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
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.
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.
# NEC Levels of Ground Fault Protection

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**GFPE**
- Equipment protection
- Up to 1200 amps
- ~15-20 amps are minimum
- Up to 1-second delay

**GFP**
- Required on Service Entrance Mains 1000amps or greater with more than 150v to ground
- 6-100 milliamps
- No time delay

**GFCI**
- Personnel protection - Required when in vicinity of water
- 4 to 6 milliamps
- No time delay
- Class A
- ANSI/UL943 Listed
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.
Ground Fault Sensing

Three Methods of Sensing Ground Faults:

1. Residual Sensing
   - Utilizes individual current sensors for each current carrying conductor
   - Relay / Trip Unit sums

2. Zero Sequence Sensing
   - All current carrying conductors route through a single current sensor
   - Current sensor sums

3. Ground Return Sensing
   - Current sensor placed around the actual ground return path
   - Current sensor reads actual GF current
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

If 3-wire load (i.e. no L-N 277v loads)
- 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.
Ground Fault Protection - Residual

If 4-wire loads (i.e. L-N 277v loads connected)
- 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

Residual Ground Fault

Circuit Breakers with Integral Ground Fault use a Residual Ground Fault scheme internal to the breaker. (Because the neutral does not run through the breaker, a 4th CT must be utilized and wired to the printed circuit board via a terminal block on the side of the breaker.)

Circuit Breaker (With Integral Ground Fault Protection)

Neutral sensor
Ground Fault Protection – Zero Sequence

Zero Sequence Ground Fault detection
• Like residual, measures all currents except 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.
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
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 \textit{load side} of the CT as shown. Use #6 wire with 600V insulation.

- Switchgear Terminals
- Power Cables
- Zero Sequence Transformer

Ground Cable Shields on load side of CT

Lead, armor, conduit, Interstice ground conductors, and so on. Must be terminated and solidly grounded on the load side of the current transformer.
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
High Resistance Ground System - Fault Detection Using Clamp-On Ammeter
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
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
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 Return (Source Sensing) Ground Fault Detection

- Ground CT is placed 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.

Diagram:

[Diagram showing the flow of current with labels: Normal phase current flow, Unbalanced neutral return current, Main bonding jumper, GFR (Ground Fault Relay), Grounding Electrode Conductor, Equipment Grounding Conductor, Typical 4W Load, and sensor location.]
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
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.

Neutral sensor does NOT account for all neutral return current.

Normal Neutral Current
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”
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

\[
\begin{align*}
\text{DT 52-1} &= I_{GF-52-1} + I_{GF-52-T} = (1-x) + x = 1 \\
\text{DT 52-T} &= I_{GF-52-1} + I_{GF-52-2} = (1-x) + x = 1 \\
\text{DT 52-2} &= I_{GF-52-2} - I_{GF-52-T} = x - x = 0
\end{align*}
\]
Ground fault isolation with loads fed from separately derived sources

Introduction

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

Source ground sensing

If the neutral to ground fault at the source is accessible, a current sensor can be placed to monitor current flowing through that fault. Depending on the nature of problems detected, this method can be very effective. In general, the sensor output should be compared to the neutral current input at the source-ground input. Non-zero current flowing through the faulted phase indicates a fault. This method is most effective in situations where the fault is close to the source. The Eaton Digital™ I-125 system is one example.

Residual sensing

If all current is assumed to only flow in the "normal" current-carrying conductors, then at any instant in time, the current flowing from the source to the load will equal the current flowing from the load, thus completing the circuit.

Ground Fault Isolation Whitepaper
Generator and Transfer Switch
Grounding
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
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
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
Standard **3-pole 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

**Results:**
- Possible nuisance tripping of the GF protection during normal operation
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
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
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.

Results:
- 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
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
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
3-Pole and 4-Pole Transfer 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 ensure 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 (or, source derived) system?

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

1. How much circulating neutral current is created when using overlapping neutral switching transfer switches?
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.

Off 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’.
Questions?