Earthing for Lighting Protection

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The Perimeter Ring Earth (PRE) or Ring Earth are required for safety critical installations such as Electronic Interlocking Systems for providing protection from lightning. RDSO typical bonding & earthing arrangement is available for provision of Perimeter Ring Earth for Electronic Interlocking installations. But it neither provides guidelines for its design nor provides method to check its effectiveness. More ever, the arrangement is typical but not specific. Specific designs will vary for different installations especially where buildings are different in shapes and sizes, varying soil resistivities from place to place and varying flash density of lightning from region to region.

The Perimeter Ring Earth is the earth-termination system. Earth- termination system is the continuation of the air-termination system and down conductors. It discharges the lightning current to the earth, establishes equipotential bonding between the down conductors and controls the potential in the vicinity of the building walls.

The Perimeter Ring Earth is essentially a type B Earth as per IEC / EN 62305 standards. Earthing system based on Perimeter Ring Earth requires design for a specific installation and requires proper installation practices. This article provides an insight into design and installation of Perimeter Ring Earth and its effectiveness as per IEC/EN 62305 standards.

The topic is dealt in four sections.

(i) **Calculation for requirement of number of Earth Electrodes in a Perimeter Ring Earth** - illustrates the criteria for sufficiency of earth electrodes provided in a Ring Earth for the measured soil resistivity, level of class of lightning protection and area of the building.

(ii) **Selection of Earth Electrodes** - lists various materials available for earth electrodes and the minimum dimensions required for the earth electrodes.

(iii) **Soil Resistivity** - discusses various parameters of soil resistivity and measurement of soil resistivity by Wenner method.

(iv) **Norms and Precautions** - discusses the norms and precautions to be followed in installation of Perimeter Ring Earth.
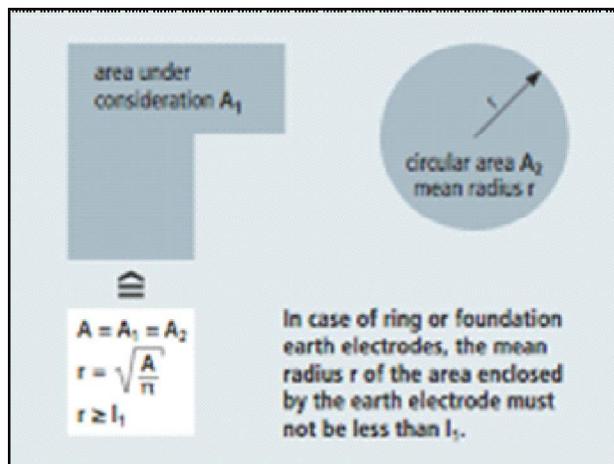
The definitions of technical terms are given at the end.

I. CALCULATION FOR REQUIREMENT OF NUMBER OF EARTH ELECTRODES IN A PERIMETER EARTH

Type B Earth electrodes are ring earth electrodes encircling the object to be protected.

The total length of Earth electrodes provided in Perimeter Ring Earth depends upon 3 parameters (i) total area of building to be protected from lightning (ii) class of lightning protection being provided Class I or II or III or IV (iii) Mean Soil Resistivity in the vicinity of the building.

Criteria for effective lightning protection is that the mean radius, r of the area encircled by a perimeter


area under consideration A_1

circular area A_2 mean radius r

$$A = A_1 = A_2$$
$$r = \sqrt{\frac{A}{\pi}}$$
$$r \geq l_1$$

In case of ring or foundation earth electrodes, the mean radius r of the area enclosed by the earth electrode must not be less than l_1.

ring earth must be not less than the specified minimum length, l_1.

To determine the mean radius r, the area under consideration is transferred into an equivalent circular area and the radius is determined as shown in above figures.

$$r = \sqrt{(A/\pi)}$$

Where r = Mean radius, A = Area of the building being protected

The specified minimum length, l_1 can be obtained from the following graph.

Minimum length of earth electrode
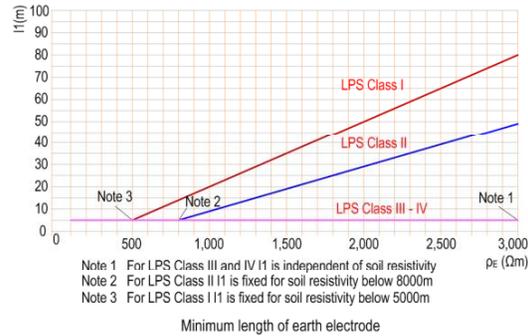
A minimum earth electrode length of 5 m is required for class of LPS III and IV. For class of LPS I and II the length of the earth electrode is defined as a function of the soil resistivity.

The minimum length of each earth electrode is
(i) l_1 x 0.5 for vertical or inclined earth electrodes
(ii) l_1 for radial earth electrodes
As vertical earth electrodes are preferred to radial earth electrodes in our Perimeter Ring Earth installations, the minimum specified total earth electrode length shall be half of the value, l_1 obtained from the graph for a given soil Resistivity and class of lightning protection.

If the required value of l_1 is greater than the value of r corresponding to the structure, further radial or vertical earth electrodes must be added whose relevant lengths l_r (radial/horizontal) and l_v (vertical) result from the following equations:

l_r $= l_1 - r$
l_v $= (l_1 - r) / 2$

For example:

Let us consider the following example.

The station building housing IPS, EI and SM's Panel with Panel Processor are having overall dimensions 16m x 9m.

The IPS is fed from unprotected power source (normally from a CLS Panel). It requires, therefore, Class I Protection.

The Earth Resistivity is measured around the building at 14 places, 1m away from periphery of the building and whose average value is found to be 1,000 Ω m.

The Earth Resistivity can be measured using an Earth Meter by Wenner method. Wenner method is explained in the Soil Resistivity section.

The building is to be provided with the Perimeter Ring Earth for lightning protection.

Now the question is that how many earth electrodes are to be provisioned for Perimeter Ring Earth for protecting the building housing safety critical equipment from lightning effectively?
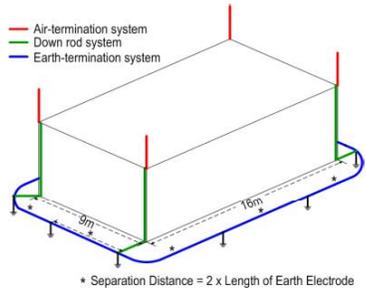
A   =   Area of the building being protected
       =   16 x 9 m^2
       =   144 m^2

r   =   Mean radius
       = $\sqrt{(A / \pi)}$
       = $\sqrt{(144 / \pi)}$
       $\approx$ 6.77 m

From the graph, the minimum length of the earth electrode for 1,000 Ω m soil resistivity and for Class I Lightning protection, the value, l_1 is 20m.

For vertical earth electrodes, the minimum length of the earth electrode has to be l_1 x 0.5. Therefore, the minimum length of the earth electrode, is 20 x 0.5 m = 10m.

When compared r with l_1, r is less than l_1, which is not met the criteria as specified.
In which case, the additional earth electrodes are required to be provided and whose length shall be

l_v $= (l_1 - r) / 2$

l_v = (20 - 6.77) /2 = 6.62 m

Therefore, the total length of earth electrodes required for the Perimeter Ring Earth will be

L_v = 10m + 6.62m
= 16.62m

If earth electrode lengths of 2.0m are being used for Perimeter Earth, the number of earth electrodes require are
= 16.62 / 2.0
≈ 9

II. SELECTION OF EARTH ELECTRODES

Commonly used earth electrode materials and their minimum dimensions are listed in table below.

Material	Configuration	Minimum Dimensions		
		Earth Rod, Ø	Earth Conductor (mm^2)	Earth Plate (mm)
Hot-dip Galvanised Steel	Solid round	14	78	
	Pipe	25		
	Solid Tape		90	
	Solid Plate			500x 500
	Lattice Plate			600x 600
Copper, Tin-plated copper	Stranded		50	
	Solid Round	15	50	
	Solid tape		50	
	Pipe	20		
Bare Steel	Stranded		70	
	Solid Round		78	
	Solid tape		75	
Copper-coated steel	Solid Round	14	50	
	Solid tape		90	
Stainless steel	Solid Round	15	78	
	Solid tape		100	

- Mechanical and electrical characteristics as well as corrosion resistance properties must meet the requirements of the IEC 62561 series
- Must be embedded in concrete for a minimum depth of 50 mm
- Lattice plates should be constructed with a minimum total conductor length of 4.8 m
- Different profiles are permitted with a cross-section of 290 mm^2 and a minimum thickness of 3 mm
- In case of a type B foundation earth electrode, the earth electrode shall be correctly connected at least every 5 m with the reinforcing steel

Hot-dip galvanised steel
Hot-dip galvanised steel can also be embedded in concrete. Foundation earth electrodes, earthing and equipotential bonding conductors made of galvanised steel in concrete may be connected with reinforcing bars.

Steel with copper sheath
In case of copper-sheathed steel, the comments for bare copper apply to the sheath material. Damage to the copper sheath, however, presents a high risk of corrosion for the steel core. Therefore, a completely closed copper layer must always be applied.

Bare copper
Bare copper is very resistant due to its position in the electrochemical series. Moreover, when

connected to earth electrodes or other installations in the ground made of more "non-precious" materials (e.g. steel), bare copper additionally provides cathodic protection, however, at the expense of the more "non-precious" metals.

Stainless steel

Certain high-alloy stainless steels according to EN 10088-1 are inert and corrosion-resistant in the ground. The free corrosion potential of high-alloy stainless steels in normally aerated soils is mostly close to the value of copper. Since the surface of stainless steel earth electrode materials passivate within a few weeks, they are neutral to other (more precious and non-precious) materials. Stainless steels should consist of at least 16% chromium, 5% nickel and 2% molybdenum. Stainless steels without molybdenum are not suited for use as earth electrode material and are not permitted by the standard.

Other materials

Other materials can be used if they are particularly corrosion-resistant in certain environments or are at least equivalent to the materials listed in table.

III.   Earth Resistivity

Earth resistance, R_A

The magnitude of the earth resistance, R_A plays only a minor role for protecting a building or installation against lightning. More important is that the equipotential bonding is established consistently at ground level and the lightning current is safely distributed in the ground. Nevertheless, the Earth Termination system constitute the important ingredient of Lightning Protection System.

Earth resistivity, ρ_E

The earth resistivity ρ_E , which is decisive for the magnitude of the earth resistance R_A of an earth electrode, depends on the soil composition, moisture in the soil and the temperature. It can fluctuate within wide limits.

Seasonal fluctuations

Extensive measurements have shown that the earth resistivity varies greatly depending on the burial depth of the earth electrode. Owing to the negative temperature coefficient of the

ground ($\alpha = 0.02$ to 0.004), the earth resistivity reaches a maximum in winter and a minimum in summer. It is, therefore, advisable to convert the measured values obtained from earth electrodes to the maximum prospective values since the permissible values must not be exceeded even under unfavourable conditions (very low temperatures).

It is to note that the variation of Earth Resistance for the electrode lengths of 1.5m and above during seasonal changes is about 30% and for the electrode lengths of 1.5m and below is about 10%. By using Wenner method, Earth Resistivity can be measured. The value so obtained on a particular day can be converted to maximum value that to be expected.

Specific Earth resistivity ρ_E of different soils
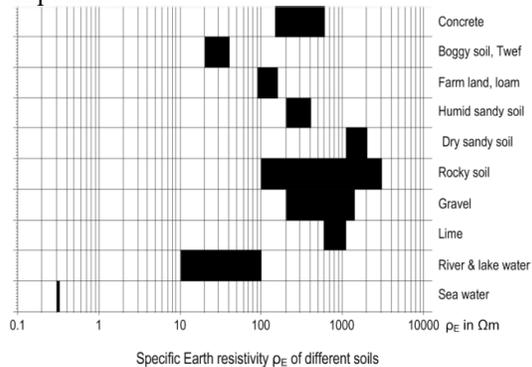
Soil Resistivity varies for different type of soils which is illustrated above.

Measurement of Earth Resistivity

Wenner Method:
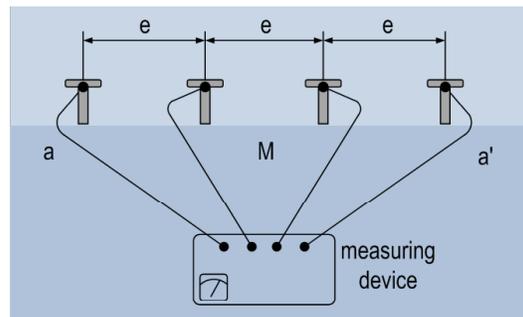
The measurement is carried out from a fixed central point M which is kept for all subsequent measurements. Four measuring probes (30 to 50 cm long earth spikes) are driven into the soil along a line a – a' pegged out in the ground. The earth resistivity ρ_E of the ground can be determined from the

measured resistance R:

ρ_E = $2 \pi e R$

Where

e = robe spacing in meters

R = measured earth resistance in Ω (measured Voltage, V / measured current, I)

ρ_E = average earth resistivity in Ω m up to a depth according to the probe spacing, e

Earth rod

The earth resistance R_A of an earth rod is calculated as follows:

$R_A = (\rho_E / 2 \pi 1) \log_e (2 1 / r)$

Where

R_A = Earth resistance in Ω

ρ_E = Earth resistivity in Ω m

l = Length of the earth rod in m

r = Radius of the earth rod in m

However, when earth electrodes are interconnected in Ring formation for Perimeter Ring Earth and in such cases, the earth resistance R_A of an earth rod is

R_A = $\rho_E / (\pi^2 d) \log_e (\pi d / r)$

$\approx$ $(2 \rho_E / 3 d)$

d = $1.13 \sqrt{A}$

Where

R_A = Earth resistance in Ω

ρ_E = Earth resistivity in Ω m

d = Diameter of a ring earth electrode, the area of the equivalent circuit or a hemispherical earth electrode

A = Area (m^2) of the enclosed area of a ring earth electrode

R = Quarter width of the strip earth electrode

The lightning current **i** raises the object to be protected to the earth potential U_E with respect to reference earth.

U_E = $i R_A + \frac{1}{2} L \, di/dt$

The potential of the earth's surface decreases as the distance from the earth electrode increases. The magnitude of the earth resistance must be limited to minimise touch and step voltages. The conventional earthing impedance of earth electrodes depends on the

maximum value of the lightning current and of the earth resistivity. As an approximation, the effective length of the earth electrode in case of lightning currents is calculated as follows:

l_{eff} = $0.2 \sqrt{ (i . \rho_E) }$

Where

l_{eff} = Effective length of the earth electrode in m

î = Peak value of the lightning current in kA

ρE = Earth resistivity in Ω m

Earth rods are easy to assemble and achieve excellent constant earth resistances without requiring excavation work and damaging the ground, these earth electrodes are also suitable for improving existing earth-termination systems.
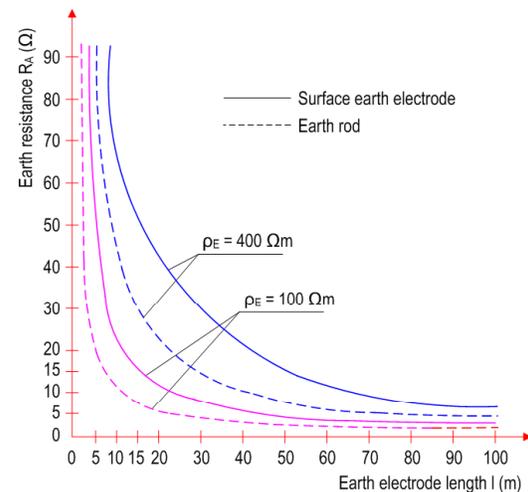
Earth Resistance for a given electrode length and soil resistivity is given as above.

IV. NORMS & RECAUTIONS

1. A common earth-termination system is to be preferred for the different electrical systems (lightning protection systems, low-voltage systems and telecommunications systems).

2. This earth-termination system must be connected to the equipotential bonding system via the main earthing busbar (MEB).

3. The The earth electrode must be spaced at equal interval.

4. The spacing between 2 earth electrodes shall be minimum 2 times the length of the electrode.

5. The earth electrodes are preferably to be placed at building corners, as down rods of air-termination system normally be run thru the corners of the building.

6. The earth electrode must be in contact with the soil for at least 80 % of its total length to ensure that a type B earth electrode can be used as a base for calculating the separation distance.

7. The minimum lengths of type B earth electrodes depend on the class of LPS. In case of classes of LPS I and II, the minimum earth electrode length also depends on the soil resistivity.

8. The number of additional earth electrodes must not be less than the number of down conductors, but at least two. These additional earth electrodes should be connected to the ring earth electrode so as to be spaced equally around the perimeter.

9. The lightning current is not conducted to earth at one point via the earth electrode, but rather energises a certain area around the earth electrode.

8. Since the IEC 62305-3 (EN 62305-3) standard requires consistent lightning equipotential bonding, no particular value is specified for the earth resistance. In general, a low earth resistance ($\leq 10\ \Omega$, measured with a low frequency) is recommended.

9. The requirements on the minimum earth electrode length must be taken into account depending on the class of LPS.

10. When installing the ring earth electrode, it must be also observed that it is buried at a depth > 0.5 m and 1 m away from the building.

11. If the earth electrode is driven vertically into the soil, it reduces the step voltage and thus controls the potential around the building.

12. This ring earth electrode should be installed in natural soil. If it is installed in back filled or soil filled with construction waste, the earth resistance is reduced.

13. When choosing the earth electrode material with regard to corrosion, local conditions must be taken into consideration. It is advisable to use stainless steel. This earth electrode material does neither corrode nor subsequently require time consuming and expensive reconstruction measures for the earth-termination system such as removal of paving stones, tar surfaces or even steps for installing a new earthing material.

14. In addition, the terminal lugs must be particularly protected against corrosion.

15. In rocky or stony ground, surface earth electrodes such as ring or radial earth electrodes are often the only way to create an earth-termination system.

16. Earth entries made of galvanised steel must be protected against corrosion over a distance of at least 0.3 m above and below the surface of the earth. Generally, bituminous coatings are not sufficient. A moisture-proof sheath, e.g. butyl rubber strips, heat-shrinkable sleeves or preferably stainless steel, provides protection.

17. Buried connection points: Cut surfaces and connection points in the ground must be designed so as to ensure that they have an equivalent corrosion resistance as the corrosion protection layer of the earth electrode material. Connection points in the ground must therefore be equipped with a suitable coating, e.g. wrapped with an anticorrosive tape.

18. When filling ditches and pits where earth electrodes are installed, pieces of slag and coal must not directly contact the earth electrode material. The same applies to construction waste.

19. If it is not possible to encircle the structure by means of a closed ring, the ring must be complemented by means of conductors inside the structure. Pipework or other permanently conductive metal components can also be used for this purpose.

20. Connecting cables / terminal lugs

between earth electrodes and down conductors should be laid in concrete or masonry until they are above the surface of the earth.

21.   If the connecting cables are led through the ground, terminal lugs with e.g. 1 x 16 mm^2 Cu, stainless steel (V4A), or fixed earthing terminals must be used.

22.   Earthing conductors installed in the masonry can also be led upwards without corrosion protection.

TERMINOLOGY

Earth
is the conductive ground and the part of the earth in electrical contact with an earth electrode whose electric potential is not necessarily zero. The term "earth" also describes both a place and a material, e.g. humus, loam, sand, gravel and rock.

Reference earth
(neutral earth) is the part of the earth, especially the surface of the earth outside the area influenced by an earth electrode or an earth-termination system, in which no perceptible voltages arising from the earthing current occur between two arbitrary points

Earth electrode
is a conductive part or several conductive parts in electrical contact with earth which provide(s) an electrical connection with the earth (also foundation earth electrodes).

Earth-termination system
all conductively interconnected earth electrodes which are physically separated or metal components acting as such (e.g. reinforcements of concrete foundations, metal cable sheaths in direct contact with earth).

Earthing conductor
is a conductor which connects a system part to be earthed to an earth electrode and which is installed above the ground or insulated in the ground.

Foundation Earth Electrodes
consists of one or several conductors embedded in concrete which are in contact with earth over a large area.

Ring earth electrode
earth electrode that forms a closed ring around the structure underneath or on the surface of the earth.

Earth resistivity
E is the electric resistivity of the earth. It is specified in Ωm and represents the resistance of an earth cube with 1 m long edges between two opposite sides of the cube.

Earth resistance
R_A of an earth electrode is the resistance of the earth between the earth electrode and reference earth. R_A is practically an effective resistance.

Earth surface potential
is the voltage between one point of the surface of the earth and reference earth

Touch voltage
is the part of the earth surface potential which can be bridged by persons, the current path via the human body running from hand to foot (horizontal distance from the touchable part of about 1 m) or from one hand to the other.

Step voltage
is the part of the earth surface potential which can be bridged by persons taking one step of 1 m, the current path via the human body running from one foot to the other.

REFERENCES

1.   IEC/ EN 62305 - 3 & 4 Lightning Protection Standards

2.   DEHN + SÖHNE – Lightning Protection Guide, 3rd updated edition as of December 2014 ISBN 978-3-9813770-1-9

3.   RDSO typical drawing for earthing and connections for EI systems