GROUND FAULT PROTECTION

TECHNICAL GUIDE

CONVERTING UNGROUNDED SYSTEMS TO HIGH RESISTANCE GROUNDING

Post Glover™

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Table of Contents

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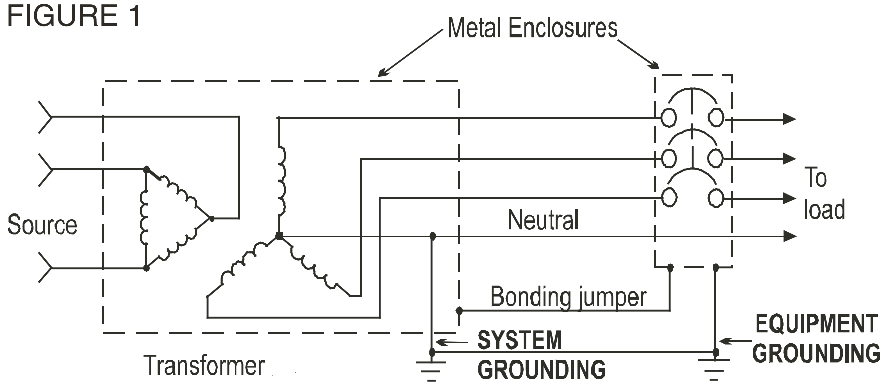
1.1 What is Grounding?

The term grounding is commonly used in the electrical industry to mean both “equipment grounding” and “system grounding.” “Equipment grounding” means the connection of a non-current carrying conductive materials such as conduit, cable trays, junction boxes, enclosures and motor frames to earth ground. “System grounding” means the connection of the neutral points of current carrying conductors such as the neutral point of a circuit, a transformer, rotating machinery, or a system, either solidly or with a current limiting device to earth ground. Figure 1 illustrates the two types of grounding.

FIGURE 1



1.2 What is a Grounded System?

Grounded System – a system with at least one conductor or point (usually the middle wire or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through an impedance. IEEE Standard 142-1991 1.2

1.3 What are the Different Types of System Grounding?

The types of system grounding normally used in industrial and commercial power systems are:

1) Solid grounding
2) Low resistance grounding
3) High resistance grounding
4) Ungrounded IEEE Std 242-2001 8.2.1

1.4 What is the Purpose of System Grounding?

System grounding, or the intentional connection of a phase or neutral conductor to earth, is for the purpose of controlling the voltage to earth, or ground, within predictable limits. It also provides for a flow of current that will allow detection of an unwanted connection between system conductors and ground [a ground fault].

1.5 What is a Ground Fault?

A Ground Fault is an unwanted connection between the system conductors and ground.

1.6 Why are Ground Faults a Concern?

Ground faults often go unnoticed and can cause problems with plant production processes. They can also shut down power and damage equipment, which disrupts the flow of production leading to hours or even days of lost productivity.

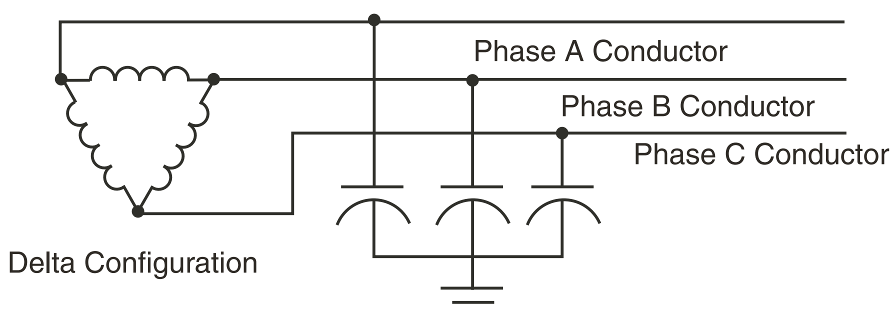
Undetected ground faults pose potential health and safety risks to personnel. Ground faults can lead to safety hazards such as equipment malfunctions, fire and electric shock.

Ground faults cause serious damage to equipment and to your processes. This damage can seriously affect your bottom line.

2.1 What is an Ungrounded System?

An ungrounded system is one in which there is no intentional connection between the conductors and the earth ground. However, in any system, a capacitive coupling exists between the system conductors and the adjacent grounded surfaces. Consequently, the "ungrounded system" is, in reality, a "capacitively grounded system" by virtue of the distributed capacitance. This is shown in Figure 2.

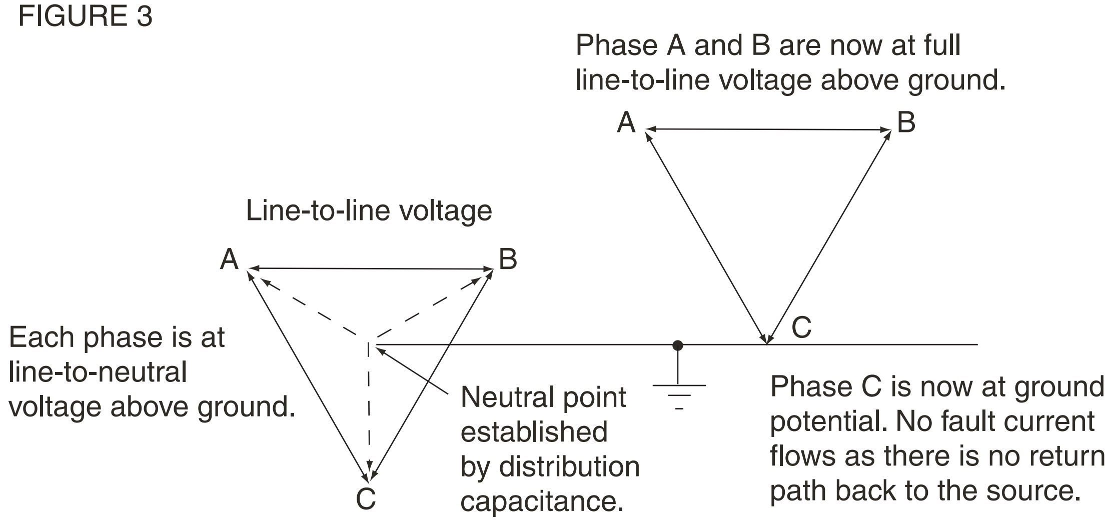
FIGURE 2



Under normal operating conditions this distributed capacitance causes no problems. In fact, it is beneficial because it establishes, in effect, a neutral point for the system, as shown in Figure 3a. As a result, the phase conductors are stressed at only line-to-neutral voltage above ground.

However, problems can arise under ground fault conditions. A ground fault on one line results in full line-to-line voltage appearing on the other two phases. Thus, a voltage 1.73 times the normal voltage is present on all insulation on the ungrounded phase, as shown in Figure 3b. This situation can often cause failures in motors and transformers, due to insulation breakdown.

FIGURE 3



Voltage Relationships.

(a) normal operation (b) ground fault on phase C

2.2 What Does IEEE Say About Ungrounded Systems?

Ungrounded systems employ ground detectors to indicate a ground fault. These detectors show the existence of a ground on the system and identify the faulted phase, but do not locate the ground, which could be anywhere on the entire system.

If this ground fault is intermittent or allowed to continue, the system could be subjected to possible severe over-voltages to ground, which can be as high as six or eight times phase voltage. This can puncture insulation and result in additional ground faults.

A second ground fault occurring before the first fault is cleared will result in a phase-to-ground-to-phase fault, usually arcing, with a current magnitude large enough to do damage, but sometimes too small to activate over-current devices in time to prevent or minimize damage.

Ungrounded systems offer no advantage over high-resistance grounded systems in terms of continuity of service and have the disadvantages of transient over-voltages, locating the first fault and burndowns from a second ground fault. IEEE 242-2001 8.2.5

3.1 Why Consider Grounding Your System?

If the ground fault is intermittent (arcing, restriking or vibrating), then severe over-voltages can occur on an ungrounded system. The intermittent fault can cause the system voltage to ground to rise to six or eight times the phase-to-phase voltage leading to a breakdown of insulation on one of the unfaulted phases and the development of a phase-to-ground-to-phase fault. Over-voltages caused by intermittent faults can be eliminated by grounding the system neutral through an impedance, which is generally a resistance, which limits the ground current to a value equal to or greater than the capacitive charging current of the system.

The intentional connection of the neutral points of transformers, generators and rotating machinery to the earth ground network provides a reference point of zero volts. This protective measure offers many advantages over an ungrounded system, including:

- Reduced magnitude of transient over-voltages
- Simplified ground fault location
- Improved system and equipment fault protection
- Reduced maintenance time and expense
- Greater safety for personnel
- Improved lightning protection
- Reduction in frequency of faults

3.2 What is a Resistance Grounded System?

There are two broad categories of resistance grounding: low resistance and high resistance. In both types of grounding, the resistor is connected between the neutral of the transformer secondary or generator winding and the earth ground.

3.3 What is a Low Resistance Grounded System?

Low resistance grounding of the neutral limits the ground fault current to a high level (typically 50 amps or more) in order to operate protective fault clearing relays and current transformers. These devices are then able to quickly clear the fault, usually within a few seconds. The importance of this fast response time is that it:

- Limits damage to equipment
- Prevents additional faults from occurring
- Provides safety for personnel
- Localizes the fault

The limited fault current and fast response time also prevent overheating and mechanical stress on conductors. Please note that the circuit must be shut down after the first ground fault.

Low resistance grounding resistors are typically rated 400 amps for 10 seconds, and are commonly found on medium and high voltage systems.

3.4 What is a High Resistance Grounded System?

IEEE Standard 142-1991, Recommended Practice for Grounding of Industrial and Commercial Power Systems (Green Book), defines a high resistance grounded system as follows:

> A grounded system with a purposely inserted resistance that limits ground-fault current can flow for an extended period without exacerbating damage. This level of current is commonly thought to be 10A or less. High-resistance grounded systems are designed to meet the criteria $R_o \leq X_{co}$ to limit the transient over-voltages due to arcing ground faults. Ro is the per phase zero sequence resistance of the system and Xco is the distributed per phase capacitive reactance-to-ground of the system.

4.1 Why Consider High Resistance Grounding?

High resistance grounding solves the problem of transient over-voltages, thereby reducing equipment damage. Over-voltages caused by intermittent (arcing) faults can be held to phase-to-phase voltage by grounding the system neutral through a resistance which limits the ground current to a value equal to or greater than the capacitive charging current of the system. Thus, the fault current can be limited in order to prevent equipment damage and arc flash hazards.

In addition, limiting fault currents to predetermined maximum values permits the designer to selectively co-ordinate the operation of protective devices, which minimizes system disruption and allows for quick location of the fault.

4.2 Why Limit the Current Through Resistance Grounding?

The reason for limiting the current by resistance grounding may be one or more of the following, as indicated in IEEE Std. 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems 1.4.3.

1. To reduce burning and melting effects in faulted electric equipment, such as switchgear, transformers, cables, and rotating machines.
2. To reduce mechanical stresses in circuits and apparatus carrying fault currents.
3. To reduce electric-shock hazards to personnel caused by stray ground-fault currents in the ground return path.
4. To reduce arc blast or flash hazard to personnel who may have accidentally caused (or who happen to be in close proximity) to the ground fault.
5. To reduce the momentary line-voltage dip occasioned by the occurrence and clearing of a ground fault.
6. To secure control of transient over-voltages while at the same time avoiding the shutdown of a faulty circuit on the occurrence of the first ground fault.

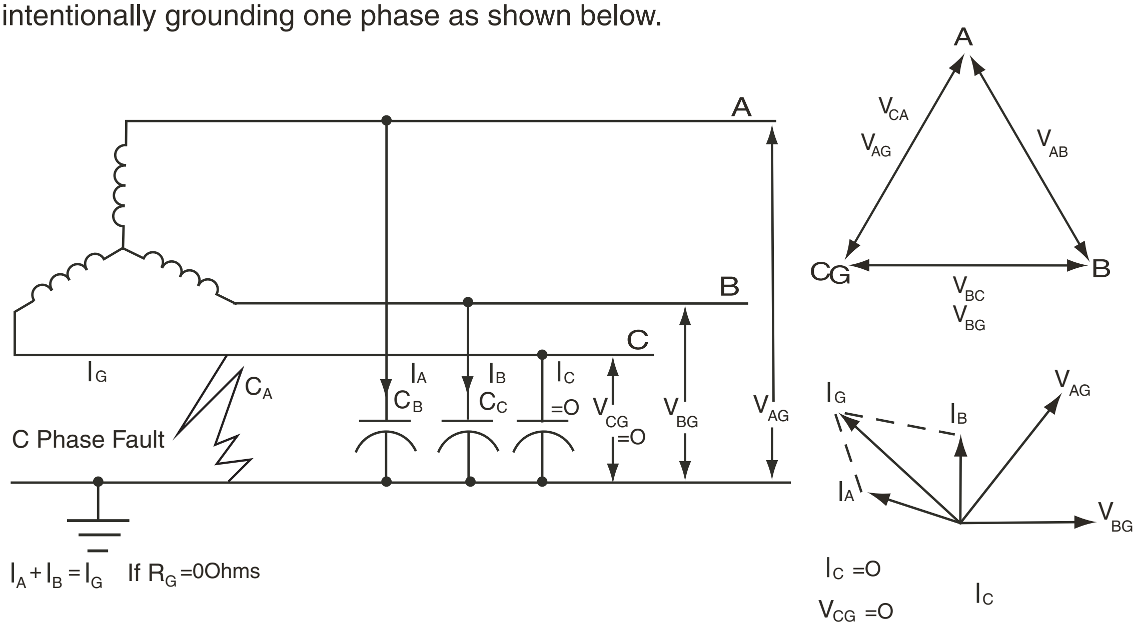
4.3 What are the Requirements for Sizing the Resistor?

The line-to-ground capacitance associated with system components determines the magnitudes of zero-sequence charging current. The resistor must be sized to ensure that the ground fault current limit is greater than the system's total capacitance-to-ground charging current. If not, then transient over-voltages can occur. The charging current of a system can be calculated by summing the zero-sequence capacitance or determining capacitive reactance of all the cable and equipment connected to the system.

4.4 Measuring the System Capacitive Charging Current.

It is preferable to measure the magnitude of the charging current on existing power systems for correct grounding equipment selection. The measured values must be adjusted to obtain the maximum current if not all system components were in operation during the tests.

The measurement of system charging current 3 Ico is a relatively simple procedure, but, as on all occasions when one deals with energized distribution systems, a careful consideration of the problem, followed by the use of the proper precautions, is essential. On ungrounded low voltage systems, the charging current can be measured by intentionally grounding one phase as shown below.



The apparatus required for measurement on low voltage systems consists of an Ammeter, with ranges up to 10 amps, an HRC fuse and a disconnecting switch with adequate continuous and interrupting rating, such as a QMQB switch or a circuit breaker connected in series as shown in the diagram. The fuse is provided for equipment and personnel protection against the occurrence of a ground fault on one of the other phases while the measurement is being made. For this test the entire system should be energized, if possible.

It is recommended that a properly rated variable resistor should also be series connected in the circuit to minimize transient changes in the system charging current when the phase conductor is brought to ground potential by progressively decreasing the resistance to zero.

With the resistance set for Maximum, the current should be limited to half the estimated charging current (Table A2.1).

$$R_{MAX} = \frac{2 \cdot V_{LL}}{\sqrt{3 \cdot 3I_{CO}}} \text{ (Ohms), where}$$

$3I_{CO}$ = the estimated charging current

V_{LL} = the system line-to-line voltage

Table A2.1 Typical Charging Currents

System Voltage	Charging Current ($3IC_O$) Amps/1000 kVA of System Capacity
480	0.1 - 2.0
600	0.4 - 2.0
2400	2.0 - 5.0
4160	2.0 - 5.0
13800	5.0 - 10.0

NOTE: Contribution of surge capacitors are not included in Table A2.1.

An essential requirement is a firm electrical connection to one phase of the system. As the measurement can be made anywhere on the system, one of the best ways is to de-energize a part of the system, than bolt or clamp the ground, and bolt or clamp on the electrical apparatus to one phase, then reenergize the system. During the tests it is required that the entire system be energized.

The test procedure should adhere to the following sequence. All resistance of the variable resistors should be in before closing the disconnect switch ahead of the fuse. After closing the disconnect switch, slowly reduce the resistance to zero and the Ammeter will indicate the system charging current. It is advisable to have several ranges available on the Ammeter, but the disconnecting switch should always be opened before a range change is made, to eliminate the possibility of opening the circuit with the range switch.

To remove the test connections, the sequence should be reversed. First, increase the resistance to maximum, and then open the disconnecting switch. Although the three phases usually have approximately equal charging currents, all three should be measured, and the average value used. By using properly rated equipment, similar measurements may be made on medium voltage systems also.

4.5 Rule of Thumb for System Charging Current.

When it is impractical to measure the system charging current, the “Rule of Thumb” method may be used.

SYSTEM PHASE-TO-PHASE VOLTAGE	ESTIMATED RESISTOR CURRENT VS. SYSTEM KVA CAPACITY WITHOUT SUPPRESSORS	ADDITIONAL CURRENT FOR EACH SET OF SUPPRESSORS
600	1A/2000 KVA	0.5A
2400	1A/1500 KVA	1.0A
4160	1A/1000 KVA	1.5A

4.6 Is There Any Performance Downside to Applying a 5A Resistor to a System that May Only Have 1A of Charging Current?

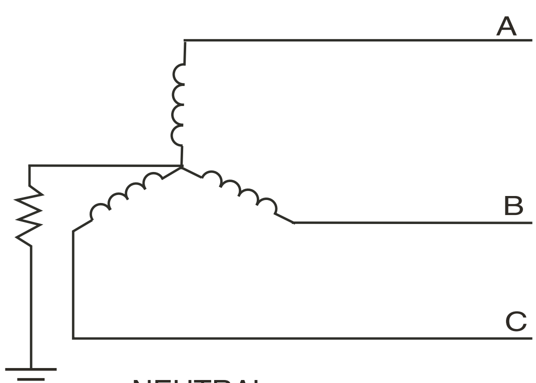
There is no performance downside to having ground let through current of 5A, even on smaller 480V systems with only 1A charging current. It is critical to have it more than 1A and it can be up to 10A. There is only a marginal effect on cost of 1A resistor vs. 5A resistor at 277V and the same for the zig-zag transformer.

4.7 What is the Probability that a 480V Industrial System 4000 KVA Would Require More Than a 5A Resistor?

It is unlikely that a 480V system would have a charging current larger than 5A. The only way it can happen is if the customer has added line to ground capacitance for surge suppression. If there is doubt, do a verification that the charging current is less than 5A and simply install a 5A Resistor on any 480V system.

4.8 What are the Necessary Steps to Upgrade My System?

Once we have determined the size requirements for the resistor, the next step typically would be to connect the current limiting resistor into the system. On a wye-connected system the neutral grounding resistor is connected between the wye-point of the transformer and ground as shown below.



NEUTRAL GROUNDING RESISTOR (NGR)

$$R_{NGR} = \frac{V_{LL}}{\sqrt{3}I_G} \text{ Ohms}$$

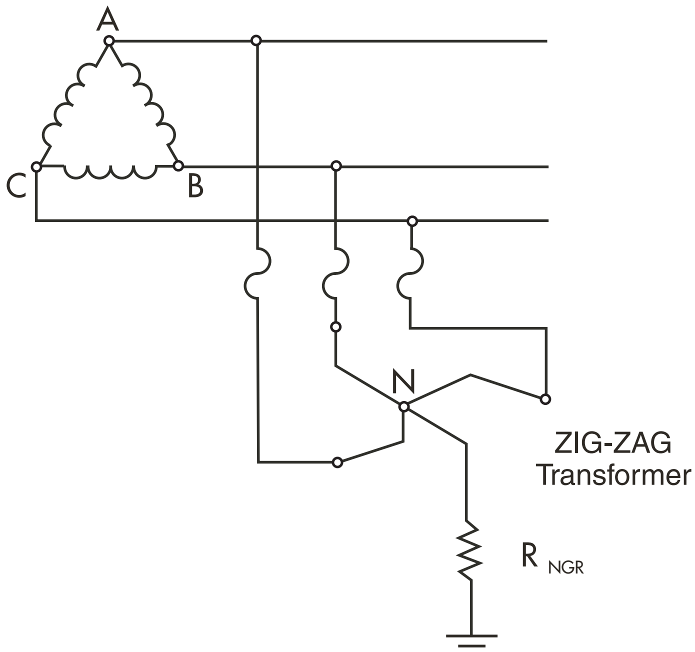
$$R_{NGR} \leq \frac{X_{CO}}{3} \text{ Ohms}$$

$$I_G \geq 3I_{CO} \text{ Amperes}$$

$$P_{NGR} = I_G^2 R_{NGR} \text{ Watts}$$

Where I_G = Maximum Ground Current (A)

On a delta-connected system, an artificial neutral is required. Since no star point exists this can be achieved by use of a zig-zag transformer as shown.



$$S = V_{LL} \cdot I_G \quad \text{VA}$$

$$R_{NGR} = \frac{E}{\sqrt{3I_G}} \quad \text{Ohms}$$

$$R_{NGR} \leq \frac{X_{CO}}{3} \quad \text{Ohms}$$

$$I_G \geq 3I_{CO} \quad \text{Amperes}$$

$$P_{NGR} = I_G^2 R_{NGR} \quad \text{Watts}$$

With pre-packaged High Resistance Grounding Systems available from Post Glover, all with enclosed current limiting Neutral Grounding Resistors and artificial neutrals, the process is to determine the protective features that you require and install the product of choice.

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