

High voltage systems and their development in marine field

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- **What is High Voltage?**

In Marine Practice majority of merchant ships have a 3-phase 3 wire, 440 V insulated neutral earth power systems. This power system falls in the category of Low Voltage and meets the power demands of medium capacity motors up to 200 kW.

Voltages upto & Including 1000V is known as Low Voltage system and Voltages above 1000V is called as High Voltage system

- **Why HV in ships?**

Higher power requirements on board vessels is the foremost reason for the evolution of HV in ships.

Higher power requirements have been necessitated by

- Development of larger vessels required for container transport particularly reefer containers
- Gas carriers needing extensive cargo cooling
- Electrical Propulsion

For ships with a large electrical power demand it is necessary to utilise the benefits of a high voltage (HV) installation.

The design benefits relate to the simple ohms law relationship that current (for a given power) is reduced as the voltage is increased. Working at high voltage significantly reduces the relative overall size and weight of electrical power equipment.

AS PER OHMS LAW

POWER = VOLTAGE x CURRENT

For a given Power,

Higher the Voltage, *Lesser* is the Current

440 KW = 440,000 Watts = 440 Volts x 1000 Amps

1100 Volts x 400 Amps

11000 Volts x 40 Amps

When large loads are connected to the LV system the magnitude of current flow becomes too large resulting in overheating due to high iron and copper losses.

$P = VI \cos\phi$

Copper loss = $I^2 R$ [kW]

HV levels of 3.3 kV, 6.6 kV and 11 kV are regularly employed ashore for regional power distribution and industrial motor drives.

The main disadvantage perceived by the user/maintainer, when working in an HV installation, is the very necessary adherence to stringent safety procedures.

- **Advantages/Disadvantages of using HV**

Advantages:

For a given power, Higher voltage means Lower current, resulting in:

- Reduction in size of generators, motors, cables etc.
- Saving of Space and weight
- Ease of Installation
- Reduction in cost of Installation
- Lower losses – more efficient utilization of generated power
- Reduction in short circuit levels in the system which decides the design and application of the electrical equipment used in the power system.
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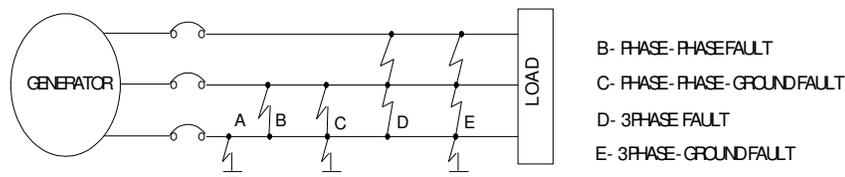
Disadvantages:

1. **Higher Insulation Requirements** for cables and equipment used in the system.
2. Higher risk factor and the necessity for **strict adherence to stringent safety procedures.**

● Possible faults in a power system:

Short circuit fault:

1. Phase to phase fault
2. Phase to phase to ground / earth fault
3. 3 phase fault
4. 3 phase to ground / earth fault



What is a Short Circuit & SC level?:

A **short circuit (or a fault)** is said to have taken place when the current is not confined to its normal path of flow but diverted through alternate path(s).

During short circuit, the current rises much above the normal value.

Short circuit level is the maximum possible current that flows at the point of fault during a short circuit.

Effects of short circuit:

High currents during Short circuits can cause damage to electrical installation by giving rise to excessive

- Thermal Stresses
- Mechanical Stresses
- Arcing

Methods adopted to prevent effects of short circuit in a system:

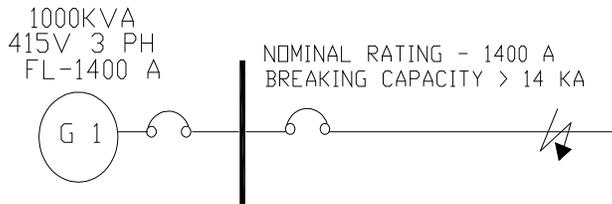
A well-designed Protective Relay system trips out a breaker(s) and isolates the faulty circuit from the power source within a short time to prevent/minimise effects of high short circuit current, as and when it occurs.

The equipment in the system, the cables, the switchgear, the busbar, the generators are designed to withstand the effects of short circuit during that short period.

Calculation of the short circuit levels in the system is therefore required to help in

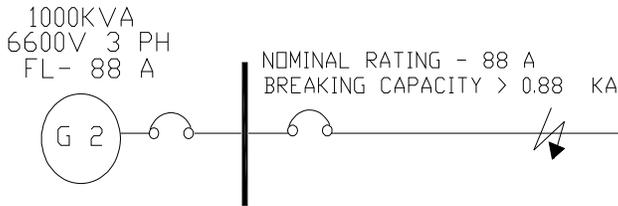
- a. Designing an appropriate Protective Relay System
- b. Choosing the right switchgear with suitable short circuit withstand capacity to be used in the system.

Reduction in S.C. Level by using HV An example:



$$\text{FAULT LEVEL} = *10 \times 1400 \text{ A} = 14000 \text{ A} = \underline{14 \text{ KA}}$$

(* 10 IS A THUMB-RULE CONSTANT)



$$\text{FAULT LEVEL} = 10 \times 88 \text{ A} = 880 \text{ A} = \underline{0.88 \text{ KA}}$$

● Possible hazards:

Arcing: An unintentional Electric Arc occurs during opening of a breaker, contactor or switch, when the circuit tries to maintain itself in the form of an arc.

During an insulation failure, when current flows to ground or any other short circuit path in the form of accidental tool slipping between conducting surfaces, causing a short circuit.

Results of an Electric Arc:

Temperatures at the arc terminals can reach or exceed 35,000° F or 20,000°C or four times the temperature of sun's surface.

The heat and intense light at the point of arc is called the **ARC FLASH**.

Air surrounding the arc is instantly heated and the conductors are vaporised causing a pressure wave termed as **ARC BLAST**.

Hazards of an Arc Flash:

During an arc flash, sudden release of large amounts of heat and light energy takes place at the point of arc.

Exposure frequently results in a variety of serious injuries and may even be fatal, even when the worker is ten feet or more from the arc center.

Equipments can suffer permanent damage

Nearby inflammable materials may be ignited resulting in secondary fires.

Hazards of Arc Blasts & ejected materials:

An arc flash may be accompanied by an arc blast

The arc blast causes equipment to literally explode ejecting parts with life threatening force.

Heated and vaporised conducting materials surrounding the arc expand rapidly causing effects comparable to an explosive charge.

They may project molten particles causing eye injuries.

The sound that ensues can harm the hearing

- **Potential injuries:**

At some distance from the arc, temperatures are often high enough to instantly destroy skin and tissue. Skin temperatures above 100°C (about 210°F) for 0.1sec result in irreversible tissue damage, defined as an incurable burn.

Heated air and molten materials from arc faults cause ordinary clothing to burst into flames even if not directly in contact with the arc. Synthetic fibers may melt and adhere to the skin resulting in secondary burns.

Even when safety goggles are worn, arc flash may cause severe damage to vision and or blindness. Intense UV light created by arc flash can damage the retina. Pressure created from arc blasts can also compress the eye, severely damaging vision.

Hearing can also be affected by the loud noise and extreme pressure changes created by arc blasts. Sound blasts with arc blasts exceed 140dB which is equal to an airplane taking off. Sudden pressure changes exceeding 720lbs/sq.ft for 400ms can also rupture eardrums. Even at lesser pressure, serious or permanent damage to hearing may occur.

- **Work Procedures**

Working procedures are divided in to three distinct groups.

- Dead working
- Live working
- Working in the vicinity of live parts

Working in the vicinity of live parts:

All work activity in which the worker enters the vicinity of live zone with his body or with tools and equipment without encroaching in to live zone.

Using the correct personal protective equipment (PPE) and following safe work practices will minimize risk of electrical shock hazards

Dead Working:

Work activity on electrical installations which are neither live nor charged, carried out after taking all measures to prevent electrical danger.

PRECAUTIONS BEFORE STARTING WORK

- Obtain PTW/Sanction- to- Test Permit before commencing work
- Test and prove that the equipment is DEAD before earthing. (with a HV line tester)
- Earth the equipment

General Information PERMIT-TO-WORK:

Issued by an authorised person to a responsible person who will perform the task of repair/maintenance

Generally valid only for 24-Hrs. Permit to be re-validated by the permit-holder if work extends beyond 24 Hrs. after issue

Formats will vary and be customized for a particular vessel/marine installation.

Permit To Work- BROAD GUIDELINES:

Prepared in Carbon-copied Duplicate and has atleast five sections.

FIRST section states the nature of work to be carried out.

SECOND section declares where electrical isolation and earthing have been applied and where Danger /Caution notices have been displayed.

THIRD section is signed by the Person receiving the Permit acknowledging that he is satisfied with the safety precautions taken and the Isolation/ Earthing measures adopted.

FOURTH section is signed by the Permit-holder that the work has been completed/suspended.

FIFTH Section is signed by the Issuing authority cancelling the Permit.

INSULATION RESISTANCE TESTS OF HV EQUIPMENT:

A 5000 VDC Megger, Hand-cranking or Electronic can be used for equipments upto 6.6KV.

For routine testing of IR, 5000 VDC must be applied for 1 minute either by cranking at constant speed with a Hand-cranking megger or by maintaining a 5000 VDC continuously by a PB in an Electronic Megger.

IR values taken at different temperatures are unreliable, particularly if the temperature differences are more than 10 degrees.

Before applying an IR test to HV equipment its power supply must be switched off, isolated, confirmed dead by an approved live-line tester and then earthed for complete safety. The correct procedure is to connect the IR tester to the circuit under test with the safety earth connection ON. The safety earth may be applied through a switch connection at the supply circuit breaker or by a temporary earth connection local to the test point. This is to ensure that the operator never touches a unearthed conductor. With the IR tester now connected, the safety earth is disconnected (using an insulated extension tool for the temporary earth). Now the IR test is applied and recorded. The safety earth is now reconnected before the IR tester is disconnected. This safety routine must be applied for each separate IR test.

At prescribed intervals and particularly after a major repair work on an equipment or switchgear, a *Polarisation Index(PI)* may be taken to assess the condition of insulation of the equipment. PI readings are less sensitive to temperature changes.

POLARISATION INDEX (PI):

When the routine IR value tests (taken at different temperatures) are doubtful or during annual refit or after major repairs are undertaken, a PI test is conducted.

PI value is the ratio between the IR value recorded after application of the test voltage continuously for 10 minutes to the value recorded after 1 minute of application.

A PI value of 2.0 or more is considered satisfactory.

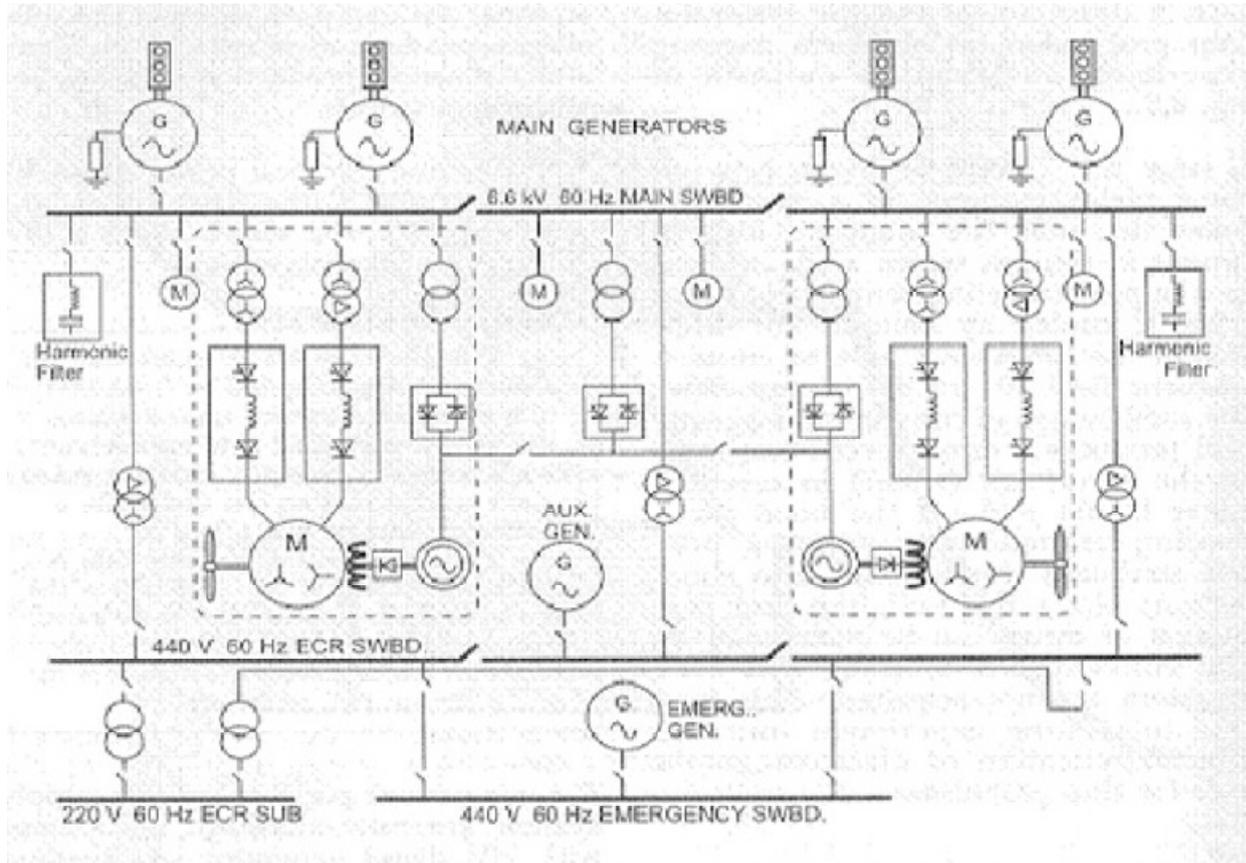
A motor-driven megger is essential for carrying out a PI test.

Safety testing of HV equipment:

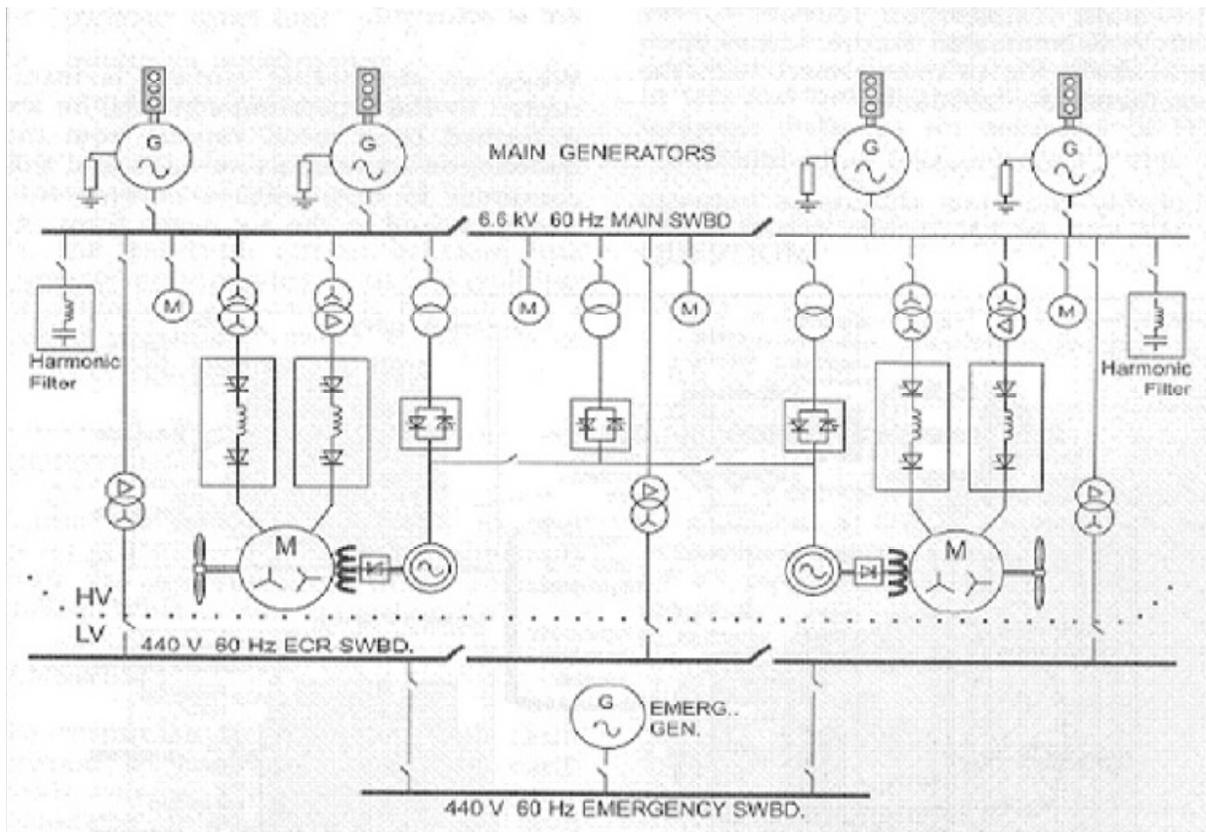
Normally the safe testing of HV equipment requires that it is disconnected from its power supply. Unfortunately, it is very difficult, impossible and unsafe to closely observe the on-load operation of internal components within HV enclosures. This is partly resolved by temperature measurement with an recording infra-red camera from a safe distance. The camera is used to scan an area and the recorded infra-red image is then processed by a computer program to display hot-spots and a thermal profile across the equipment.

- A typical HV layout:

(propulsion plant)



HV/LV Power Supply system:



Developments :

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 onboard 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. HVSC is often referred to as **Cold Ironing**

High Voltage (HV): The system nominal voltage is considered to be in the range from 1 kV AC to 15 kV AC.

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), including ground potential transformer method. 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 onboard, 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.

Onboard 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.

Capacity

HVSC installation is to be sufficiently rated to supply the following:

- i) Normal services required in port
- ii) Emergency services
- iii) Services needed to support the ship's operations in port

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.

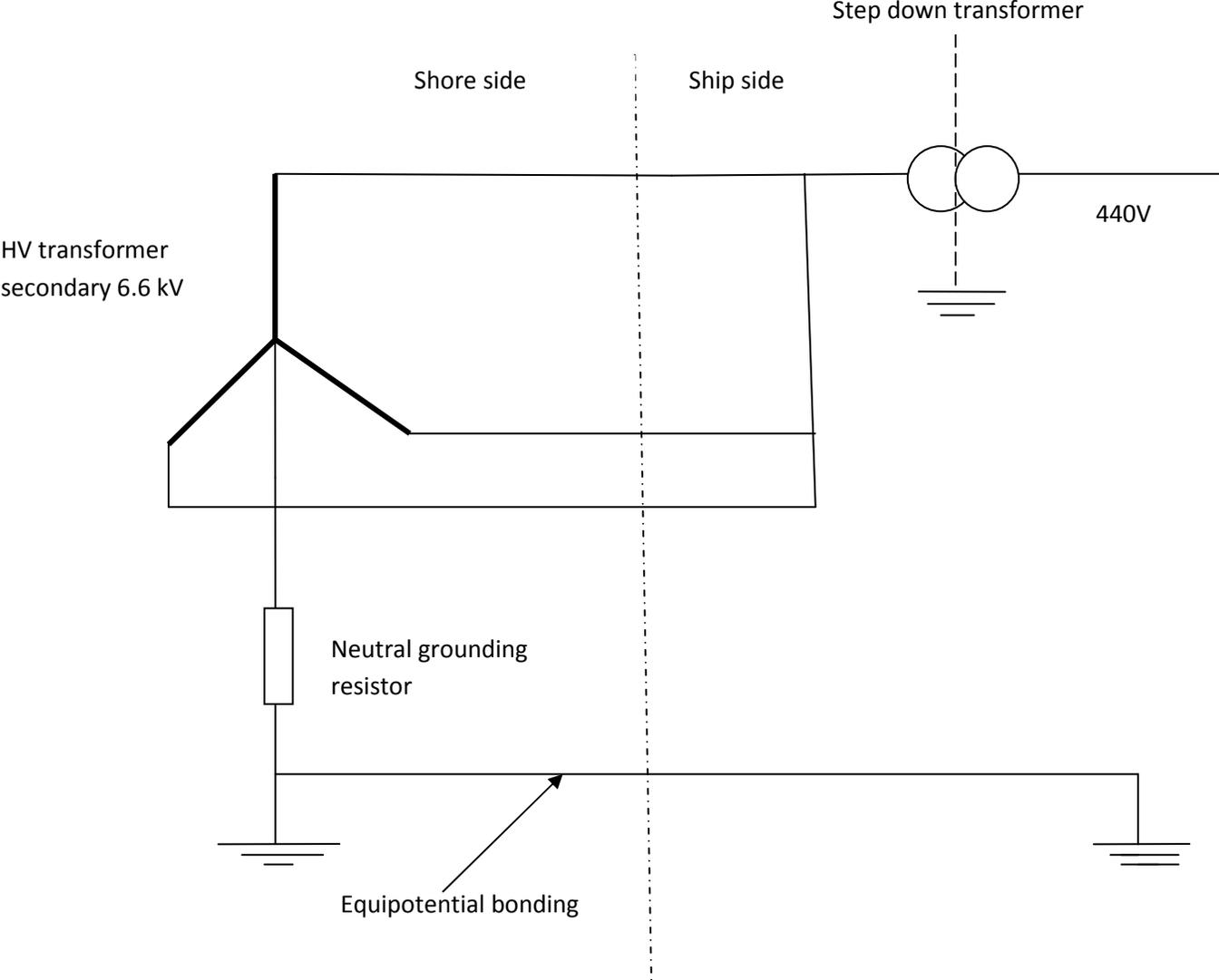
System Grounding Compatibility

Arrangements are to be provided so that when the shore connection is established, the resulting system grounding onboard 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.

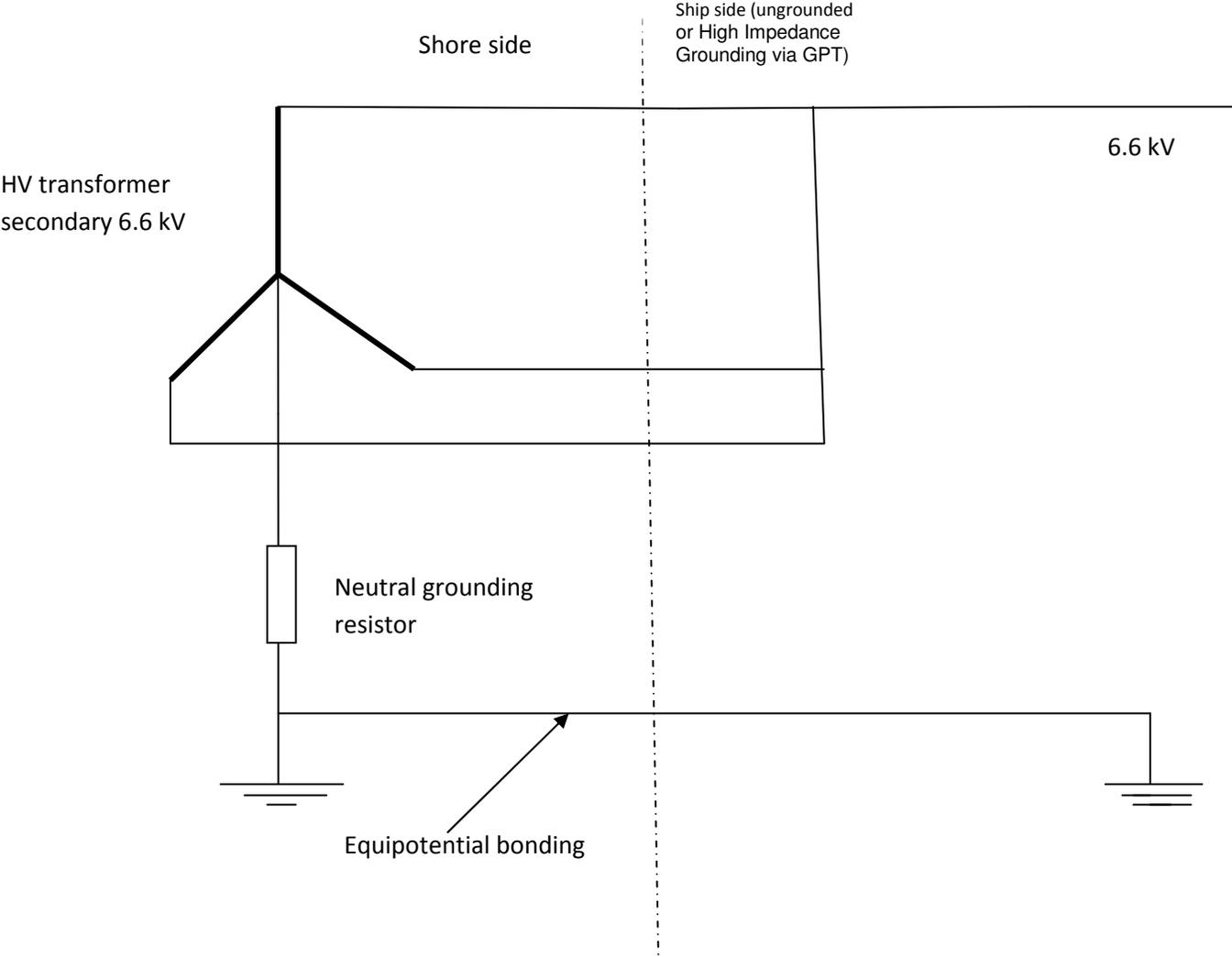
Voltage rating

The voltage rating of electrical equipment insulation materials is to be appropriate to the system grounding method, taking into consideration the fact that the insulation material will be subjected to $\sqrt{3}$ times higher voltage under single phase ground fault condition.

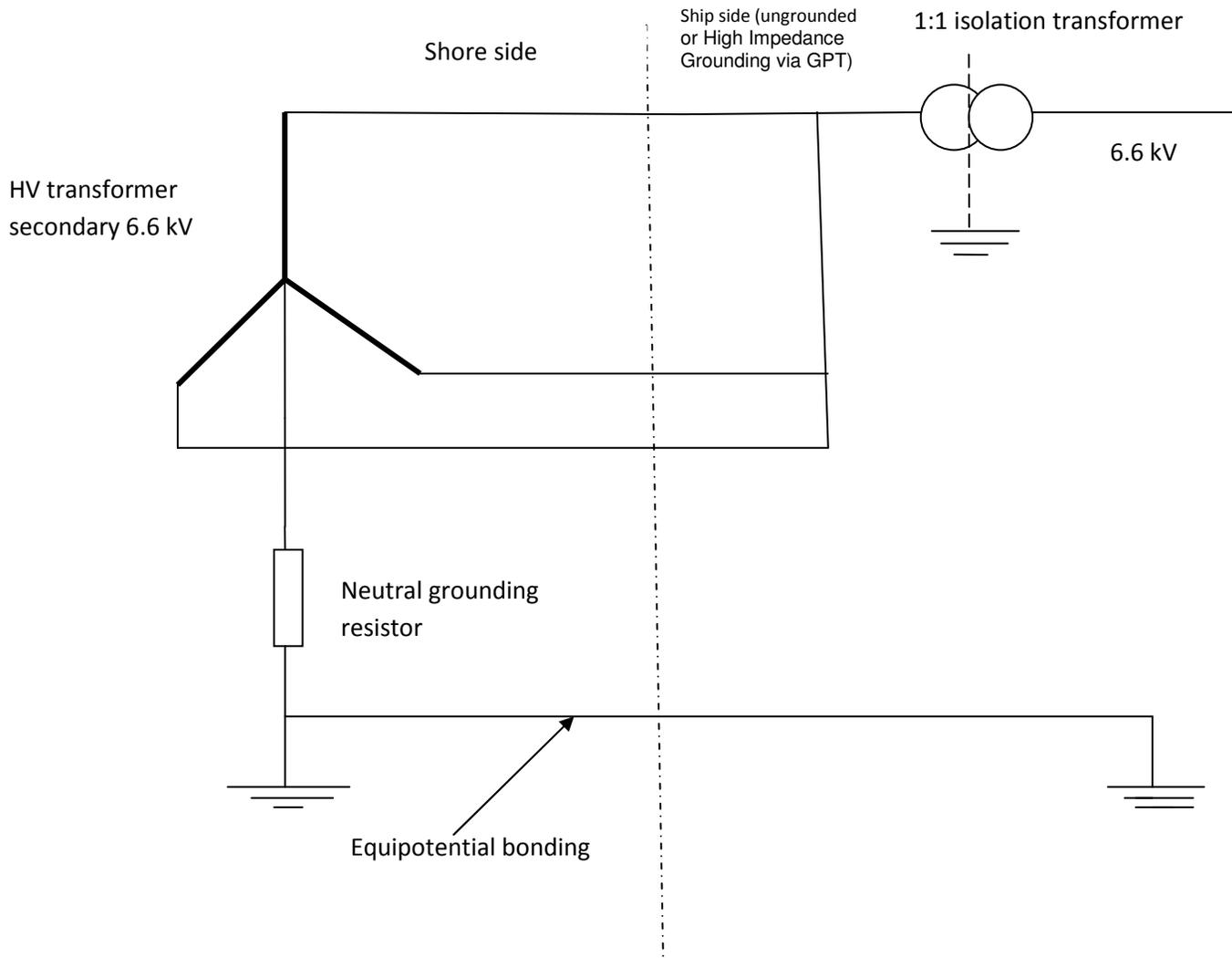
Example for Ungrounded LV Ship's System:



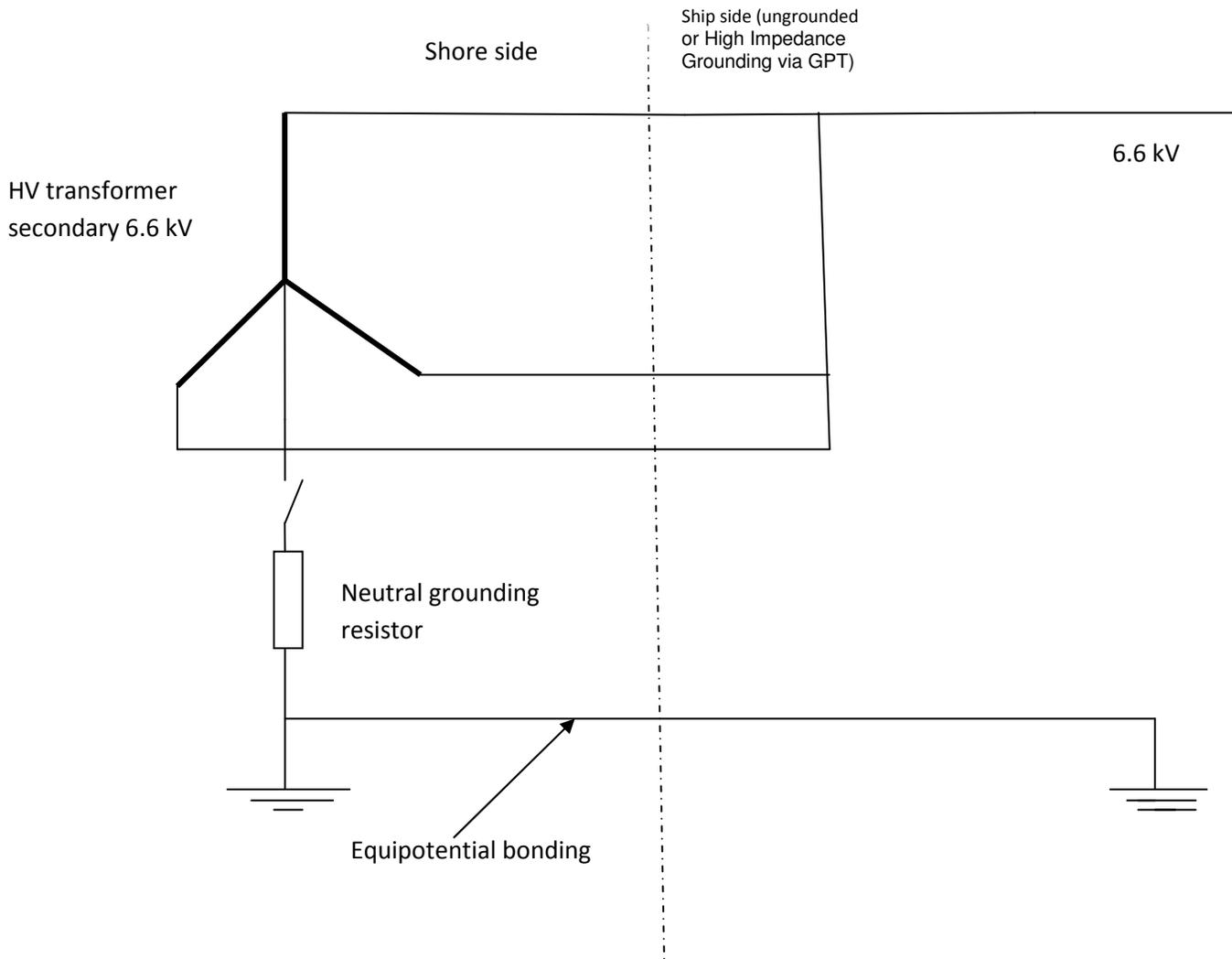
Example for Grounded HV Ship's System (where NGR Value is Compatible with the Ship's Design Ground Current Range, Otherwise 1:1 Isolation Transformer may be Required)



Example for Ungrounded Ship's System (e.g., Oil Carriers and Gas Carriers):



Example for Ungrounded Ship's System where Shore side Option for Ungrounded Neutral is Available (e.g., Oil Carriers and Gas Carriers)



Load Transfer

Temporary Parallel Running:

Where the shipboard generator is intended to run in parallel with the shore power for a short period of time for the purpose of connecting to the shore power or back to ship power without going through a blackout period, the following requirements are to be complied with:

- i)* Means are to be provided to verify that the incoming voltage is within the range for which the shipboard generator can be adjusted with its automatic voltage regulator (AVR)
- ii)* Means are to be provided for automatic synchronization
- iii)* Load transfer is to be automatic
- iv)* The duration of the temporary parallel running is to be as short a period as practicable allowing for the safe transfer of the load. In determining the rate of the gradual load transfer, due regard is to be paid to the governor characteristics of shipboard generator in order not to cause excessive voltage drop and frequency dip.

Load Transfer via Blackout

Where load transfer is executed via blackout (i.e., without temporary generator parallel running), safety interlock arrangements are to be provided so that the circuit breaker for the shore power at the shore connection switchboard cannot be closed while the HV switchboard is live with running shipboard generator(s).

Safety Interlocks

An interlock, which prevents plugging and unplugging of the HV plug and socket outlet arrangements while they are energized, is to be provided.

Handling of HV Plug

While the HV shore connection circuit breakers are in the open position, the conductors of the HV supply cables are to be automatically kept earthed by means of an earthing switch. A set of pilot contactors embedded in the HV plug and socket-outlet may be used for this purpose. The earthing switch control is to be designed based on a fail-to-safe concept such that the failure of the control system will not result in the closure of the earthing switch onto the live HV lines.

HV Shore Connection Circuit Breakers

Arrangements are to be provided to prevent the closing of the shore connection circuit breaker when any of the following conditions exist:

- i)* Equipotential bonding is not established
- ii)* The pilot contact circuit is not established
- iii)* Emergency shutdown facilities are activated
- iv)* An error within the HV connection system that could pose an unacceptable risk to the safe supply of shoreside power to the vessel. These errors may occur within the alarm system, whether on board the ship or at the shoreside control position, or within any relevant safety systems including those which monitor system performance.
- v)* The HV supply is not present

HVSC Circuit Breaker Control:

HV shore connection circuit breakers are to be remotely operated away from the HVSC equipment. HV shore connection circuit breakers are to be made only when it has been established that personnel are evacuated from the HV shore connection equipment compartments. The operation manual is to describe these established procedures.

HVSC Emergency Shutdown:

In the event of an emergency, the HV system shall be provided with shutdown facilities that immediately open the shore connection circuit breaker. These emergency shutdown systems are to be automatically activated.

Any of the following conditions are to cause emergency shutdown of the shore power supply:

- i)* Loss of equipotential bonding
- ii)* High tension level of HV flexible shore connection cable, or low remaining cable length of cable management system
- iii)* Shore connection safety circuits fail
- iv)* The emergency stop button is used
- v)* Any attempts to disengage the HV plug while live (this may be achieved by the pilot

contactors embedded in the plug and socket such that the pilot contactors disengage before the phase contactors can disengage)

Harmonics

Where power converter equipment is provided within the shore connection system in order to obtain desired voltage and/or frequency, the total voltage harmonic distortion of the converter is not to exceed 5 percent at any operating load.

Tests:

HV Switchboard

Type Test

HV switchboards are to be subjected to an AC withstand voltage test in accordance with Table-2 or other relevant national or international standards. A test is to be carried out at the manufacturer's test facility in the presence of the Surveyor.

Onboard Test

After installation onboard, the HV switchboard is to be subjected to an insulation resistance test in accordance with Table-2 in the presence of the Surveyor.

Equipment Design:

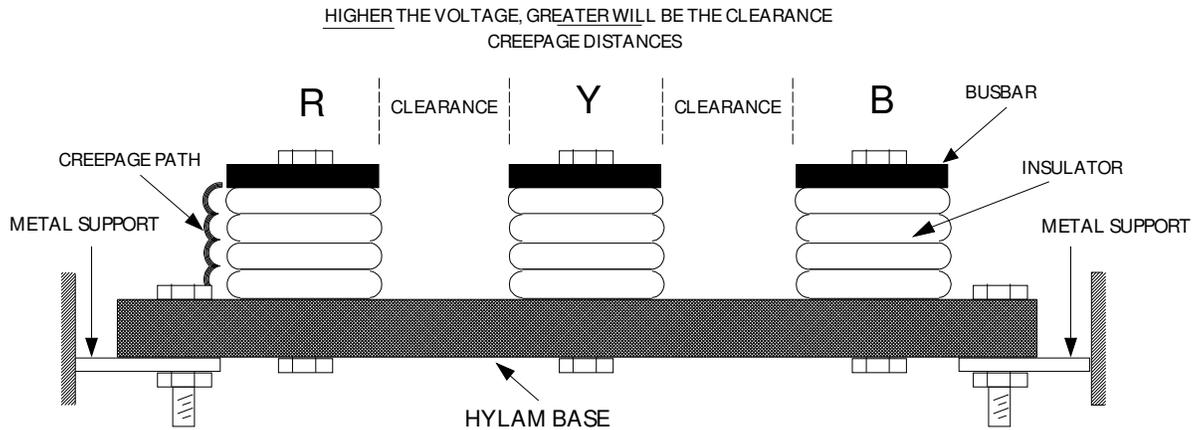
Air Clearance

Phase-to-phase air clearances and phase-to-earth air clearances between non-insulated parts are to be not less than the minimum, as specified in Table

<i>Nominal Voltage kV</i>	<i>Minimum Air Clearance mm (in.)</i>
3 - 3.3	55 (2.2)
6 - 6.6	90 (3.6)
10 - 11	120 (4.8)

Creepage Distance

Creepage distances between live parts and between live parts and earthed metal parts are to be adequate for the nominal voltage of the system, due regard being paid to the comparative tracking index of insulating materials under moist conditions according to the IEC Publication 60112 and to the transient overvoltage developed by switching and fault conditions.



Shore Connection Switchboard:

Construction

The HV shore connection switchboard is to be designed, manufactured and tested in accordance with a recognized standard code of practice as given by IEC.

Circuit Breaker

- i) Shore connection HV circuit breaker is to be equipped with low voltage protection (LVP)
- ii) The rated short-circuit making capacity of the circuit breaker is not to be less than the prospective peak value of the short-circuit current
- iii) The rated short-circuit breaking capacity of the circuit breaker is not to be less than the maximum prospective symmetrical short-circuit current
- iv) HV shore connection circuit breaker is to be remotely operated

HV Circuit Breakers may be

- Air-Break (scarcely used)
- Oil-Break (not used in ships)
- Gas-Break (SF – 6 - Sulphur Hexafluoride)
- Vacuum-Break (Most Popular)

CONCLUSION:

Future Electrical ship:

- Future HV ships systems at sea may require voltages up to 13.8 kV to minimize fault levels
- It is therefore essential that all Marine Engineering personnel are trained in safe working practices for these voltages.
- The Electrical officers of the near future must be fully trained to carry out maintenance and defect rectification on Medium Voltage (MV) systems.
- This will mean a considerable increase in the electrical content of all training.
- Training will also need to be given to non-technical personnel to ensure everybody is aware of the dangers of these higher voltages.