Ground Fault Circuit Interruption (GFCI)

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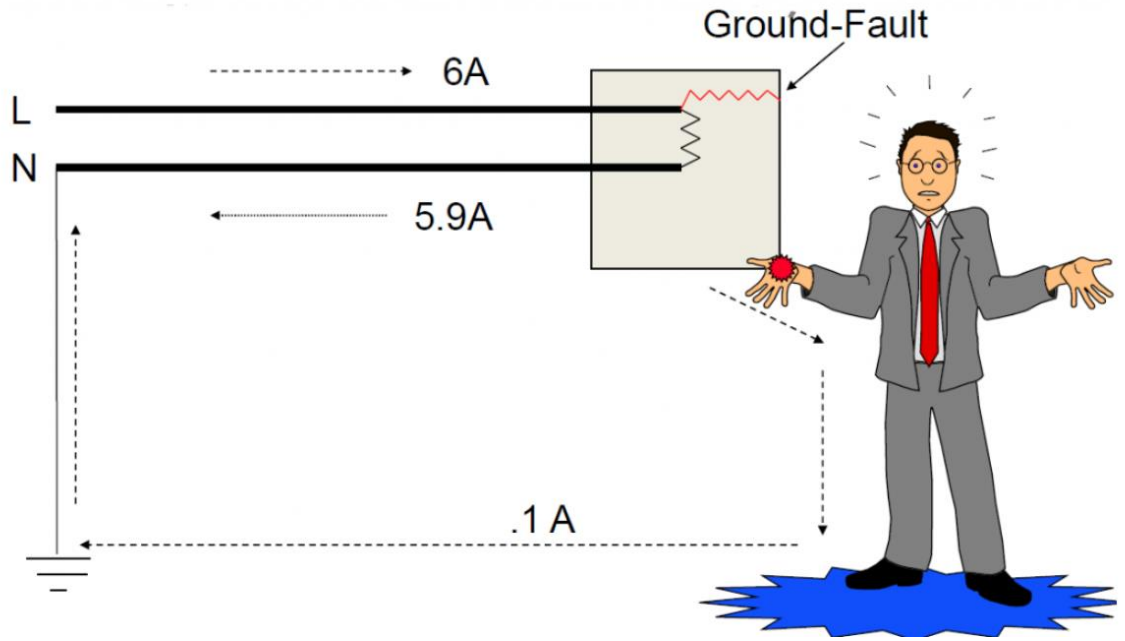
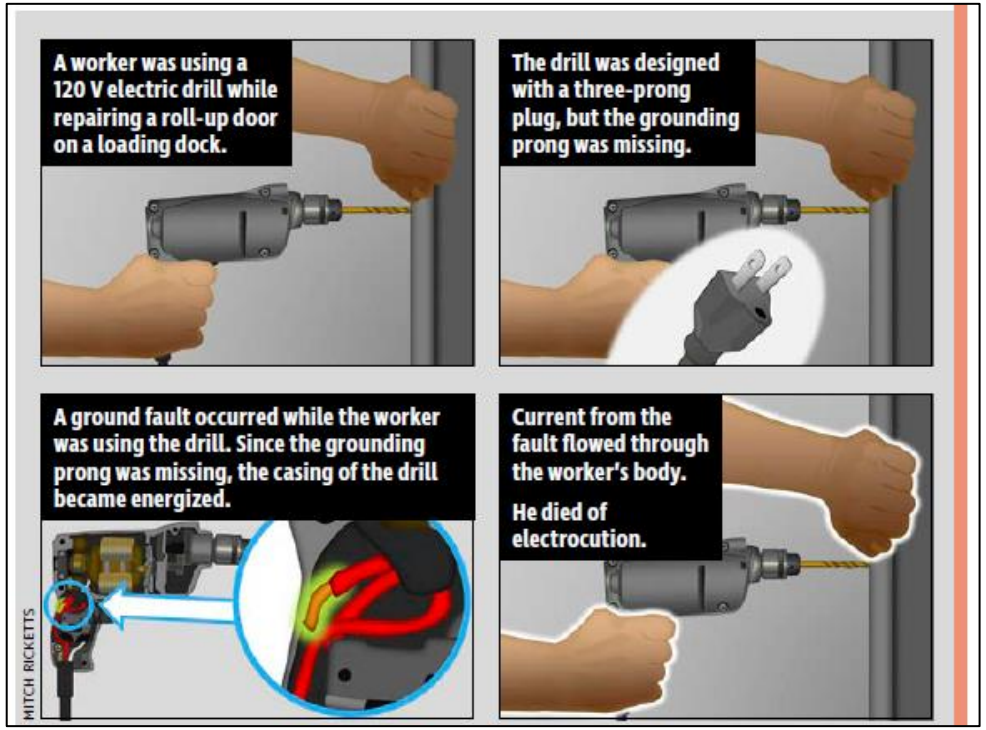
What is a Ground Fault?

- Any unplanned and non-restricted flow of charge to ground
- A ground fault is defined by the National Electric Code as an unintentional conductive connection between an ungrounded conductor and ground or a normally non-current carrying conductor
  - Non-current carrying conductor include personnel or equipment



Example of a Ground Fault?

- Worker was using a 120 VAC drill to complete a repair
- Drill was missing the ground prong on the power cable
- Ground fault occurred inside of the drill causing the drill casing to become energized
- Worker died of electrocution



Why is Ground Fault Protection Important?

- Electric shock claims about 300 lives and causes thousands of nonfatal injuries per year
- Ground faults are among one of the leading causes of electrical injuries
- Sources of electric shock vary from high voltage power lines to household appliances such as a coffee maker
- Electrical fires to homes and equipment are another hazard that is causes by ground faults

Ground Fault Pathways

- Series Ground Fault
  - When a person is the only pathway current to ground
  - Example
    - Ground fault occurs on a piece of equipment that requires a 3-wire prong plug, but the operator uses a 2 to 3 wire adapter, and does not properly ground the ground wire to the outlet plate
    - A person operating this equipment and the equipment has a ground fault that energizes the equipment case
- Parallel Ground Fault
  - Path to ground and person is in parallel
  - Example
    - Equipment is grounded, but no GFCI in place
    - Equipment experiences a ground fault, and the operator is touching a ground such as a metal pipe

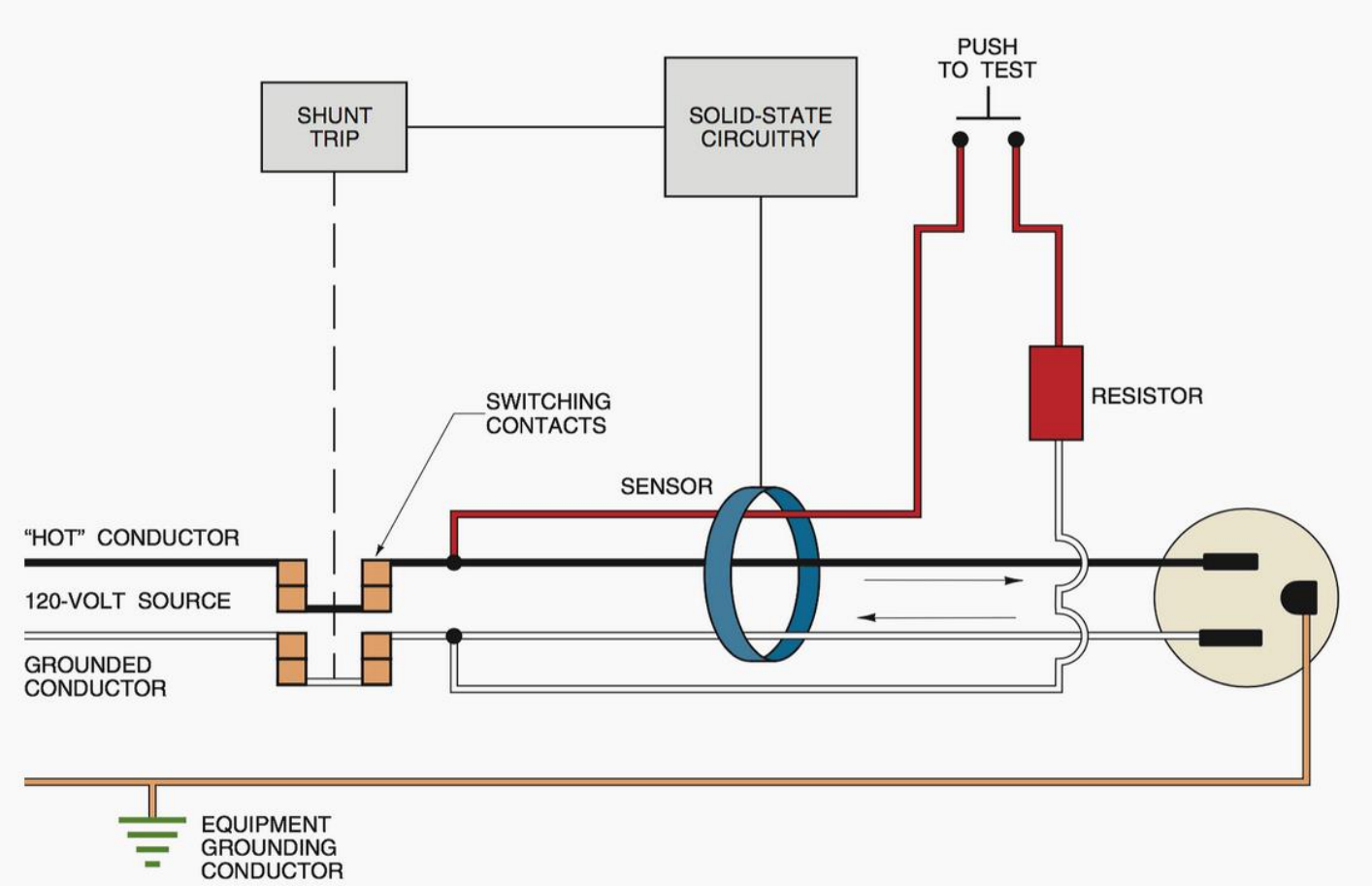
Ground Fault Circuit Interrupter (GFCI) Classes

- Class A
  - Maximum current setting of 6 mA (+/- 1 mA)
  - Maximum operating voltage of 150 V to ground
  - Normally found in households
- Class B
  - Obsolete
- Class C
  - Maximum current setting of 20 mA
  - Maximum operating voltage of 300 V
  - Industrial Applications
- Class D
  - Maximum current of 20 mA
  - Operating voltage above 300 V
  - Industrial Applications
- Class E
  - Similar to class D but required faster trip time

How Ground Fault Circuit Interrupters work?

- A GFCI consists of a differential sensing transformer that detects any unbalanced current between the neutral and hot wires
- Includes an amplifier to actuate the trip coil that de-energizes the circuit
- Trip coil is connected to both the neutral and how wires
- GFCI’s are designed to operate at a level below the “let go” threshold and commonly operate within 1/40 of a second

Typical Class A GFCI Circuit



How Ground Fault Circuit Interrupters work?

- Circuit trip times
  - Instantaneous
    - Transformer senses a larger imbalance between and de-energizes the circuit as soon as possible
  - Delayed Time
    - After an imbalance is sensed, a delay timer begins
    - After a pre-determined time above a current level the circuit is de-energized
    - Time delayed based on UL 943

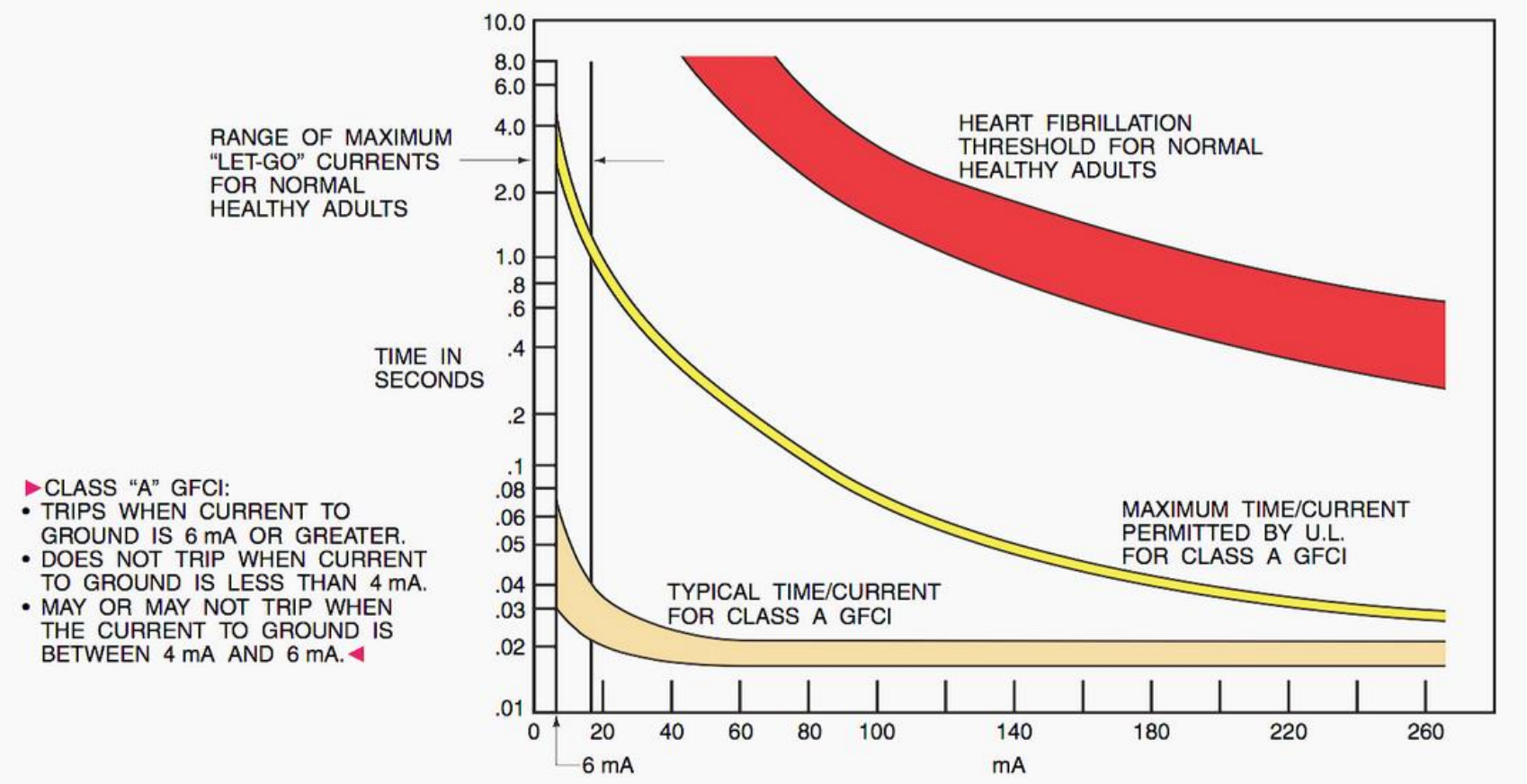
$$T = \left(\frac{20}{I}\right)^{1.43}$$, where T is in seconds, I is in milliamperes

GFCI Circuit Trip Time

$$\left(\frac{20}{40\ mA}\right)^{1.43} = 0.371\ \text{s}$$

$$\left(\frac{20}{100\ mA}\right)^{1.43} = 0.10\ \text{s}$$

$$\left(\frac{20}{140\ mA}\right)^{1.43} = 0.062\ \text{s}$$



Difference Between GFCI and Circuit Breaker Protection

- Normal Circuit Breakers
  - A standard circuit breaker de-energizes a circuit when the current reaches a pre-determined value
  - Designed to protect equipment and wiring from circuit overloads
    - Typical household allow for a maximum current between 10 Amps and 20 Amps
    - Service level circuit breakers range between 100 Amps to 200 Amps
- GFCI
  - Designed to protect people from a short to ground
  - Sense current imbalances within a circuit
  - Current limits are within the “let go” threshold of 6 mA
  - GFCI receptable not intended to replace the use of a circuit breaker for equipment protection from overloads and other shorts

Types of Class A GFCI's

Circuit Breaker GFCI

Portable GFCI

Receptable GFCI

Where are Ground Fault Circuit Interrupt (GFCI) required?

- Outdoor Equipment such as HVAC units or outdoor receptacles
- Bathrooms
  - Defined by NEC are any area that contains a basin such as a tub, shower, faucet, or toilet
- Garages
- Kitchens
- Crawl Spaces and unfinished basements per section NEC 210-8 (a)(4)
- Wet bar sinks
- Laundry and utility sinks

Why Trip Setting 6 mA?

- Based on population and the “let go” threshold for AC circuits
- Any current over 6 mA would leave a large portion unprotected
- Shock level is also based on current level, duration, and size of the person
- Someone with heart conditions are at a higher risk

Table 14-1
Percentage of the Population Estimated to Be Protected Against Inability to Let Go for Several Levels of Shock Current

Level of Shock Current	6mA(rms)	10mA (rms)	20mA (rms)	30mA (rms)
Men	100%	98.5%	7.5%	0%
Women	99.5%	60%	0%	0%
Children*	92.5%	7.5%	0%	0%

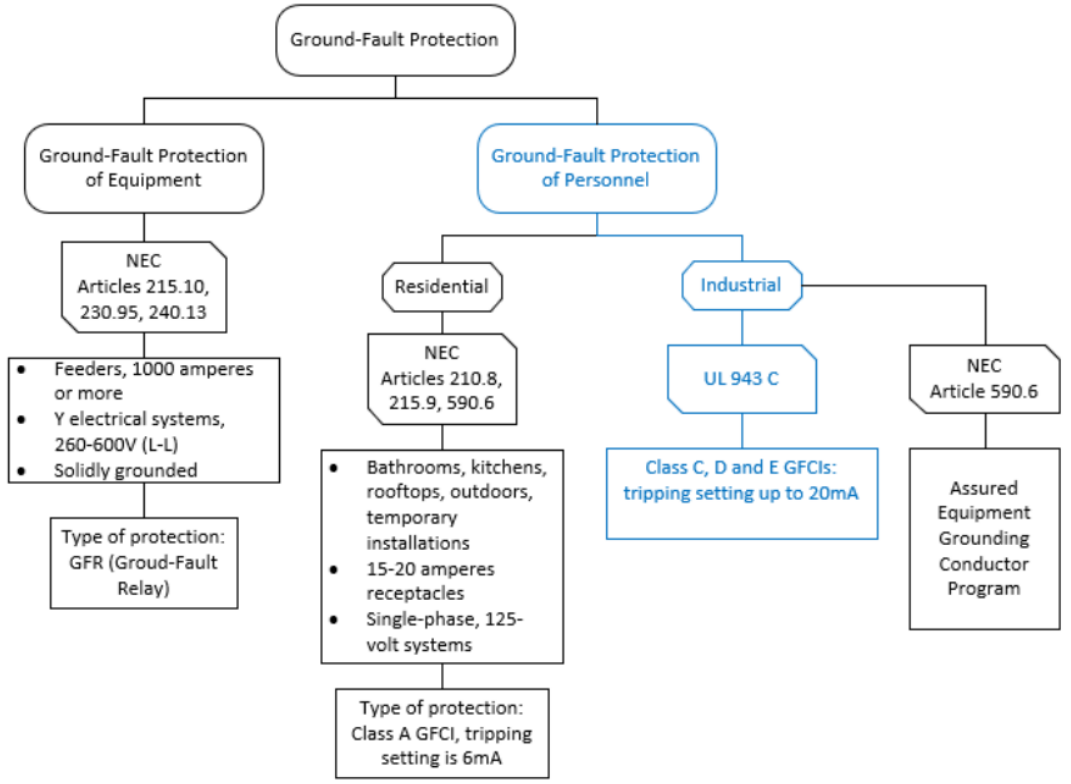
*half of let-go threshold for men

Why Trip Setting 6 mA?

- More than 99% of adults will not be able to “let go” at 22 mA for an AC circuit
- AC current repeatedly stimulates nerves and muscles causing the muscles to contract as long as the current is flowing through the person
- Below 300 mA DC rms, a person may experience painful shocks when making and breaking the circuit
- Above 300 mA DC rms, a person may not be able to “let go”

Ground Fault Protection Implementation

- National Electric Code (NEC) classifies ground fault protection into two main categories:
  - Equipment Protection
  - Personnel Protection
- Residential ground protection current ratings are low for industrial applications
- NEC regulates ground fault protection requirements
- Underwriters Laboratory (UL) is a safety standard
  - UL test equipment to meet specific specifications



NEC Requirements

- NEC Article 210.8
  - Explains locations where a Class A GFCI is required
  - Single phase branch circuits under 150 V
  - GFCI within 6 ft. of water source
  - Exclusions (critical care facilities)
- NEC Article 215.9
  - Feeder Protection provisions
- NEC Article 590.6
  - Temporary wiring installation requirements and exceptions

GFCI in Mario Kart Capstone Design

- Portable Class A GFCI
- Tower Mfg. Shock Buster - 15 Amp GFCI
- Power cord to be wired into the GFCI plug
- Installed to protect both equipment and personnel

GFCI Limitations

- Capacitive Coupling
  - Cables are buried underground
    - Both the top and bottom conductors act like capacitors due to current leakage between the conductors
  - Cable length
    - Increasing the cable length increases the cable capacitance
- Spurious Signals
  - Unintentional trip GFCI when sudden load changes occur which causes a sudden unbalance between the input and output
  - Pumps, Compressors, Motor Loads, On/Off switching of induction loads

GFCI Testing

- When to test a GFCI
  - After installation
  - Once a month
  - After each power failure
  - Superseded Manufacturer Recommendations
- How to Test
  - Connect an electrical device such as a lamp to the protected circuit
  - Press the test button
    - Lamp should go out
    - If lamp does not go out, then GFCI is defective or mis-wired
  - Press the reset button
    - Lamp should turn back on
    - If lamp stays on, replace GFCI

Things to know: Unintended GFCI Trips

- The maximum 6 mA current limit is not feasible for some equipment, such as equipment that have a large inrush current. These types of equipment include but is not limited to:
  - Compressors
  - Pumps
  - Motor loads
  - Welders

Other considerations

- Industrial and 3-Phase application
  - Ground fault protection for industrial application focuses on protection of equipment
  - Maximum current ratings are much higher
  - Utilizes ground fault relays to detect
    - SEL and ABB are two common relays
  - Protection and settings are based on protection schemes and can be more complex depending on the power system

Ground Fault Circuit Interrupter (GFCI) Exceptions

- Industrial Considerations
  - Facilities were continuous industrial process, where a nonorderly shutdown will introduce addition or increasing hazards
  - Installations where ground-fault protection is provided by other requirements for services or feeders
  - Fire Pumps
  - Temporary feeder conductors used to connect a generator to a facility for repair, maintenance, or emergency operations
    - Time period shall not exceed 90 days

Applying Lessons to Capstone

- Ground faults are a dangerous and can lead to serious harm or death
- Mitigate harm or damage by installing GFCI within power system
- Ensure all connections are properly terminated
- Ensure proper grounding of equipment and equipment enclosure

Sources

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