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Short time current withstand strength of earth electrodes-experiences with testing

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The earth electrode is the main component of the earthing system which is in direct contact with the ground and thus provides a means of releasing or collecting any earth leakage currents. The electrode shall have good electrical conductivity and shall not corrode in a wide range of soil conditions. The design of these electrodes shall be such that they have good current carrying capacity under the earth fault conditions. This paper describes current withstand capability of these Earth Electrodes during earth fault conditions. Recent developments in Electrodes and their performance for different fault currents are given. Failure cases are studied from the laboratory tested Electrodes and appropriate recommendations were proposed. This can give an insight for estimating fault current withstand capability of a given dia and material of Electrode. Also different filler materials used for earth electrodes have been discussed.

Keywords: *Earth Electrode, Pipe, Strip, Pipe in pipe, Strip in pipe, Short-circuit current, Coating Thickness Measurement, Touch Potential.*

1.0 INTRODUCTION

Earthing systems have the following general purpose [1]:

Protection of life and property in the event of

– Short circuits and earth faults

– Lightning, switching operations

Therefore the design of the Earthing system shall be :

- Capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits
- Maintain its integrity for its expected lifetime with due allowance for corrosion and mechanical constraints
- Designed to prevent a touch potential under fault conditions not exceeding 50 V

Earth Electrode is very important component in earthing systems. It is a conductor embedded in the ground and electrically connected. It is basically a conductive material generally in the form of a pipe or plate or solid rod with a coating to prevent corrosion of the material. The length of earth electrode used generally depends on the soil conditions.

Any significant length generally passes through soil horizons of varying conductivity. They are particularly useful where more conductive lower soil horizons are available and the rod earth electrodes can penetrate these horizons sufficiently (approximately 3 m).

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Typical ground resistance value for an earth-pit are given in Table 1.

TABLE 1

GROUND RESISTANCE VALUE

Sl. No.	Location	Resistance Value
1.	Large power stations	< 0.5 Ω
2.	Major sub-stations	< 1.0 Ω
3.	Sub-stations upto 33 kv	< 2.0 Ω
4.	Distribution T/F centers	< 5.0 Ω
5.	Towers	< 10.0 Ω

The power system is growing day by day to cater for increasing demand in electrical power. Interconnections between systems of various supply authorities are also increasing for improved reliability and voltage conditions. Because of this the short circuit levels and the frequency of occurrence of faults have increased.

The earth fault is due to

a) Capacitive earth-fault current in networks with isolated neutral.

b) Earth-fault residual current in networks with earth-fault compensation.

c) The zero-sequence current in networks with low-resistance neutral earthing and also includes networks with isolated neutral point or earth-fault compensators in which the neutral point is briefly earthed at the start of the fault.

During earth faults, the currents suddenly increase to a large value applying huge theraml and mechanical stress on the earthing system until the fault is cleared. Unless these earth electrodes are designed to withstand these stresses failures can occur. i.e. damages like breaking of earth electrode due to high temperatures or bending of electrode. Hence to ascertain the current withstand capability of these earth electrodes under earth fault conditions which they experience during life period, they are subjected to short circuit test.

2.0 TYPES OF EARTH ELECTRODES [1]

I. Classification by location

a) Surface earth electrodes:

Are earth electrodes that are generally positioned at shallow depths to about 1 m long. They can be of strip, bar or stranded wire and be laid out as radial, ring or meshed earth electrodes or as a combination of these.

b) Deep earth electrodes:

Are earth electrodes that are generally positioned vertically at greater depths. They can be of tubular or solid rod generally of length 3 m or more.

II. Classification by shape and cross section

- Strip, stranded wire and tube earth electrodes.
- Natural earth electrodes are metal parts in contact with the ground or water, directly or via concrete, whose original purpose is not earthing but they act as an earth electrode. They include pipes, caisson walls, concrete pile reinforcement, steel parts of buildings etc. Cables with earthing effect are cables whose metal sheathing, shield or armoring provides a leakage to earth similar to that of strip earth electrodes.
- Foundation earths are conductors embedded in concrete that is in contact with the ground over a large area. Foundation earths may be treated as if the conductor were laid in the surrounding soil.
- Control earth electrodes are earth electrodes that by their shape and arrangement are more for potential control than for retaining a specific dissipation resistance.
- Rod earth electrodes of any significant length generally pass through soil horizons of varying conductivity. They are particularly useful where more conductive lower soil horizons are available and the rod earth electrodes can penetrate these horizons sufficiently (approximately 3 m). To determine whether more conductive lower soil horizons are available, the specific resistance of the soil at the site is measured.

Commercially available types:

Based on the manufacturing process commercially available types are :

1. Pipe Electrode
2. Strip in pipe Electrode
3. Pipe in pipe Electrode
4. Solid Electrode

3.0 MATERIAL FOR EARTH ELECTRODES

The material of earth electrode shall have high electrical conductivity and low underground corrosion [3]. When designing the earth electrode for thirty to fifty years, it is preferable to increase the size to take care of corrosion during its life. Present-day used materials are

1. Galvanized Iron tube
2. MS with copper coating
3. Copper tube

Generally GI tubes are filled with filler material such as crystalline conductive (like graphite) filling to improve further conductivity.

Figure 2 to Figure 5 show different types of Earth electrodes. Galvanized steel, if used, retards the rate of corrosion in initial stages. MS rod with copper coating / bonding are also used as earth electrodes as copper coating prevents corrosion of MS. Tha coating thickness generally employed is 250 microns. However, if the copper coating is scratched or eroded at some locations, the rate of corrosion increases. Thickness of erosion depends on the corrosivity of soil and electode may be destroyed after few years.

Further [1]

- Hot-dip galvanized steel is very durable in almost all soil types. This is also suitable for embedding in concrete.
- Copper is suitable as an earth electrode material in power systems with high fault currents because of its significantly greater electrical conductivity compared to steel. Bare copper is generally very durable in the soil.
- Copper coated with tin is, like bare copper, generally very durable in the soil. Tinplated copper has no electrochemical advantage over bare copper.

4.0 MATERIAL COMPOSITION

(a) Rod earth electrode

High tensile-low carbon steel rod having required diameter with molecularly bonded by 99.99% pure high conductivity copper on outer surface with desired copper coating thickness and Length usually of 3 m. Length of the electrode may be increased in multiple of 1 m to reduce earth resistance if required. To increase the length, pieces of similar rod shall be either exothermically welded to basic 3 m electrode or connected using socket of suitable size. These sockets shall also be molecularly bonded by 99.99% pure high conductivity copper on inner & outer surface with required copper coating thickness.

Coating thickness Measurement

Thickness of copper coating is very important w.r.t current carrying capacity and CPRI is having facility to measure the coating thickness by using scanning electron microscope as shown in Figure 1.

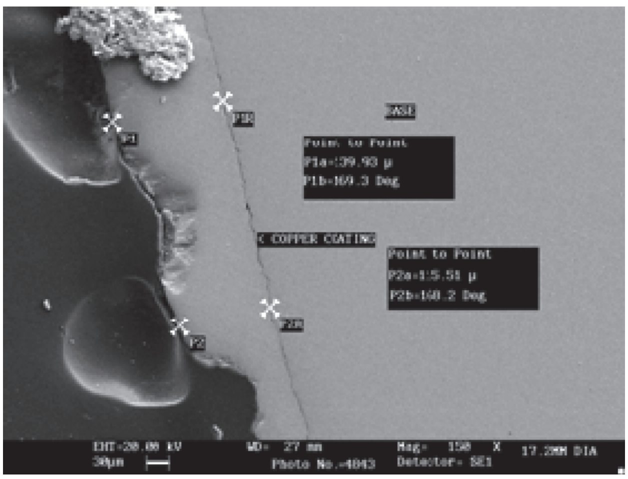

FIG. 1 CU COATING THICKNESS MEASUREMENT

FIG. 2 GI PIPE ELECTRODE

FIG. 4 PIPE IN PIPE GI ELECTRODE

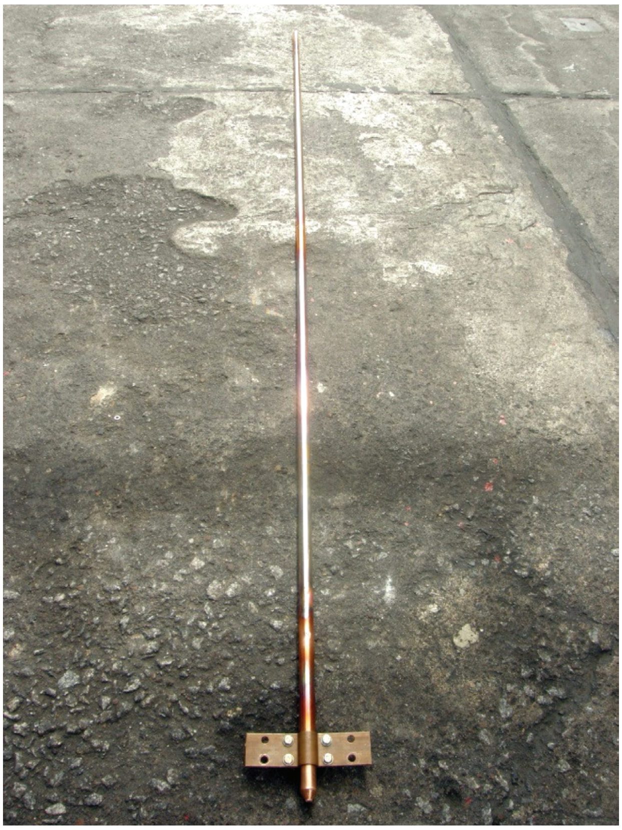

FIG. 3 COPPER BONDED STEEL ELECTRODE

FIG. 5 STRIP IN PIPE GI ELECTRODE

FIG. 6 COPPER PIPE ELECTRODE

(b) Concentric pipe electrode

These electrodes can be formed either Strip in pipe Electrode or Pipe in pipe Electrode. The inside one i.e. strip/pipe will act as a primary conductor and outer pipe acts as a secondary conductor.

Conductive mixture for concentric pipe electrodes

For hermetically filling inside the cavity i.e. between secondary conductor & primary conductor, crystalline conductive compound is to be injected in the electrode assembly. It is a combination of high conductivity metal alloys, like copper & aluminium powder, conductive carbon/cement and bonding material etc. mixed in different proportion. The mixture is force (pressurized) filled inside the earthelectrode in the powder/paste form. After solidification of the same, the end caps are welded. The metal alloys help in conducting the current and conductive carbon gives anti corrosive property. Bonding material should provide strength to the mixture.

5.0 SELECTION OF EARTH ELECTRODES FOR APPLICATION

Depending on the installations viz. house hold earthing, commercial buildings, Transformers, substation earthing, LT/HT line equipment and soil type viz. normal soil, sandy soil, rocky soil and value of resistivity, single/multiple electrode system shall be used.

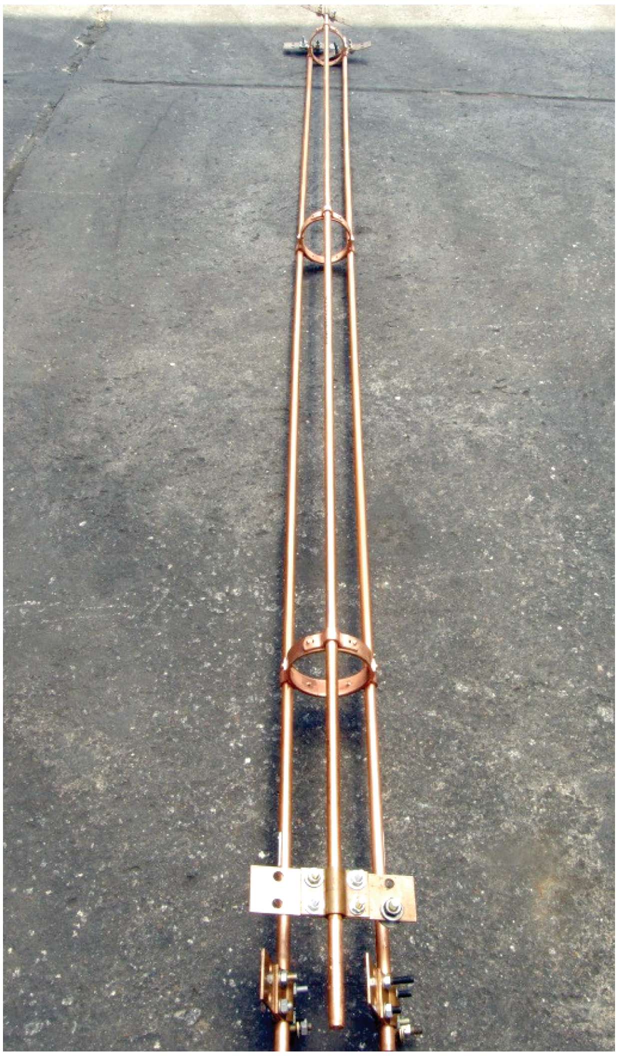

FIG. 7 TRI POLAR COPPER BONDED ELECTRODE

6.0 UNDERSTANDING OF CURRENT CARRYING CAPACITY OF ELECTRODE

Size of earth electrode conductor shall be such that

i. It has thermal stability to flow earth fault currents

ii. It lasts for 30 - 50 years without causing break in earthling circuit due to corrosion

iii. It is mechanically strong

The cross-section of earth electrodes and earthing conductors must be measured so that in the event of a fault current I_f, the strength of the material is not reduced. The required cross-section may be determined with considerable safety factor as follows:

$$A = I_f \cdot \frac{\sqrt{t_f}}{k} \quad \text{....(1)}$$

Where

I_f is fault current in A

t_f is fault current duration in s

k is material co-efficient

$$k = 226\sqrt{ln(1 + \frac{\theta f - \theta i}{234.5 + \theta i})} \quad \text{....(2)}$$

Where Θ_f is final temperature in °C

Θi is initial temperature in °C

7.0 RESULTS AND DISCUSSIONS

Based on the experience, Typical Short-circuit current capacity of various types of earth electrodes are given in Table 2, Table 3 and Table 4.

TABLE 2

TEST RESULT FOR COPPER BONDED EARTH ELECTRODES

Cross-section	Typical Short-circuit current carrying capacity
14 mm	12 kA rms for 1.0 s
17 mm	20 kA rms for 1.0 s
20 mm	25 kA rms for 1.0 s
25 mm	30 kA rms for 1.0 s

TABLE 3

TEST RESULT FOR PIPE IN PIPE EARTH ELECTRODES

Cross-section	Typical Short-circuit current carrying capacity
50 mm dia (outer pipe) & 25 mm dia (inner pipe)	20 kA rms for 1.0 s
76 mm (Outer pipe) & 42 mm (Inner pipe)	30 kA rms for1.0 s
80 mm dia (outer pipe) & 40 mm dia (inner pipe)	40 kA rms for 1.0 s
90 mm dia (outer pipe) & 50 mm dia (inner pipe)	42 kA rms for 1.0 s

TABLE 4

TEST RESULT FOR STRIP IN PIPE EARTH GI ELECTRODES WITH PASTE OF MOISTURIZED CONDUCTIVE MIXTURE FILLING

Cross-section		Typical Short-circuit current carrying capacity
Pipe	Strip	
60 mm dia GI	40x6 mm GI	15 kA rms for1.0 s
88 mm dia GI	50x6 mm GI	20 kA rms for 1.0 s

Design Phase:

Selection of material →determination of size and length →preliminary arrangement of conductor of earth electrode system →calculation of earth resistance of earthling system →checking its strength for earth fault current

8.0 RECOMMENDATIONS

The evaluation criterion for Short time current test is

1. No visible damage to the Earth electrode including terminals
2. No visible damage to joints (if exo-thermic joint or couplers are used)
3. Electrode shall not bend or deform in any nature

4. Coating / bonding shall be intact. Decolourization of coating may be allowed. The resistance of the earth electrode shall be measured before and after the short time current test and resistance measured after the test shall not increase considerably.

9.0 CONCLUSIONS

This paper presented various aspects like different types, design, significance of material composition, selection and short time current withstand capabilities of earth electrodes. As IEC 62561-2 – Part 2 does not deal with the short -time withstand capability of earth electrodes with experiences few recommendations have been proposed in this regard.

Short-time withstand current test is an important test for earth electrodes as it may see several earth faults during its life time. Hence earth electrodes shall be designed properly such that the temperature attained during the flow of fault current shall be within the permissible value in order to prevent its damage. Proper factor of safety shall be considered keeping the above requirement in to consideration.

REFERENCES

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