Ground Fault Coordination

An Online Continuing Education Course for Engineers

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Ground Fault Coordination

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Introduction

When designing a power distribution system, the chosen method of grounding is just as important as the ground fault protection scheme. The operating and reliability requirements of the system should be carefully considered to design a safe system while avoiding nuisance trips. Ground fault protection requires a thorough understanding of the grounding system design and the electrical components which require protection.

It is important to understand the fundamentals of protective device coordination, equipment short circuit ratings, and the electrical properties of three-phase power systems under normal and faulted conditions. All these concepts interact with each other and will affect the selection of trip settings for and the operation of ground fault protection devices.

What is grounding?

Electrical grounding is the intentional connection of non-current-carrying components of a power distribution system to the earth. This provides a zero-reference point for the system and an electrical return path to the source in the event of unintentional phase-to-ground short circuits. Grounding improves the safety of electrical equipment by ensuring that non-current carrying components such as equipment enclosures, or metallic structures they may be installed on will have zero potential. In addition, an effective system grounding can reduce electrical noise in the distribution system.

What are ground faults?

When a current-carrying conductor becomes shorted to ground, it is called a ground fault. Below are some common examples of ground faults, but there are countless other scenarios that can result in a ground fault.

- A cable was pulled through a metallic conduit, and its insulation was damaged. When energizing the cable, a ground fault occurred.
- Water leaking into equipment, and shorting the conductors to the enclosure, which is grounded.
- Digging during construction pierces an underground cable and causes a short to ground.
- Rodents chewing through insulation, exposing conductors
- Overheated equipment melted feeder insulation and exposed the conductor.
- A temporary grid disturbance resulted in elevated voltage, which caused cable insulation to break down, and leak current to ground.

Types of grounding systems [4]

Solidly Grounded

Where the connection to ground is made with no intentional impedance. This is most common in low-voltage power distribution. Note that this term is not interchangeable with effectively grounded. It is possible for components of a solidly grounded system to not be effectively grounded due to cable impedance. Solidly grounded electrical systems will exhibit very high ground fault currents as the only impedance to ground will be very minimal from the ground conductors.

Inductance Grounded

The connection to ground is made through an impedance which is primarily inductive. Inductance grounding will reduce ground fault current to several thousand amperes, bringing it to a similar level to the three-phase fault current levels. An example where this is useful is in a substation with multiple step-down transformers that exhibit a total zero sequence impedance that causes a single line-to-ground current to be significantly greater than the three-phase fault current.

Resistance Grounded

The connection to ground is made through an impedance that is primarily resistive. Categorized as high- and low-resistance grounded, where high-resistance grounded systems can withstand ground faults indefinitely, and low resistance must utilize circuit protection to safely interrupt the fault. Note that conditions dangerous to personnel may still be present before ground fault protection trips with low-resistance grounds.

Resonant Grounded

A specific type of inductance grounding where the reactance is tuned to the capacitance of the unfaulted conductors, causing the current flow between the faulted and unfaulted conductors to be out of phase and mostly cancel each other out. Also known as a ground fault neutralizer, arc-suppression coil, or Peterson coil.

Capacitance Grounded

The connection to ground is made through an impedance which is primarily capacitive. This is a very uncommon configuration and can lead to overvoltage during fault conditions and may also increase fault current.

Ungrounded (Isolated Neutral)

Where the connection between neutral and ground is intentionally omitted, or only made through high-impedance instrumentation. An ungrounded system is still coupled to ground through the distributed capacitance of the phase conductors.

Neutral Grounding Equipment

Neutral Ground Resistors and how they affect ground fault protection

Including a Neutral Grounding Resistor (NGR) can be an effective way to reduce ground fault current to manageable levels. They may also be commonly referred to as Earth Fault Protection or Neutral Earthing Resistors. Neutral Ground Resistors will limit current flow during a ground fault, and when properly designed, they can improve the reliability and fault tolerance of the power distribution system. With a high resistance configuration, ground fault current can be reduced to a level that is safe for the electrical equipment to withstand indefinitely, which allows a technician to investigate and possibly even clear the fault without interrupting service. A low resistance can also be used to mitigate damage to equipment, but the fault cannot be sustained, and ground fault protection must trip before equipment damage occurs.

There are some drawbacks that should be considered when designing a neutral grounding resistor in your distribution system. While the neutral grounding resistor can be sized such that ground fault current will flow at similar levels to a typical load current, this can create difficulties in detecting a ground fault. There is also a risk of circuit protection tripping on overload if a fault is introduced in a heavily loaded system. In addition, a neutral grounding resistor can only be used for systems with three-phase loads. Any unbalanced or single-phase loads will result in severe voltage fluctuations where phase-to-ground voltage is greater than phase-to-phase voltage, and neutral-to-ground voltage is greater than phase-to-neutral voltage. [4]

Ground Fault Detection and Protection Methods

The purpose of ground fault protection is to protect electrical equipment from damage should low-level phase currents return through ground. Ground fault protection does not prevent ground faults from occurring and offers no protection against high-level phase-to-phase faults. Protection against high-level faults is achieved via phase overcurrent devices such as fuses and circuit breakers, which is outside the scope of this course. There are also some protective relays that include both phase and ground protection functions. These devices are fairly common and provide very precise control of trip settings for coordinating circuit protection.

Ground Fault Protection and Ground Fault Circuit Interrupter (GFCI) – What's the difference?

Ground fault protection and ground fault circuit interrupters (GFCI) serve two different functions and cannot be used interchangeably. While exposure to ground fault hazards is mitigated by a properly designed ground fault protection system, its primary purpose is to minimize damage to equipment when low levels of phase current return to the source through ground. Ground fault protection will not protect personnel against shock hazards. Ground fault protection can be applied to both single- and three-phase systems.

On the other hand, GFCI is intended to prevent shock hazards on single-phase systems only. Per the NEC a GFCI is "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." Class A GFCI devices will trip on extremely low levels of current in the range of 4mA to 6mA.

Positive, Negative, and Zero Sequence Currents

An understanding of positive, negative, and zero sequence currents is important to see how they relate to ground fault detection. Positive sequence current represents a balanced three-phase electrical load and has the same rotation as the power system. When the load is perfectly balanced, and phase currents are equally spaced at 120°, the only component that exists is the positive sequence.

The zero-sequence component of current is the sum of the three-line currents in a three-phase system, divided by 3. When there is no ground fault present, the zero-sequence current is zero. We can measure zero sequence current by measuring all three phase conductors with a current transformer (CT). When used for this purpose, this type of CT is known as a zero-sequence CT. It will measure the sum of the three-line currents, which is equivalent to the sum of the zero sequence currents returning to the source through ground. If the zero-sequence CT detects current, this indicates that there is a ground fault in the system, and energy is leaked out of the system. Note that while a zero-sequence CT and therefore zero-sequence current may be useful for analyzing an unbalanced system, there will not be any zero-sequence components in an unbalanced system if there are no ground faults present.

Negative Sequence Current is derived from the three-phase currents and has a rotation opposite of the power system. When it comes to ground fault protection, the Negative Phase Sequence can detect certain conditions which may be missed by other methods. For example, the negative sequence current is a directional element, which can identify the direction of the fault. If the Negative Sequence Current leads the Negative Sequence Voltage by 180° minus the characteristic angle of the transmission line, then a forward fault is present.[1] The same concept applies to a reverse direction fault, however, the phase angle would be 180° out of phase in relation to the forward fault example.

Directional Zero Sequence Overcurrent

Zero sequence current flows in an unbalanced ground fault as well as normal unbalanced loads. Typically, the zero-sequence current generated under normal load conditions is low, and the impact of load flow changes is minimal. This allows the ground fault pickup settings to be set very low for fast detection of ground faults. However, care should be taken when choosing the pickup settings, because a small zero-sequence current may flow under normal operating conditions if the load is not perfectly balanced and increases as the system becomes more unbalanced. This may complicate coordination between the normal and ground fault zero-sequence currents, leading to nuisance trips. Pickup settings should be set high enough such that the normal system unbalance will not trip the ground fault protection. [2] Ground fault protection schemes utilizing zero-sequence overcurrent need to coordinate with both phase and ground overcurrent devices. A fault study can determine the magnitude of fault currents to aid in the selection of reliable pickup settings.

Directional Negative Sequence Overcurrent

Negative-Sequence current exhibits similar properties to zero-sequence current under normal imbalanced load conditions. They can be useful for detecting resistive ground faults at the end of long transmission lines as the negative sequence current will be significantly higher than the zero-sequence current. [2] Another advantage of using negative-sequence current is the insensitivity to zero-sequence mutual coupling observed in parallel transmission lines. Keep in mind that this method of protection is not perfect. Normal system load imbalance, open phase conductors, and in-line switching will affect the negative sequence overcurrent. Also because of load imbalance, coordination with both phase and ground fault elements is required.

Quadrilateral Ground Distance

The quadrilateral ground distance method excels at detecting resistance faults. It is useful for detecting resistive faults on shorter transmission lines that have strong power source(s). Protection relays can use zero-sequence current polarization, which uses phase difference to detect faults within a certain distance. This is accomplished via an extra tap setting with phase angle T, which represents the phase angle of the zero sequence sources at each end of the transmission line. When this tap setting is explicitly set, the reach of the ground detection will be independent of the load. It should be set as the largest negative fault value calculated in a power system study, which will ensure that any errors will cause underreach and bring detection closer to the fault, improving reliability. [3]

Why is coordination important?

Protective device coordination plays an important role in system reliability and safety. There are numerous risks that can be mitigated with proper protective device coordination. Isolation of faults can reduce unnecessary downtime, prevent costly repairs resulting from equipment damaged by electrical faults, and reduce the risk of fire. In addition, fully coordinated overcurrent and ground fault protection combined with redundancy in key areas of the system can greatly improve reliability and availability in order to meet service level agreements.

Coordination is important for several reasons:

1. Faults will be isolated to only the affected equipment. The benefit of this is twofold. Reliability and availability are maximized, as only the parts of the system which are faulted will experience downtime. Costs associated with locating and clearing the fault will be reduced by narrowing the scope of affected equipment.

2. Equipment damage is prevented by ensuring that the equipment’s withstand ratings are not exceeded. If protective devices are not coordinated, or if settings are set higher than equipment withstand ratings, there is a risk that the upstream protective device may be too large to offer protection to smaller equipment loads downstream.

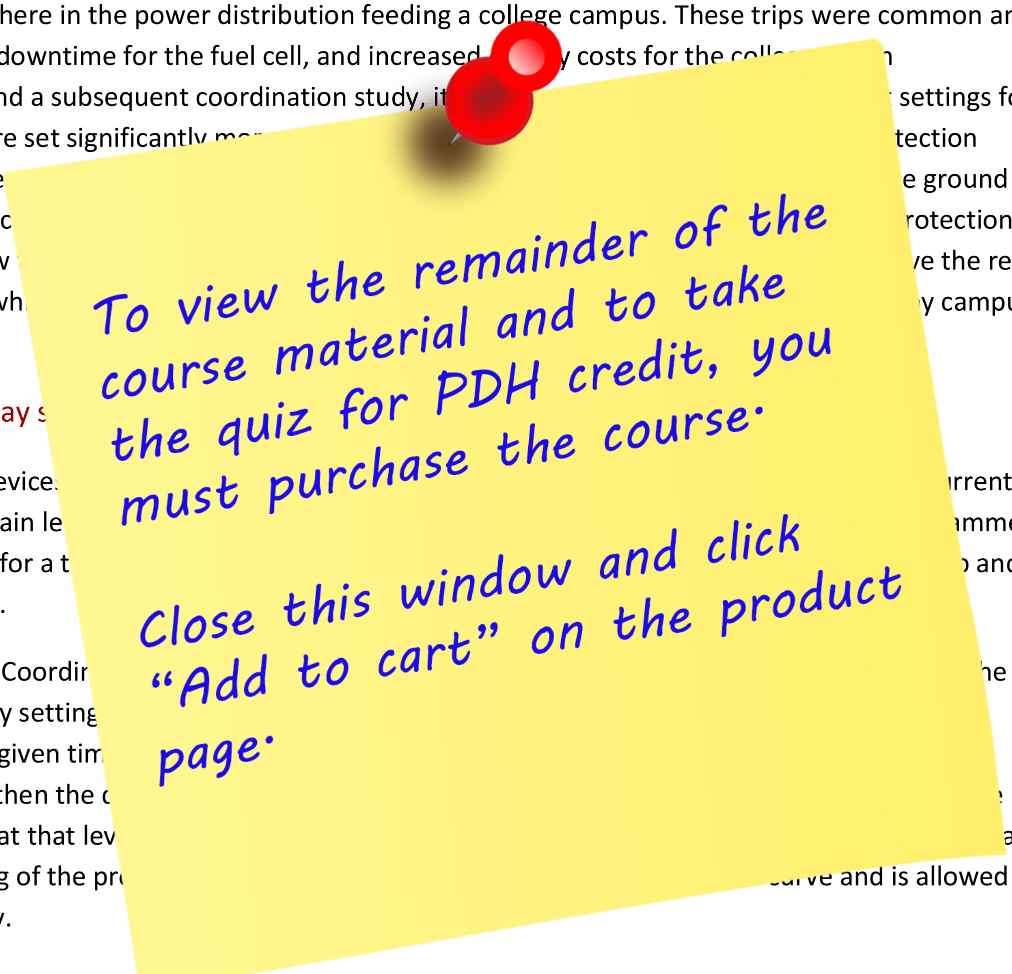
3. Minimizing trip settings for clearing faults quickly can reduce arc flash levels, improving the safety of personnel.

A real-world example of why ground fault coordination is important can be seen in a distributed generation installation. A fuel cell plant was experiencing frequent trips for ground faults which were occurring elsewhere in the power distribution feeding a college campus. These trips were common and would result in downtime for the fuel cell, and increased y costs for the colle n
investigation, and a subsequent coordination study, it settings for
the fuel cell were set significantly mor tection
devices elsewhe e ground
fault settings suc rotection.
This would allow ve the rest
of the campus wh y campus
personnel.

Pickup and delay s

All protective device rrent to
flow within certain le ammed
pickup current, for a t) and
open the circuit.

A Time-Current Coordir he
pickup and delay setting
applied for any given tim
device's curve, then the c
current to flow at that lev at is
within the rating of the pr curve and is allowed to
flow indefinitely.



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The time-current coordinatio curve for some devices such as thermal magnetic protective devices may be drawn on the graph with a large area inside the curve. This area represents the manufacturing tolerances of the device, and it may trip anywhere inside of the curve. For this reason, to ensure coordination with these devices, other protective device curves should avoid any overlap on the TCC graph. More sophisticated devices such as protective relays are significantly more precise and will appear on the TCC graph as a thin line.

There are two settings that must be adjusted when coordinating ground fault protection. The first is the pickup setting. This adjusts the level of current which will cause the protective device to trip. The second is the time delay setting. This allows you to set the amount of time that the protective device will allow elevated current levels to flow before tripping. Both settings combined will allow us to control when multiple protective devices will trip such that coordination can be achieved.