Substation Engineering

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

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Earthing Systems (IS 3043) (Part 3)

- Substation Earthing System
- Earth Grid Design, Step & Touch Potentials

Lecture Agenda

- The Substation Earth Grid (Earth Mat)
- Ground Potential Rise (GPR)
- Human Body Limits to Electric Current
- Understanding Step Potential
- Understanding Touch Potential
- Mesh and Transferred Potentials
- Earth Grid Design Steps (IEEE 80 / IS 3043)
- Safety Enhancements (Crushed Rock, Rods)

The Substation Earth Grid (Earth Mat)

- In large substations, isolated earth pits (pipes/plates) cannot handle massive fault currents (e.g., 40 kA to 60 kA).
- Instead, a network of bare conductors is buried in a crisscross pattern over the entire substation area.
- This is called an Earth Grid or Earth Mat.
- Equipment is connected to this mat via multiple risers.
- Buried typically at 0.5m to 1.0m depth.

Ground Potential Rise (GPR)

- During a severe earth fault, thousands of amperes flow into the earth mat.
- Ohm's Law applies: $V = I * R$.
- GPR = (Maximum Grid Current) * (Grid Resistance).
- If grid current = 10,000 A and Grid Resistance = 0.5 Ohms, the voltage of the grid (and everything connected to it) rises to 5,000 Volts above remote earth.
- This voltage rise creates life-threatening gradients on the surface.

Human Body Resistance & Limits

- For earthing calculations, the human body resistance is standardized at 1000 Ohms.
- Currents above 50-100 mA can cause ventricular fibrillation (fatal disruption of heart rhythm).
- Tolerable body current depends on fault duration (clearing time).
- Faster relay operation means higher tolerable current limits.
- Formula (50kg body): $I\_B = 0.116 / sqrt(t)$, where t is fault clearing time in seconds.

Step Potential

- Definition: The voltage difference between a person's two feet while standing 1 meter apart on the ground during a fault.
- As current flows through the earth, voltage drops occur across the soil.
- If a person steps across this voltage gradient, a current path forms up one leg and down the other.
- Current bypasses the vital organs, but can cause violent muscle contraction.

Diagram/Visual: Diagram of a person walking near a fault. Equipotential lines on the ground show different voltages under each foot. Current loops up one leg and down the other.

Touch Potential

- Definition: The voltage difference between the ground where a person is standing and the grounded metallic structure they are touching.
- Current path: Enters via the hand, flows through the heart region, and exits via the feet.
- Highly dangerous and often fatal if limits are exceeded.
- Grid must be designed so Actual Touch Potential ¡ Tolerable Touch Potential.

Diagram/Visual: Diagram of a person touching a transformer tank. Current flows from the tank, through the hand, heart, out the feet into the ground.

Mesh and Transferred Potentials

- Mesh Potential: The maximum touch voltage within a mesh of the grid. Occurs at the center of the grid square, furthest from any buried conductor.
- Transferred Potential: A special case of touch potential where a voltage is transferred into or out of the substation by an external conductor (e.g., a railway track, communication cable, or neutral wire).
- Transferred potentials can subject distant personnel to the full Ground Potential Rise of the substation.

Designing the Earth Grid: IEEE 80 / IS 3043

- The standard for earth grid design globally is IEEE 80. IS 3043 incorporates these principles.
- Goal 1: Ensure Grid Resistance is low enough.
- Goal 2: Ensure Step and Touch potentials are within safe limits.
- Design is an iterative process: guess a layout, calculate potentials, check if safe. If not, add more conductors.

Earth Mat Design Steps

- 1. Collect Field Data: Soil resistivity (ρ), Fault current (If), Fault duration (tc).
- 2. Calculate Conductor Size: Based on thermal limits to withstand short circuit current.
- 3. Calculate Tolerable Limits: E_step and E_touch for 50kg/70kg body.
- 4. Initial Design: Lay out a grid with spacing D, depth h, total length L.
- 5. Calculate Grid Resistance (R).
- 6. Calculate Actual Mesh and Step Potentials.
- 7. Verify: Actual ¡ Tolerable. If so, design is safe.

Conductor Sizing

- The grid conductor (usually Mild Steel or Copper) must not melt during the fault.
- Size depends on:
- - Maximum RMS fault current.
- - Fault clearing time.
- - Maximum allowable temperature (e.g., 500°C for welded joints).
- Formula relies on the specific heat and thermal conductivity of the material.

Improving Safety: Crushed Rock Layer

- Substation yards are covered with a 10-15 cm layer of crushed rock (gravel).
- Why?
- High Surface Resistivity: Dry rock has a resistivity of ˜3000 Ω·m.
- It acts as a high-resistance layer under the feet of personnel.
- This drastically increases the contact resistance of the feet, thereby increasing the Tolerable Step and Touch potential limits.

Use of Earth Rods in Grid Design

- A purely horizontal grid might not reach deep, low-resistivity soil layers.
- Vertical earth rods (pipes/rods) are welded to the grid at the perimeter and key interior points.
- Benefits:
- - Lowers overall grid resistance (reaches moisture).
- - Prevents surface freezing from ruining grid performance.
- - Discharges lightning and steep-front surges effectively.

Grid Spacing Optimization

- Mesh spacing is not always uniform.
- Voltage gradients are steepest at the edges and corners of the grid.
- To economize on copper/steel, engineers use unequally spaced grids.
- Meshes are closely spaced at the perimeter (e.g., 1m x 1m) and widely spaced in the center (e.g., 5m x 5m).

Comparison of Mitigation Methods

Problem	Mitigation Technique	Effect
High Grid Resistance	Add vertical rods / treat soil	Lowers R, lowers GPR
High Step Potential	Decrease mesh spacing / add gravel	Smooths gradient, increases foot resistance
High Touch Potential	Tighter mesh near equipment	Reduces voltage diff between mat and soil
Transferred Potential	Isolate fences / use fiber optics	Prevents voltage export

Summary of Substation Earthing

- Earthing grids distribute high fault currents over a large area.
- Ground Potential Rise (GPR) creates dangerous surface voltage gradients.
- Step and Touch potentials dictate human survival during faults.
- IEEE 80 / IS 3043 provide the iterative steps for safe mat design.
- Gravel surfacing is a critical safety component in substations.

Next Unit Preview: Compensation Equipment

- Next, we begin Unit 6: Reactive Power Compensation.
- Why do we need compensation in power systems?
- Shunt Capacitors for power factor improvement.
- Series Capacitors for line reactance compensation.