UNGROUNDED AC SUPPLY SYSTEMS AND THE RISK OF ELECTROCUTION

BY

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ABSTRACT

The article highlights the effects of electrocution with details taken from medical studies. It shows how earthing arrangements protect personnel, with theoretical proof and more importantly, emphasises the need for regular maintenance on earthing cables.

Answers to key questions of 'how and why' we use ungrounded supply systems along with the type of earthing arrangements have been included.

Results from analysing previous data and collating information from several different sources have provided a wider picture into the dangers of electricity onboard ships. Technical evidence contained within this article provides a strong case for justifying existing maintenance, which regularly comes into question from the Fleet.

The safety of personnel serving onboard HM Ships is of great importance. A ship's company has to be made aware of the dangers from electrocution and the simple way in which these risks can be reduced.

Introduction

As part of the Warship Support Agency, the Marine Electrical Systems Integrated Project Team is the sponsor for electrical safety within the Royal Navy. It has become apparent over recent years that the earthing arrangement of equipment and systems varies in safety standard from very good in some areas to poor in others.

In most cases, an apparent lack of appreciation of the type of supply system used in the Royal Navy, along with an understanding of how adequate earthing arrangements protect personnel from electrocution, impacts on the standards observed.

A statement from Flag Officer Sea Training to a team investigating Reliability Centred Maintenance, said that out of an average 2,000 earth leads fitted to ship equipment, 20% were defective when inspected, rising to 50% on older vessels. It is my intention in this article to highlight the effects of poor earth bonding, with proof, that if properly maintained, earth bonding will save life.

There has been a wide range of electrical equipment in operation since the early 1870's and with the advent of the All Electric Ship which, will operate with voltages in the range of 4 to 13KV, the emphasis on electrical safety is paramount. The risk of electrocution is greatly increased because of the harsh environment and metal surroundings in which equipment is installed.

Information supplied by the Defence Analytical Services Agency, show that in the period from 1991 to 1999 there have been two fatalities and eight cases of serious injury requiring hospitalisation due to electrocution in the Armed Forces. However, these figures do not reflect the number of incidents, which go unreported each year.

The Health and Safety at Work Act places an obligation on designers to develop equipment and systems, which are inherently safe. It is the engineer's responsibility to ensure that these systems are maintained to the required standard, so that they continue to be safe. At home, at work in a large factory or on a ship at sea, there is a requirement to have earthing arrangements fitted to electrical installations and equipment, whether fixed or portable. This is to safe guard human lives against contact with any extraneous part, which may have become live due to an earth fault.

As with any shore side installation, electrical systems are installed to well proven standards. These ensure that equipment operates correctly and that it meets relevant safety standards. Whether merchant or military, ships electrical installations should meet the requirements laid down in the following publications:

- Naval Engineering Standards.
- Lloyds Register – Rules and Regulations for the Classifications of Ships Part 6: Control, Electrical, Refrigeration and Fire.
- IEE Regulations for the Electrical and Electronic Equipment of Ships with Recommended Practice for their Implementation.
- Recommendations for the Electrical and Electronic Equipment of Mobile and Fixed Offshore Installations.
- BS7671:1992, Requirements for Electrical Installations (IEE Wiring Regulations, 16th Edition).

The specific areas that this article will look at are:

- Effects of electrocution on the human body.
- Ungrounded and Grounded earthing arrangements.
- Effects of Capacitance on Main Supply Systems.
- Implications of no or poor earth bonding.
- The design and fit of earthing arrangements.
- The cost and type of maintenance required to ensure effective earth bonding.

The majority of supply systems in the surface fleet are AC systems, therefore only the effects of AC currents will be examined for this article. It must be emphasised that DC currents have great potential to endanger life, so extreme care should also be used when working on DC systems.

ELECTRICAL POWER SUPPLIES

Generated supplies in AC ships

The Main Generators produce 450V AC 3 phase at 60 Hz, which is supplied via associated switchgear to a power and distribution network at 440V AC. The volt drop allows for any cable losses, (FIG.1).

The type of AC generators used in-service are 3 wire Star connected machines. The load across each phase is approximately balanced which means that the value of current at the star point of the generator is zero*. Hence, there is no requirement for a neutral conductor. An added advantage is that it reduces the amount of cabling required onboard ships by 25%. A further reduction can be made with the use of modern types of cable, which have a greater current carrying capacity due to improved insulation. This leads to a considerable saving in cost and weight when building ships.

*Kirchoffs Second Law:

The sum of the currents flowing into and out of a single point for a balanced load is always zero

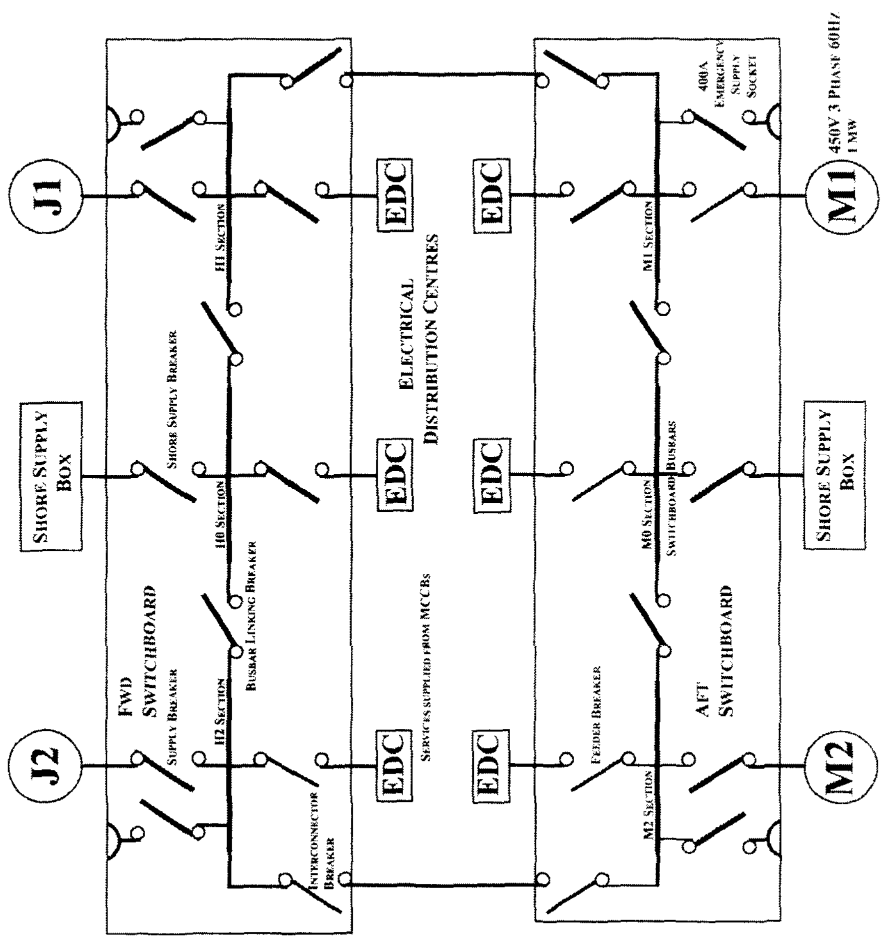


FIG.1 – TYPE 42 450V MAIN AC SUPPLY SYSTEM

Domestic arrangements

Domestic power supplies are derived from 440V, which is transformed down to 115V and has its secondary-winding centre tapped to earth. This lower voltage is much safer for use with portable equipment, as any earth fault would only have an earth potential of 57.5V. 115V lighting transformers, however, do not have the secondary-winding centre tapped therefore have an earth potential of the full 115V.

Domestic 230V AC is supplied from amenity panels incorporating a single 115/230V transformer. This isolated supply limits any chance of completing an earth leakage circuit through a second fault on the other supply line. Amenity panels are provided for use within mess decks and certain offices. Only domestic equipment such as computers, televisions or shavers should be used with these panels due to their limited power rating (20VA or IOOVA). Incorporated into the IOOVA transformer is a thermal cut-out for protection in the event of an overload.

Modem ships now have 230V AC radial circuits within mess decks, some of these are protected by Residual Current Devices (RCD). This greatly reduces the risk of electric shock in the event of an earth fault, as the current developed is sufficient to operate the RCD.

Converted supplies

Due to the diverse range of electrical and electronic equipment installed on HM Ships, other power supplies are required. These supplies are termed 'Converted Supplies' and provide power to systems such as navigation, radar and weapons.

The converted supplies are derived from the main 440V 60Hz 3-phase network. Typical voltages produced include:

24V DC	–	Internal Communications
50V DC	–	Machinery Controls
115V 400Hz	–	Steering Gear Controls
200V 400 Hz	–	Radar Equipment

There are numerous other converted supplies for other equipment and systems.

EFFECTS OF ELECTROCUTION

There have been extensive studies carried out into the effects of electrocution on the human body, in particular establishing thresholds at which electric shock levels are likely to become fatal.

Involuntary reaction

When a person receives an electric shock, current flows through the body due to its ability to conduct electricity (70% water). If sufficiently large enough, the flow of current will stimulate the muscles. It is this intense stimulation that causes legs and arms to straighten. This phenomenon is known as 'involuntary reaction'. People have been known to receive more harm from being thrown because of involuntary reaction, than from receiving the severe shock that caused it.

It is worthy of note that it is the level of current and not the magnitude of the voltage that presents the greatest risk to life.

Let go current

Conversely to involuntary reaction, receipt of an electric shock can cause the muscles to contract. If the person touches a live component with the palm of their hand, the flow of current through the arm can cause the muscles in the hand to grip. As the current and pain increase so the grip tightens which prevents the person from letting go.

In the 1950's PROFESSOR C.F. DALZIEL[1] performed experiments on volunteers to determine at what level they could not let go of live equipment. 147 healthy males had varying currents passed through the body from one hand to the other, results showed that all healthy males could let go of currents up to 9mA at a frequency of 60Hz. Not one of the volunteers could let go of currents in excess of 24mA at 60Hz.

The frequency of supply has an impact on the let go current, it can be seen from (FIG.2) that 60Hz has the most effect on the ability to let go. As frequency either decreases or increases from 60Hz, the current level at which man can let go increases.

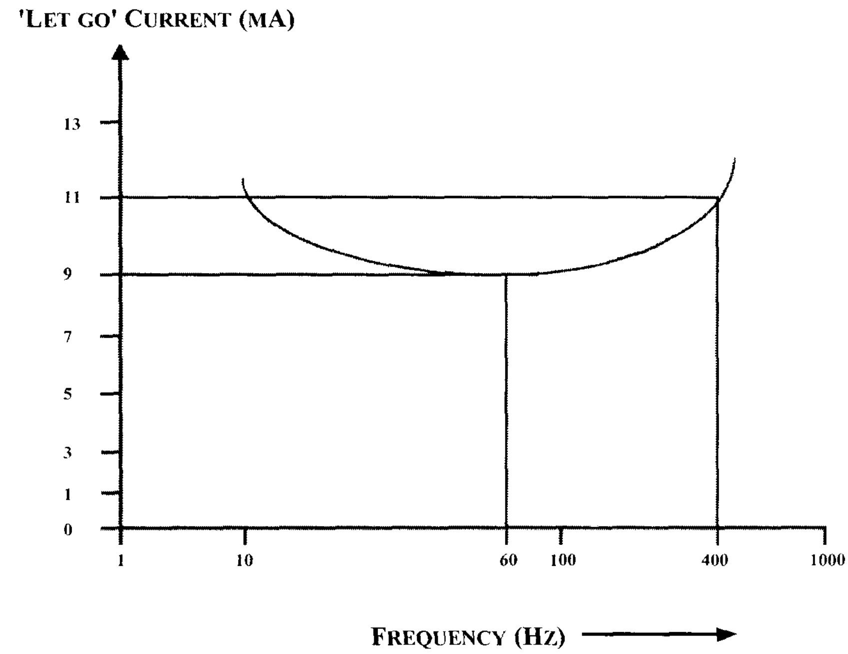


FIG.2 – THE EFFECT OF FREQUENCY ON MAN'S 'LET GO' CURRENT

Asphyxia and Respiratory Arrest

Electrocution from currents in excess of 20mA will cause asphyxiation due to contraction of the lungs, however once the power has been removed recovery should follow naturally and without resuscitation.

A similar effect to asphyxia may occur when the Respiratory System suffers paralysis and is termed Respiratory Arrest. This is when the respiratory area of the brain, at the base of the skull, receives a severe shock. Paralysis of the nervous system controlling the lungs will prevent them functioning, resulting in asphyxiation as described above.

Ventricular Fibrillation and Ventricular Asystole

After receipt of an electric shock the heart may stop, called Ventricular Asystole or go into a state of Ventricular Fibrillation. In both instances blood is not being pumped to the brain so starving it of its oxygen supply.

Ventricular Fibrillation is where the heart goes into spasm because of the current that has passed across it. To stop the heart from fibrillating, it must be stopped and restarted again with a second electric shock from a de-fibrillator. It has been found that the greatest risk from Ventricular Fibrillation was at 150mS into the cycle of a heartbeat. At this point the Ventricles start to relax and if the heart receives stimulation from an external source such as from an electric shock, it causes the heart to go into spasm. This period of risk is called the Vulnerable Period.

If the electric shock has stopped the heart, once the current is removed the heart may start again naturally or by the application of Cardiac Massage. It is easy to see that for the victim of an electric shock, the condition of Ventricular Fibrillation is more dangerous and life threatening. The level of current required to stop the heart or cause Ventricular Fibrillation is difficult to ascertain due to lack of experimental volunteers! From experiments on animals by DALZIEL and LEE[2] it was found that there is a linear relationship between the level of current and body weight. This relationship holds true for a range of animal weight from a Guinea pig to a Cow. A current and time relationship has been published[3] and is summarized in (FIG.3) and Table 1.

It has been found that the level of current to cause Ventricular Fibrillation is much lower than that required to stop the heart. So when determining the maximum safe current, Ventricular Fibrillation is the most important factor. Ventricular Fibrillation is considered to be the main cause of death from electric shock.

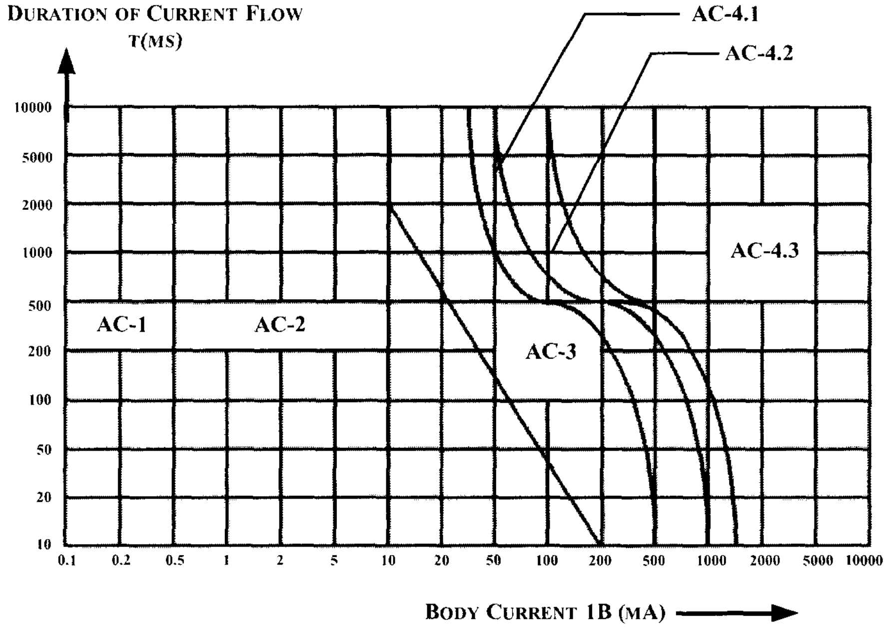


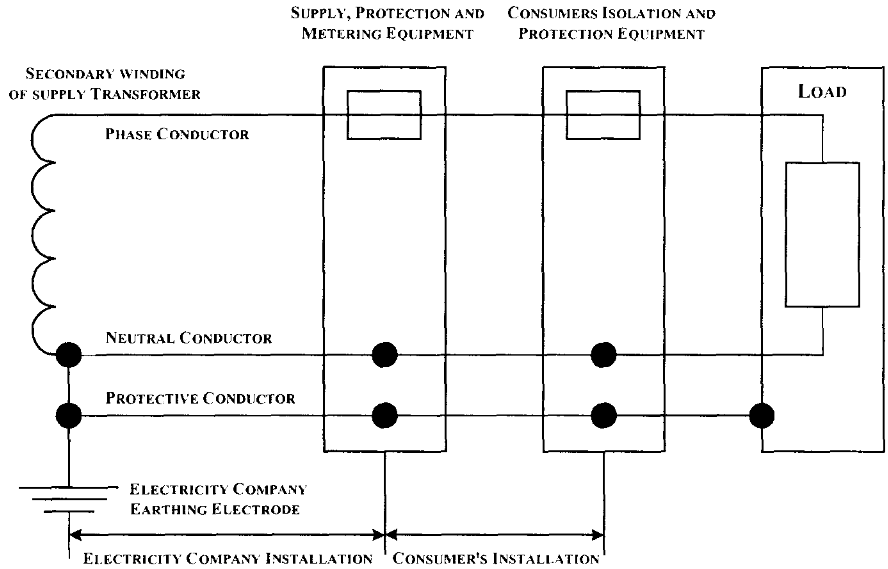
FIG.3 – THE TIME/CURRENT ZONES FOR A FIT HEALTHY MALE FOR AC 15 – 100 HZ

TABLE.1 – *Effects of Time/Current Zones for AC 15 – 100Hz*

Zone	Physiological Effects
AC-1	Usually no reaction.
AC-2	Usually no harmful physiological effects.
AC-3	Usually no organic damage but can expect cramplike muscular contactions and difficulty in breathing for duration of current flow in excess of 2 seconds.
AC-4.1	Probability of ventricular fibrillation increasing up to 5%.
AC-4.2	Probability of ventricular fibrillation increasing up to 50%.
AC-4.3	Probability of ventricular fibrillation above 50%.
Note	AC-4 increasing with magnitude and time effects such as cardiac arrest, breathing difficulty and severe burns are likely.

Grounded electrical system

The National Grid operates a grounded electrical system. It connects the neutral conductor of the secondary winding of the supply transformer directly to earth. This ensures that if an earth fault occurs on any phase conductor, the fault current generated will have a direct path back to the neutral star point allowing the protection system fitted (circuit breakers, fuses etc.) to operate (FIG.4).



TN-S
T = ONE OR MORE POINTS OF THE SUPPLY ARE CONNECTED TO EARTH.
N = EXPOSED CONDUCTIVE PARTS CONNECTED DIRECTLY TO THE EARTHED POINT OF THE SOURCE OF THE ELECTRICAL SUPPLY.
S = SEPARATE NEUTRAL AND PROTECTIVE CONDUCTORS.

FIG.4 – SCHEMATIC DIAGRAM OF A TN-S SUPPLY AND EARTHING SYSTEM

Ungrounded electrical system

All main electrical supply systems within RN Ships are electrically isolated from ground (earth). Earthing of equipment is provided by earth straps and cables, connecting all metal casings (which in the event of an earth fault may become live) to the Ships structure. The distribution system is designed to tolerate one earth fault without disrupting supplies to that equipment. The fault current developed will not have a return path to any other phase because of the electrical isolation of the other phases from earth.

This has a distinct advantage during battle damage, when equipment may become earthed and which is of vital importance to the fighting capability of the ship. (FIG.5) shows a typical ungrounded system used within the Royal Navy. When a phase to earth fault of negligible impedance occurs, the potential of the metalwork is raised to a dangerous level.

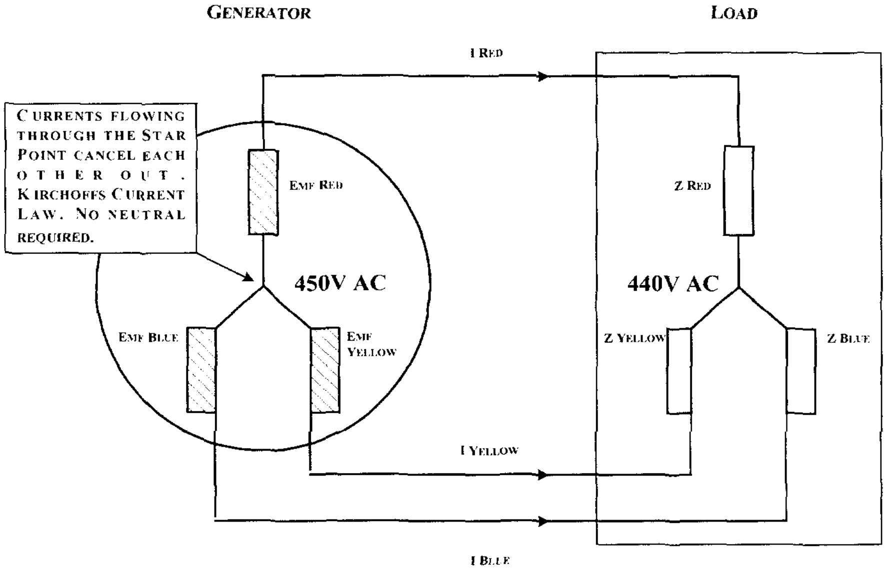


FIG.5 – DIAGRAM OF AN UNGROUNDED SUPPLY SYSTEM AS USED ON RN SHIPS

If a second fault occurs on another phase, then this completes the earth circuit, operating the protection system, disconnecting the equipment from the supply.

A common misconception with the understanding of the ungrounded system, is the belief that a person can touch one bare conductor without receiving an electric shock, since there is no circuit for the current to flow. In practice there is always a path for the current to flow, either via a combination of several small earth leakage current paths or through cable capacitance of the distribution network.

SYSTEM IMPEDANCE TO EARTH IN AN UNGROUNDED SYSTEM

Resistive component

The integrity of the resistive components are checked periodically using suitable test equipment, the value obtained gives an indication of the condition of the insulation. Values of insulation are measured in ohms, the higher the value, the greater the integrity of the insulating material resulting in minimal earth leakage current flow. Table 2 gives minimum values of insulation expected from tests on different circuits.

TABLE 2 – *Minimum values of insulation resistance*

Equipment or Circuit	Minimum insulation resistance (Cold 20-25 degrees)
Main Generator Stators	1 megohm
Main Generator Rotors	0.1 megohm, trend from 1MΩ
Switchboards	2 megohms.
Transformers	10 megohms.
Lighting Circuits	10 megohms divided by the number of lamps in the circuit.
Electronic Equipment	20 megohms.
Galley Equipment	2 megohms divided by the kilowatt load of the equipment or 2 megohms if loading is less than 1 kilowatt

Cable capacitance

The construction of a capacitor is made up of two metal conducting plates with a potential difference across them, separated by an insulating material (FIG.6).

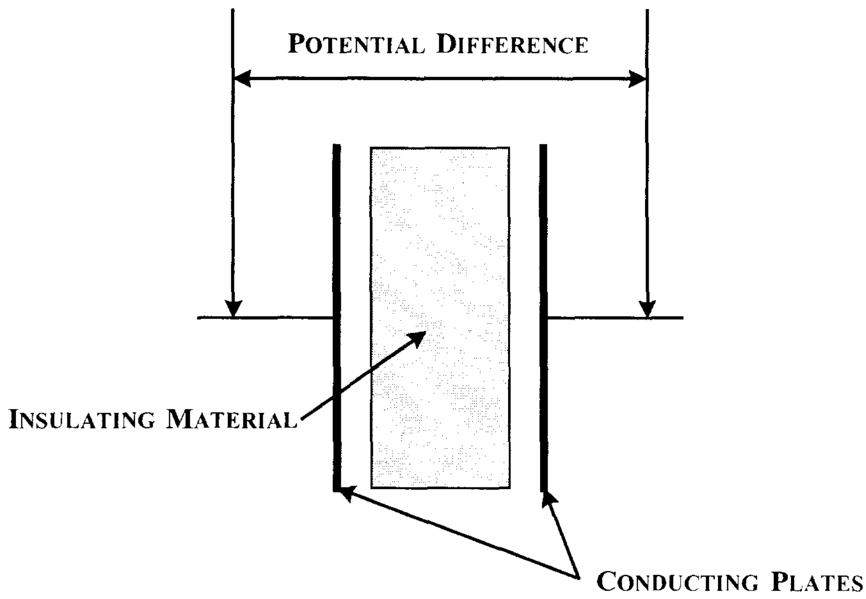


FIG.6 – CONSTRUCTION OF A CAPACITOR

Electrical cables can act as capacitors when installed in channel plates and ducting. An insulating material surrounds the copper core, which is the mounted on a metal bulkhead. When it is conducting a potential difference exists between the copper core and the metal bulkhead. This is in effect a capacitor (FIG.7).

The value of the capacitance (measured in Farads) between the conductor and earth, depends on several factors. These factors are:

- Radius of the conductor.
- The distance between the conductor and the metal bulkhead.
- The dielectric constant of the insulation material.
- Length of the cables.

Low earth impedance due to capacitance cannot be detected when carrying out insulation checks, as capacitors have infinite impedance to any DC test injected.

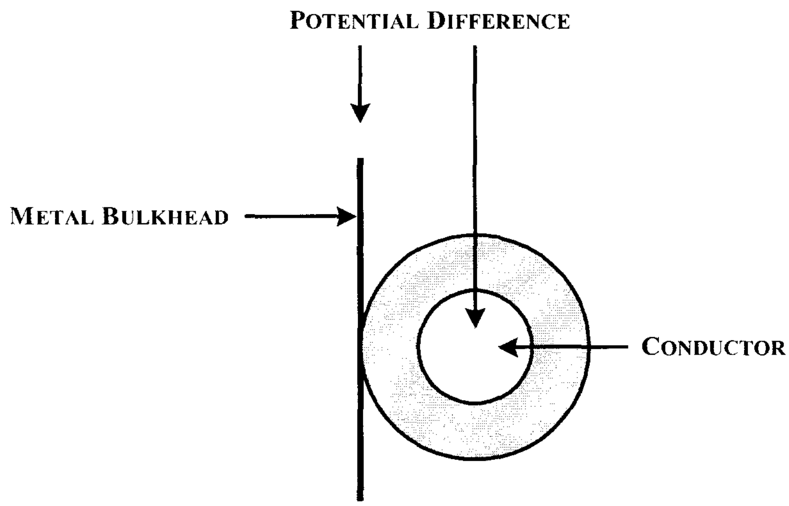


FIG.7 – DIAGRAM OF ELECTRIC CABLES ACTING AS A CAPACITOR

Radio interference suppression

As well as generator and cable capacitance, other major contributions come from suppression filters on electronic equipment. These are connected between each supply line and earth and fitted to suppress radio interference on sensitive communication equipment. The capacitance of filters to earth will vary in different ships, values up to 50µF have been measured between each phase and earth.

Total capacitance of a distribution system can be in the region of 70µF. In modern ships, 440V supply system capacitance is limited to 10µF per megawatt of generating capacity. The impedance of current flow to earth of this capacitance is also measured in ohms and is the Capacitive Reactance (Xc) to earth. Capacitive Reactance can be determined from the following equation:

$$Xc\ (\text{ohms}) = \frac{1}{2\pi FC}$$

where F = Frequency of supply and C = Capacitance

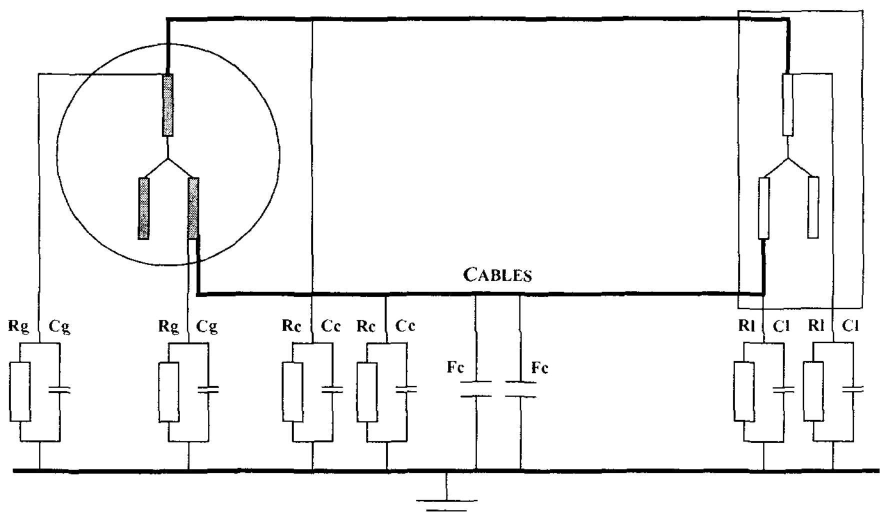
This capacitance cannot be eliminated as it is an intrinsic part of electrical theory but its value may vary slightly, due to the addition and removal of electronic equipment. There is no requirement to measure the reactance since its value remains relatively constant.

Overall effects of Impedance to Earth

(FIG.8) shows these resistive and reactive components broken down into their component parts. As can be seen, the impedance to ground of a Ships Supply System is made up from three main components:

- Generator
- Cables
- Equipment fitted.

The total impedance of the system is a combination of the Capacitive Reactance and the Insulation Resistance, of these component parts.



Rg	–	Generator Insulation Resistance	**Cg**	–	Capacitance of the Generator
Rc	–	Cable Insulation Resistance	**Cc**	–	Cable Capacitance
Rl	–	Insulation Resistance of the equipment	**Cl**	–	Capacitance of the Load
Fc	–	Equipment Filter Capacitance			

FIG.8 – EFFECT OF CAPACITIVE REACTANCE ON AN UNGROUNDED SHIPS ELECTRICAL SYSTEM

The total resistance of a man's body can be as low as 600Ω, depending on the environment and the type of work being undertaken. If an earth fault occurs, the combination of low body resistance (600Ω) and the system impedance to ground (150Ω) can produce a high enough fault current to cause serious electrocution. This could prove fatal if there is no earth cable fitted, or the condition of the cable is poor.

Applying simple Ohms Law can calculate the level of shock current which could flow in the event of a single earth fault:

$$I_{shock} = \frac{\text{Supply Voltage (V)}}{\text{System Impedance (Z) plus Man}}$$

$$I_{shock} = \frac{450\text{V}}{750\Omega} = 0.6\text{A}$$

This value will be greatly increased if a second earth fault occurs before the first is cleared. It has already been ascertained that small currents of 20mA - 100mA can cause death due to asphyxiation depending on the duration.

Methods of protection

There are two methods from which a person can receive an electric shock. These are:

- Direct contact between a person and part of the system that is designed to carry electric current.
- Indirect contact between a person and an exposed conductive part that has become live due to an earth fault.

Protection from direct contact

To protect personnel from the risk of electric shock due to direct contact, two key areas of protection are employed on HM Ships:

Insulation of Live Parts

This is the most common method employed, conductive parts are physically insulated with non-conductive materials. The level of insulation must be suitable to prevent earth leakage and be resistant to external effects such as heat, water, oil and mechanical stresses.

Protection by Barriers and Enclosures

Protection is offered by placing live conductive parts within enclosures or behind barriers. These enclosures should prevent access to objects down to 12mm diameter. Access to operate the equipment or to allow maintenance is allowed, although suitable precautions must exist to prevent inadvertent contact with any live component.

Other methods used to prevent direct contact are by placing obstacles between the live part and personnel, or by placing live components out of reach. RCDs are now being employed on 230V supplies for mess decks to disconnect the supply in the event of an earth leakage current.

Protection from indirect contact

Due to the supply system in HM Ships being electrically isolated from earth, and the probability that equipment will continue to operate in the event of a single earth fault, it is essential that all equipment is earthed correctly. Earth bonding straps are fixed between all extraneous conductive parts and the ships structure. This ensures that in the event of an earth fault, the majority of current flow is through the earth cable to ground and not through anyone coming into contact with a live equipment casing.

When using portable electrical equipment, the use of Class II power tools will prevent electrocution, since the casings are made of an insulating material designed to protect the operator from any live component. Due to their construction, Class II equipment is not fitted with any earth

RCDs are used on particular 230V AC supplies to mess decks and on certain types of 440V emergency portable pump sockets. The latter can be overridden in the event of an emergency. RCDs disconnect supplies in the event of an earth leakage current flow. Selection of the RCD depends on the level of protection required for different risk areas. RCDs are available at values of 10mA, 30mA (most common), 100mA and 300mA.

REQUIREMENTS OF EARTH BONDING

Earthing arrangement

The majority of equipment fitted to ships is constructed of metal and is fixed to steel bedplates or bulkheads. It may appear that any subsequent earthing arrangement is nugatory, this is not so! To reduce the noise level transmitted to the ship's hull and to prevent damage to machinery from shock blasts, the majority of equipment is resiliently mounted. The mounts incorporate rubber, which attenuates the amplitude of the noise to the ship's structure by absorbing shock and vibration. In conjunction with the mounts, paint, rust and poor contact area between the equipment and the ship's structure add to the resistance path to earth.

There is a requirement to ensure that all equipment offers adequate protection in the event of an earth fault current. This is provided in the main by the use of earth bonding straps fitted between the equipment and the ship's structure. Earth bonding allows the majority of current to flow to earth through its low resistance path (0.1Ω), rather than through the body of anyone who inadvertently touches a live equipment casing due to an earth fault.

(Fig.9) shows a typical earth bonding arrangement. It is worthy of note that there are several variants, so reference to the documentation is important for selection of the correct bonding arrangement. Earth Straps can be locally manufactured and fitted to equipment

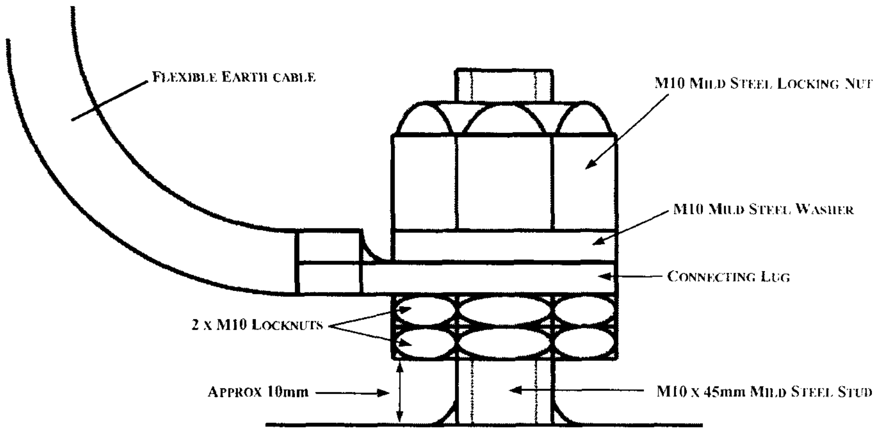


FIG.9: DIAGRAM OF EARTH CABLE AND STUD ASSEMBLY CONNECTED TO A STEEL STRUCTURE OR EQUIPMENT.

Regulations regarding Earth Bonding

Equipment operating or supplying voltages in excess of 35V AC or 50V DC, are to have any extraneous part earthed to the ship's structure. With the exception of some equipment fitted in electronic compartments, all equipment should be bonded in accordance with current regulations.

Summary of the requirements for Earth Bonding

(*a*) Only rigidly mounted equipment, with a volume less than $0.003m^3$ (15cm x 15cm x 15cm) may rely on the fixing arrangements to adequately bond the casing to earth.

(*b*) Earth bonding should be in the form of a flexible strap connecting the equipment casing to the ship's structure.

(*c*) Portable Class I equipment should have a separate earth core within the supply cable.

(*d*) Equipment mounted on insulating materials should be bonded together using an earthing tree. The common point is then grounded to earth on the ship's structure.

(*e*) The Cross Sectional Area (CSA) of the earthing cable should be equal to the largest current carrying conductor of the equipment, up to a value of $16mm^2$. For current carrying conductors in excess of this value, the CSA of the earthing cable should be equal to 50% of the CSA of the largest current carrying conductor.

(*f*) The resistance value of the earthing cable has to be measured on initial installation. On confirmation that it is below the maximum permitted level, the studs connecting the cable should be preserved using either paint in harsh areas such as bilges, or light grease elsewhere.

(*g*) The maximum value of resistance for fixed equipment, between its casing and the ship structure, should not exceed 0.1Ω.

(*h*) Hinged doors on equipment should be earthed if electrical components are supplied with voltages greater that 35V AC or 50V DC.

MAINTENANCE REQUIREMENTS

The planned maintenance for the earthing arrangements is simple to carry out and can be done by semi-skilled personnel.

Earth bonding inspection

Every 6 months the earthing cable should be visibly examined for any signs of deterioration or mechanical failure. Any repairs are to be carried out immediately, after which, the resistance should be measured to confirm it is below 0.1Ω.

Earth bonding measurement

Every 12 months the resistance of the bonding should be measured with a suitable test instrument. If values above 0.1Ω are obtained, then the cable will have to be removed and possibly replaced. On re-assembly confirmation should be made that a resistance value below 0.1Ω has been established.

Maintenance cycle

There could be up to 2,000 earth cables fitted to equipment on a frigate size ship. It is essential for maintainers to establish a rolling program of maintenance to ensure that all cables remain capable of offering the protection that they have been designed for, in the event of an earth fault.

Insulation test

To ensure the integrity of the insulation is above the minimum values detailed in Table 2, the insulation resistance of equipment should be measured every 12 months. To reduce the danger to personnel and to equipment, any earth fault has to be located and cleared immediately as a second earth on another phase will cause high fault currents to flow due to the low impedance to earth.

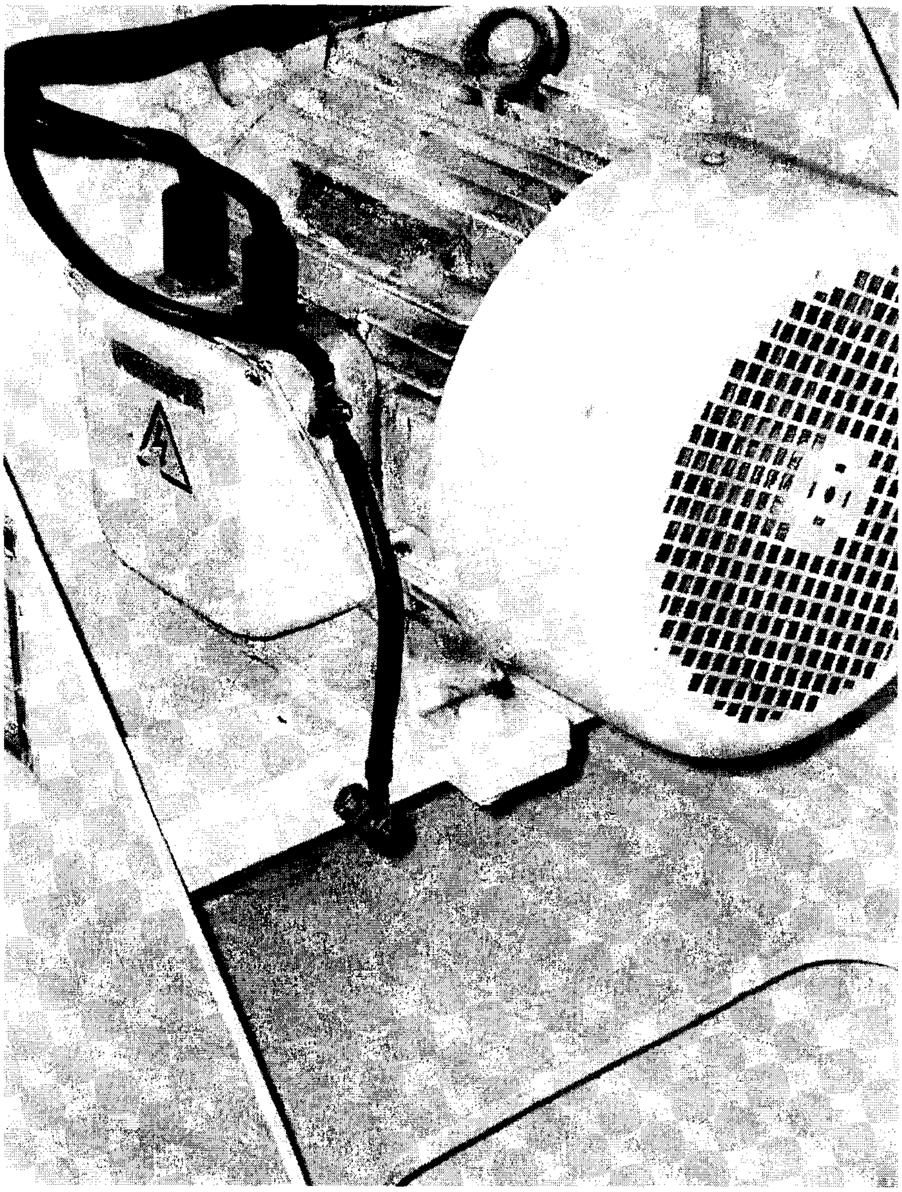


FIG.8 – TYPICAL EARTH BONDING ARRANGEMENT

Earthing arrangement of an electric motor (FIG.8). The earthing cable provides a low resistance path to the ship's structure in the event of an earth fault.

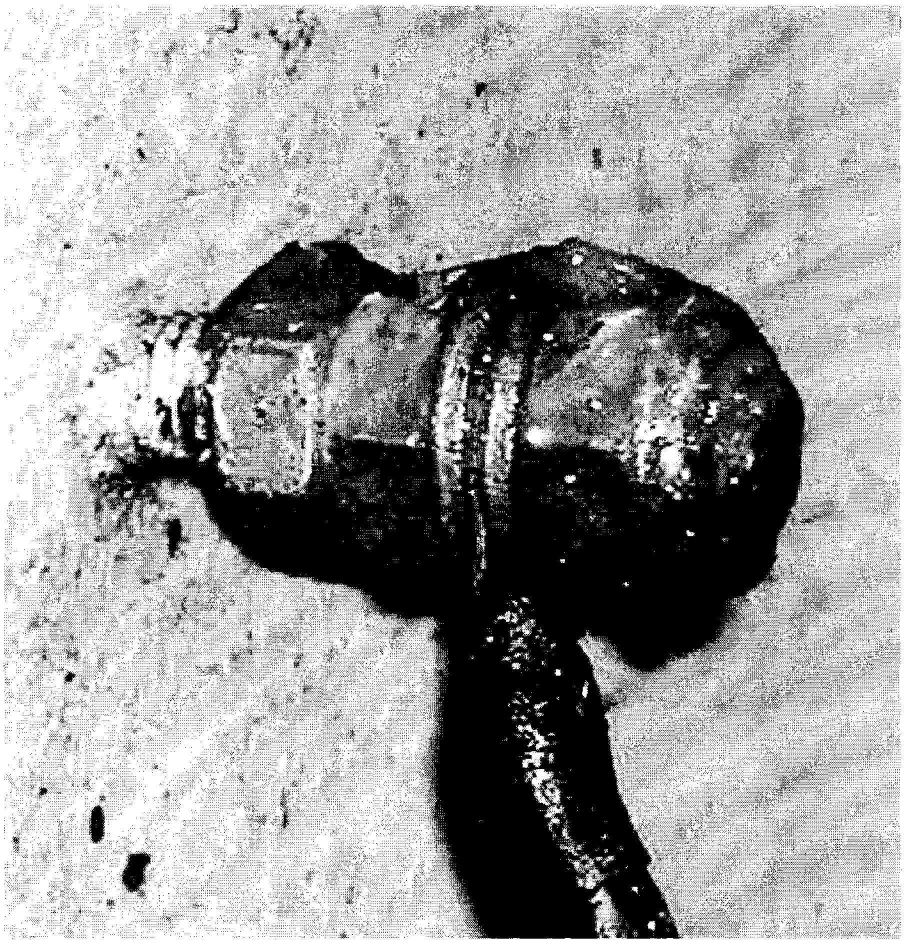


FIG.9 – EXAMPLE OF POOR EARTH BONDING

Poor maintenance and preservation has led to a build up of corrosion on the above earth cable (FIG.9). This will eventually lead to a high resistance path for any earth fault current and may fail in its ability to protect personnel from electric shock.

Earth test monitoring

On ships without an automatic alarm for indication of earths on the system, it is a requirement that plant operators check for 440V earths. An earth monitoring facility is built into the Primary Control Position and tested every 4 hours. Any phase to earth leakage above 10% should be investigated immediately.

For 115V circuits, built in earth test facilities are incorporated into the first fuse panel after a 440V/115V transformer. This facility is fitted because the transformer isolates the 115V supplies from the 440V earth test arrangement. A daily earth check should be made to ensure that circuits are earth free, any earth discovered should be investigated and removed immediately. Some 115V transformers have the secondary winding centre tapped to earth. These types of transformers supply portable electrical equipment. There is no requirement for the first fuse panel to have an earth test facility, as the centre-tapped earth would be detected by the earth test facility in the fuse panel.

Any 440V or 115V equipment which is discovered to have an earth, which cannot be investigated immediately, should be taken off load and electrically isolated for safety!

Cost of maintenance

The cost of maintaining earth bonding is not cheap. Average costs taken from contracts raised between Superintendent Fleet Maintenance (Devonport) and Plymouth Electric average £1,500 per Ship. Type 23 frigates undergo maintenance periods at intervals of 6 months (operational commitments allowing). In a 6-month period this equates to approximately £6,000 for 4 Ships. This does not include the cost of maintenance to ships that are not entitled to contract assistance.

The justification for these high maintenance costs is the requirement to ensure that the safety of the ship's company is upheld at all times.

CONCLUSION

The environment, in which naval personnel live and work, is inherently dangerous. High voltages and currents flow in areas where excessive amounts of water and metal exist. This problem is amplified due to the distribution network being electrically isolated from the ship's ground.

It has been established that very low currents can cause death by Ventrical Fibrillation, these currents can be as low as 100mA for a duration of 1 second. The longer the duration of the shock current, the lower the value required to cause Ventrical Fibrillation. Frequency of supply also has implications on the seriousness of electrocution. This is because at 60 Hz the ability to let go is greatly reduced.

Only effective earth bonding will ensure that in the event of an earth fault, personnel will be afforded protection from serious injury or even death.

Maintenance of the earthing arrangements is relatively simple and can be undertaken by semiskilled workers. The quantity of earth cables fitted and the lack of manpower available to carry out this maintenance in lean man ships negate this advantage.

Lack of manpower also impacts on shore side maintenance authorities (Captain Fleet Maintenance), which have to undertake these maintenance tasks for ships during busy maintenance periods, for which they are already over-stretched.

For lean manned Type 23 Frigates, a civilian, semi-skilled maintenance group is now allocated this type of maintenance routine and is termed 'Low Level Maintenance'. This prevents the use of over-skilled manpower, in carrying out low level maintenance tasks.

Low-level maintenance groups are not available for other classes of ship, as there is sufficient manpower to undertake the maintenance tasks whilst at sea. Any outstanding earth bonding maintenance may be submitted for approval, to Captain Fleet Maintenance teams for inclusion into the next maintenance period.

The cost of undertaking earth bonding inspection and continuity tests every 6 and 12 months is high (in the region of £1,500 per ship, per maintenance period). These costs can be justified, as there is no alternative form of protection from electrocution, presently fitted to Royal Navy ships.

It is considered that earth bonding can and will save life if correctly installed and maintained, in accordance with the established maintenance routines. Ship's staff should endeavour to maintain the earth bonding straps at a high standard due to their importance in protecting personnel from electric shock.

To reduce the burden on ship's staff in carrying out this large amount of low level maintenance, earth bonding inspection and continuity testing could be separated into two groups; 'Harsh' and 'Normal' environment.

Earth bonding in harsh environments, e.g. machinery spaces or the upperdeck would keep the existing maintenance/periodicity. Earth bonding in a normal environment, which offers a certain amount of natural protection, e.g. electronic compartments or offices, could have the same maintenance undertaken but the periodicity put back to 18 months and 2 yearly.

The safety of personnel serving on board HM Ships is of great importance. A members of a ship's company has to be made aware of the dangers from electrocution and the simple way in which these risks can be reduced.

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