Ground Fault Protection

Requirements

Ground fault protection is equipment protection from the effects of ground faults. The National Electrical Code® (NEC®) has specific ground fault equipment protection requirements in 215.10, 230.95, 240.13 and 517.17. Ground fault relays (or sensors) are used to sense low magnitude ground faults. When the ground fault current magnitude and time reach the G.F. relay pick up setting, the control scheme signals the circuit disconnect to open. Ground fault relays can only offer protection for equipment from the effects of low magnitude ground faults. Equipment protection against the effects of higher magnitude ground faults is dependent on the speed of response of the conventional overcurrent protective devices (fuses or circuit breakers.)

What It Is Not

Ground Fault Protection IS NOT:
- People protection. It will not prevent shock
- Ground fault prevention
- Protection from 3-phase, phase-phase, or phase-neutral faults
- Protection from high level ground faults
- A guarantee of a selectively coordinated system. In fact, coordination may be compromised.

Reliability

Ground fault relays are not simple and the ultimate reliability depends on the reliability of each element such as solid state sensor, monitor, control wiring, control power source, shunt trip, and circuit disconnecting means. If one element is incorrectly wired, inoperative, miscalibrated, or damaged, the low level ground fault protection may be negated. If the system neutral is incorrectly or accidentally grounded on the load side of the sensor, a ground fault can have a return path over the neutral and never trip the relay. Unfortunately, a nuisance outage often encourages the building owner or maintenance crew to disconnect the ground fault relay so that the power “stays on.”

Ground fault relays are not maintenance free devices. Ground fault relay equipment relies on sensing equipment, shunt trips, switching devices, control circuits, etc. Complete periodic maintenance and electrical testing of the equipment by qualified personnel is necessary since it has components and mechanisms that can fail, malfunction, and/or lose calibration.

NEC® Section 230.95 — Ground Fault Protection of Equipment

This Section means that 480Y/277V, solidly grounded “wye” only connected service disconnects, 1000A and larger, must have ground fault protection in addition to conventional overcurrent protection. Ground fault protection, however, is not required on a service disconnect for a continuous process where a non-orderly shut down would increase hazards. All delta connected services are not required to have ground fault protection. The maximum setting for the ground fault relay (or sensor) can be set to pick up ground faults at a maximum of 1200A and actuate the main switch or circuit breaker to disconnect all phase conductors. A ground fault relay with a deliberate time-delay characteristic of up to 1 second, may be specified, for currents greater than or equal to 3000A. (The use of such a relay greatly enhances system coordination and minimizes power outages).

Ground fault protection in itself will not limit the line-to-ground or phase-to-phase short-circuit current. When non-current-limiting mechanical protective devices such as conventional circuit breakers are used with GFP, all of the available short-circuit current will flow to the point of fault, limited only by circuit impedance. Therefore, it is recommended that current-limiting overcurrent protective devices be used in conjunction with GFP relays.

This system offers:
1. Some degree of arcing and low magnitude ground fault protection by the ground fault relay operating the switch.
2. Current-limitation for high magnitude ground faults and short circuits by current-limiting fuses, which provides component protection for the switchgear.

This system offers:
1. Some degree of arcing and low magnitude ground fault protection by the ground fault relay operating the circuit breaker.

Note: This system DOES NOT provide current-limitation for high magnitude ground faults and short circuits.

Where Ground Fault Relays are NOT Required

There are many services and feeders where 230.95, 215.10, and 240.13 do not require ground fault protection including:
1. Continuous industrial process where a non-orderly shut down would increase hazards.
2. All services or feeders where the disconnect is less than 1000 amps.
3. All 208Y/120 Volt, 3ø, 4W (wye) services or feeders.
4. All single-phase services or feeders including 240/120 Volt.
5. High or medium voltage services or feeders. (See NEC® 240.13 and 215.10 for feeder requirements.)
6. All services or feeders on delta systems (grounded or ungrounded) such as 240 Volt, 3ø, 3W delta, or 240 Volt, 3ø, 4W delta with midpoint tap.
7. Service with six disconnects or less (230.71) where each disconnect is less than 1000 amps. A 4000A service could be split into 5 - 800A switches.
8. Resistance or impedance grounded systems.
9. Fire Pumps
10. For feeders where Ground Fault Protection is provided on the service (except for Health Care Facilities. See 517.17.)

For instance, ground fault relays are not required on these systems.
215.10. Ground Fault Protection of Equipment

Equipment classified as a feeder disconnect must have ground fault protection as specified in 230.95.

GFP will not be required on feeder equipment when it is provided on the supply side of the feeder (except for certain Health Care facilities requirements, Article 517).

This requirement for GFP on feeders may subject the system to blackouts due to downstream ground faults as discussed previously. A selective coordination analysis is required to assure that needless blackouts do not occur.

240.13. Ground Fault Protection of Equipment

Equipment ground fault protection of the type required in 230.95 is now required for each disconnect rated 1000A or more, 480Y/277V systems, that will serve as a main disconnect for a separate building or structure. Refer to 215.10 and 230.95.

Note: GFP without current-limitation may not protect system components. See 110.10 and 250.1(FPN).

This requirement for GFP on equipment may subject the system to blackouts due to downstream ground faults, as discussed previously. A selective coordination analysis is required to assure that needless blackouts do not occur.

517.17. Ground Fault Protection For Healthcare Facilities

If ground fault protection is placed on the main service of a health care facility, ground fault relays must also be placed on the next level of feeders. The separation between ground fault relay time bands for any feeder and main ground fault relay must be at least six cycles in order to achieve coordination between these two ground fault relays. In health care facilities where no ground fault relay is placed on the main, no ground fault relays are required on the feeders. Therefore, if the requirements of 230.95 do not require a ground fault relay and no ground fault relay is placed on the main service disconnect, then no ground fault relays are required on the feeders either (unless required by Sections 215.10 and 240.13).

A ground fault relay time band includes the disconnect operating time and any tolerances in the G.F. relay control signal.

Healthcare Facility

1. When a ground fault relay is placed on the main service of a health care facility then,
2. Ground fault relays must also be placed on the feeders, and the feeder ground fault relay time band must have a 6 cycle separation from the main ground fault relay.

Note: Merely providing coordinated ground fault relays does not prevent a main service blackout caused by feeder ground faults. The overcurrent protective devices must also be selectively coordinated. The intent of 517.17 is to achieve “100 percent selectivity” for all magnitudes of ground fault current and overcurrents. 100% selectivity requires that the overcurrent protective devices also be selectively coordinated for medium and high magnitude ground fault currents because the conventional overcurrent devices may operate at these levels.

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Ground Fault Protection

Overcurrent Protective Devices

Analysis of Ground Fault Relay Curves and Overcurrent Device Curves

To a fuse or circuit breaker, ground fault current is sensed just as any other current. If the ground fault current is high enough, the fuse or circuit breaker responds before the ground fault relay (this depends on the ground fault relay setting, overcurrent device characteristics, speed of response of the overcurrent device, and ground fault current magnitude). Therefore, when analyzing ground fault protection it is necessary to study the characteristics of the ground fault relay and overcurrent protective device as a combination.

The combination of the ground fault relay and overcurrent device have a ground fault “effective curve.” This is a composite of the ground fault relay and overcurrent protective device curves. When analyzing line-to-ground faults, the “effective” curve of the ground fault relay and conventional overcurrent protective device must be examined.

The graph below is the “effective” ground fault curve for a 1600A circuit breaker in combination with a ground fault relay scheme set at 1200A and 12 cycle delay.

Notice that for ground faults above approximately 14,000A the fused bolted pressure switch combination has the advantage of faster response and above 22,000A the fused switch has the advantage of current-limitation.

“Effective” time current curve for line to ground fault with 1600A circuit breaker and ground fault sensor setting at 1200A.
Coordination Considerations

Coordination is the act of isolating a faulted circuit from the remainder of the electrical system, thereby eliminating unnecessary power outages. However, the term coordination is sometimes interpreted to mean a “degree of coordination” where more than one protective device is allowed to open under a given short circuit condition. Therefore, the term selective coordination or selectivity is used to mean positive coordination over the entire range of possible fault currents, assuring that the faulted circuit is cleared and that other parts of the system are not affected.

Modern current-limiting fuses can be selectively coordinated simply by maintaining at least a minimum amp rating ratio between two fuses in series. This ratio is dependent on the fuse types used.

When ground fault relays are used in a system, selective coordination considerations are more difficult. The relay curve must be studied in reference to the overcurrent protective devices in the system. The topic of selective coordination that follows has been separated into two parts:

A. One Step Ground Fault Relaying

When a ground fault occurs on a feeder or branch circuit it is highly desirable for the feeder or branch circuit overcurrent device to clear that fault before the main device opens, thus preventing an unnecessary system blackout. However, this is not always the case when a ground fault relay is located on the main or when the overcurrent protective devices are not selectively coordinated.

To avoid unnecessary service disruptions (or BLACKOUTS):

1. the characteristics of the feeder and/or branch circuit overcurrent devices must be analyzed with relation to the main ground fault relay characteristics and;
2. the characteristics of the main overcurrent device must be analyzed with relation to the feeder and branch circuit overcurrent protective devices.

Selective coordination should be investigated for low and high magnitude ground faults. Generally on low magnitude ground faults the feeder overcurrent device must be selective with the main ground fault relay. For high magnitude ground faults it is necessary also to consider selective coordination between the main overcurrent device and feeder overcurrent device.
Low Magnitude Ground Faults on Feeders — One Step Ground Fault Relaying.

For low magnitude feeder ground faults, the feeder overcurrent protective device can clear the circuit without disrupting the main service if the feeder overcurrent device lies to the left of the ground fault relay and does not cross at any point.

In the following two graphs, the ground fault relay located on the main has an operating time-delay of 18 cycles and 1200A pickup. Its inverse-time characteristic with the maximum 1 second opening time at 3000A improves selective coordination with downstream devices.

Fuse System

![Fuse System Diagram]

Circuit Breaker System

![Circuit Breaker System Diagram]

Selective coordination considerations for low magnitude feeder ground faults. Longer G.F. relay delay permits larger feeder fuse to coordinate with main relay.

The graph above illustrates that an inverse-time main ground fault relay may permit a larger size feeder fuse to selectively coordinate with the ground fault relay. In this case the inverse time ground fault relay is set at 1200A, 18 cycle delay. A LPS-RK-200SP amp feeder fuse coordinates with this main ground fault relay.
High Magnitude Ground Faults on Feeders — One Step Ground Fault Relaying

For higher magnitude ground faults, it is generally necessary to consider the characteristics of the main overcurrent protective device as well as the ground fault relay. Conventional overcurrent protective devices, fuses or circuit breakers, cannot differentiate between a high magnitude ground fault or a high magnitude phase-to-phase short circuit. Therefore, when a high magnitude feeder ground fault occurs the main overcurrent device must be considered in relation to the feeder overcurrent device. To achieve selective coordination and prevent a blackout for high magnitude ground faults, the feeder overcurrent device must be selective with the main overcurrent device.

Fuse System

Selective coordination considerations for high magnitude feeder ground faults requires analysis of main and feeder overcurrent devices. In this case the fuses are selectively coordinated so that an unnecessary blackout does not occur.

The graph above illustrates that for high magnitude feeder ground faults the LPS-RK-200SP amp fuse opens before the main service KRP-C-1200SP amp fuse. This is referred to as selective coordination for ground faults. This assures that any high magnitude ground faults on the branch circuits or feeders will be isolated without disrupting the main service.

Circuit Breaker System

Selective coordination considerations for high magnitude feeder ground faults requires analysis of main and feeder overcurrent devices. In this case feeder ground faults greater than 11,000A will cause the main circuit breaker to open unnecessarily creating a BLACKOUT! Thus the entire service is blacked-out because of a lack of coordination. The ground fault relay is not of concern because it has an 18 cycle delay.

The graph above illustrates that for feeder ground faults above 11,000A the main service 1200A circuit breaker as well as the 200A circuit breaker will open. This is because an 11,000A or greater fault current unlatches both the 200A and 1200A circuit breakers. This condition will create a service blackout when a feeder ground fault occurs.

In addition, ground faults between approximately 1200A and 1800A on the load side of the 200A circuit breaker will open the main circuit breaker, thereby blacking out the entire service.
Ground Fault Protection

Coordination Considerations

This fact is commonly overlooked when applying ground fault relays. Generally, the short-time-delay on the ground fault relay is thought to provide coordination for higher magnitude feeder ground faults. However, as shown by this example the main circuit breaker operates to cause an unnecessary blackout.

Note: Circuit breakers with short-time-delay trip settings were not considered in this section. The reason is that a short-time-delay on a circuit breaker defeats the original purpose of protection. Short-circuit currents and high magnitude ground fault currents, when intentionally permitted to flow for several cycles, dramatically increase the burn time and damage to the system as well as increasing the arc-flash hazards to personnel.

Electrical systems are not designed to withstand, for long periods, the torturous forces that fault currents produce. Circuit breaker short-time-delay trip settings with typical delays of 6, 18, 24, or 30 cycles can greatly exceed the short circuit withstandability of system components. According to industry standards, the duration for equipment short-circuit current testing is three cycles for switchboard bus (UL891) and three cycles for busway (BU1-1999). The short-circuit current withstandability for insulated conductors decreases as the overcurrent device operating time increases (reference Insulated Cable Engineers Association Publication P-32-382, “Short-Circuit Characteristics of Cable”). Short-circuit currents and high magnitude ground fault currents must be interrupted as rapidly as possible (preferably with current-limiting devices) to minimize equipment damage.

Whenever insulated case and molded case circuit breakers have a short-time-delay feature they also have an instantaneous override. This requires the sensing mechanism to override the short-time-delay feature for high ground fault or line-line faults. The result is a lack of coordination with the feeder breakers for any fault current above the instantaneous override setting. Selective coordination is therefore very difficult to achieve.

B. Two Step Ground Fault Relaying

Two step ground fault relaying includes ground fault relays on the main service and feeders.

In many instances, this procedure can provide a higher degree of ground fault coordination to prevent unnecessary service blackouts. Yet it is mistakenly believed by many that two step ground fault relays assure ground fault coordination. For complete selective coordination of all ground faults, the conventional overcurrent protective devices must be selectively coordinated as well as the ground fault relays. The fact is that even with this two step relay provision, ground fault coordination is not assured on many systems designed with mechanical overcurrent protective devices which incorporate instantaneous unlatching mechanisms.

RESULT: BLACKOUT

The two step ground fault relays give a false sense of security. The graph above illustrates that the ground fault relays are coordinated, but overcurrent devices are not coordinated for feeder or branch circuit ground faults above 11,000 amps. This is indicated as the BLACKOUT AREA on the curve. In this case the main overcurrent device and the feeder overcurrent device both open on a feeder circuit fault. Thus the entire system is blacked out; even though two step ground fault relays are provided.

For Health Care Facilities: Section 517.17 requires the main and feeders to be 100% selectively coordinated for all magnitudes of ground fault current - including low, medium, and high ground fault currents.
In many cases two step relays do provide a higher degree of ground fault coordination. When properly selected, the main fuse can be selectively coordinated with the feeder fuses. Thus on all feeder ground faults or short circuits the feeder fuse will always open before the main fuse. When selectively coordinated main and feeder fuses are combined with selectively coordinated main and feeder ground fault relays, ground fault coordination between the main and feeder is predictable.

The above figure illustrates a selectively coordinated main and feeder for all levels of ground faults, overloads and short circuits. Any fault on the feeder will not disrupt the main service. This system offers full selective coordination for all levels of ground faults or short circuits.

1. The feeder ground fault relay is set at a lower time band than the main ground fault relay, therefore the relays are coordinated.
2. The feeder fuses are selectively coordinated with the main fuses for all ground faults, short circuits, or overloads on the load side of the feeder. The feeder fuses would clear the fault before the main fuses open.

Conclusion: This system is completely selective for all levels of ground faults and short circuits. This system meets the intent of NEC® 517.17 for 100% selectivity.

Complete Ground Fault Selective Coordination Is Necessary To Prevent Blackouts!

To assure complete selective coordination for all ground faults, it is essential that the conventional overcurrent protective devices be selectively coordinated as well as the ground fault relays’ requirement. The intent of 517.17 is to achieve “100 percent selectivity” for all magnitudes of ground fault current.
The Need for Current-Limitation

If ground fault protection is required, then the best protection is a switch equipped with a ground fault relay scheme, a shunt trip mechanism, and current-limiting fuses. The reason is that this system will offer protection for high magnitude ground faults as well as low magnitude ground faults. Ground fault relay schemes and shunt trip mechanisms on switches or circuit breakers can protect equipment against extensive damage from low magnitude ground faults - this is their intended purpose. However, burn downs still occur in switchboards, large motor control centers, and large distribution panels generally located in equipment rooms where high available ground fault currents are present.

The National Electrical Code® requires ground fault protection for intermediate and high ground faults as well as low grade ground faults. For high magnitude ground faults, ground fault relay schemes operate too slowly to prevent extensive equipment damage. The main or feeder overcurrent devices, such as fuses or circuit breakers must clear the circuit. Current-limiting fuses substantially limit the energy let-through for higher magnitude ground faults and thereby offer a higher degree of protection. Conventional circuit breakers are not current-limiting protective devices and during higher magnitude ground faults can let-through large amounts of damaging energy.

Clearing characteristic for a 1600A fuse. A 20,000 amp fault is cleared by the KRP-C-1600SP fuse in 0.019 to 0.039 seconds (between one and two cycles). For currents greater than 25,000A the fuse enters its current-limiting range. Then the clearing time is less than one half cycle (less than 0.008 seconds).

Clearing characteristic for 1600A circuit breaker. A 20,000A fault is cleared by the 1600A circuit breaker in 0.05 seconds. The circuit breaker has a fixed operating time for high values of current. This time is approximately 0.05 seconds (three cycles). Therefore, high magnitude ground faults and short circuits are permitted to flow for at least three cycles.
The previous two figures illustrate the time-current characteristics for a 1600A current-limiting fuse and a 1600A circuit breaker. The higher the fault current the faster the fuse operates. Notice, the mechanical overcurrent protective device reaches an irreducible operating time. For large conventional service entrance circuit breakers this fixed operating time varies from 1½ cycles to five cycles depending on the type and size. (If short-time-delay trip settings are used, the operating time can be as long as 30 cycles.)

Of importance is the fact that modern, rejection type fuses are current-limiting protective devices. For faults above approximately 25,000A, the 1600A fuse operates in its current-limiting range; clearing the circuit in less than ⅓ cycle and limiting the peak current and energy let-through to the circuit components.

**Current-Limitation**

The effect of a fuse protecting the circuit is to limit the instantaneous peak current and thermal or heating effect current to a value less than that which would flow in the first half cycle had the fuse not been in the circuit. Current-limitation for high level ground faults can substantially reduce the damaging effect.

The large conventional mechanical overcurrent protective device reaches an irreducible minimum clearing time and therefore permits the full fault current flow for several cycles. The damaging peak current and thermal or heating effect current flow unrestricted without limitation for several cycles. At higher magnitude fault currents, large amounts of heating energy and magnetic forces are permitted to flow and the equipment must absorb the full available fault current energy.

**Compare the Difference**

*Arc-flash when circuit protected by 601A Class L current-limiting fuses.*

*Arc-flash when circuit protected by a 1600A non-current limiting circuit breaker set at 640A with short time delay: circuit interrupted in six cycles.*