Combined HV-LV earthing of substations in the built environment

Dr Tony Sung* CEng FCIBSE,
Lindsay Moody CEng MCIBSE
* Corresponding Author
CIBSE Electrical Services Group
tony.sung@dr-tonysung.com
Aim and Objectives

• Requirements of a safety earthing system.
• Earthing Standards - BS and BSEN.
• Review of Earthing system design parameters.
• Soil resistivity and Earthing resistance.
• 0.6Ω and 2Ω examples.
• Conclusion - 1Ω earth is no longer acceptable without calculation.
Requirements of a Safety Earthing System

Protection for safety:
1. to comply the legislative requirements: e.g., Electricity Safety, Quality and Continuity Regulations and Electricity at Work Regulations

2. to satisfy the safety criteria for BS EN 50522 and BS7430
   - Earth Potential Rise (EPR)
   - Stress Voltage - for equipment at/in near vicinity of the substation in built environment
   - Step Voltage - protect people at/in near vicinity of the substation in built environment
   - Touch Voltage - for people at/in near vicinity of the substation in the built environment
there is more to safety earthing

• To provide safety to personnel during normal and fault conditions by limiting step and touch voltages.
• Limit the stress voltage to prevent damage to electrical and sensitive electronic equipment.
• To dissipate the energy from direct or indirect lightning strikes.
• To provide a low impedance path to carry electric currents into the earthed metalwork under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting the continuity of services.
• To provide a reference earth for equipment to work correctly.
Design Standards

• National Engineering Specifications (NES) states:
  – BS EN 50522 - Earthing of power installations exceeding 1 kV a.c.
  – BS 7430 - Code of Practice for Earthing
  – BS7671 - Requirements for Electrical Installations
Other Design Standards

- Energy Networks Associations
  - TS 41-24:Issue 1 ‘Guidelines for the design, installation, testing and maintenance of main earthing systems in substations’
  - ER S34 Engineering Recommendation, ‘A guide for assessing the ROEP at substation sites’
  - ER P25 ‘The short-circuit characteristics of Public Electricity Suppliers low voltage’
Review of earthing design parameters

Earth Potential Rise (EPR) $U_E$ is the difference in voltage rise between an earthing system and the remote reference earth (normally - the true earth).

The electrical resistivity of soil $\rho_E$ is sometimes called apparent resistivity. It is measured in $\Omega$-m.

Overall earth resistance (in $\Omega$) of the earthing system $R_E$.

Power frequency stress voltage $U_2$ the difference in voltage rise appearing in Class 1 equipment between exposed-conductive-parts and any of its line conductors during earth fault conditions.
Combined HV-LV Earthing of substations

Source: BS EN 50522
Maximum Earth Fault current

• National Engineering Specifications (NES) states that "Calculation of earth fault currents ($I_E$) including the associated zero sequence impedance diagram".

• ENA ER S34 ‘A guide for assessing the ROEP at substation sites’ gives examples in how to use $I_E$ and the earthing resistance to calculate voltage potential differences at the ground surface for different earth electrode configurations.
Ground surface potential differences

- $U_E$
- Touch Voltage
- Step Voltage
Soil Electrical Resistivity

• National Engineering Specifications (NES) states that the substations soil electrical resistivity should be surveyed and tested and a minimum of a two-layer model for apparent resistivity be generated prior to the design and installation being carried out.

• Method of measurements - Wenner's 4-rods method
A multi-layer soil model is normally derived from a set of measure apparent soil resistivity values.
Earthing Resistance

The earthing resistance of an earth nest is normally made up of a number of parallel earth rods.

**Rod electrode**

The resistance of a rod $R_r$ in ohms ($\Omega$) may be calculated from:

$$R_r = \frac{\rho}{2\pi L} \left[ \log_e \left( \frac{8L}{d} \right) - 1 \right]$$

where:

- $\rho$ is the resistivity of soil, in ohm metres ($\Omega$m);
- $L$ is the length of the electrode, in metres (m);
- $d$ is the diameter of the rod, in metres (m).

Source: BS7430
Stress Voltage (TN-S)

Source: BS7430

\[ U_E = I_E \times R_E \]

Slide 14, 16/4/2015
Stress Voltage (TN-C-S)

Source: BS7430

\[ U_E = I_E \times R_E \]
### BS EN 50522 safety criteria for combined HV-LV earthing

**Table 2 - Minimum requirements for interconnection of low voltage and high voltage earthing systems based on EPR limits**

<table>
<thead>
<tr>
<th>Type of LV system&lt;sup&gt;a, b&lt;/sup&gt;</th>
<th>Touch Voltage</th>
<th>EPR Requirements</th>
<th>Stress Voltage&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TT</strong></td>
<td>Not applicable</td>
<td>EPR ≤ 1 200 V</td>
<td>EPR ≤ 1 200 V</td>
</tr>
<tr>
<td><strong>TN</strong></td>
<td>EPR ≤ F · U&lt;sub&gt;r&lt;/sub&gt;&lt;sup&gt;d, e&lt;/sup&gt;</td>
<td>EPR ≤ 1 200 V</td>
<td>EPR ≤ 250 V</td>
</tr>
<tr>
<td><strong>IT</strong></td>
<td>Distributed protective earth conductor</td>
<td>As per TN system</td>
<td>EPR ≤ 1 200 V</td>
</tr>
<tr>
<td></td>
<td>Protective earth conductor not distributed</td>
<td>Not applicable</td>
<td>EPR ≤ 250 V</td>
</tr>
</tbody>
</table>

<sup>a</sup> EPR = Effective Protective Residual

<sup>b</sup> U<sub>r</sub> = Residual voltage

<sup>c</sup> Fault duration:
- \( t_r \leq 5 \text{ s} \)
- \( t_r > 5 \text{ s} \)
Example case no. 1

A 0.6Ω $R_E$ and $I_E=3,300$A,
Stress Voltage=1,980V > 1,200V
Here a 0.6Ω $R_E$ is unsafe.
Example case no. 2

a $2.0 \Omega \, R_E$ and $I_E=150A$,
Stress Voltage=$300V < 1,200V$
Here, a $2.0 \Omega \, R_E$ is safe.
**BS EN 50522 Safety criteria**

### Table NA.1 – Permissible touch voltages for typical fault clearance times

<table>
<thead>
<tr>
<th>Permissible touch voltages V</th>
<th>0.1</th>
<th>0.15</th>
<th>0.2</th>
<th>0.5</th>
<th>1</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>405</td>
<td>362</td>
<td>320</td>
<td>135</td>
<td>68</td>
<td>52</td>
</tr>
<tr>
<td>2 150</td>
<td>2 070</td>
<td>1 808</td>
<td>1 570</td>
<td>578</td>
<td>233</td>
<td>162</td>
</tr>
<tr>
<td>2 500</td>
<td>2 341</td>
<td>2 043</td>
<td>1 773</td>
<td>650</td>
<td>259</td>
<td>180</td>
</tr>
<tr>
<td>3 000</td>
<td>2 728</td>
<td>2 379</td>
<td>2 064</td>
<td>753</td>
<td>298</td>
<td>205</td>
</tr>
</tbody>
</table>

### Table NA.2 – Permissible step voltages for typical fault clearance times

<table>
<thead>
<tr>
<th>Permissible step voltages V</th>
<th>0.1</th>
<th>0.15</th>
<th>0.2</th>
<th>0.5</th>
<th>1</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11 131</td>
<td>9 663</td>
<td>8 357</td>
<td>2959</td>
<td>1 101</td>
<td>733</td>
</tr>
<tr>
<td>8 600</td>
<td>A)</td>
<td>A)</td>
<td>A)</td>
<td>A)</td>
<td>17 571</td>
<td>11 727</td>
</tr>
<tr>
<td>10 000</td>
<td>A)</td>
<td>A)</td>
<td>A)</td>
<td>A)</td>
<td>20 253</td>
<td>13 517</td>
</tr>
<tr>
<td>12 000</td>
<td>A)</td>
<td>A)</td>
<td>A)</td>
<td>A)</td>
<td>24 083</td>
<td>16 074</td>
</tr>
</tbody>
</table>

A) Limits could not foreseeably be exceeded.
Safety Earthing consists of:

- Soil Survey
- Correct Earth Nest Design
- Safety Precautions
- Determine If & Disconnection time

Safety Earthing Compliance BS, BSEN
Conclusion

The design and installation of the earth nest resistance of an earthing installation can no longer use a less-than-1Ω rule to fit all situations.

All earthing installations should be designed, installed, tested and commissioned on an individual basis.
Thank you for your attention.

Q & A