Earth Electrode System
Design

Presented by
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Design Manager – Technical Services
Who are A N Wallis & Company Ltd?

• **Then**

• **Now**
Technical Services we offer:-

• Initial Design Consultancy
• Soil Resistivity Testing
• Full System Design to National & International standards
• Manufacture & Supply fully compliant, high quality materials
• Support installers with product training
• Installation verification inspections
• Overall system testing
• Ongoing system testing and maintenance
• Retrospective design and surveying
Other Services:-

- Surge Protection specification, design, manufacture & supply
- Power, Data, DC, RF etc
Other Services:-

• Lightning Protection specification, design, manufacture & supply
Simon Sorsby GCGI CEng MIET - Design Manager

• Originally trained with the UK MoD
• Systems Engineer for BAE Systems
• Field Engineer for Weatherford
• Senior Engineer, then Contracts Manager for UK’s largest Earthing & Lightning Protection installer.
• Primary System Design Engineer for Western Power Distribution
• Senior Electrical Engineer for Energetics Networked Energy
• Member of the BSI PEL99 Committee (BS EN 50522)
Health & Safety

• **NEVER** approach a lightning protection system or earth electrode system when there is a risk of Lightning.

• **NEVER** approach an earth electrode system when a switching event is likely to take place.

• **NEVER** break ground until you are sure the area is clear of buried services.
Health & Safety

• Earth systems are not inert and can, in *certain circumstances*, be as dangerous as a live conductor.

• **NEVER** disconnect an earth system, unless you are trained, competent and authorised to do so.

_An earthing system should be treated as you would any other part of the electrical system._
IF IN DOUBT – ASK!
LV Earthing – Applicable Standards

• **BS 7671:2018** – Requirements for Electrical Installations (18th Edition IET Wiring Regulations)
• **BS 7671:2018 Guidance Note 8** – Earthing & Bonding
Applicable Standards

- BS EN 50522:2010 – Earthing of power installations exceeding 1kV a.c.
- BS EN 13601:2013 – Copper and copper alloys – Copper rod, bar and wire for general electrical purposes.
Applicable Standards

• Energy Networks Association Engineering Recommendation S34 – A guide for assessing the Rise of Earth Potential at Substation sites
• Any other local or industry specific standard
Applicable Standards

- IEEE80-2013 – Guide for safety in AC Substation Grounding
- IEEE81-2012 – Guide for measuring earth resistivity, ground impedance, and earth surface potentials of a grounding system.
Identify the requirement and to which standard or specification you are working to.

Attend site and carry out a soil resistivity survey, *(the survey max spacing should generally match the size of the proposed system)*

Analyze the soil survey data using CDEGS RESAP Software and produce a representative soil model for the site.

Compare the soil model to local geology data.

Is the soil model representative?

Collate Electrical system fault current data inc 3ph symmetrical, 1ph to earth, duration, etc.

Determine connection to feeder substation:
- OHL fed 100% fault current to earth,
- Underground cable/OHL mix 100% fault current to earth
- Underground cable fed (no Cable sheath gaps) % split cable sheath/earth electrode system

Carry out layout design of the earth electrode system and analyze using CDEGS software.

Are the Touch, Step and RoEP potentials < permissible values?

Complete Design report & drawings, issue for approval.
The <1Ω Theory

• <1Ω may be applicable, but the driving factor is ‘Is the site safe and suitable’?
• Historic figure used when lead sheathed cables, etc were more prevalent.
• Fault currents tend to be higher with low loss distribution transformers and distributed generation.
The <1Ω Theory

- Extract from ENA TS 41-21 Iss2

‘For ground-mounted substations, traditional custom and practice (permitted by previous versions of this TS) was to apply a target resistance (before connection to the network) of 1Ω (including contributions from the wider network). If this could be achieved, it was permissible to combine the HV and LV earthing systems. No perimeter or grading electrodes were installed in such legacy systems, and often only one vertical rod or horizontal electrode would be installed. This approach relied heavily on contributions from lead-sheathed cables radiating away from the substation, often passing under the operator’s position. These cables provided a degree of potential grading (thus reducing touch potentials) as well as reducing the overall (combined) earth resistance of the substation. Experience has shown that this approach is no longer applicable, particularly given the now widespread use of insulated sheath cables.’
Soil Resistivity

• Soil resistivity is a measure of how much the soil resists the flow of electricity.
• Measured in Ohm-metres (Ω·m)
• Varies with local geology
• Measured using the Wenner method
• Can also be measured using the Schlumberger method (not preferred due to lack of accuracy)
• Standard separation distances (BS EN 50522)
Soil Resistivity

\[ R = \frac{V}{I} \]

\[ \rho = 2\pi a R \]
# Soil Resistivity

## Typical Values

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Soil Resistivity $\rho_E$ (Ω-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marshy soil</td>
<td>5 to 40</td>
</tr>
<tr>
<td>Loam, clay, humus</td>
<td>20 to 200</td>
</tr>
<tr>
<td>Sand</td>
<td>200 to 2,500</td>
</tr>
<tr>
<td>Gravel</td>
<td>2,000 to 3,000</td>
</tr>
<tr>
<td>Weathered Rock</td>
<td>Mostly below 1,000</td>
</tr>
<tr>
<td>Sandstone</td>
<td>2,000 to 3,000</td>
</tr>
<tr>
<td>Granite</td>
<td>Up to 50,000</td>
</tr>
</tbody>
</table>

Data extracted from BS EN 50522:2010
Fault level data

• If cable fed, a percentage of the earth fault will travel to the feeder substation via the cable sheath/armour.
• 3 phase symmetrical fault current used to determine conductor size (ENA TS 41-24/BS EN 60909-3)
• Fault clearance time from Electricity Supply Company to determine Touch, Step and Rise of Earth Potential (RoEP/EPR/GPR) limits.
Conductor size

BS EN 60909-3:2010
– Short circuit currents in three-phase a.c. systems

*Earth conductor size usually matched to the HV/MV switchgear short time withstand rating (3s)*
Conductor size

- In the UK various standards exist, use the most onerous.
- Various data to determine the required conductor size
  Conductor material
  Starting temperature
  Maximum allowable temperature rise
  Fault current
  Conductor jointing methodology
  Fault duration

BS 7430 Table 4 gives guidance
Conductor size

Current rating calculation of earthing conductors and earth electrodes based on Annex D of BS EN 50522:2010

<table>
<thead>
<tr>
<th>Material of conductor</th>
<th>β (°C)</th>
<th>K (Amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>234.5</td>
<td>226</td>
</tr>
<tr>
<td>Aluminium</td>
<td>228</td>
<td>148</td>
</tr>
<tr>
<td>Steel</td>
<td>202</td>
<td>78</td>
</tr>
</tbody>
</table>

\[ A = \frac{I}{K} \sqrt{\frac{\tau_f}{\ln(\frac{\Theta_f + \beta}{\Theta_i + \beta})}} \]

Conductor current in amperes (RMS Value) I = 31500 A

Material constant K = 226

Fault duration \( \tau_f = 3 \) s

Initial temperature \( \Theta_i = 30^\circ\)C

Final temperature \( \Theta_f = 250^\circ\)C

Constant from table above \( \beta = 234.5^\circ\)C

Minimum conductor cross sectional area (Spur - 100% rating) \( A = 310.3 \text{ mm}^2 \)

Minimum conductor cross sectional area (Parallel - 60% rating) \( A = 186.2 \text{ mm}^2 \)

In this case the next standard conductor size up would be 400mm² copper cable or 50x6.3mm copper tape
Conductor size

- 100% rating to items of HV plant or equipment or single spur connections where full fault current may be seen.

- 60% rating where a conductor loop may be formed such as the main earth electrode system.
System Design

• Ring conductor around all HV equipment to protect personnel from Touch potentials
• Two fully rated connections between the earth system and all HV plant, earth bars etc. to allow redundancy.
• Determine what area is available for the installation of the earth electrode system.
• Copper, copper bond earth rods or stainless steel are commonly installed in the ground
• Maximum earth rod depth is determined by local geology, usually 4.8m
System Design

• Determine perimeter fence type or otherwise, (metallic fences must be considered either independently earthed or as part of the main earth system)

• Remaining area of the site to be divided up in a mesh of conductor tape to lower earth resistance, also may be utilised as a grading electrode to limit Step potentials.

• All extraneous metalwork within the site is to be equipotentially bonded to the main earth system.

• Earth conductor to be installed 500mm to 1000mm below finished ground level
System Design

Main transformer surrounded with conductor

Main transformer surrounded with conductor

Other equipment surrounded to limit Touch potential issues

Bonds across door/gate hinges to main equipotential connections
System Design
Determine % of fault current that flow to the earth electrode system ($I_{gr}$) and % of that current that will flow back to the feeder substation via the feeder cable sheath ($I_{sr}$)
System Design

33/11kV Primary Substation

% Fault current ($I_f$)

Flow of power

Cable screen

% Fault current ($I_f$)

11/0.4kV Secondary Substation
System Design
Earth fault current

- Only a percentage of the earth fault current will go to ground via the earth network.
- A percentage will travel to the source via the cable sheath.
- $I_{gr}$ required to calculate the Rise of Earth Touch & Step Potentials.
- Fault clearance time required to calculate acceptable Touch and Step potentials.
Earth fault current
Earth fault current
Analysis Software

• CDEGS (Current Distribution, Electromagnetic Interference, Grounding and Soil Structure Analysis) (SES Technologies, Canada)
• RESAP - Soil Resistivity Analysis
• MALT - Low Frequency Grounding/Earthing Analysis
• MALZ - Frequency Domain Grounding/Earthing Analysis
• FCDIST - Simplified Fault Current Distribution Analysis
• UK Standard software
• Only software accepted by National Grid and Western Power Distribution
Earth Potential Rise

‘Earth Potential Rise’ (EPR) also called Ground Potential Rise (GPR) or Rise of Earth Potential (RoEP) occurs when a large current flows to earth through an earth grid impedance.

The potential relative to a distant point on the Earth is highest at the point where current enters the ground, and declines with distance from the source.
Earth Potential Rise

LEGEND
MAXIMUM VALUE: 11746.51
MINIMUM VALUE: 1485.775
Level 13 (11666.7 )
Level 12 (10833.3 )
Level 11 (10000.0 )
Level 10 (9166.67 )
Level 9 (8333.33 )
Level 8 (7500.00 )
Level 7 (6666.67 )
Level 6 (5833.33 )
Level 5 (5000.00 )
Level 4 (4166.67 )
Level 3 (3333.33 )
Level 2 (2500.00 )
Level 1 (1666.67 )

Potential Profile Magnitude (Volts)
Earth Potential Rise
To combine or not?

• Always better to segregate HV & LV Earths
• Not possible with modern integral substations or where LV supplies enter or leave the sub
• Separation distance dependant on fault levels and ground resistivity (usually 25m approx.)
• Requirements for a combined system
  • RoEP <1,200V (maybe lower due to local regulations)
  • Fault clearance time of <5 seconds
  • See BS EN 50522 Table 2 for full parameters
To combine or not?

- 5000V
- 3750V
- 1200V

- 11kV RMU
- 11/0.4kV Transformer

- Installation with local LV earthing or Lightning Protection
Touch Potential

‘Touch potential’ is the potential difference between the energized object and the feet of a person in contact with the object. It is equal to the difference in voltage between the object and a point some distance away (1m).
Touch Potential

High soil resistivity = high voltage from tower to ground surface

Ground Network
Figure NA.2 – Permissible touch voltages with additional resistances

NOTE 1 Tolerable touch voltage without additional resistances as Figure NA.1 (Left hand to both feet)
NOTE 2 \( R_1 = 2150 \Omega \) (Footwear resistance: 4 kΩ, earth foot resistance of 300 Ω based on \( \rho_e = 100 \Omega \).
NOTE 3 \( R_2 = 2000 \Omega \) (Footwear resistance: 4 kΩ, effective chippings resistance 1000 Ω per foot based on 75 mm chippings thickness).
NOTE 4 \( R_3 = 3000 \Omega \) (Footwear resistance: 4 kΩ, effective chippings resistance 2000 Ω per foot based on 150 mm chippings thickness.)
Touch Potential
Step Potential

‘Step potential’ is the potential difference between the feet of a person standing near an energized grounded object.

It is equal to the difference in voltage, given by the voltage distribution curve, between two points at different distances from the "electrode".

A person could be at risk of injury during a fault simply by standing near the grounding point.
Step Potential

[Diagram showing electrical components and concepts related to step potential, including fault duration, current, surface layer thickness,电阻ivity, and ground network.]
Step Potential
Installation

• It is vital that the earth electrode system is installed as designed, variance from the design can lead to the presence of dangerous touch and step potentials.
• Records should be taken of where conductor joints are and the resistance of each joint recorded.
• Earth rods should be installed away from any buried services etc.
• HSG47 should be followed at all times.
Joint Testing

- Measured using a 10A Micro Ohmmeter such as the Megger DLRO10 series of meters
- Welded or brazed joints should have a similar resistance to an unbroken conductor of a similar length
- A brazed/welded joint should be $\approx 50\mu\text{A}$
- A bolted/clamped joint should be $\approx 20\text{m\Omega}$
System Testing
BS 7430 section 10.1

c) *Personal protective equipment.* Introducing earth electrodes (extraneous-conductive-parts) into an otherwise bonded earthing arrangement can result in high touch voltages. Consequently appropriate insulated footwear, fire-retardant clothing and insulated gloves (7.5 kV) should be worn during testing.
Questions?
Thank you for your time