Grounding and Bonding Testing

Presented by Mike Lewis
Senior Application Engineer
Megger
Objective

- Review Proper soil resistivity techniques
- Identify ground electrode system components and bonding materials
- Ensure proper installation
- Measure the effectiveness of the ground electrode and bonding system by means of ground testing
Simply Put…

- Step 1 Earth (Soil) Test
- Step 2 Install System
- Step 3 Test System
I. Earth (Soil) Resistivity Testing

What is Earth Resistance?

• Earth’s resistance to current flow from the ground electrode
• Largest factor influencing ground system effectiveness

What Affects Earth Resistance?

• Type of soil
• Amount of moisture/presence of salts
• Temperature
# Resistivities of Different Soils

<table>
<thead>
<tr>
<th>Soil</th>
<th>Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface soils, loam, etc.</td>
<td>100 - 5,000</td>
</tr>
<tr>
<td>Clay</td>
<td>200 - 10,000</td>
</tr>
<tr>
<td>Sand and gravel</td>
<td>5,000 - 100,000</td>
</tr>
<tr>
<td>Surface limestone</td>
<td>10,000 - 1,000,000</td>
</tr>
<tr>
<td>Limestones</td>
<td>500 - 400,000</td>
</tr>
<tr>
<td>Shales</td>
<td>500 - 10,000</td>
</tr>
<tr>
<td>Sandstone</td>
<td>2,000 - 200,000</td>
</tr>
<tr>
<td>Granites, basalts, etc.</td>
<td>100,000</td>
</tr>
<tr>
<td>Decomposed gneisses</td>
<td>5,000 - 50,000</td>
</tr>
<tr>
<td>Slates, etc</td>
<td>1,000 - 10,000</td>
</tr>
</tbody>
</table>

* Evershed & Vignoles Bulletin 245
Why Earth (Soil) Test?

- Tells you how “good” (conductive) your soil is
- Good indication on whether or not generic ground specification design will work
- Helps reduce “surprises” at the end of the installation
5 Ohm Requirements

Soil Resistivity ranges:

100 - 15,000 Ohms cm – Standard Design Ok

15,000 - 25,000 Ohms cm – Maybe

25,000 - 50,000 Ohms cm – Special

50,000 + – Very Special; maybe not practical
Earth (Soil) Resistivity Testing

- How do we test the soil?
- 4 Part Wenner Test
Measuring Earth Resistivity

- Use a 4-terminal ground tester.
- Space the electrodes an equal distance “a” apart.
- Insert the electrodes a distance of a/20 into the ground.
- Measures the average soil resistivity to a depth equal to the electrode separation.
Measuring Earth Resistivity

The diagram illustrates a setup for measuring earth resistivity. The diagram includes labels for points C1, P1, P2, and C2, with distances marked as 'a' and 'a/20'. The equipment labeled DET2/2 is connected to these points, indicating the setup for the resistivity measurement.
Measuring Earth Resistivity
Actual Site Testing Procedures

Test at Multiple locations across the site
Actual Site Testing Procedures

Soil is not Homogenous; test at various soil depths as well

<table>
<thead>
<tr>
<th>Rod Spacing</th>
<th>Soil Depth Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.52 m (5 ft.)</td>
<td>1.52 m (5 ft.)</td>
</tr>
<tr>
<td>3 m (10 ft.)</td>
<td>3 m (10 ft.)</td>
</tr>
<tr>
<td>6.1 m (20 ft.)</td>
<td>6.1 m (20 ft.)</td>
</tr>
<tr>
<td>9.1 m (30 ft.)</td>
<td>9.1 m (30 ft.)</td>
</tr>
<tr>
<td>12.2 m (40 ft.)</td>
<td>12.2 m (40 ft.)</td>
</tr>
</tbody>
</table>

Motorola R56 2000
Soil Resistivity Test Summary

- If the Results of the Soil Test are in the 15,000 Ohm-cm range or less, it is prudent to go with the generic ground system specified.
- If the Results of the Soil Test are substantially above 15,000 Ohm-cm; contact the carrier, owner and the engineering firm.
Ground Electrode System Components

- Ground Electrodes
- Ground Conductors
- Ground Bars
- Bonding Connectors
  - Mechanical
  - Compression
  - Exothermic
1. Ground Electrodes

Types -

Ground Rods:
- Copper Clad Steel
- Solid Copper
- Galvanized
- Stainless Steel
- Enhanced

Ground Plates

Copper Ground Mesh
Ground Electrodes... Considerations

**Soil Resistivity** - Some soils, (such as sandy soils), have such high resistivities that conventional ground rods or ground electrode systems may be unable to attain the desired ground resistance requirement. Enhanced ground electrodes or ground enhancement materials may be required to meet the grounding specification.

**Soil PH/type** - PH a factor in choosing. Some ground rod types work better in different soils.

**Soil Characteristics** - Some sites may have only a few inches of soil (or none) sitting on top of bedrock. In this case, ground mesh is the preferred electrode. (Never drill into bedrock).
**Ground Electrodes... Considerations**

**Ground Rod Diameter** - Doubling diameter of ground rod reduces resistance only 10%. Using larger diameter ground rods is mainly a strength issue (i.e., in rocky conditions, a larger diameter ground rod might be advantageous).

**Ground Rod Length** - Doubling length theoretically reduces resistance 40%, actual reduction depends on soil resistivities encountered in multi-layered soils.

**Ground Rod Spacing** - Approximately twice the length (in good soil).
Ground Rod Driving Tip

• Don’t do this!
Ground Rod Spacing Rule of Thumb

Proper Spacing
1 x length

Too Close

Bicsi
**Ground Electrodes... Considerations**

**Ufer Grounds** - Concrete encased electrode. For example, tying into the tower footing rebar or building pad rebar provides a Ufer ground. Ufer grounds should never be used as the sole ground electrode.
Enhanced Grounding Material

- Should be > 95% pure carbon
- Should not contain concrete or bentonite fillers

Ultrasill is a low resistance carbon based backfill material, which dramatically lowers ground system resistance in difficult soil situations. Ultrasill contains no bentonite or concrete components, which, in very dry conditions, can cause shrinkage around the ground electrode, thus rendering it ineffective.

Ultrasill is ideal for use in rocky soil, sand, gravel or any other high resistance soil conditions. It is also the ideal backfill material for use around enhanced ground rods and ground grid systems.

Ultrasill is easy to use, safe and effective. Unlike other backfill products, Ultrasill is dust free and does not require mixing in water prior to installation. (However, Ultrasill does mix readily with water if required).

Ultrasill may be either used in a horizontal trench or grid, or in vertical applications.
Applications

Vertical Application

Horizontal Application
Enhanced Ground Rods

Contain electrolytic salts that lower ground resistivity over time
Grounding Conductors

Types -
  Grounding: Solid
           Stranded
           Flat Strap
  Lightning: Rope Lay
Conductors... Considerations

**Inductance** - Flat strap conductors have less inductance than their similarly sized round conductor counterparts.

**Strength/Durability** - Round conductors whether solid or stranded are much stronger than a 24 or 26 gauge flat strap conductor. This should be a consideration when backfilling trenches.

**Exothermic Connections** - The preferred type of connection for underground uses. Availability as well as ease of connection is better for the round conductors than the flat strap conductors.

**Cost Effectiveness** - Although the inductance may be less for the flat strap conductors, their cost is much higher. It may be more cost effective to use multiple round conductors, thus lowering overall ground system impedance than single flat strap conductors.
Conductors...Considerations

Lightning Travels on the outside surface of a conductor, the so called “skin affect”. Therefore, the larger the surface area of a conductor, the better path it makes.

Remember, multiple parallel paths are very important. The fewer paths you have the larger the surface area or diameter the conductor needs to have.

Remember, a Tower is the down conductor.
Conductor…Considerations

- Selection of Proper Size
  - In the absence of a Specified Requirement…
- No Standards exist in Wireless Telecommunications. (ANSI J-Std 607)

- LP Standards state if building height is equal or greater than >75’ use class II
- Size Should be Dependent on the length and number of paths
Conductor... Considerations

Conductor Routing and Placement

General Rules of Thumb for Placement:

As far as possible from communications cable
(12” minimum for a ground conductor. Reference NEC 800
for Power lines).

Lightning conductors must be 6’ away from power &
communications cable. (Reference NEC 800 & NEC 250).

Cross in a perpendicular fashion if needed.
Not Good....

Placement....
Placement....

Even Better....
A little Better...

Placement...
Good example…

Routing….
Conductor...Considerations

Routing and Placement

General Rules of Thumb for Routing:

Maintain downward sloping path to ground (equipotential bonds exception)

Do not run conductors uphill (1/4 rise acceptable to a point)

Maintain at least an 8” radius of bend
- Uphill path to ground

- Radius of bend less than 8"

- Bonding issue

- Water pipe?
Not bonded to conduit…
Routing in conduit...

- Sometimes required by local codes

- If run in metallic conduit, it must be bonded on both ends

- Might be beneficial if run in metallic conduit
- Conduit on left a little better....

- Needs to be bonded as close to the opening as possible...

- Two conduits on right not bonded to conduit
Better yet...
- A really good idea !!!

- Used “romex” style fittings
Ground Bars
Ground Bar

• What is a Ground Bar?
  – Simply a connection point

• What does it do?
  – Facilitates ease of bonding connections

• Issues
  – Theft
    ▪ Tamper resistant
  – Galvanized
    ▪ Bad idea, galvanic couple
Grounding/Bonding Connections

Three Types of Connections

- Mechanical
- Compression
- Exothermic
Mechanical Connections

- Use Standard Tools & Hardware
Mechanical Connections

- Used when compression or exothermic connections are not practical/feasible
- Surface preparation essential
- Use appropriate hardware
- Tighten to proper torque rating
Mechanical Connections

• Advantages
  – Can be removed
  – Use common tools
  – Lower material Cost

• Disadvantages
  – Can be removed
  – Loosen over time
  – Require more maintenance
Surface Preparation
Surface Preparation
Hardware Requirements

- Stainless Steel
- or
- Silicon Bronze
- No Zinc!
Galvanic Series

- Galvanic Series
  - >.3 volts difference in potential can cause corrosion
  - Use stainless steel hardware instead of zinc
Zinc Hardware
Proper Torque
## Proper Torque

### TABLE I
Tightening Torques

<table>
<thead>
<tr>
<th>Bolt Diameter</th>
<th>Nominal Torque Values</th>
<th>Silicon Bronze, Galvanized or Stainless Steel</th>
<th>Aluminum Alloy (Lubricated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/16 - 18</td>
<td></td>
<td>15</td>
<td>180</td>
</tr>
<tr>
<td>3/8 - 16</td>
<td></td>
<td>20</td>
<td>240</td>
</tr>
<tr>
<td>1/2 - 13</td>
<td></td>
<td>40</td>
<td>480</td>
</tr>
<tr>
<td>5/8 - 11</td>
<td></td>
<td>55</td>
<td>660</td>
</tr>
<tr>
<td>3/4 - 10</td>
<td></td>
<td>80</td>
<td>960</td>
</tr>
</tbody>
</table>

*Bicsi*
More Mechanicals

• Possible “burn through” issues
**More Mechanicals**

**FIGURE 4-49  FENCE FABRIC AND DETERRENT WIRING BONDING EXAMPLE**
Mechanicals More
More Mechanicals

• Dissimilar metals
Compression Connections

• Used when it is desirable to make an irreversible electrical connection

• Less maintenance than a mechanical connection

• Not a molecular bond, (Not recommended for underground use)
Compression Connections

• Specialized tools/dies required
  - Generate, 2, 6 and 13 tons of crimping force

[Images of specialized tools]
Compression Connections

- **Advantages**
  - Irreversible
  - UL listed
  - Low/no maintenance

- **Disadvantages**
  - Expensive tooling
  - Sometimes hard to make, (location)
  - Not a molecular bond
Compression Lugs

- Long Barrel
- Inspection Port
- 2-Hole
Connection Process

Trim insulation back so that bared conductor is slightly longer than barrel.
Connection Process

Insert conductor so that it butts up against end of barrel. View this thru inspection port.
Connection Process

2 crimp minimum

Make sure end of conductor remains at end of barrel;
Make first crimp
Repeat crimping process
Connection Process

2 Crimp Minimum
More Compression

- H-Taps
- C-Taps
Bad Examples

Poor Mechanical Connections

Poor Compression Connections
Exothermic Connections
Exothermic Connections

What is an exothermic connection?

An exothermic connection is used to form a molecular bond between two metals such as copper and steel.
Exothermic Connections

Provides a Molecular Bond

- Ampacity exceeds that of conductors
- Connections will not loosen
- Connections never increase in resistance
- Does not deteriorate with age
- Maintenance free
Compression vs. Exothermic

Point-to-Point Contact

Molecular Bond
The Exothermic Process

Tools Required
Tools

Mold

Handle

Weld Metal

Flint Igniter

Disks
Exothermic Connection Process

Safety First

- Protective Glasses
- Gloves
- Cover Arms
Connection Process

Step 1 –
Torch dry the mold to eliminate moisture!
(First connection and...)
Connection Process

Step 2 –
- Dry conductors
- Clean conductor surfaces
- Position conductors in mold
- Close mold

CCBRSH1

CCBRSH2
Connection Process

Step 3 –

Position the disk in the mold evenly, concave side up
Connection Process

Step 4 –

• Pour weld metal into mold

• Sprinkle 2/3 of starting material over the weld metal

• Close mold lid
Step 5 –

• Pour remaining starting material into ignition pocket on top of the mold lid.
Connection Process

Step 6 –

• Stand to the side of the mold

• Ignite the starting material with a flint igniter
Connection Process

Step 7 –

• Allow 15-20 seconds to complete the process

• Open mold and remove the finished connection.

• Clean mold to prepare for the next connection.
Exothermic Inspection Process
General Indicators:

- Size - No conductor portion should be exposed
- Color - bright gold to bronze
- Surface Finish - smooth; free of slag deposits
- Porosity - few pinholes acceptable
Exothermic Inspection Criteria

- Good connection
- Bright, shiny & free from porosity
Exothermic Inspection Criteria

Unacceptable connection

Slag > 20%

Leakage - Mold not seated properly
Exothermic Inspection Criteria

Unacceptable connection

Not enough weld metal
Common Problems

- Connection not sticking to Ground Bar
- Connection not sticking to Tower Leg
- Burn thru on Fence Post
- Melt thru on Cable to Ground Rod
Ground Electrode System Testing

- Ok, So the System is installed
- Let’s Test!
Choose the Proper Instruments:

- Use a dedicated ground tester (designed to make this measurement).
- **Don’t** make the measurement with a generalized ohmmeter or multimeter - results will be erroneous.
- **Don’t** use an insulation tester.
3-Terminal Earth Tester

Current Supply

Ammeter (I)

Voltmeter (E)

Potential Probe

Ground Electrode Under Test

P

C

X

Earth

Earth

Current Probe

Bicsi
4-Terminal Earth Tester

- Current Supply
- Ammeter (I)
- Voltmeter (E)
- Auxiliary Current Electrode
- Ground Electrode Under Test
- Auxiliary Potential Electrode
- Earth
- X

Symbols:
- C₁ P₁
- P₂
- C₂
Theoretical Background
Ground Rod Sphere of Influence
Theoretical Background
Current Probe Sphere of Influence

Ground Electrode Under Test (X)

Auxiliary Potential Probe (P)

Auxiliary Current Probe (C)
Theoretical Background - Resistance Curve

- **Resistance in Ohms**
  - True Resistance

- **Distance of Potential Probe from X** ($d_p$)
  - **X**
  - Ground Electrode Position
  - **C**
  - Current Probe Position
Theoretical Background
Insufficient Probe Spacing

Ground Electrode Under Test (X)

Potential Probe (P)

Current Probe (C)

Resistance in Ohms

Distance of Potential Probe from X (d_p)
Test Methods Serve Two Primary Purposes:

- Verify that correct spacing is being used to assure reliable results.
- Provide specific shortcuts to reduce testing time.
Ground Testing Methods

- Fall of Potential Method
- 61.8% Rule/Method
- Four Potential Method
- Intersecting Curves Method
- Slope Method
- Dead Earth Method
- Star-Delta Method
Fall of Potential Method

**Advantage:** Extremely reliable.

**Disadvantage:** Extremely time consuming and labor intensive.
Theoretical Background - Fall of Potential

Ground Electrode Under Test (X) - Potential Probe (P) Positions - Current Probe (C)

Distance of Potential Probe from X ($d_p$) - Resistance in Ohms

Ground Electrode Position - X - C

Current Probe Position
Site Testing Fall of Potential Method

1. Determine size of ground grid system and calculate length of test leads required. (Pythagorean theorem). Lead Length Critical.

2. Make sure that the ground system under test is non connected to the Utility ground system grid. (Telephone as well).

3. Starting at 50’, record readings every 50’ to obtain a ground resistance curve. (Or enough points to ensure a good graph.

4. The point where curve flattens out is the system’s ground resistance. (62%)
# 3 Point Test Format

<table>
<thead>
<tr>
<th>Distance In Feet</th>
<th>Readings in Ohms, Easterly Direction</th>
<th>Readings in Ohms, Northerly Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1.16</td>
<td>0.84</td>
</tr>
<tr>
<td>125</td>
<td>1.39</td>
<td>1.1</td>
</tr>
<tr>
<td>150</td>
<td>1.67</td>
<td>1.27</td>
</tr>
<tr>
<td>175</td>
<td>1.8</td>
<td>1.46</td>
</tr>
<tr>
<td>200</td>
<td>2.18</td>
<td>1.67</td>
</tr>
<tr>
<td>225</td>
<td>2.59</td>
<td>1.99</td>
</tr>
<tr>
<td>250</td>
<td>3.04</td>
<td>2.49</td>
</tr>
<tr>
<td>275</td>
<td>3.47</td>
<td>2.95</td>
</tr>
<tr>
<td>300</td>
<td>3.67</td>
<td>3.17</td>
</tr>
<tr>
<td>325</td>
<td>3.86</td>
<td>3.35</td>
</tr>
<tr>
<td>350</td>
<td>3.97</td>
<td>3.51</td>
</tr>
<tr>
<td>375</td>
<td>4.25</td>
<td>3.62</td>
</tr>
<tr>
<td>400</td>
<td>4.68</td>
<td>4.02</td>
</tr>
<tr>
<td>425</td>
<td>5.4</td>
<td>4.92</td>
</tr>
<tr>
<td>450</td>
<td>6.52</td>
<td>5.91</td>
</tr>
<tr>
<td>475</td>
<td>8.08</td>
<td>7.79</td>
</tr>
<tr>
<td>500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing the relationship between distance and readings in Ohms for Easterly and Northerly directions.](image)
Advantages of Fall of Potential Testing

- Conforms to IEEE 81; only approved method.
- Operator has complete control of the test set-up.
- Far more accurate:
  - 4-wire configuration/no additional loop resistances included.
  - Significant for low resistance (1-2Ω) grounds
Simplified Fall of Potential Method

- Based on the theory behind the full Fall of Potential method.
- Take measurements at three points.
- **Advantage**: Much faster than full Fall of Potential method.
- **Disadvantage**: Less reliable since fewer measurements being made.
Simplified Fall of Potential Method
Simplified Fall of Potential Method

- \( R_A = R_1 + R_2 + R_3 \)
- \( R_{\text{Max Deviation}} = R_A - R_X \)  
  \( (R_X \text{ is furthest } R \text{ value from } R_A) \)
- \( \% \text{ deviation} = \left( \frac{R_{\text{Max Deviation}}}{R_A} \right) \times 100 \)
- If \( (\% \text{ deviation}) \times 1.2 > 10\% \); C2 must be moved further away
61.8% Rule/Method

- Based on the theory behind the full Fall of Potential method.
- Take measurement at only one point.
- **Advantage:** Extremely quick and easy.
- **Disadvantage:** Assumes that conditions are perfect (adequate probe spacing and soil homogeneity).
61.8% Rule/Method

\[ d_p = 61.8\% d_c \]
Theoretical Background - 61.8% Rule

Ground Electrode Under Test (X)
Potential Probe (P)
Current Probe (C)

Distance of Potential Probe from X ($d_p$)

61.8%
The Problem of Limited Distance/Space

- Ground Electrode Under Test (X)
- Potential Probe (P)
- Current Probe (C)

Diagram showing:
- Resistance in Ohms
- Distance of Potential Probe from X ($d_p$)
Stakeless/Clamp-On Method
Disadvantages
Stakeless/Clamp-On Method

- Effective only in situations with multiple grounds in parallel (pole grounds).
- Cannot be used on isolated grounds.
  - no return path
- Cannot be used if an alternate lower resistance return exists not involving the soil.
  - Cellular towers
  - Substations
Disadvantages Stakeless/Clamp-On Method

- Subject to influence if another part of the ground system is in “resistance area”.
- Test is less representative of a fault at power frequency.
- Accuracies are greatly reduced.
Disadvantages
Stakeless/Clamp-On Method

• Requires a good return path.
• Connection must be on the correct part of the loop.
• Susceptible to noise from nearby substations and transformers (no reading).
Clamp-on Application

Power Company Feed

To Telco or Other Utility Connection

Meter must be placed BELOW this point

Clamp-On Ohmmeter

Single grounding electrode (or multiple grounding electrodes bonded underground)

Meter placed at this point will “see” single grounding electrode (or multiple grounding electrodes) as one grounding electrode. As such, an accurate measurement is achieved.
Ground Testing Summary

- 3 Point Fall of Potential Method most accurate
  - Must disconnect from Utility Grid
  - Testing Area often an issue
- Clamp-On Style has limited Applications
  - Large potential for misuse
  - Not as accurate as 3 point method
- Testing must be done correctly to determine if the desired ground resistance specification is met
Summary

• Proper Testing and Installation methods are often over-looked.
• Following these guidelines will help lessen future issues with grounding and bonding related events.
• For more information please contact BICSI or Megger.