SDCS-03

DISTRIBUTION NETWORK GROUNDING

CONSTRUCTION STANDARD

(PART-III)
REV-01

GROUNDING RESISTANCE

MEASUREMENTS AND IMPROVEMENT

TABLE OF CONTENTS

1.0 GENERAL:

1.1 Scope:

This Grounding Standard describes factors affecting the ground resistance and the method of measuring ground resistance of Distribution System Network installations.
It also describes the methods for improving soil resistivity.

1.2 Objective:

Objectives of this Grounding Standard are as follows;

a) To verify the adequacy of a new grounding system.
b) Specify corrective steps, if any, for lowering the grounding resistance.
c) Detect changes in the existing grounding system.

1.3 Factors Effecting Ground Resistance:

The ground resistance at a given location is dependent on a number of factors, some of which are as follows:

1.3.1 Soil Resistivity

The ground resistance of a single rod type electrode is dependent upon the resistivity of the soil immediately surrounding the electrode. The soil which is far from the electrode has little effect on the ground resistance.
The soil resistivity depends on the nature of soil, its chemical composition, amount of moisture in it and soil temperature. Compact soil has lower resistance than non compact soil of the same type. Soils having high content of salts like magnesium sulphate, copper sulphate, etc. have low resistivity.
Increasing moisture content in the soil decrease the ground resistance considerably. However beyond approximately 20 % the moisture has less effect on reducing the ground resistance. Decreasing soil temperature increases ground resistance.

1.3.2 Arrangement of Grounding System

As the ground rod resistance: $R = \rho L/A$
Where: ρ is the resistivity of material, L is the length of the rod, A is the area cross-section.

Therefore ground resistance can be reduced by:

- Use of large diameter of rod
- Use of longer rod length
- Use of parallel rods
- Use of Low Resistance Material (LRM)

LRM are described further in para 4.
As such grounding resistance at a location can be reduced by proper arrangement of ground rods. Two (2) ground rods when spaced one meter apart and interconnected have combined ground resistance approximately 40 % more than the combined resistance of the same rods when spaced 4 meters apart. Depth of ground rod has a significant effect on the ground resistance.
Usually the ground resistance decreases as the ground rod depth increases. This is so because the surface layers of soil have less moisture content than the deep layers.

2.0 GENERAL REQUIREMENTS FOR MEASUREMENT

2.1 Ensure that the equipment whose ground resistance is to be measured is de-energized.

2.2 Isolate the ground under test from all other grounds like cable screens, cable neutrals, primary neutrals, equipment body, etc.

2.3 The limits for the values of resistance for respective installations shall be as per SDCS-03 part-1 and part-11

3.0 GROUND RESISTANCE MEASUREMENTS

Below mentioned methods shall be adopted for measurement of grounding resistance:

i) Measurement through Fall of Potential method.

ii) Measurement through Clamp On Meter Method.

iii) Measurement through Attached Rod Technique Method.

The description of each method is given as under:

3.1 Fall of Potential Method

3.1.1 General

The fall of potential method, also known as three terminal method, used to measure ground resistance is illustrated in Fig. 1. This method involves passing a current through the ground under test (G), and noting the influence of this current in terms of voltage between (G) and a test potential electrode (P). A test current electrode (C) is used to permit the passing of current into G, which for convenience, is measured at zero potential. The ground resistance is given as ratio of measured voltage to the imposed current.
The null balance type earth tester shall normally be used for measuring ground resistance in this method. The instrument is supplied with 3 test leads and 2 electrodes (C & P).

3.1.2 Measuring Procedures

Ensure that the equipment whose ground resistance is to be measured is de-energized. During testing the test personnel must wear the required safety gears like shoes, hat, gloves, etc.
Isolate the ground under test from all other grounds like cable screens, cable neutrals, primary neutrals, equipment body, etc.
Refer to Fig. 1. Here C1, P1, P2, and C2 are four terminals on the instrument.

i) Connect C1 and P1 together with a copper jumper wire. Connect C1 to the ground under test G. This connection should be as short as possible.
ii) Drive current electrode C into the soil at a distance of approximately 30 meters from G. Let this distance be called as ' D'. Connect C to C2.
iii) Drive potential electrode P at a distance of 0.62 D from G and along a straight line between G and C. Connect P to P2.
iv) Obtain null point on the instrument and read off the corresponding resistance.
v) Similarly take readings at a distance of (0.62D +2) meters and (0.62D -2) meters from G by driving P at these locations without changing the location of C. If the three reading are very close to each other then the resistance reading obtained at 0.62D is the true ground resistance and is so recorded.

In some cases the three readings mentioned above may not be close to each other. In such cases proceed to take more readings at equal increments of two meters on either side of 0.62D distance and plot a curve of distance versus resistance readings as indicated in Fig.2. Read the true ground resistance, in such cases, as the one corresponding to the flat portion of the curve and record it so, if the flat portion on the curve is not obtained , then move the current electrode 'C' further away from 'G' in a different direction and repeat the procedure stated above.
If reasonable care is exercised in initial locations of C and P, then in general, it will not be necessary to plot the curve or move the location of C.
The following precaution should be taken in choosing the location of C & P and installation of these electrodes.

i) Locate C as for away from G as possible.
ii) Locate C and P away from any known buried bare metallic objects.
iii) G, C and P should be located in a fairly uniform soil.
iv) C and P should be driven firmly into the soil so that there is no tendency for them to sway.

The measured ground resistance and other related information shall be recorded.

3.2 Clamp On Meter method

3.2.1 General

This method is based on passing a current in the grounding conductor encircled by a current transformer using a voltage source with a constant value. The probe head or jaw of the clamp on meter is the key component in the current measurement.
Typically grounded distribution system may be simulated by the basic circuit shown in Fig. 3. If the voltage (V) is applied to any measured grounding electrode with resistance Rx through a special current transformer, current (I) flows through the circuit thereby establishing the following equation:

$$V/I = Rx + 1/\sum_{i=1}^{n} 1/R$$

Where usually

$$Rx \gg 1/\sum_{i=1}^{n} 1/R$$

Therefore V/I= Rx is established.

If I is detected and measured with V kept constant, the measured grounding electrode resistance Rx can be obtained. A signal is fed to a special transformer via a power amplifier from a constant voltage oscillator. The resulting current is then sensed by a detection CT. An active filter is used to dampen earth current at commercial frequency and high frequency noise.
If case we clamp on the meter around any grounding electrode in a multi grounded system, the measured value of the electrode under test will be the resistance of that particular rod in series with the equivalent parallel resistance value that the rest of multi grounded system represents.
As an example, if the number of grounding rods in a distribution feeder reaches hundred and if each has a resistance value of 25 ohms, in case we clamp around any electrode in the system, the measured value would be 25 ohms in series with the equivalent parallel resistance with negligible value say 0.25 ohms. The displayed value would be 25.25 ohms (i.e $V/I = 25\ \Omega + 0.25\ \Omega$)

3.2.2 Typical illustrations of measurement of the ground resistance for a pole, transformer and service box is given in Figures 4 to 6.
For measurement, select the current range 'A'. Clamp on the meter to the ground conductor and measure the ground current. Note that if ground current is above 5 Amp or noise exceeds 50 V, grounding resistance measurements shall not be possible. Note the location for maintenance and move to another location for measurement.
After noting the ground current, select the ground resistance range and measure the resistance directly. The reading measured as such indicates not just the resistance of the rod itself but of the connected system neutral and all bonded connections between the neutral and the rod.

3.3. Attached Rod Technique Method

Fall-of-Potential testing is extremely reliable, highly accurate, conforms to IEEE 81 and gives the operator complete control over the set-up. However it is exceedingly time consuming and labor intensive and requires that the individual grounding electrodes be disconnected from the system.
Clamp-on testing is quick and easy but has many limitations. This method requires a good return path, is susceptible to noise, has reduced accuracies and can not be used on isolated grounds. It is not applicable for installation checks or commissioning new checks or commissioning new sites and has no built in proof.

The Attached Rod technique (ART) provides some of the advantages on clamp-on testing (not having to disconnect the ground electrode) while remaining true to the theory and methodology of fall-of-potential testing.

To understand the method, it is necessary to understand the theory and math behind it. In theory a fall of potential measurement could be made without disconnecting the ground electrode if additional measurements were made with an earth leakage clamp meter (milliamp meter). Figures 7 and 8 show the three measurements that would be made.

The first step is to measure the resistance (R_T) of the entire system using a typical fall-of-potential configuration. In this example, the reading for R_T is 1.9 Ω.

Step two involves measuring the total current (I_T) being injected into the system from C1.From this example, I_T is 9.00 mA. The next step is to measure the amount of current (Iu) following to the service. In this case Iu is 5.00 mA. With these measurements the voltage drop from the selected volume of soil to the point of P2 can be determined as follows:

$$V = I_T \times R_T$$
$$V = 0.009\ A \times 1.9\ \Omega$$
$$V = 0.017\ V$$

The current through the ground electrode (I_G) can also be determined.

$$I_G = I_T - Iu$$
$$I_G = 9.00\ mA - 5.00\ mA$$
$$I_G = 4.00\ mA$$

Using the voltage drop and the current through the ground electrode, the resistance of the ground electrode (R_G) can be determined.

$$R_G = V \div I_G$$
$$R_G = 0.017V \div 0.004\ A$$
$$R_G = 4.25\ \Omega$$

As noted, this is a theoretical approach that requires perfect conditions. Any additional current flowing from the service through the ground electrode would reduce the accuracy of the measurement. The earth leakage clamp meter would have to filter out all but the current generated by the instrument through C1 to ensure the accuracy. Additionally, this approach requires that a number of mathematical, calculations be made.

The Attached Rod Technique is based on the theory outlined above. Figure 9 shows an ART test being made.

Ground testers that are designed to make ART measurements include a special built-in current clamp that is placed between the C1 connection and the earth. This type of instrument includes noise protection and digitally filters out all currents other than that generated by the instruments. The instruments microprocessor automatically performs all the calculations necessary to generate a resistance measurement for the ground electrode.

The test is a fall-of-potential test, meaning that all the "rules" still apply. Ideally, the operator would take ten measurements and plot the results to determine true resistance. Proper probe spacing remains critical, and fall-of- potential procedure and methodology must be followed. As with a traditional fall-of- potential test, the results can be proved by increasing the probe spacing.

The advantage of the ART method over traditional fall-of-potential testing is that the ground electrode under test does not have to be disconnected from the system

4.0 GROUNDING SYSTEM DESIGN AND IMPROVEMENT

Common minimum values of grounding resistance required for various network installations lie in the range of 5 to 25 Ω. as discussed in grounding procedures part1 and part-11. For large transmission and distribution substations, resistance of about 1 Ω is required. Such cases will certainly need grounding grids. For other cases, grounding rods or wires may be used. The recommended grounding rod is 16 mm diameter copper clad steel rod of 2.4 m length for use in normal soil and 1.2 m length for use in hard areas.

In the areas with resistivity up to 100 Ohm-meters grounding shall be carried out using additional rods. Tables below describe the earth resistance values achieved versus approximate no. of ground rods required.

In the areas with resistivity value higher than 100 ohm-meter Low Resistivity Materials (LRM) shall be used to improve the resistivity.

Table 1 and 2 show the variation of resistance and resistivity and number of rods for rods, 2.4 m and 1.2 m lengths, respectively.

Table 1: Variation of grounding resistance with number of rod and soil resistivity on 2.4 m long, rod depth, rod diameter = 16 mm.

ρ (Ω.m)	Grounding Resistance (Ω)					
	1 rod	2 rods	3 rods	4 rods	8 rods	12 rods
10	3.54	2.05	1.52	1.20	0.74	0.53
30	10.62	6.15	4.56	3.61	2.23	1.59
50	17.7	10.26	7.61	6.01	3.71	2.65
100	35.38	20.52	15.2	12.03	7.43	5.31
300	106.2	61.5	45.6	36.1	22.3	15.9
500	177	102.6	76.1	60.1	37.1	26.5
1000	354	205.2	152.1	120.3	74.3	53.1

Table 2: Variation of grounding resistance with number of rod and soil resistivity at 1.2 m rod depth, rod diameter = 16 mm.

ρ (Ω.m)	Grounding Resistance (Ω)					
	1 rod	2 rods	3 rods	4 rods	8 rods	12 rods
10	6.42	3.69	2.76	2.18	1.35	0.96
30	19.25	11.01	8.28	6.55	4.05	2.89
50	32.01	18.45	13.80	10.89	6.74	4.82
100	14.16	36.9	27.6	21.8	13.5	9.63
300	192.47	110.7	82.8	65.5	40.2	28.9
500	320.78	184.5	138	109.1	68.1	48.2
1000	641.57	369	276	218	135	96.3

Using these tables, it is possible to decide how many grounding rods are required to achieve a selected or specified value of ground resistance. Table 3 gives the required number of rods of two sizes, in soils of different resistivity values. In this table NP = Not Practicable is assigned to cases where too many rods are required. It is clear from this table that for medium to high soil resistivity, it is difficult to get less than 25 Ω grounding resistance by using rods only. Therefore, in such cases, soil resistivity has to be modified by using LRM

Table 3: Number of rods required to obtain different grounding resistance values for various soil resistivity values.

Grounding	5 Ω		10 Ω		15 Ω		25 Ω	
ρ (Ω.m)	No. of 2.4 m rods	No. of 1.2 m rods	No. of 2.4 m rods	No. of 1.2 m rods	No. of 2.4 m rods	No. of 1.2 m rods	No. of 2.4 m rods	No. of 1.2 m rods
10	1	2	1	1	1	1	1	1
30	3	6	2	3	1	2	1	1
50	6	12	3	6	2	3	1	2
100	12	NP	6	10	4	7	2	4
300	NP	NP	23	NP	14	NP	8	15
500	NP	NP	NP	NP	27	NP	13	NP
1000	NP	NP	NP	NP	NP	NP	NP	NP

The specific grounding system design is usually based on the space available for installation and the desired specific value of grounding resistance. Installation of vertical ground rods is not always practical at certain locations. A horizontal electrode provides an effective alternative for narrow paths or shallow rock substructures. It might be a rod or more typically, a length of bare copper wire buried in the earth. Horizontal electrodes are often used to interconnect a system of multiple vertical electrodes for further reduction of overall system ground resistance. A horizontal electrode configuration can be either a straight line, a ring, or perimeter (square, circular, or triangular) or a star radiating from a single point. There is reduction in resistance with the increase in depth, but 0.5 m depth is found to be adequate for applications in the Kingdom. The resistance value of ring formation exhibits ~10% higher Rg value than straight horizontal wire of the same length.

Star configuration (radially extending out) presents almost the same resistance as the equal length of straight wire. The perimeter of ring can be changed to square or rectangular formation without changing appreciably the value of earth resistance.

4.1 APLICATION OF LRM

Systematic investigations lead to the conclusion that the best choice for high resistivity soils are the vertical ground rods placed in LRM filled augered holes.
Table 4 summarizes earth resistance values that can be obtained with the number of LRM treated 2.4 m long rod electrodes when used either alone or arranged in parallel, spaced at least 2.4 m apart of each other and placed in a straight line. Table 5 presents the required number of LRM treated vertical rod electrodes for each specific value of soil resistivity.

Table 4: Variation of ground resistance of 2.4 m rod in augered holes of 0.1m diameter and filled with LRM

Native Soil ρ (Ω.m)	Number of Rods							
	1	2	3	4	6	8	10	12
100	28.5	16.5	12.3	9.7	7.4	6.0	5.0	4.3
200	56.7	32.9	24.4	19.3	14.6	11.9	9.9	8.5
300	84.6	49.0	36.4	28.8	21.8	17.8	14.8	12.7
500	141.5	82.9	60.9	48.1	36.5	29.7	24.8	21.2
1000	282.7	163.9	121.6	96.1	72.9	59.4	49.5	42

Table 5: Number of LRM treated rods in augered holes required for specific ground resistance in soil with ρ ≥ 100 Ω.m.

Soil Resistivity ρ (Ω.m)	Earth Resistance			
	5 Ω	10 Ω	15 Ω	25 Ω
	No. of 2.4 m long rods	No. of 2.4 m long rods	No. of 2.4 m long rods	No. of 2.4 m long rods
100	10	4	3	2
200	–	10	6	3
300	–	–	10	6
500	–	–	–	10
1000	–	–	–	24

For rocky and arid sandy terrains where the required specific resistance values cannot be obtained with 2.4 m long rods, then longer rods of either 3.6 m or 4.8 m length can be opted. Table 6 summarizes the values of resistances that can be obtained with these rods when placed in 10 cm diameter augered holes filled with LRM.

Yet, another alternative is the use of horizontal buried wire with LRM. The use of LRM on these buried grounding systems will also reduce their surge impedance by increasing the effective contact area of electrode to soil. The horizontal wire shall be buried at a depth of 0.5 m and embedded in 5 cm × 5 cm trench filled with LRM as shown in figure 11. The design engineer can select a specific electrode configuration as per the geodetic terrain, the prevailing soil resistivity, the importance of the intended site, the costs of copper rod /horizontal buried conductor and LRM.

Table 6: Number of electrodes embedded in 10 cm diameter LRM filled augered holes for specific ground resistance. Spacing between rods should be equal to length of rod.

Resistivity (ρ)	Earth Resistance							
	5 Ω		10 Ω		15 Ω		25 Ω	
	Rod Length		Rod Length		Rod Length		Rod Length	
	3.6 m	4.8 m	3.6 m	4.8 m	3.6 m	4.8 m	3.6 m	4.8 m
200	20	12	8	5	6	3	3	2
300	24	18	10	8	8	5	5	3
500	–	24	24	10	16	10	8	5
1000	–	–	–	–	–	20	20	12

4.2 PREPARATION OF LRMs

The LRM for application in 'augered holes' (Fig.10) or in trenches prepared for horizontal layout of ground wire formations (Fig.11) shall be prepared as under.

4.2.1 LRM for 'Augered Hole' (Type H_b)

To fill a 2.4 long and 10 cm diameter hole, around 20 liters of LRM is required. For longer holes, multiples can be used. To get 20 liters, the ingredients have to be prepared in two steps (X and Y). In case of 'X', take 2.5 liters of bentonite clay and mix it with 10 liters of clean water (non salty) and then add and churn 53 ml of sodium carbonate (this salt is commercially known as 'Soda Ash). Please do not use sodium chloride (the common kitchen salt) as it will spoil the bentonite. For part 'Y', take 160 ml of SAP and soak it in 6.7 liters of clean water (non salty). In about one hour SAP's granules will absorb all of this water and swell into the form of small ice cubes. For areas where the ambient temperatures are below 20 °C, it may take a bit longer than one hour. Now mix well both (X+Y) and when done, the LRM is ready for pouring in the augered hole. The rod should be placed in the middle of the hole. Inserting the rod prior to filling of hole with LRM is the better way for such cases.

4.2.2 LRM for Trenches (Type P_b)

To embed the copper wire in LRM in a 5cm x 5 cm trench, an LRM layer thickness of 5 cm is recommended. To prepare 100 liters of LRM of type '$\mathbf{P_b}$' , the ingredients have to be prepared in two steps (X and Y). For step 'X', take 15.2 liters of bentonite clay and mix it with 40 liters of clean water (non salty) to make a soft dough. Now add 320 ml of sodium carbonate and mix it well. For step 'Y', take 905 ml of SAP and soak it in 40 liters of clean water (non salty) for about one hour till it fully absorbs all of this water. Now mix well both (X+Y). LRM type $\mathbf{P_b}$ is ready for pouring in the trench. Cover the layer of LRM with a polyethylene sheet of at least 1-2 mm thickness, before refilling with the native soil. To prepare a different quantity of LRM, the same ratio of ingredients of step 'X' and 'Y' must be maintained.

For laying earth wire embedded with LRM, prepare the trench as shown in Figure 11. Spread out enough LRM uniformly in the bottom of the trench up to a thickness of 2.5 cm (1.0") and then place the horizontal wire conductor on the top of LRM. Spread more LRM to completely cover conductor about 2.5 cm thick. Preferably use ground staples to maintain wire conductor in the center of the LRM filling. Pour some soil in the trench at the top of the LRM and gently tamp it down. Now fill the rest of the trench.

<u>Important Notes:</u>

(a) Do not use salty water as it will spoil the bentonite clay for producing LRM. Clean water with conductivity < 500 μS/cm (micro Siemens/centimeter) is recommended.
(b) For preparation of smaller quantities of LRM, plastic mixing tubs or wheel borrow, and for larger quantities cement mixer can be used.
(c) Never indigest the granules of SAP.

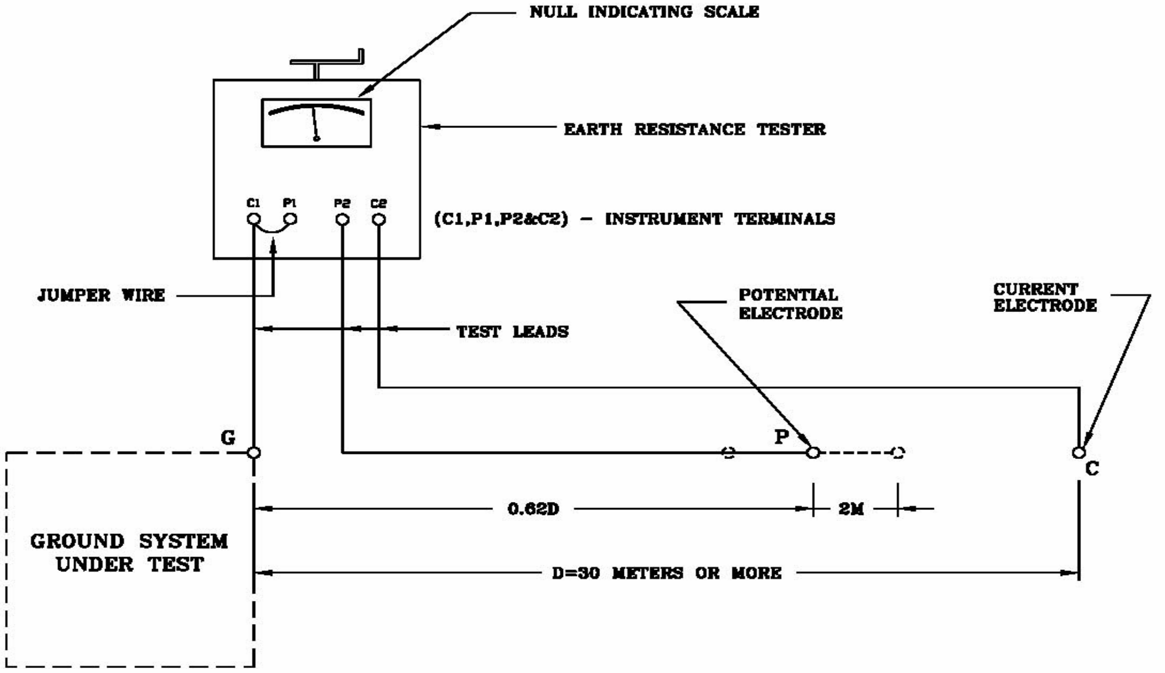


FIGURE – 1

ELECTRODES ARRANGEMENT – MEASUREMENT OF GROUND RESISTANCE (FALL OF POTENTIAL METHOD)

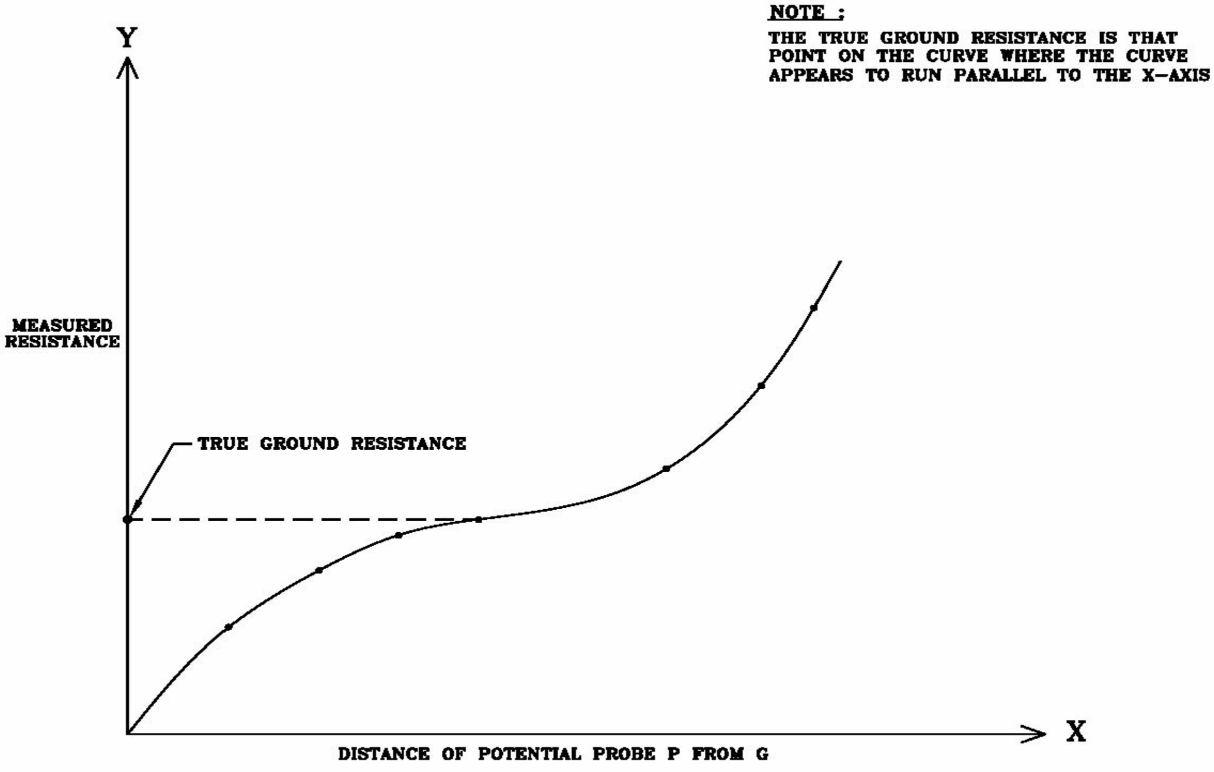


FIGURE – 2

GROUND RESISTANCE MEASUREMENT CURVE

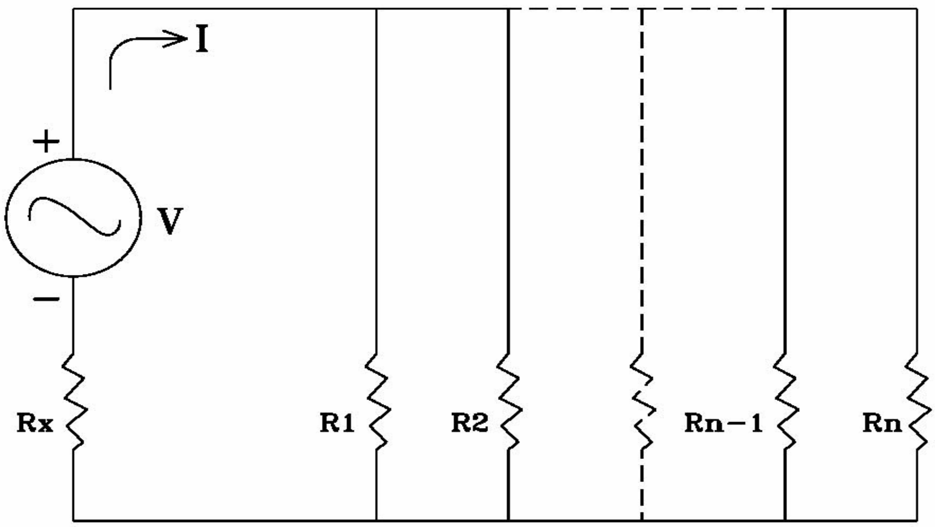


FIGURE – 3

MEASUREMENT OF GROUND RESISTANCE WITH CLAMP ON METER

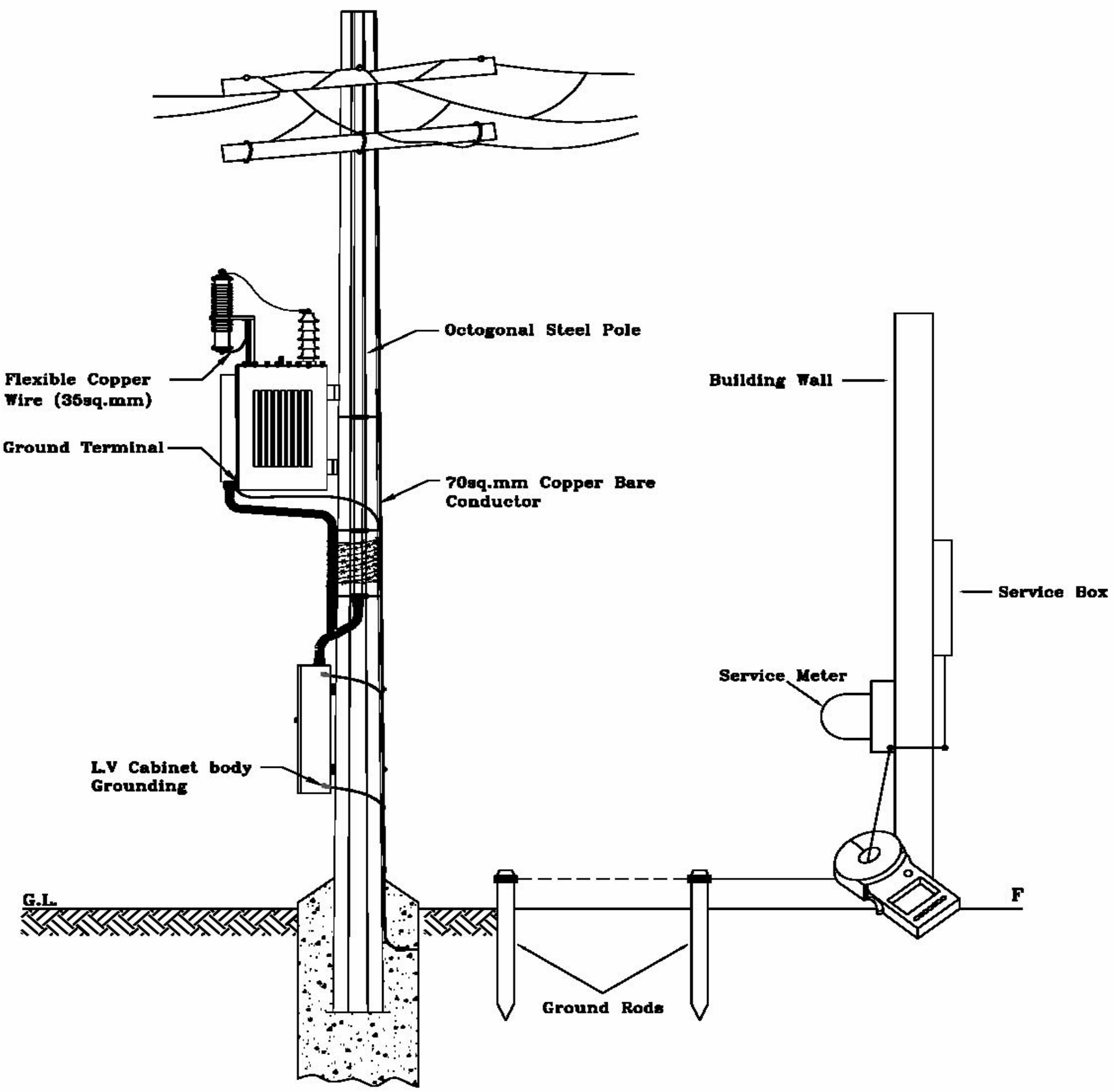


FIGURE – 4

MEASUREMENT OF GROUND RESISTANCE FOR SERVICE METER

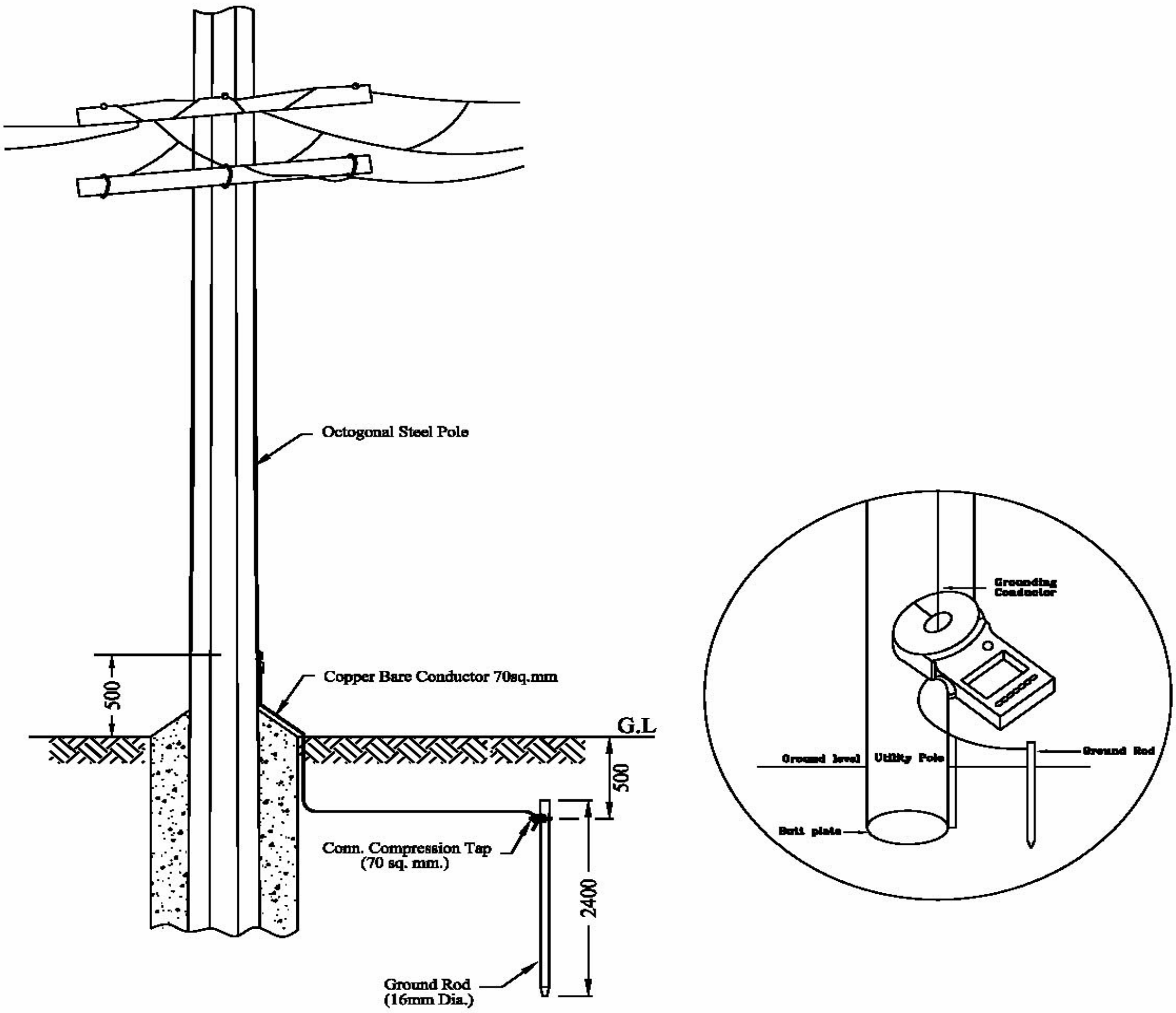


FIGURE – 5

GROUND RESISTANCE MEASUREMENT FOR A LINE POLE & PMT

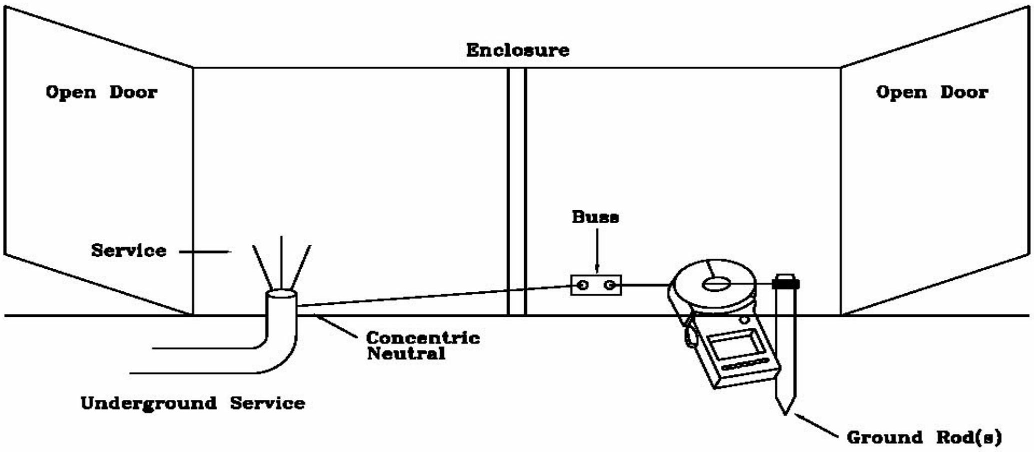


FIGURE – 6

GROUND RESISTANCE MEASUREMENT FOR A DISTRIBUTION CABINET

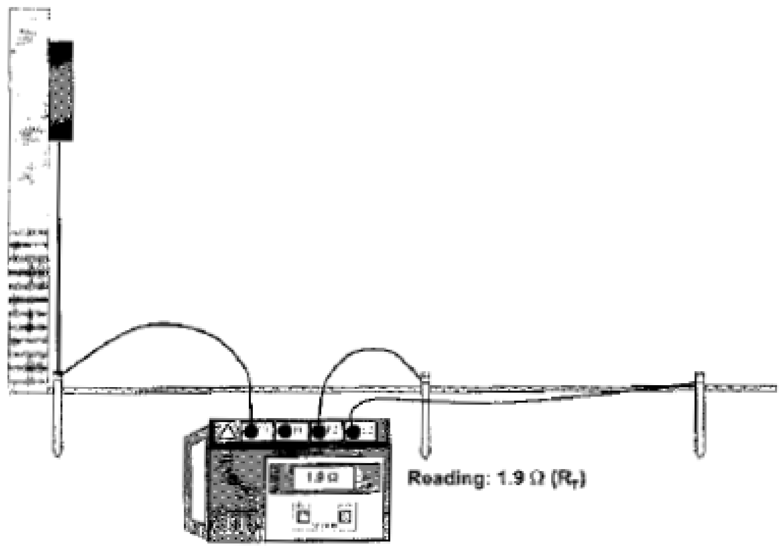


Figure-7: Ground Resistance measurements

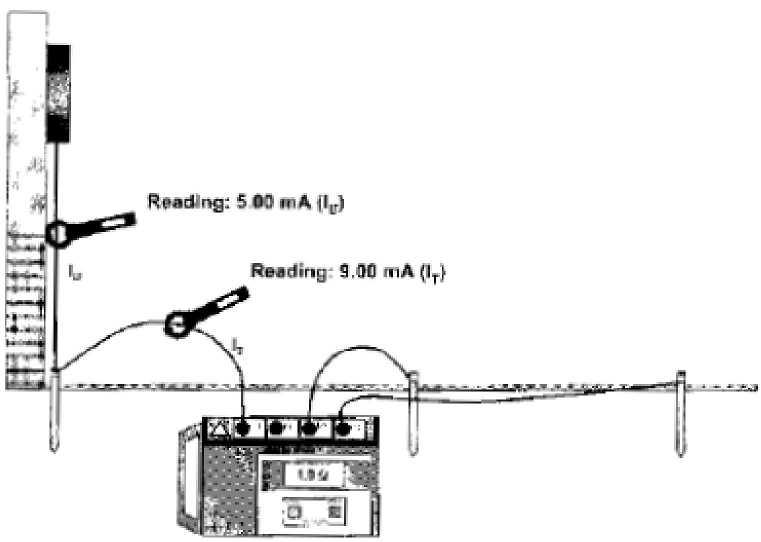


Figure-8: Leakage Current Meaurement

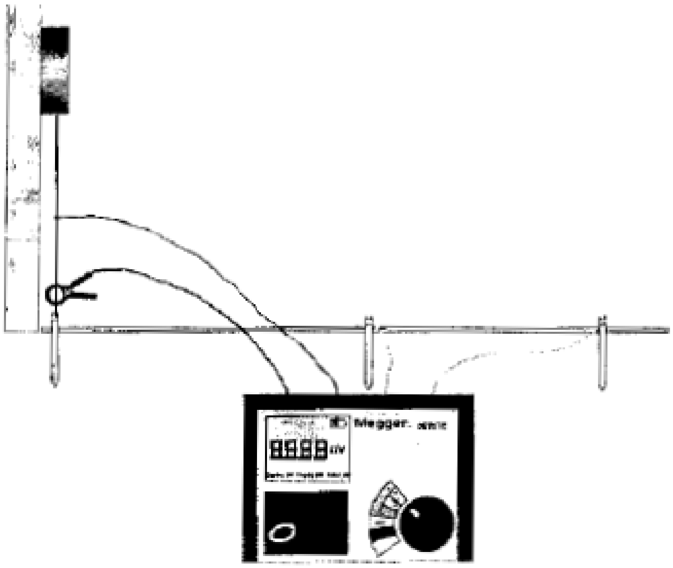
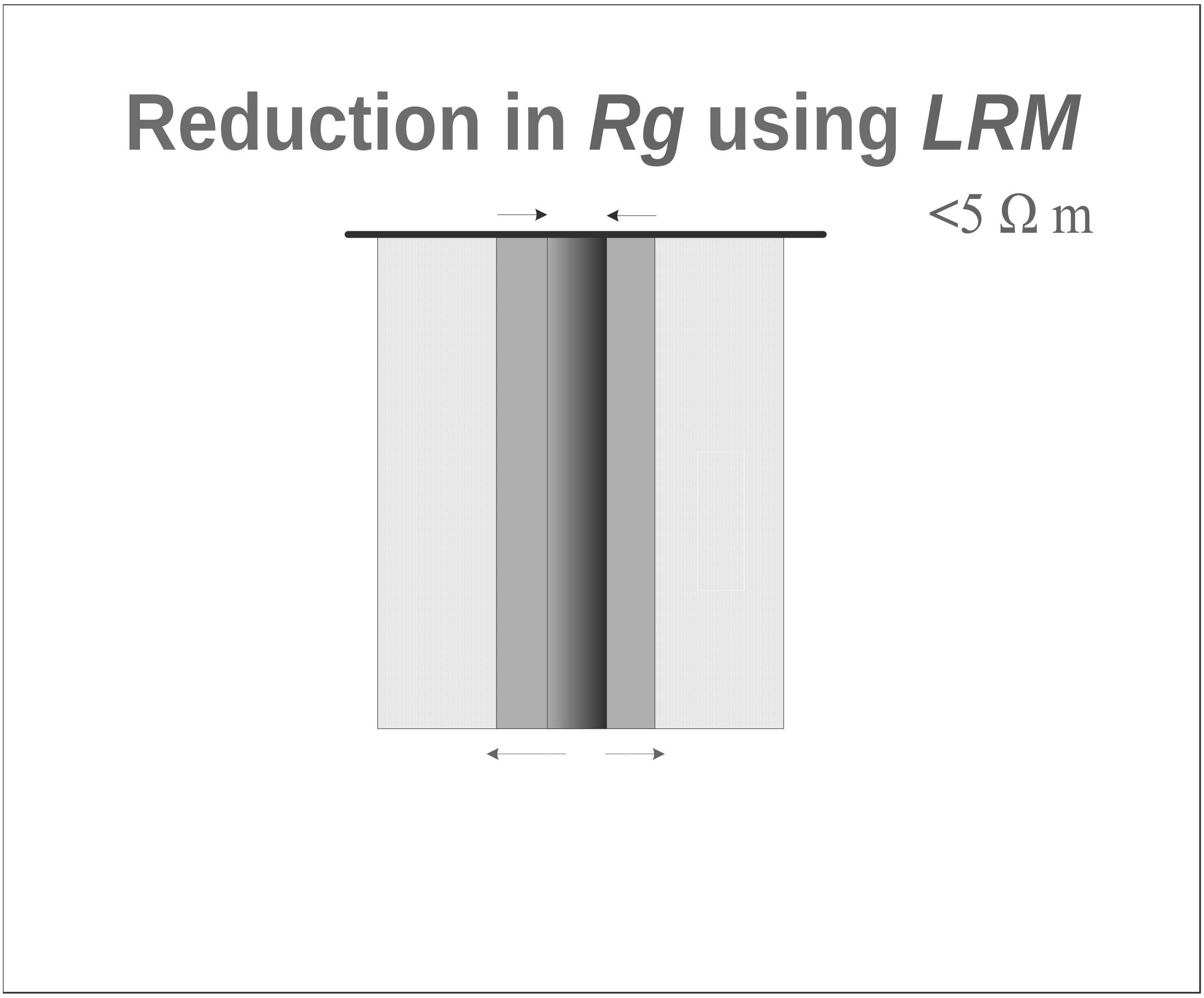


Figure-9: **Attached Rod Technique measurement.**



r- Radius of the ground rod
L- Length of the ground rod
D- Bore diameter

FIGURE – 10: LRM for 'Augered Hole' (Type H_b)

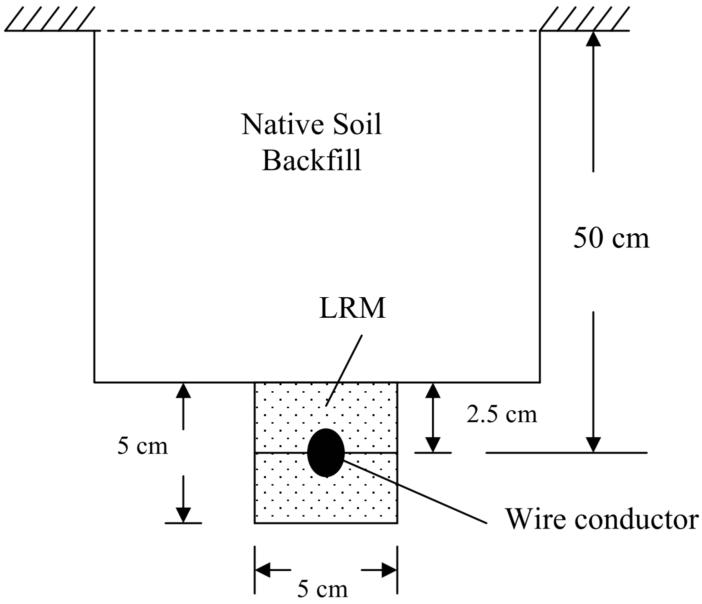


Figure-11: Preparation of trench for LRM embedded horizontal wire conductor