

Expertise Applied | Answers Delivered



WHITE
PAPER



PROTECTION RELAYS

Ground-Fault Protection • Motor Pump Protection • Feeder Protection • Supplemental Monitoring

PROTECTION OVERVIEW

Introduction to Protection Relays and Applications

What is a Protection Relay?

A protection relay is a smart device that receives inputs, compares them to set points, and provides outputs. Inputs can be current, voltage, resistance, or temperature. Outputs can include visual feedback in the form of indicator lights and/or an alphanumeric display, communications, control warnings, alarms, and turning power off and on. A diagram is shown below.

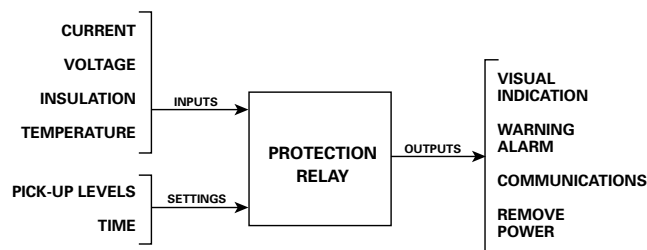


FIGURE 1

Protection relays can be either electromechanical or electronic/microprocessor-based. Electromechanical relays are an obsolete technology consisting of mechanical parts that require routine calibration to stay within intended tolerances. Microprocessor or electronic relays use digital technology to provide quick, reliable, accurate, and repeatable outputs. Using an electronic or microprocessor-based relay instead of an electromechanical design provides numerous advantages including improved accuracy, additional functions, reduced maintenance, smaller space requirements and lifecycle costs.

Inputs

A relay needs information from the system to make a decision. These inputs can be collected in a variety of ways. In some cases, the wires in the field can be connected directly to the relay. In other applications, additional devices are needed to convert the measured parameters to a format that the relay can process. These additional devices can be current transformers, potential transformers, tension couplers, RTDs or other devices.

Settings

Many protection relays have adjustable settings. The user programs settings (pick-up levels) that allow the relay to make a decision. The relay compares the inputs to these settings and responds accordingly.

Processes

Once the inputs are connected and the settings are programmed, the relay compares these values and makes a decision. Depending on the need, different types of relays are available for different functions.

Outputs

The relay has several ways of communicating that a decision has been made. Typically the relay will operate a switch (relay contact) to indicate that an input has surpassed a setting, or the relay can provide notification through visual feedback such as a meter or LED. One advantage of electronic or microprocessor relays is an ability to communicate with a network or a PLC.

As an example, a thermostat can be evaluated using the diagram in **Figure 1**. The input that is measured is temperature and the protection relay input device is the temperature sensor. The user sets the desired temperature setting (pick-up level). The relay measures the existing air temperature and compares it to the setting. The outputs can be used to provide controls (turning an air conditioner or furnace on or off) and visual indication on the thermostat display.

How Do Protection Relays Solve Electrical Problems?

Similar to how the thermostat solves the problem of automating the control of the air conditioner or furnace in a home, protection relays can solve electrical problems.

The purpose of the protection relay is to detect a problem—ideally during its initial stage, and to either eliminate or significantly reduce damage to personnel and/or equipment.

The following stages illustrate how an electrical problem develops:

Stage 1: When conductors with good insulation are exposed to fault initiators such as moisture, dust, chemicals, persistent overloading, vibration or just normal deterioration, the insulation will start to slowly deteriorate. Such small changes will not be immediately obvious until the damage is severe enough to cause an electrical fault. Relays can detect that a problem is developing by identifying slight deviations in current, voltage, resistance, or temperature. Due to the small magnitude in change, only a sophisticated device such as a sensitive protection relay or a monitor can detect these conditions and indicate that a problem may be developing, before any further damage has occurred.

Stage 2: As the problem becomes more severe, further changes take place such as insulation breakdown, overheating, or overvoltage. Since the change from normal to abnormal is great, traditional devices can be used to interrupt power. Protection relays can also be used to provide additional protection by detecting the fault contributors (overheating, overvoltage, etc.) not possible with fuses and circuit breakers.

Stage 3: At this point, the problem has occurred and caused damage. Different types of protection relays and monitors can reduce or eliminate damage because they detect problems in advance of traditional devices.

As an example, if a facility is continually resetting circuit breakers, replacing fuses, or repairing equipment and cannot locate the problem, they may be experiencing overcurrents. If this is the case, the user can install a protection relay that has an overcurrent feature. The relay measures the current (input) and allows the user to program limits (settings) into the relay. The settings typically are more sensitive than the fuses or circuit breakers. Once these limits are exceeded, the relay will operate an internal switch (relay contacts). The user has the option to use the switch to turn on a light (alarm indication) or remove power (shunt-trip) before greater problems occur. The user can use the alarm indication to help identify the faulty equipment prior to the traditional device clearing the fault.

Relay Applications

Ground-Fault Protection

The primary purpose of grounding electrical systems is to provide protection against electrical faults. However, this was not realized until the 1970's. Until then, most commercial and industrial systems were ungrounded. Although ungrounded systems do not cause significant damage during the first ground fault, the numerous disadvantages associated with ground faults resulted in a change to the grounding philosophy. There are other advantages for a grounded system, such as reduction of shock hazards and protection against lightning.

Electrical faults can be broken down into two categories: phase-to-phase faults and ground faults. Studies have shown that 98% of all electrical faults are ground faults (Source: Woodham, Jack, P.E. "The Basics of Grounding Systems" May 1, 2003 <http://www.ecmweb.com/mag/electric_basics_grounding_systems_2/index.html>). Where fuses can protect against phase-to-phase faults, additional protection, such as protection relays, are typically required to protect against ground faults.

Definition of Ground Fault

A ground fault is an inadvertent contact between an energized conductor and ground or equipment frame. The return path of the fault current is through the grounding system and any personnel or equipment that becomes part of that system. Ground faults are frequently the result of insulation breakdown. It's important to note that damp, wet, and dusty environments require extra diligence in design and maintenance. Since water is conductive, it exposes degradation of insulation and increases the potential for hazards to develop.

Table 1 shows the leading initiators of electrical faults.

Leading Initiators of Faults	% of All Faults
Exposure to moisture	22.5%
Shorting by tools, rodents, etc.	18.0%
Exposure to dust	14.5%
Other mechanical damage	12.1%
Exposure to chemicals	9.0%
Normal deterioration from age	7.0%

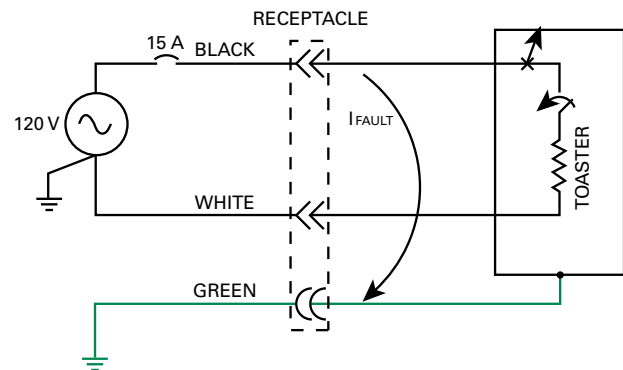


FIGURE 2

As an example, in the toaster circuit in **Figure 2**, the black or hot wire is shorted to the metal casing of the toaster. When the circuit closes, all or part of the current is channeled through the toaster frame and then the green ground wire. When sufficient current flows (typically $6 \times 15 \text{ A} = 90 \text{ A}$), the circuit breaker will open. A protection relay could be installed to detect currents as low as 5 mA, which would open the circuit breaker at a significantly lower level, hence, much quicker than the traditional circuit breaker.

Although the example above shows a solidly grounded single-phase circuit, the philosophy is the same on three-phase circuits discussed later. Relays and monitors are specifically designed to look for the leading initiators shown in **Table 1** by detecting low-level changes in current, voltage, resistance or temperature.

DC Systems

Direct current (dc) systems have positive and negative buses. If either bus is grounded, then it is referred to as a grounded system. If neither bus is grounded, then it is referred to as an ungrounded dc system. A ground fault on a dc system may cause damage to the source as well as in the field.

If the system is ungrounded, then it is possible to use a ground-fault relay by installing a ground-reference module between the two buses to establish a neutral point (see **Figure 3**). The ground-fault relay uses this neutral point as a reference to detect low-level ground faults.

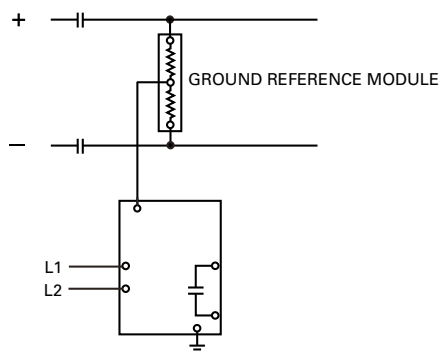


FIGURE 3

Ungrounded AC Systems

Ungrounded ac systems, such as shown in **Figure 4**, were used where continuity of power was critical. For example, chemical plants or refineries involving processes that cannot be interrupted without extensive dollar or product loss may have an ungrounded system. However, experience has proven that these systems are problematic and are being replaced with resistance grounded systems. Two major problems with ungrounded systems are transient overvoltages and difficulty locating ground faults.

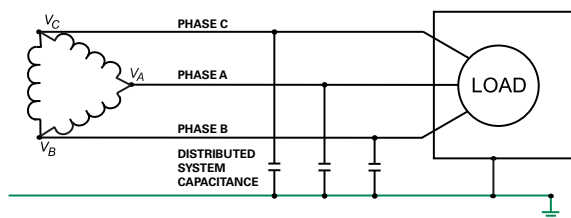


FIGURE 4

- An ungrounded system has no point in the system that is intentionally grounded (other than the normal bonding which is always present to connect the non-current-carrying metal parts to ground). Grounding occurs only through system capacitance to ground (as shown in **Figure 4**).
- Continuity of power occurs because the system can operate with one phase faulted to ground.
- An intermittent or arcing fault can produce high transient overvoltages to ground. These voltages are impressed on the phase conductors throughout the system until the insulation at the weakest point breaks down. This breakdown can occur at any point in the electrical system, causing a phase-to-ground-to-phase fault.
- Although a ground fault can be detected or alarmed on the system, there is no way to determine the location of the fault.

There are two methods used to detect ground faults in ungrounded systems. One method is to monitor the voltages between the phases and ground. As a ground fault develops, the faulted phase will collapse to ground potential, causing an indicator light to dim. The indicator lights on the unfaulted phases become brighter.

A better method to detect a ground fault is to measure the insulation resistance. As the insulation deteriorates, a relay continuously monitoring the insulation resistance can alarm at different levels for predictive maintenance. A visual indication or meter can also be used.

Solidly Grounded Systems

Due to the problems of ungrounded systems, a shift in philosophy occurred and designs moved from ungrounded to grounded systems. In most cases, the type of grounding system chosen was solidly grounded. A solidly grounded system is a system of conductors in which at least one conductor or point is intentionally grounded (usually the neutral point of transformer or generator windings). The problem with the direct connection is that ground fault current can be excessive, causing Arc-Flash hazards, extensive equipment damage, and possible injury to personnel.

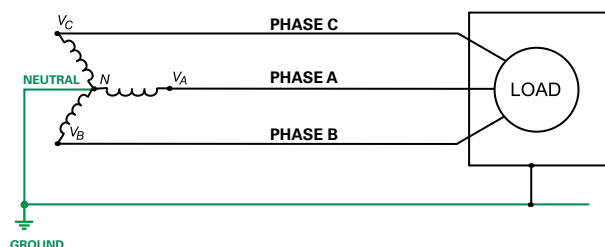


FIGURE 5

- In a solidly grounded system, the wye point (or neutral) of the power source is connected solidly to ground and offers a very stable system that maintains a fixed phase-to-ground voltage.
- The high ground-fault current is easy to detect with fuses, circuit breakers, or protection relays, allowing for selective tripping (tripping the faulted feeder and not the main feeder).
- When a ground fault occurs, high point-of-fault damage can quickly result since the energy available to the ground fault is only limited by the system impedance (which is typically very low).
- Due to excessive ground-fault current and Arc-Flash Hazards, the faulted feeder must be removed from service. This does not allow for continuous operation during a ground fault.

Figure 6 illustrates an example of the dangers associated with solidly grounded systems. In this example, a ground-fault occurs and the overcurrent protection is set at 600 A.

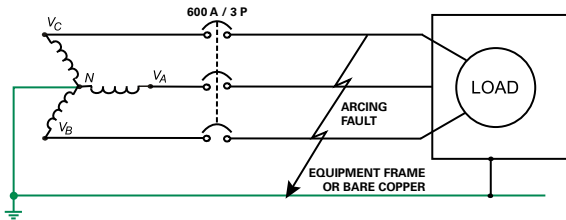


FIGURE 6

- Assume that this ground-fault is not a bolted fault, but an arcing fault due to an insulation breakdown or a partial reduction of clearances between the line and ground.
- Because of the arc resistance, the fault current may be reduced to as low as 38% of the bolted-fault level. The fault current can be in the range of a normal load or a slight overload.
- The fault current may be low enough that the overcurrent device (600 A circuit breaker) does not sense the fault current, or may pick it up but not trip for a long time.
- The energy being supplied by the source is concentrated at the arc and could cause severe equipment damage very quickly. This energy release could cause a fire that in turn, could damage the premises and present an extreme hazard to personnel.

Aside from converting this solidly grounded system to resistance grounding, the best way to prevent damage is to detect low-level ground leakage prior to it becoming a ground fault. In order to accomplish this, the protection relay must be able to sense a low-level ground leakage without nuisance tripping.

In modern facilities, equipment often generates noise or harmonics that may interfere with a protection relay's ability to function properly. For example, the noise or harmonics may be higher than the desired ground-fault relay settings, causing the relay to falsely operate when there is no fault on the system. The protection relay must be able to filter out noise or harmonics to provide reliable protection.

Resistance-Grounded Systems

Resistance grounding is the only method of grounding that solves the problems commonly associated with both ungrounded systems and solidly grounded systems. The name is derived from the addition of a resistor between the system neutral and ground. The specifications of the resistor are user determined to achieve a desired ground fault current, which must be greater than the system capacitive charging current (explained later in this section).

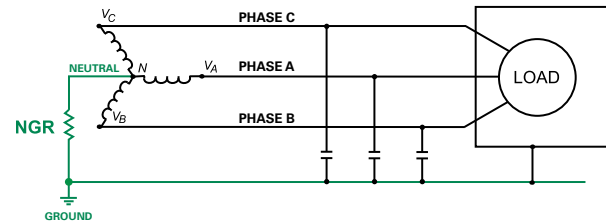


FIGURE 7

- Transient overvoltages can be eliminated by correctly sizing the neutral grounding resistor (NGR) to provide an adequate discharge path for the system capacitance.
- Continuity of operation with one ground fault is allowable in some applications when ground fault is ≤ 10 A.
- The NGR limits the available ground current. This eliminates or minimizes point-of-fault damage (Arc Flash Hazards) and controls the ground-fault voltage.
- Pulsing can be used to locate ground faults when ground fault is ≤ 10 A. Pulsing is created by using a shorting contactor to short out half of the resistance, causing the ground-fault current to double (usually one cycle per second). A hand-held zero-sequence meter is used to detect the fluctuating ground-fault current, and locate the ground fault.

The only disadvantage of resistance grounding is that if the resistor fails, the system will become ungrounded. Resistor monitoring is recommended to protect against this.

A protection relay for resistance grounded systems is used to detect a ground fault and to monitor the neutral-to-ground connection. It can be used to provide alarms or to trip the faulted feeder from service during a ground fault. The relay can provide a pulsing circuit that can be used to locate the ground fault. The relay can also alarm or trip if the neutral-to-ground path fails. For systems 5 kV and less, high-resistance grounding can be used. High-resistance grounding typically limits the resistor current to 10 A or less. By doing so, the ground fault can remain on the system, given that the system is rated for the voltage shift.

For systems 2.4 kV and higher, low-resistance grounding systems can be used. Typically in those systems the ground fault current is 25 A or above and is cleared within 10 s.

System Capacitive Charging Current

Although not physically connected to ground, electrical conductors and the windings of all components are capacitively connected to ground. Consequently, a small current will flow to ground from each phase. This current does not occur at any particular location; rather, it is distributed throughout the system just as the capacitance to ground is distributed throughout the system. For analysis, it is convenient to consider the distributed capacitance as lumped capacitance, as shown in **Figure 8**.

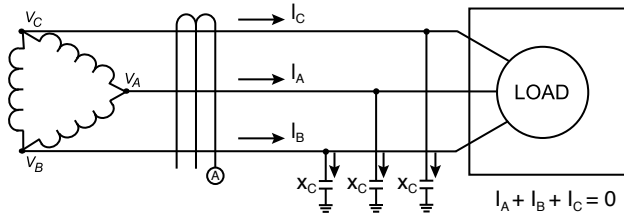


FIGURE 8

Even if the distributed capacitance is not balanced, the ammeter will read zero because all the current flowing through the CT window must return through the CT window.

System charging current is the current that will flow into the grounding connection when one phase of an ungrounded system is faulted to ground (see **Figure 9**). It can be measured as shown below if appropriate precautions are taken:

- If the fault occurs on the supply side of the CT, the sum of the currents in the CT window is not zero.
- Ammeter A will read the sum of the capacitive currents in the unfaulted phases. This value is the charging current of all the equipment on the load side of the CT.

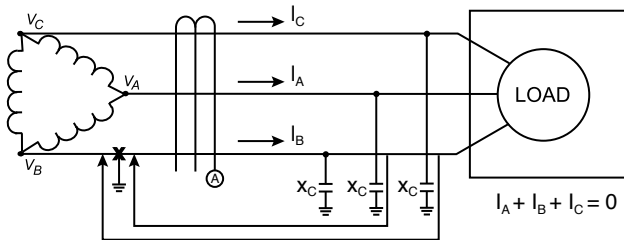


FIGURE 9

A single-line diagram of a three-feeder, resistance-grounded system with a fault on feeder 3 is shown in **Figure 10**.

- A CT (A1 and A2) on unfaulted feeders will detect the charging current of that feeder.
- A CT (A3) on a faulted feeder will detect the sum of the resistor current (I_R) and the charging currents ($I_1 + I_2$) of the unfaulted feeders.

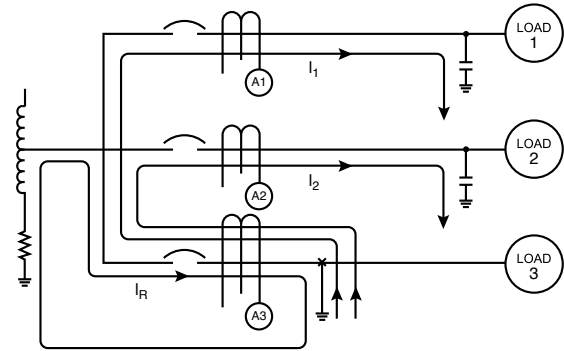


FIGURE 10

Selective coordination in a resistance-grounded system can be achieved if the pick-up setting of each ground-fault relay is greater than the charging current of the feeder it is protecting. If the pick-up setting of a ground-fault relay is less than the charging current of the feeder it is protecting, it will trip when a ground fault occurs elsewhere in the system. This is known as sympathetic tripping. If the relative size of the feeders can change, or if the advantage of using one operating value for all ground-fault relays in a system is recognized, then it is prudent to select a pick-up setting for all ground-fault relays that is larger than the system charging current.

In order to eliminate transient overvoltages associated with an ungrounded system, it is necessary to use a grounding resistor with a let-through current equal to or larger than the system charging current.

What is the minimum acceptable NGR current? Select a pick-up setting for the ground-fault relays that exceeds the system charging current and multiply the operating value by an acceptable tripping ratio. Use the next-largest available standard let-through current rating.

Additional technical information and application data for Littelfuse POWR-GARD® protection relays, fuses and other circuit protection and safety products can be found on www.littelfuse.com. For questions, contact our Technical Support Group (800-832-3873). Definitions of terms used in this white paper can be found in the Technical Application Guide section of the POWR-GARD Catalog. To download a copy visit www.littelfuse.com/catalogs.