

Ground Fault Protection

Digital Specification Program

Latin America



Ground Fault.

I. Introduction

In the electrical systems always exists the possibility of having shutdowns due to over currents or short circuits produced by operation mistakes, ambient conditions, lack of maintenance or atmospheric discharges.

In the case of short circuit, this can be classified in the next types:

1.- Bolted Faults.

It occurs when the conductors (phase, neutral or ground) are solidly connected, having an impedance equal to zero on this connection and because this, a maximum current condition is present.

2.- Ground Fault

It occurs when one of the system phases get on direct contact to ground or to any metallic part that is grounded.

3.- Arcing Fault

It happens between two close conductors but are not in direct contact.

Any of these faults is really dangerous for both equipment and personnel.

In this document we will discuss more in detail the ground fault.

II. Why protect against Ground Fault.

The ground fault has its origin on different ways but the more common are reduced insulation, physical damages to insulation system or excessive transient or steady-state voltage stresses on insulation. These problems can be produced due to moisture, atmospheric contamination, insulation deterioration, mechanical stresses, etc. Although the situations mentioned before can be avoided following a good maintenance Schedule, always exists the latent risk of a fault, commonly during the installation or major maintenance to equipment.

Ground Fault current magnitudes can vary according to the grounding method used in the system. Although the ground fault currents can reach values up to thousands of amps, the NEC 2011 in the article 230.95(A) mentions that the maximum setting for ground fault protection must be 1200Amps and the maximum time-delay must be 1 second for currents of 3000Amps or higher.

Selection of setting in amperes for every protection device is based primarily on the features of the circuit being protected, for example if the circuit serves to individual loads the pickup setting can be low as 5 Amp to 10 Amp, but on the other side, if the circuit serves multiple loads and every load has its own Protection the settings in the feeder should be higher in order to allow the operation of downstream protection devices on ground fault currents of lower magnitude on their respective circuits.

If the system doesn't have a proper Protection scheme, the ground fault effects can be very destructive.

The consequences of a ground fault can be as simple as a shutdown if there is a proper protection system or can destroy completely the equipment due the arc blast or fire, and can produce burning or electrical shock to the personnel that could be working close to the equipment failed. These consequences are directly linked to the grounding method that is being used.

III. When the Ground Fault Protection is Required?

Despite the NEC (NOM001 for Mexico)has passed through several changes in the last years, the articles regarding ground fault protection have not suffered changes.

NEC-2011 Edition (NOM001-SEDE-2005 for Mexico)

***215.10** Ground-Fault Protection of Equipment. Each feeder disconnect rated 1000 amperes or more and installed on solidly grounded wye electrical systems of more than 150 volts to ground, but not exceeding 600 volts phase-to phase, shall be provided with ground-fault protection of equipment in accordance with the provisions of 230.95.*

***230.95** Ground-Fault Protection of Equipment. Ground fault protection of equipment shall be provided for solidly grounded wye electric services of more than 150 volts to ground but not exceeding 600 volts phase-to-phase for each service disconnect rated 1000 amperes or more.*

***240.13** Ground-Fault Protection of Equipment. Ground fault protection of equipment shall be provided in accordance with the provisions of 230.95 for solidly grounded wye electrical systems of more than 150 volts to ground but not exceeding 600 volts phase-to-phase for each individual device used as a building or structure main disconnecting means rated 1000 amperes or more.*

From the articles in the codes mentioned before, we can summarize the features that an electrical system must have in order to be required to include a ground fault protection system.

1. Solidly grounded wye system.
2. Where phase-to-phase voltage is between 260 ("more than 150 volts to ground") to 600VAC, inclusive.
3. The service or feeder or building/structure main disconnect device(s) is (are) rated 1000A or greater.
4. The load must be different to Fire pumps.

The 4 features mentioned before apply for NOM001 and for NEC- 2011, however, there are a couple of additional features included in the NEC-2011

1. The maximum setting of the ground-fault protection shall be 1200 amperes, and the maximum time delay shall be one second for ground-fault currents equal to or greater than 3000 amperes.(NEC 230.95A)
2. The ground fault Protection system shall be performance tested when first installed on site.(NEC 230.95C)

IV. Grounding Methods.

Nowadays the interest on the using of ground fault Protection systems has been increasing due to this Protection is required for NEC, NOM and NFPA in some equipment and feeders, besides the interest of improving safety for personnel.

The intention of grounding systems is to control the voltage with respect to ground and provide a current path that allows us to detect the unwanted connection between line and phase conductors and then be able to send a signal to trip the protection devices to remove the voltage on these conductors.

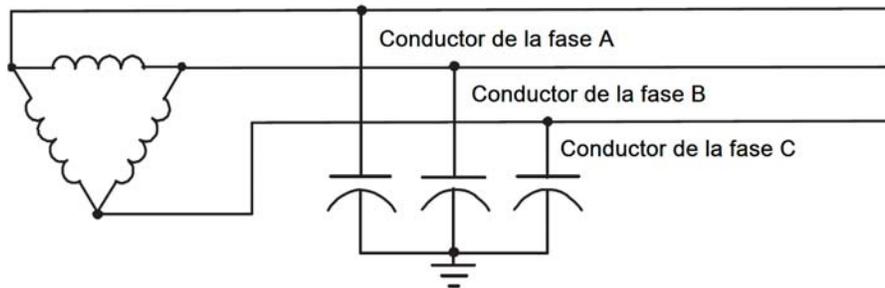
There are several devices for Ground Fault protection on the market and they have their use depending on the grounding method used in our system.

Whenever working on the design of an electrical system the question of how to ground the system came up. Grounding electrical systems is generally recommended, however there are exceptions. There are several methods and criteria for grounding systems and each has its own purpose.

Listed below are some of the existing methods and which are their advantages and disadvantages:

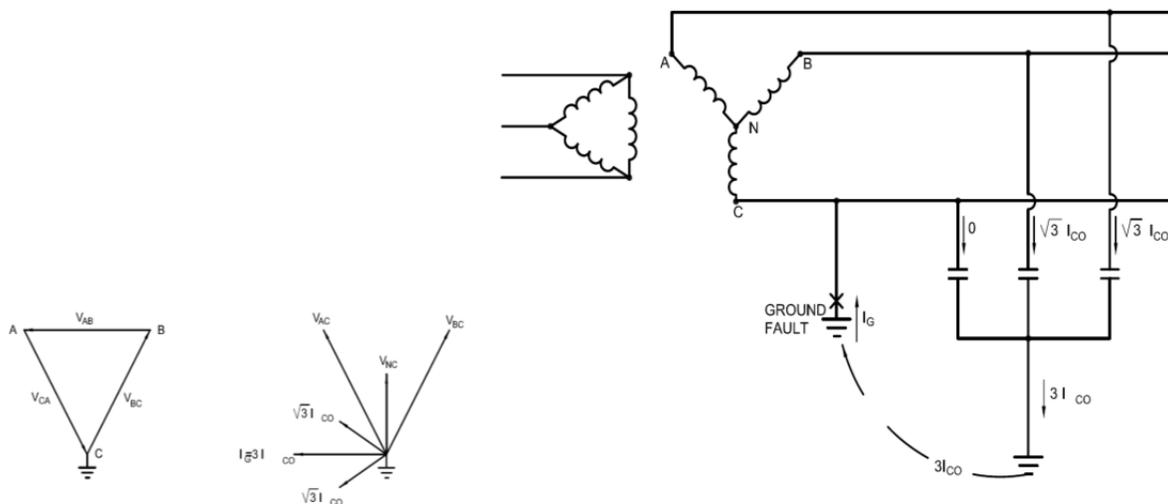
-Ungrounded System

This system is defined as one who does not have an intentional connection to ground. However, there is always a capacitive coupling between the line conductors and ground. This system is also known as grounded by capacitance.



When the system is operating normally, capacitive currents and phase to ground voltages are equal and displaced 120° of each other so that a vector system is fully balanced.

If any of the phases is in contact with ground, the current flow through this phase to ground will stop because there will be no potential difference between conductors. At the same time in the remaining phases the current flow is increased by root 3 and will be moved only 60° each other. Therefore, the vector sum of these currents is increased by 3 times the current I_{c0} .



Each time that a fault is presented in this configuration, it generates an over-voltage that can be many times greater in magnitude than the nominal (6 to 8 times) which is a result

of resonance between the inductive reactance of the system and the distributed capacitance to ground. These over voltages can cause failure of the insulation system.

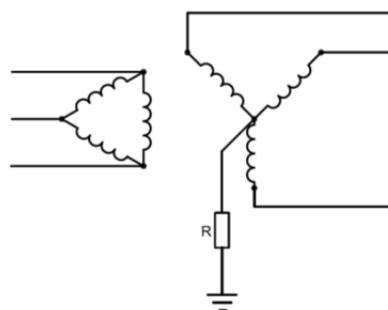
-Resistance Grounding

A system grounded through resistance is defined as one in which the neutral of a transformer or generator is grounded through a resistor.

The reasons for limiting the current using a resistor are:

1. To reduce damage during a fault of electrical equipment such as panels, transformers, motors, cable, etc.
2. To reduce mechanical stresses in circuits and devices leading fault currents.
3. To reduce the risk of electrocution to personnel.
4. To reduce the risk of arc flash to personnel that could accidentally cause a failure or that is near to the fault location.
5. To reduce momentary voltage drop that occurs when a fault is present.
6. To secure control of transient voltages while at the same time avoiding shutdown of a faulted on the occurrence of the first ground fault (High Resistance Grounding)

Grounding through resistance can be 2 types High Resistance or Low Resistance which are distinguished by the amount of current permitted to flow.



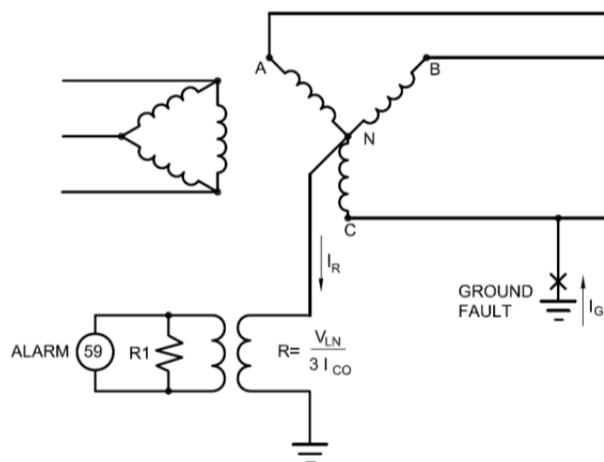
Resistance Grounding System

-High Resistance Grounding

High-resistance grounding employs a neutral resistor of high ohmic value. The Resistor is used to limit the ground fault current (I_g) and typically is limited to 10A or less.

When you have a system like this, does not require an immediate release of the fault as the current is limited to a very low level. Protective devices associated with a High Resistance system allows the system to continue working with the presence of a ground fault and send an alarm instead of tripping and open the associated protection.

A typical scheme for detecting a ground fault in a high resistance grounding system is shown in the figure below, where under normal operation the neutral point of transformer is at zero potential, but when a line to ground fault occurs, phase voltage at the neutral is raised to almost the value of the line-to-neutral voltage which is detected by a relay. This relay activates a visual and / or sound alarm to notify to maintenance personnel and then attend, locate and repair the fault.



Simple Scheme for High Resistance Grounding System

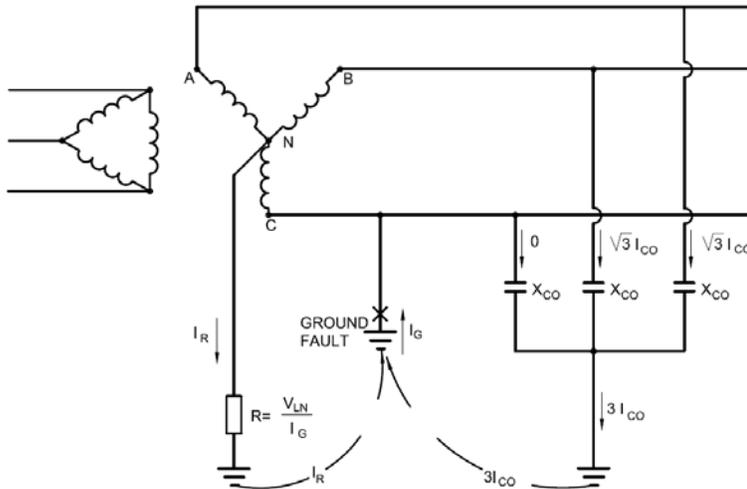
The advantages of using system could be listed as follows:

1. Service continuity. The first ground fault does not require equipment to be shutdown.
2. Transient over voltages due to re-striking are reduced.
3. A pulse system can help to locate the fault.
4. The need of coordinated ground fault relaying is eliminated.

Typically this system can be used in low voltage systems where single-phase loads are not present, in MV where continuity of service is required and the capacitive current is not very high, and in retrofits where they had previously ungrounded system.

-Low Resistance Grounding

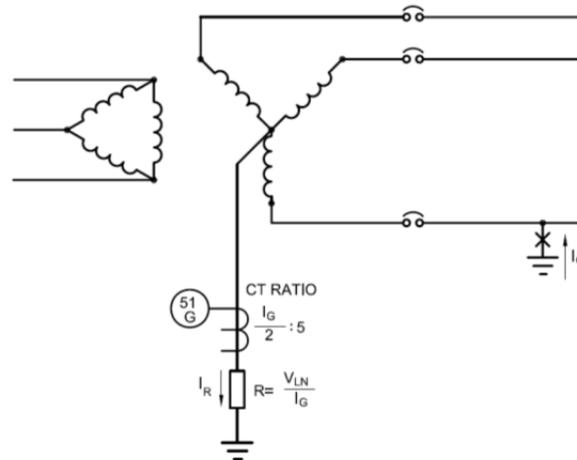
This system limits the ground fault current to a value between 100A and 1000A, being the most common value 400A. The value of this resistance is calculated as $R = V_{LN} / I_g$, where V_{LN} is the line to neutral voltage of the system and fault current I_g is the ground fault current desired.



Low Resistance Grounding

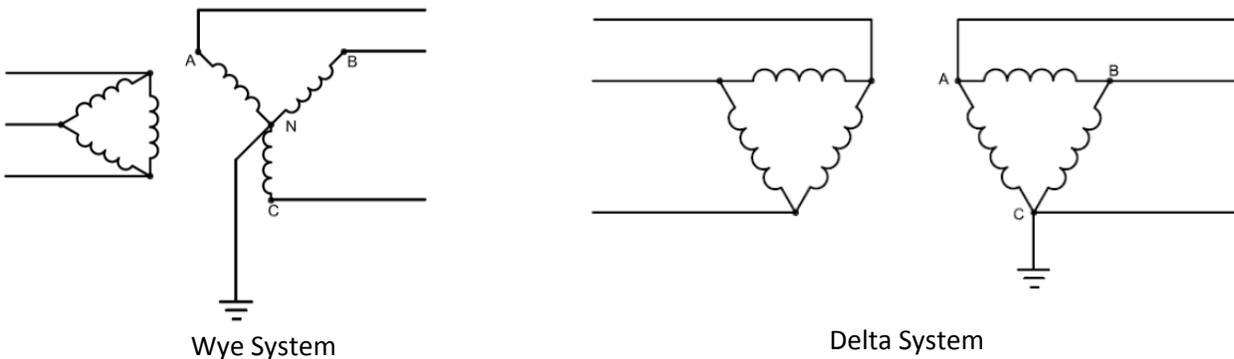
This system has the advantage of facilitating the immediate release and selectively to ground fault. The method used to detect this fault is to use an overcurrent relay 51G. At the moment of a fault the neutral voltage rises almost to the line to neutral voltage and a current begins to flow through the resistance. Once the relay detects this current sends the signal to open the associated low-voltage switch.

Grounding through a low resistance is used in medium voltage systems of 15KV and lower, particularly where large rotating machines are used and where is wanted to reduce ground fault to hundreds rather than thousands of amperes



-Solid Grounding

Solid grounding refers to the connection of the neutral conductor directly to ground.



This configuration can be suitably protected against voltage surges and ground faults. This system allows flexibility and allows the connection of line to neutral loads.

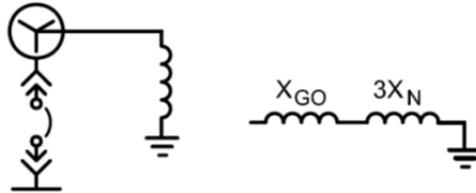
When using this configuration in systems of 600V or higher, will have to use residual or zero sequence protective relays. The circuit breakers are normally provided with current transformers that provide the signal from each of the phases for over current relay and ground fault relay takes the signal from the star that forms from the current transformers to increase the sensitivity of ground faults. The methods of detection as zero-sequence and residual will be discussed later.

One disadvantage of the solidly grounded system is that the ground fault magnitudes reached may be so large that they could completely destroy the equipment. However, if these faults are quickly released the damage to equipment would be within "acceptable" levels.

-Reactance Grounded System

In this configuration a reactor between the neutral and earth is installed. The levels of ground fault current when grounding through a reactor are considerably higher than desirable levels in systems grounded through resistance, because this grounding through a reactor is not commonly used as an alternative of grounding by low resistance.

Grounding through a reactor is a good option when you want to limit the ground fault current to levels close to the magnitude of three-phase faults. Normally this option is more economical than using resistors to ground.



-Resonant Grounding

This configuration is also known as ground fault neutralizer, and basically consists of grounding the system through a "tuned" reactor (X_1) to resonate with the distributed capacitance of the system (X_{co}) so that a resulting ground fault is resistive and low in magnitude.

This configuration is not commonly used, but can be applied to systems of high voltage like transmission substations or generating stations. If the system changes its features, that is, if you have often circuit changes or reconfigurations, the resonant grounding is not an option because it would have to re-tuned the reactor each time there is a reconfiguration.

The advantages and disadvantages of each grounding system mentioned above are summarized by the IEEE as follows:

	Ungrounded	Solid grounding	Reactance grounding		Ground-fault neutralizer	Resistance grounding	
			Low value reactor	High value reactor		Low resistance	High resistance
Current for phase-to-ground fault in percent of three-phase fault current	Less than 1%	Varies, may be 100% or greater	Usually designed to produce 25% to 100%	5% to 25%	Nearly zero fault current	20% and downward to 100 A to 1000 A	Less than 1% but not less than system charging current, $3I_{CO}$
Transient over-voltages	Very high	Not excessive	Not excessive	Not excessive	Not excessive	Not excessive	Not excessive
Surge arresters	Ungrounded-neutral type	Grounded-neutral type	Grounded-neutral type if current 60% or greater	Ungrounded-neutral type	Ungrounded-neutral type	Ungrounded-neutral type	Ungrounded-neutral type
Remarks	Not recommended due to overvoltages and non-segregation of fault	Generally used on systems (1) 600 V and below and (2) over 15 kV		Not used due to excessive overvoltages	Best suited for application in most medium-voltage industrial and commercial systems that are isolated from their electric utility system by transformers. ^a	Generally used on systems of 2.4 kV to 15 kV particularly where large rotating machines are connected.	Used on systems 600 V and below where service continuity is desired. ^a

^aCaution should be applied in using this form of grounding with industrial generation (see IEEE Std 367™). Best suited for application in most medium-voltage industrial and commercial systems that are isolated from their electric utility system by transformers. Ideal for use on medium-voltage generators. Also occasionally found on mission-critical 2.4 kV or 4.16 kV industrial or commercial distribution systems.

V. Ground Fault Detection Methods.

The ground fault current can be monitored in different ways, could be monitored either as it flows out of the fault or returning to the neutral point of the source transformer or a generator. When monitoring the current coming out from the fault all the conductors of the system are monitored individually and when monitoring the return to neutral point only neutral is monitored.

To perform this monitoring power transformers are used either in all the line conductors or in the neutral depending on the method being used. Protection devices that receive signals from the current transformers must have the ability to adjust the values of pick-up and the ability to adjust the time delays.

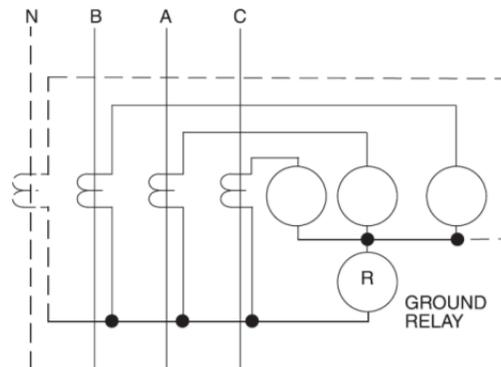
There are several methods of ground fault detection for solidly grounded systems which can be analyzed on the following link:

<http://www.geindustrial.com/publibrary/checkout/GET-6533A?TNR=Application%20and%20Technical|GET-6533A|PDF>

Below the 3 detection methods commonly used are reviewed

-Residual Ground Fault Protection

Residual protection is commonly used in medium voltage systems. This system consists of the use of 3 interconnected current transformers which send a signal proportional to the flow of ground fault current to the protection relay or device to trip. This system is not often used in low voltage equipment, but there are available low-voltage systems with 3 current transformers connected on a residual basis.



In 3-phase 3-wires systems the resulting from the vector sum of phase currents is zero even if a fault is present between phases. When one of the phases get in contact to ground short circuit current flows through the earth and not anymore by the line faulted

line producing an imbalance in the circuit generating a residual current that is detected by the protective device.

When you have systems of 3 phase 4 wire where they feed single phase loads, you should add a fourth current transformer to monitor the current consumed by such loads as well as single-phase zero sequence harmonic currents produced by nonlinear loads such as fluorescent lighting. If this fourth sensor is not used the protection device would see the imbalance between phases as a ground fault and will open the circuit.

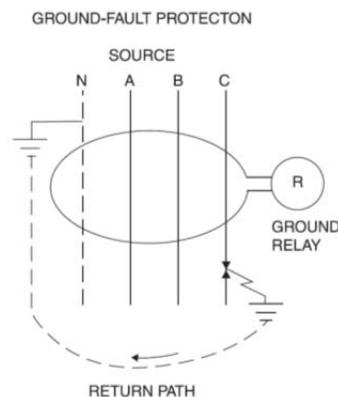
The selectivity of the residual protection scheme depends on the ratio of the CTs which should be sufficient capacity for normal loads of the circuit. In this system instantaneous trip is not used because when starting some loads such as motors can generate a "normal" imbalance between phases which could generate a protective device tripping.

If more selectivity is required, the Balanced Core scheme must be used.

- Core Balance (Zero sequence sensor).

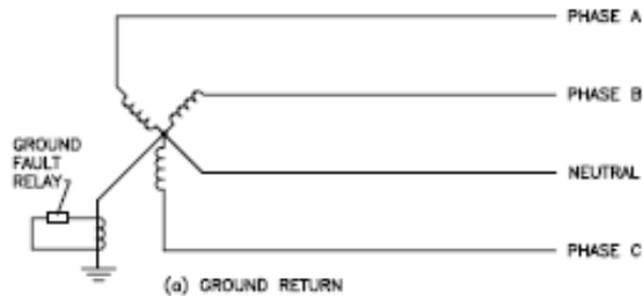
The core balance method is based on the flux summation. This method uses only one current transformer which monitors the three phases of the system (and neutral if exists) at the same time. Unlike the method residual current transformer is less amperage capacity and only monitors a possible imbalance and no load current of each line, it helps to have a better selectivity.

In normal operating conditions (balanced, unbalanced, single phase loads or short circuits between phases) the flux summation of the currents flowing through the CT is zero. When a ground fault current flows through the ground wire it creates an imbalance in the CT output which generates the operation of the protection



-Ground Return

Placing a current transformer on the grounded neutral and using a related protection relay, provides a ground fault detection method of low cost. Because only will monitor the ground fault current, adjustments can be set at very low current values.



In low-resistance grounded systems at 5 and 15KV this method is often used where ground fault currents are relatively low.

It is also used in solidly grounded 480V, 3 phase 3 wire or 3 phase 4 wire. To provide adequate protection, the relay must be wired to trip the main circuit breaker at secondary side of the transformer and set a time delay to allow the circuit breaker to trip and if once the circuit breaker is tripped the fault is still sensed the relay must send a signal to that protection on the primary side to operate.

References

IEEE Green Book IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems

IEEE Buff Book IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

IEEE Red Book IEEE Recommended Practice for Electric Power Distribution for Industrial Plants

GROUND FAULT PROTECTION FOR SOLIDLY GROUNDED LV SYSTEMS

NOM001-SEDE-2005

NEC-2011