University of Idaho
College of Engineering

ECE 528 – Understanding Power Quality

http://www.ece.uidaho.edu/ee/power/ECE528/

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Lecture 25

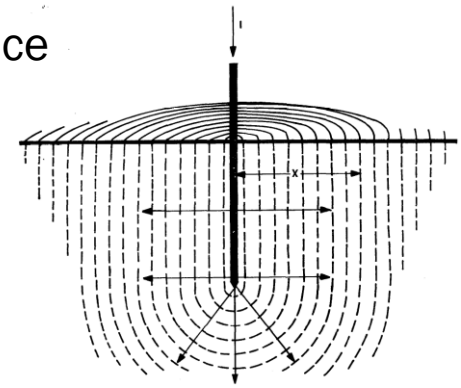
University of Idaho

Today…

- More wiring and grounding
  - Ground rods, step and touch potentials
  - The GFCI – Ground Fault Circuit Interrupter
  - Isolated grounds
  - Separately derived systems
  - Ground loops

Calculating ground rod resistance

$$R_{rod} = \frac{\rho}{2 \cdot \pi \cdot L} \cdot \left(\ln\left(\frac{4L}{a} \right) - 1 \right)$$



ρ soil resistivity in Ω-m (Ohm-meters)
L rod length in meters
a rod radius in meters
(1 Ω-m = 100 Ω-cm)

Equation is valid for L>>a

Approximate Soil Resistivity:

Wet Organic Soil:	10 Ω-m
Moist Soil:	100 Ω-m
Dry Soil:	1,000 Ω-m
Bed Rock:	10,000 Ω-m

From MIL-HDBK-419A, 1987

Calculating earth surface potentials near a ground rod

$$U_g(y) = \frac{I_g \cdot \rho}{2 \cdot \pi \cdot L} \cdot \ln\left(\frac{\sqrt{L^2 + y^2} + L}{y} \right)$$

I_g = current through ground rod
y = distance from ground rod (m)

$U_g(y)$ is the voltage on the earth surface, at distance y from the ground rod, with respect to "remote" earth.

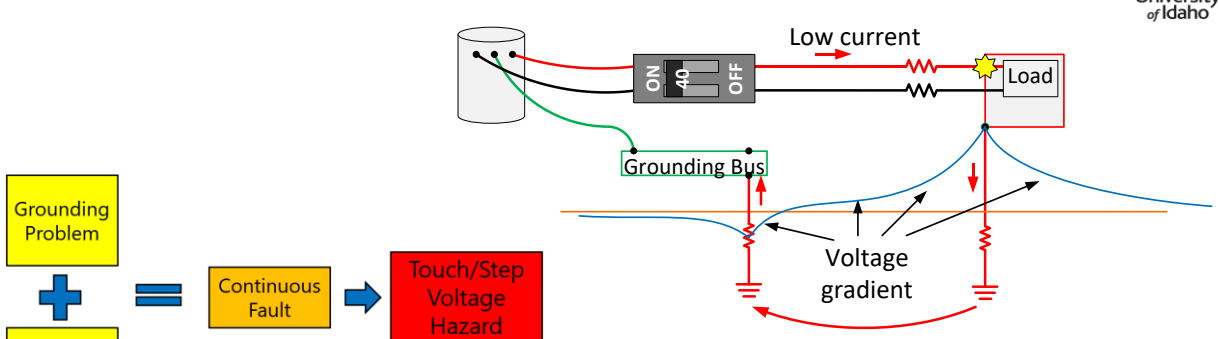
Step voltage between two points: $U_g(y_1) - U_g(y_2)$

Touch voltage between ground rod and earth at distance y: $V_{fault} - U_g(y)$

Effect of resistivity: dry or moist soils

- No effect on voltage magnitude – fault current changes inversely with resistivity.
  - Moist soil = low-resistivity, increased fault current
  - Increase in fault current is inversely proportional to decrease in resistivity, keeping step potentials constant
- But higher resistivity = less current through someone standing on the earth surface
  - High soil resistance in series with each foot reduces the current for a given step potential
  - This is why we use gravel in substation yards
- Contact resistance is an important factor and can be difficult to determine
  - May depend on shoes, gloves, surface moisture, etc.
  - Also why we use gravel in substation yards

Understanding the hazard



There are almost always **two** problems in these cases:

1. The fault
2. Damaged or missing equipment grounding conductor; the "safety ground"

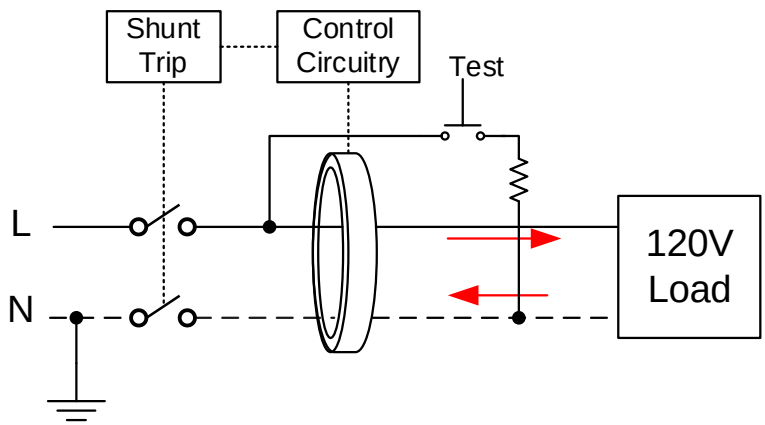
Issues with ground faults
Circuit breaker response to current

- 15-amp single-pole circuit breaker trip times:
  - 15 A 5+ min, (maybe)
  - 30 A 8s – 30s
  - 60 A 1.5s – 5s
  - 300A – 10kA 1-cycle (“instantaneous”)
    - Based on the time-current curve for a standard residential circuit breaker

  min = minutes, s = seconds
- Resistance of the fault current path during a ground fault may be too high for even the smallest regular circuit breaker to respond.

Bridging the gap between circuit breaker response and human response

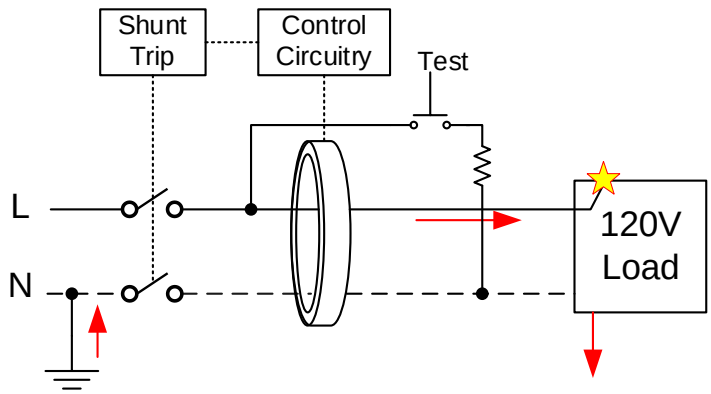
The Ground-fault circuit interrupter (GFCI)



The GFCI during a ground fault

- Current imbalance at sensing coil causes trip, **IF** the GFCI is working properly and wired properly
- Threshold is 4-6mA* per UL 943 – Standard for Ground Fault Circuit Interrupters

*Fault duration is limited; current magnitude is not.



A few GFCI precautions

- The GFCI does not limit the ground-fault current magnitude
- A non-grounding receptacle (two-prong) may be replaced with a grounding type receptacle supplied through a GFCI. No equipment grounding conductor shall be connected between the grounding receptacles.
- GFCIs may be prone to "nuisance tripping"
  - Downstream neutral connections
  - Motor loads
  - Long circuits
  - Many loads
- Incorrect wiring may defeat the safety benefits of the GFCI

GFCI circuit breakers and receptacles

- Nuisance tripping
  - In any circuit, there is distributed capacitance between the line or phase conductors, the grounding conductor, and the surrounding conductive materials
  - This capacitance will result in a small "leakage current"
  - The leakage current may "pre-load" the GFCI circuit breaker, reducing the normal trip level

GFCI circuit breakers and receptacles

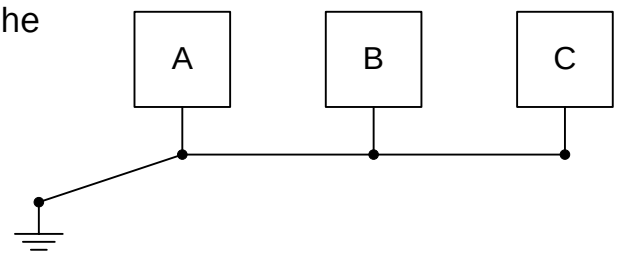
- Nuisance tripping continued:
  - Under severe conditions (long circuits, water in conduits) the leakage current could cause nuisance trips of the GFCI circuit breaker
  - One manufacturer recommends limiting the total downstream circuit length to 250 feet
  - Long extension cords may be used on outdoor receptacles, where GFCIs are required or on indoor receptacles in large buildings

GFCI circuit breakers and receptacles

- Pros and cons of each
  - GFCI receptacles
    - Reduced circuit length, reduced leakage current, reduced nuisance tripping
    - May be more expensive if multiple receptacles are used instead of a single GFCI circuit breaker
  - GFCI circuit breakers
    - May "nuisance trip" on long circuits or where conditions may significantly increase the normal leakage current
    - May be less expensive

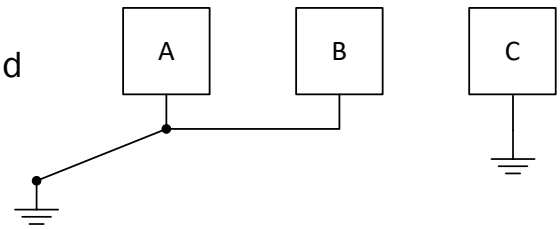
Isolated and shared grounds

- Shared grounds
  - May result in some noise on the grounding system due to adjacent loads
  - Even in a "perfect" system there will be current on the grounding conductor due to capacitive and inductive coupling and the availability of current paths (conduit, building steel, etc.)



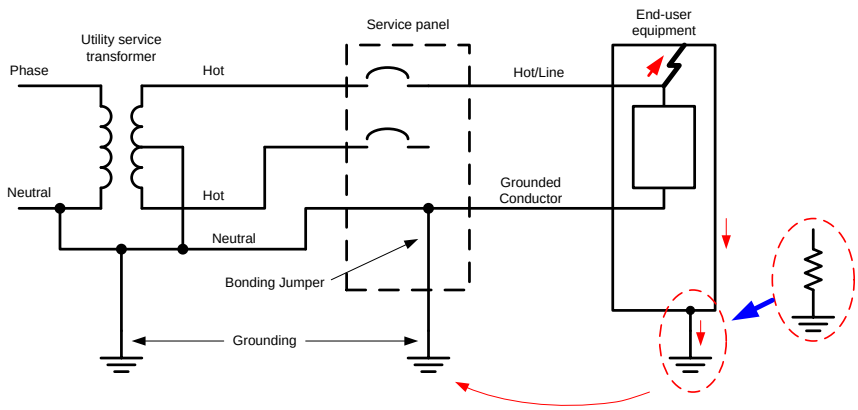
Isolated and shared grounds

- Incorrectly isolated grounds – ungrounded equipment
  - Sometimes called a “clean” ground
  - Occasionally found on CNC machines, and other “sensitive” industrial equipment
  - Perception is that this avoids “noise” on the grounding system – This is wrong, and dangerous



Wiring and grounding problems

- “Ungrounded” or poorly grounded equipment



Wiring and grounding problems

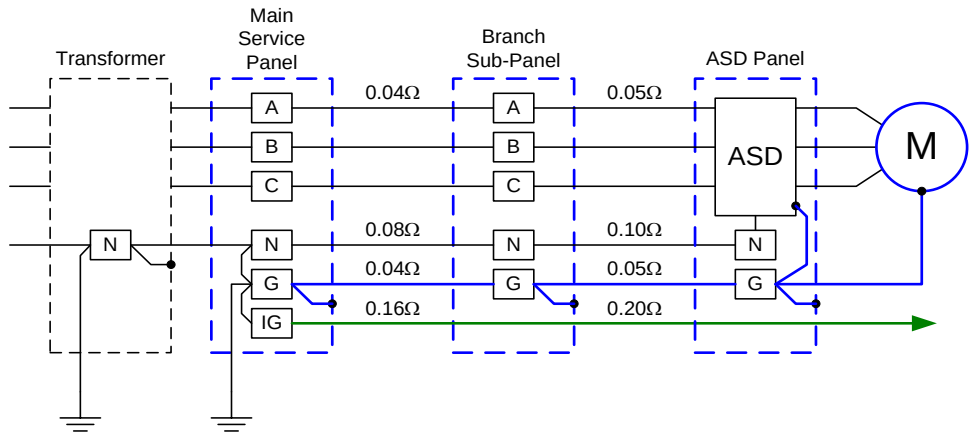
- Ungrounded equipment
  - NEC violation
  - Unlikely to resolve interference problems
  - May result in high touch potentials even without a fault due to capacitive coupling inside the equipment
  - Ground fault in the equipment is unlikely to trip some upstream protective device

Isolated grounds – the right way

- "Isolated" can be misleading
- "Dedicated" or "Insulated" might be better terms
- An isolated equipment grounding conductor is a separate, additional grounding conductor
- It is only connected to the grounding system at the ground bus in the main service panel or a separately derived system
- It is insulated as it passes through downstream panels to some end device where it is used as that device's equipment grounding conductor

Isolated grounds – the right way

- Where does the noise come from?



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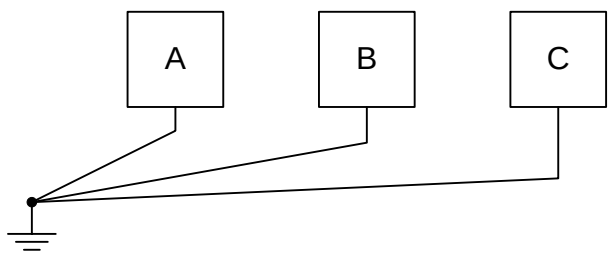
Isolated and shared grounds

- Isolated grounds – the right way
  - Reduces noise on the grounding system due to adjacent loads
  - Other ground current paths between devices are carefully eliminated
  - Remember Kirchhoff's current law…



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Isolated grounds – the right way

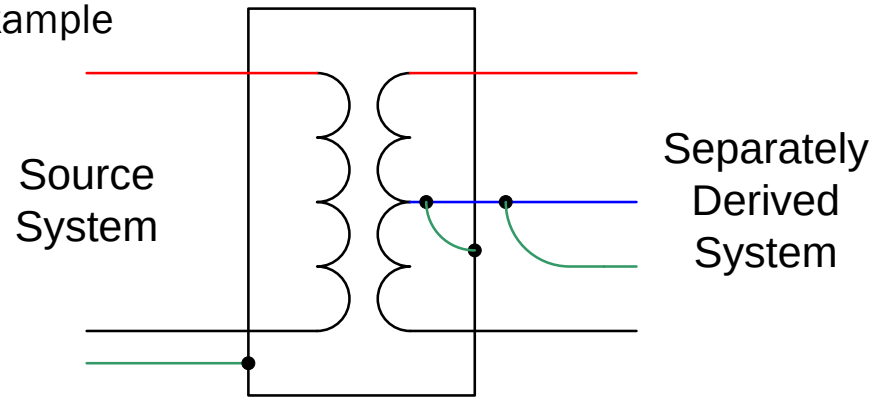
- Isolated grounds are used to reduce noise on the equipment grounding conductor associated with other loads on the system
- Covered in the 2023 NEC in article 250.96
- Usually used for computers or other “sensitive” equipment
- Receptacles are color-coded orange or have an orange triangle on their face

Separately derived systems

- A wiring system with power derived from a source other than a main service
  - Generators
  - Battery systems
  - Transformers
- Can help reduce “noise” on grounding system and Neutral-to-ground voltage
  - Provides a local ground reference and a nearby Neutral-to-ground bond
  - Usually, a less extensive system
    - One floor of an office building
    - A server room

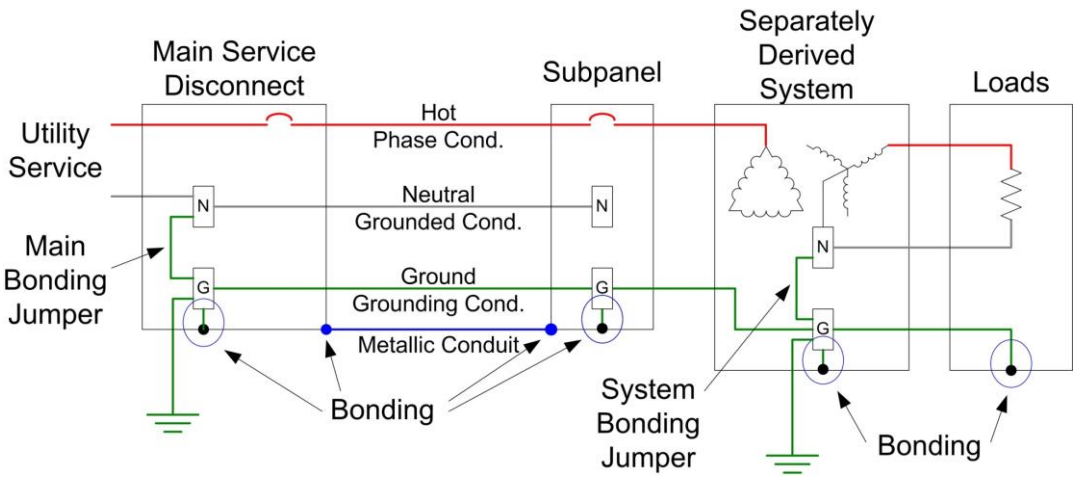
Separately derived systems

- Example



Note: The source system and separately derived system grounding conductors are still connected to each other. A facility cannot have multiple, distinct grounding systems.

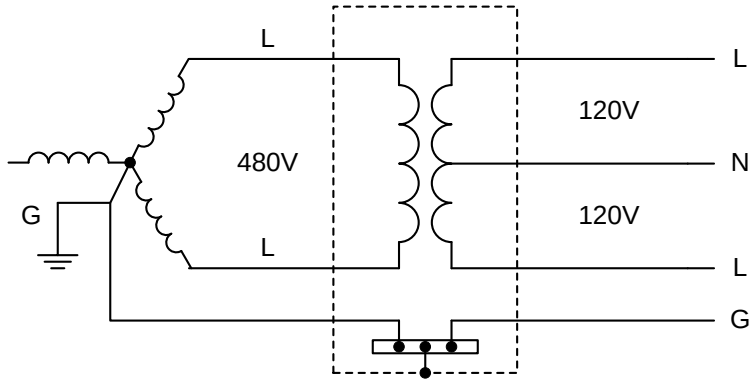
Separately derived systems



Also see figure 10.5 in PSQ

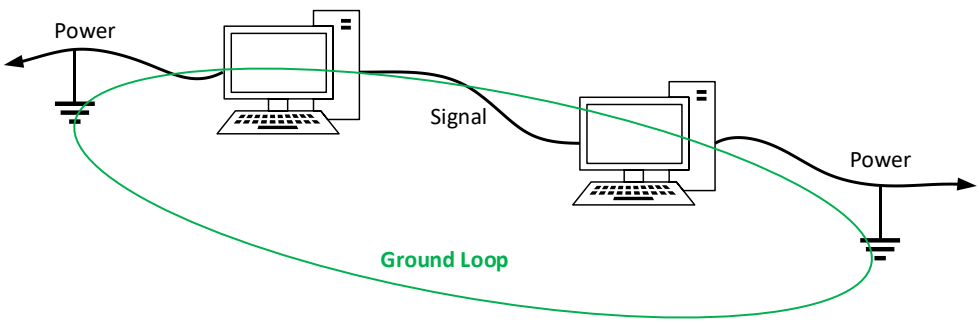
Separately derived systems and neutral-to-ground bonds

- A missing ground – common mistake in separately derived systems



Ground loops

- An electrical connection (usually in a communication circuit) between two or more devices that are connected to different ground references



Ground loops

- Causes equalizing current flow between devices on communication circuits
- Where it's a problem:
  - Communication circuits with ground connections at both ends
    - Serial cables, including USB
    - Parallel cables
    - Some remote transducer signal cables
    - Most audio/video signal cables
  - Ever wonder why it's hard to find a 50' USB cable?

Ground loops

- Symptoms
  - Audible "hum" in audio systems
  - Remote sensing errors
  - Bars on video screens
    - What about flat panel displays?
  - Data errors
  - Damaged equipment

Ground loops - Solutions

From: audiovideodirect.net

Picture from B & B Electronics

- Establish a single, nearby ground point for interconnected devices
- Use a “ground loop isolator” – essentially a high frequency isolation transformer
- Use differential mode communication systems with appropriate surge suppression at both ends of the circuit
- Use optical isolation / fiber-optic cables (this is becoming easier)

Coming up…

- More wiring and grounding
  - Communication wiring
  - Troubleshooting wiring issues
  - Diagnosing wiring problems from symptoms

References for ground rod resistance and step potential calculations:

EPRI Distribution Grounding Volume 1: Handbook, August 1996
Earth Conduction Effects in Transmission Systems, E.D. Sunde, 1949.
Military handbook - Grounding, Bonding, and Shielding for Electronic Equipments and Facilities, volume I of 2 volumes - Basic Theory, MIL-HDBK-419A - 1987