Ground Fault Protection

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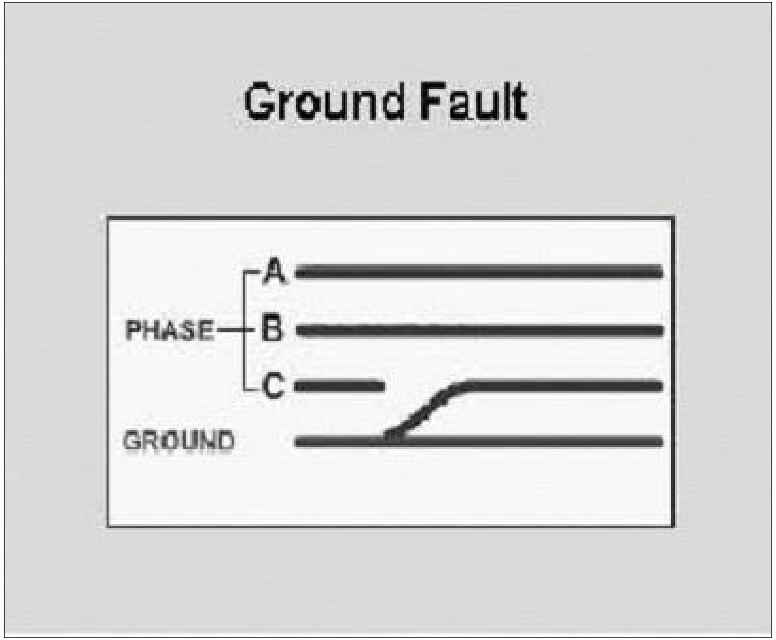
Ground Fault Protection



Ground Fault Protection

- Ground Fault protection is essential for safety of personnel and equipment
- The degree of protection depends upon the device selected.
- Ground Fault Protection Devices
  - Ground Fault Circuit Interrupter (GFCI) – People Protection
  - Ground Fault Protection of Equipment (GFPE) – Equipment Protection

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GFCI Protection

- NEC Article 100 – GFCI Definition
  - A device intended for the protection of personnel that functions to de-energize a circuit or portion thereof within an established period of time when a current to ground exceeds the values established for a Class A device.
    - Note: Class A ground-fault circuit interrupters trip when the current to ground has a value in the range of 4mA to 6mA.

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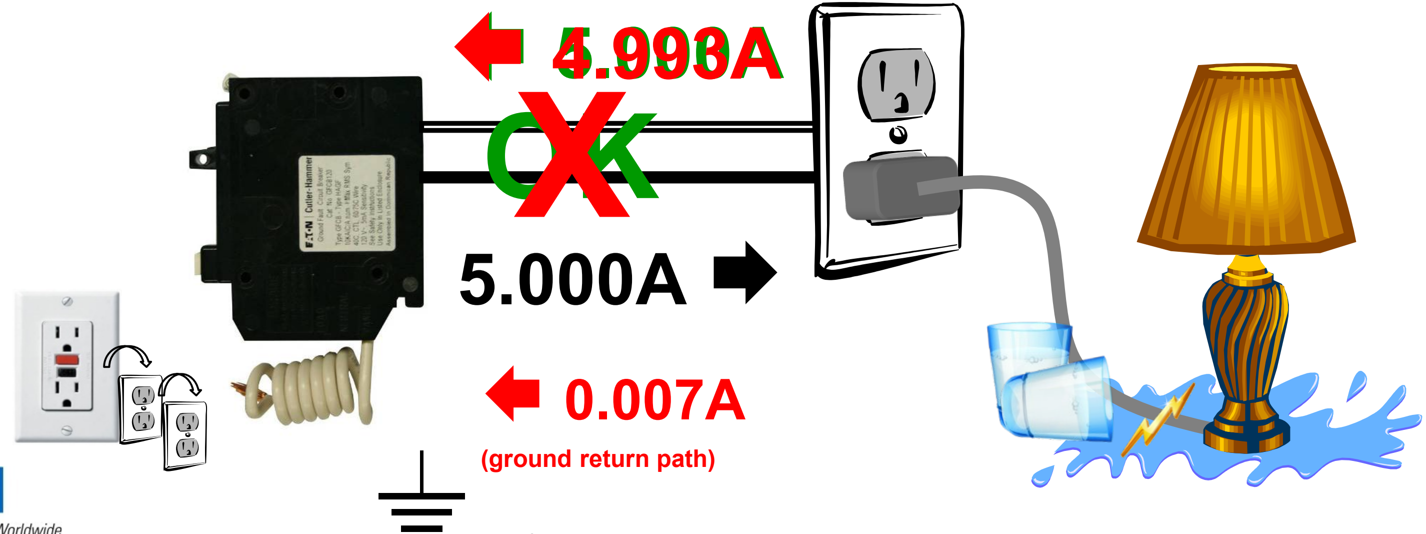
Ground Fault Circuit Interrupters (GFCI)

- Monitor the difference in the current returning to the breaker versus the current leaving the breaker
- Typical use a Zero Sequence Sensing method (single sensor)
- If an unacceptable difference is measured, the device trips and interrupts power to the load.



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GFP(E) Protection

- NEC Article 100 – Ground-Fault Protection of Equipment Definition
  - A system intended to provide protection of equipment from damaging line-to-ground fault currents by operating to cause a disconnecting means to open all ungrounded conductors of the faulted circuit. This protection is provided at current levels less than those required to protect conductors from damage through the operation of a supply circuit overcurrent device.

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NEC Levels of Ground Fault Protection

Ground Fault Requirement	Protection Level	Examples:

• GFP
  • Required on Service Entrance Mains 1000amps or greater with more than 150v to ground
	• Up to 1200 amps
	  • ~15-20 amps are minimum
	• Up to 1-second delay
		Services – Art. 230.95

• GFCI • Personnel protection - Required when in vicinity of water	• 4 to 6 milliamps • No time delay • Class A • ANSI/UL943 Listed	Art. 210.8 – Areas near water, outdoor, roof, garage, kitchen, crawl space Art. 555 – Marina receps
• GFPE • Equipment protection	• 6-100 milliamps • No time delay	Art 426 Snow Melt / Deicing equipment Art 427.22 Heat trace Art 555 Marina Feeders/Branch Circuits/Shore Power recep

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Ground Fault Protection 215.10 – Feeder Circuits (Similar requirement in 210.13 Branch Circuits)

- Ground Fault Protection is required on feeder disconnect switches, in accordance with 230.95, where:
  - System voltage is more than 150V to ground, but not exceeding 600V phase to phase
  - Rated 1000A or more
  - Exceptions:
    - If ground-fault protection is provided on the supply side of feeder.

This typically applies to 6-disconnect rule systems without a single Main. Only Health Care systems (Art. 517) require GF on Feeders as well as the Main.

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Ground Fault Sensing

Three Methods of Sensing Ground Faults:

1. Residual Sensing

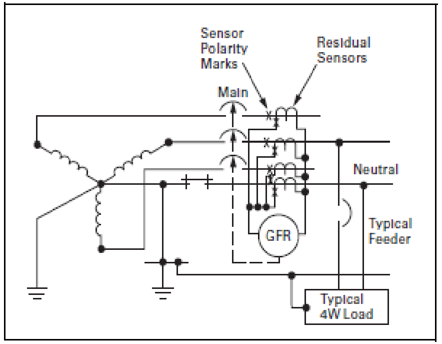

Figure 1.4-7. Residual Sensing Method

- Utilizes individual current sensors for each current carrying conductor
- Relay / Trip Unit sums

2. Zero Sequence Sensing

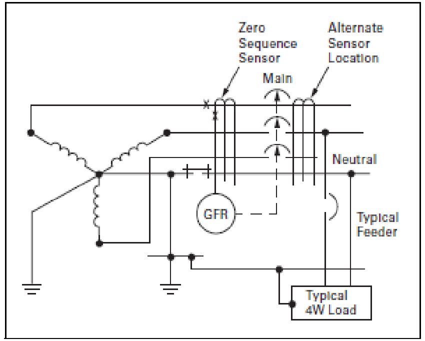

Figure 1.4-6. Zero Sequence Sensing Method

- All current carrying conductors route through a single current sensor
- Current sensor sums

3. Ground Return Sensing

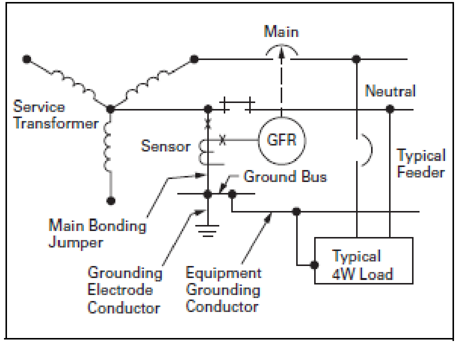

Figure 1.4-5. Ground Return Sensing Method

- Current sensor placed around the actual ground return path
- Current sensor reads actual GF current

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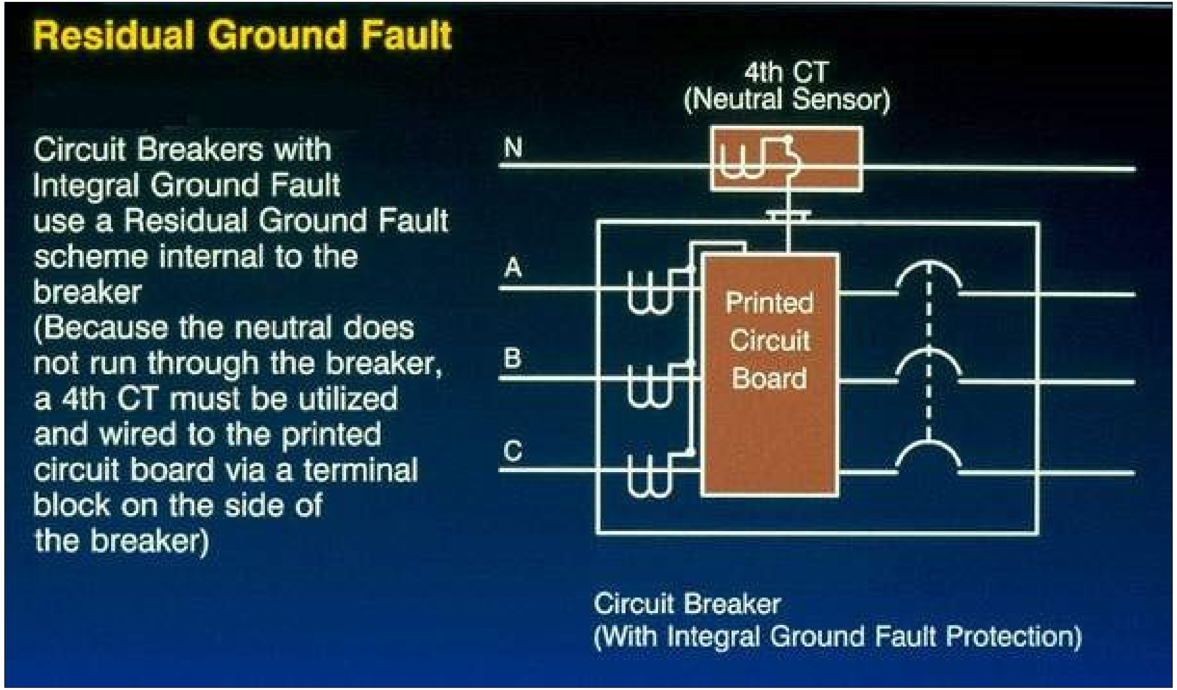
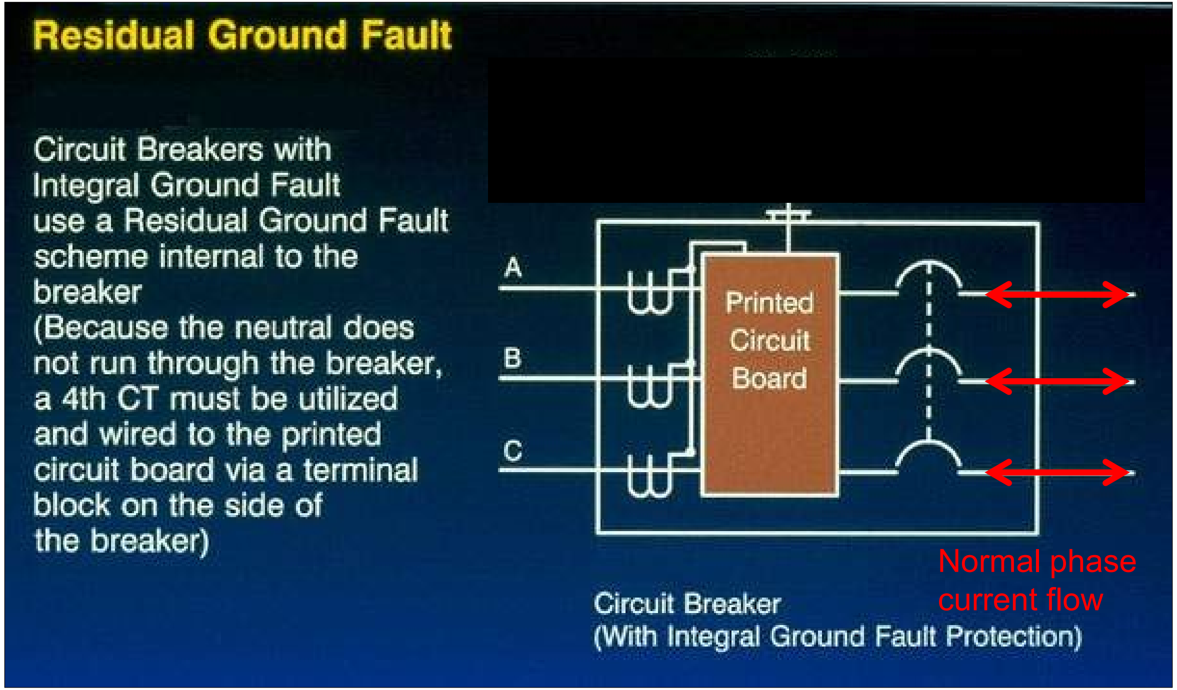
Ground Fault Protection - Residual



Residual Ground Fault detection

- Breaker measures all currents except for ground fault current
- Any "leftover" or "residual" current must be ground current

Ground Fault Protection - Residual



<u>If 3-wire load (i.e. no L-N 277v loads)</u>

- No Ground Fault
  - Sum of currents = 0
- Ground Fault
  - Sum of currents > 0

NOTE: Imbalanced current between the phases does NOT cause GF tripping. Only current that takes an alternate path back to the source is calculated as ground current.

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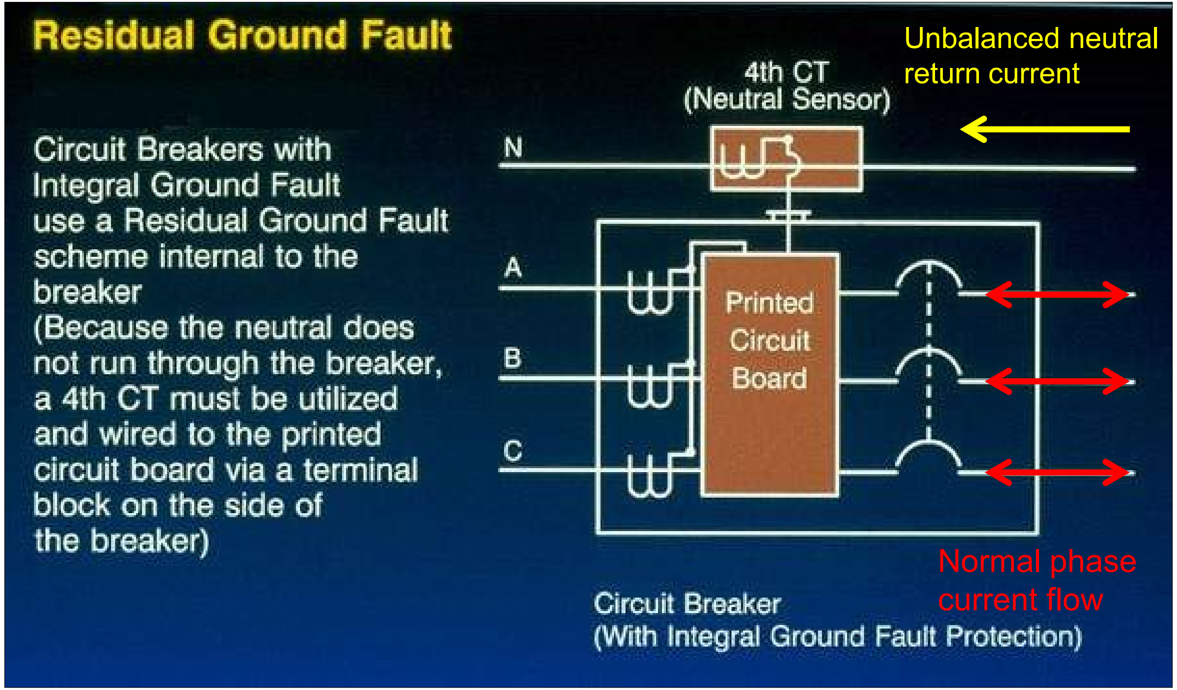
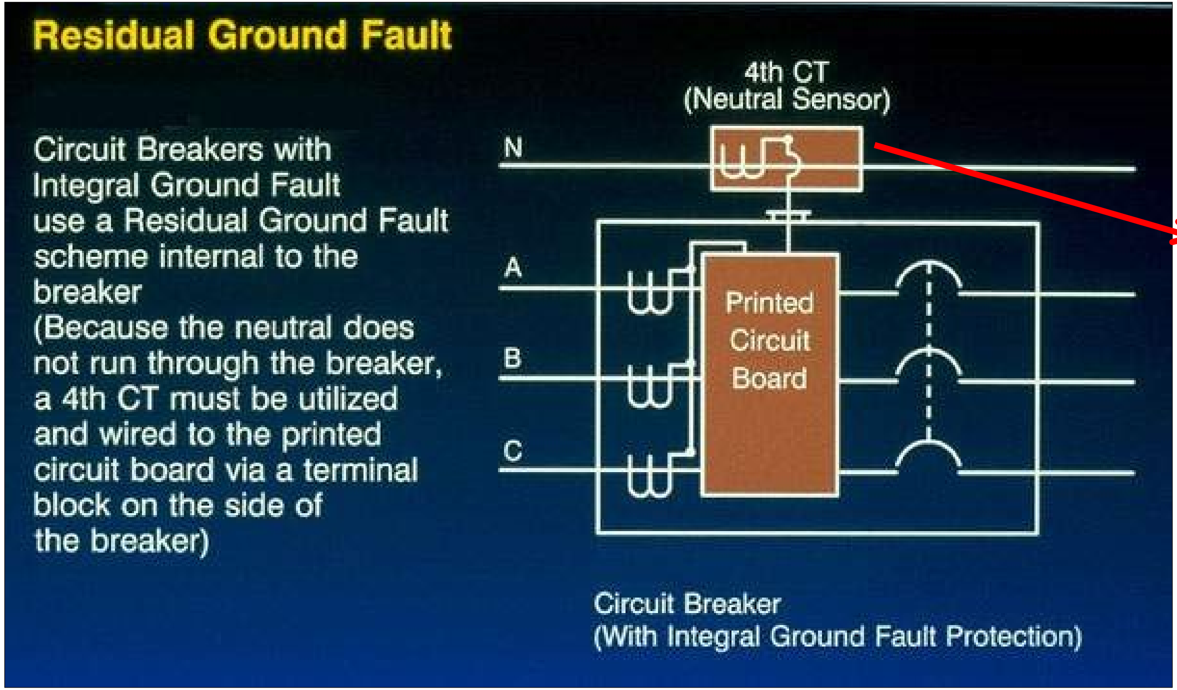
Ground Fault Protection - Residual

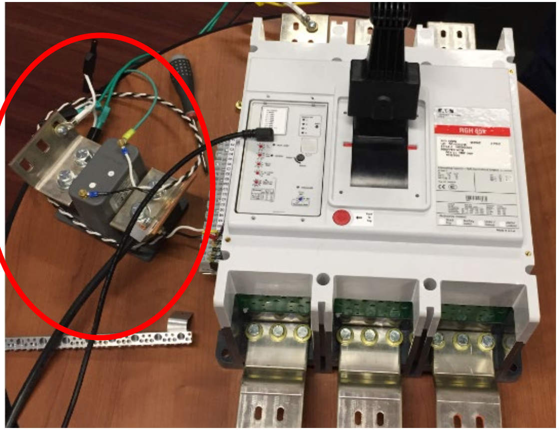


<u>If 4-wire loads (i.e. L-N 277v loads connected)</u>

- Unbalanced current between the phases returns on the neutral. (i.e. around the breaker)
- Additional neutral sensor required
- No Ground Fault
  - Sum of currents (A+B+C-Neu) = 0
- Ground Fault
  - Sum of currents (A+B+C-Neu) > 0

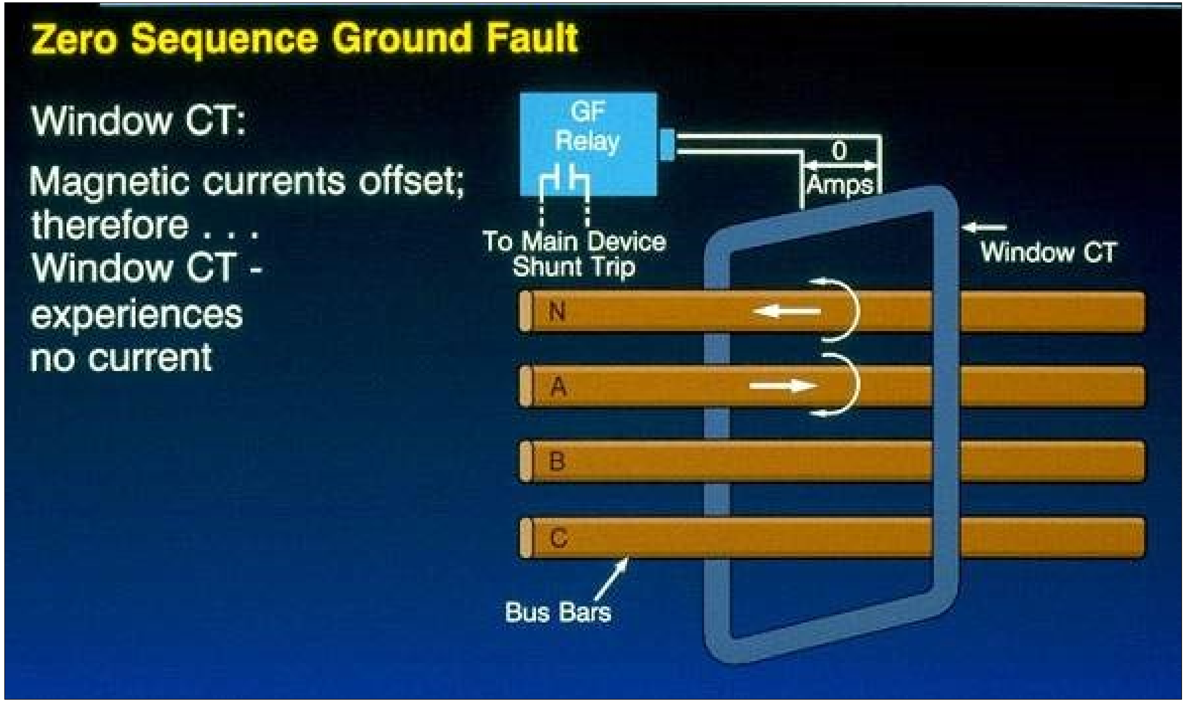
Ground Fault Protection - Residual





Neutral sensor

Ground Fault Protection – Zero Sequence



<u>Zero Sequence Ground Fault detection</u>

- Like residual, measures all currents <u>except</u> for ground fault current
- Net current through the CT should be zero.
- Anything > zero indicates current is taking an alternate path back to the source.

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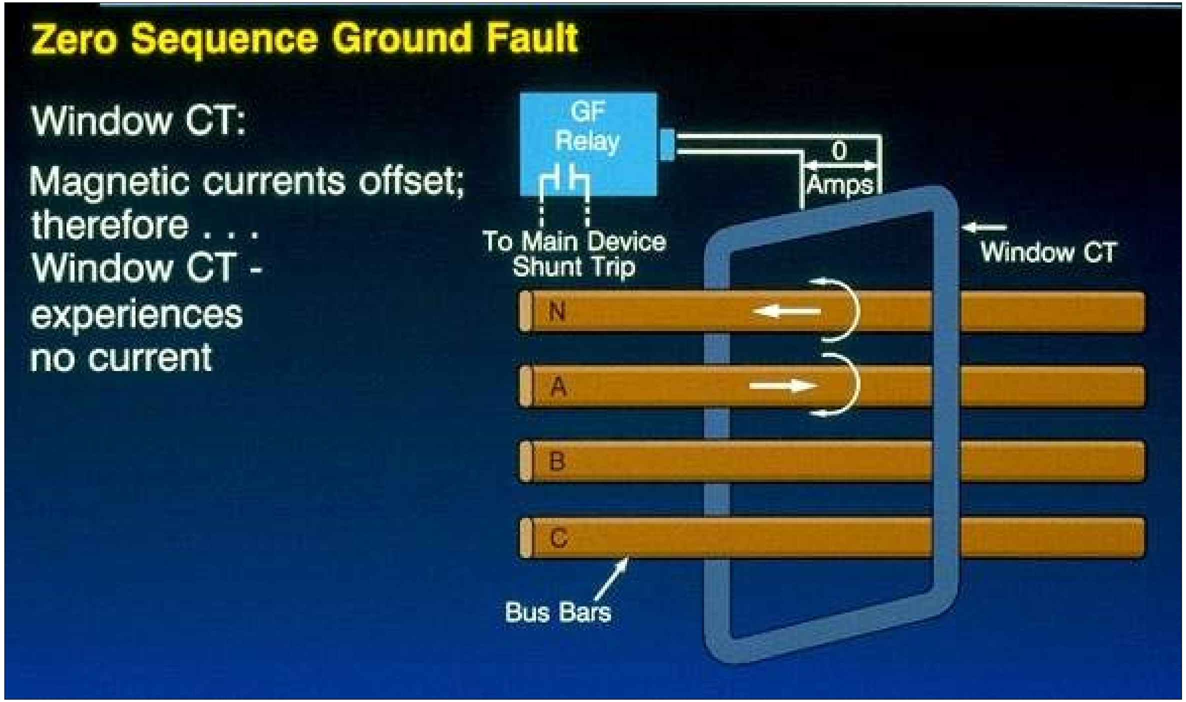
Ground Fault Protection – Zero Sequence



Zero Sequence Ground Fault detection

- Allow much more sensitive GF protection than residual sensing
- Normal condition is zero current flow to the relay / trip unit
- High resistance grounding systems typically require zero sequence sensing for fault tracing

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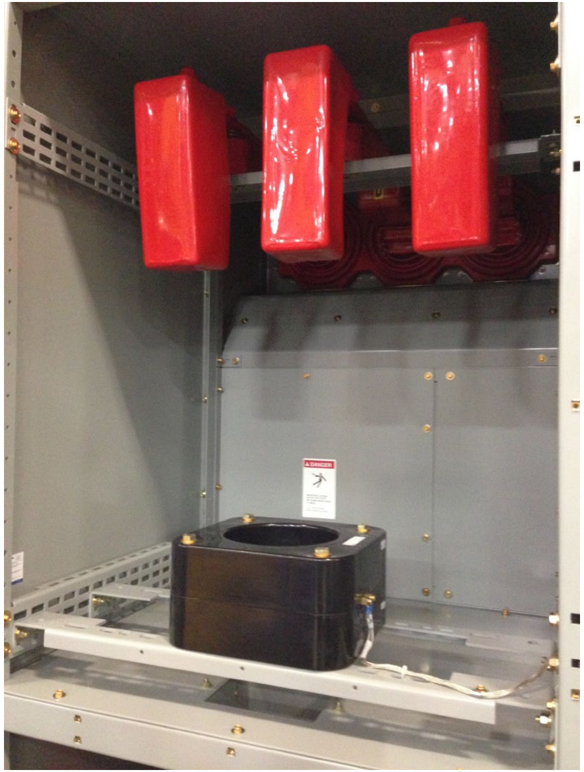
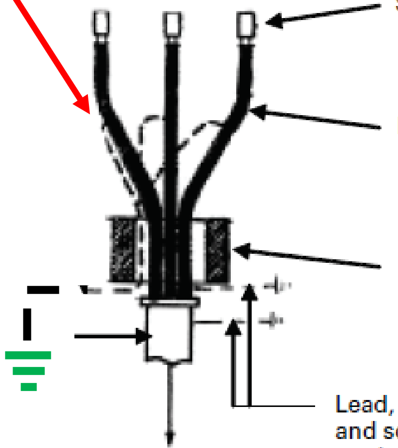
Ground Fault Protection – Zero Sequence Shielded Cables



All connections to ground (Such as shielding) must be carried through the current transformer and solidly grounded on the load side of the CT as shown. Use #6 wire with 600V insulation.



Resistance-Grounded Systems

Characteristics:

- Connected to ground (earth) through a fixed resistance
- Produces very low currents on first fault
  - Enough to allow alarming and fault tracing, but not enough to cause damage
  - Typically 5 – 10 amps
- Maintains continuity of service under first fault
- No overvoltage issues under fault
- Eliminate arcing line to ground faults
- Can only feed loads at one voltage
  - No L-N connected loads
- Higher first cost vs. solidly grounded

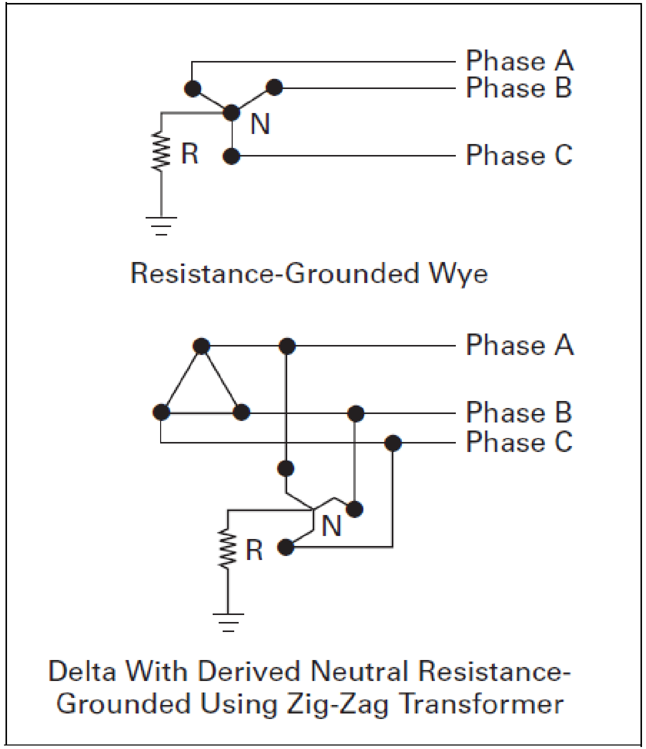
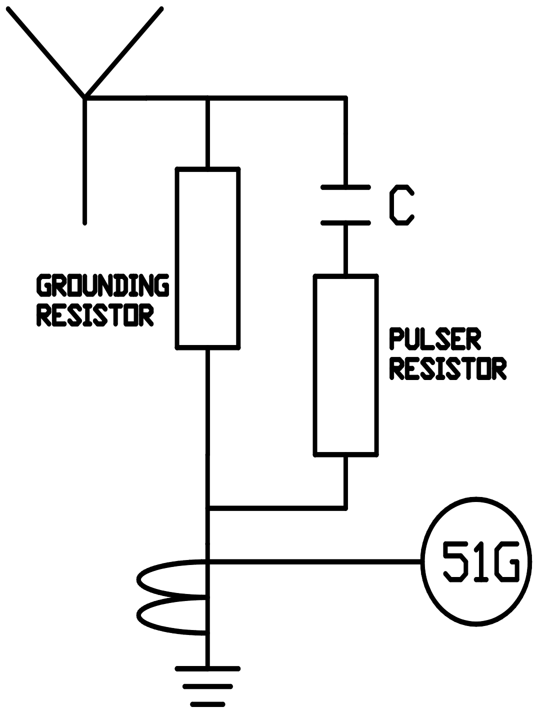


Figure 1.6-3. Resistance-Grounded Systems

Pulsing High-Resistance Grounded System

- Pulsing Circuit for quickly locating faults
  - Current Relay “51G” Detects Ground Fault; Alarm Sounds
  - Pulsing Function Enabled By Operator or automatically
  - Contactor “C” Pulses Resistor



High Resistance Ground System - Fault Detection Using Clamp-On Ammeter

- Clamp around each 3-phase circuit and look for pulsing readout on ammeter
- Continue downstream of circuits with pulsing current to next panel
- Repeat process until reach faulted branch

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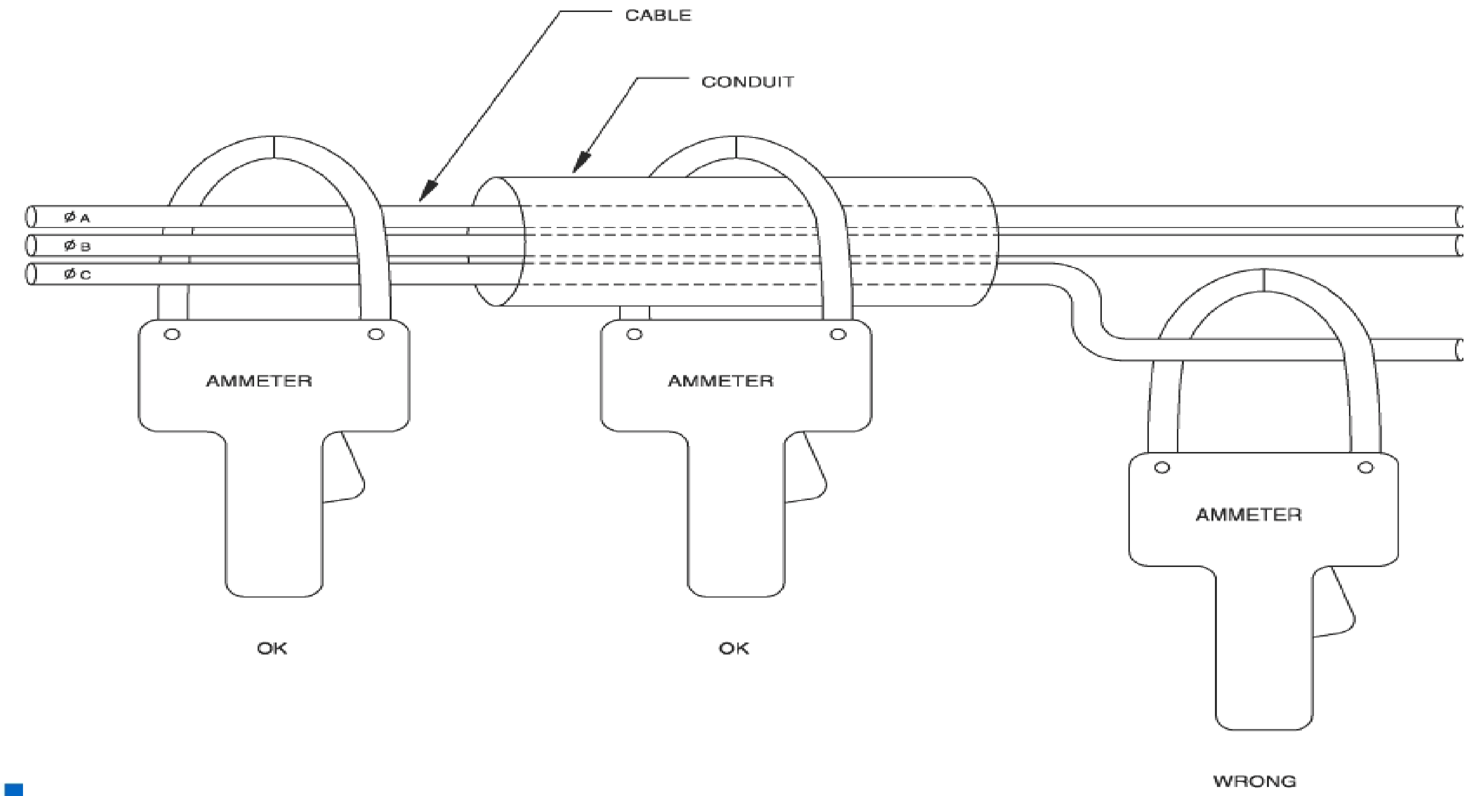
High Resistance Ground System - Fault Detection Using Clamp-On Ammeter



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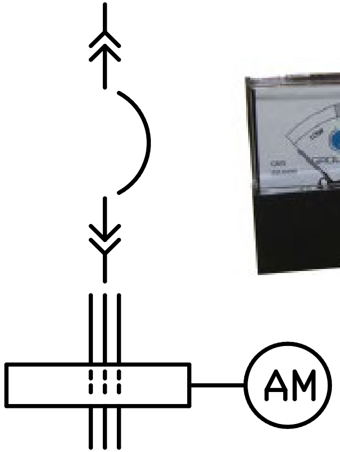
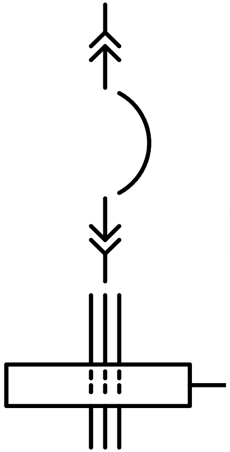
Ground Fault Detection Using Fixed Zero-Sequence CT And Ammeter

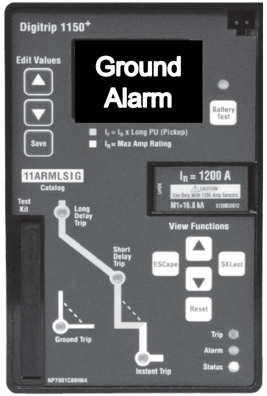
- Zero-Sequence CT and Ammeter in Each Feeder-Breaker Cubicle
- Individual Ammeter on each feeder breaker cubicle indicates pulsing current
- Requires separate ammeter
- No remote monitoring or annunciation

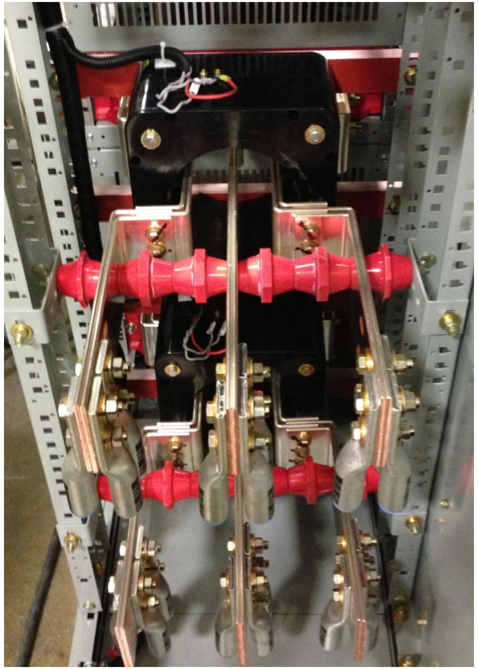


Ground Fault Detection Using Fixed Zero-Sequence CT And Trip Unit

- Certain trip units can accept zero sequence CT input
- Ground alarm sensing of the 5 amps the flows during fault
- Grounded circuit annunciates ground alarm condition
- Can be remotely monitored across comms or annunciate with relay output







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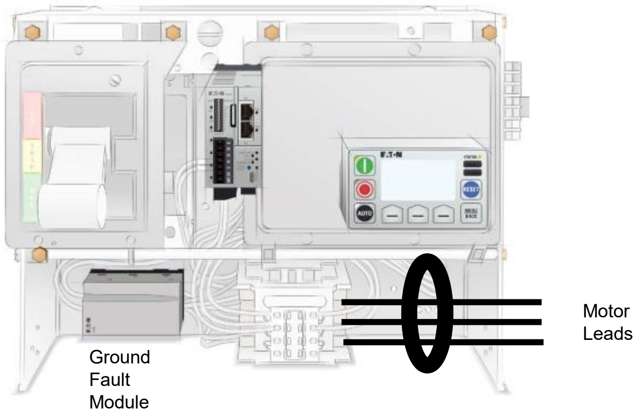
Ground Fault Detection - Motor Control Center

- High Resistance Ground systems limit ground current to 5 – 10 amps
- For automated fault localization, Zero sequence CT and additional overload relay module required
- Allows quick identification of faulted motor circuit
- Process is not interrupted
- Takes additional space in the bucket



Overload Relay Indicates faulted circuit

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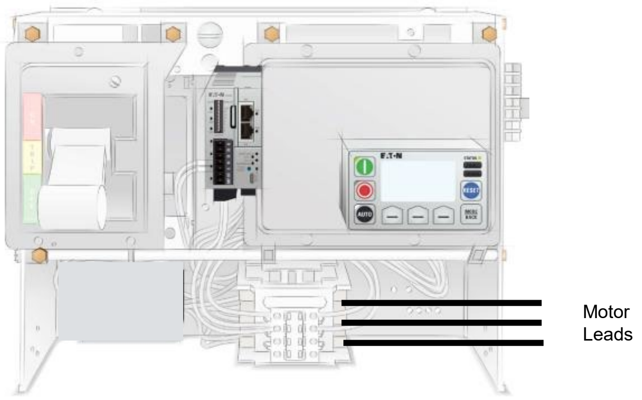
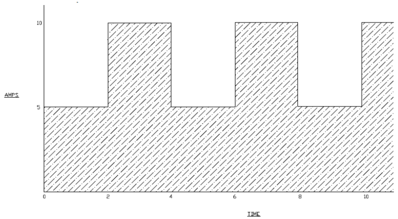
Ground Fault Detection - Motor Control Center
Pulse Detection

- High Resistance Ground systems limit ground current to 5 – 10 amps
- HRG systems with pulsing circuits allow for simpler fault tracing
- Pulse detection algorithm recognizes the ground pulses of a Pulsing HRG System
- No zero sequence CT, additional hardware, or additional space required!



Ground pulses from HRG System



Overload Relay Indicates faulted circuit

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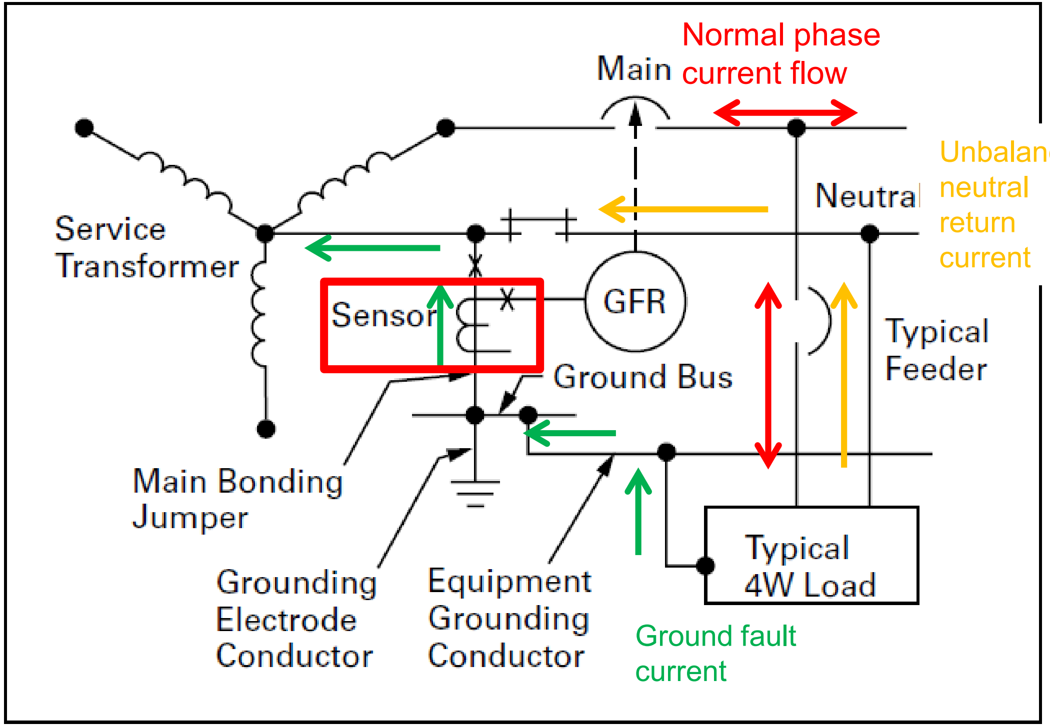
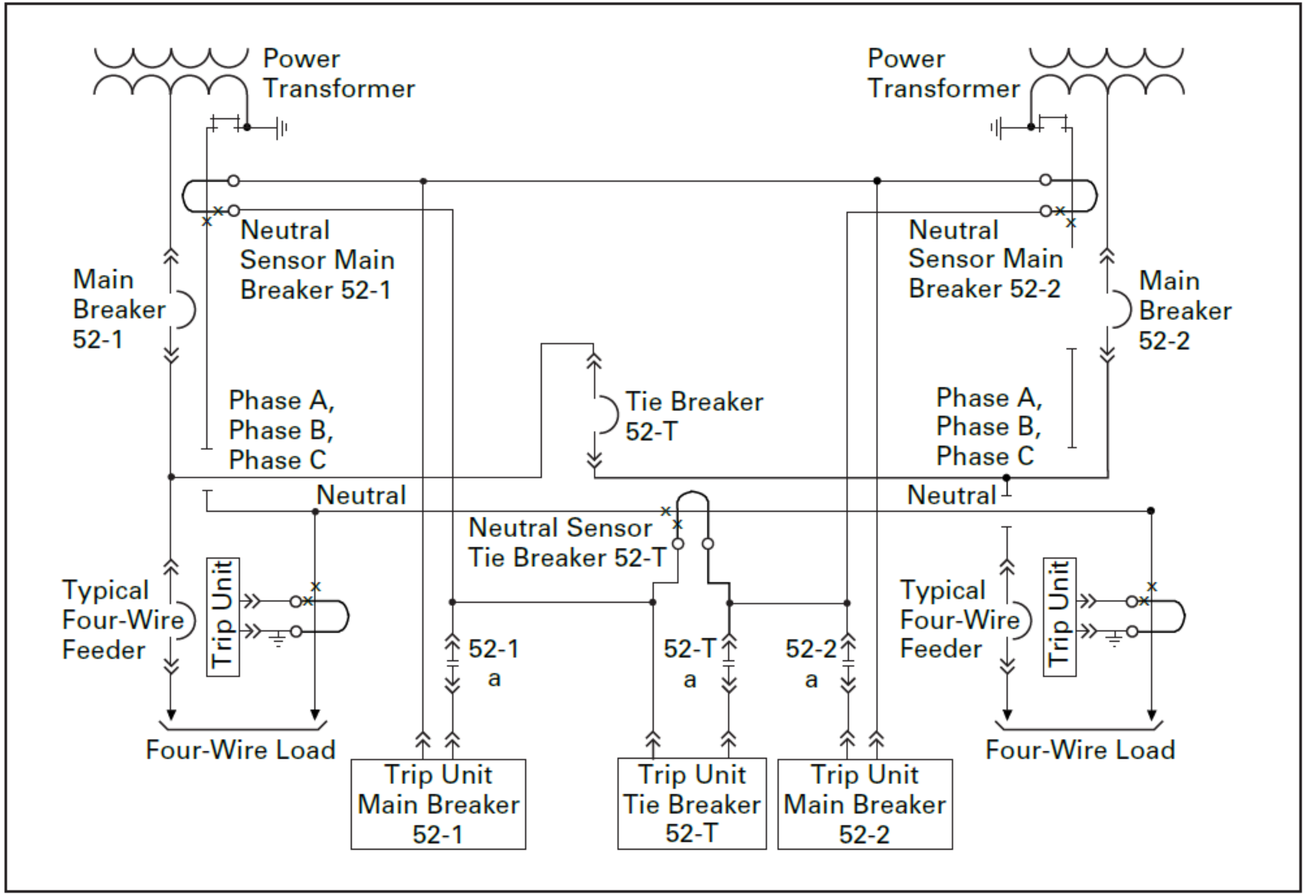
Ground Return (Source Sensing) Ground Fault Detection



- Ground CT is place on the neutral to ground bond of the separately derived source.
- Senses actual ground current returning to the source
- Ground current is sensed by relay or trip unit

Ground Fault Protection for Multiple Separately Derived Sources

- Systems fed from multiple separately derived sources make add to the complexity of GF sensing
- Example: Main-Tie-Main



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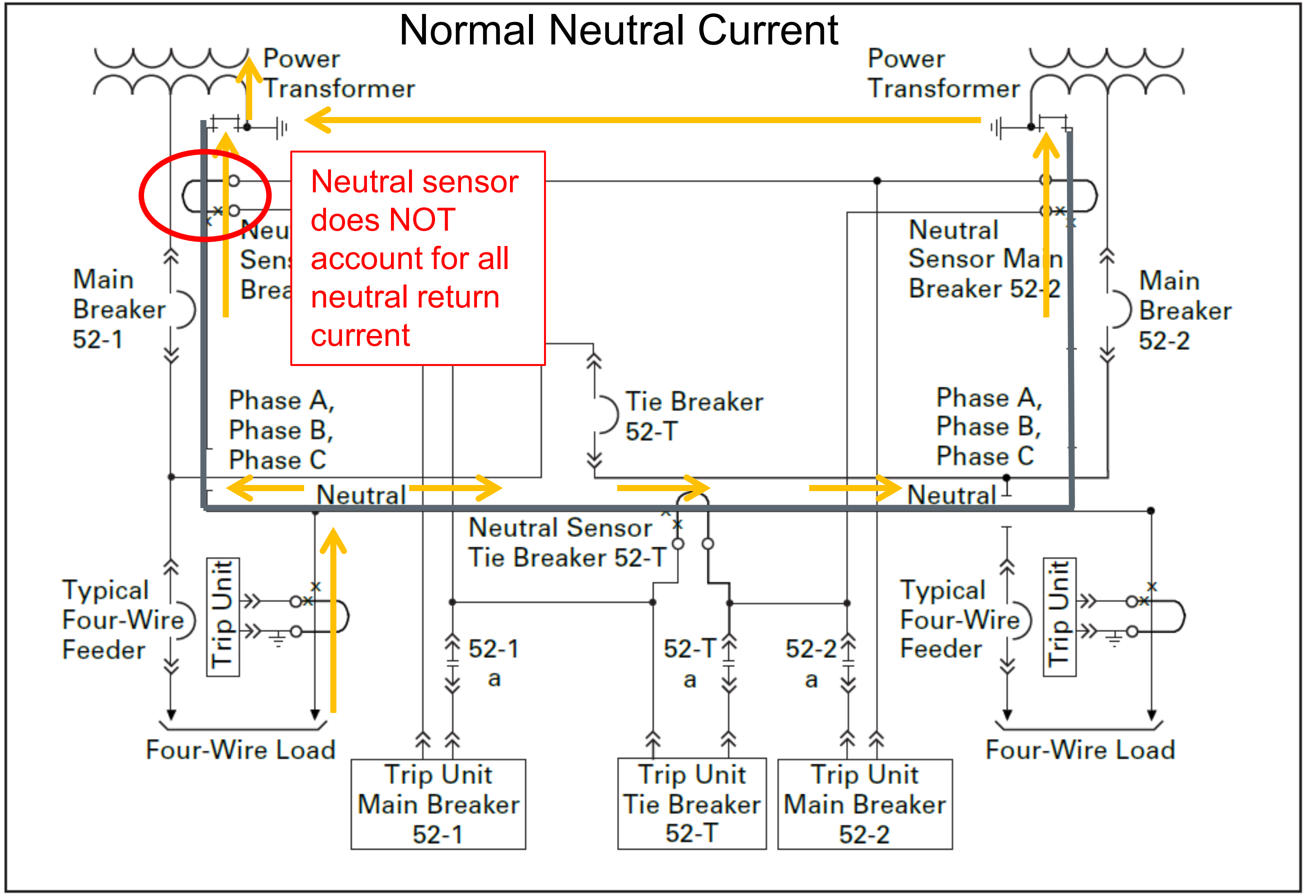
Ground Fault Protection for Multiple Separately Derived Sources

- Neutral return current from unbalanced loads has multiple paths for returning to the source
- Solid neutral bar running through the gear



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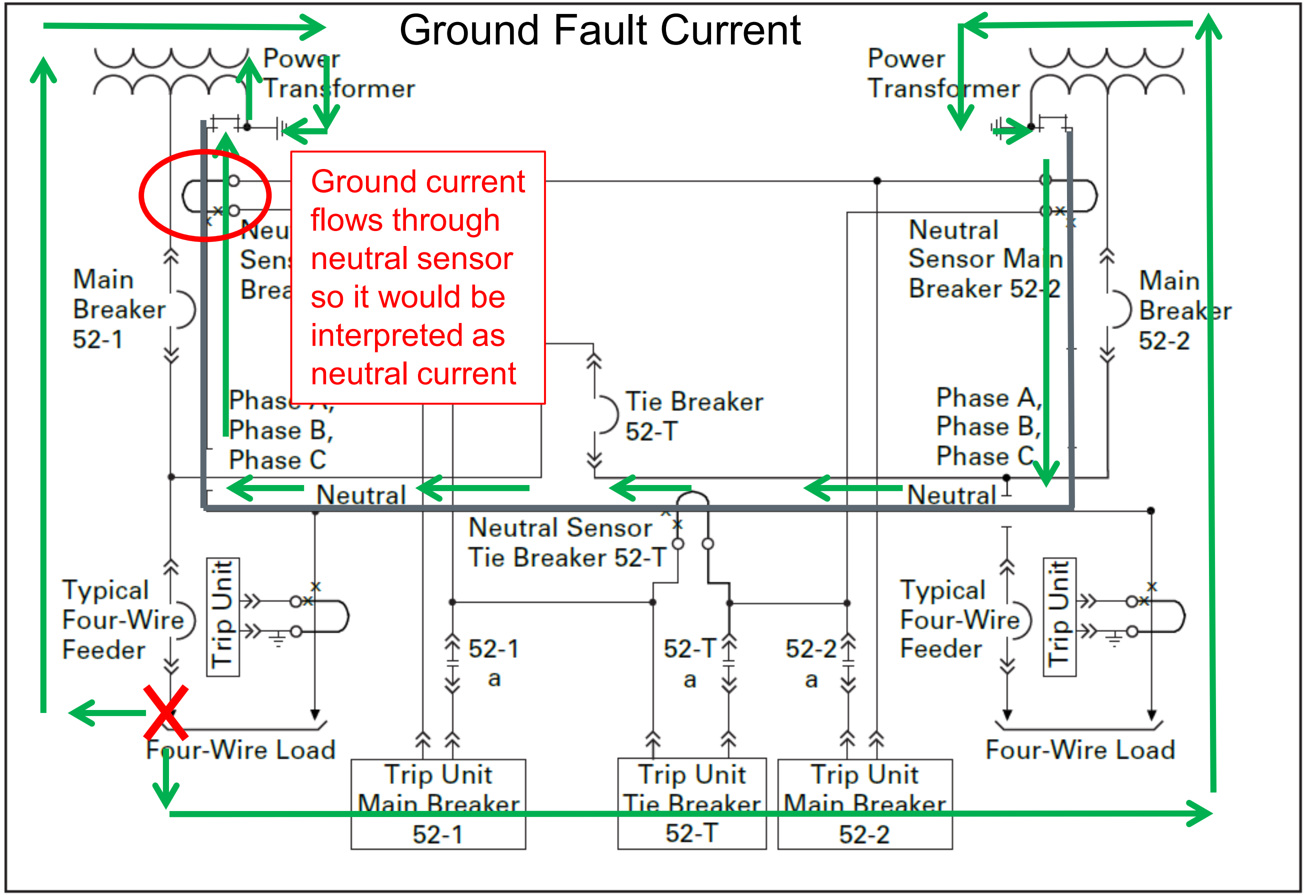
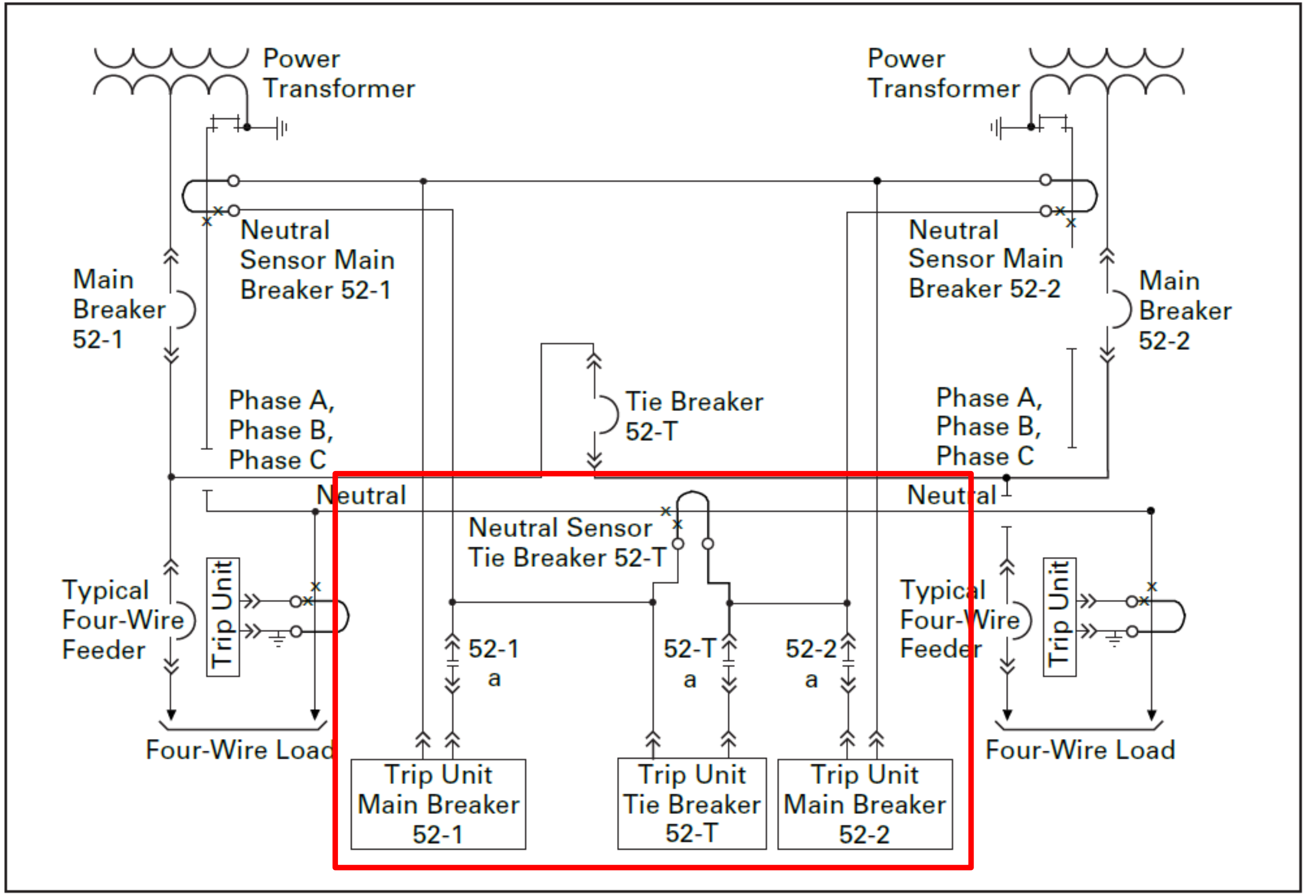
Ground Fault Protection for Multiple Separately Derived Sources

- Ground fault current from unbalanced loads has multiple paths for returning to the source
- Can lead to ground current routing through the neutral sensor
- Desensitizes the GF protection



Differential Ground Fault Scheme

- Differential (or Modified Differential) Ground Fault schemes are used on systems with multiple separately derived sources
- Connect together multiple GF (or neutral) sensors in a way to accurately account for ground current in / out of a particular “zone”



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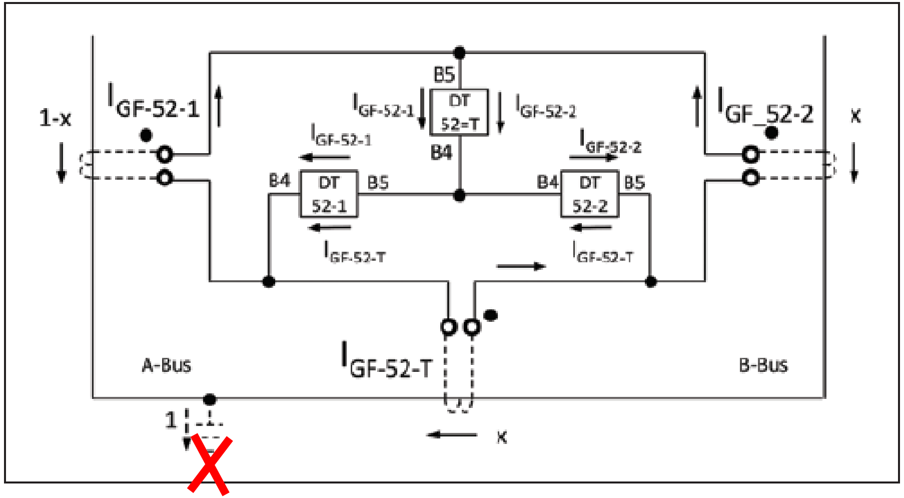
Modified Differential Ground Fault

- Ground fault sensors (or neutral sensors) are tied together in a “bridge” with different polarities to add or subtract current readings for a given “zone”
- Only the OCPD’s for the given “zone” see the current amount of ground current
- In this example, for a fault on A-Bus, only the 52-1 Main and 52-T Tie see the ground current
  - Total ground fault current = 1 pu
  - X = unknown ground current flowing through the B-bus path
  - 1-x = ground current flowing through the A-bus path



- DT 52-1 = $I_{GF\text{-}52\text{-}1} + I_{GF\text{-}52\text{-}T} = (1\text{-}x) + x = 1$
- DT 52-T = $I_{GF\text{-}52\text{-}1} + I_{GF\text{-}52\text{-}2} = (1\text{-}x) + x = 1$
- DT 52-2 = $I_{GF\text{-}52\text{-}2} - I_{GF\text{-}52\text{-}T} = x - x = 0$

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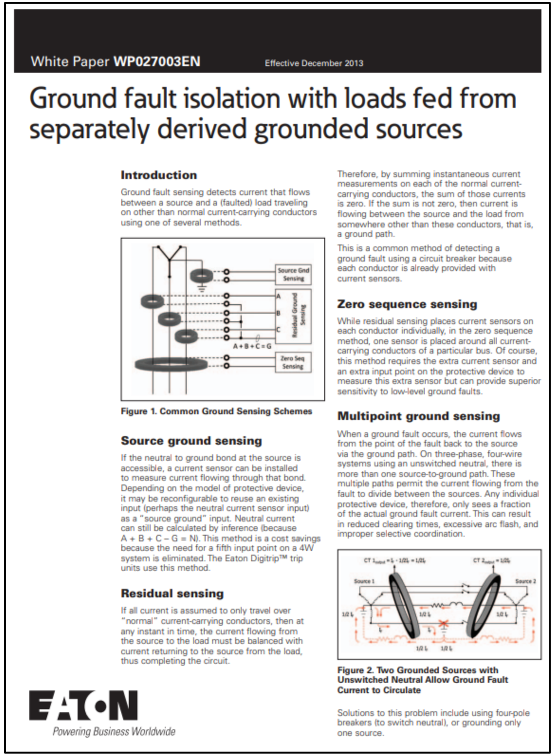
Modified Differential Ground Fault



White Paper **WP027003EN** Effective December 2013

Ground fault isolation with loads fed from separately derived grounded sources

Introduction

Ground fault sensing detects current that flows between a source and a (faulted) load traveling on other than normal current-carrying conductors using one of several methods.

Figure 1. Common Ground Sensing Schemes

Source ground sensing

If the neutral to ground bond at the source is accessible, a current sensor can be installed to measure current flowing through that bond. Depending on the model of protective device, it may be reconfigurable to reuse an existing input (perhaps the neutral current sensor input) as a "source ground" input. Neutral current can still be calculated by inference (because A + B + C – G = N). This method is a cost savings because the need for a fifth input point on a 4W system is eliminated. The Eaton Digitrip™ trip units use this method.

Residual sensing

If all current is assumed to only travel over "normal" current-carrying conductors, then at any instant in time, the current flowing from the source to the load must be balanced with current returning to the source from the load, thus completing the circuit.

Therefore, by summing instantaneous current measurements on each of the normal current-carrying conductors, the sum of those currents is zero. If the sum is not zero, then current is flowing between the source and the load from somewhere other than these conductors, that is, a ground path.

This is a common method of detecting a ground fault using a circuit breaker because each conductor is already provided with current sensors.

Zero sequence sensing

While residual sensing places current sensors on each conductor individually, in the zero sequence method, one sensor is placed around all current-carrying conductors of a particular bus. Of course, this method requires the extra current sensor and an extra input point on the protective device to measure this extra sensor but can provide superior sensitivity to low-level ground faults.

Multipoint ground sensing

When a ground fault occurs, the current flows from the point of the fault back to the source via the ground path. On three-phase, four-wire systems using an unswitched neutral, there is more than one source-to-ground path. These multiple paths permit the current flowing from the fault to divide between the sources. Any individual protective device, therefore, only sees a fraction of the actual ground fault current. This can result in reduced clearing times, excessive arc flash, and improper selective coordination.

Figure 2. Two Grounded Sources with Unswitched Neutral Allow Ground Fault Current to Circulate

Solutions to this problem include using four-pole breakers (to switch neutral), or grounding only one source.

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[Ground Fault Isolation Whitepaper]

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Generator and Transfer Switch Grounding

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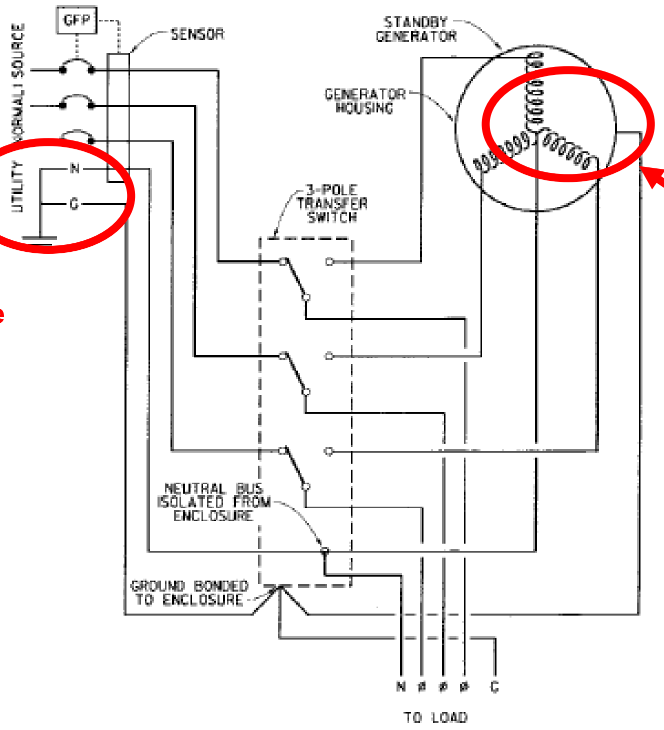
Standard 3-pole ATS and Generator neutral NOT bonded at the gen (not Separately Derived)

Utility service = Separately Derived

Neutral is bonded to ground at the service



Generator source = NOT Separately Derived

Neutral is NOT bonded to ground at the generator

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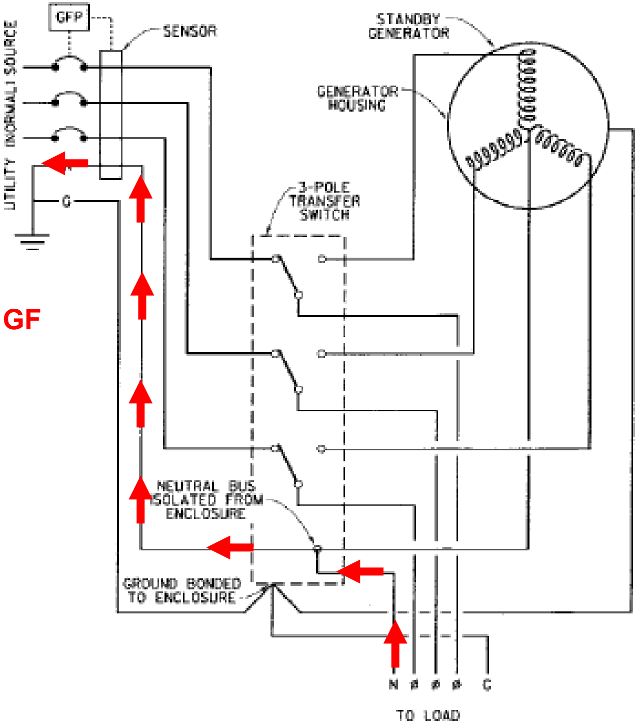
Standard 3-pole ATS and Generator neutral NOT bonded at the gen (not Separately Derived)

Normal Neutral Current

Only path for neutral current is through the neutral sensor

Results:
- Correct detection of GF



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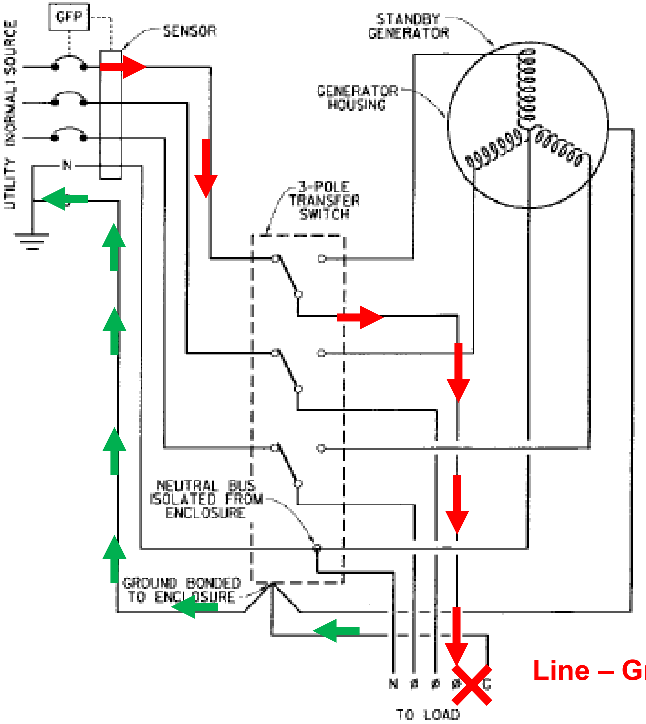
Standard 3-pole ATS and Generator neutral NOT bonded at the gen (not Separately Derived)

Ground Fault Current

Ground Fault current travels back on the ground conductor and around the neutral sensor

Results:
- Correct detection of ground fault condition



Line – Ground Fault

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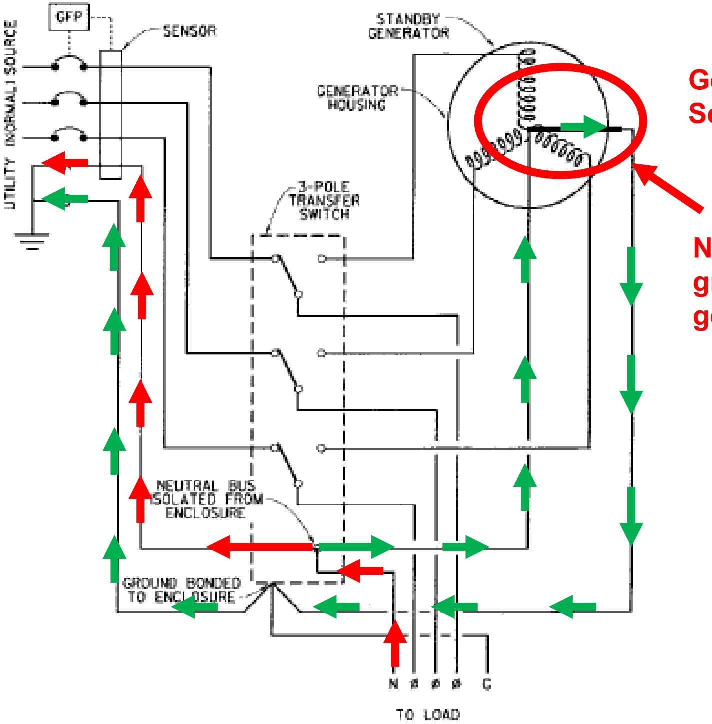
Standard <u>3-pole</u> ATS and Generator neutral bonded at the gen (2 Separately Derived systems)

Normal Neutral Current

Neutral current can return through the ground path AND around the neutral sensor

<u>Results:</u>
- Possible nuisance tripping of the GF protection during normal operation



Generator source = Separately Derived

Neutral is bonded to ground at the generator

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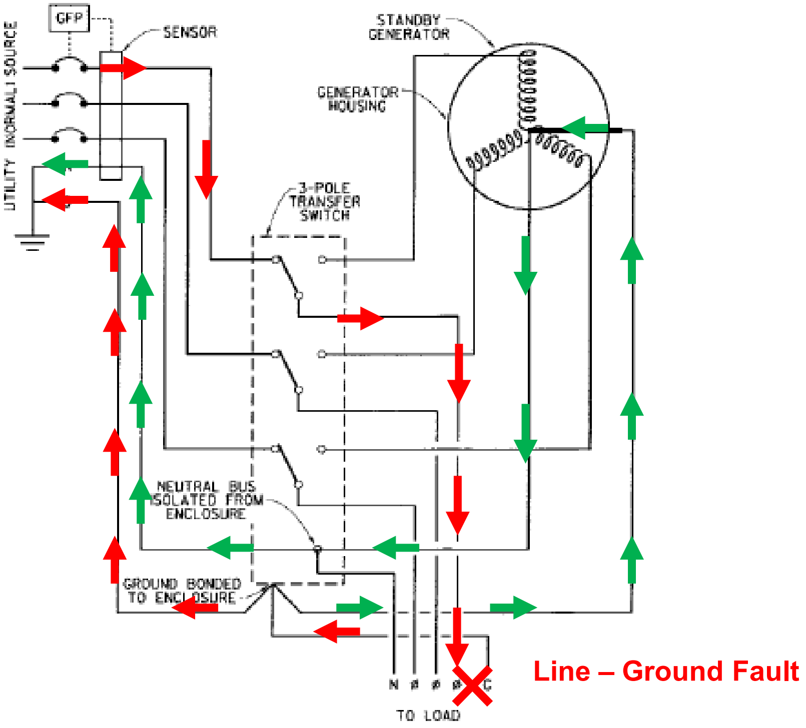
Standard 3-pole ATS and Generator neutral bonded at the gen (2 Separately Derived systems)

Ground Fault Current

Fault current can return through the neutral path and thru the neutral sensor

Results:

- Some GF current flows through the neutral sensor
- Desensitizes GF protection
- Violates NEC because neutral is grounded at two locations



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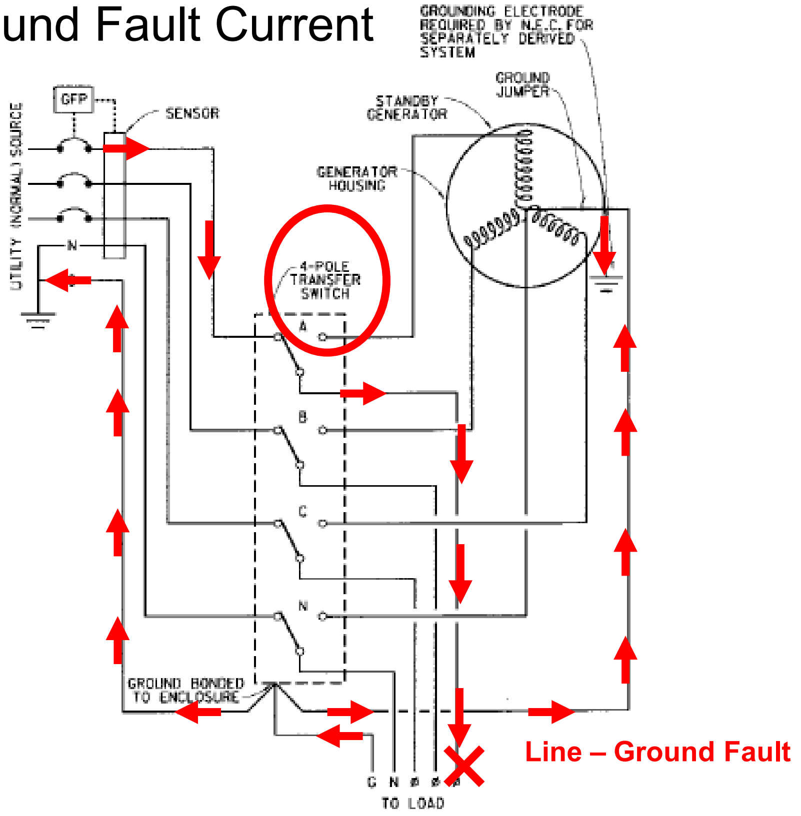
Standard 4-pole ATS and Generator neutral bonded at the gen (2 Separately Derived systems)

- Fault current can only return through the ground path
- Neutral current only has single path since neutral is switched

Results:
- Correct sensing of neutral and ground fault current
- Meets NEC because neutrals for each system are only grounded at one location

Ground Fault Current



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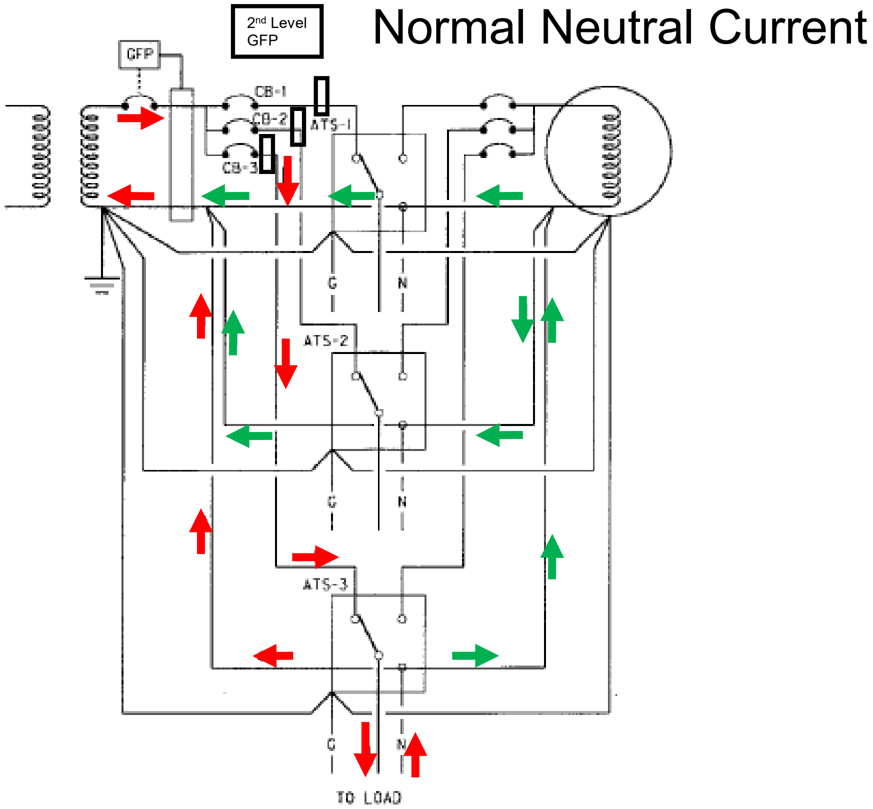
Single service, Gen(s) not separately derived, Multiple 3-Pole ATS

Neutral current can return through multiple paths (any ATS). Amount of current to flow depends on the impedance of each path.

Results:

- **Correct sensing of neutral current for Main Breaker GFP**
- **Feeder Breaker (2nd Level) GFP may not see all neutral current**
- **Can cause nuisance tripping of Feeder GFP if settings are too low**
- **Same condition can also affect GF Alarms when on Emergency Source**



Multiple Services, Gen(s) not separately derived, Multiple 3-Pole ATS

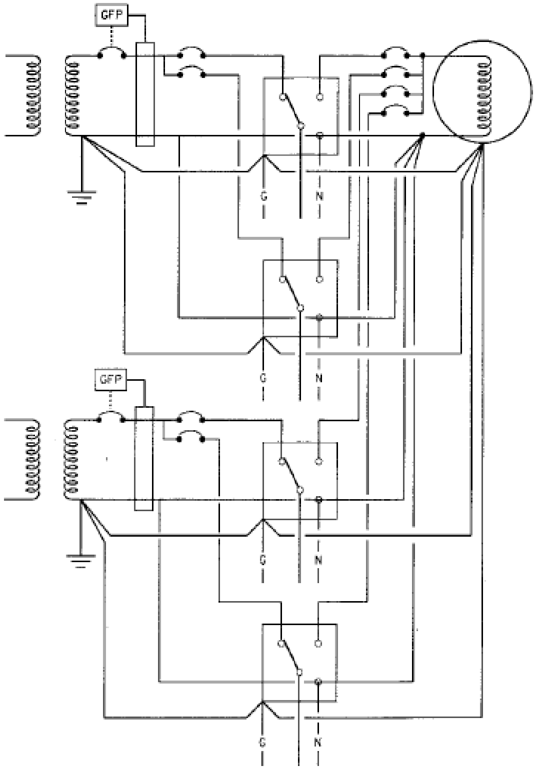
Neutral current can return through multiple paths due to multiple ground points and ATS. Amount of current to flow depends on the impedance of each path.

<u>Results:</u>

- Multiple neutral ground bonding points create multiple paths for neutral current and ground current

- Can cause nuisance tripping of GFP if settings are too low

- Same condition can also affect GF Alarms when on Generator Distribution Switchboard



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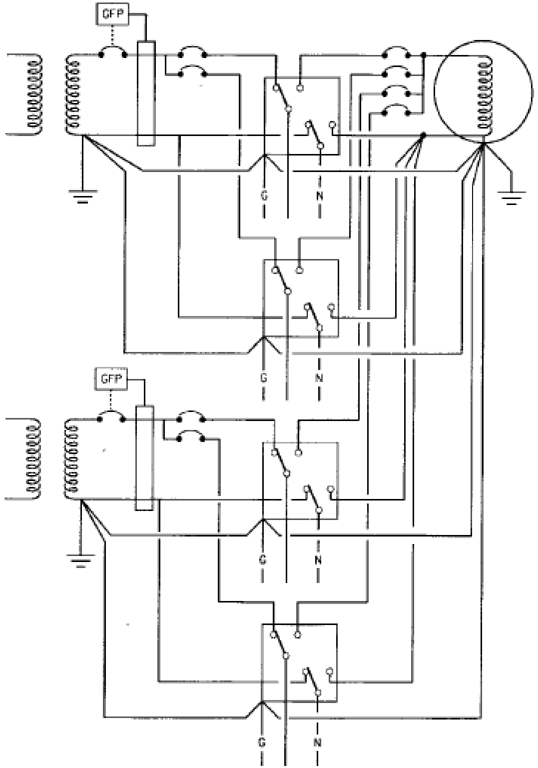
Multiple Services, Gen(s) separately derived, Multiple 4-Pole ATS

Neutral current can only return through the correct neutral sensor



Results:
- NEC compliant (3 separately derived services)
- Correct sensing of neutral currents and ground fault currents

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Transfer Switch and Grounding Options Summary

- Use 4-pole anytime the generator is separately derived (bonded at the gen)
- Recommend 4-pole anytime there are multiple utility services
- Avoid mixing the use of 3-pole and 4-pole ATS
    - Exception: Only need 3-pole if feeding only 3-wire loads
- Consider future expansion – If new service is likely to be added, use 4-pole ATS
- Overlapping neutral switching is not necessary or recommended
    - History, testing, and modeling shows that neutral switching does not produce appreciable transients
    - Overlapping neutral can cause nuisance tripping due to momentary connection to both separately derived sources
- Number of generators typically is irrelevant since they are typically all separately derived, or none are separately derived
- Take care to balance loads at all ATS to minimize problems
    - Limits neutral current flow

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3-Pole and 4-Pole Transfer Switching Whitepaper

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White Paper

3-Pole and 4-Pole Transfer Switch Switching Characteristics

Abstract

Whether to, and how to, switch a neutral connection when transferring a load between two separate three-phase sources is a topic of frequent discussion [1][2][3][4][5][6]. Should a three-pole or four-pole switch be used? If the neutral is switched, should it be done in an "overlapping" way to insure that during the switching operation the neutral connection to the load is always maintained? Is there a way of successfully using three-pole switching devices on a separately derived (that is, source derived) system?

There are many issues to consider, and those issues have been, by and large, covered adequately in the previously referenced texts. However, what hasn't been covered in those texts is the exact quantification of two key problems.

1. How much circulating neutral current is created when using overlapping neutral switching transfer switches and,
2. How large are the transient overvoltages produced when switching a neutral in a non-overlapping manner

The first point focuses on accurate GF sensing when using overlapping neutral switching schemes. To understand this issue we first examine a system that has only one grounded source. By definition, all ground current must flow through that single ground. Placing a sensor on that grounded connection makes it easy to capture and measure all ground current. By convention, a single-point grounded system with multiple sources is called a "non-separately derived system".

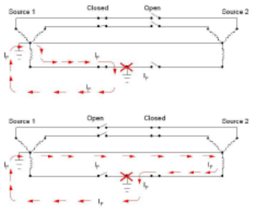

Figure 1: *Regardless of which source is energized, a ground fault on a single point grounded system always returns to the grounded source.*

GF sensing becomes more difficult when multiple sources each have their own grounded conductor and when the neutral conductor is not switched. In such a case, ground current can flow through multiple paths. This complicates the ground fault sensing scheme. Systems with multiple grounded sources are called "separately derived systems."

[3-Pole and 4-pole Transfer Switch Switching Characteristics](#)

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Questions?

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