Facility and Equipment Grounding to Enhance Equipment Performance 2011

Grounding

- **Earthing (European convention)**
  - Establishing a bond to earth at the facility service entrance for the electrical distribution system.

- **Grounding (U.S. convention)**
  - Establishing fault clearing paths within a facility for the electrical distribution system and for equipment within the facility.

- **Referencing**
  - Establishing a chassis contact to an external point to limit voltage rise.

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The Equipment Ground Connection

- DC return referenced to chassis
- Chassis bonded to safety ground

Grounding Concepts & References

- The effects of impedance & frequency
- Faraday cage & Kirchoff's Voltage and Current Laws
- National Electrical Code
What Drives PQ Inspections?

- Ground resistance measurements required for new construction
- Equipment problems
- Nuisance GFI (ground fault interrupt)
- Communications problems
- Lighting problems
- Lightning problems
- “If it’s not power quality – then it must be grounding.”

Common Grounding Issues

- There isn’t any grounding.
- There is too much “grounding”.
- The grounding is misapplied.
- There are some serious/stupid wiring problems.
- The equipment is really the problem
  - Power frequency leakage currents
  - EMI/RFI.
Origins For Grounding Concepts

- Electrical code
  - Single point grounding
  - Fault path to electrical service
- Telecommunications grounding
  - Traditional DC grounding practices
  - Ground start & signaling
- RF grounding
  - Antenna grounding
- Isolated grounding
  - U.S. practice

"Earthing" Systems

- Three or four letter designation
- First letter is supply earthing
  - T indicates one or more points directly earthed
  - I indicates the supply is not earthed or is earthed through a fault limiting impedance
- Second letter indicates installation earthing
  - T indicates that conductive metalwork is directly connected to earth
  - N indicates that conductive metalwork is directly connected to the earthed neutral.
- US convention is TN -- not TT or IT
- Third and fourth letter describes earthed conductor arrangement
  - S indicates separate neutral and earthed conductors
  - C indicates combined neutral and earth conductor
  - TN-S: consumers earth terminal connected to the supply protective conductor
  - TN-C: consumers neutral and protective functions (ground) in a single conductor
  - TN-C-S: consumers supply neutral and protective functions (ground) are combined and earthed
Earthing (Grounding) Systems

**IT Earthing System**
- Utility not earthed or earthed via impedance
- Facility earthed independently of utility

**TT Earthing System**
- Utility directly earthed
- Facility earthed independently of utility

**TN Earthing System**
- Utility directly earthed (and frequently in US)
- Facility grounding bonded to earthed utility

---

Soil Conditions
### Soil Type vs Resistivity

- IEEE Std. 142-1991
  - Grounding of Industrial and Commercial Power Systems

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Average Resistivity Ohms per CM</th>
<th>5/8” x 10’ Driven Rod Ohms Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well graded gravel, gravel-sand</td>
<td>60,000 – 100,000</td>
<td>180 – 300</td>
</tr>
<tr>
<td>Loose gravel, gravel-sand</td>
<td>100,000 – 250,000</td>
<td>100 – 150</td>
</tr>
<tr>
<td>Clayey gravel, sand-clay</td>
<td>20,000 – 40,000</td>
<td>60 – 120</td>
</tr>
<tr>
<td>Silty sands, sand-silt mixtures</td>
<td>15,000 – 50,000</td>
<td>40 – 100</td>
</tr>
<tr>
<td>Clayey sands, sand-clay mixtures</td>
<td>5,000 – 20,000</td>
<td>15 – 60</td>
</tr>
<tr>
<td>Silty or clayey fine sands w/plasticity</td>
<td>3,000 – 8,000</td>
<td>9 – 24</td>
</tr>
<tr>
<td>Fine sandy or silty soils, elastic silts</td>
<td>8,000 – 30,000</td>
<td>24 – 90</td>
</tr>
<tr>
<td>Gravelly clays, sandy clays, silty clays, lean clays</td>
<td>2,500 – 6,000 (moisture related)</td>
<td>17 – 18 (moisture related)</td>
</tr>
<tr>
<td>Inorganic clays, high plasticity</td>
<td>1,000 – 5,000 (moisture related)</td>
<td>1 – 16 (moisture related)</td>
</tr>
</tbody>
</table>

### Soil Resistivity Vs Water Content 1

- IEEE Std. 142-1991

<table>
<thead>
<tr>
<th>Moisture Content (by weight)</th>
<th>Resistivity Ohms/cm Sandy Loam</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>185,000</td>
</tr>
<tr>
<td>4</td>
<td>60,000</td>
</tr>
<tr>
<td>6</td>
<td>38,000</td>
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<tr>
<td>8</td>
<td>28,000</td>
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<td>10</td>
<td>22,000</td>
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<tr>
<td>12</td>
<td>17,000</td>
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<tr>
<td>14</td>
<td>14,000</td>
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<tr>
<td>16</td>
<td>12,000</td>
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<td>18</td>
<td>10,000</td>
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<tr>
<td>20</td>
<td>9,000</td>
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<tr>
<td>22</td>
<td>8,000</td>
</tr>
<tr>
<td>24</td>
<td>7,000</td>
</tr>
</tbody>
</table>
Effects of Moisture Content

- 8 Foot Rod
- Sandy Loam

Soil Resistivity vs Temperature

- IEEE Std. 142-1991 (Green Book)

<table>
<thead>
<tr>
<th>Temperature (centigrade)</th>
<th>Temperature (Fahrenheit)</th>
<th>Resistivity Ohms/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
<td>23</td>
<td>70,000</td>
</tr>
<tr>
<td>0</td>
<td>32</td>
<td>30,000</td>
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<tr>
<td>0</td>
<td>32</td>
<td>10,000</td>
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<tr>
<td>10</td>
<td>50</td>
<td>8,000</td>
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<td>20</td>
<td>68</td>
<td>7,000</td>
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<tr>
<td>30</td>
<td>86</td>
<td>6,000</td>
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<tr>
<td>40</td>
<td>104</td>
<td>5,000</td>
</tr>
<tr>
<td>50</td>
<td>122</td>
<td>4,000</td>
</tr>
</tbody>
</table>
Effects of Temperature

Soil Resistivity vs Salt Content

- Soil type -- sandy loam - moisture content 15% by weight - 17°C
- Salts (copper sulfate, sodium carbonate etc.) must be EPA or local ordinance approved for use
- AEMC -- *Understanding Ground Resistance Testing*

<table>
<thead>
<tr>
<th>Added Salt % by weight of moisture</th>
<th>Resistivity Ohms/centimeter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10,000</td>
</tr>
<tr>
<td>0.1</td>
<td>1,800</td>
</tr>
<tr>
<td>1.0</td>
<td>450</td>
</tr>
<tr>
<td>5</td>
<td>190</td>
</tr>
<tr>
<td>10</td>
<td>130</td>
</tr>
<tr>
<td>20</td>
<td>100</td>
</tr>
</tbody>
</table>
Electrode Grounding Resistance

• NEC
  • 25 Ohms or supplement
  • NEC 250-56 [2005]
  • NEC 250.53(A)(2) Exception [2011]

• Health Care
  • IEEE Std. 602-1996 (White)
  • Section (10.4.5.2)
  • No more than 10 ohms
  • 5 Ohms or less preferred

• Industrial Plants
  • ANSI/IEEE Std. 141-1986 (RED)
  • Section 7.5.2
  • 1 ohm or less for substations
  • 5 ohms or less for industrial plants

• Sphere of influence
  • Radius equals length of buried rod

Grounding Sphere of Influence

• Common Grounding Electrode
  • NEC 250.58 [2011]
  • Parallel ground rods considered a single grounding electrode
  • Multiple services serving the same facility must use the same grounding electrode(s).

• Radius < length
  • Combined resistance

• Rod length
  • No less than 8 feet (2.5m)
  • NEC 250.52(A)(5) [2011]
Grounding Sphere of Influence (2)

- 6 foot minimum separation
  - NEC-250-53(A)(3) [2011]
- Local codes may specify ground rod separation
- IEEE Std. 142-1991 (Green Book)
  - Grounding of Industrial and Commercial Power Systems
  - Table 13 – provides resistance calculation methods

Grounding Protection?
Chemical Treatments

- Soil treatment
- Specialized system
  - Bentonite (kitty litter)
  - Calsolite (salts)
- Open systems
  - Local requirements
  - EPA impact

Electrolysis

- Electrochemical series
  - Magnesium (-2.34V)
  - Aluminum (-1.67V)
  - Iron (-0.44V)
  - Tin (-0.14)
  - Copper (+0.34V)
  - Stainless Steel
  - Gold (+1.42V)

- Galvanic Battery
Measuring Electrode Resistance

Made Electrode Earth Resistance

• NEC 250.53 Grounding Electrode System Installation
• NEC 250.53(A)(2) [2011]
  – A single rod, pipe or plate electrode shall be supplemented by an additional electrode of a type specified in 250.52(A)(2) through (A)(8).
• NEC 250.53(A)(2) Exception [2011]
  – “If a single rod, pipe or plate grounding electrode has a resistance to earth of 25 ohms or less, the supplemental electrode shall not be required.”
Grounding Measurements - 3 Pt.

3 Pt. Measurement Complications

Earth Ground Resistance Testing for Low Voltage Power Systems
Kenneth M. Michaels
IEEE Transactions - Industry Applications
Jan/Feb 1995

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2 Pt. Clamp-on Measurements

- Designed for use with power poles
- Common neutral/ground connections provides essentially an "infinite" ground connection
- Measurement reflect attachment point versus all utility ground connections

Clamp-On Complications

- Four separate measurement points
- Results vary from 2.8 Ohms to >1990 ohms
- Variable results caused by loop inductance/resonance

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Four Point Resistivity Measurement

- Undisturbed native soil necessary
- Current injected between C1 and C2 with voltage measured from P1 to P2.

Earthing & Grounding

- General
- NEC 250 I [2011]
- System Grounding
- NEC 250 II [2011]
- Grounding Electrode System
- NEC 250 III [2011]
The Roles of Grounding

- General requirements
  - NEC 250.4 [2011]
  - Establish voltage reference
  - Limit touch potential
  - Clear electrical faults
  - Carry lightning currents
- Performance issues
  - Provide equipment reference
  - Provide RF/ESD discharge path

Grounding Electrode System (GES)

- National Electrical Code Article 250
  - Electrical service entrance bonding
    - NEC 250-20 [2011]
    - Incoming utility neutral or internal facility neutral
  - Grounding electrode system
    - NEC 250.59 [2011]
    - Structural steel where effectively grounded
    - "All grounding electrodes as described in 250.52(A)(1) through (A)(7) that are present at each building or structure served shall be bonded together to form the grounding electrode system."
    - Ufer grounds (concrete encased electrode)
    - Building footings if designed as Ufer grounds
    - Water pipes
    - Ground ring
    - Plate electrodes
    - Driven grounding rods
Grounding Electrode System

- GES - NEC 250-50 [2011]
  - Water Pipe - NEC 250.52(A)(1)
  - Driven Ground - NEC 250.52(A)(5)
  - Structural Steel - NEC 250.52(A)(2)
- Water Pipe must be supplemented
  - NEC 250.53(D)(2) [2011]
- Grounding electrode conductor must be continuous
  - NEC 250.64(C) [2011]
- Not allowed
  - Metal underground gas pipes
  - Aluminum electrodes
  - NEC 250.52(B) [2011]

Bonds to Water Pipes

- Underground water pipe cannot be the sole grounding means
  - NEC 250.53(D)(2) [2011]
  - Must be supplemented by a made electrode
- Bond within 5’ of point of entry
  - NEC 250.68(C)(1) [2011]
- Connection Quality???
Water Meters & the GES

- Metering
  - Must not impede grounding path
  - NEC 250.68(B) [2011]

Gas Pipes

- Underground gas pipes
  - “shall not be used as grounding electrodes”
  - NEC 250.52(B)(1) [2011]

- Gas pipes inside facility
  - Bonding after shutoff valve
  - “If installed in, or attached to, a building or structure, a metal piping system(s), including gas piping, that is likely to become energized shall be bonded to the service equipment enclosure; the grounded conductor at the service; the grounding electrode conductor, if of sufficient size; or to one or more of the grounding electrodes used.”
  - NEC 250.104(B) [2011]
  - The problem lies with the term “likely.”
Faults to CSST

- Multiple adjacent holes of similar size
  - Frequently reported from indirect lightning
  - Adjacent arcs unlikely to exist concurrently
  - Likely serial from multiple-stroke lightning flash
  - Power system only source likely to deliver similar energy in successive arcs
  - CSST = Corrugated stainless steel tubing

CSST Arc Damage Mechanisms

- Direct Lightning Strikes
  - Fraction of lightning current flows onto CSST through arc
    - Return stroke
    - Continuing current
  - Sufficient current magnitude and duration to cause observed damage

- Indirect Lightning Strikes
  - Indirect lightning currents too small and too short duration to damage CSST
  - Indirect overvoltage (> 50 kV) causes multiple flashovers, including AC power system
  - AC power fault current flows through arc
  - Sufficient current magnitude and duration to cause observed damage
  - Power fault currents also likely cause of many fires not involving gas pipes
Solutions to Gas Pipe Damage

- Direct Strikes
  - Install at least minimal lightning protection system
  - Bond all metal services to main building and power system ground
    - Including gas pipes on building side of service
      - All gas pipes, not just CSST!

- Indirect Strikes
  - Ground ungrounded roof penetrations
    - Preferably through lightning protection system
  - Bond all metal services to main building and power system ground
    - Including gas pipes on building side of service
  - Evaluate benefit of earth-leakage relays on AC power system

Grounding Connections 2005

- NEC 250.8 [2005]
  - “Grounding conductor and bonding jumpers shall be connected by exothermic welding, listed pressure connectors, listed clamps, or other listed means. Connection devices or fittings that depend solely upon solder shall not be used. Sheet metal screws shall not be used to connect grounding conductors or connections devices to enclosures.”
Grounding Connections 2011

- Recognized attachment methods
  - NEC 250.8(A) [2011]
  - Exothermic
  - Clamp
  - Listed pressure connectors
  - Machine type or thread forming screws with at least two threads for contact (sheet metal screws not included)
- Sole use of solder not allowed
  - NEC 250.8(B) [2011]

Grounding Conductor Bonding

- Bond grounding conductor to both ends
  - NEC 250.64(E) [2011]
  - Connections must be clean and permanent
  - No sheet metal screws
Protecting Against Corrosion

- Protection of clamps and fittings
  -- NEC 250.10 [2011]
- Clean surfaces
  -- NEC 250.12 [2011]
  -- Remove paint, varnish etc.
- If not resistant - Protection from corrosion
  -- NEC 250.62 [2011]
- Kopr-Shield Compound
  -- Slurry of copper
  -- Anti-corrosive

Facility Grounding & Structural Continuity
Types of Grounding Electrodes

- Driven ground rods
  - Copper clad steel
- Plate electrode
  - Two square feet minimum - 1/4 inch thick steel (6.35mm) - 21/2' depth
- Ring ground
  - Grounding conductor buried around building perimeter
- Chemical grounds
  - Traditional rod or ring with chemical treatment
  - Specialized ground rod with integral chemical treatment
- Concrete encased electrode (Ufer ground & GRIF)
  - Metallic conductor embedded in structural concrete

Ground Ring

- Ground ring
  - NEC 250.52(A)(4) [2011]
    - Buried at least 2.5’ (762mm)
    - At least 20’ long
    - No smaller than No. 2 gauge
- Augmented ring
  - Driven rods
  - Surface radials
  - Bond to structural steel
    - At corners
    - At regular intervals
Concrete Encased Electrode

- Concrete encased electrode (Ufer ground)
  - NEC250.52(A)(3) [2011]
  - At least 20 feet (6.1m) of zinc galvanized conductor or steel reinforcing bar not less than 1/2 inch or 20 feet of bare No. 4 copper conductor
  - Encased in at least 2 inches (50.8mm) of concrete
  - Reinforcing bar may be bonded together by the usual steel tie wires
  - NEC Reinforcing bar currents
  - Exterior bars carry more current

Safety Vs Performance

- NEC 250.52(A)(3) [2011] Concrete-encased Electrode
  - “An electrode encased by at least 50mm(2in) of concrete, located within and near the bottom of a concrete foundation or footing that is in direct contact with the earth...reinforcing bars shall be permitted to be bonded together by the usual steel tie wires or other effective means.”
  - Construction practices often leave the steel reinforcing bars without grounding/bonding.
  - NEC Commentary: “If multiple concrete encased electrodes are present at a building or structure, it shall be permissible to bond only one into the grounding electrode system.
  - NEC Informational note: Concrete installed with insulation vapor barriers, films or similar items separating the concrete from the earth is not considered to be in “direct contact” with the earth
Reinforced Concrete Construction

Steel Beam Construction

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Ungrounded REBar

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Ground Floor</th>
<th>Second Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Band</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 kHz</td>
<td>2.7 µA</td>
<td>2.35 µA</td>
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<tr>
<td>1.1 MHz</td>
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<td></td>
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<tr>
<td>3.1 MHz</td>
<td></td>
<td></td>
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<tr>
<td>5.1 MHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 MHz</td>
<td></td>
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</tr>
<tr>
<td>15 MHz</td>
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<tr>
<td>Low VHF 1st oct.</td>
<td>6.49 mA</td>
<td>6.28 mA</td>
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<tr>
<td>100 Hz</td>
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<td>100 Hz</td>
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<tr>
<td>High VHF 1st oct.</td>
<td>1.88 mA</td>
<td>1.67 mA</td>
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</table>

Table 1: Interference results recorded on Element Cable

Ungrounded Metalwork

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Electrically Conductive Concrete

- Conductive components
  - Carbonaceous particles & metallic compounds
- Uses
  - Deicing & snow melting of roadways & bridges
  - Ground plane effects in data centers & barns
  - Reducing electrolysis in grounding systems
  - Reducing earth resistance in grounding systems
  - Increasing surge current capabilities
  - Enhanced screen room control (Tempest)

San Earth Enhanced Concrete

- Graphs showing resistance and surge impedance compared to copper ground wire.
- Specifications:
  - SAN-EARTH Electrode Depth: 0.5 meters
  - ELECTRIC Electrode Width: 0.5 meters
  - Surge Waveform: 1/100 μsec
  - Electrode Length: 40 meters
  - SAN-EARTH Electrode Width: 6.5 meters
Metal Cladding & Framework

- NEC 250.104(C) [2011]
  - Bonding of piping systems and exposed structural steel
  - Exposed metal building framework that is not intentional or inherently grounded and likely to be energized must be grounded per NEC 250.64.

Multiple Building Grounding 2005
- NEC 250.32 [2005] Common ac service
- If no common grounding conductor extends between the buildings with multiple circuits then each building must have an established grounding electrode system with a separate neutral-to-ground bond in each building.
- If a common grounded and grounding conductor extends between the buildings, and multiple circuits exist then a grounding terminal will be required in the connected buildings and no individual neutral-to-ground bonds will be permitted in each additional building.
- If a single circuit extends to a second building and both grounded and grounding conductors extend to the second building then no ground terminal will be required and a neutral-to-ground bond cannot be established at the second building.
Multiple Building Grounding 1

- NEC 250.32 [2005] Common ac service
  - If a common grounded and grounding conductor extends between the buildings, and multiple circuits exist then a grounding terminal will be required in the connected buildings and no individual neutral-to-ground bonds will be permitted in each additional building.
- NEC 250.32(B)(1) (2011) Buildings or Structures supplied by a Feeder(s) or Branch Circuit(s).
  - An equipment grounding conductor, as described in 250.118, shall be run with the supply conductors and be connected to the building or structure disconnecting means and to the grounding electrode(s).”
- Substantial neutral-ground voltages can develop that may adversely affect equipment in the second building.

Multiple Building Grounding 2

- NEC 250.32 [2005] Common ac service
  - If no common grounding conductor extends between the buildings with multiple circuits then each building must have an established grounding electrode system with a separate neutral-to-ground bond in each building.
- NEC 250.32(B)(1) Exception [2011]
  - “For installations made in compliance with previous editions of this Code that permitted such connection, the grounded conductor run with the supply to the building or structure shall be permitted to serve as the ground-fault return path if all of the following requirements continue to be met.”
Multiple Building Grounding 3

- Regardless what grounding is implemented, data networks extending between the buildings are at risk.
- Shielded data cables grounded at each end can end up carrying return and fault currents.
- Lightning can easily destroy linked equipment.

Lightning Protection Systems
Facility Grounding & Lightning

- Lightning treatment
  - Bond ground terminals to GES
    - NEC 250-106 [2011]
  - Air terminal conductors and ground terminals are not to be used in lieu of intended GES
    - NEC 250.106 [2011]
  - NFPA 780-2011 provides calculation for clearance from down conductors due to high voltage & ionization.
  - Formerly, 250.106 FPN 2 in earlier Code specified 6' (1.83m) clear air spacing to conductive metalwork or 3' (0.92m) spacing through wood, concrete or brick

- Low impedance paths to earth
  - Current density and path resistance determine voltage rise
  - Low dc resistance does not guarantee effective current handling
  - Surface radials may be most effective with sandy soil but well watered topsoil
  - Lightning grounding systems bonded to electrical service and to facility structural steel

Effective Earth Terminals
## Lightning Transient Characteristics

- **Return-stroke current**
  - Unidirectional impulse (30 kA, 10 x 100 μs)
  - Continuing currents (100 A, 10 mS)
- **Non-connecting upward leaders**
  - Bipolar impulse (100 A, 10 x 100 μs)
- **Induced currents**
  - Unipolar & bipolar (10 A, 2 x 50 μs)
- **Self Inductance Vs Voltage Rise**
  - 30kA return stroke with 10 meter conductor length
  - Conductor inductance; 1uH per meter
  - Voltage rise: \(-V = L \frac{di}{dt} = 10E-06(30E03/10E-06) = 30,000V\)
  - Single conductor discharge path does not work!!!

## Electrical Services
Common Facility Power Systems

- Single phase
  - 240/120
- Three phase
  - 480/277 & 208/120

Common & Problematic Service

- Three phase delta voltages (240 delta)
- Single phase voltages (240/120)
- High leg delta (crazy leg, red leg etc.)
Power/Grounding Variations

- **Floated wye**
  - Ground referenced voltages vary with leakage currents

- **Floated delta-delta**
  - Ground referenced voltages vary with leakage currents

- **Corner grounded delta**
  - One leg at earth potential, others at phase-to-phase potential

Floated Delta-Delta Service

- Absence of solid ground reference allows ground referenced voltage fluctuations
  - Load related fluctuations usually within voltage envelope of service
  - Utility related fluctuations reflect primary voltages
  - Lightning transients create severe dv/dt
Impedance Grounded Source

- High-impedance grounded neutral systems
  - NEC 250-36 [2011]
  - Typically resistive but may be resonant or inductive
  - 480 to 1000Vac three phase systems with No line-to-neutral loads
  - Ground fault detection required
  - Impedance sized to prevent arcing faults
  - Neutral-to-ground bond sized for maximum current per the grounding impedance (ANSI/IEEE 142-1991 Green Book)
  - Equipment bonding jumper (from equipment grounding conductors to the grounding impedance) shall be sized per 250.66 or 250.30B.

Wye-to-Wye Services

- Facility transformers
- Utility systems
Transferred Earth Potential

Transferred Earth Potential (TEP)

- IEEE Std 142-1991 (Green Book)
- Sections 1.6.4, 1.6.7, & 4.2.6
- Wye-to-Wye & 240/120
- Padmount applications prone to TEP

High Voltage

Equipment

Low Voltage

Ground-to-Ground Voltage

Equipment Ground Current

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TEP; Lightning Two Miles Distant

Distribution Grounding

- Feeders
- Transformers
- Separately derived sources
- Branch circuit wiring

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Feeder Grounding

- Permanent, Continuous, & Contiguous
- Ampacity sufficient for fault currents
  - Conductors
  - Raceway
  - Conduit

Grounding Conductor Sizing

- Article 250-122 [2011]
  - Wire size (AWG) tied to overcurrent protection (A)
  - If circuit length requires larger conductors, then grounding conductor size must also increase proportionally
  - In a parallel circuit each grounding conductor must be fully sized per the overcurrent protection for that parallel circuit
  - Table 250-122 conductor sizing
    - 15A = 14 cu or 12 al
    - 20A = 12 cu or 10 al
    - 60A = 10 cu or 8 al
    - 100A = 8 cu or 6 al
    - 1000A = 2/0 cu or 4/0 al
Parallel Feeders (1)

- NEC
  - NEC 310.10(H)(1) [2011]
  - Symmetrical
  - Prevent objectionable ground current
  - Use same material for conductors
  - Use same material for conduits/raceways
  - Maintain same lengths
  - Use proper conductor placement
  - 1/0 and larger
  - Grounding conductor sizing
  - NEC 250-122 [2011]

Parallel Feeders (2)

- RIGHT
- WRONG
- WRONG
Separately Derived Sources

- Neutral continuity is the key determinant. If the neutral is interrupted or switched then the source is probably separately derived.
- If separately derived then the source must be bonded to the building grounding electrode system (GES).
- Autotransformers (voltage changers) are not separately derived.

Separately Derived Sources

- NEC 250-30 [2011]
  - Major re-write in 2011
  - Transformers, UPS equipment, Motor generators
- Figure status
  - A = Not Separate -- Neutral is continuous
  - B = Separately derived -- Neutral not continuous
- Bonding
  - NEC 250.30(A)(4) [2011]
  - Water pipes or steel, but water pipes not preferred unless metal pipes are continuous and maintained
  - Bonding to water pipes in areas served
  - NEC 250.104(A)(1) [2011]
Fault Clearing

- Primary Fault
- Secondary Fault

Common Grounding Electrode

- In facilities lacking structural steel or continuous, metal water piping, a common grounding electrode may be used for separately derived equipment.
- NEC 250.30(A)(6)(a) [2011]
- Conductor sizing
  - Minimum size per is 3/0 AWG copper or 250 kcmil aluminum.
Continual Neutral Generator Setup

- Not separately derived
- 3 Pole ATS
  - Automatic transfer switch
- GES
  - Grounding electrode system

Switched Neutral Generator Setup

- Separately derived
- 4 Pole ATS
  - Automatic transfer switch
- GES
  - Grounding electrode system

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Ground Fault Detection

Ground Fault Circuit Interrupt

• Protection for personnel: NEC 210.8 [2011]
Facility Ground Fault Protection

- Service entrance
  - Protection for switchgear
  - NEC 230-95 [2011]
  - >1000 ampere
  - >150V L-G but not exceeding 600V Phase-to-phase
  - Maximum response levels: 1200 amperes & 1 second
  - Slowest and highest response levels at service entrance

- Exceptions
  - Service entrances with multiple input breakers (six or less) with ampacities equal to or less than 800 amperes.
  - Continuous industrial services where the interruption of power poses more hazard than relying upon normal overcurrent interruption
  - Services with high impedance grounded neutral systems.

- Emergency services
  - Interrupt not required; NEC 700.26 [2011]
  - Ground fault detection required - NEC 700.6(D) [2011]

Ground Fault Interrupt 1

- Polyphase -- single CT GFI -- "zero sequence"
**Ground Fault Interrupt 2**
- Polyphase -- Multiple CT GFI -- "residual"

**Ground Fault Interrupt 3**
- Neutral-to-ground bond detect - "source"
GFI Problems

- Magnetic pickup from adjacent circuits
- Voltage and current harmonics vs CT response
- EMI/RFI sensitivity
- Trips settings too low for the application
- GFI on primary of N/G bond in wye-to-wye systems
- Neutral return current flow through N/G bond CT in multiple grounding systems

Equipment Grounding
Equipment Grounding

• 250 VI & VII [2011]
  – Effectively grounded
  • NEC 250.4(A)(3) [2011]
  – Continuous & Contiguous - Capacity to safely conduct fault current
  – Limit voltage to ground (touch potential) - Ensure rapid fault clearing

• NEC 250.4(A)(5) [2011] Effective Ground-Fault Current Path
  – “Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a permanent, low-impedance circuit facilitating the operation of the overcurrent device or ground detector for high-impedance grounded systems. It shall be capable of safely carrying the maximum ground-fault current likely to imposed on it from any point on the wiring system where a ground fault may occur to the electrical supply source. The earth shall not be considered as an effective ground-fault current path.”

Equipment Performance Issues

• Complications
  – Equipment reference
  – Leakage current
  – DC common & ac ground
  – Induced chassis potentials
Grounding Discontinuity

- Neutral/Ground Voltage
  - Leakage current
  - Grounding discontinuity
  - Chassis voltage
  - Data loss
  - Equipment reset

Connection Quality

- Connections become loose with age
- Screw connections
  - Too loose -- bad
  - Too tight -- bad
  - Proper torque -- rare
- Grounding wire essential

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Equipment Emissions

- High frequency emissions
  - Pulse width modulation
  - Power factor correction
  - Clock/logic circuits
  - I/O circuits
  - Intentional RF use

- FCC limits
  - Class A (commercial)
  - Class B (residential)
  - 9kHz and higher
    - 450kHz is the lower measurement level
    - 127dBuV = 2.24Vrms

High Frequency Leakage Current

- Kirchoff's Laws prevail
  - Pulse width modulation (PWM) Noise
  - Power factor correction (PFC) Noise

- Skin effect & inductance dominate

- Ground is a path, not the terminus
Flexible Wiring Systems

- **Intended use**
  - Limited length, voltage and ampacity
  - Usual use - lighting circuits

- **Types**
  - FMC - Flexible metallic conduit
  - FMT - Flexible metallic tubing
  - Metal Clad (MC)

- **Grounding**
  - NEC 250.118(5) [2011]
  - 6 feet length (1.83m)
  - Less than 20 amperes

---

Equipment Leakage Current

- **UL limits**
  - 3.5mA power frequencies
  - Formerly 0.5 mA to 5mA
  - Portable, cord connected devices

- **Circuit Testers**
  - 2mA maximum
  - Read & follow instructions!
  - Disconnect loads before use

- **Sources**
  - Capacitive coupling
  - Wiring errors
  - I/O circuits
Receptacle Orientation

- NEC
  - No specified position
- IEEE White Book
  - IEEE Std. 602-1996
  - Section 4.2.2
  - "Ground pin or neutral blade up"
  - Reduces accidental contact with exposed live contacts.

Randomly Placed Raceway Wiring

- NEC 300.20 Induced currents in metal enclosures or metal raceways [2011]
  - "Where conductors carrying alternating current are installed in ferrous metal enclosures or ferrous metal raceways, they shall be arranged so as to avoid heating the surrounding ferrous metal by induction. To accomplish this, all phase conductors and, where used, the grounded conductor and all equipment grounding conductors shall be grouped together."
- PQ Implications: Grouping the wires will reduce coupling to adjacent circuits!
Conductor Types

Cable 1 = NEC/MC
3 phase, 3 grounds, no shield, aluminum interlocked

Cable 2 = NEC/TC
3 phase, 3 grounds, no shield, no armor, tray cable

Cable 3 = NEC/MC
3 phase, 3 grounds, no shield, galvanized interlocked steel

Cable 4 = NEC/MC
3 phase, 1 ground, no shield, aluminum continuous

Cable 5 = NEC/MC
3 phase, 3 ground, copper tape spiral shield, galvanized steel interlocked

Cable 6 = IEC/MCMK
3 phase sectored symmetrical, no grounds, copper tape & wire shield, no armor

Cable 7 = IEC/MCMK
IEC 3 phase sectored symmetrical, 1 ground, copper tape & wire shield, no armor

Cable 8 = NEC/MC
3 phase, 3 grounds, no shield, aluminum continuous

Symmetrical Cable Variations

- Equal inductive coupling
  - Magnetic field
- Equal capacitive coupling
  - Electric field
- Shielding controls common mode emissions
- 400Hz applications require symmetrical cabling
Parity Ground Conductor Sizing

- Parity sizing
  - Grounding conductor the same size as current carrying conductors
  - Not a code requirement
  - Normally a vendor requirement
  - Attempt to improve equipment reference
  - Larger conductor size
    - May magnetically or capacitively couple
    - Use may increase ground current

Parity Sizing Problem
Reference Grounding

Computer rooms
Raised floor environments
Data processing centers

A Tale of Two Towers

- 500MCM conductors added to "improve reference"
- Added grounding adversely affected equipment
Interference Signals in Equipment Wiring

- Federal Information Processing Standards Publication
  - FIPS PUB 94 -- 1983 September 21 -- Now discontinued
  - US Department of Commerce - National Bureau of Standards
- Guideline on Electrical Power for ADP Installations

Ground Voltage Rise (200' Romex)

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Ground Voltage Differentials

- Energy Generator
- Tektronix THS720
- Receptacle
- 50 Feet
- 150 Feet
- Signal Reference Grid (SRG)

- FIPS PUB 94
  - 4 AWG copper conductors -- clamped intersections
    - Not a bad reference grid
  - 1" metal braid and pedestal clamps
    - A better reference grid

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4'x4' Reference Grid

- SRG intersection points not bonded together
- Less effective than would be with good connections.

Connections to Reference Grid

- Short flat straps best
- Metal braid OK
- Bond at opposite corners of equipment
- Bond all equipment within room
Signal Reference Grid

- A very good reference grid

Information Technology Rooms

- Article 645 of NEC
  - NEC 645.15 Grounding [2011]
    - Power systems that supply power through receptacles or cable assemblies supplied as part of the system are not considered as separately derived.
    - Signal reference systems must be bonded to the equipment grounding system provided for the information technology room.

- Recommended References
  - NFPA 75-1995
    - Standard for the Protection of Electronic Computer/Data Processing Equipment
  - IEEE Std. 1100-1992 -- Emerald Book
    - IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment
Communications Grounding

Point of Entrance (POE) Grounding

- Article 800 [2011]
  - Communications Circuits
- Article 810 [2011]
  - Radio & TV Equipment
- Article 820 [2011]
  - Community Antenna Television and Radio Distribution System
- Article 830 [2011]
  - Network Powered Broadband Communications Systems
Communications Grounding 2002-2005

- NEC recommendation
  - Sheath grounding at point of entrance NEC 800-33 [1996, 1999, 2002]
    - The metallic sheath of communications cables entering buildings shall be grounded as close as practicable to the point of entrance or shall be interrupted as close to the point of entrance by an insulating joint or equivalent device.
    - This entire reference was removed in 2011 Code.
  - NEC 800.2 Definitions [2011]
    - Within a building, the point at which the wire or cable emerges from an external wall, from a concrete floor slab, or from a rigid metal conduit or an intermediate metal conduit grounded to an electrode in accordance with NEC 800.100(B) [2011].

Cable Sheath Grounding - 2005

- NEC 800.40(B)[2002] & 800.100(B)[2005]
  1 Building or structure grounding electrode system
  2 Grounded interior metal water piping system within 5 ft. from its point of entry into the building [per 250.52 [2005]
  3 The power service accessible means external to enclosures as covered in 250.94
  4 The metallic power service raceway
  5 The service equipment enclosure
  6 The grounding electrode conductor or the grounding electrode conductor metal enclosure
  7 The grounding conductor or the grounding electrode of a building or structure disconnecting means that is grounded to an electrode as covered in 250.32.
Communications Grounding 2008

- Sheath grounding at point of entrance NEC 800.93(A)
  - The metallic sheath of communications cables entering buildings shall be grounded per 800.100 as close as practicable to the point of entrance or shall be interrupted as close to the point of entrance by an insulating joint or equivalent device.

- Grounding Methods 800.100 & 820.110
  - Grounding conductor shall be listed and insulated.
  - Grounding conductor shall be copper or other corrosion resistant material – stranded or solid.
  - Grounding conductor shall not be smaller than 14AWG and should be sized to match the current carrying capacity of the shield. It need not be larger than 6AWG.
  - The conductor shall not be longer than 6.0m (20 ft). If longer then a separate driven ground rod shall be installed and a bonding jumper should be installed to the building grounding means.
  - The conductor shall be run in a straight line as practicable.
  - If intersystem grounding exists between buildings then the grounding should connect to the intersystem grounding.

Telecom Entrance

- Telecom Grounding
  - Bond to GES
    - Sheath
    - Protectors
  - Never bond to the SRG!!
  - Bond at point of entry
    - Penetration through wall or floor
  - Code Exception
    - Bond at point where cable emerges from rigid conduit
    - This practice brings unwanted interference into building
Ground Windows

- Theory
  - All grounding contacts single point
  - Create equipotential grounding
- Reality
  - DC concept
  - Path for circulating currents
  - Small scale application

Telecom Demarcation

- Demarcation is not always the point of entrance
  - Typical - Point where cable emerges from rigid conduit
- Demarcation
  - Point of transfer from Telecom supplier to facility
- Over-voltage-protectors (OVP)
  - Gas tube
  - Carbon block
Protector & Sheath Grounding

Telco Protector Grounding 1

- Will Not Work -- BAD!!!!
- Common -- May Not Work
Telco Protector Grounding

- Better -- Might Even Work!
- Separate grounding paths
  - Sheath & protectors
  - Grounding point part of building grounding electrode system
- Placement is critical
  - Too close to load and secondary protectors will fire rather than intended primary protectors

**Coupling to Communications**

- Common trench
  - Bell recommendations
    - 1 foot separation minimum
    - Bonding every 1K feet
- TIF
  - Telephone Influence Factor
  - Harmonic content affects data and voice signals
Telco Sheath Current

- Sheath Grounded
  - 2.8 Amperes RMS
- Sheath Not Grounded
  - 15 Volts RMS
- Interference worse without sheath grounding

Shield Grounding Dilemma

- Grounding concerns
  - Ground one end or both ends?
  - Ground loops
  - Emissions?
  - Data integrity?
- Grounding Realities
  - Floated at one end causes potential
  - Grounded at both ends causes current
Shield Grounding Surge Test

- 8 x 20 uS Pulse
  - 1000Vpk
  - 500Apk
- 100kHz Ringwave
  - 6000Vpk
  - 500Apk

Test Pulse

Coax Current = 42Apk
Center pin voltage = 4.88Vpk
Open Shield

Coax Current = 4.4Apk
Center pin voltage = 180Vpk

2" Drain Wire (Pig Tail)

- 8 x 20 uS Unipolar
- Coax Current = 41.6Apk
- Center pin voltage = 16Vpk
- 100kHz Ringwave
- Coax Current = 35.2Apk
- Center pin voltage = 72Vpk
**Shield Grounding Concerns**

– Shields are intended to carry current
  • Current must flow to chassis without interruption
– Floated shields
  • May flash over
  • May leak high frequencies into "protected" circuits
– FCC testing
  • Usually performed with shields grounded at each end
– Data circuit may be grounded at both ends
  • RS-232 & RS-423

**MOV**

Coax Current = 27.2Apk
Center pin voltage = 58Vpk
Grounding Complications

Sensitive Equipment
Isolated grounding
Supplemental grounds

Sensitive Electronic Equipment

- **NEC 647 [2011]**
  - Originally intended for audio studios -- now Industrial/commercial applications
- **Requirements**
  - Separately derived system
  - 2 pole breakers
  - 2.5% & 1.5% feeder/branch circuit voltage drop
  - All 15 & 20 amps circuits must be GFCI protected
  - Ground bus label -- Technical Power
  - IG receptacles allowed
  - Three phase applications require the use of 6 phase transformers
Isolated Grounding (IG)

- Isolated grounding receptacles
  - NEC 250-146(D) [2011]
- Isolated grounding passing through panelboards
  - NEC 408.40 Exception [2011]
- Grounding must terminate within the derived service

IG vs Regular Receptacle

- IG Receptacle
- Regular Receptacle
IG Application

- IG Normal application
  - IG passes back through panels to service origin.
  - Grounding wire size must increase to match ampacity of panels it passes through.

- Derived service
  - IG must terminate at the derived service.
  - Stepdown transformer is the derived service, not the main electrical entrance.

IG Position – Reality Check

- Normal distribution wiring spreads incoming signals across many circuits.
- IG circuit extending back to service entrance assures larger signals at "protected" load.
IG Circuit Coupling

- \( V = L \frac{di}{dt} \) -- mutual inductance
- Functions as a 1:1 transformer
- IG use may contribute to "ground loops"

**IG Circuit Induced Voltage**

- Chassis voltage and data cable current
- Phase current & induced chassis voltage
IG Ground Referenced Oscillation

Common IG Errors

- Top figure
  - IG run separately from current carrying conductors
  - IG does not terminate at the derived service

- Bottom figure
  - IG grounding is separate from facility grounding.
  - Supplemental grounding at IG cannot serve as the sole grounding
Isolated Ground Path Problem

- Common mode voltage propagation - Source is equipment leakage current due to an overloaded EMI/RFI power supply filter.
- Effects include lockup, reset & blown serial ports.

Isolated Grounding Effects

- Destructive Common mode voltage
- Voltages develop across I/O circuits
**Auxiliary (Supplementary) Grounding**

- Use is permitted
  - NEC 250.54 [2011]
  - Earth is not an effective grounding means and cannot be the sole grounding means as specified in 250.4(A)(5) [2011] and 250.4(B)(4) [2011]
  - Supplemental grounding need not meet the electrode grounding provisions of NEC 250.50 or 250.53(C) [2011]

**Auxiliary Grounding**

- Supplemental grounding provides a path for external ground referenced interference to enter a facility
- Avoid use if at all possible
Supplementary Grounding Solutions

- Re-derive & Re-reference
- Bond to facility reference

DC Grounding
DC Grounding Connections

- NEC 250.162(A) [2011]
  - Two wire, direct-current systems
  - Operating voltage greater than 50V but less than 300V shall be grounded
- NEC 250.162(B) [2011]
  - Three wire, direct-current systems
  - The neutral shall be grounded
- NEC 250.164 [2011]
  - Point of connection for direct-current systems
  - Grounding must occur at the first system disconnecting means and not at individual services or at any point of use in the premises wiring
- NEC 250.166 [2011]
  - Size of Direct-Current Grounding Electrode
- NEC 250.169 [2011]
  - Ungrounded Direct-Current Separately Derived Systems

Isolated Vs Contiguous Grounding

- A = Isolated grounding
  - DC return grounded independently
  - Voltage differential possible between AC power and dc system
- B = Contiguous grounding
  - DC bonded to ac grounding means
  - DC grounding run with ac conductors
Separate DC Grounding Conductor

- DC grounding tied to main facility grounding
- DC grounding conductor run independent of ac conductors
- Attempt to prevent cross-talk between ac and dc conductors

Multiple DC Reference

- Extra dc reference points turns grounding into a dc path
- DC current flows everywhere (inversely proportional to the dc resistance values).
DC Systems and SRG

- Provides an installation consistent with the IEEE Emerald Book

DC Bus Grounding

- A = Isolated grounding
  - DC return grounded independently
  - Voltage differential possible between AC power and dc system
- B = Contiguous grounding
  - DC bonded to ac grounding means
  - DC grounding run with ac conductors
Separate DC Grounding Conductor

- DC grounding tied to main facility grounding
- DC grounding conductor run independent of ac conductors
- Attempt to prevent cross-talk between ac and dc conductors

Multiple DC Reference

- Extra dc reference points turns grounding into a dc path
- DC current flows everywhere (inversely proportional to the dc resistance values).
Bonding Dual Power Sources

- Dual power sources used to ensure redundancy.
- Dual sources can be affected by “ground skew.” Ground skew refers to voltage differences between sources.
- Bonding the sources together as well as bonding to the BGES helps reduce ground loop currents through equipment powered from the dual sources.

AC & DC Sources

- AC & DC sources must also be bonded to the BGES to reduce common mode potentials in equipment powered from the sources.
- Supplemental DC return bonds to ground cannot be placed at equipment. This causes unwanted DC current flow throughout the facility.
**DC Bus Grounding**

- **A** = Isolated grounding
  - DC return grounded independently
  - Voltage differential possible between AC power and dc system
- **B** = Contiguous grounding
  - DC bonded to ac grounding means

**Common Mode Problems**

- AC reference?
- DC reference?
- Potential between systems?
Separate DC Grounding Conductor

- DC grounding tied to main facility grounding
- DC grounding conductor run independent of ac conductors
- Attempt to prevent cross-talk between ac and dc conductors

Multiple DC Reference

- Extra dc reference points turns grounding into a dc path
- DC current flows everywhere (inversely proportional to the dc resistance values).
SRG & DC Systems

SRG & AC Systems

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Misapplied SRG

- Attempt to reference equipment independently of facility grounding.

- Violates NEC.
  - SRG not bonded to BGES per NEC 645.
  - SRG serves as sole grounding means independent of SRG.

Unwanted Ground Current
Utility Distribution Related

- Stray Current
- Open Neutral
- Interconnected utility neutral and communications grounding
- Coupling to communications circuits

Utility Stray Vs Open Neutral Currents
Interconnected Utility Neutrals

Utility Transformers

- L/G Primary
- L/L Primary

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Facility Related Ground Current

- N/G bonds
- N/G reversals
- Direct use of grounding as a return
- Coupling and induction

Neutral/Ground Bonds

LEGEND:

- **Load Current**
- **Neutral Return Current**
- EGC = Equipment Ground Conductor

Earth Ground (Main Building Electrical Ground)

"Isolated" Ground, Ground Rod, Cold-Water-Pipe Ground, etc.
End User Solution to Ground Loops

- Disconnected N/G bond at power distribution unit
- Violates code
- Safety hazard
- Performance problem
- Certainly not the correct solution to a problem

Neutral and Ground Problems

- Crossed neutrals
- N/G reversal
Grounding Conductors & Current

- Grounded conductor problem
- Induced current due to grounded conductor placement

Interference & Ground Loop Measurements
Tracing Ground Currents

LEAKAGE CURRENTS
COMMON MODE EMISSIONS
LONGITUDINAL GROUND CURRENT

Zero Sum Measurements
Compare Sum & Neutral

Summing Bus Bars
Checking Branch Circuits

- N/G bond is the ground fault return point
- Current patterns help ID sources

Check Transformers
**AC Gaussmeter**

- Measures flux density
  - Milligauss & MicroTeslas
- Problems arising from flux density
  - CRT waver
  - Induced current flow in data cables
- Great tool to ID ground loops
  - Easy to use
  - Single axis vs triaxial

**Digital Storage Oscilloscope**

- Digitizing rate -- 100MS/s & higher
- Bandwidth -- 100MHz & higher
- Vertical resolution -- 8 bit or better
- Single channel triggering
  - Some scopes may have or-gate triggering on multiple channels
- Single ended signal acquisition
  - Differential measurements require multiple channels or external devices.
- Extended monitoring capabilities
  - Metratek software
    - Stores triggered waveforms & rearms scope
    - DFT of acquired waveforms
High Frequency Measurements

- Everything grounded - interference voltages are small - difficult to distinguish from normal equipment operating noise.
- Currents much larger, easier to measure
- Couple using high-frequency transformer
- Digital storage oscilloscope and spectrum analyzer

Conventional Current Transformers

- Fluke, AEMC
- Multiple ranges
  - 1mV/A
  - 10mV/A
  - 100mV/A
- Voltage output versus current output
Hall Effect Current Probes

- AEMC, Fluke
- May have multiple ranges
- Provides a proportional voltage output for DC currents
- AC currents can also be recorded
- Requires zero adjustment
- Calibration required

High Frequency CTs

- Commercial products
- Manufacturers
  - EMCO, Tegam, Fischer Custom Communications, Amplifier Research
- Intended use
  - 50 Ohm interface
  - Scopes & spectrum analyzers
- Range
  - 100kHz to 100MHz
  - 1MHz to 1GHz
Line Decouplers

- Oneac, PowerVAR
- Depending upon model may have
  - L/N low frequency output
  - High frequency L/N and/or N/G output
  - Bandwidth typically from kHz to low MHz
- Isolates scope from measurement point
- Converts single ended input into differential

Plate Antenna

- Construction
  - Metal top and bottom
  - Plastic sides
  - Probe
    - 10MegOhm – 10x
    - Total capacitance 35pF
  - Intended use
    - Digital storage scopes
    - Record radiated signals, cable potentials, floor potentials
Commercial Loop Antenna

• Manufacturers
  – EMCO, Antenna Research
• Frequency range
  – depends upon model

Ferrite Rod Antennas

• Construction
  – 6” ferrite rod
  – 100 turns of 24 gauge telephone type wire
  – BNC fitting
• Termination provided by scope
• Frequency range
  – 50/60Hz to low kHz
Hioki 3145 Noise Logger

Color LCD Noise Level Display
View instantaneous values of measured noise, and noise level variations over time.

LAN Connector (10BASE-T)

PC Card

ENC Jack
For the CLAMP ON NOISE SENSOR or other voltage input, from antenna or short-range magnetic probe.

CLAMP ON NOISE SENSOR (Option)
Measure noise current without direct connection.

SRG Noise Currents
Largest Signal

- Voltage from chassis to plug strip mounted on the cabinet with isolated plastic standoffs.
- Equipment in cabinet mounted on teflon glides.
- Solution was to bond the plug strip to the cabinet.

Conclusion
Grounding Items to Avoid

- Supplementary grounding at equipment
  - Parallel to service entrance grounding
- Conduit killers
  - No grounding wire – loose connections
- Needless IG use
  - Grounding bypass of separately derived source
- Grounding "antennas"
  - Daisy chain grounding wires in workstation clusters
  - Lift or defeat data cable shielding of disconnect pin 7 for RS-232-C
- N/G bond removal at transformers to stop ground loops
- Avoid grounding differentials within facilities
  - Control interference at point of origin

Grounding Do's

- Augment service entrance grounding when needed
  - Match the surroundings
- Ensure grounding at wye-to-wye service transformers
- Ensure grounding for padmount transformers inside facilities
- Use parity grounding for branch circuits
- Integrate facility grounding into a "Grounding electrode system"
- Remember Kirchoff's laws
- Use Faraday concept for facility grounding
- Employ reference grids in raised floor environments
Concluding Statements

- Current Flows in Paths - Kirchoff's Laws Prevail
- Ground is a path - not a terminus - and understanding the paths is the key to good grounding
- Interference can compromise good grounding – if something looks ugly – fix it!
- Electrical Codes cannot be compromised by grounding practices