University of Idaho
College of Engineering

ECE 528 – Understanding Power Quality

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

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Lecture 24

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Today…

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Wiring and grounding:
- Why it's important
- References
- Terms and definitions
- Start on some common problems
- Ground faults
- Human response to current

Goals of this portion of the course:
- Become familiar with some important power quality-related wiring and grounding issues, and the resources available to engineers for more information on wiring and grounding.

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Introduction – Why this is important

- Wiring and grounding problems…
  - May result in property damage, injury, or death
  - Are frequent contributors to power quality problems
  - Can significantly impact the operation of sensitive equipment
  - Are preventable

Standards and references

- National Electric Code (NEC)
  - Published by the NFPA – National Fire Protection Association
  - Requirements are designed to protect persons and property from hazards associated with the use of electricity - NOT to prevent power quality problems
  - It's a "minimum standard" - not a design specification or "how-to" manual
  - The National Electric Code *Handbook* adds a considerable amount of explanatory material and is recommended over the code book itself
  - Online subscription makes searching easier

Standards and references

- References:
  - *Soares Book on Grounding and Bonding*, (latest edition)– published by the International Association of Electrical Inspectors
  - *Electrical Wiring, Residential*, by R.C. Mullen and Phil Simmons
  - *Electrical Wiring, Commercial*, by R.C. Mullen and Phil Simmons
  - *Electrical Wiring, Industrial*, by Stephen L. Herman
- IEEE Standards:
  - IEEE Std. 142 (2007)– (The Green Book) – *Recommended Practice for Grounding of Industrial and Commercial Power Systems*
  - IEEE Std. 1100 (2005)– (The Emerald Book) – *Recommended Practice for Powering and Grounding Sensitive Electronic Equipment*

IEEE Standards continued: 3000 Series

- A planned series of recommended practice standards for industrial and commercial power systems intended to replace the "Color Book" series.
- 3001…: Power Systems Design
- 3002…: Power Systems Analysis
- 3003…: Power Systems Grounding
- 3004…: Protection and coordination
- 3005…: Emergency, Standby Power, and Energy Management Systems
- 3006…: Power Systems Reliability
- 3007…: Power Systems Maintenance, Operations, and Safety

A good list of the existing and proposed standards in the series is in the IEEE paper:
"Coordinating the development cycles of the IEEE 3000-series recommended practices with the NFPA 70 series-documents"

Terminology

- NEC use of “grounded” and “grounding”
  - “Grounded conductor”
    - An intentionally grounded circuit conductor – often the neutral conductor
    - Remember – Not Dead
  - “Grounding conductor”
    - Connects equipment (cases) or the grounded conductor to grounding electrodes (ground rods, etc.) – the ground wires
    - Remember – In or near ground

Grounding versus bonding

- Grounding
  - Connecting equipment and points on electrical systems to the earth or an earth substitute
  - Purpose is to limit overvoltages between the equipment and the earth due to lightning, faults, etc.
- Bonding
  - Connecting equipment together to establish electrical continuity and conductivity
  - Purpose is to limit voltages between equipment and to provide a path for ground fault current

Reasons for grounding and bonding

- Safety grounding and bonding
  - Minimum requirements are described in NEC- 2023, primarily in article 250
  - Personnel safety
    - Prevent voltage differences between electrical enclosures and devices, and surrounding conductive surfaces
  - Ensure protective device operation
    - Provide low-impedance path for the flow of "ground fault" current so that enough fault current flows to quickly blow a fuse or trip a circuit breaker

Reasons for grounding and bonding

- Power Quality or "Performance" grounding and bonding - Noise control
  - Purpose is to create an equipotential ground system – may be a "signal reference grid" or "signal reference plane"
  - A grid or plane can provide a relatively uniform impedance across a very wide range of frequencies
  - Minimizes voltage differences between the "grounds" of interconnected sensitive electronic devices – typically computers or communications systems

Reasons for grounding and bonding

- Power Quality or “Performance” grounding and bonding - Noise control
  - Typically requires more specialized grounding than what is described in NEC article 250
    - NEC-2023, Article 645 briefly covers computer room grounding and bonding
    - NEC-2023, Article 725 covers remote-control and signaling systems
    - NEC-2023, Article 800 covers communication systems

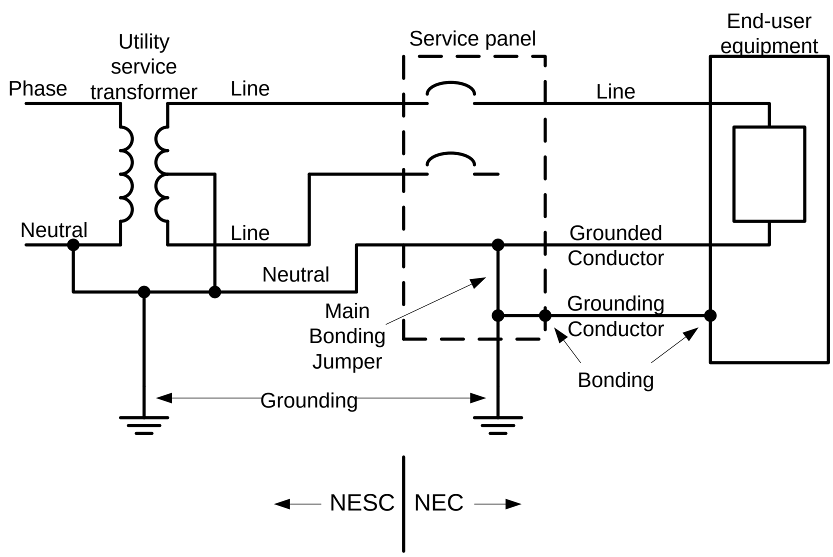
Grounding and bonding frequency considerations

- Safety grounding and bonding
  - Frequencies of interest tend to be low; dc to several hundred or a few thousand Hz
  - Wavelength is not a consideration
- Power Quality or performance grounding and bonding
  - Frequencies of interest are dc to tens of MHz or higher
  - Wavelength becomes a consideration

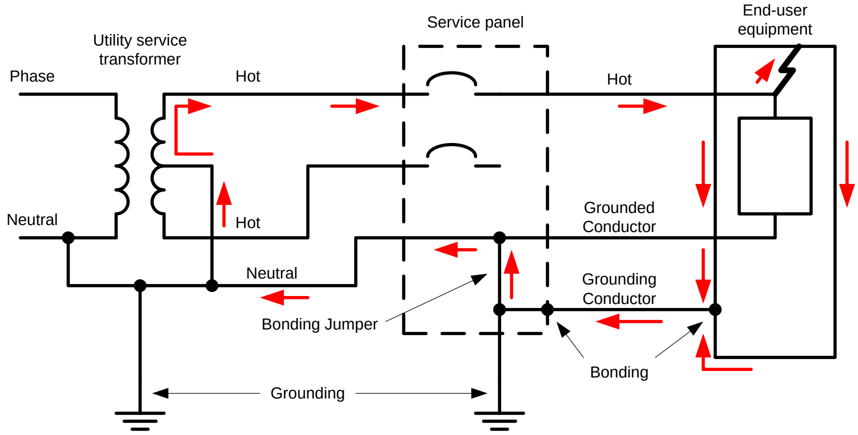
Grounding and bonding problems

- The grounding and bonding requirements designed to ensure safety <u>always apply</u> and take precedence over any other grounding and bonding objectives
- Many safety issues associated with grounding and bonding are the result of misguided efforts to improve power quality
- These efforts often hurt power quality as well

Grounding and bonding terminology



Safety - A faulted system



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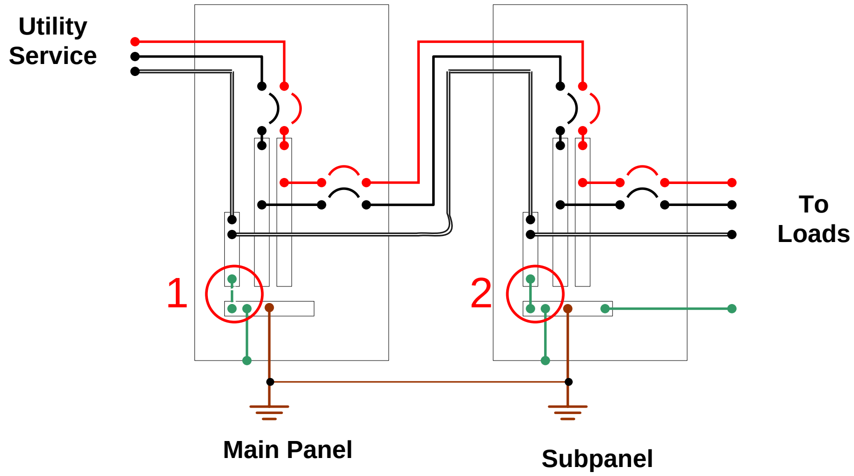
Wiring and grounding problems: Multiple neutral-to-ground bonds



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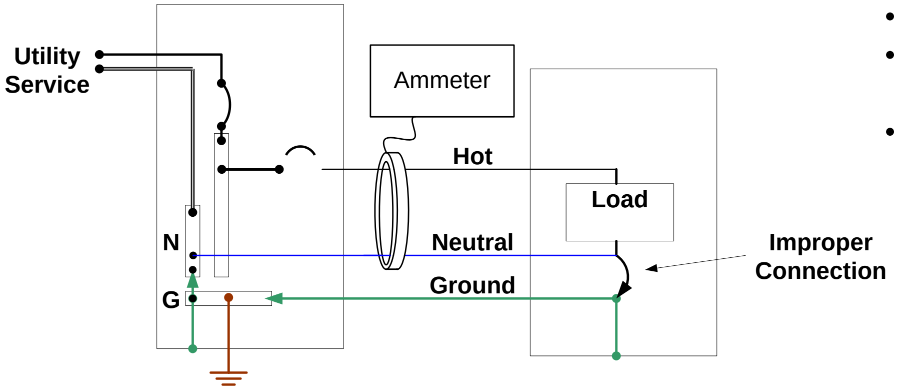
Wiring and grounding problems: Multiple neutral-to-ground bonds

- Issues:
  - Results in load current on the grounding system
  - May interfere with protective devices
  - Creates "ground loops"
  - Results in "net current" and elevated magnetic fields around cables and conduits

Locating extra neutral-to-ground bonds:

Circuit With Improper Neutral-to-Ground Connection



This test is minimally invasive and can be done without dismantling the circuits.

Methods
- Visual inspection
- Measure current on grounding system
- Measure net current in circuits

Wiring and grounding problems: Missing equipment grounding

- Issues (PSQ page 474, fig. 10-2)
  - Return path impedance for ground-fault current is high, (sometimes very high)
  - Equipment case may become energized
  - Ground-fault current may not trip a circuit breaker
  - How would you locate this problem? Let's see…

Locating missing grounding

- Visual inspection
- Measure voltage between points that should be bonded together
  - Measure neutral-to-ground voltage at receptacles
    - Should be low (~<3V)
    - Zero may indicate an extra N-G bond
  - Measure line-to-ground voltages in panels
    - Lo-Z meter can aid in finding "floating" grounds
    - Should be close to nominal L-G voltage for the system

Ground Faults

- What is a "ground fault"?
  - Insulation failure resulting in current through:
    - Equipment ground*ing* conductor (best scenario)
    - Other unintentional conductors, including:
      - The earth
      - 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

Issues with ground faults
Human response to current

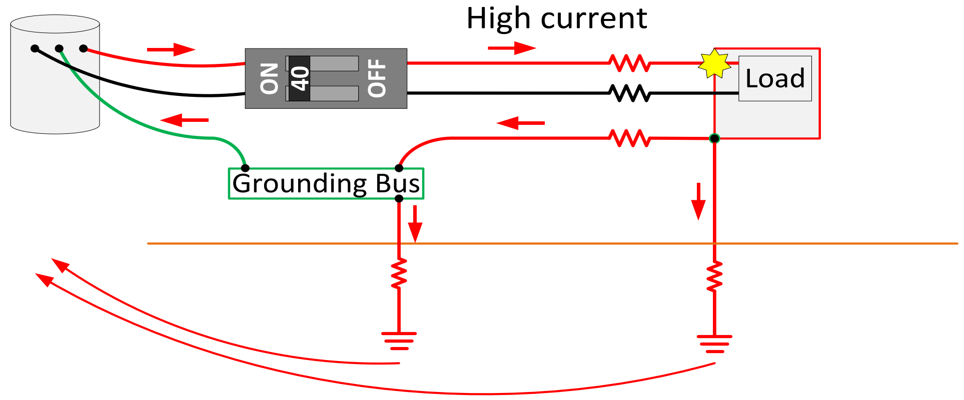
- Response to 60Hz current*
  - Perception 1mA
  - Mild shock 2mA
  - Painful shock 4-9mA
  - Cannot let-go 10-20mA
  - Heart fibrillation 100-300mA

*All values are approximate; people and research results vary

Reference:

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

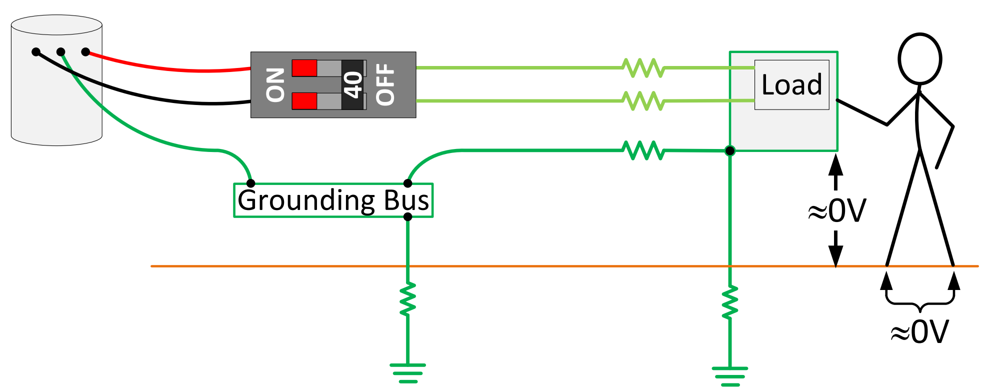
Fault in a properly grounded system



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.

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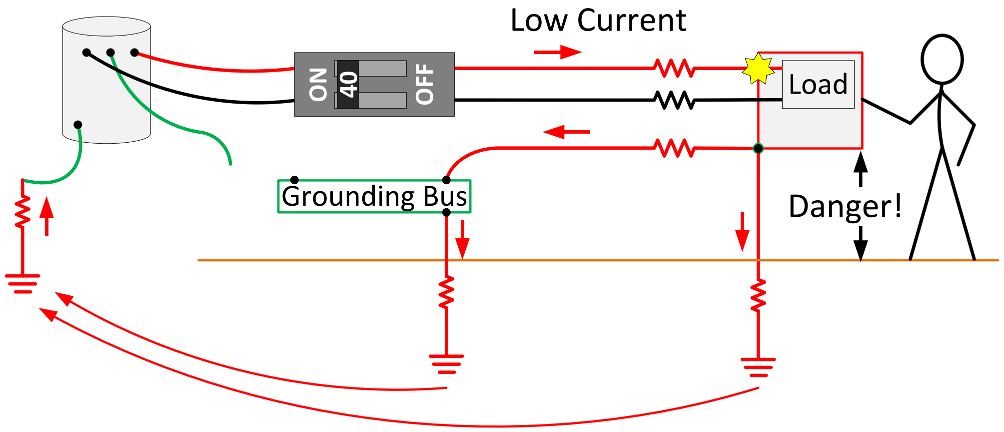
Faulted system with missing or broken neutral/ground



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

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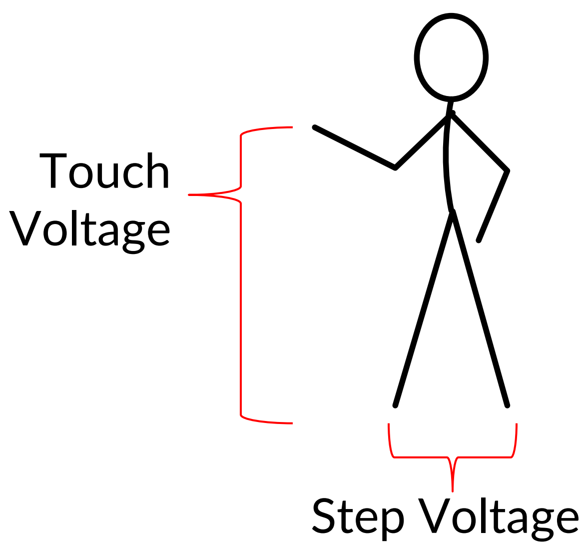
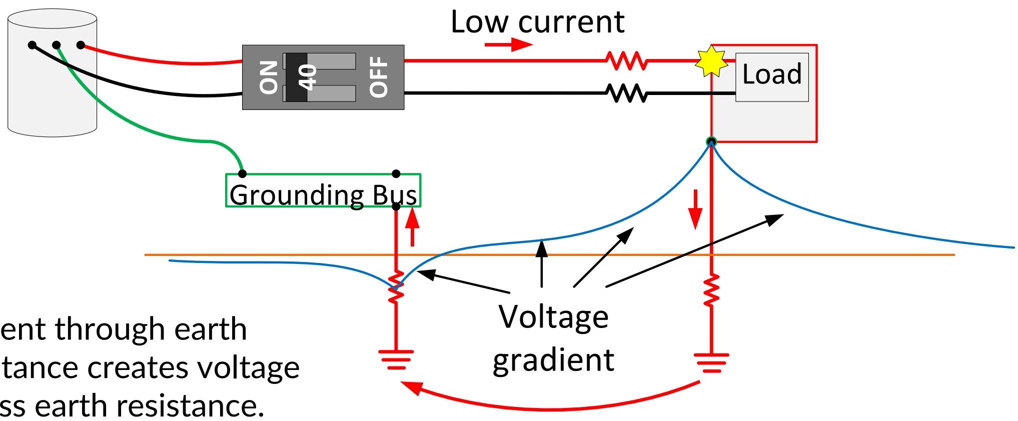
Hazards with continuous faults

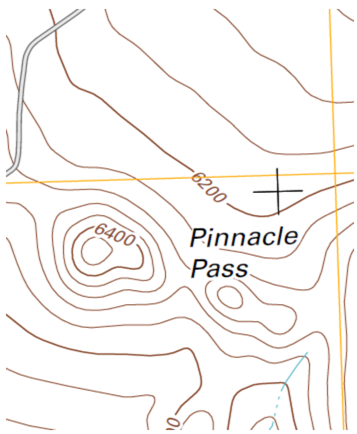


Voltage gradients:
Where current enters or leaves the earth

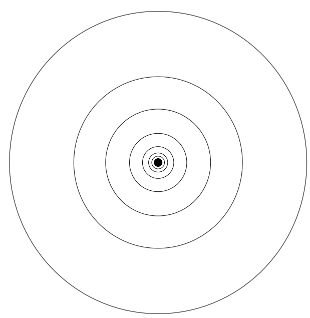


Current through earth resistance creates voltage across earth resistance.

Earth faults and voltage gradients

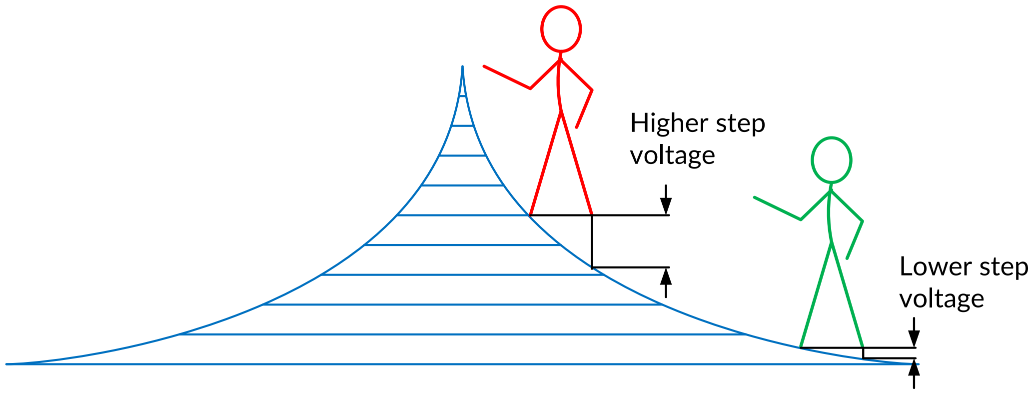


Altitude gradient



Voltage gradient

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



Coming up…

- More wiring and grounding
  - Grounding electrode (ground rod) resistance
  - Touch and step potentials
  - The GFCI
  - Neutral sizing
  - Separately derived systems
  - Isolated grounds
  - Wiring for communications