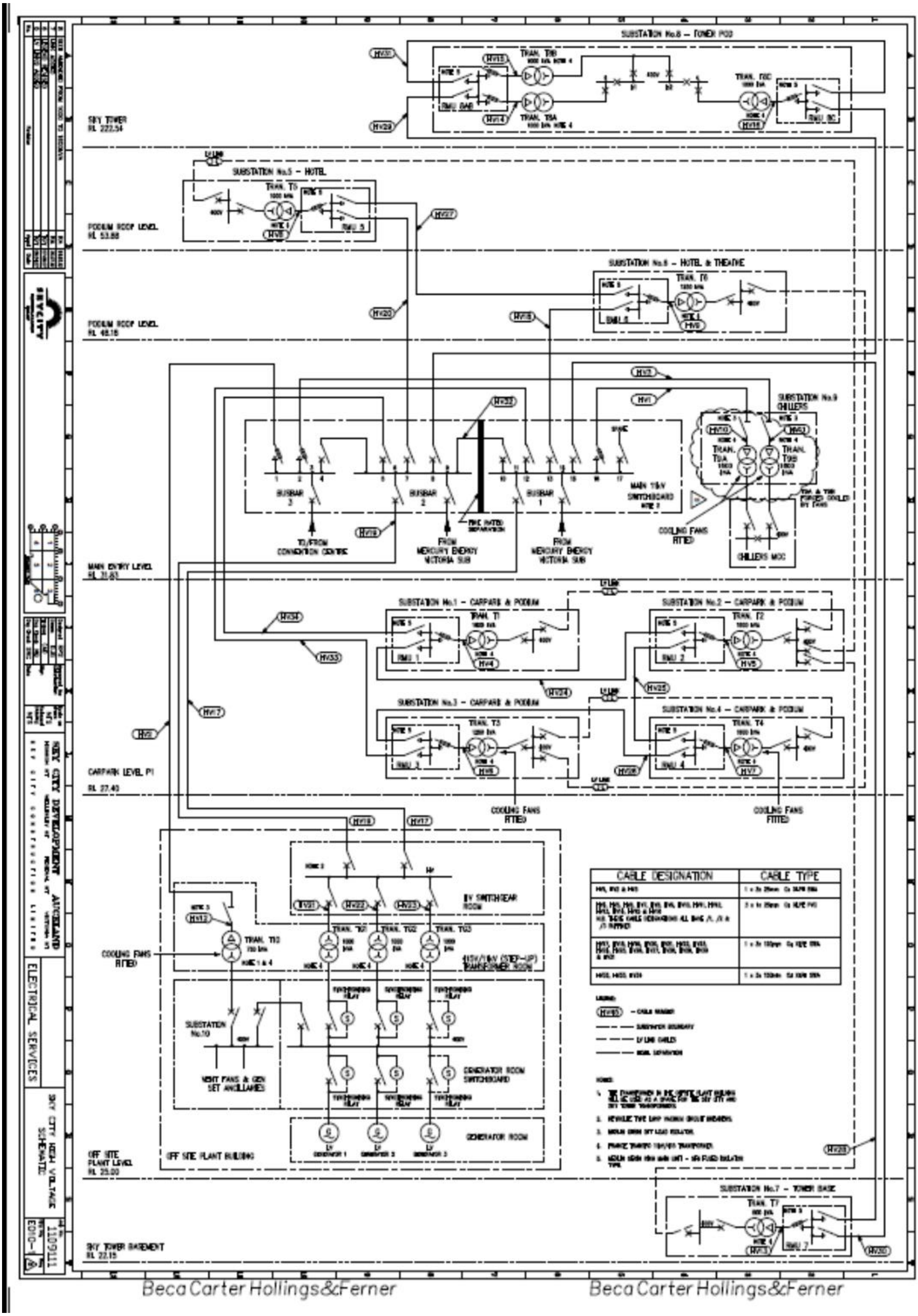
- *Improperly grounded electrical equipment or wiring*.
- *Fires from defective batteries*.
- Defective ventilation systems that cause a back-up of hazardous fumes.
- Improperly stored fuel or other combustible substances.
- Poorly maintained hoses, pipes, or pipelines that leak or spray fuel.
- Improper use of welding devices or torches near combustible substances.
- *Corrosion of electrical equipment.*
- *Failed equipment*.
- Failure to follow proper procedures for maintaining or cleaning the equipment.
- *Human error.*
- *Failure to adhere to the JSA and other safety procedures.*

Injuries Caused by Fires and Explosions on Oil Platforms

A worker on an offshore oil platform may be at risk of sustaining debilitating or life-threatening injuries and even death in an explosion or fire. Some of the injuries that may be caused by these incidents include:

- Death from the fire or explosion;
- Burns;
- Broken bones, lacerations and crush injuries caused by the force of the explosion;

- Crush injuries caused by falling objects or debris;
- Exposure to toxic chemicals or other hazardous substances;
- Electrocution and electric shock;
- Loss of hearing;
- Brain damage;
- Spinal cord injuries; and
- Dismemberment / loss of limb.


SUBSTATION No.8 – TOWER POD
SKY TOWER
SUBSTATION No.5 – HOTEL
PODIUM ROOF LEVEL
SUBSTATION No.6 – HOTEL & THEATRE
SUBSTATION No.9 CHILLERS
BUSBAR 3
BUSBAR 2
BUSBAR 1
MAIN 11kV SWITCHBOARD
TO/FROM CONVENTION CENTRE
FROM MERCURY ENERGY VICTORIA SUB
COOLING FANS FITTED
CHILLERS MCC
MAIN ENTRY LEVEL
SUBSTATION No.1 – CARPARK & PODIUM
SUBSTATION No.2 – CARPARK & PODIUM
SUBSTATION No.3 – CARPARK & PODIUM
SUBSTATION No.4 – CARPARK & PODIUM
CARPARK LEVEL P1
CABLE DESIGNATION
CABLE TYPE
GENERATOR ROOM
OFF SITE PLANT BUILDING
OFF SITE PLANT LEVEL
SUBSTATION No.7 – TOWER BASE
SKY TOWER BASEMENT
SKY CITY DEVELOPMENT AUCKLAND
ELECTRICAL SERVICES
SKY CITY HIGH VOLTAGE SCHEMATIC
Beca Carter Hollings&Ferner
Beca Carter Hollings&Ferner