EARTHING SYSTEM
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1. GENERAL

This training document covers the general technical information on “Earthing System” in residential, commercial and industrial installations, especially for Oil and Gas plants. Detailed and more specialized data and specifications on earthing systems shall be provided to electrical and instrument trainees later during the period of specific course. Sections and paragraphs which are marked with asterisk (*) are more or less specialized and therefore shall be skipped to be offered during the specific course.

1.1. Concept of Earthing Systems

All the people living or working in residential, commercial and industrial installations, particularly the operators and personnel who are in close operation and contact with electrical systems and machineries, should essentially be protected against possible electrification. To achieve this protection, earthing system of an installation is defined, designed and installed according to the standard requirements. Also, earthing system in an oil gas complex shall provide the best protection system against sparking, which could lead to disastrous explosions.

1.1.1. Under earthing system measures, the metal covering body and enclosure of all the equipments are connected to each other as a grid by means of appropriate conductors to establish an equal zero level potential among all the points which may come in contact with the operators. Zero potential, which is built-up and applied to the earthing conductor grid, is produced by special earth wells and their associated accessories.

1.1.2. Further to protection against the risks of electrification, earthing system is particularly installed in industrial areas where equipments are in possible exposure to explosive material and gas such as oil and gas plants. Difference of electrical potential between the equipment, and machinery is inevitably a source of spark, which definitely leads to an explosion in presence of explosive gases. Therefore a properly installed earthing systems can provide an equal zero electrical potential throughout the plant equipment, thus eliminating the risks of sparks and explosions.

1.1.3. Lightning, with its high electrical potential, is one of the most serious and dangerous environmental threats, which could cause sever damages to both human life and the installations. Lightning arresters, as part of the earthing system in an installation, are the protective devices, which avert the risks of lightnings.

2. EARTHING SYSTEM COMPONENTS

Earthing system in an installation is normally comprised of these components:
2.1. Earth wells and accessories

2.2. Earthing grid conductors

2.3. Marshalling earth buses (earthing distribution buses)

2.4. Earthing wires and cables.

2.5. Lightning arresters and accessories

3. EARTH WELLS AND ACCESSORIES

Earth wells for an specific building or installation are actually the location, where the pure zero potential is provided and practically act as drain pits for any rush current which accidentally appears in the earthing system grid in the event of an earth fault (connection of electrical live parts to the earthing system).

3.1. Earth Well Components

Depending on the soil conductivity of the location in which the earth wells are installed and also depending on the required technical specifications of the earthing system, different types of components can be used to set up an earth well. Followings are the prime components and accessories of an earth well.

3.1.1. Earth rod
3.1.2. Earth plate
3.1.3. Earthing clamp
3.1.4. Earthing rod coupling
3.1.5. Earthing rod tip
3.1.6. Earthing rod driving head
3.1.7. Carbon bedding mixed with salt
3.1.8. Concrete earth pit
3.1.9. Concrete slab cover

3.2. Earth Rods

Depending on the design for an specific earth well, a number of rods are driven into the ground by means of hammering to form the main earthing electrode in the earth well. In cases where two or more earth rods are to be driven, the individual rods are coupled to each other by means of “earth rod coupling”.

3.2.1. During the driving of rod into the ground, and to protect the earth rod against impact of hammering, a "driving head" is screwed onto the top of the rod.

3.2.2. For easy and convenient driving of the earth rod into the ground an earth rod tip with sharp point is screwed to the first rod.

3.2.3. Earth rods are used in installation of plain earthing well where, based on design specification of the earthing system the carbon bedding is not necessary and applicable.

3.2.4. Earthing Clamp

Earthing grid conductors are connected to the earth rods, already driven into the ground, by means of earthing clamps. Connection is essentially made by tightly clamping of the grid conductor to the rod using the bolt and nut assembly of the earthing clamp. Earthing clamps and associated bolts nuts, washers, etc. are made of either brass or copper.

3.2.5. Earth Rod Material

Earthing rod and the associated accessories (coupling, tip and head) are made of both steel and copper. A steel core, coated with pure copper to the appropriate thickness, provides the sufficient rigidity for the earthing rod to help driving it straightly into the ground without any harm and bending. The copper coating of the earth rod provides the sufficient conductivity for the earthing system.

3.2.6. Earth Rod Dimensions

Depending on the design specification of the earthing system and the corresponding earthing wells, various earth rods of different dimensions would be incorporated.

3.2.6.1. The range of diameter for the earth rods vary from 13 mm to 25mm (13mm, 16mm, 20mm, 25mm)

3.2.6.2. Different lengths of earthing rods are used in design and installation of earth wells:

The standard lengths are:
- 1200mm
- 2400 mm (2 × 1200 mm)
- 3600 mm (3 × 1200 mm)
- 4800 mm (4 × 1200 mm)

The coupling material is essentially the same as the material for the earth rod with respect to the rigidity and the required conductivity.
3.2.7. Earth Rod Tip
The specification and application of this component was already described in section 3.2. The earth rod tip material is not necessarily the same as the earth rod itself, as only a rigid quality is essentially required for the tip other than conductivity. Therefore the earth rod tip is primarily made of steel with slight coating of the copper for conductivity purpose as well as protection against corrosion reasons.

3.2.8. Earth Rod Driving Head
The specification and application of this components was already described in section 3.2. The driving head material is not necessarily the same as the earth rod itself, as only a rigid and robust quality is essentially required for the driving head to withstand the impact of hammerings. Driving head is practically discarded when the earth rods are all driven and installed in the ground.

3.3. Carbon Bedding
Depending on the technical design specification of the earthing system and primarily for soil conductivity reasons of the area where the earth wells are to be installed, the earth rods are embedded in carbon bedding. To install the carbon bedded earth wells, pre-excavation of the ground, to sufficient size and dimension, would be carried out to provide room for the carbon bedding and the earthing components (rods, plates, etc.). To achieve the maximum conductivity for the earth well, an appropriate amount of salt is added to the carbon and mixed before charging into the earth well.

3.3.1. Earth Plate
In earth wells with carbon beddings, earthing plates are normally used instead of earthing rods. The earth plate is made of copper and shaped in the following forms:

3.3.1.1. Flat rectangular copper plate.
3.3.1.2. Perforated rectangular copper plate (a grate-like framework of copper plate) the standard dimension of the flat rectangular earth plate is normally 100 × 100 × 3 mm.

The standard cross section area for the copper rod or copper strips used in construction of the perforated rectangular earth plate is normally 75 sq-mm.

3.4. Concrete Earth Pit
To provide access to the earth rod and its corresponding connection to the earthing grid at the top section of the rod, a small pit-like space is fabricated over the earth well, which is referred to as “earth pit”. Earth pit’s side walls are constructed of concrete material to appropriately isolate the earth rod’s top connection from the surrounding soil and protect it for future reference test and maintenance practices. Earth pits are essentially, constructed flush with respect to the surrounding finished ground.
3.5. Concrete Slab Cover
To protect the earth pits against ingression of foreign material, an appropriate concrete cover is provided to be placed atop the earth pit.

The slab-like concrete cover is equipped with a rigid handle for convenient removing and replacement practices.

4. EARTHING GRID CONDUCTORS
All electrical earth wells in a specific residential, commercial and industrial installation should essentially be interconnected to plant earthing systems form the main earthing grid.

4.1. Different Types of Grid Conductors
Interconnecting conductor used for the grid are in the following forms:

- 4.1.1. Bare copper strip conductor
- 4.1.2. Single core bare stranded copper cable
- 4.1.3. Single core stranded copper cable with PVC sheath
- 4.1.4. Copper strip conductor with PVC covering

4.2. As described earlier, the technical specification and design of the form of the earthing system is bound and dependent on various factors such as:

- 4.2.1. Soil conductivity
- 4.2.2. Soil moisture (dry soil, or wet soil)
- 4.2.3. Soil condition (natural soil, or concrete)
- 4.2.4. The grid shall be directly buried in the ground (soil) or it shall run in open trenches (open channels)

4.3. Corrosive or Non-Corrosive Soil
Depending on the above mentioned types of installation of the earthing grid, selection of the grid conductor would be one of the following options:

- 4.3.1. Bare copper strip conductor
  For direct buried grid in dry and non-corrosive grounds (soils)
- 4.3.2. PVC-Covered copper strip conductor for direct buried grid in wet or corrosive ground.
- 4.3.3. Single core stranded copper conductor for direct buried grid in dry, and non-corrosive grounds.
4.3.4. Single core stranded copper conductor with PVC sheath for direct buried grid in wet or corrosive grounds.

4.3.5. Since steel strips/rods/pipes are very rarely used in industrial earthing systems, therefore we shall not go into details for such earthing grid conductors in this document.

4.4. Earthing Grid Conductors Dimension

Depending on the design specification of the earthing system, the size of the grid conductors, would be different as followings:

4.4.1. For bare or PVC-covered cables, the cross section area of the cable could be either 35mm², or 70mm², or 95mm² depending on the design specification.

4.4.2. For bare or PVC-covered copper strips, the cross section dimension of the strip is normally 25 × 3mm.

5. MARSHALING EARTH BUS

To provide easy access to the earthing grid, particularly to make proper and convenient connections of the equipment to the grid, several common connection points in the form of a flat bar of copper material are established and erected throughout the grid and referred to as “earthing marshalling points” or “earthing marshalling bus”, or simply as “earth bus”.

5.1. The main incoming earthing cable connected to the earth bus is branched off from the main earthing grid.

5.2. The outgoing earthing cables, connected to the earth bus in one end, shall be connected to the corresponding equipment on the other end.

5.3. All the connections of the main incoming and outgoing earth cables shall be made to the earth bus by means of appropriate cable lugs the compression type and zinc coating, using bolts, nuts, flat washers and spring washers for well-tight connections.

6. EARTHING WIRES (CABLES)

Connections between the marshalling earth buses and the equipments are carried out by means of single wires or cables of appropriate size, which are referred to as “earthing wire”, or “earthing link”. The connection between the earthing buses and the earthing grid is also made by means of earthing cables.
6.1. Earthing wires and cables are used either bare or PVC-covered (preferably bare) and are normally single core of the different cross section area, depending on the design specification. The common range of the cable size used is 16mm², 25mm², 35,50mm² and 70mm². Earthing wires (cables) of smaller and higher size could be used depending on the design specification and requirements.

6.2. Connections of earthing wires (cables) on both ends is made by appropriate compression-type cable lugs, fitted with bolts, nuts, flat washer and spring washers for tight connections.

7. LIGHTNING ARRESTOR AND ACCESSORIES

To protect the installation against the damages which could happen in the event of a lightning strike, special equipment of different installation set-up are used. The prime element of these electrical safety equipment is the lightning arresters which are installed on the highest point of an installation which are most liable to be struck by the lightning. Lightning arresters are actually part of the earthing system of an installation and are, therefore, appropriately connected to the main earthing grid by means of separate purpose-made earth wells.

To provide sufficient technical information and training material on protective measures and systems developed to avert the risks of possible lightning, a separate training subject has already been opened up and dedicated to the lightning issue (P/TM/TRG/E.LN/001) to be offered during the common course sessions. The protect the plant against lightning, a quite separate independent earthing system is installed in the plant which has no interface and connection with the other earthing systems.

8. EARTHING RESISTANCE

Under fault condition on an specific point in the overall earthing grid and earthing network, a relatively high amount of rush current flows into the earthing system to find its way to the earth wells. The closer an earth well to the fault point, the greater portion of the fault current is absorbed and drained by that well, and the remaining fault current is absorbed by the other nearby earth wells.

8.1. Based on the specification and location of the fault point, the fault current value can be calculated and therefore predicted. Four factors are influential with respect to the fault current value.

8.1.1. The value of voltage applied to the fault point.
8.1.2. The pure ohmic resistance of the fault point with respect to the ground, which includes the ohmic resistance of each individual well, as well as the earthing grid conductors and earthing wires and earthing cables.

8.1.3. The number of rotating machineries (motors and generators) and their rated power at the time of fault.

8.1.4. The distance between the fault point and the rotating machineries.

8.2. Earthing Resistance Measurement

Based on the overall electrical specification of an earthing system, established and erected in an installation, computerized measuring of the pure ohmic resistance for any specific point in the earthing network system is practically possible for electrical design engineers using the available software material and software packages. As an alternative to the above-mentioned method, the pure ohmic resistance of the earthing network at a specific point is also practicable by means of an “earth-resistance measuring equipment” or simply “earth tester”

8.2.1. Earthing resistance for each individual earth well is measured by means of the earth tester once the earth rods are driven into the ground or once the earthing plates are positioned inside the carbon beddings.

8.2.2. The earthing resistance value measured for each earth well should not be lower than the prescribed value in the design specifications.

8.2.3. In the event of greater earthing resistance that that of deemed and prescribed in the design specification, the number of earth rods should be inevitably increased and more rods shall be driven into the ground.

8.2.4. To drive the additional earth rods into the ground, following alternative ways could be implemented depending on the existing condition of the earthing well due improved.

8.2.4.1. Coupling of additional earth rods to the existing rods already driven, and driving the new arrangement into the ground by means of hammering.

8.2.4.2. In cases where coupling of additional rods to the existing (already driven) earth rods is not practically possible, the additional rods could be driven somewhere in the close vicinity of the existing earth well to form a separate but interconnected earth well. The overall earthing resistance is actually lower as a result of two earth wells now in parallel.
8.2.4.3. To achieve a low earthing resistance, the normal practice in design of the earthing system is to introduce three separate earth wells of similar specification in the form of a triangle configuration. Actually the overall earth resistance (with the wells interconnected) shall be one third of the value for each individual well.

8.2.5. Earthing resistance for the lightning protection system shall not exceed 5 OHM.

8.2.6. Earthing resistance for the power system earthing in power station and power plants shall not exceed 5 OHM.

8.2.7. Earthing resistance for the electrical earthing (equipment earthing) shall not exceed 4 OHM.

8.2.8. Earthing resistance for the electronic devices and instrumentations shall not exceed 1 OHM.

9. TYPES OF EARTHING SYSTEM

In industrial installations, where both electrical and instrumentation equipment are incorporated and installed, three types of earthing system is generally introduced, designed and erected to provide safety and protective measures.

9.1. Electrical Earthing Systems

The earthing system, which is designed, installed and connected to all electrical machineries and equipment as well as the plant's bulk equipment is called the “Electrical earthing system” or “Electrical earthing network”

9.1.1. The overall earthing resistance of the electrical earthing system should not be greater than 4 OHM, no matter which point of the grid is put under measurement.

9.1.2. In earthing systems, where bare conductors of the earthing grid is buried directly underground, each section of the underground grid actually acts as an individual earth well, parallel to the existing earth wells, thus contributing in reduction and improvement of the overall earthing resistance.

9.1.3. Earthing connections made to the marshaling earth buses, equipment’s earth bosses etc. should be carried out with such skill and workmanship to prevent any possible misconnections, which could lead to added earth resistance other than established and required.
9.2. Instrument Earthing Systems

In an industrial installation with sophisticated power and electronic equipment, protective measures should be taken to safeguard the instrumentation and the relevant control panels against the sudden high voltages which might hit the earthing system in the event of a fault (short-circuit) in the power circuit of the installation. To achieve this, as a standard design practice, a separate earthing system is defined, designed and installed in such plants. Technical specification, particularly, the installation of instrument earthing system is quite the same as that of electrical system, described in detailed in earlier sections, except for that the earthing resistance should not be greater than 1 OHM throughout the instrument earthing network. Details on instrument earthing system, particularly the different types of instrument earthing shall be offered during the specific course. In this document several concept of instrument earthing is introduced to the trainees of common course period.

- 9.2.1. Sufficient distance should be maintained between the instrument earth wells and the electrical earth wells. Standard distance is at least twice that of the greatest length of the earth rod driven in either the instrument or the electrical well.
- 9.2.2. Separate earthing marshalling points (Marshalling buses) is defined and installed to be used for independent connections to instrument devices.
- 9.2.3. Instrument earth buses are generally installed inside the control building where the instrumentation control are installed and centralized.
- 9.2.4. The metal clad body of the instrument panels, particularly those which accommodate the power supply line, should be connected to the electrical earth system.
- 9.2.5. Instrumentations installed inside the plant, shall be connected to the instrument earthing system via the shield wires of the corresponding instrument cables.
- 9.2.6. Instrument earth wells are installed adjacent to the control building.

9.3. lightning earthing system

10. OUTSTANDING POINTS ON EARTHING SYSTEMS

Regarding the installation and maintenance of an earthing system in an installation, certain outstanding points and notices is worth to be included in this training document due to high importance of the earthing concept in industrial areas, particularly oil and gas plants.

10.1. Earthing Continuity

Once the installation of the earthing system is completed and put into service, under no circumstance should exist an open, disconnected or loose connection within the overall earthing network. In other words, the earthing continuity should essentially be well
achieved, maintained and regularly inspected to ensure reliability and establish the safety for both the operators and the equipment.

- **10.1.1.** To ensure and achieve a reliable connection to the underground earthing grid, all the branch-off (TEE-OFF) connections to the grid are made by means of copper welding, which is also termed as “Thermoweld connection”.

  For grid conductors of different sizes, various thermoweld kits and tools of various sizes are manufactured and available in the market.

Thermoweld kits comprise of apparatus and provisions for accommodating the cable ends due welded together. Special welding powder (welding material) is charged into the apparatus in appropriate quantity to provide the welding heat. Once the cable ends are fixed in position and the welding powder charged, the sparker tool initiates the welding which takes place very rapidly following a well-enclosed and well-trapped heat released by chemical reaction.

To ensure and achieve a reliable connection to the above ground earth buses and the corresponding equipment, all connection points should essentially be made by means of compression cable lugs of appropriate size. Cable lugs of smaller or larger size than that of the cable should not be used. To protect the connections against loosening, caused by mechanical impacts or vibration of the nearby machineries, the cable lugs are tightened sufficiently according to the “standard torque”, tables. Spring washers along with flat washers should be incorporated in cable lug connections.

**10.2.** To protect the above ground connections in the overall earthing network, particularly at marshaling earth buses against the severe environmental conditions such as dust, moisture and corrosive atmosphere, the exposed earthing connections are treated in two ways:

10.2.1. The copper earth buses are lead-plated and the cable lugs, nuts, bolts, washers, etc. used shall be of zink-plated type.

10.2.2. The copper earth buses are totally with an spread of special silicon grease, and the cable lugs, nuts, bolts, washers, etc. used shall be of zink-plated type.

**Note:** Even in cases where the earth buses and connection accessories are all lead or zink plated and corrosion resistant, application of silicon grease to the earth buses is recommended for double protection.

- **10.3.** For underground earthing grids, where the PVC-covered grid conductors are used, the thermowelded tee-off (branch-off) points should be essentially covered with appropriate insulating tapes to prevent direct contact with the soil.
10.4. Bulk equipment in an industrial installation, such as separators, steel structures, outdoor electrical equipment, vessels, large and small machineries, etc. are equipped with an appropriate earth connection provision called commonly as “earth boss”.

Earth bosses are normally small projected angle plate welded to the equipment for earthing purposes. The material of the earth boss should preferably be the same as the equipment’s material. Earthing connections to the earth bosses is carried out by means of bolted cable lugs and normally protected with silicon grease against corrosion.

10.5. Earthing cables, branching off from the underground earthing grid, should be conducted aboveground using appropriate PVC or steel cable riser pipes to protect the cable. To protect the pipe-riser against ingression of foreign material, they are filled with appropriate sealing compound material.

• 10.6. Power transformers shall have separate earthwells installed adjacent to the transformer bay. The transformer earth well is connected to the main earthing network of the plant.

• 10.7. Lightning protection system shall have separate earth wells installed adjacent to the building which the lightning arresters are installed atop it. These earth wells shall not be connected to the main earthing network of the plant.

• 10.8. Power stations and power plants have their own separate earth wells. These earth wells shall be connected to the main earthing system of the plant.

10.9. In power stations and power plants system the earthing wells are separate from the equipment earthing wells. Both power system earthing wells and equipment earthing wells should be interconnected to each other and to the main earthing network of the plant. The minimum distance between the power system earthing and equipment earthing should be twice the length of the longest earth rod driven in the either wells.

• 10.9.1. Power system earthing provides the protection against the fault (short-circuit) in the generators and transformers. Earth resistance for the power system earthing shall not exceed 5 OHM.

• 10.9.2. Equipment earthing provides the protection against the fault (short-circuit) inside the distribution panels and elsewhere within the electrical earthing grid. Earth resistance for equipment earthing system shall not exceed 4 OHM.
10.10. Earth rods in triangle earth well configuration shall be connected to each other by means of bare copper strip of 25 × 3mm or equivalent size stranded cable.

10.11. Once a year, during the annual shutdown maintenance practices all the earthing connections should be inspected, serviced and retightened.

ANNEX 1
(a) : The neutral point of the transformer is connected to the Earth / Ground.
(b) : Earth connection due to poor / broken-down insulation
(c) : Line capacitance with respect to the ground
(d) : Transformer's neutral point connected to the earth / ground
(e) : The floor of the area is wet and conductive
(f) : The floor of the area is insulated, but the connection is made by other conductive material

FIG.1 (Examples of human electrocution)
FIG. 2 Various fault currents and voltages
FIG. 3 PROTECTIVE GROUNDING OF THE EQUIPMENT
FIG. 4  PROTECTIVE ISOLATION OF THE VOLTAGE SOURCE

a) socket outlet  
b) isolated transformer  
c) BI-metal overload relay  
d) plug  
e) isolated transformer
FIG.5 EARTHING SYSTEM COMPONENTS AND ACCESSORIES

a) Earthing system using ULG & ALG water pipes
b) Earthing copper plate
c) Earthing copper rods and beams
d) Underground earthing copper grid.
FIG. 6 SCHEMATIC LAYOUT OF EARTHING SYSTEM SYSTEM IN CONTROL BLDG.
E.E.M.P : ELECTRICAL EARTHING MARSHALLING POINT (BUS)
I.E.M.P : INSTRUMENTATION EARTHING MARSHALLING POINT (BUS)
I.E.M.P (I.S.) : INSTRUMENTATION EARTHING MARSHALLING POINT (BUS) FOR INTRINSICALLY SAFE EQUIPMENT.

EXTENSIBLE COPPER ROLLED EARTH ROD

EXTENSIBLE COPPER BOND EARTH ROD
EXTENSIBLE COPPER EARTH ROD (BICC TYPE)

- DRIVING STUD
- CONDUCTOR CLAMP
- EARTH ROD
- DOWEL
- SPIKE

EXTENSIBLE STAINLESS STEEL EARTH ROD

- DRIVING STUD
- CONDUCTOR CLAMP
- EARTH ROD
- DOWEL
- SPIKE