Design of a Low Impedance Grounding System for Telecom Applications

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Objectives

• Discuss typical existing performance criteria
• Discuss relationship between resistance and impedance
• Identify broadband response of grounding system components and systems
• Relate grounding system impedance to telecom applications
• Discuss impedance performance criteria
Impulse Current Effects

- V(t) = i(t) R + L (di/dt)
- High frequency content is important for overvoltages
- Low frequency content is important for energy dissipated in the earthing system
Lightning Current Paths
Impulse Current Principles

• Lightning takes the lowest impedance path to remote earth
  – lowest resistance and lowest inductance paths preferred
• High inductance path leads to high voltage on LPS
  – current cannot change instantaneously through an inductance
  – overvoltage is created and spark over to a less inductive path can result
• Lightning currents flow radially from the point of injection into earth as a function of earth resistivity or conductors (earth electrodes) embedded in the earth
• Providing multiple paths for current injection into the earth decreases current density at earth / electrode interface; reducing overvoltages
Grounding System Performance Criteria

• Resistance-to-earth
  – 5 Ω typical for Telecom applications
  – Can be as low as 1 - 2 Ω
  – NFPA 70 – 25 Ω or drive 2\textsuperscript{nd} electrode
  – DoD / DOE Explosives – \(<25 \Omega\)
  – IEC 62305-3 - \(< 10 \Omega\) recommended
  – NFPA 780 / UL 96A /\(\) no specification

• Proposed TIA-607-B
  – Grounding electrode: conductor … for the purpose of providing a low impedance path to earth
Circuit Model

\[ Z = \sqrt{\frac{R + j\omega L}{\sqrt{G + j\omega C}}} \]
Impedance vs. Resistance

- $v(t) = i(t) R + L \frac{di}{dt} + \frac{i(t)}{C} = i(t) Z$
- Resistance
  - often dominated by earth resistivity
  - increases with frequency due to skin effect
- Inductance
  - influenced by geometry of conductors / electrodes
  - increased by bends in conductor routing
- Capacitance
  - dominated by electrode-to-earth interface
Impedance Measurement Method
Vertical Rod in 300 Ωm soil

Vertical Rod in 300 Ωm soil

IMPEDANCE in Ω

vertical rod
300 Ω.m
Vertical Rod in 300 $\Omega$ m soil

- Impedance decreases with frequency due to dominate capacitance
- Impedance high even in low resistivity soil (70 to 120 $\Omega$).
- Additional experiments (data not shown)
  - Same behaviour found for horizontal grid in 300 $\Omega$ m soil
  - 3 rods in triangle in 200 $\Omega$.m soil : $Z \approx$ constant (30 – 40 $\Omega$)
  - Earth Enhancement Compound decreases local resistivity and improves contact (decreases R and Z)
Crow Foot Arrangement in Rocky Soil

**IMPEDANCE in Ω**

**FREQUENCY IN Hz**

crow foot
rocky soil
Crow Foot Arrangement in Rocky Soil

- 200 Ωm soil
- Low increase of impedance (Z)
- Less than 20 ohms change across entire frequency spectrum
- Efficient lightning protection grounding system
25 meter long Horizontal Tape

![Graph showing impedance and frequency]

25 m horizontal tape
110 Ω.m
25 meter long Horizontal Tape

- Buried 0.5 meters in 110 Ωm soil
- Low increase of impedance (Z)
- 20 ohms change from 10 Hz to 1 MHz
- Additional experiments (data not shown)
  - Z almost doubles for 50 meters of tape
  - Similar behavior from 20 m to 50 m vertical well in 200 Ωm soil
    - 50 m deep well –
      - Z = 10 Ω at low frequency / 70 Ω at 1MHz
Telecom Application

- 3 legged tower
- Equipment cabinet
- Driven rod per leg
- Driven rod for cabinet
- Ground loop conductor tying together driven rods
Tower Leg Impedances

South Tower Leg

East Tower Leg
Tower Test Points

South Tower Leg

East Tower Leg
Cabinet Ground Impedance
Summary of Observations

- Data from tower legs similar (w/in 3 Ω)
  - Effect of ground rods noted @ 202 kHz
- R (tower leg – cabinet bus) = 1 mΩ
- Bend in solid wire between copper bus bar and grounding electrode shows up as L
- Rgnd Cabinet = South tower leg = 9 Ω
- Rgnd (1MHz): Cabinet = 79.2; tower = 52Ω
- All 3 less than 10 Ω @ low frequency but test “bad” given HF criteria
Impedance Acceptance Criteria
Case Studies

- A: Building with large grounding system
- B: Factory Extension
- C: Metal Silos
- D: Metallic-framed Shed
- E: Group of Chimneys
- F: Metallic Tanks
Case A: Building with large earthing system
Case B: Factory Extension

- Extension of existing factory
- Bad soil, mainly rocks
- Crow foot system
- $R = 150 \ \Omega$
- Clearly a bad earthing system
Case B: Building with a crow foot in bad soil
Case C: Metallic Silos

- Small contact surface between metal and soil
- $R = 15 \, \Omega$
Case C: Silo in contact with soil
Case D: Large shed with metallic frame

• $R = 4 \, \Omega$
Case D: Shed with metallic frame
Case E: Group of Chimneys

- Earthing on each chimney
- Connected together by copper tape
- $R = 5 \ \Omega$
- Good low frequency resistance but gets very high at frequencies above 100 kHz
- bad lightning earthing system
Case E: Group of chimneys
Case F: Metallic Tanks

• Tank diameter 6 meters
• Near the sea
• Concrete base immersed in sand/water mixture
• No dedicated earthing system
• $R = 1 \, \Omega$
Case F: Metallic tank near the sea
Proposed Criteria Development

• Difficult to establish a single criteria for quality of earthing system to dissipate lightning current while minimizing overvoltages

• Examples for consideration:
  – 30 Ω from low frequency to 1 MHz
  – 10 Ω at low frequency and 100 Ω at high frequencies

• To evaluate the earthing systems we will calculate the voltage generated by the injection of a 10 kA 1/20 current pulse into the earthing impedance measurements reported earlier.

• Determine equivalent resistance ($R_{HF}$)
The mean value of the measured impedance between 63 kHz and 1 MHz (Mean Z) computed from data provided by high frequency earth impedance test equipment.

This value is consistent with $R_{HF}$ and is suggested as criterion.
Proposed Criteria

- Based on $R_{HF}$ (or $Z_{mean}$)
  
  \[
  \begin{align*}
  R_{HF} & \leq 10 \, \Omega & : & \text{very good earthing} \\
  10 \, \Omega & < R_{HF} \leq 30 \, \Omega & : & \text{good earthing} \\
  30 \, \Omega & < R_{HF} \leq 40 \, \Omega & : & \text{acceptable earthing} \\
  40 \, \Omega & < R_{HF} & : & \text{bad earthing}
  \end{align*}
  \]

- Quality of earthing is based on experience and has been presented to the scientific community (ICLP, SIPDA)
## Application of the Proposed Criteria

<table>
<thead>
<tr>
<th></th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
<th>Case D</th>
<th>Case E</th>
<th>Case F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{LF}$ (Ω)</td>
<td>4</td>
<td>150</td>
<td>15</td>
<td>4</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>$R_{HF}$ (Ω)</td>
<td>47</td>
<td>203</td>
<td>35</td>
<td>22</td>
<td>47</td>
<td>16</td>
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<tr>
<td>Mean Z (Ω)</td>
<td>46.7</td>
<td>184</td>
<td>40.7</td>
<td>22.9</td>
<td>45.5</td>
<td>17.9</td>
</tr>
<tr>
<td>eq. length (m)</td>
<td>24</td>
<td>102</td>
<td>18</td>
<td>11</td>
<td>24</td>
<td>8</td>
</tr>
</tbody>
</table>

- Earthing systems for A, B and E are considered bad earthing systems.
- Case C is acceptable.
- Cases D and F are good earthing systems.
Earthing Impedance Factors

\[ Z = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \]

- **R** is function of material used for grounding system
  - often negligible but flat conductor better than round at high frequency (skin effect) given same cross sectional area
- **G** - earth conductance: related to earth resistivity and contact resistance between earth electrode and soil
  - may be increased through use of additives to increase contact between soil and earth conductors.
Earthing Impedance Factors

\[ Z = \sqrt{\frac{R + j \omega L}{G + j \omega C}} \]

- **L** – Inductance of earthing system hardware
  - reduced by use of shorter multiple conductors instead of single one of equivalent total length

- **C** – Capacitance between earth and earthing electrodes
  - reduced by increasing earth contact area (plates and flat conductors better than round conductors)
  - reduced by increasing contact between electrode and earth such as through earth enhancing material
Summary and Conclusions

• High frequency behavior of an earthing system is different from low frequency
  \[ Z \neq R \]

• Microsecond rise time of lightning current pulse leads to high frequency components

• High frequency lightning current content leads to overvoltage problems
Summary and Conclusions

Earthing system impedance reduced by:

- Lowering resistance of electrode(s) and associated conductors (typically negligible)
- Lowering inductance of electrode(s) and associated conductors
- Lowering resistance-to-earth
- Increasing capacitance of earth-electrode interface

Increasing length of electrodes can reduce resistance-to-earth but resulting effectiveness offset by increased inductance (impedance)
Summary and Conclusions

• Long earthing conductors good for R but not Z
  – Multiple paths better for high frequency response
• Flat conductors and plates increase capacitance and reduce impedance
• Earthing enhancing compounds can help reduce R and Z
Summary and Conclusions

• Engineering criteria in standards are better than citing earthing resistance requirement
• Devices exist for measurement of high frequency response of grounding systems
• Recommendations available for standards / specifications incorporating impedance values for earthing systems
  – Average value of impedance between 60 kHz and 1 MHz (5 kHz not high enough to identify critical value)
  – High Frequency Resistance based on 10 kA impulse ($R_{HF} \leq 40 \, \Omega$)
Thank You

QUESTIONS ?