Substation Engineering

Earthing Systems (IS 3043) (Part 2 of 3)

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Earthing Systems (IS 3043) (Part 2)

- Substation Earthing System
- Soil Resistivity & Earth Resistance Measurement

Lecture Agenda

- Concept of Soil Resistivity (ρ)
- Factors Affecting Soil Resistivity
- Wenner 4-Pin Method for Soil Resistivity
- Earth Resistance vs Soil Resistivity
- Acceptable Limits of Earth Resistance
- Measurement of Earth Resistance
- Fall of Potential Method and the 61.8% Rule

What is Soil Resistivity?

- Soil Resistivity (ρ) is a measure of how much the soil resists the flow of electricity.
- It is the resistance of a cube of soil of unit dimensions (1 meter x 1 meter x 1 meter).
- Unit: Ohm-meters (Ω·m).
- It is a key variable in designing any substation earthing grid; you cannot design an earth grid without knowing this value.

Importance in Earthing Design

- Determines the size, spacing, and burial depth of the earth grid conductors.
- Affects the Step and Touch potentials (which we cover in Part 3).
- High soil resistivity requires more extensive and expensive earthing networks (more electrodes, longer trenches).
- Soil resistivity varies wildly from place to place and even at different depths in the same location.

Factors Affecting Soil Resistivity: Moisture & Temp

- Moisture Content: Dry soil has high resistivity. Adding moisture drastically lowers resistivity up to about 20% moisture content.
- Temperature: Resistivity increases as temperature drops. If soil freezes (drops below 0°C), resistivity spikes dramatically.
- This is why earth electrodes must be buried deep enough to be below the frost line and reach permanent moisture.

Factors Affecting Soil Resistivity: Soil Type & Salts

- Type of Soil: Loam, clay, and marshy soils have low resistivity (10-50 Ω·m). Sandy and rocky soils have high resistivity (1000+ Ω·m).
- Chemical Composition (Salts): Pure water is a poor conductor. The presence of dissolved salts provides ions for current flow.
- Artificial Treatment: IS 3043 recommends treating soil with salt (NaCl), magnesium sulfate, or copper sulfate if natural resistivity is too high.

Measuring Soil Resistivity

- To design an earthing system, the designer needs a soil resistivity profile of the site.
- Measurements must be taken at multiple locations across the substation site.
- Measurements should reflect conditions at different depths.
- The standard method endorsed by IEEE 80 and IS 3043 is the Wenner 4-Pin Method.

Wenner 4-Pin Method

- Four test spikes (electrodes) are driven into the ground in a straight line at equal spacing 'a'.
- An earth tester injects a known current (I) between the two outer current spikes (C1, C2).
- The voltage drop (V) is measured between the two inner potential spikes (P1, P2).
- The tester calculates the resistance $R = V/I$.

Diagram/Visual: Diagram of four pins labeled C1, P1, P2, C2 with spacing 'a'. Current loops going deep into the earth.

Wenner Method Formula

- The apparent soil resistivity (ρ) is calculated as:
- $\rho = 2$ * π * a * R
- Where:
- $\rho =$ Apparent soil resistivity in Ohm-meters
- a $=$ Distance between adjacent spikes in meters
- R $=$ Resistance value read from the earth tester in Ohms
- Note: The depth of the spikes (b) should be small compared to 'a' (usually b ¡ a/20) so it can be ignored.

Earth Resistance vs Soil Resistivity

- Soil Resistivity (ρ): A property of the earth itself. Measured before the substation is built. Used to design the grid.
- Earth Resistance (R): The resistance of the installed electrode/grid to the earth. Measured after installation to verify the design.
- Objective: Design an electrode system in soil of resistivity ρ such that the final Earth Resistance R meets the required safety limits.

Acceptable Limits of Earth Resistance

Installation Type	Maximum Acceptable Resistance
Large Power Stations	0.5 Ohms
Major Substations (Grid)	1.0 Ohms
Small Substations	2.0 Ohms
Industrial Plant	1.0 Ohms
Domestic Installation	5.0 - 8.0 Ohms

Measurement of Earth Resistance

- Once an electrode (or grid) is installed, its resistance to the general mass of earth must be tested.
- Requires measuring the voltage drop and current flow through the electrode.
- The standard method used is the Fall of Potential Method (also known as the 3-terminal method).
- Uses an Earth Megger (Earth Tester).

Fall of Potential Method

- The electrode under test is terminal 'E'.
- A current spike 'C' is driven far away from 'E'. Current I is passed between E and C.
- A potential spike 'P' is driven between E and C. Voltage V is measured between E and P.
- Resistance R = V / I.
- The potential spike 'P' is moved to different positions to find the true resistance.

Diagram/Visual: Diagram showing the Earth electrode E, Potential probe P, and Current probe C. E, P, and C are in a straight line.

Fall of Potential: Procedure and Curve

- Plot resistance values on the Y-axis and distance of probe 'P' on the X-axis.
- Near 'E', the resistance rises steeply (influence zone of electrode E).
- Near 'C', the resistance rises steeply again (influence zone of spike C).
- In the middle, there should be a flat section (the 'plateau').
- The true earth resistance is the value at this flat plateau.

The 61.8% Rule

- Finding the plateau can be tedious.
- Mathematical analysis shows that for a hemispherical electrode, the true resistance occurs when the potential probe 'P' is placed at exactly 61.8% of the distance to the current probe 'C'.
- If distance to C is D, place P at 0.618 * D.
- This is widely used in field testing to get a quick and accurate reading.

Practical Challenges in Measurement

- Stray Currents: Underground pipes, railway tracks, and existing grid currents can interfere with the earth tester readings.
- Large Grid Sizes: For a large substation, the current probe 'C' must be placed very far away (up to 5-10 times the diagonal of the grid) to get a true plateau. Finding space for this is hard.
- Test Frequency: Testers use AC (e.g., 128 Hz) rather than 50 Hz to avoid interference from the power system frequency.

Summary of Lecture 27

- Soil resistivity is critical for design and depends heavily on moisture, temp, and soil type.
- Wenner 4-pin method is standard for measuring soil resistivity ($\rho = 2\pi$aR).
- Earth resistance must be ¡ 1 Ohm for major substations.
- Fall of Potential method (3-pin) is used to measure installed earth resistance.
- The 61.8% rule simplifies finding the true resistance on the Fall of Potential curve.

Next Lecture Preview

- In Part 3, we will cover:
- Substation Earth Grid (Mat) design.
- Tolerable limits of body current.
- Understanding Step Potential and Touch Potential.
- Design considerations based on IEEE 80 / IS 3043.