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College of Engineering

ECE 528 – Understanding Power Quality

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

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Lecture 38

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Today…

- Wiring, grounding, and bonding
  - Ground faults
  - Human response to current
  - Grounding electrode (ground rod) resistance
  - Touch and step potentials
  - The GFCI

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Ground Faults

- What is a "ground fault"?
  - Insulation failure resulting in current through:
    - Equipment ground*ing* conductor (ground wire)
    - Other unintentional conductors
    - A person
    - Any combination of these pathways
  - Issues with ground faults
    - Touch and step potentials may be hazardous
    - Resulting ground fault current may not be sufficient to trip an overcurrent protective device

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Issues with ground faults
Human response to current

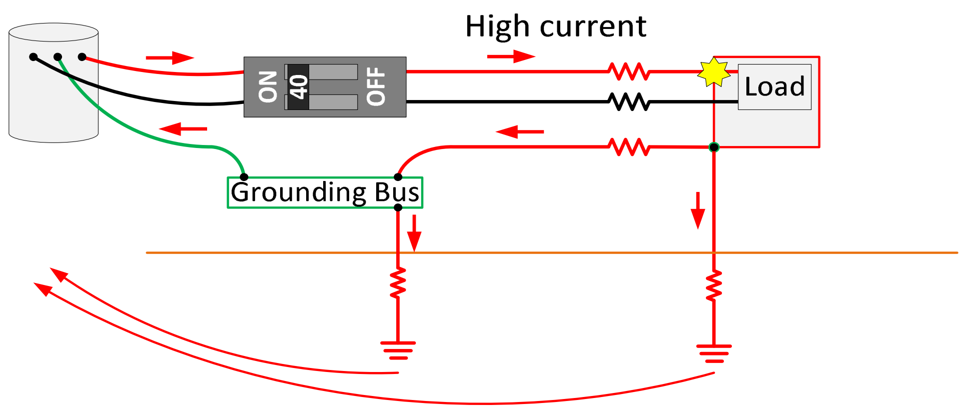
- Response to 60Hz current*
  - Perception 1mA
  - Mild shock 2mA
  - Painful shock 4-9mA
  - Cannot let-go 10-20mA
  - Heart fibrillation 100-300mA

*All values are approximate; people and research results vary

Reference:

Applied Bioelectricity-From Electrical Stimulation to Electropathology, J. Patrick Reilly

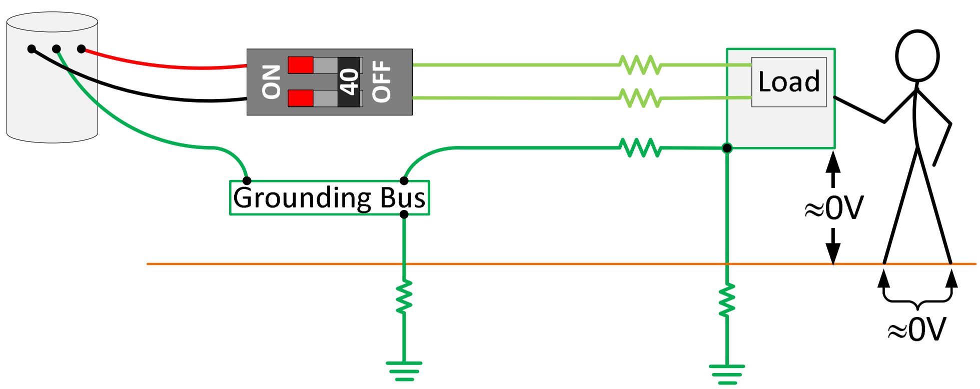
Fault in a properly grounded system



A small amount of fault current flows in the earth.

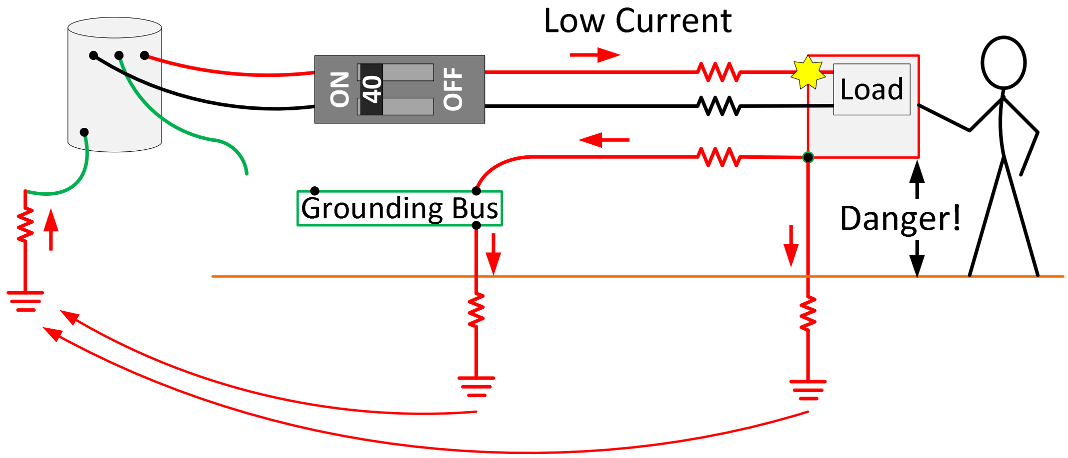
This condition ends very quickly; when the breaker trips.

The properly grounded system shortly after the fault.



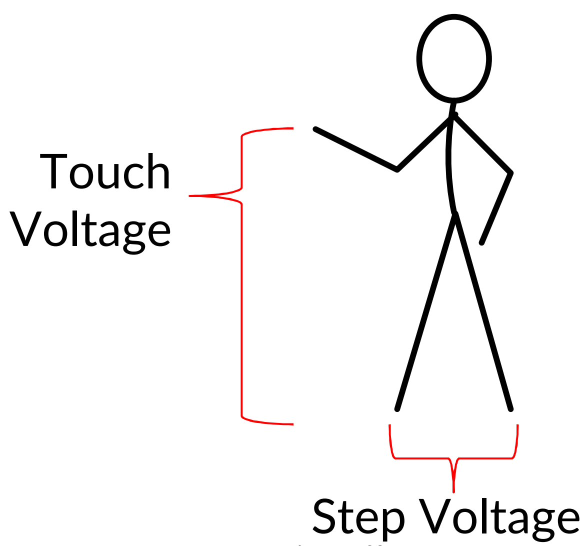
Circuit breaker trips quickly, fault is de-energized.

Faulted system with missing or broken neutral/ground

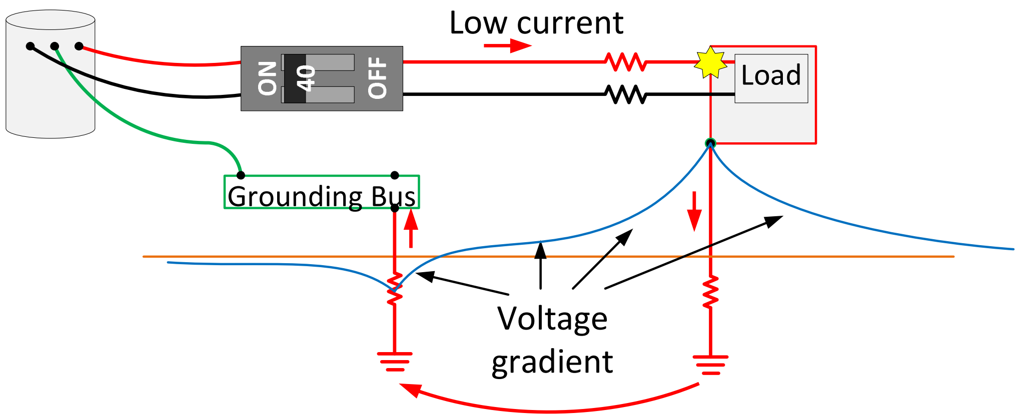


ALL of the fault current flows in the earth at some point.
Fault current is too low to trip the breaker; the fault is continuous.

Hazards with continuous faults



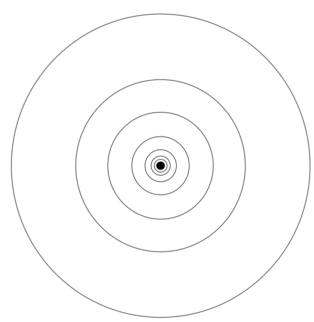
Voltage gradients: Where current enters or leaves the earth



Current through earth resistance creates voltage across earth resistance.

Earth faults and voltage gradients

Altitude gradient



Voltage gradient

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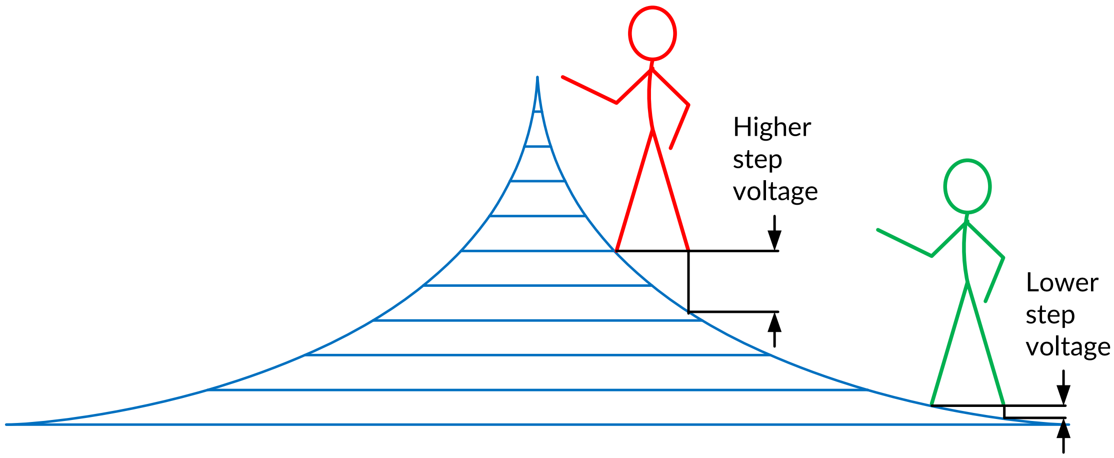
Voltage gradients and step potentials - a few steps can make a big difference



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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

Equation is valid for L>>a

Mathcad and Mathcad Prime will automatically handle unit conversions so that you may mix Ohm-meters, feet, inches, etc.

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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: $V_{fault} - U_g(y)$

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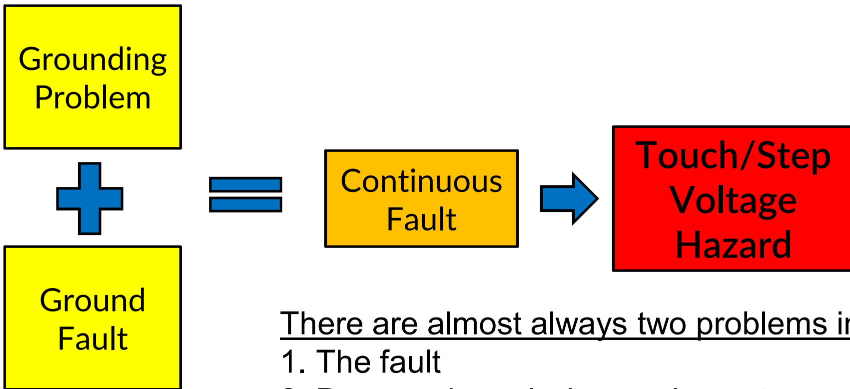
Effect of resistivity: dry or moist soils

- No effect on voltage magnitude – fault current changes inversely with resistivity.
  - Moist soil = low-resistivity, increased fault current
  - Drop in resistivity is proportional to increase in fault current, keeping step potentials constant
- But, higher resistivity = higher contact resistance to the soil = less current through us
  - 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

Understanding the hazard



<u>There are almost always two problems in these cases:</u>

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

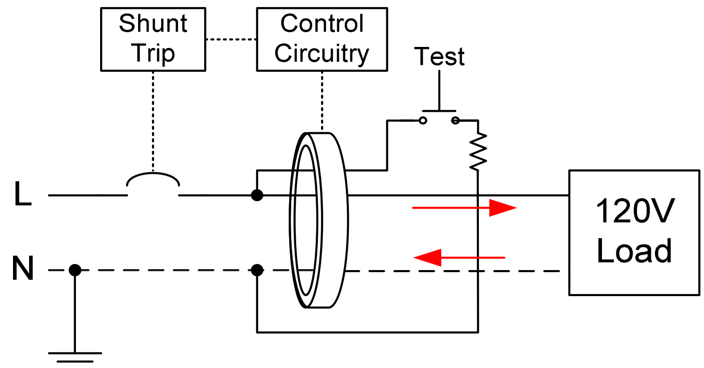
Issues with ground faults
Circuit breaker response to current

- 15-amp single-pole circuit breaker trip times:
  - 15 A 5+ min, (maybe)
  - 30 A 15s – 1min
  - 60 A 1.5s – 5s
  - 150A – 250A 0.02s ("instantaneous")
    - Based on the time-current curve for a standard residential circuit breaker

  min = minutes, s = seconds

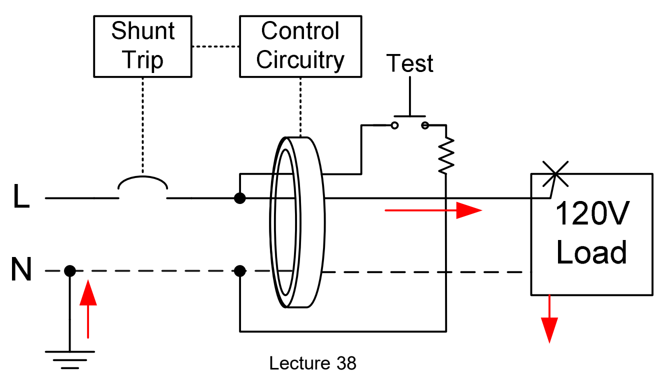
Bridging the gap between circuit breaker response and human response

- The Ground-fault circuit interrupter (GFCI)



The GFCI during a ground fault

- Current imbalance at sensing coil causes trip
- Threshold is 4-6mA
  (UL 943, Standard for Ground Fault circuit Interrupters.)



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"
  - Long circuits
  - Many loads
  - Downstream neutral connections

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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

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.