Understanding GFCIs
Developed by the NEMA 5PP Personnel Protection Technical Committee
What Is to Be Covered?

- Electrical Shock - Why Have GFCIs?
- How GFCI’s Operate
- Proper Installation of a GFCI
- Wiring Errors
- Grounded Neutral Detection
- Testing GFCIs
Electrocutions Associated With Consumer Products
Effects of Electric Shock

- **4 AMPERES AND OVER**
  - Heart Paralysis, Serious Tissue and Organ Burning

- **50 mA - 4 Amps Fibrillation**

- **50 mA**
  - IEC RCD Standards
  - Breathing Difficult, Fibrillation in children

- **30 mA**
  - Muscles “Freeze” in 50% of the Population

- **15 mA**
  - Let-Go Threshold

- **10 mA**
  - 4-6 UL 943 Class A GFCI Trip Level

- **4-6 mA**
  - Perception Level

- **1 mA**
  - Perception Level
Electric Shock Prevention System

- Isolation (Physical)
- Insulation
- Double Insulation
- Equipment Grounding
- GFCI (solves shortcomings of above systems)
Normal Circuit Operation

The same amount of current flow from line to load and returns from load to line.
Ground - Fault (Indirect Contact)

- L: 12A
- N: 6A
- EGC: 5.94A
- Ground-Fault: 0.06 A

Ground-Fault
Ground - Fault (Direct Contact)

Ground-Fault

6A

5.9A

.1 A

L

N
How GFCIs Operate

Knowing how GFCIs work will enable you to understand:

1. Why GFCIs must be installed a certain way
   - For Circuit Breaker GFCI:
     To prevent constant tripping, MUST connect Load Neutral to circuit breaker neutral terminal, NOT panelboard neutral.
   - For Receptacle GFCI:
     If line and load conductors are reversed, per 2010 edition UL 943, no power is available at:
       1. Face terminals or
       2. Line terminals connected to downstream receptacles.

2. Why do GFCIs trip under various circumstances
   - Mis-wiring will cause GFCI to trip if:
     1. Ground current is flowing
     2. Neutral is grounded on load side of GFCI.
   - Portable GFCIs will trip if open neutral is present on the line side of the GFCI.

3. What conditions causes unexpected tripping
   - Ground current exceeding 6 mA when a load is applied.
   - Load neutral is not connected to correct terminals.
If the current out = current back, the differential current transformer shows no output.
Current “Adding Machine”

\[ I_{\text{IN}} \rightarrow L_1 \]

\[ L_2 \rightarrow I_{\text{Out}} \]

\[ 240V \text{ Load} \]

\[ 120/240V \text{ Load} \]

Differential Current Transformer
Current “Adding Machine” Under Ground Fault Conditions

If $I_{\text{out}}$ does not equal $I_{\text{in}}$, the differential current transformer creates an output signal.
What’s in the GFCI? (Receptacle)

- Reset Button
- Test Button
- Cover
- Tamper Resistant Mechanism (Optional)
- Bridge
- Face Contacts
- Middle Barrier
- Terminals
- Printed Circuit Board
- Base
What’s in the GFCI?
(Receptacle)

GFCI circuitry with grounded neutral detection

120V Trip Mechanism

15K Resistor

Push-to-test Button

Load Terminals

Line Terminals

Hot

Neutral

EGC

Receptacle Face
What’s in the GFCI? (Circuit Breaker)

- Over-Current trip
- Push-To-Test Button
- Trip Solenoid
- Handle (ON-OFF)
- Trip Mechanism
- Printed Circuit Board
- Panel Neutral wire
- “Load Power” Terminal
- Sensing Coil
- “Load Neutral” Terminal
- Primary Current-carrying Contacts
- “Line” Terminal
- Printed Circuit Board
What’s in the GFCI?
(Circuit Breaker)

- Trip Solenoid
- Electronic circuitry with Grounded Neutral detection
- Push-To-Test Button
- Test Resistor
- “Load Power” Terminal
- “Load Neutral” Terminal
- Panel Neutral wire
- “Line” Terminal
- “Load Power” Terminal
- “Load Neutral” Terminal
- Primary Current-carrying Contacts
- Sensing Coil
- Trip Mechanism
What’s in the GFCI? (Plug-in)

- Electro-Mechanical Latching Device
- Current Imbalance and Grounded Neutral Sensors
What’s in the GFCI? (Plug-in)

- Electro Mechanical Latching Device
- Push-to-test Button
- Current Imbalance and Grounded Neutral Sensor
- 15k Resistor
- Load Hot
- Load Neutral
- EGC

Circuitry with Open and Grounded Neutral detection
Standard 120V Connection
(GFCI Circuit Breaker)

120/240Vac Source

1-POLE CIRCUIT BREAKER WITH GFCI

DUPLEX RECEPTACLE

EQUIPMENT GROUND
Standard 120 Volt Connection (GFCI Receptacle)
240 Volt Load – No Neutral

120/240Vac Source

N  L1  L2

Note: Load neutral circuit not used in this circuit

2-POLE CIRCUIT BREAKER WITH GFCI

250V DUPLEX RECEPTACLE

HOT A

HOT B

EQUIPMENT GROUND

GND
120/240 Volt Load

120/240Vac Source

2-POLE CIRCUIT BREAKER WITH GFCI

120/240 VAC LOAD

EQUIPMENT GROUND
Single Phase 120V Circuit
Multi-Wire Circuits

One leg of multi-wire circuit in use

Switch Open
Multi-Wire Circuits

Both legs of multi-wire circuit in use

If what goes out… Comes back.. The GFCI sees zero total current on the circuit.
GFCI Circuit Breaker on Multi-Wire Circuits

120/240Vac Source

N  L1  L2

2-POLE CIRCUIT BREAKER WITH GFCI

HOT B

DUPLEX RECEPTACLE

120

NEUTRAL

HOT A

DUPLEX RECEPTACLE

EQUIPMENT GROUND
GFCI Receptacle on Multi-Wire Circuits

Use two GFCI receptacles

Junction Box

Separate Neutrals

GFCI Receptacles

Downstream Receptacles
This “Old House” Problem

GFCl installed on one circuit

Second circuit installed and neutral “stolen” from a close-by circuit
Line and Load Reversal on Receptacles

In the case of incorrect wiring, there will be no power at the face or downstream.

Incorrect Wiring
To Downstream Receptacle

Correct Wiring
To Panelboard

To Downstream Receptacle
GFCI Circuit Breaker Miswiring

120/240Vac Source

1-POLE CIRCUIT BREAKER WITH GFCI

Current does not return through the sensor in the circuit breaker

DUPLEX RECEPTACLE

EQUIPMENT GROUND
Grounded Neutral Detection

GFCI Device

L

N

6A

Leakage Current

EGC

Neutral grounded downstream
UL GFCI Tests

Every GFCI must pass the following end-of-line manufacturing tests:

1. no trip below 4mA (no load)
2. must trip at 6mA (no load)
3. no trip below 4mA (with load) at rated voltage
4. must trip at 6mA (with load) at rated voltage
5. must trip with 2 ohm grounded neutral
6. must trip within 25 ms with a 500 ohm fault
7. must trip with test button at +10/-15% rated voltage
8. must not trip with noise test of GFCI Standard
9. calibration test at +10/-15% rated voltage
GFCI Testers

Why are testers used?

- verify operation of the GFCI
- check protection of downstream receptacles

Will not test:

- GFCI calibration
- ALL types of improper installation
- Danger on 2-wire circuits

Will test for some types of improper installation:

- line/load reversal
- which outlets are protected by GFCI
- reverse polarity
- presence of the equipment ground
Test and Reset Buttons (Receptacle)

- Test and reset buttons verify proper functioning of the GFCI
- Test button will initiate end-of-life indication or power denial if product is no longer operational
GFCI Testers

Plug-in testers divert current to the equipment grounding conductor

What if there is not equipment ground....? Such as in a 406.3(D)(2)(b) and 406.3(D)(2)(c) application?

The GFCI will not trip with the external tester. The test button must be used.
Benefits of UL943 (GFCI) vs. IEC (RCD)

Increased Safety Benefits

- UL943 Max 6 mA - threshold for “let-go” current. IEC Min 20 mA - threshold current for ventricular fibrillation.
- Receptacle End of Life indication
- Grounded Neutral protection
- Portable units - Load protection if both supply neutral and ground conductors are open together.
Summary

вед GFCIs have contributed significantly to the reduction in the number of deaths due to electric shock

вед GFCIs look at the current going out and compare it to the current coming back

вед Remember that GFCIs detect ground to neutral connections downstream

вед Test the GFCI by using the test button and a load

вед GFCIs will not protect between line and neutral

вед Only Class A GFCIs (6mA) protect from electrocution from “let-go” situations