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GUIDELINES ON **EARTHING SYSTEMS FOR SHIPS AND OFFSHORE STRUCTURES**

SEPTEMBER 2024

Guidelines

Earthing Systems for Ships and Offshore Structures

September 2024

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Section 1

General

1.1 Scope

1.1.1 The scope of these guidelines is to identify the best practices for protective earthing for steel, aluminium or non-metallic vessels and mobile or fixed offshore Units.

1.1.2 The guidelines are intended to give an overview of system earthing philosophy and earthing for lightning protection in maritime installations. The guidelines also give a brief overview of hazardous area earthing.

1.2 Introduction

1.2.1 Conceptualization of a proper earthing philosophy for a specific type of power distribution system on board vessel or offshore installation, is essential for safe and reliable electrical systems. Improper earthing methodology has the potential to bring disastrous results from an operational as well as a safety standpoint.

1.2.2 The earthing system is to be appropriate for the “types of distribution system” with respect to “types of earthing” adopted for all or parts of the installation to prevent dangerous current flows or overheating that can result in burns or a fire.

1.3 Types of earthing

The following types of earthing are carried out on board vessels and offshore installations, where each type of earthing system is designed to meet a specific function:

a) System earthing and Protective earthing (Equipment body earthing)
b) Earthing and bonding in explosion-hazardous areas (Tankers)
c) Earthing and electrical isolation during ship operations
    i) Gas fuel bunkering operations
    ii) Fuel oil bunkering operations
    iii) Docking operations (Shore connection)
    iv) Cargo operations (terminal electrical isolation)
d) Earthing in non-metallic vessels and aluminium vessels
e) Earthing for offshore Units
f) Earthing for offshore helicopter facilities

Section 2

Terms and definitions

2.1 *Earth-continuity conductor*: A wire, cable or other conductor connecting to the earthing-lead those parts which must be earthed. For example, it may be in whole or in part the metal conduit or the metal sheath of the cables, or the special earth continuity conductor of a cable or flexible cord incorporating such a conductor.

2.2 *Earthing-lead:* A conductor by which the connection is made to the metal hull of the ship.

2.3 *Earthing:* Electric connections between conductive parts and local earth (in this case local earth, ship's hull or metallic structure).

2.4 *System earthing*: Functional earthing and protective earthing of an electric system.

2.5 *Earth / Ground*: Part of the earth that is in electrical contact with the earth electrode and has an electric potential not necessarily equal to zero.

2.6 *Earthing / Grounding*: To make an electric connection between a conductive part and local earth. The connection to the local ground can be:

- Intentional; or
- unintentional or accidental and can be permanent or temporary.

NOTE: The terms earthing and grounding are used interchangeably throughout this document and have the same meaning.

2.7 *Equipotential bonding*: Set of electric connections intended to achieve equipotentiality between conductive parts.

2.8 *Primary Structural damage (from lightning)*: Damage which can result from a stroke of lightning to ships which do not provide a path of low resistance to earth for the passage of lightning currents, for example, seen on ships of non-metallic construction or those having substantial non-metallic members.

2.9 *Secondary damage (from lightning):* Damage to ships or to their electrical installation which can result as an indirect consequence of a lightning stroke to a ship or to its immediate vicinity. A path to earth of low resistance may not prevent the consequence of secondary damage which may occur as result of high values of induced or resistance drop voltages produced by the passage of lightning currents.

2.10 *Safety voltage*: AC: - A voltage which does not exceed AC 50 V r.m.s. between conductors, or between any conductor and earth, in a circuit isolated from the supply by means such as a safety isolating transformer, or converter with separate winding.
DC: - A voltage which does not exceed DC 50 V between conductors, or between any conductor and earth, in a circuit which is isolated from higher voltage circuits.

Section 3

Earthing design guidelines

3.1 System earthing

System earthing should be considered for all electrical power supply systems in order to control and keep the system's voltage to earth within predictable limits. It has to also provide for a flow of current that will allow detection of an unwanted connection between the system conductors and earth, which should instigate automatic disconnection of the power system from conductors with such undesired connections to earth. Earth indicating devices should be so designed that the flow of current to earth through it is as low as practicable, but in no case the current should exceed 30 mA.

3.1.1 General

3.1.1.1 Method of earthing low-voltage (voltage not exceeding 1000 V AC) power distribution systems is to be determined considering the following:

a) To the maximum extent possible, the system design should allow for continuity of service under single-line-to-earth fault conditions, particularly in distribution systems supplying critical ship's service.

b) Systems should be designed to minimize the magnitude of earth fault currents flowing in the hull structure.

3.1.1.2 To satisfy these criteria, it is recommended that systems be designed in accordance with the earthing philosophies:

- **Unearthed**: All current-carrying conductors completely insulated from earth throughout the system. Unearthed systems should have provisions for continuous earth fault monitoring. The exposed non-current carrying conductive parts of the electrical installation are to be earthed. (see Fig 3.1.1.2 a))

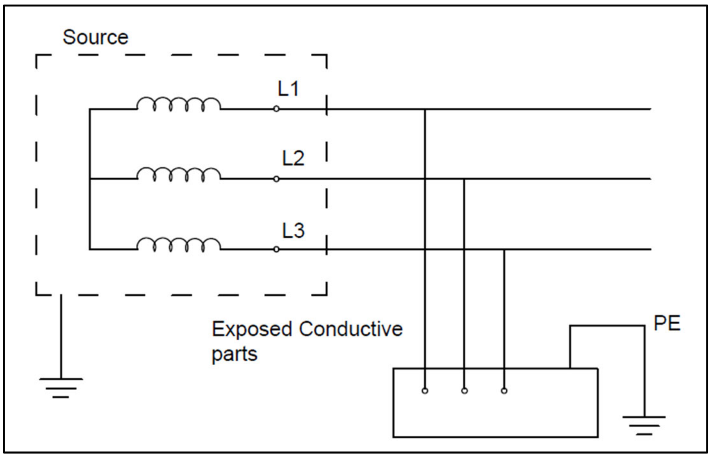

Fig 3.1.1.2 a)

- **High-resistance earthed**: The neutral point of the system connected to earth through impedance. The neutral may or may not be distributed (see fig 3.1.1.2 b)). Single-line-to-earth faults are limited to 5A, maximum. High resistance earthed systems should have provisions for continuous earth fault monitoring.

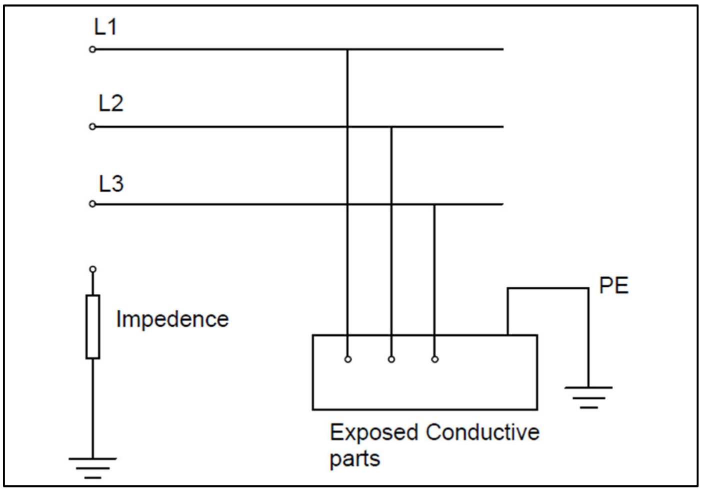

Fig 3.1.1.2 b)

- **Solidly earthed:** Solidly earthed designs should be limited to systems supplying noncritical loads, such as normal lighting, galley circuits, and so on. When a solidly earthed distribution system is used, the neutral conductor should be full-sized to preclude overheating due to harmonic distortion from nonlinear loads. (see Fig 3.1.1.2 c))

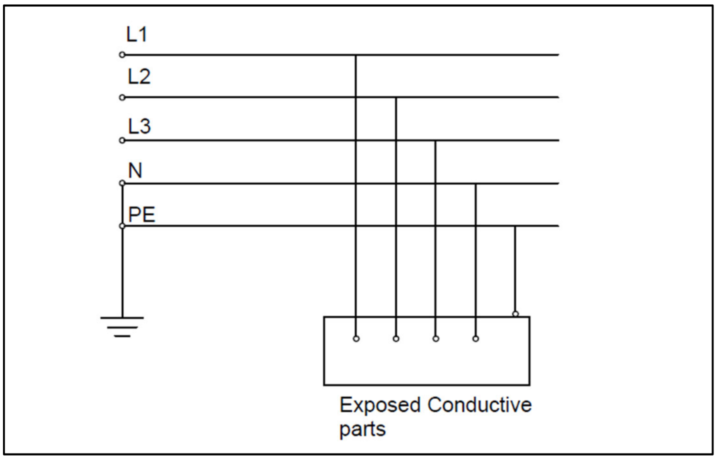

Fig 3.1.1.2 c)

3.1.2 Earth Points

3.1.2.1 The system earthing point should be selected based on the following basis:

- Three-phase system: At the neutral
- Single-phase, three wire system: At the phase midpoint
- Single-phase, two wire system: At either power conductor

The earthing connection to the system or parts of a system should be made as close to the source of power as possible, rather, at the load ends of the system.

3.1.3 Arrangements

3.1.3.1 Earthed low-voltage (1000 V AC or less) should be solidly earthed or high- resistance earthed. The connection to the hull should be made to a suitable structural frame or longitudinal girder. In the case of a large-capacity system the connection should be made to both a frame and a girder.

3.1.3.2 For earthed systems, a disconnect feature should be provided for each generator earth connection to permit checking the insulation resistance of the generator-to-earth before the generator is connected to the bus.

3.1.4 Hull Return

3.1.4.1 A vessel's hull is not to carry current as a conductor, except as part of impressed cathodic protection systems, or limited and locally earthed systems. Examples of limited or locally earthed systems are as follows:

a) a battery system for engine starting that has a one-wire system and the earth lead connected to the engine;

b) insulation level monitoring devices where the circulation current does not exceed 30 mA under the most unfavourable conditions;

c) welding systems using hull return.

3.1.5 Earthed distribution systems

3.1.5.1 The system earthing of earthed distribution systems should be carried out by means independent of any earthing arrangements of non-current-carrying parts.

3.1.6 Requirements for earthing in the power distribution systems

3.1.6.1 Neutral grounding

Each propulsion, power, lighting, or distribution system having a neutral bus or conductor should have the neutral grounded at a single point. The neutral of a dual-voltage system (i.e. three-phase four wire ac; three-wire dc; or single phase, three wire ac) should be solidly grounded at or directly adjacent to the generator switchboard. Where the grounded system includes a power source, such as a transformer, the single-point ground connection should be made at or directly adjacent to the switchboard or distribution panel for the power source.

3.1.6.2 Generation and distribution system grounding

.1 The neutral of each grounded generation and distribution system should be grounded at the generator switchboard, except the neutral of an emergency power generation system which should be grounded with no direct ground connection at the emergency switchboard. The Emergency switchboard neutral bus should be permanently connected to the neutral bus on the ship service switchboard, and no switch, circuit breaker, or fuse should be in the neutral conductor of the bus-tie feeder connecting the emergency switchboard to the main switchboard.

.2 The ground connection should be accessible for checking the insulation resistance of the generator to ground before the generator to the bus. Fuses should not, and circuit breakers need not, be provided for the neutral of a circuit. The grounded conductor of a circuit should not be disconnected by a switch or circuit breaker unless the ungrounded conductors are simultaneously disconnected. Medium voltage transformer primary neutrals should not be grounded except when all generators are disconnected, and power is being supplied from shore.

3.1.6.3 Ground detection on grounded neutral ac systems

.1 Ground detection for each ac system that has grounded neutral should have an ammeter and ammeter switch that can withstand the maximum available fault current without damage. The ammeter should indicate the current in the ground connection and should have a scale that accurately, and with clear definition, indicates current in the 0-A to 10-A range. The ammeter switch should be the spring return-to-on type.

.2 The ammeter and current transformer should both be of such a design that they are not damaged by ground fault currents. Where the ammeter is in a remote enclosure from the current transformer, a suitable protective device should be provided to prevent high voltage in the event of an open circuit. A short-circuiting-switch should be connecting in parallel with the protective device for manually short-circuiting the remote part of the current transformer.

.3 For high resistance grounded systems, an indicating ammeter or voltmeter should be provided to indicate ground current flow.

3.2 Protective Earthing (Equipment Earthing)

Exposed non-current-carrying metal parts of fixed equipment that may become energized because of any condition for which the arrangement and method does not ensure positive earthing should be permanently earthed through separate conductors of earthing straps, securely attached, and protected against damage.

3.2.1 Parts for which earthing is required

a) Unless specifically exempted as indicated in the following, all accessible metal parts of the electrical installation, other than current-carrying accessible parts, should be earthed.

   Exemptions:

   - Lamp Caps;
   - Shades, reflectors and guards, supported on lamp holders or luminaires constructed of, or shrouded in non-conducting material;
   - Metal parts on, or screws in or through, non-conducting material, which are separated by such material from current-carrying parts, and from earthed non-current-carrying parts;
   - Portable appliances having double and/or reinforced insulation provided that the appliances conform with relevant safety requirements;

- Bearing housings which are insulated in order to prevent circulation of current in the bearings;

- Clips for fluorescent lighting tubes;

- Apparatus supplied at safety voltage;

- Cable Clips

Note: Consideration should be given to the earthing of the non-current- carrying parts which are not accessible but which under fault conditions might become live and hence constitute a fire hazard, such as a metal junction-box mounted on a wooden panel.

b) To minimize shock from high frequency induced by the radio transmitter, handles, handrails, etc., or metal on the bridge or upper decks should be in good electrical connection with the hull or superstructure.

c) Secondary windings of instrument transformers should be earthed.

3.2.2 Earthing Methodology

Accessible non-current-carrying parts should be earthed as follows:

a) Metal frames or enclosures of apparatus may be fixed to, and in metallic contact with, the ship's structure, provided that the surfaces in contact are clean and free from rust, scale or paint when installed and are firmly bolted together. A lead cable sheath is not to be solely relied upon for this purpose.

b) The metal coverings of cables and earthing of mechanical protection of cables should be earthed as follows:

   i. All metal coverings of cables should be electrically connected to the metal hull of the ships at both ends, except single core cables, where in order to avoid current loops, the metallic screen should be earthed at one point only and single-point earthing is admitted for final sub-circuits and in those installations (Control and instrumentation cables, mineral-insulated cables, intrinsically safe circuits, control circuits, etc.) where it is required for technical or security reasons, if any.

   ii. Earthing connections should be carried out with conductors having cross-sectional areas (as given in Table I of IEC 60092-401 - Annexure I) related to the current ratings of the cables, or by equivalent means, such as metal clamps gripping the metal covering of the cable and connected to the metal hull of the ship.

   The metal covering of cables may be earthed by means of glands intended for the purpose and so designed as to ensure an effective earth to the metal hull of the ship.

   The glands should be firmly attached to, and in effective contact with, metal structure earthed.

iii. The electrical continuity of all metal coverings throughout the length of the cables, particularly at joints and tapping's should be ensured.

iv. Metal casings, pipes and conduits or trunking should be effectively earthed.

v. Conduits may be earthed by screwing into a metal enclosure, or by nuts on both sides of the wall of a metallic enclosure, provided the surfaces in contact are clean and free from rust, scale or paint and the enclosure is earthed.

The connection should be painted immediately after assembly in order to inhibit corrosion.

vi. Cable sheaths and armour, and conduit, may be earthed by means of clamps or clips of corrosion resistant metal making effective contact with sheath or armour and earthed metal.

vii. All joints in metal conduits and ducts and in metallic sheath of cables used for earth continuity should be soundly made and protected, where necessary, against corrosion.

viii. Every earthing connection should be of copper or other corrosion-resistant conductive material and should be securely installed and protected where necessary against damage and, where necessary against galvanic corrosion.

ix. Metal parts of portable appliances should be earthed by means of an earth-continuity conductor in the flexible cable or cord, which complies with Table I (IEC 60092-401 – Annexure I) and which is earthed for example through the associated plug and socket-outlet.

x. Under no circumstances should the lead sheathing of cables be relied upon as the sole means for earthing.

c) Every connection of an earth-continuity conductor or earthing lead to the ship's structure should be made in an accessible position and should be secured by a screw of brass or other corrosion resistant material of diameter not less than 6 [mm] which should be used for this purpose only. In all circumstances, care should be taken to ensure bright metallic surfaces at the contact areas immediately before the screw is tightened.

3.3 Earthing and bonding in hazardous areas

3.3.1 Earthing system requirements for installations in hazardous areas

a) In case for both insulated and earthed distribution systems a device, or devices, should be installed to continuously monitor the insulation to earth and to give an audible and visual alarm at a manned position in the event of an abnormally low level of insulation resistance and/or high level of leakage current.

The above requirement does not apply to the following Systems:

i. Limited and locally earthed systems outside any hazardous area;
ii. Intrinsically safe systems

iii. Impressed current cathodic protection systems.

b) Where any circuit, other than an intrinsically safe circuit, passes into any Zone 0 area the circuit should be disconnected automatically and/or should be prevented from being energized in the event of an abnormally low level of insulation resistance and/or high level of leakage current.

c) Where a circuit passes into any Zone 0 area, the protective systems should be arranged so that manual intervention is necessary for the reconnection of the circuit after disconnection as the result of a short-circuit, overload or earth-fault condition.

d) Equipotential Bonding

To avoid the possibility of dangerous sparking between metallic parts in the event of an electrical fault, exposed and extraneous conductive parts, other than the following, should be connected to earth:

i. the apparatus exempted only by virtue of being supplied by safety voltage.
ii. certified safe type apparatus not intended to be earthed.

Note 1: The means by which parts are earthed may include conduits, metal cable sheaths, metal armouring and metallic parts of structure, but should not include neutral conductors.

Note 2: Special consideration should be given to the temperature rise, under fault conditions, of earthing conductors in Zone 1 and Zone 0 areas.

Note 3: Special consideration should be given to potential equalization between electrically separate structures, for example between the fixed structure and machinery on anti-vibration mounts.

e) Static Electricity

i. Account should be taken of the effects of static electricity.

To avoid the hazard of an incendive discharge due to the build-up of static electricity resulting from the flow of liquid/gases/vapours, the resistance between any point on the surface of the cargo and slop tanks, piping systems and equipment, and the hull of the ship is not to be greater than 10^6 ohms [Ω]

Note 1: This value of resistance may be achieved without the use of bonding straps where cargo and slop tanks, piping systems and equipment are directly, or via their supports, either welded or bolted to the hull of the ship.

Note 2: It will be generally necessary initially to achieve a resistance value below 10^6 ohms [Ω] to allow for deterioration.

Note 3: The manufacture or construction of non-metallic pipes should allow the dissipation of static charge.

i. Bonding straps are required for cargo and slop tanks, piping systems and equipment which are not permanently connected to the hull of the ship, for example:

- independent cargo tanks;

- cargo tanks, piping systems which are electrically separated from the hull of the ship;

- pipe connections arranged for the removal of spool pieces.

ii. Where bonding straps are required, they should be:

- clearly visible so that any shortcomings can be clearly detected;
- designed and sited so that they are protected against mechanical damage and that they are not affected by high resistivity contamination, for example corrosive products or paint;
- easy to install and replace.

iii. Where tanks or piping systems for poorly conductive fluids, other than cargo, are located in a hazardous area, i, ii and iii above also apply to these tanks and systems.

iv. For fans installed in a hazardous area or serving a space that would be classified hazardous in the absence of ventilation, electrostatic charges both in the rotating body and the casing should be prevented by the use of antistatic materials and satisfactory earthing, ensuring that the resistance between any point on the surface of the unit and the hull of the ship is not greater than 10^6 ohms [Ω]

3.3.2 Bonding requirements for installations in hazardous areas

3.3.2.1 Potential equalization is required for installations in hazardous areas. All exposed and extraneous conductive parts should be connected to the equipotential bonding system. The bonding system may include protective conductors, metal conduits, metal cable sheaths, steel wire armouring and metallic parts of structures, but should not include neutral conductors.

3.3.2.2 Connections should be secure against self-loosening and should minimise the risk of corrosion which may reduce the effectiveness of connection. An internal earth continuity plate may be fitted, for example, to allow for use of metallic cable glands without the use of separate individual earthing tags.

3.3.2.3 The material and dimensions of the earth continuity plate should be appropriate for the anticipated fault current. If the armour or screens of cables are only earthed outside the hazardous area (e.g., in the control room) then this point of earthing should be included in the potential equalization system of the hazardous area.

3.3.2.4 If the armour or screen is earthed only outside of the hazardous area, then dangerous sparks may be created at the ending of the armour or screen in the hazardous area. Therefore, this armour or screen should be treated like unused cores.

3.3.2.5 The hazardous area end of each unused core in multi-core cables should either be connected to earth or be adequately insulated by means of terminations suitable for the type of protection. Insulation by tape alone is not permitted.

3.3.2.6 Alternative requirements apply for unused cores in multicore cables of intrinsic safety and energy-limited circuits as below:

Each unused core in a cable should either:

- be adequately insulated from earth and from each other at both ends by the use of suitable terminations; or
- if other circuits in the cable have an earth connection (e.g., via the associated apparatus), be connected to the earth point used to earth any intrinsically safe circuits in the same cable but should be adequately insulated from earth and from each other by the use of suitable terminations at the other end.

The use of heat-shrink tubing or terminating the unused core in suitable terminals would satisfy the above requirements.

3.3.2.7 Exposed conductive parts need not be separately connected to the equipotential bonding system if they are firmly secured to and are in conductive contact with structural parts or piping which are connected to the equipotential bonding system.

3.3.2.8 Cable glands which incorporate clamping devices which clamp the braiding or armour of the cable can be used to provide equipotential bonding. The minimum size for bonding conductors for the main connection to a protective rail should be 6 [mm^2] and supplementary connections should be a minimum of 4 [mm^2].

3.3.2.9 Consideration should also be given to using larger conductors for mechanical strength. Metallic enclosures of intrinsically safe or energy-limited apparatus need not be connected to the equipotential bonding system, unless required by the equipment documentation or to prevent accumulation of static charge.

3.3.2.10 Installations with cathodic protection should not be connected to the equipotential bonding system unless the system is specifically designed for this purpose.

3.3.2.11 Temporary bonding

.1 Temporary bonding includes earth connections that are made to moveable items such as drums and portable equipment for control of static electricity or potential equalisation.

.2 It is recommended that the final connection of a temporary bonding connection should be made either:

- in a non-hazardous area; or
- using a connection that meets the Equipment Protection Level (EPL) requirements of the location; or
- using a documented procedure which reduces the risk of sparking to an acceptable level.

.3 For temporary bonding the resistance between metallic parts should be less than 1 [MΩ]. This should be ensured either by measuring or by monitoring of the value. Conductors and connections should be durable, flexible and of sufficient mechanical strength to withstand in service movement. Mechanical strength of the conductor should be equivalent to at least 4 [mm^2] copper or be part of a flexible cabling system incorporating a monitoring and control system.

.4 Consideration should be given to the use of a permanent monitoring system to demonstrate that the connection system is always below 1 [MΩ].

3.4 Earthing and electrical isolation during ship operations

3.4.1 Earthing during gas fuel bunkering operations

3.4.1 Electric isolation

.1 A single isolation flange should be provided, in each arm or hose of the transfer system, between the receiving ship manifold and the bunker pipeline. The installation should not permit shorting out of this insulation for example by, leaving the flange resting in stainless steel drip tray. This flange prevents galvanic current flow between the receiving ship and the bunkering facility. Steel to steel contact between receiving ship and bunkering facility e.g., via mooring lines, ladders, gangways, chains for fender support etc. should be avoided through the use of insulation. Bunker hoses/pipes should be supported and isolated to prevent electrical contact with the receiving ship.

.2 When bunkering from trucks, the truck should be grounded to an earthing point at the quay to prevent static electricity build up. Where approval has been given for the bunkering truck to be parked on the deck of the ship then the truck should be grounded to the receiving ship.

.3 Ship-shore bonding cables/straps should not be used unless required by national or local regulations.

.4 If national or local regulations require a bonding cable/strap to be used, the circuit continuity should be made via a 'certified safe' switch (e.g., one housed inside a flame proof enclosure) and the connection on board the receiving ship should be in a safe area in a location remote from the hazardous area. The switch should not be closed until the bonding cable/strap has been connected, and it should be opened prior to disconnection of the bonding strap.

3.4.2 Earthing during fuel oil bunkering operations

.1 Earthing and bonding minimise the dangers arising from:

- Faults between electrically live conductors and non-current carrying metalwork.
- Atmospheric discharges (lightning)
- Accumulations of electrostatic charge

3.4.3 Earthing during docking operations

Proper earthing during docking operations is essential to ensure the safety of both the vessel and the port infrastructure. It prevents the buildup of static electricity and protects against electrical faults. The following subsection detail specific earthing measures in shore connection boxes.

3.4.3.1 Earthing in Shore Connection Boxes

a) In cases where power is supplied from three-wire neutral earthed systems, earth terminals should be provided for connecting hulls to appropriate earth/external earth.

b) Where necessary for systems with earthed neutrals, the box should be provided with an earthed terminal for connection between the shore's and ship's neutrals.

c) The protective earthing onboard and the shore should be connected.

Note: In case of shore connection via insulating transformer, shore and ship's earth connections should be separated.

3.4.3.2 Earthing in High Voltage Shore Connection

a) General

i. Protective earthing between the ship's hull and shore earthing system should be provided.

ii. Equipment-earthing conductors terminated at the shore’s three-phase socket-outlets should be connected to the ship and continued to the ship to make an equipotential bond between the shore side and ship side.

b) HV interlocking

v. Interlock should be provided so that the circuit breakers cannot be closed unless the plug and socket are correctly connected and earthing switches on both shore-side and shipside are opened.

3.4.3.2.1 Shore Side Installation

An automatically operated circuit-breaker and earth switch should be provided.

3.4.3.2.2 System component requirements

.1 Neutral earthing resistor

The neutral point of the HVSC system transformer should be earthed.

- through a neutral earthing resistor, or
- where frequency conversion of the shore supply is required, either through a neutral earthing resistor, or through an earthing transformer with a resistor on the primary or secondary side.

.2 Equipment-earthing conductor bonding

.1 A system earthing conductor should connect the neutral earthing resistor's earthing connection to a nearby system-earthing electrode. An additional system-bonding conductor should connect the neutral earthing resistor's earthing connection to the earthing bus of the primary shore power switchboard. Bonding should be in accordance with 8.2.3 of IEC 60204-11:2000.

.2 Equipment-earthing conductors terminated at the shore's three-phase socket-outlets should be connected to the ship and continued to the ship to create an equipotential bond between the shore and ship. This should require bonding to the ship's switchgear earthing bus and/or bonding to the ship's hull.

3.4.3.2.3 HVSC systems dedicated to tankers and liquefied natural gas carriers (LNG) ship types:

.1 For LNG Carriers

The HVSC system should operate with the neutral point of the system transformer feeding the shore-to-ship power socket-outlets unearthed where the LNG Carriers connected to the system is designed with an insulated or high-resistance earthed power system for compliance with the requirements of SOLAS, Ch II-1/D, Regulation 45.4.3, and IEC 60092-502. Where an earthing impedance designed for compliance with the SOLAS requirements is provided ashore, or an on-board transformer is provided for galvanic separation or voltage matching, an insulated neutral on the shore side may not be required.

.2 For Tankers

Other earthing arrangements may be allowed because of the need to limit earth fault current in hazardous areas. The neutral earthing resistor rating in amperes should not be less than 1.25 times the prospective system charging current. The rating should be minimum 25 A for 5 s. The continuity of the neutral earthing resistor should be continuously monitored. In the event of loss of continuity, the shore-side circuit breaker should be tripped. An earth fault should not create a step or touch voltage exceeding

30 V at any location in the shore-to-ship power system.

3.4.4 Terminal electrical Isolation for cargo operations (loading/unloading)

3.4.4.1 General

.1 Due to possible differences in electrical potential between the tanker and the berth, there is a risk of electrical arcing at the manifold during connection and disconnection of the terminal hose or MLA (Marine Loading Arm). To protect against this risk, there should be a means of electrical discontinuity at the tanker/terminal interface. This should be available at the terminal.

.2 It may be noted that the aspect of tanker to terminal electric currents is separate from static electricity.

3.4.4.2 Tanker to terminal electric currents

.1 Large current can flow in electrically continuous pipework and flexible hose systems between the tanker and terminal. The sources of these currents include:

- Cathodic protection of the jetty or the hull of the ship provided by either an impressed current system or by sacrificial anodes
- Stray currents arising from galvanic potential differences between ship and shore or leakage effects from electrical power sources.

.2 An all-metal MLA provides a very low resistance connection between tanker and terminal and there is a possibility of electrical arcing when the ensuing large current is suddenly interrupted during the connection or disconnection of the MLA at the tanker manifold. Similar arcs can occur with metallic connections between the flanges of each length of a flexible hose string.

.3 To prevent electrical flow and subsequent arcing between a tanker and a terminal during connection or disconnection of the terminal hose or MLA, the terminal operator should ensure that there is sufficient electrical discontinuity between the jetty and the tanker. This can be achieved by:

- Fitting MLA with an insulating flange
- Using Type R or Grade M (Type S or L) electrically continuous hoses with an insulating flange or insulating block fitted at one end of the hose string
- Including one length only of electrically discontinuous hose in each continuous string
- Using Grade Ω (Type S or L) hoses without an insulating flange and provided the resistance of each hose assembly has been tested and exceeds 25,000 [ohms] (it may be noted that Grade Ω hoses are not marked as electrically discontinuous. Therefore, the test records should be checked to determine whether they provide adequate electrical discontinuity).

.4 A single length of electrically discontinuous hose is, typically provided on the terminal side of the hose string but may be provided at any location as long as all segments remain isolated from materials they could potentially touch, including the tanker hull and/or jetty deck. Use of more than one section of electrically discontinuous hose may result in electrically isolated sections that allow for the build-up of electrical potential within the isolated section. When non-conductive hoses are used for isolation purposes, care should be taken to ensure that conductive pathways are not introduced by lifting equipment, such as nylon or other non-conductive materials for lifting straps.

.5 The additional resistance limits the flow of stray current, through the MLA or the hose string, to a safe level. However, the whole system should remain earthed, either to the tanker or to the shore.

.6 All metal on the seaward side of the insulating section should be electrically continuous to the tanker and all metal on the landward side should be electrically continuous to the jetty's earthing system. This arrangement will ensure electrical discontinuity between tanker and terminal and prevent arcing during connection and disconnection. Loading arm swivels should include bonding wires across flanges to ensure electrical continuity. If hoses are used for draining or purging loading arm contents and/or for hydraulics or lubricating systems, then these should also follow the same continuity and isolation requirements as the arm itself. When hoses are deployed on reels, they should be electrically isolated.

.7 The insulating flange or single length of discontinuous hose should not be short circuited by contact with external metal.

.8 It should be noted that the requirements for electrical discontinuity also apply to the vapour recovery connection.

3.4.4.3 Earthing and bonding practice in the terminal

.1 Earthing and bonding minimise the dangers arising from:

- Faults between electrically live conductors and non-current carrying metalwork.
- Atmospheric discharges (lightning)
- Accumulations of electrostatic charge.

.2 Earthing and bonding system requirements will depend on the results of a risk assessment.

3.5 Earthing in non-metallic vessels and aluminium vessels

a) On wood and composite ships, a continuous-earth conductor should be installed to facilitate the earthing of non-current carrying exposed metal parts. The earth conductor should terminate at a copper plate of area not less than 0.2 [m^2] fixed to the keel below the waterline in a location that is fully immersed under all conditions of heel.

b) Methods of securing aluminium superstructures to the hull of a ship often include insulation to prevent galvanic corrosion between these materials. In such cases, a separate bonding connection should be provided between the superstructure and the hull. The connection should be made in a manner that minimizes galvanic corrosion and permits periodic inspection.

3.6 Earthing for Offshore Units

3.6.1 System Earthing

3.6.1.1 General requirements

.1 System earthing, i.e. an intentional connection of the neutral point of the electrical power supply system to the hull or structure.

.2 One of the following methods of treating the neutral should be used:

a) solidly earthed (TN system);
b) impedance earthed (IT system);
c) isolated (IT system).

The method selected should be based on technical and operational factors.

NOTE 1: The principal features of these methods are indicated in Table 3.6.1.1(as per Table 1 of IEC 61892 (2019-04)).

NOTE 2: For power distribution systems, the so-called "un-earthed" or "isolated" system design is capacitor earthed by distributed capacitances throughout the system, together with any interference suppression capacitors.
Where solidly or impedance earthed systems are used in a distribution system that can be divided into two or more separate networks, means for neutral earthing should be provided for each separate network.

NOTE: For installations in hazardous areas, refer IEC 61892-7.

For emergency power systems, including UPS, consideration should be given to the need for continuous operation of the consumers in the presence of an earth fault. If continuous operation in the presence of an earth fault is required, the isolated or high impedance (IT) system should be used; otherwise, low impedance earthed, or solidly earthed systems can be used. For high impedance systems, the earth-fault current should not be more than 5 [A].
In the case of impedance earthing, the maximum earth fault should be limited to a current that the magnetic circuit of a generator normally can withstand for a defined time period without damage to the core.

3.6.2 Neutral earthing for systems up to and including 1000 [V] AC

.1 Solidly earthed neutral systems should be achieved by connecting the neutral point directly to earth.

.2 Calculation of earth loop impedance should be based on the following:

a) for TN systems, IEC 60364-4-41:2005, 411.4;
b) for IT systems, IEC 60364-4-41:2005, 411.6.

.3 Where phase to neutral loads is served, systems should be solidly earthed.

.4 Automatic tripping devices should be provided for disconnecting circuits with earth fault. Where the earth-fault current cannot exceed 5 [A], an indicator may be provided as an alternative to the automatic tripping device, provided. Conditions of fault elimination by the phase protective devices are verified, should a second fault occur. The maximum disconnection time for TN systems should be according to IEC 60364-4-41:2005, 411.3.2.2 and 411.3.2.3.

<table>
<tr><th colspan="4">Table 3.6.1.1 : Summary of principal features of the neutral earthing methods</th></tr>
<tr><th>Means of earthing</th><th>Not intentionally earthed "Isolated" "IT"</th><th>Impedance earthed "IT"</th><th>Solidly earthed "TN"</th></tr>
<tr><td>System voltage</td><td colspan="3">All methods are potentially applicable. Solidly earthed neutral is regularly used in high-voltage transmission networks, where insulation costs are high. For installations on offshore units, the short-circuit fault levels normally associated and vital ignition control in design would make solidly earthed systems less attractive. Insulated systems and impedance earthed systems prevail in such units.</td></tr>
<tr><td>Overvoltage</td><td colspan="3">The most significant overvoltage is less influenced by the method of neutral earthing.</td></tr>
<tr><td>Electric shock risk</td><td colspan="3">All major installations are potentially lethal whatever method of neutral earthing is used.</td></tr>
<tr><td>Use of residual current device for electrical safety</td><td>Will normally not function.</td><td>Acceptable</td><td>Acceptable</td></tr>
<tr><td>Use of 3-phase 4-wire supply</td><td>Not acceptable</td><td>Not acceptable</td><td>Acceptable</td></tr>
<tr><td>Earth-fault current magnitude</td><td>Depends on system capacitance but usually very low,
e.g. 1 [A] in an LV system.</td><td>Depends on impedance value, typically.
High impedance: Less than 5 [A]</td><td>May be up to 50 % greater than symmetrical 3-phase value.</td></tr>
<tr><td>Sustained operation with earth fault</td><td>Possible, fault shall be location detected and de- coupled in the shortest possible time period.</td><td>May be possible but not advisable, depending on impedance value.</td><td>Not possible</td></tr>
<tr><td>Minimum earth-fault protection required</td><td>Depending on maximum earth-fault current,
alarm/indication (< 5 [A]) or earth-fault relay (> 5 [A])</td><td>Alarm/indication, earth-fault relay, overcurrent protection.
Depending on impedance</td><td>Overcurrent protection</td></tr>
<tr><td>Switchgear fault rating</td><td colspan="2">May be rated on normal phase to phase or 3-phase symmetrical fault value.</td><td>May have to be rated on single-phase-to-earth or phase-to-phase-to-earth value.</td></tr>
<tr><td>Earth-fault location</td><td>Faults not self-revealing can normally be located manually unless core balance current transformers are fitted.</td><td>If relays fitted, faults self-revealing.
Otherwise, must be located manually.</td><td>Faults are self-revealing on overcurrent.</td></tr>
<tr><td>Fire risk</td><td>Very low, provided that earth-fault current does not exceed 1 [A]. Prolonged fault may present a hazard.</td><td colspan="2">Risk of igniting flammable gases. High impedance faults can lead to burning at fault location.</td></tr>
<tr><td>Flash hazard (phase-to- earth)</td><td colspan="3">Low -------------------------- Increasing -------------------------- High</td></tr>
<tr><td>Availability of suitable equipment</td><td colspan="2">Similar generation and distribution equipment is applicable on all systems.</td><td>Allows use of land-based equipment designed for TN-S systems.</td></tr>
</table>

3.6.3 Neutral earthing for systems above 1000 [V] AC

.1 Solidly earthed systems should not be used for local HV distribution on offshore units. For other systems, such as interconnected units with supply from external power sources, the selection of system earthing should be stated in the written design philosophy.

.2 For neutral point treatment on semiconductor variable speed drives, the manufacturer's standard design should be followed.

.3 In impedance earthed systems, the earth-fault current should be limited to an acceptable level either by inserting an impedance in the neutral connection to earth or by an earthing transformer.

.4 In the case of use of an earthing transformer, the fault current is the same whatever the number of generators. The limiting current is to be defined by engineering studies.

.5 In the case of high resistance earthing, the resistance value should be such that the resistive earth-fault current is higher than the total capacitive fault current of the system in any operating configuration/number of generators running. When sizing the earthing resistor, consideration should also be given to the earth-fault protection discrimination.

.6 If the total capacitive fault current is "high" because of a long subsea cable for example, such that the total capacitive fault current of the system becomes higher than the resistive earth fault current from the NER, this can be handled by use of directional earth-fault relays in these feeders with long cable lengths.

.7 In the absence of precise equipment data for neutral earthing resistor rating, a value of 20 [A] may be used as guidance per generator and per transformer. This value may be used for local generation when the voltage is not normally higher than 15 [kV].

NOTE: The current limitation will be determined according to the overall length of the network and its total capacitive current.

.8 In isolated IT systems, efficient means should be provided for detecting defects in the insulation of the system.

.9 Automatic tripping devices should be provided for disconnecting circuits with an earth fault. Where the earth-fault current cannot exceed 5 A, an indicator may be provided as an alternative to the automatic tripping device.

.10 For supply to hazardous areas, additional requirements are given in IEC 61892-7.

3.6.4 Generators operated in parallel with source transformers

.1 Where direct connected generators are, or may be operated in parallel with source transformers, the neutral earthing arrangements should provide for either system operating independently. The neutral earthing equipment should, wherever practical, be identically rated for all power sources.

.2 The resistors should reduce the fault current to a level sufficient to operate the distribution system earthing protection and provide suitable discrimination.

.3 Where the normal ratings of the source transformer and parallel running generators are significantly different, the resistor rating selection should be dictated by the requirement to ensure that the most insensitive earth-fault protection on any incoming or outgoing circuit operates positively with the smallest possible source of earth-fault current connected to the system.

.4 In distribution systems with solidly earthed neutral, generator manufacturers should be informed so that the machines can be suitably designed to avoid excessive circulating currents. This is particularly important if they are of different size and make.

3.6.5 Earthing resistors, connection to hull/structure

.1 Earthing resistors should be provided with insulation suitable for the phase-to-phase voltage of the systems to which they are connected. They should be designed to carry their rated fault current for at least 10 [s] in addition to any continuous loading, without any destructive effect to their component parts.

.2 Earthing resistors should be connected to the unit's structure or hull. Suitable disconnecting links should be provided for measuring purposes.

.3 The point of connection should be separate from that provided at the unit's structure or hull for radio, radar and communications circuits in order to avoid interference.

3.7 Earthing and bonding for helicopter facilities

3.7.1 It is best practice to fit flange to flange earth bonding straps across every flanged connection where there is a flow of fuel in order to dissipate electrostatic charge generated by the movement of fuel, however, as a minimum, earth bonding straps should be fitted when a paint lining is applied ensuring paint is bared back on both sides of one flange bolt hole to allow a metal-to-metal contact.

3.7.2 Earth bonding / EPU (Earth Proving Unit)

.1 Check for general condition, security, and electrical continuity (maximum permissible reading of 25 [Ω]) on the following earth bonding equipment:

- Tank earth leads and clamps.
- Pressure refuelling coupling / gravity nozzle secondary bonding lead, jack plug and clips.
- Primary aircraft bonding / EPU lead, and jack plug.

.2 Carry out checks for correct function of the following:

- Primary aircraft bonding / EPU reel automatic or manual rewind mechanism.

3.7.3 Offshore helicopter landing areas

.1 Earth bonding is a requirement throughout the system, including tank earthing leads and clamps, system pipework and equipment bonding, aircraft primary bonding lead and pressure refuelling coupling / gravity nozzle secondary bonding leads.

3.7.4 Primary bonding lead

.1 To ensure that no difference in electrical potential exists between the aircraft, fuelling equipment and pressure refuelling coupling / gravity nozzle, a stranded single core bonding lead, with high visibility coating should be provided to bond the helicopter airframe to the refuelling installation structure before any fuelling commences. The lead should be connected to a manual or spring-rewind reel which is earth-bonded, common to the system pipework, and the lead should be fitted with a correct jack plug adaptor to attach to the approved aircraft earth bonding point.

Section 4

Lightning Conductors

4.1 General

.1 This section provides guidance on the measures to be taken to minimize the risks of damage to a ship and its electrical Installation due to lightning.

4.2 Protection against primary structural damage

Protective systems for primary structural damage include air Terminals (conducting bar fitted at the top of the mast), down conductors (conducting cable or tape that run between the air terminal and the earth plate) and earth terminals (unpainted lightning earth plate).

4.2.1 Protective Systems

i. Where protection systems are required, they should include air terminals, down conductors and earth terminations so installed as to minimize the possibility of voltages being induced into electric cables due to the passage of lightning currents.

ii. A protective system need not be fitted to a ship of metallic construction where a low resistance path to earth will be inherently provided by masts, structural members and the hull.

iii. A protective system should be fitted to any ship of non-metallic construction or having a substantial number of non-metallic members.

iv. Metallic masts and metallic structural members may form part or all of any protective system.

v. Metal rigging, such as stays, shrouds, etc., may act as fortuitous down conductors and should be bonded to the protective system.

vi. Joints in down conductors should be accessible and be located or protected so as to minimize accidental damage. They should be made by means of copper rivets or clamps. Clamps may be of copper or of copper alloy and should, preferably, be of the serrated contact type and effectively locked. No connection should be dependent on a soldered joint.

vii. The resistance between air terminals and earth terminals should not exceed 0.02 [Ω].

viii. Suitable means should be provided to enable ships when in dry dock, or in a slipway to have their protective systems or metal hull connected to an efficient earth on shore. Connecting cables to the shore earth should be external to the earth throughout their length.

4.2.2 Air Terminals

i. An air terminal should be fitted to each non-metallic mast.

ii. Air terminals should be made of copper or copper alloy conducting bar of not less than 12 mm diameter and should project at least 300 [mm] beyond the top of the mast. Other materials may be used, for example stainless steel or aluminium alloys, or steel bar effectively protected against corrosion and the resistance between air terminals and earth terminals should not exceed 0.02 [Ohm]. The material should be resistant to sea water.

iii. Vent outlets for flammable gases located at or near the top of masts on tankships should be protected by air terminals which extend at least 2 [m] above the vent outlet. A steel mast may serve as the air terminal if it extends 2 [m] above the outlet.

4.2.3 Down Conductors

i. Down conductors should be made of copper, or copper alloy tape or cable. Cable is preferred as both the insulation and the circular shape inhibit surface discharge. Other materials may be used, for example stainless steel or aluminium alloys, subject to the requirement of the resistance between down conductor and earth terminal is not to exceed 0.02 [Ohms]. The material should be resistant to sea water.

ii. Down conductors of copper should have a minimum cross-section of 70 [Sq.mm], be firmly secured to the structure and be run as straight as possible between the air terminal and the earth terminal. Bends, where necessary, should have a minimum radius of at least ten times the equivalent diameter of the conductor.

4.2.4 Earth Terminals

i. An unpainted lightning earth plate of not less than 2 [mm] thickness and not less than 0.25 [mm^2] in surface including pillars should be installed below the light-load water lines so as to remain immersed under all conditions of heel. It has to be provided with pillars to facilitate the connection of the down conductor(s). Pillars should be made of the same material as the earthing plate and solidly connected to it by welded joints.

ii. Earth plates should be of copper or other conducting material compatible with sea water, for example stainless steel, and have a surface area sufficient to provide the equivalent low resistance path to earth. The formation of electro chemical corrosion cells with other immersed metallic fittings should be avoided.

iii. No earthing conductor should be attached to the lightning conductor plate. The copper plate should be separate from and in addition to the copper plate for terminating the earthing conductor.

4.3 Protection against secondary damage

On all ships, whether metallic of non-metallic, equipment should be so installed as to limit the effect of secondary damage to the electrical system. Protective measures against secondary damage include earthing of metallic enclosures, separate earthing for cable screens or armour, following the most direct route for lightning earth connections etc.

4.3.1 Protective Measures

i. Metallic enclosures should be earthed to the metal hull or to the protective system. Particular attention should be paid to navigation lights and other equipment at the top of masts and on other elevated structures.

ii. Cable screens or armour, though normally earthed for signal interference suppression, is not to provide the sole lightning path to earth for equipment. Separate earthing, as required by i) above should be provided.

iii. Lightning earth connections to the protective system should follow the most direct route.

iv. The formation of cable loops, or metallic loops such as pipework, in proximity to down conductors should be avoided. Cables in close proximity to down conductors should be installed in metal pipes.

v. On metal ships, cables along decks should be installed close to the deck to minimize the cross-sectional area of the loop existing between the cable and the deck. When choosing cable routes along decks, advantage should be taken of the screening effect of earthed metallic structures near to or above the cable runs, for example handrails, pipes, etc.

vi. Means should be provided for discharging to the earth of any lightning energy that may be induced in for example radio and navigational equipment antennas. Consideration should be given to installing devices such as spark gaps or surge diverter to provided protection from voltage transients.

References

[1] IEC 60092-401, Third Edition, 1980, Electrical Installation in ships-Part 401: Installation and test of completed installation and IEEE Std 45-2002 Recommended Practice for Electrical Installation on Shipboard

[2] IEC 60050-195 - 2021 International Electro technical Vocabulary (IEV) - Part 195: Earthing and protection against electric shock

[3] IEC 60092-401 Amendment 2-1997, Electrical Installation in ships-Part 401: Installation and test of completed installation and IEEE Std 45-2002 Recommended Practice for Electrical Installation on Shipboard

[4] IEEE std 45-2002 Recommended Practice for Electrical Installation on Shipboard.

[5] IEC 60092-502, Fifth Edition,1999, Electrical installations in ships-Part 502: Tankers-Special features

[6] IEC 61892-2, Edition 2, 2019 Mobile and fixed offshore units – Electrical installations –Part 2: System design

[7] IEEE 80005-1:2019 Utility connections in port - Part 1: High Voltage Shore Connection (HVSC) Systems — General requirements

[8] Explosive atmospheres – Part 14: Electrical installations design, selection, and erection - IEC 60079-14 Edition 5.0 ,2013

[9] IACS LNG Bunkering Guidelines No.142 – June 2016

[10] Standards for offshore helicopter landing areas CAP 437 – February 2023

[11] ISGOTT Sixth Edition

[12] IEC 60092-509:2011 Electrical installations in ships – Part 509: Operation of electrical installations

Annexure I

<table>
<tr><th colspan="4">Table 5 : Sizes of earth-continuity conductors and earthing connections</th></tr>
<tr><th>Sl. No.</th><th>Type of earthing connection</th><th>Cross-sectional area of associated current carrying conductor</th><th>Minimum cross-sectional area of copper earthing connection</th></tr>
<tr><td>1</td><td>Earth-continuity conductor in flexible cable or flexible cord</td><td>Any</td><td>Same as current-carrying conductor up to and including 16 [mm^2] or one-half above 16 [mm^2] but at least 16 [mm^2]</td></tr>
<tr><td>2</td><td>Earth-continuity conductor incorporated in fixed cable</td><td>Any</td><td>For cables having an insulated earth-continuity conductor:

- a cross-section equal to the main conductors up to and including 16 [mm^2] but minimum 1.5 [mm^2]

- a cross-section not less than 50 % of the cross-section of the main conductor when the latter is more than 16 [mm^2], but at least 16 [mm^2]

For cables with a bare earth wire in direct contact with the lead sheath:

<table><tr><th>Cross-section of main conductor</th><th>Earthing conductor</th></tr><tr><td>1 to 2.5 [mm^2]</td><td>1 [mm^2]</td></tr><tr><td>4 to 6 [mm^2]</td><td>1.5 [mm^2]</td></tr></table></td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Separate fixed earthing-conductor</td><td>Not exceeding 3 [mm^2]</td><td>Same as current-carrying conductor subject to minimum of 1.5 [mm^2] for stranded earthing connection, or 3 [mm^2] for unstranded earthing connection</td></tr>
<tr><td>Exceeding 3 [mm^2] but not exceeding 125 [mm^2]</td><td>One-half the cross-sectional area of the current-carrying conductor subject to a minimum of 3 [mm^2]</td></tr>
<tr><td>Exceeding 125 [mm^2]</td><td>64 [mm^2]</td></tr>
</table>

End of Guidelines