Facility and Equipment Grounding - 2005

Course: PQE203

Presented by:

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Grounding

- Earthing
  - –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.

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

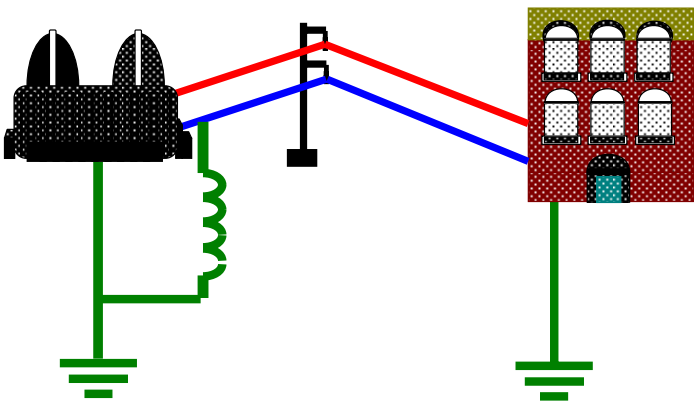
- Three or four letter designation
- First letter is supply earthing
  - –T indicates one or more points directly earthed
  - –I indicates the supply is not earthed or is earthed through a fault limiting impedance
- Second letter indicates installation earthing
  - –T indicates that conductive metalwork 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

Earthing Systems 2

- 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 at several points (US Convention)

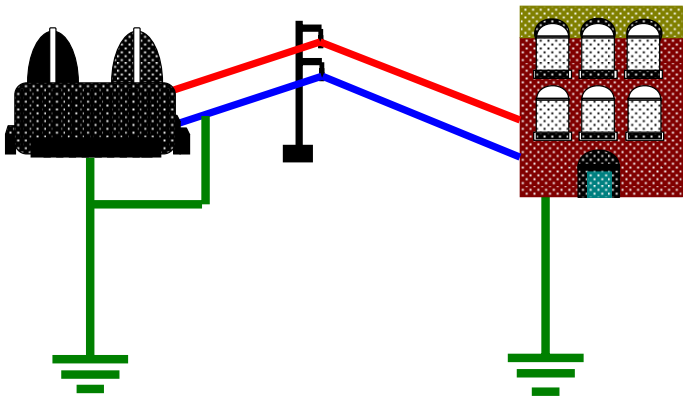
IT Earthing System

- Utility not earthed or earthed via impedance
- Facility earthed independently of utility



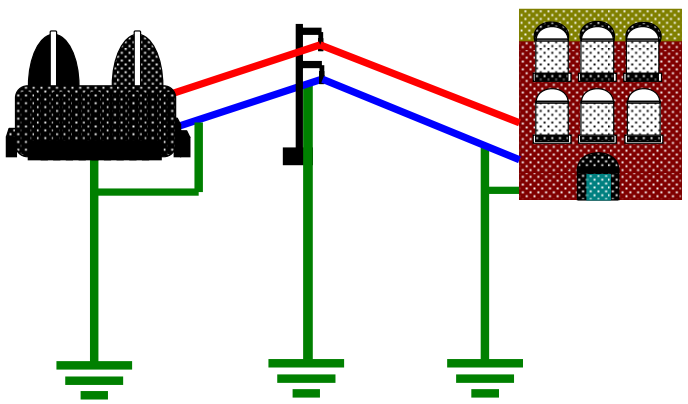
TT Earthing System

- Utility directly earthed
- Facility earthed independently of utility



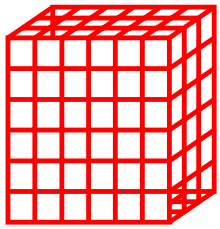
TN Earthing System

- Utility directly earthed (and frequently in US)
- Facility grounding bonded to earthed utility

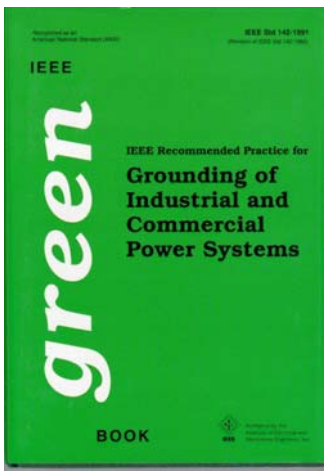


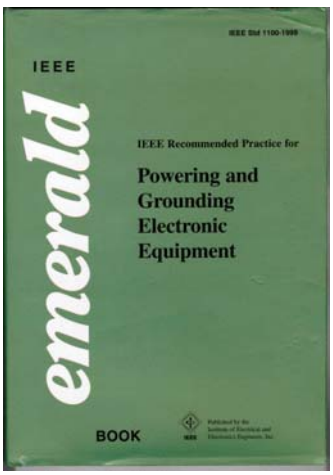
Grounding Concepts

- The effects of impedance & frequency
- Faraday cage & Kirchoff's Voltage and Current Laws
- National Electrical Code
  - **76 different references in the 2002 code**
  - **Extensive changes to Articles 250 and 800**
  - **Many exemptions for grounding of cord and plug connected equipment in NEC 250.114 [2002 - 2005]**



Essential Grounding References



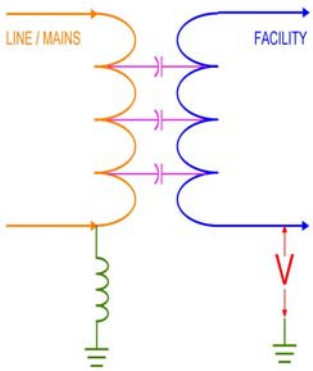


Earthing/Grounding Means

Grounding Electrode System

The Roles of Grounding

- General requirements
  - –NEC 250.4 [2002 & 2005]
  - –Establish voltage reference
  - –Limit touch potential
  - –Clear electrical faults
  - –Carry lightning currents
- Performance issues
  - –Provide equipment reference
  - –Provide RF/ESD discharge path

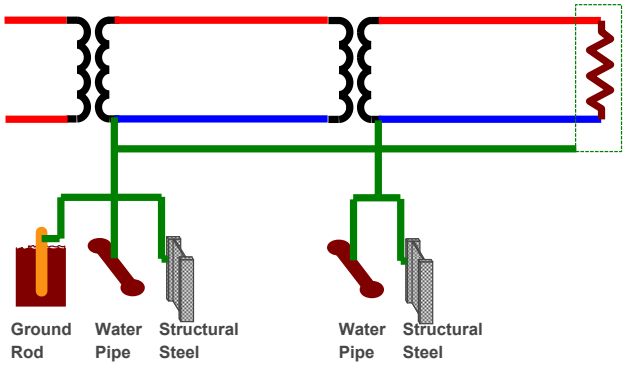


Grounding Electrode System (GES)

- National Electrical Code Article 250
  - –Electrical service entrance bonding
    - •NEC 250-5 [1996] & NEC 250-20 [1999 - 2005]
    - •Incoming utility neutral or internal facility neutral
  - –Grounding electrode system - NEC 250.50
    - •Structural steel where effectively grounded
    - •"All grounding electrodes as described in 250.51(A)(1) through (A)(6) 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

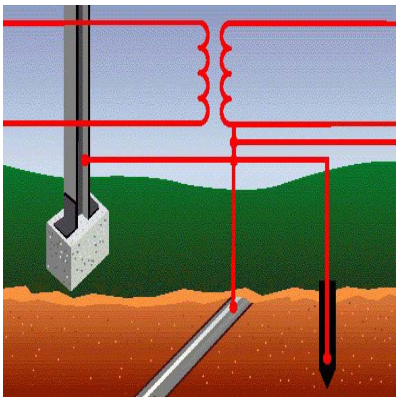
Bonds to Water Pipes

- –Underground water pipe cannot be the sole grounding means
  - •NEC 250-(a)(2) [1999] & NEC 250.53(D)(2) [2002-2005]
  - •Must be supplemented by a made electrode
  - •Bond within 5' of point of entry



Grounding Electrode System 2

- GES - NEC 250-50 [2005]
  - **Water Pipe - NEC 250.52(A)(1)**
  - **Driven Ground - NEC 250.52(A)(5)**
  - **Structural Steel - NEC 250.52(A)(2)**
- Grounding electrode conductor must be continuous
  - **NEC 250.64(C) [2002 & 2005]**
- Not allowed
  - **Metal underground gas pipes**
  - **Aluminum electrodes**
  - **NEC 250.52(B) [2002 & 2005]**

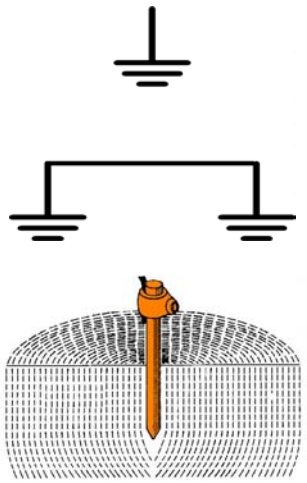


Grounding Electrode System 3

- Metering
  - Must not impede grounding path
  - NEC 250-50(a)(1)[1999]
  - NEC 250.53(D)(1) [2002 & 2005]
- Underground gas pipes
  - Not part of GES
  - NEC 250-51(a) [1999]
  - NEC 250.52(B)(1) [2002 & 2005]
- Gas pipes inside facility
  - Bonding after shutoff valve
  - NEC 250-104(b)[1999 - 2005]

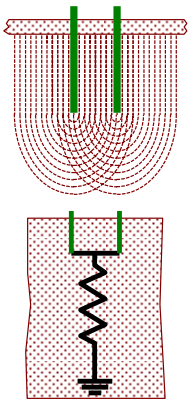
Grounding Quality

- **NEC**
  - **25 Ohms or supplement**
  - **NEC 250-84 [1996]**
  - **NEC 250-56 [1999 - 2005]**
- **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**



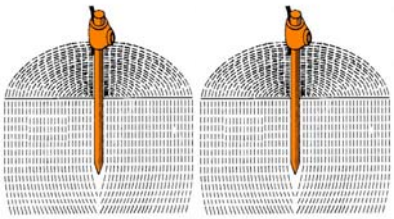
Grounding Sphere of Influence

- Common Grounding Electrode
  - NEC 250.58 [2002 - 2005]
  - 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) [2002 - 2005]



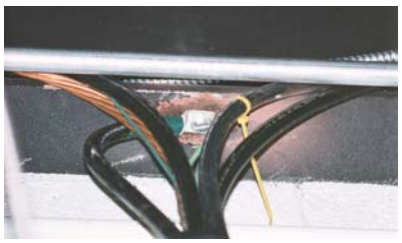
Grounding Sphere of Influence (2)

- 6 foot minimum separation
  - –NEC-250-52 [1999] & NEC 250.56 [2002 - 2005]
- 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



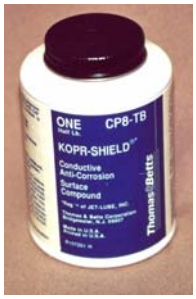
Grounding Connections

- 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."



Protecting Against Corrosion

- Protection of clamps and fittings
  - –NEC 250-110 [1999] & NEC 250.10 [2002 - 2005]
- Clean surfaces
  - –NEC 250.12 [2002 - 2005]
  - –Remove paint, varnish etc.
- Protection from corrosion
  - –NEC 250-62 [1999]
  - –NEC 250.62 [2002 - 2005]
- Kopr-Shield Compound
  - –Slurry of copper
  - –Anti-corrosive



Ground Rod Attachment

- Recognized attachment methods
  - NEC 250.8 [2002]
  - Exothermic
  - Clamp
  - Listed pressure connectors
  - Sheet metal screws or the sole use of solder not allowed

Grounding Conductor Bonding

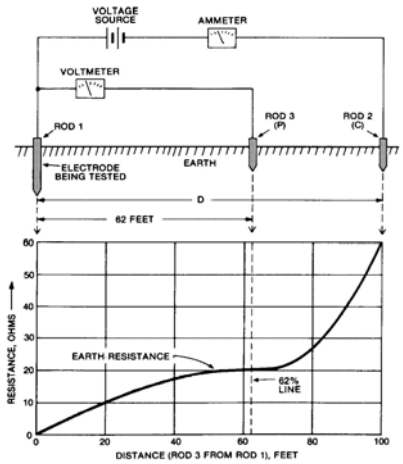
- Bond grounding conductor to both ends
  - NEC 264(e) [1999]
  - NEC 250.64(E) [2002 - 2005]
  - Connections must be clean and permanent
  - No sheet metal screws

Ground Rod Protection

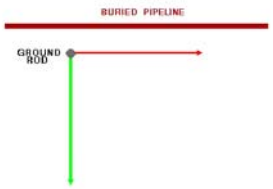
- Exposed/Corroded

- Enclosed/protected

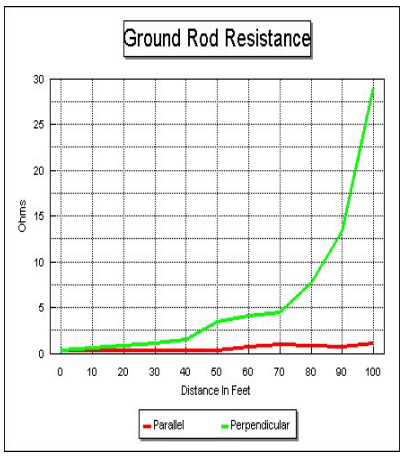
Grounding Measurements - 3 Pt.



3 Pt. Measurement Complications

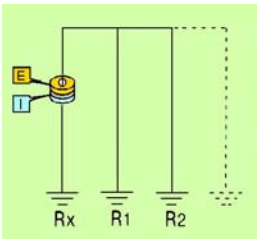


Earth Ground Resistance Testing for Low Voltage Power Systems
Kenneth M. Michaels
IEEE Transactions - Industry Applications
Jan/Feb 1995



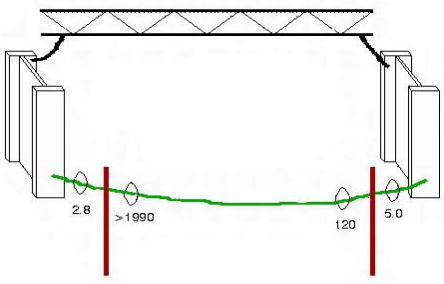
2 Pt. Clamp-on Measurements

- 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



Earth Ground Resistance Testing for Low Voltage Power Systems
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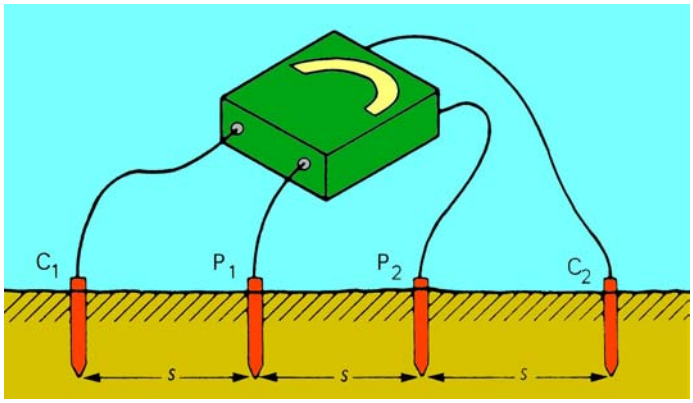
Four Point Resistivity Measurement

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



Soil Type vs Resistivity

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

Soil Type	Average Resistivity Ohms per CM	5/8" x 10' Driven Rod Ohms Resistance
Well graded gravel, gravel-sand	60,000 -- 100,000	180 -- 300
Loose gravel, gravel-sand	100,000 -- 250,000	300 -- 750
Clayey gravel, sand-clay	20,000 -- 40,000	60 -- 120
Silty sands, sand-silts mixtures	10,000 -- 50,000	30 -- 150
Clayey sands, sand-clay mixtures	5,000 -- 20,000	15 -- 60
Silty or clayey fine sands w/plasticity	3,000 -- 8,000	9 -- 24
Fine sandy or silty soils, elastic silts	8,000 -- 30,000	24 -- 90
Gravelly clays, sandy clays, silty clays, lean clays	2,500 -- 6,000 (moisture related)	17 -- 18 (moisture related)
Inorganic clays, high plasticity	1,000 -- 5500 (moisture related)	3 -- 16 (moisture related)

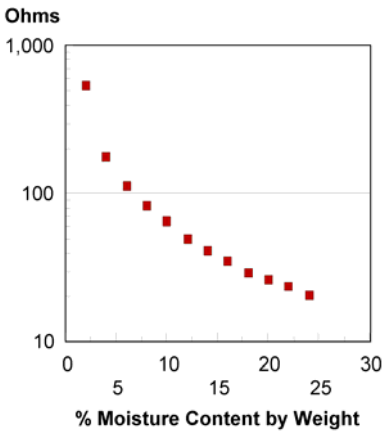
Soil Resistivity Vs Water Content 1

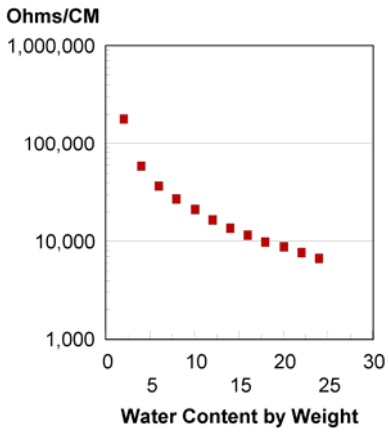
- IEEE Std. 142-1991

Moisture Content (by weight)	Resistivity Ohms/cm Sandy Loam
2	185,000
4	60,000
6	38,000
8	28,000
10	22,000
12	17,000
14	14,000
16	12,000
18	10,000
20	9,000
22	8,000
24	7,000

Effects of Moisture Content

- 8 Foot Rod
- Sandy Loam



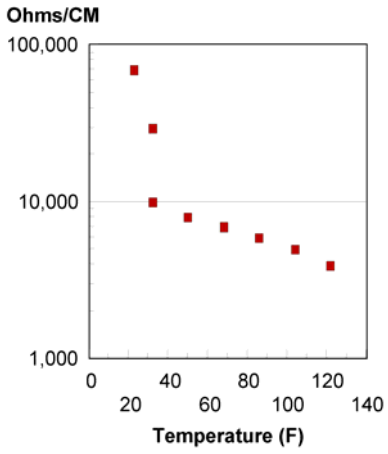


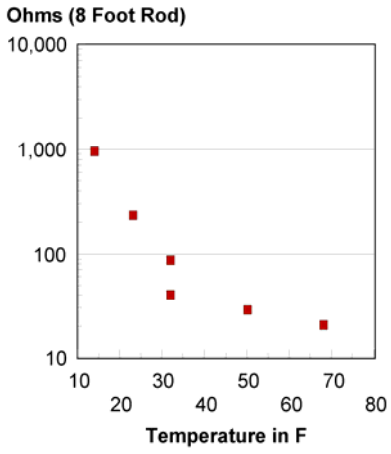
Soil Resistivity vs Temperature

- IEEE Std. 142-1991 (Green Book)

Temperature (centigrade)	Temperature (Fahrenheit)	Resistivity Ohms/cm
-5	23	70,000
0	32	30,000
0	32	10,000
10	50	8,000
20	68	7,000
30	86	6,000
40	104	5,000
50	122	4,000

Effects of Temperature





Soil Resistivity vs Salt Content

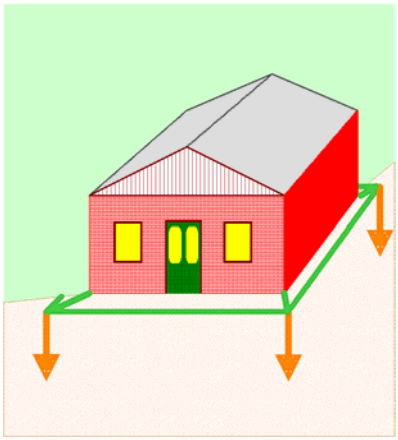
- Soil type -- sandy loam - moisture content 15% by weight -- temperature - 17°C
- Salts (copper sulfate, sodium carbonate etc.) must be EPA or local ordinance approved for use
- AEMC -- ***Understanding Ground Resistance Testing***

Added Salt % by weight of moisture	Resistivity Ohms/centimeter
0	10700
0.1	1,800
1.0	450
5	190
10	130
20	100

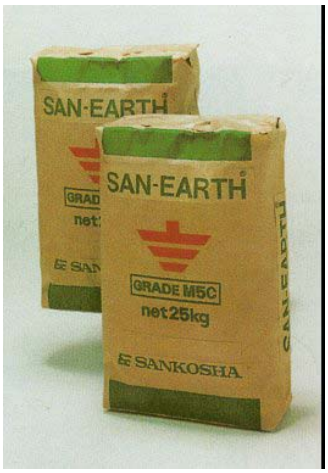
Facility Grounding & Stuctural Continuity

Ground Ring

- Ground ring
  - NEC 250-81 [1996]
  - NEC 250-50(d) [1999]
  - NEC 250.52(A)(4) [2002 - 2005]
    - 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



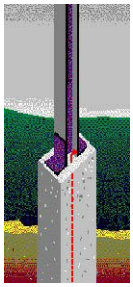
Enhanced Conductivity Concrete



Concrete Encased Electrode

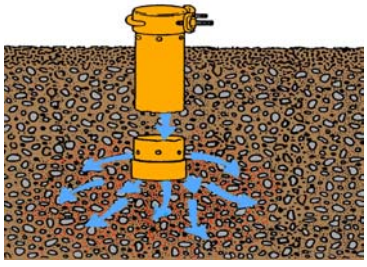
- Concrete encased electrode
  - –Ufer ground
  - –At least 20 feet (6.1m) of zinc galvanized conductor or steel reinforcing bar not less than 1/2 inch or 20 feet of bare No. 4 copper conductor
  - –Encased in at least 2 inches (50.8mm) of concrete
  - –Reinforcing bar may be bonded together by the usual steel tie wires
  - –NEC 250-81-1996 & NEC 250-50(d) [1999] & NEC 250.52(A)(3) [2002-2005]
- Required use - NEC 250.50 [2005]
- Reinforcing bar currents
  - –Exterior bars carry more current
  - –Surge current per foot (psihq.com)

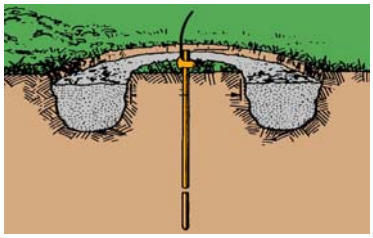
Rebar Diameter In Inches	Surge Amperes Per Foot
–.375	3400
–.500	4500
–.625	5500
–.750	6400
–1.000	8150



Chemical Treatments

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



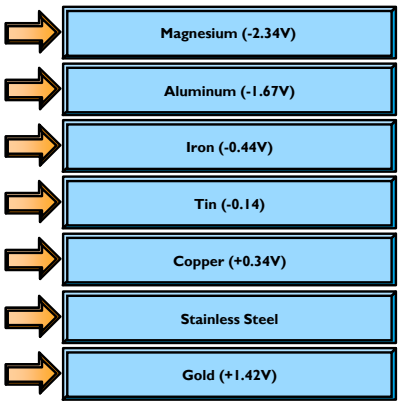


Types of Grounding Electrodes

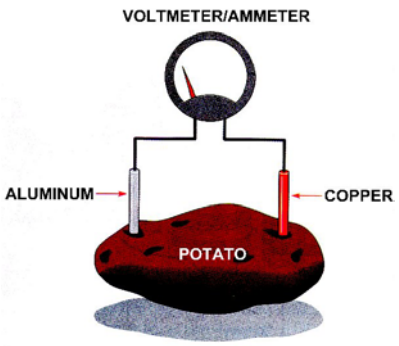
- Driven ground rods
  - Copper clad steel
- Plate electrode
  - Two square feet minimum - 1/4 inch thick steel (6.35mm) - 21/2' depth
- Ring ground
  - Grounding conductor buried around building perimeter
- Chemical grounds
  - Traditional rod or ring with chemical treatment
  - Specialized ground rod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

Electrolysis

- Electrochemical series

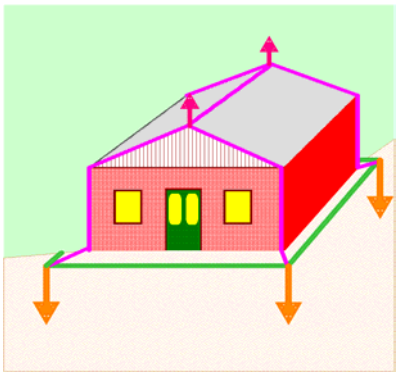


- Galvanic Battery



Facility Grounding & Lightning

- Lightning treatment
  - –Bond ground terminals to GES
    - •NEC 250-106 [1999 - 2005]
  - –Air terminal conductors and ground terminals are not to be used in lieu of intended GES
    - •NEC 250.60 [2005]
  - –250.106 FPN 2
    - •6' (1.83m) clear air spacing to conductive metalwork or 3' (0.92m spacing through wood, concrete or brick)
  - –NFPA 780-2004 (4.21.2) provides calculation for clearance from down conductors due to high voltage & ionization



Effective Earth Terminals

- 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

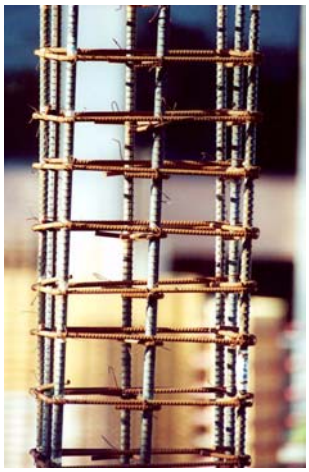
Lightning Transient Characteristics

- 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 = Ldi/dt = 10E-06(30E03/10E-06) = 30,000V
  - –Single conductor discharge path does not work!!!

Concrete Floors

- Construction practices often leave the steel reinforcing bars without grounding/bonding
- NEC 250.52(A)(3) [2005] 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."

Reinforced Concrete Construction



Steel Beam Construction

Metal Cladding & Framework

- NEC 250.104(C) [2005]
  - –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 Power/Grounding

- NEC 250.32 [2002 - 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.