

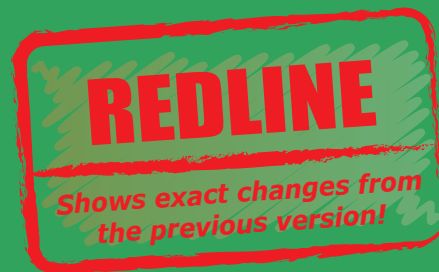
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142™

IEEE Recommended Practice for

Grounding of Industrial and Commercial Power Systems



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(Revision of
IEEE Std 142-1991)

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IEEE Std 142™-2007

(Revision of
IEEE Std 142-1991)

IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems

Sponsor

**Power Systems Engineering Committee
of the
IEEE Industry Applications Society**

Approved 7 June 2007

IEEE-SA Standards Board

Abstract: The problems of system grounding, that is, connection to ground of neutral, of the corner of the delta, or of the midtap of one phase, are covered. The advantages and disadvantages of grounded vs. ungrounded systems are discussed. Information is given on how to ground the system, where the system should be grounded, and how to select equipment for the ground of the neutral circuits. Connecting the frames and enclosures of electric apparatus, such as motors, switchgear, transformers, buses, cables, conduits, building frames, and portable equipment, to a ground system is addressed. The fundamentals of making the interconnection of a ground conductor system between electric equipment and the ground rods, water pipes, etc., are outlined. The problems of static electricity—how it is generated, what processes may produce it, how it is measured, and what should be done to prevent its generation or to drain the static charges to earth to prevent sparking—are treated. Methods of protecting structures against the effects of lightning are also covered. Obtaining a low-resistance connection to earth, use of ground rods, connections to water pipes, etc., are discussed. A separate chapter on electronic equipment is included.

Keywords: connection to earth, electronic equipment grounding, equipment grounding, lightning protection, static protection, system grounding

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Introduction

This introduction is not part of IEEE Std 142-2007, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.

This book is a revision of IEEE Std 142-1991, the *IEEE Green Book*[™]. This recommended practice has served electrical engineers seeking electrical system grounding information since the first edition in 1956. It reflects the experience and sound judgment of a working group made up of engineers active in the design and operation of electrical systems for industrial and commercial power systems.

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IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems

Chapter 1

System grounding

1.1 Introduction

1.1.1 Overview

This chapter provides recommended procedures for the system grounding of industrial and commercial power systems, and the proper selection and application of grounding impedances. Special cases of system grounding are also addressed for generators, uninterruptible power supplies (UPS), portable mining equipment, and multi-voltage systems.

1.1.2 General

Grounding of an electrical system is a decision that must be faced sometime by most engineers charged with planning or modifying electrical distribution. Grounding in some form is generally recommended, although there are certain exceptions. Several methods and criteria exist for system grounding; each has its own purpose.

It is the intention of this chapter to assist the engineer in making decisions on the subject by presenting basic reasons for grounding or not grounding and by reviewing general practices and methods of system grounding.

The practices set forth herein are primarily applicable to industrial power systems that distribute and utilize power at medium or low voltage, usually within a smaller geographical area than is covered by a utility.

Where distances or power levels may dictate circuitry and equipment similar to a utility, consideration of utility practices is warranted. However, restrictions of the National Electrical Code® (NEC®), NFPA 70¹ particular needs of service and the experience and training of the workforce should also be considered.

Where an industrial power system includes power-generating equipment, the reasons for grounding these components may be the same as those for grounding similar components of public utility systems. The methods of grounding would generally be similar under like conditions of service. However, in the industrial setting, conditions of service may be altered by the following:

- a) Location within the power system
- b) Individual generator characteristics
- c) Manufacturing process requirements

⁴~~The numbers in brackets correspond to those of the references in 1.12.~~

All of these may affect grounding decisions.

The NEC, sponsored by the National Fire Protection Association, contains regulations pertaining to system and equipment grounding applicable to industrial, commercial, and special occupancy facilities. These rules are considered minimum requirements for the protection of life and property and should be carefully reviewed during the course of system design. The recommended practices in this document are intended to supplement, and not negate, any of the requirements in the NEC.

1.2 Definitions

For the purposes of this document, the following terms and definitions apply. The Authoritative Dictionary of IEEE Standards Terms [B8]² and the NEC should be referenced for terms not defined in this subclause.

~~The varieties of system grounding and definitions of related terminology follow. The definitions of additional terms may be found in IEEE Std 100-1988 [2] and the NEC~~

1.2.1 effectively grounded: Grounded through a sufficiently low impedance such that for all system conditions the ratio of zero-sequence reactance to positive-sequence reactance (X_0/X_1) is positive and than 3, and the ratio of zero sequence resistance to positive-sequence reactance (R_0/X_1) is positive and than 1.

1.2.2 equipment grounding conductor (EGC): The conductor used to connect the non-current-carrying metal parts of the equipment, raceways, and other enclosures to the system grounded conductor, the grounding electrode conductor (GEC), or both, at the service equipment or at the source of a separately derived system.

1.2.3 ground: A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some other body that serves in place of the earth.

1.2.4 grounded: Connected to earth or to an extended conducting body that serves instead of the earth, whether the connection is intentional or accidental.

1.2.5 grounded system: A system in which 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.

1.2.6 grounding system: A system that consists of all interconnected grounding connections in a specific power system and is defined by its isolation from adjacent grounding systems. The isolation is provided by transformer primary and secondary windings that are coupled only by magnetic means. Thus, the system boundary is defined by the lack of a physical connection that is either metallic or through a significantly high impedance.

1.2.7 high-resistance grounded: A resistance-grounded system designed to ~~with a purposely inserted resistance~~ limit ground-fault current to a value that can be allowed to flow for an extended period of time, ~~without exacerbating damage.~~ while still meeting the criteria of $R_0 < X_{c0}$, so that transient voltages from arcing ground faults are reduced. The ground-fault current is usually limited to less than 10 A, resulting in limited damage even during prolonged faults ~~resistance-grounded systems are designed to meet the criterion of to limit due to arcing ground faults. X_{c0} is the distributed per phase capacitive reactance to ground of the system, and R_0 is the per-phase zero-sequence resistance of the system~~

1.2.8 low-resistance grounded: A resistance-grounded system that permits a higher ground-fault current to flow to obtain sufficient current for selective relay operation. Usually meets the criteria of R_0/X_0 less than or equal to 2. Ground-fault current is typically between 100 A and 1000 A. ~~in which the purposely inserted resistance has lower ohmic value than would meet the high resistance grounding criteria. The resistance is selected to provide the desired relaying current~~

1.2.9 per-phase charging current (I_{co}): The current (V_{ln}/X_{co}) that passes through one phase of the system to charge the distributed capacitance per phase to ground of the system; V_{ln} is the line-to-neutral voltage and X_{co} is the per-phase distributed capacitive reactance of the system.

1.2.10 reactance grounded: Grounded through an impedance, the principal element of which is inductive reactance.

1.2.11 resistance grounded: Grounded through an impedance, the principal element of which is resistance.

~~-resonance: The enhancement of the response of a physical system (electrical system or circuit) to a periodic excitation when the excitation frequency (f) is equal to a natural frequency of the system. In a series circuit of resistance (R), inductance (L), and capacitance (C), when L and C parameters are such that the resultant reactance becomes zero and the current reaches maximum, then the circuit is in series resonance. This happens when,—~~

$$\omega L = \frac{1}{\omega C} \text{ or } f = \frac{1}{2\pi\sqrt{LC}}$$

~~Similarly, in a parallel circuit consisting of R , L , and C , the admittance is the lowest when $1/X_L = 1/X_C$, and the circuit is in parallel resonance.~~

1.2.12 resonant grounded: A system in which the capacitive charging current is neutralized by an inductive current produced from a reactor connected between the system neutral and ground. By properly “tuning” the reactor (selecting the right tap), a low magnitude of fault current can be achieved. In general, when this occurs the arc will not maintain itself and the ground fault is extinguished or “quenched.” In a parallel circuit, consisting of L and C , this happens when,

$$\omega L = \frac{1}{\omega C} \text{ or } f = \frac{1}{2\pi\sqrt{LC}}$$

1.2.13 R_n : The value of the resistance connected from the neutral to the ground of a resistance-grounded system. For high-resistance grounded systems where R_n is a major component of R_0 , the relationship $R_0 = 3R_n$ applies.

1.2.14 R_0 The per-phase zero-sequence resistance of the system.

1.2.15 separately derived system: A wiring system whose power is derived from a generator, transformer, or converter windings and has no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system.

1.2.16 solidly grounded: Connected directly through an adequate ground connection in which no impedance has been intentionally inserted.

1.2.17 static charge: The electricity generated when two dissimilar substances come into contact. Conveyor belts are active producers of static electricity.

1.2.18 switching surge: A transient wave of overvoltage in an electric circuit caused by the operation of a switching device interrupting ~~load or fault~~ current.

1.2.19 system charging current: The total distributed capacitive charging current ($3V_{ln}/X_{co}$) of a three-phase system.

1.2.20 three-phase, four-wire system: A system of alternating current supply comprising four conductors, three of which are connected as in a three-phase three-wire system, the fourth being connected to the neutral point of the supply or midpoint of one phase in case of delta-connected transformer secondary, ~~which may be grounded for the purpose of conducting load current.~~

1.2.21 three-phase, three-wire system: A system of alternating current supply comprising three conductors, between successive pairs of which are maintained alternating differences of potential successively displaced in phase by one third of a period.

1.2.22 transient overvoltage: The temporary overvoltage ~~of short duration~~ associated with the operation of a switching device, a fault, a lightning stroke, an arcing ground fault on an ungrounded system, or other instigating events.

1.2.23 ungrounded system: A system without an intentional connection to ground except through potential indicating or measuring devices or other very high-impedance devices.

1.2.24 X_{co} : The distributed per-phase capacitive reactance to ground of the system.

1.2.25 X_0 : Zero-sequence reactance of the system.

1.2.26 X_1 : Positive-sequence reactance of the system.

1.2.27 X_2 : Negative-sequence reactance of the system.

~~**system:** A grounding system consists of all interconnected grounding connections in a specific power system and is defined by its isolation from adjacent grounding systems. The isolation is provided by transformer primary and secondary windings that are coupled only by magnetic means. Thus, the system boundary is defined by the lack of a physical connection that is either metallic or through a significantly high impedance. Fig 1 illustrates the limits and boundaries of grounding systems.~~

1.3 Purposes of system grounding

System grounding is the intentional connection to ground of a phase or neutral conductor for the purpose of:

- a) Controlling the voltage with respect to earth, or ground, within predictable limits, and
- b) Providing for a flow of current that will allow detection of an unwanted connection between system conductors and ground. Such detection may then initiate operation of automatic devices to remove the source of voltage from these conductors ~~with such undesired connections to ground~~.

The NEC prescribes certain system grounding connections that must be made to be in compliance with the code. The control of voltage to ground limits the voltage stress on the insulation of conductors so that insulation performance can more readily be predicted. The control of voltage also allows reduction of shock hazard to persons who might come in contact with live conductors.

1.4 Methods of system neutral grounding

1.4.1 Introduction

Most grounded systems employ some method of grounding the system neutral at one or more points. These methods can be divided into two general categories: *solid grounding* and *impedance grounding*. Impedance grounding may be further divided into several subcategories: reactance grounding, resistance grounding, and *ground-fault neutralizer grounding*. Figure 1-1 shows examples of these methods of grounding.

Each method, as named, refers to the nature of the external circuit from system neutral to ground rather than to the degree of grounding. In each case the impedance of the generator or transformer whose neutral is grounded is in series with the external circuit. Thus a solidly grounded generator or transformer may or may not furnish effective grounding to the system, depending on the system source impedance.

Many of the concepts involved in defining system grounding types and levels are best explained in terms of symmetrical components or equivalent circuits. The reader who is not familiar with these analytical methods is referred to Chapter 2 of Beeman and to Chapter 3 of IEEE Std 399™ (*IEEE Brown Book*™) for guidance.

Molded-case circuit-breaker interrupting capabilities can be affected by the method of grounding. In addition, if other than solidly grounded [wye systems](#) are used, the circuit breakers' [single-pole interrupting ratings](#) should be evaluated for the application

1.4.2 Ungrounded system (no intentional grounding)

In an ungrounded system, there is no intentional connection between the system conductors and ground. However, as shown in Figure 1-2, there always exists a capacitive coupling between one system conductor and another, and also between system conductors and ground. Consequently, the so-called *ungrounded* system is in reality a *capacitance grounded* system, by virtue of the distributed capacitance from the system conductors to ground. Since the capacitance between phases has little effect on the grounding characteristics of the system, it will be disregarded. For simplicity, the distributed capacitive reactance to ground, X_{co} , is assumed to be balanced.

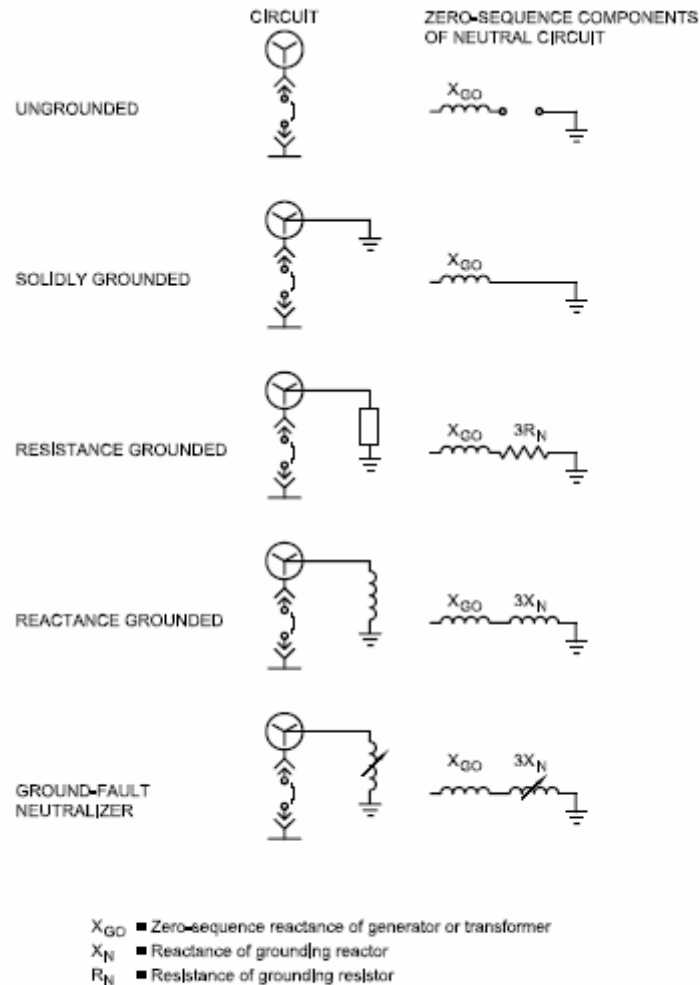


Figure 1-1—System neutral circuit and equivalent diagrams for ungrounded and grounded systems

In an unfaulted condition, with balanced three-phase voltages applied to the lines, the capacitive charging current, I_{CO} , in phase will be equal and displaced 120° from one another. The phase voltages to ground will also be equal and displaced 120° from one another. The vectors relationships are shown in part b) of Figure 1-2. Since the neutral of the distributed capacitances is at earth potential, it follows that the neutral of the transformer is also at earth potential, being held there by the capacitance to ground.

If one of the system conductors, phase C for example, faults to ground, current flow through that capacitance to ground will cease, since no potential difference across it now exists. The voltage across the remaining two distributed capacitors to ground will, however, increase from line to neutral to line to line. The capacitive charging current, I_{CO} , in the two unfaulted phases will therefore increase by the square root of 3. As shown in Figure 1-3, the line-to-ground voltages are no longer 120° , but 60° apart.

Hence, the vectorial sum of the capacitive charging current to ground is no longer zero, but is $3 I_{c0}$ or three times the original charging current per phase. The fault current, I_g , flowing from the faulted conductor to ground, leads the original line-to-neutral voltage ($V_{nc} = -V_{cn}$) by approximately 90° .

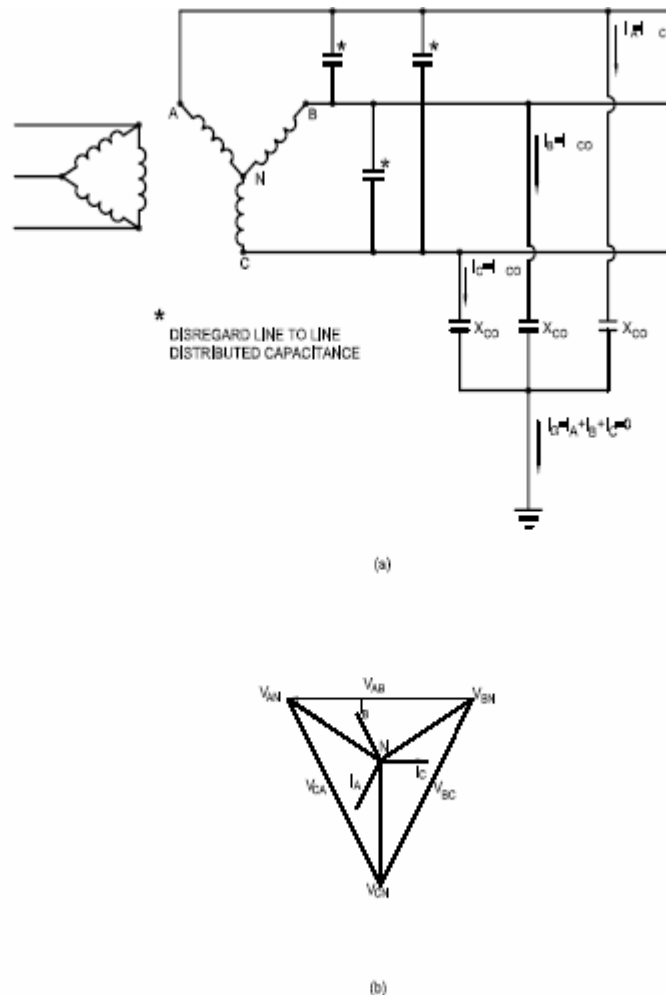


Figure 1-2—Ungrounded system: (a) circuit configuration, (b) vector diagram

In an ungrounded system, it is possible for destructive transient overvoltages to occur throughout the system during restriking ground faults. These overvoltages, which can be several times normal in magnitude, result from a resonant condition being established between the inductive reactance of the system and the distributed capacitance to ground. This phenomenon is discussed in detail by Beeman. Experience has proved that these overvoltages may cause failure of insulation at multiple locations in the system, particularly at motors. Transient overvoltages from restriking ground faults are the main reason why ungrounded systems are no longer recommended and grounded systems of some form are the predominant choice. To reduce transient overvoltages during restriking ground faults, one should ground the system using either solid or impedance grounding as indicated in Figure 1-4.

Various detection schemes are used to detect the presence of a single line-to-ground fault. The simplest scheme employs three light bulbs, each connected between line voltage and ground. Under normal operation the three bulbs are illuminated with low equal intensity. When a single line-to-ground fault occurs, that bulb connected to the faulted phase is extinguished. The remaining two bulbs increase in intensity, since the voltage on the unfaulted phases increases from line-to-neutral to line-to-line.

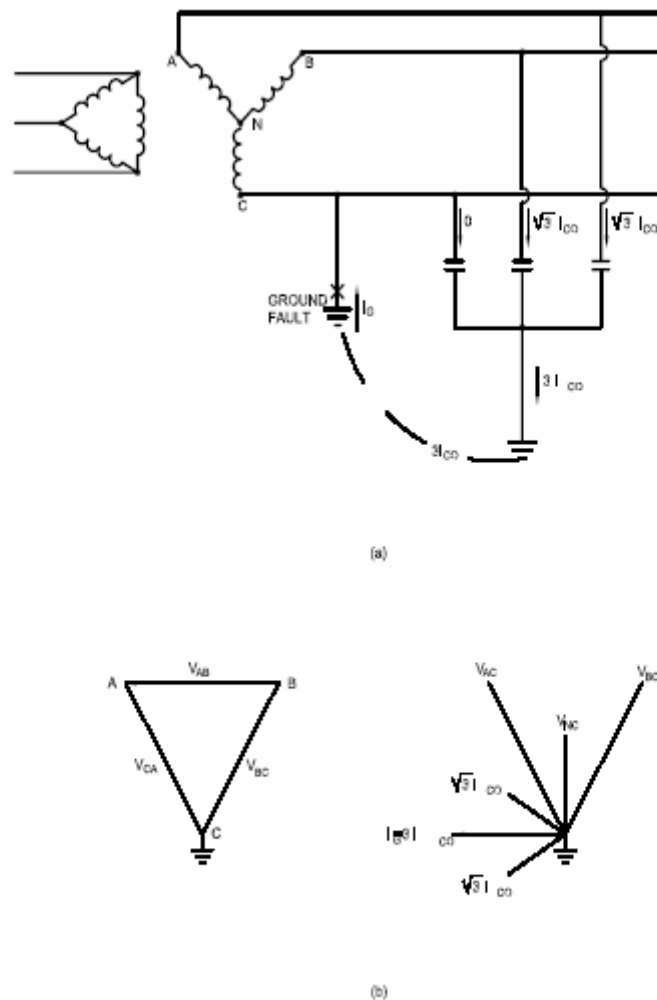


Figure 1-3—Single line-to-ground fault on an ungrounded system:
(a) circuit configuration, (b) vector diagram

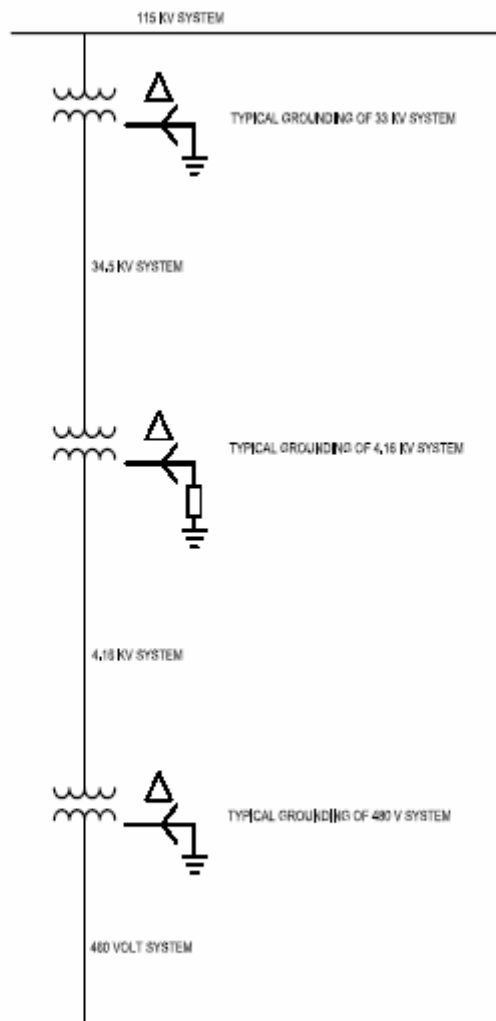


Figure 1-4—Independent grounding of each voltage level

Another scheme frequently used takes the form of three voltage transformers with their primary windings connected in wye and the neutral point grounded. The secondary windings of the transformers are connected in broken delta, with a voltage relay connected in the open corner and used to operate an indication or alarm circuit. Using this scheme, loading resistors may be required either in the primary neutral or secondary circuit to avoid ferroresonance.

The problem of locating a single line-to-ground fault on an ungrounded system can be time consuming. Usually, the first step is to open the secondary feeders, one at a time, to determine on which feeder the fault is located. Afterwards, the branch circuits are opened one at a time. Finally, the individual loads are taken off. None of these procedures improves service continuity.

If a ground cannot be located before a second line-to-ground fault occurs, whose current must be carried by the EGC or earth, the result will be a line-to-line fault. This will be contrasted later to a grounded system that develops enough ground current to clear, automatically and selectively, each faulted circuit.

~~Electrical power systems which are operated with no intentional ground connection to the system conductors are generally described as ungrounded. In reality, these systems are grounded through the system capacitance to ground.~~

~~In most systems, this is an extremely high impedance, and resulting system relationships systems are grounded through the system to ground. are weak and easily distorted.~~

~~Two principal advantages are attributed to ungrounded systems. The first is operational: The first ground fault on a system causes only a small ground current to flow, so the system may be operated with a ground fault present, improving system continuity. The second is economic: No expenditures are required for grounding equipment or grounded system conductors.~~

~~Numerous advantages are attributed to grounded systems, including greater safety, freedom from excessive system overvoltages that can occur on ungrounded systems during arcing, resonant or near-resonant ground faults, and easier detection and location of ground faults when they do occur.~~

~~Resonant effects can occur when the ground fault path includes an inductive reactance approximately equal to the system capacitive reactance to ground. Beeman [10], pp. 281–285, discusses this phenomenon in depth. For an extensive discussion of the advantages of grounded systems, see pp 345–348 of Beeman [10]. Also, Article 250–5 of [1] requires certain systems to be grounded. Grounded systems are now the predominant choice.~~

~~When an ungrounded system is chosen, a ground detection scheme may be applied to the system.~~

1.4.3 Resistance grounding

In a resistance-grounded system, the neutral of the transformer or generator is connected to ground through ~~one or more~~ a resistor. A typical resistance-grounded neutral system is shown in Figure 1-5. As commonly installed, the resistance has a considerably higher ohmic magnitude than the system reactance at the resistor location. In this method, with the resistor values normally used, and except for transient overvoltages, Consequently, the line-to-ground fault current is primarily limited by the resistor itself. the line-to-ground voltages that exist during a are nearly the same as those for an ungrounded system.

The reasons for limiting the current by resistance grounding include the following:

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

Resistance grounding may be either of two classes, high resistance or low resistance, distinguished by the magnitude of ground-fault current permitted to flow. Although there are no recognized standards for the levels of ground-fault current that define these two classes, in practice there is a clear difference.

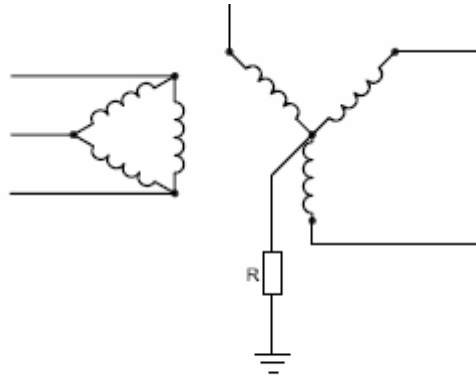


Figure 1-5—Resistance-grounded system

1.4.3.1 High-resistance grounding

High-resistance grounding employs a neutral resistor of high ohmic value. The value of the resistor is selected to limit the current, I_g , to a magnitude equal to or slightly greater than the total capacitance charging current, $3 I_{C0}$, as shown in Figure 1-6.

Typically, the ground-fault current, I_g , is limited to 10 A or less, although some specialized systems at voltages in the 15 kV class may require higher ground-fault levels. In general, the use of high-resistance grounding on systems where the line-to-ground fault exceeds 10 A should be avoided because of the potential damage caused by an arcing current larger than 10 A in a confined space (see Foster, Brown, and Pryor).~~although some specialized systems at voltages in the 15 kV class may have higher round fault current levels. Low resistance grounding typically uses ground fault current levels of at least 100 A, with currents in the 200–1000 A range being more usual.~~

Several references are available that give typical system charging currents for major items in the electrical system (see *Electrical Transmission and Distribution Reference Book*; Baker). These will allow the value of the neutral resistor to be estimated in the project design stage. The actual system charging current may be measured prior to connection of the high-resistance grounding equipment following the manufacturer's recommended procedures.

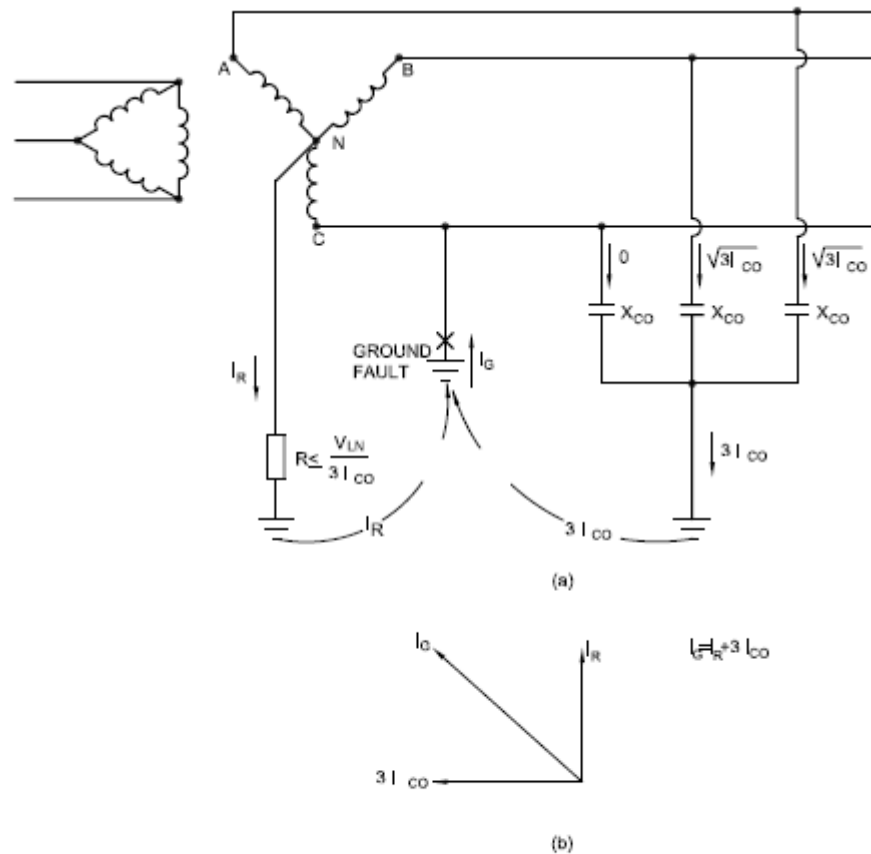


Figure 1-6—Single line-to-ground fault on a high-resistance grounded system: (a) circuit configuration, (b) vector diagram

~~Both types are designed to limit transient overvoltages to a safe level (within 250% of normal). However,~~ High-resistance grounding usually does not require immediate clearing of a ground fault since the fault current is limited to a very low level. The protective scheme associated with high-resistance grounding is usually detection and alarm rather than immediate trip out.

A typical scheme for detecting a ground fault in a high-resistance grounded system is shown in Figure 1-7. Under normal operation, the neutral point of the transformer is at zero potential. When a single line-to-ground fault occurs, the neutral point is raised to approximately line-to-neutral voltage. This rise in voltage is then detected using an overvoltage relay, 59. A step-down transformer is typically used to reduce the line to neutral voltage of the system to a level (usually 120 V) acceptable to the relay. Since a ground fault may persist for an indefinite length of time, a continuous (rather than short term) rating should be imposed on the grounding resistor.

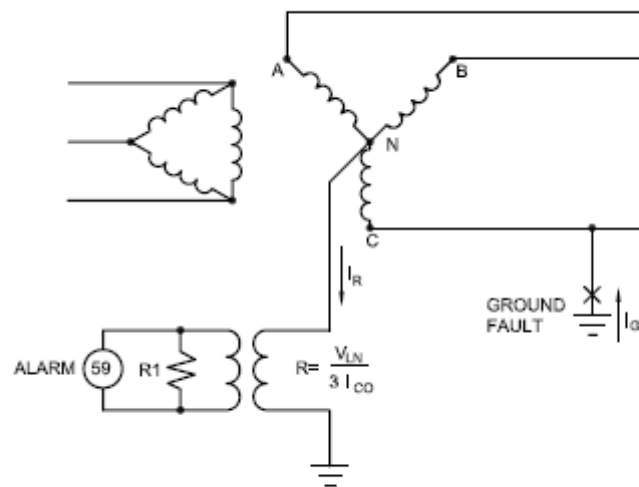


Figure 1-7—Scheme for detecting a ground fault on a high-resistance grounded system

High-resistance grounding has the following advantages:

- a) Service continuity is maintained. The first ground fault does not require process equipment to be shut down
- b) Transient overvoltage due to restriking ground faults is reduced (to 250% of normal).
- c) A signal tracing or pulse system will facilitate locating a ground fault.
- d) It eliminates flash hazards to personnel associated with high ground-fault currents.
- e) The need for and expense of coordinated ground-fault relaying is eliminated.

High-resistance grounding is generally employed in the following:

- 1) Low voltage (where permitted), i.e., commercial and industrial locations where there are no line-to-neutral loads
- 2) Medium-voltage systems where service continuity is desired and capacitive charging current is not excessive.
- 3) Retrofits of previously ungrounded systems where it is desired to reduce transient overvoltages potentially caused by restriking ground faults.

~~High resistance grounding is a method that can be applied to existing medium voltage ungrounded systems to obtain the transient overvoltage protection without the modification expense of adding ground relays to each circuit.~~

1.4.3.2 Low-resistance grounding

Low-resistance grounding is designed to limit ground-fault current to a range between 100 A and 1000 A, with 400 A being typical. The neutral resistor, R , shown in Figure 1-8, is selected according to $R = V_{LN}/I_g$, where V_{LN} is the system line to neutral voltage and I_g is the desired ground-fault current. Figure 1-9 illustrates the flow of currents for a single line-to-ground fault on a low-resistance grounded system. Since the combined effects of charging current and system source impedance will affect the ground-current value less than 0.5% in the typical range of utility supplied systems, it is permissible to ignore these effects in calculating the ground-fault resistance value. The general practice is to consider that the full system line-to-neutral voltage appears across the grounding resistor. Only in the case of systems supplied by small generators should departure from this general practice be considered.

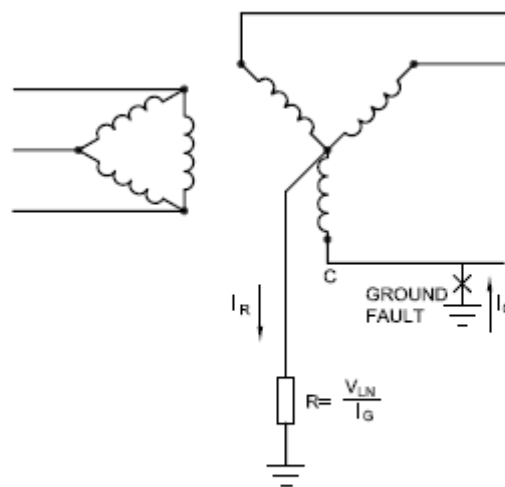
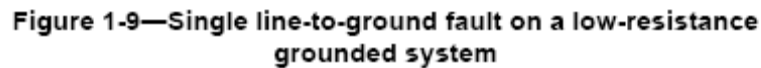


Figure 1-8—Low-resistance grounded system

Low-resistance grounding has the advantage of facilitating the immediate and selective clearing of a grounded circuit. This requires that the minimum ground-fault current be large enough to positively actuate the applied ground-fault relay. One method of detecting the presence of a ground fault uses an overcurrent relay, 51G. This method is presented in Figure 1-10. When a ground fault occurs, the neutral potential is raised to approximately line-to-neutral voltage, resulting in current flow through the resistor. A typical turns ratio for the current transformer is indicated. Upon indication that a ground fault has occurred, action would be initiated to disconnect the transformer from the secondary circuit.



Systems grounded through resistors require surge arresters suitable for use on ungrounded neutral circuits. Metal-oxide surge arrester ratings must be chosen so that neither the maximum continuous operating voltage capability nor the one-second temporary overvoltage capability is exceeded under system ground-fault conditions.

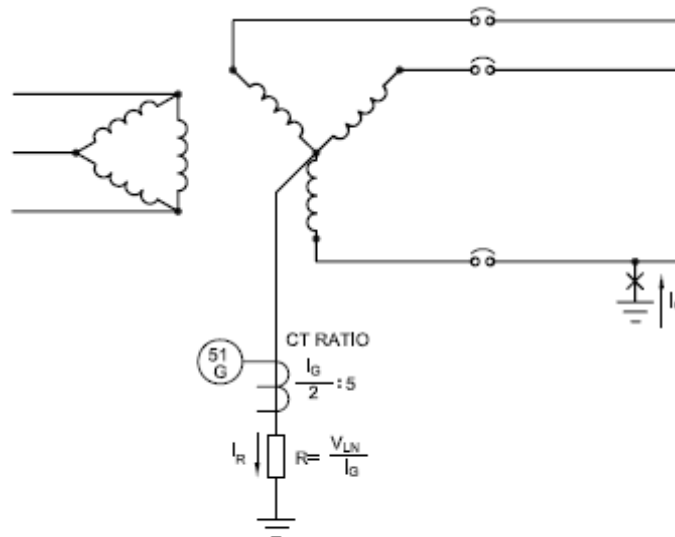


Figure 1-10—Scheme for detecting a ground fault on a low-resistance grounded system

~~High resistance grounding is a method that can be applied to existing medium-voltage ungrounded systems to obtain the transient overvoltage protection without the modification expense of adding ground relays to each circuit.~~

~~High resistance grounding is a method that can be applied to existing medium-voltage ungrounded systems to obtain the transient overvoltage protection without the modification expense of adding ground relays to each circuit.~~

1.4.4 Reactance grounding

The term *reactance grounding* describes the case in which a reactor is connected between the system neutral and ground, as shown in Figure 1-11. Since the ground fault that may flow in a reactance-grounded system is a function of the neutral reactance, the magnitude of the ground-fault current is often used as a criterion for describing the degree of grounding. In a reactance-grounded system, the available ground-fault current should be at least 25% ($X_0 = 10X_1$) and preferably 60% ($X_0 = 3X_1$) of the three-phase fault current to prevent serious transient overvoltages. The term X_0 , as used, is the sum of the source zero-sequence reactance, X_0 , plus three times the grounding reactance, $3X_n$, ($X_0 = X_{0 \text{ source}} + 3X_n$). This is considerably higher than the level of fault current desirable in a resistance-grounded system, and therefore reactance grounding is usually not considered an alternative [to low-resistance grounding](#). ~~In most generators, solid grounding, that is, grounding without external impedance, may permit the maximum ground fault current from the generator to exceed the maximum three-phase fault current that the generator can deliver and for which its windings are braced. Consequently, neutral-grounded generators should be grounded through a low-value reactor that will limit the ground fault current to a value no greater than the generator three-phase fault current. In the case of three-phase four-wire systems, the limitation of ground fault current to 100% of the three-phase fault current is usually practical without interfering with normal four-wire operation. In practice, reactance grounding is generally used only in this case and to ground substation transformers with similar characteristics.~~

Reactance grounding is typically reserved for applications where there is a desire to limit the ground-fault duty to a magnitude that is relatively close to the magnitude of a three-phase fault. Use of neutral grounding reactors to provide this fault limitation will often be found to be a less expensive application than use of grounding resistors if the desired current magnitude is several thousand amperes.

These circumstances may arise in one of two possible instances. One potential setting is where a large substation feeds a medium-voltage distribution system, and the total zero-sequence impedance of the step-down transformers in the station causes the single-line-to-ground-fault current to greatly exceed the magnitude of a three-phase fault, and ground-fault limitation is desired to keep the total fault current within the reasonable limits. These conditions tend to occur most often in electric utility distribution practice.

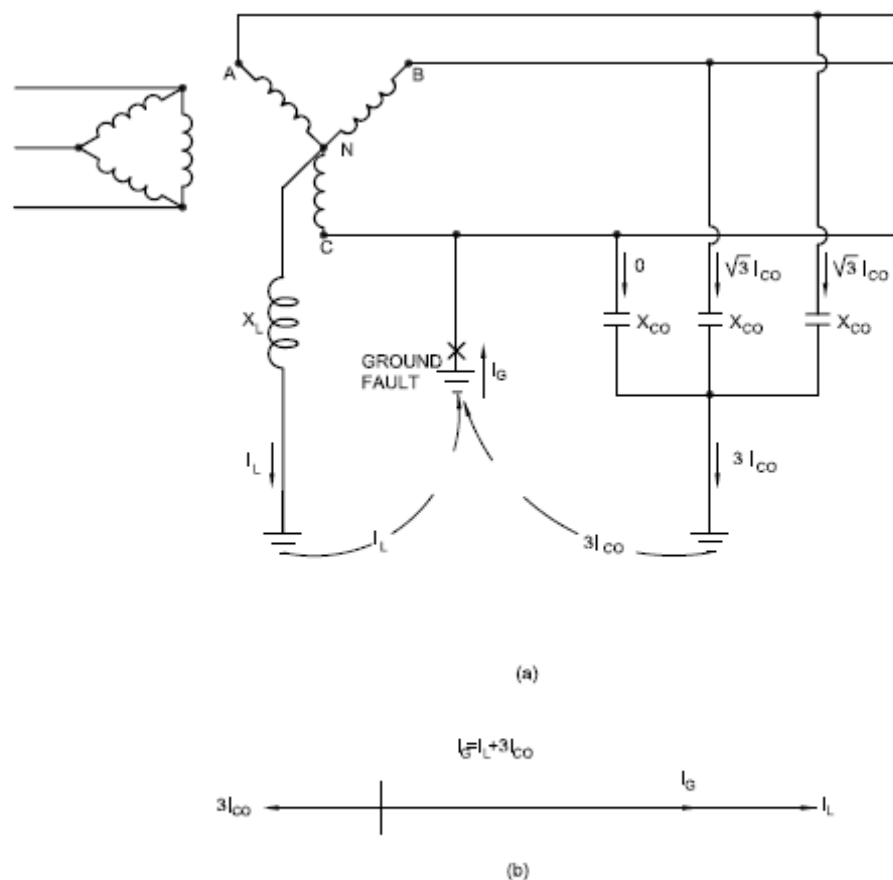


Figure 1-11—Single line-to-ground fault on a low reactance grounded system: (a) circuit configuration, (b) vector diagram

The second instance is where there is a desire to serve single-line-to-neutral-connected load directly at the terminal voltage of generators, i.e., without an intervening generator isolation transformer. In this instance, a current will flow in the generator neutral as a result of unbalance between the loads on the three phases. A resistor in the neutral circuit of the generator will limit the flow of this unbalance, thereby limiting the ability of the system to carry unbalanced single-phase load. Medium-voltage generators are typically not designed to withstand the unbalanced mechanical forces associated with supplying ground-fault currents that exceed the magnitude of current that the machine would produce to a three-phase fault at its terminals, thereby making solid grounding of the neutral undesirable. Use of low-reactance grounding to limit the ground-fault magnitude to a level slightly lower than the three-phase level is a way to resolve these application constraints. The conditions that favor low-reactance grounding of generators are relatively rare, so this practice is somewhat obscure.

1.4.5 Resonant grounding (ground-fault neutralizer)

A ground-fault neutralizer is a reactor connected between the neutral of a system and ground. The reactor, X_L , is specially selected, or *tuned*, to resonate with the distributed capacitance, X_{CO} of the system so that a resulting ground-fault current is resistive and low in magnitude. A resistance, r , is shown depicting reactor losses. The resulting ground-fault current is in phase with the line to neutral voltage so that current zero and voltage zero occur simultaneously. If the ground fault is in air, such as an insulator flashover, it may be self-extinguishing. ~~relatively high value of reactance. The reactance is tuned to the system charging current so that the resulting ground fault current is resistive and of a low magnitude. This current is in phase with the line to neutral voltage, so that current zero and voltage zero occur simultaneously. If the ground fault is in air, such as an insulator flashover, it may be self-extinguishing. This method of grounding is used primarily on systems above 15 kV, consisting largely of overhead transmission or distribution lines. Since systems of such construction are rarely used in industrial or commercial power systems, the ground fault neutralizer finds little application in these systems. For further information on the use of ground fault neutralizers, see Reference [9].~~

Operation of a ground-fault neutralizer is explained with reference to Figure 1-12. The distributed capacitance per phase is assumed to be balanced. When one phase of the system is grounded (assume phase C) a line-to-neutral voltage, V_{cn} , is impressed across the reactor. This produces a lagging inductive current, I_L , that flows from the neutralizer through the transformer, to the fault, then to the ground. At the same time a leading capacitive current, $3 I_{CO}$, flows from the two unfaulted lines through the capacitance to ground and to the fault. The lagging current from the inductor and the leading current from the distributed capacitance are practically 180° out of phase. By properly tuning the reactor (selecting the right tap), the inductive and capacitive components of current can be made to neutralize each other, leaving only a relatively small component of resistive current, I_r , to flow in the fault.

This method of grounding formerly was occasionally seen in high-voltage transmission practice. Today, it is rarely encountered in North America. There are a few instances in which it has been applied for generator grounding in large central stations, especially in the New England area. However, it is relatively common in electric utility distribution practice in the UK and Europe. A key requirement is that because the resonant circuit must be retuned if the distributed parameters of the associated circuit are changed, the ideal application is one that does not involve frequent circuit switching or reconfiguration.

1.4.6 Solid grounding

Solid grounding refers to the connection of a system conductor, usually the neutral of a generator, power transformer, or grounding transformer directly to ground, without any intentional intervening impedance. However, both the impedance of the source and the unintentional impedance in the connection to ground must be considered when evaluating the grounding. Two examples of solidly grounded systems are shown in Figure 1-13.~~Because of the reactance of the grounded generator or transformer in series with the neutral circuit, a solid ground connection does not provide a zero impedance neutral circuit. If the reactance of the system zero-sequence circuit is too great with respect to the system positive sequence reactance, the objectives sought in grounding, principally freedom from transient overvoltages, may not be achieved. This is rarely a problem in typical industrial and commercial power systems~~

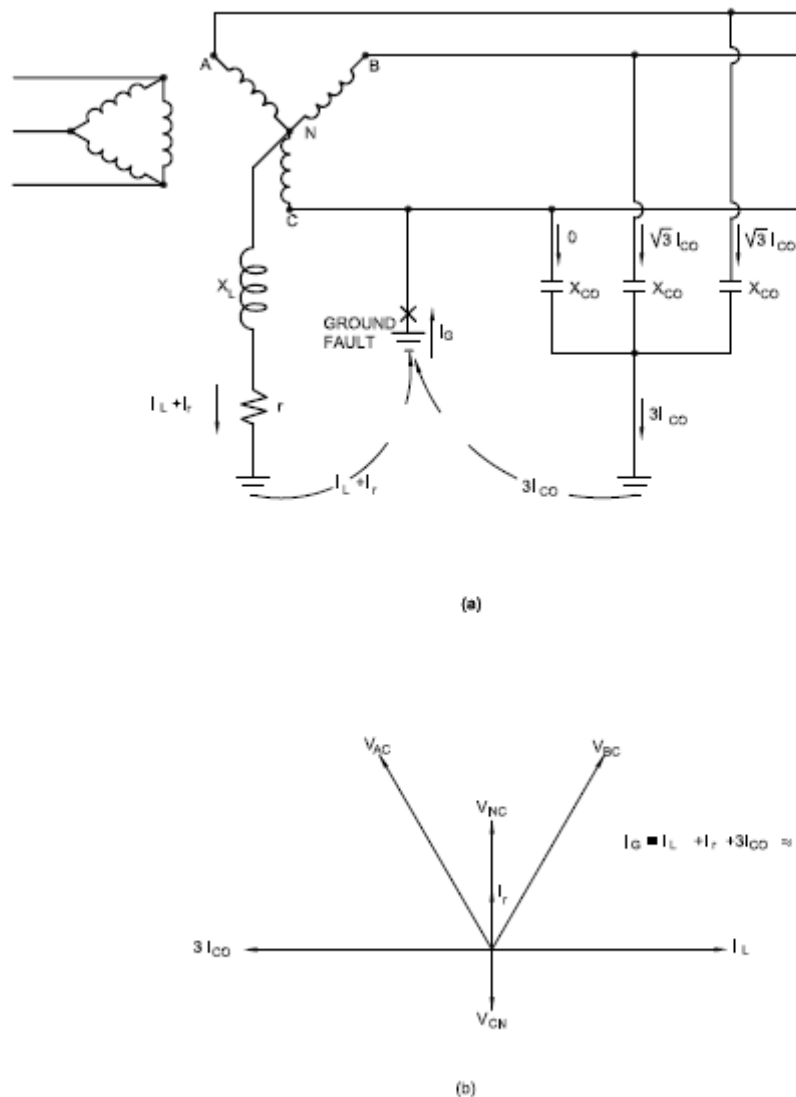


Figure 1-12—Single line-to-ground fault on a resonant grounded system:
(a) circuit configuration, (b) vector diagram

To assess the benefits of a solid connection to ground, it is necessary to determine the degree of grounding provided in the system. A good guide in answering this question is the magnitude of ground-fault current as compared to the system three-phase fault current. The higher the ground-fault current in relation to the three-phase fault current, the greater the degree of grounding in the system. Effectively grounded systems will have a line-to-ground short-circuit current of at least 60% of the three-phase, short-circuit value. In terms of resistance and reactance, effective grounding of a system is accomplished only when $R_0 \leq X_1$ and $X_0 \leq 3X_1$ and such relationships exist at all points in the system. The X_1 component used in the above relation is the Thevenin equivalent positive-sequence reactance of the complete system including the subtransient reactance of all rotating machines. The R_0 component is primarily three times the resistance of the connection to ground.

Because the reactance of a solidly grounded generator or transformer is in series with the neutral circuit (see Figure 1-1), a solid connection does not provide a zero impedance circuit. If the reactance of the system zero-sequence circuit is too great with respect to the system positive-sequence reactance, the objectives sought in grounding, principally freedom from transient overvoltages, may not be achieved. If R_0 is too high it may not create transient voltages, but it may also not provide desired suppression of voltage to ground on the unfaulted phases.

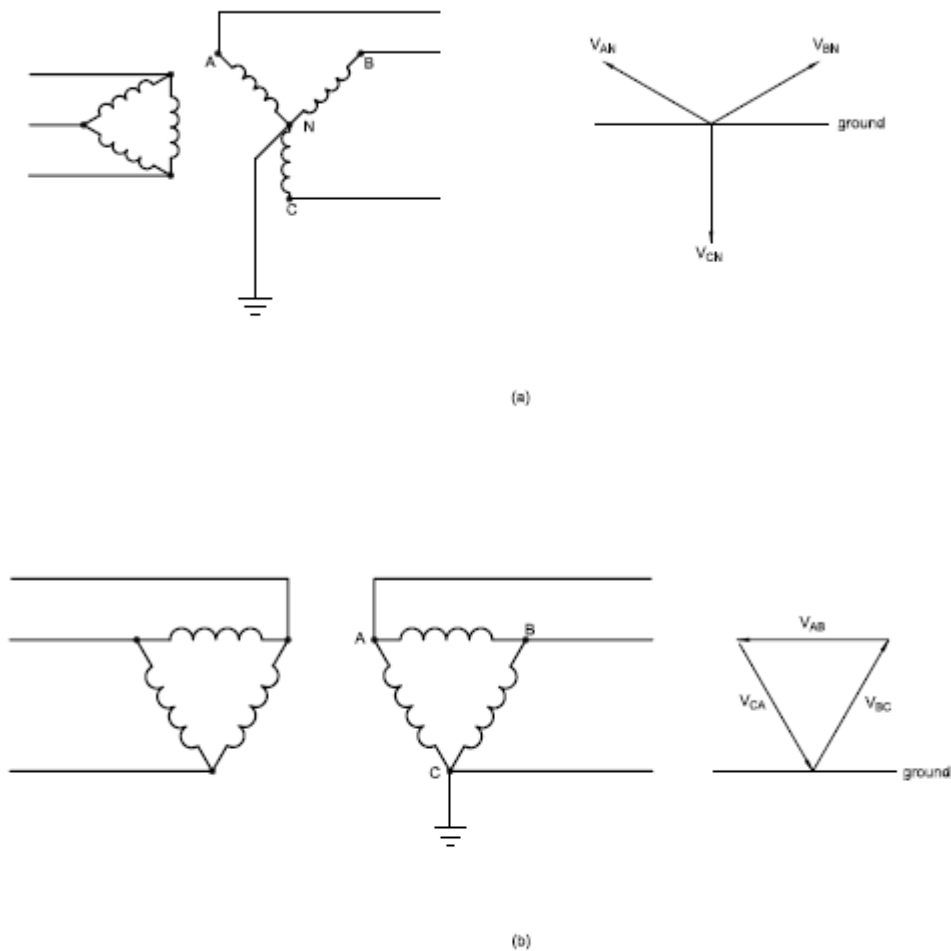


Figure 1-13—Solidly grounded systems: (a) grounded wye, (b) corner grounded delta

This is rarely a problem in typical industrial and commercial power systems. A sufficiently low resistance to earth may be difficult to achieve, but the “ground” to which faults occur will be the bonded conductive electrical enclosures. The zero-sequence impedance of most generators used in these systems is much lower than the positive-sequence impedance of these generators. The zero-sequence impedance of a delta-wye transformer will not exceed the transformer’s positive-sequence impedance. There are, however, conditions under which relatively high zero-sequence impedance may occur.

One of these conditions is a power system fed by several generators and/or transformers in parallel. If the neutral of only one source is grounded, it is possible for the zero-sequence impedance of the grounded source to exceed the effective positive-sequence impedance of the several sources in parallel.

Another such condition may occur where power is distributed to remote facilities by an overhead line without a metallic ground return path. In this case, the return path for ground-fault current is through the earth, and even though both the neutral of the source and the non-conducting parts at the load may be grounded with well-made electrodes, the ground return path includes the impedance of both of these ground electrodes. This impedance may be significant. Another significant source of zero-sequence impedance is the large line-to-ground spacing of the overhead line.

Solid grounding is generally recommended for the following:

a) Low-voltage systems (600 V and below) where automatic isolation of a faulted circuit can be tolerated or where capability is lacking to isolate a ground fault in a high-resistance grounded system.

b) Medium- or high-voltage systems (above 15 kV) in order to permit the use of equipment with insulation levels to ground rated for less than line to line voltage.

c) Medium- or high-voltage applications where the desire for a higher magnitude of ground-fault current in order to be able to provide selective ground-fault detection on lengthy distribution feeders outweighs concerns about arc flash and potential gradients as personnel hazards in a workplace setting.

1.4.7 Characteristics of grounding methods

The advantages and disadvantages of the various methods of grounding are summarized in Table 1-1.

Table 1-1—Characteristics of grounding methods

	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. ²	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. ²

~~To ensure the benefits of solid grounding, it is necessary to determine the degree of grounding provided in the system. A good guide in answering this question is the magnitude of ground fault current as compared to the system three phase fault current. The higher the ground fault current in relation to the three phase fault current the greater the degree of grounding in the system. Effectively grounded systems will have a line to ground short circuit current of at least 60% of the three phase short circuit value. In terms of resistance and reactance, effective grounding of a system is accomplished only when $R_0 \leq X_1$ and $X_0 \leq 3X_1$ and such relationships exist at any point in the system. The X_1 component used in the above relation is the Thevenin equivalent positive sequence reactance of the complete system including the subtransient reactance of all rotating machines.~~

1.5 Obtaining the system neutral

The best way to obtain the system neutral for grounding purposes in three-phase systems is to use source transformers or generators with wye-connected windings. The neutral is then readily available. Such transformers are available for practically all voltages except 240 V. On new systems, 208Y/120 V or 480Y/277 V, wye-connected transformers may be used to good advantage instead of 240 V. Wye-connected source transformers for 2400 V, 4160 V, and 13 800 V systems are available as a standard option, whereas 4800 V and 6900 V, wye-connected source transformers may be priced at a premium rate. The alternative is to apply grounding transformers.

1.5.1 Grounding transformers

System neutrals may not be available, particularly in many older systems rated 600 V or less and in many existing 2400 V, 4800 V, and 6900 V systems. When existing delta connected [or ungrounded](#) systems are to be grounded, grounding transformers can be used to obtain a neutral. The most commonly used grounding transformers ~~may be of either~~ are the zigzag and wye-delta, ~~or the T-connected~~ type.

1.5.1 Corner of the Delta Systems

~~Low-voltage systems, which in the past have been nearly all supplied from transformers with delta-connected secondaries, have been ungrounded. Grounding of one phase corner of the delta grounding has sometimes been used as a means of obtaining a grounded system. The advantages are the following:~~

~~It is the least costly method of converting an ungrounded delta system to a grounded system. This method was adapted by one very large industrial company in 1935 for their older plants. No problems have been reported and it is still in use. The first costs of a new transformer are approximately the same for either a delta or a wye secondary connection.~~

~~2) Although motor overload protection, theoretically, is needed only in the two phases that are not grounded, the NEC Table 430-37 states that for three phase systems, three overloads are required, one in each phase. The advantage in the past of having only two overloads is no longer viable.~~

~~3) With properly connected control circuits, ground faults in the control circuit will neither start the motor nor prevent stopping the motor by means of the stop push button.~~

~~4) There is a high probability of sustaining arcing for 480 V or higher, phase to phase, single phase circuit extension, without escalation to a three phase fault.~~

~~5) The corner grounded system will effectively control transient and overvoltages; however, a maximum of 1.73 times the normal phase to neutral voltage can exist between two conductors and the ground~~

~~6) A fault from phase to ground is easily detected and found. The disadvantages are the following:~~

~~1) An inability to supply dual voltage service for lighting and power loads.~~

~~2) The necessity of positive identification of the grounded phase throughout the system to avoid connecting meters, fuses, instruments, and relays in the grounded phase.~~

~~3) A higher line to ground voltage on two phases than in a neutral grounded system.~~

~~4) The possibility of exceeding interrupting capabilities of marginally applied circuit breakers, because for a ground fault, the interrupting duty on the affected circuit breaker pole exceeds the three phase fault duty. Because of its limitations, this type of grounding has not been widely used in industrial systems~~

1.5.2 Zigzag grounding transformers

One type of grounding transformer commonly used is a three-phase zigzag transformer with no secondary winding. The internal connection of the transformer is illustrated in Figure 1-14(1). The impedance of the transformer to balanced three-phase voltages is high so that when there is no fault on the system, only a small magnetizing current flows in the transformer winding. The transformer impedance to zero-sequence voltages, however, is low so that it allows high ground-fault currents to flow. The transformer divides the ground-fault current into three equal components; these currents are in phase with each other and flow in the three windings of the grounding transformer. The method of winding is seen from Figure 1-14(1) to be such that when these three equal currents flow, the current in one section of the winding of each leg of the core is in a direction opposite to that in the other section of the winding on that leg. This tends to force the ground-fault current to have equal division in the three lines and accounts for the low impedance of the transformer-to-ground currents.

A zigzag transformer may be used for effective grounding, or an impedance can be inserted between the derived neutral of the zigzag transformer and ground to obtain the desired method of grounding. This transformer is seldom employed for medium-voltage, high-resistance grounding. An example of low-resistance grounding is shown in Figure 1-14(2). The overcurrent relay, 51G, is used to sense neutral current that only flows during a line-to-ground fault.

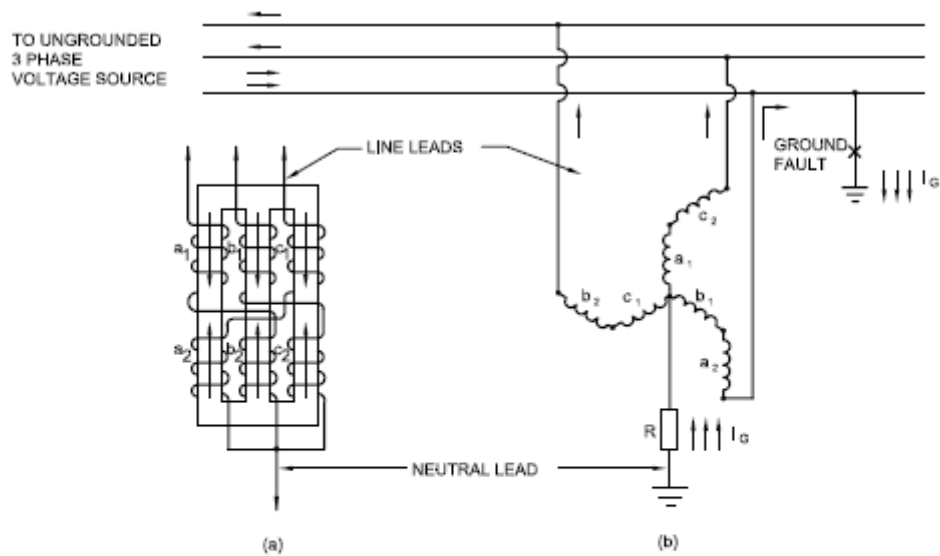


Figure 1-14(1)—Zigzag grounding transformer: (a) core windings, (b) system connection

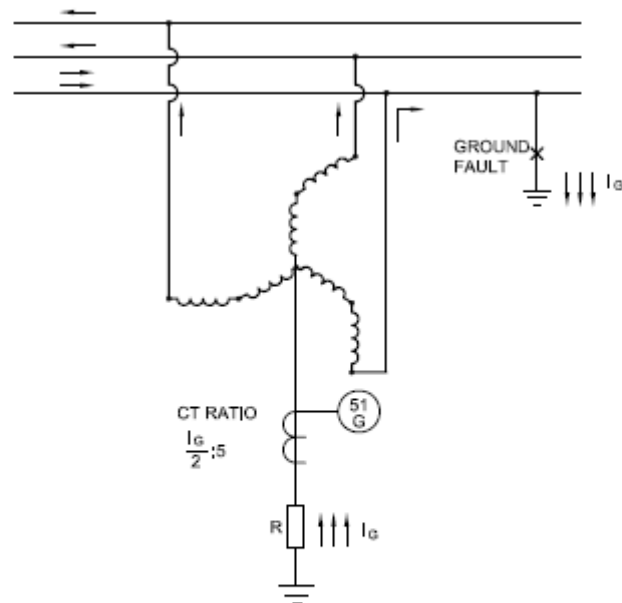


Figure 1-14(2)—Low-resistance grounding of system through a zigzag grounding transformer with neutral sensing current relay

1.5.3 Wye-delta grounding transformers

A wye-delta connected three-phase transformer or transformer bank can also be utilized for system grounding, as shown in Figure 1-15(a) and Figure 1-15(b). As in the case of the zigzag transformer, it can be used for effective grounding or to accomplish resistance-type grounding of an existing ungrounded system. The delta connection must be closed to provide a path for the zero-sequence current, and the delta voltage rating is selected for any standard value. A resistor inserted between the primary neutral and ground, as shown in Figure 1-15(a) and Figure 1-15(b), provides a means for limiting ground-fault current to a level satisfying the criteria for resistance-grounded systems. For this arrangement, the voltage rating of the wye winding need not be greater than the normal line-to-neutral system voltage. A neutral sensing current relay, 51G, is shown for detection of a single line-to-ground fault. For high-resistance grounding it is sometimes more practical or economical, as illustrated in Figure 1-16, to apply the limiting resistor in the secondary delta connection. For this configuration the grounding bank must consist of three single-phase transformers with the primary wye neutral connected directly to ground. The secondary delta is closed through a resistor that effectively limits the primary ground-fault current to the desired low level. For this alternative application, the voltage rating of each of the transformer windings forming the wye primary should not be less than the system line-to-line voltage.

The rating of a three-phase grounding transformer or bank, in kilovoltampere (kVA), is equal to the rated line-to-neutral voltage in kilovolts times the rated neutral current (see *Electrical Transmission and Distribution Reference Book*). Most grounding transformers are designed to carry their rated current for a limited time only, such as 10 s or 1 min. Consequently, they are much smaller in size than an ordinary three-phase continuously rated transformer with the same rating.

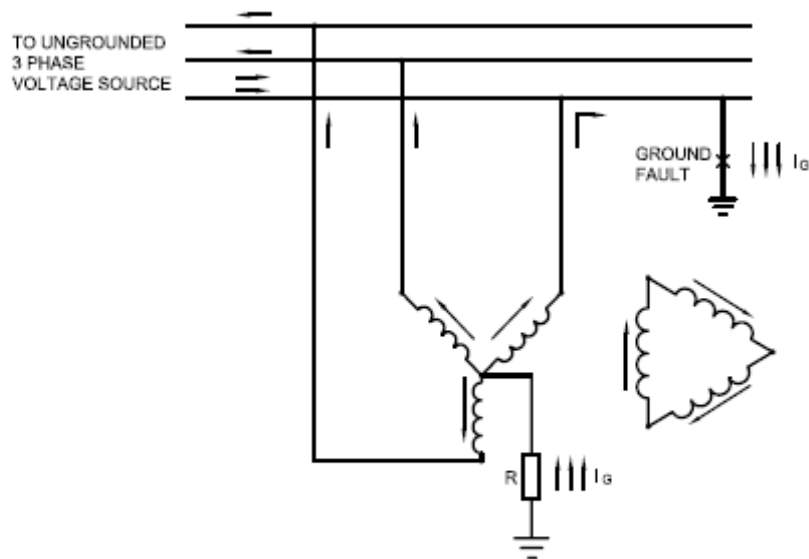


Figure 1-15(a)—Wye-delta grounding transformer showing current flow

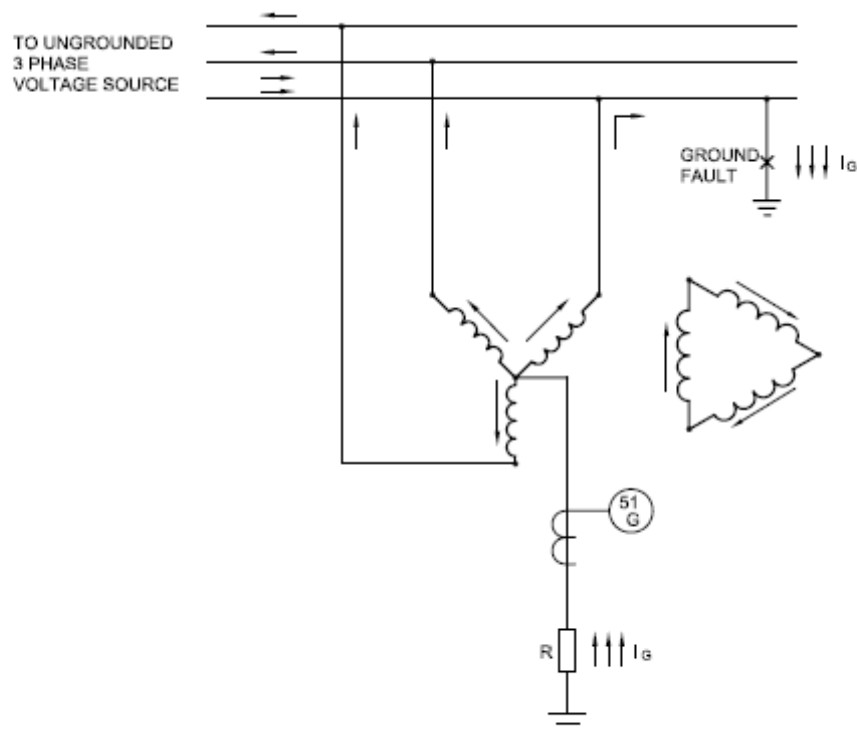


Figure 1-15(b)—Low-resistance grounding of system through a wye-delta grounding transformer with neutral sensing current relay

It is generally desirable to connect a grounding transformer directly to the main bus of a power system, without intervening circuit breakers or fuses, to prevent the transformer from being inadvertently taken out of service by the operation of the intervening devices. (In this case the transformer is considered part of the bus and is protected by the relaying applied for bus protection.) Alternatively, the grounding transformer should be served by a dedicated feeder circuit breaker, as shown in part a) of Figure 1-17, or connected between the main transformer and the main switchgear, as illustrated in part b) of Figure 1-17. If the grounding transformer is connected as shown in part b) of Figure 1-17, there should be one grounding transformer for each delta-connected bank supplying power to the system, or enough grounding transformers to assure at least one grounding transformer on the system at all times. When the grounding transformer is so connected, it is included in the protective system of the main transformer.

1.5.4 Grounding at points other than system neutral

In some cases, low-voltage systems (600 V and below) are grounded at some point other than the system neutral to obtain a grounded electrical system. This is done because delta transformer connections do not provide access to the three-phase system neutral. Two systems are in general use.

1.5.5 Corner-of-the-delta grounded systems

Some low-voltage, ungrounded systems, have been conceived, as shown in part b) of Figure 1-13, using delta connected supply transformers with no readily available neutral grounding. Because of its limitations, this type of grounding is no longer popular and is not widely used in industrial systems.

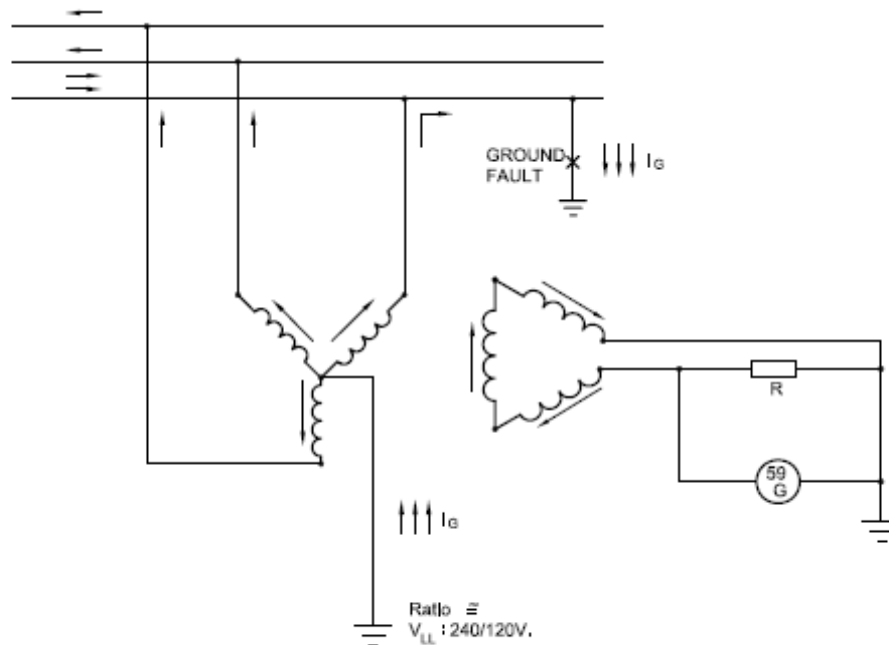


Figure 1-16—High-resistance grounding of system through a wye-broken delta grounding transformer with neutral sensing voltage relay

1.5.6 One phase of a delta system grounded at midpoint

In some areas where the utility has both a single-phase 120/240 V load and three-phase 240 V loads, they have supplied a larger single-phase 120/240 V transformer and one or two smaller 240 V transformers, all connected in delta with the midpoint of the 120/240 V grounded for a 240/120 V three-phase four-wire system. This provides neutral grounding for the single-phase 120/240 V and also grounding for the 240 V three-phase system. It is not recommended for voltages over 240 V.

The advantages of this type of grounding scheme are as follows:

- a) First cost for transformers and fuses can be less than for separate single transformer and three-phase systems.
- b) Mid-phase grounding effectively controls, to safe levels, the transient overvoltages to ground.
- c) These diverse loads can be served from a single service.

The disadvantages are as follows:

- 1) The shock hazard of the high phase leg to ground is 208 V, which is 1.73 times the voltage of a neutral grounded 240 V system. Since this voltage can appear across a single pole of a breaker, 277 V rated breakers may be required.
- 2) There must be positive identification of the conductor with the highest voltage to ground to avoid connecting 120 V loads to that conductor.
- 3) The fault currents on the single-phase system may be higher than normally expected for the size of the system, possibly requiring higher rated panelboards.

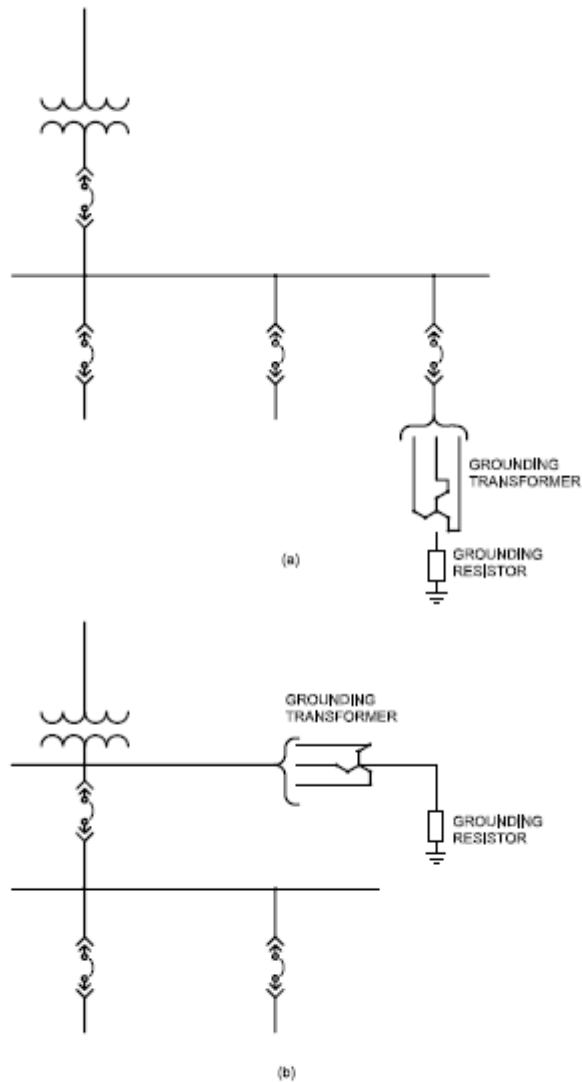


Figure 1-17—Connection of grounding transformers in delta connected or ungrounded power system to obtain neutral for system grounding:
(a) circuit feeder breaker, (b) connected between main transformer and main switch gear

1.6 Location of system grounding points

1.6.1 Selection

Each system as described in this chapter is characterized by its isolation from adjacent grounding systems. The isolation is provided by transformer primary and secondary windings. The NEC defines such a system as “separately derived.” A separately derived system is one “whose power is derived from a generator, transformer, or Therefore, the new system created by a transformer or generator requires the establishment of a new system ground if it is required or desired that this system be grounded. See Figure 1-4 for an example of grounding each separately derived system. The system ground point should always be at the power source as required or permitted by the NEC, including exceptions for multi-source systems.~~generator requires the establishment of a new system ground.~~

1.6.2 Transformer configurations ~~Single Power Source~~

There are two requirements that must be met for a transformer to provide a system ground. The first requirement is fairly intuitive: the transformer winding at the voltage where a ground is desired must be connected in wye (sometimes referred to as *star* in European practice). The wye is essential to provide a neutral point that can be connected to earth; a delta winding does not present a neutral point and therefore there is no electrical connection that could be connected to earth for the purpose of establishing a ground reference for the system. Alternatively, transformers with windings connected in the interconnected star or zigzag configuration also provide a neutral point that can be grounded.

~~When a system has only one source of power (generator or transformer), grounding may be accomplished by connecting the source neutral to earth either directly or through a neutral impedance (Fig 6).~~

The second requirement is a bit more involved. Table 1-1 lists a number of options for the mode of system grounding; in order for these options to exist, the impedance of the transformer to ground-fault current must be significantly lower than the impedance of the connection between the neutral and earth such that this neutral impedance governs the selection of grounding mode. The *Electrical Transmission and Distribution Reference Book* provides a good theoretical background for this statement. Essentially, however, this requirement translates into a requirement that the transformer contain a second winding that is connected in delta. Thus, a transformer that is intended to provide a system ground must provide a wye-connected winding at the voltage of the system to be grounded, and must also contain a delta winding. The most common configuration that meets this requirement in industrial and commercial applications is a transformer that has a delta- connected primary winding and a wye-connected secondary winding.

Wye-wye transformers alone cannot be used to ground industrial and commercial power systems. In special cases it is possible to use wye-wye transformers that are equipped with delta-connected tertiary windings to provide system grounding. This arrangement can be designed for low-resistance grounding as well as effective grounding. It is also possible to use wye-connected autotransformers provided they also have a delta-connected tertiary winding, although this is a relatively uncommon practice and should only be used to provide effective (solid) grounding—applying a neutral grounding resistor between ground and the neutral of an autotransformer can lead to undesirable neutral voltage excursions.

It is also a relatively common practice to use wye-wye transformers with special five-leg magnetic cores to serve commercial applications on effectively grounded (utility) distribution systems. This connection is chosen to address concerns with ferroresonance that come about because of single-phase switching (it is a common practice that utility distribution systems use single-point load-break switching devices, typically hook-stick operated), and this connection minimizes concerns with ferroresonance that would otherwise be present in that situation. But rather than provide system grounding itself, what the five-leg core wye-wye transformer does is to provide a continuous path for ground-fault currents from the primary distribution system into the commercial load on the secondary. Therefore, the system ground is actually established by the transformer that supplies the

host distribution system. This practice therefore results in the commercial system also being effectively grounded.

1.6.3 Delta-wye transformer

In a delta-wye connected transformer, with the load-side neutral grounded, zero-sequence components of current can flow in the secondary wye-connected windings due to a ground fault. Zero-sequence current is then induced into the primary windings of the transformer and circulates in the delta connection. Positive and negative-sequence currents pass through the transformer combining to produce high current in two of the primary phase conductors. A ground fault on the secondary of the delta-wye connected transformer appears as a line-to-line fault on the primary. See Figure 1-18.

If the neutral of the wye-connected windings is not grounded, then zero-sequence current cannot flow and the system becomes ungrounded.

Zero-sequence components of current can flow through a wye-wye connected transformer if a neutral path exists on both sides of the transformer. An example is shown in Figure 1-20 where a delta-wye connected transformer, T_1 , supplies power to a wye-wye connected transformer, T_2 . A fault on the load side of T_2 produces zero-sequence current, which flows in the primary and secondary windings of that transformer. Zero-sequence current is permitted to flow in the primary of T_2 because a path exists in the delta-wye connected transformer T_1 . Disconnecting any of transformer neutrals, on either T_1 or T_2 , would prevent the flow of zero-sequence current in both transformers, except as allowed by magnetizing reactance.

Depending upon the connections to the transformer, the use of a wye-wye transformer can result in a single system, or its load side may be a separately derived system. Figure 1-19 and Figure 1-20 show a single system, whereas Figure 1-21 shows a separately derived system.

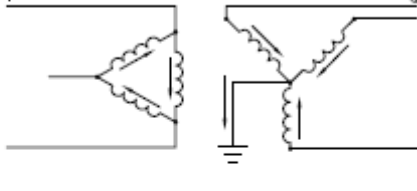
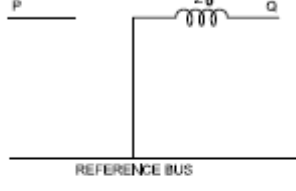
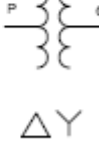
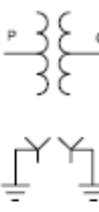
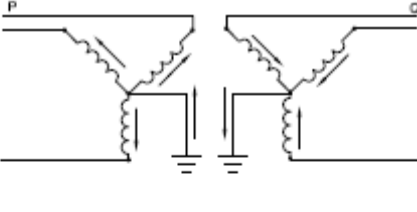
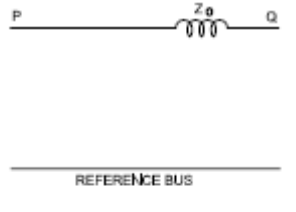
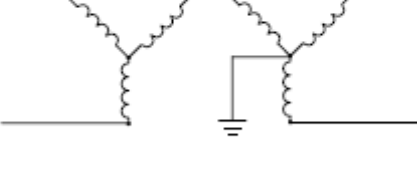
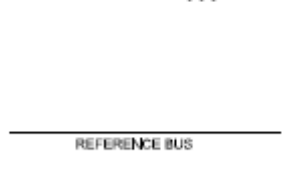
	SYMBOLS	CONNECTION DIAGRAMS	ZERO-SEQUENCE EQUIVALENT CIRCUITS
(a)			
(b)			
(c)			
(d)			

Figure 1-18—Zero-sequence impedance of different transformer configurations

1.6.4 Wye-wye transformers

A wye-wye transformer, T_2 , is shown in Figure 1-20 with the primary and secondary neutrals interconnected and grounded. This transformer configuration is used on solidly grounded utility distribution systems, particularly underground systems, to prevent ferroresonance when the supply switches can be operated one pole at a time. The utilities ground the primary neutral point to minimize the neutral-to-earth voltage throughout the length of the distribution line and by default on underground systems using bare concentric neutral cables. They ground the secondary neutral to provide an effectively grounded low-voltage service. Note that this multiple grounding of the primary at each transformer is not essential to prevent ferroresonance or provide secondary grounding as long as the fourth conductor is brought to the primary neutral of the transformer. The neutral-to-transformer case and ground connection minimizes secondary neutral-to-ground voltage during a fault between primary and transformer case.

³Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

In an industrial distribution system, the physical length of the circuit will usually be short enough so that excessive neutral-to-ground voltages will not be present even if there is no ground at the wye-wye transformer common neutral terminals, as shown in Figure 1-19. The NEC normally prohibits grounding of the neutral on the load side of the service disconnect, but allows multigrounding of the neutral of an outdoor overhead line or direct burial cable with bare neutral if the circuit voltage is over 1000 V.

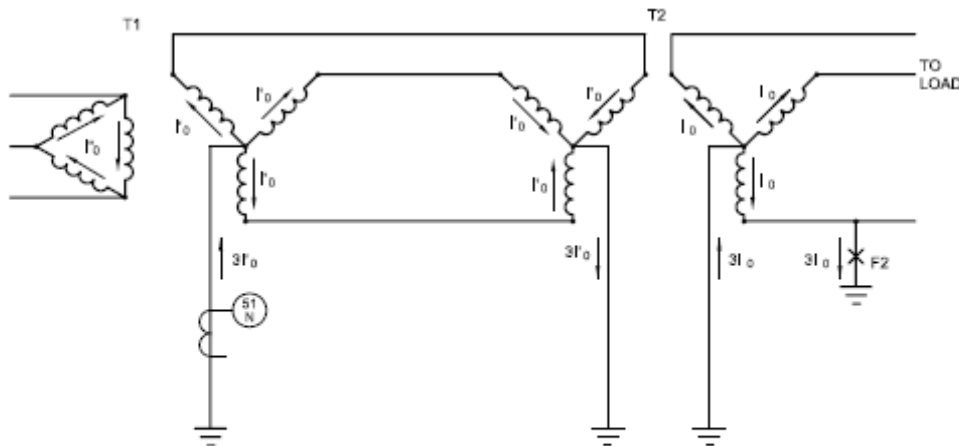


Figure 1-19—Transformer connections illustrating the flow of zero-sequence current resulting from a line to ground fault

As shown in Figure 1-19, with a continuous connection from the source neutral to the primary and secondary neutrals of the wye-wye transformer, the output of the transformer would not constitute a separately derived system as defined in the NEC. If the neutral is grounded at the source, T_1 , the output of the wye-wye transformer will be a continuation of the grounded system, though at the secondary voltage of the transformer. A fault, F_2 , on the load side of the wye-wye connected transformer, T_2 , will produce zero-sequence components of current in its primary windings. This zero-sequence current will flow back to the secondary neutral terminal of source transformer, T_1 . However, this current flowing through 51G cannot determine whether the fault is located before or after the wye-wye transformer, nor can residual or zero-sequence ground detection schemes on the output of T_1 . The main benefit of this transformer connection is to utilize the standard wye-wye transformer that contains an internal primary-to-secondary neutral connection suitable for utility practice as shown in Figure 1-20.

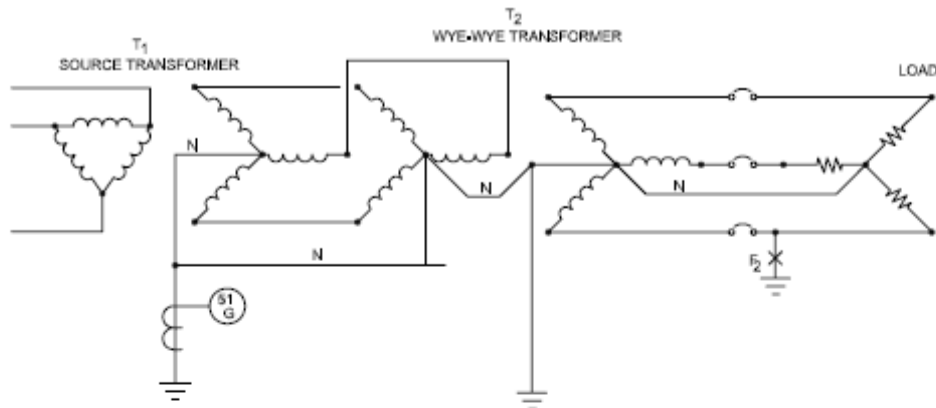


Figure 1-20—Grounded wye-grounded wye transformer with multigrounded common neutral

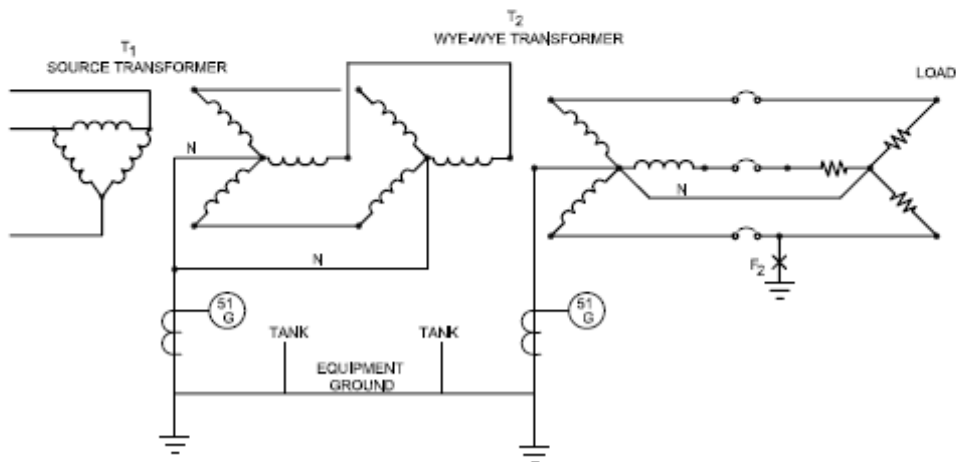


Figure 1-21—Grounded wye-grounded wye transformer with separately grounded neutrals

The circuit supplied by the wye-wye connected transformer shown in Figure 1-21 can be considered a separately derived system, since there are no direct metallic connections between the primary and secondary of the transformer. Primary and secondary ground faults are separately measured and relayed. The secondary of the transformer will not be grounded unless a connection to earth is made. The secondary could be impedance grounded. Secondary neutral grounding will also require a connection from the neutral of the primary source to the primary neutral of the wye-wye transformer to supply zero-sequence current. Unlike the delta-wye transformer, the wye-wye transformer itself is not a source of zero-sequence current. Grounding can be achieved without a primary neutral connection if a phase of the secondary rather than the neutral is grounded, since no zero-sequence current is involved. The effect is then identical to corner grounding of a delta-delta transformer.

If a delta tertiary is added to a wye-wye transformer it will not be necessary to supply zero-sequence current from the primary source, since the tertiary will act as a source of zero-sequence current.

Thus, the wye-wye transformer can be considered a part of a single multi-voltage system if the neutrals are interconnected or can be considered to create a separate system if they are not. The symmetry of the wye-wye allows it to provide grounding for its load-side system even though the source and load side may be interchanged at any time.

1.6.5 Single power source

When a system has only one source of power (generator or transformer), grounding may be accomplished by connecting the source neutral to earth either directly or through a neutral impedance (Figure 1-22). Provision of a switch or circuit breaker to open the neutral circuit is not recommended. It is not desirable to operate the system ungrounded by having the ground connection open while the generator or transformer is in service.

In the event that some means of disconnecting the ground connection is required for measurement, testing, or repair, a disconnecting link should be used and only opened when the system is de-energized.

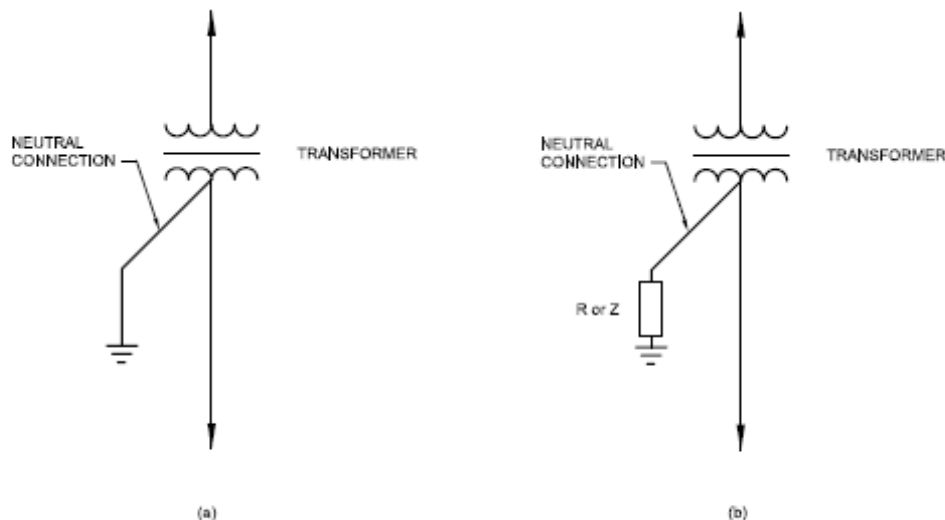


Figure 1-22—Grounding for systems with one source of power: (a) solidly grounded, (b) R or Z grounded.

1.6.6 Multiple power sources

For installation of interconnected multiple power sources (i.e., generators or power transformers), operated in parallel, system grounding can be accomplished using one of the two following methods:

- a) Each source grounded, with or without impedance (Figure 1-23).
- b) Each source neutral connected to a common neutral bus, which is then grounded, with or without impedance (Figure 1-24).

For solidly grounded systems, with multiple sources, where all sources must be solidly grounded, it is acceptable to separately ground each power source as shown in part a) ~~Levels of fault current~~ of Figure 1-23 unless third harmonics are determined by present or if it results in exceeding the number and available fault current capability of each interconnected source. Where sources are in close proximity, Common Ground Point connection [Fig 8(a) will allow for selective relaying to identify and isolate only the faulted source generators. Levels of fault current in systems where generators are paralleled with transformer sources on a four-wire basis must be calculated using symmetrical component sequence values for the sources appropriately combined in the system (see Nichols). Commercial computer programs are now available that will calculate branch currents for unbalanced faults in systems with both utility and generator sources. There can be a significant increase in the total system ground-fault current as compared to the sum of the fault current available from sources when not in a combined system, while the increase in generator currents can be proportionally even greater. Refer to 1.7.3.2.

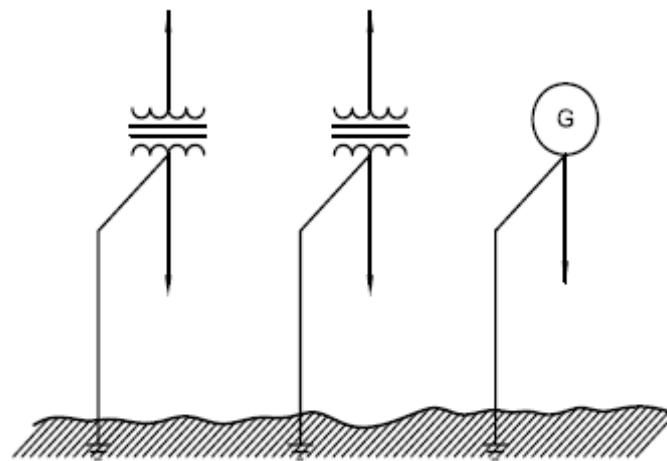
Where sources are in close proximity, or where the system is four wire, the common neutral or ground bus as shown in part a) of Figure 1-24 should be used. In a four-wire system the sources would not be considered as separately derived.

If the power sources are not in close proximity, common ground point is not recommended. The impedance in the neutral bus connection may become large enough to prevent effectively grounding the neutral of the source at the remote location. The interconnection may inadvertently become open, allowing the transformer to operate ungrounded.

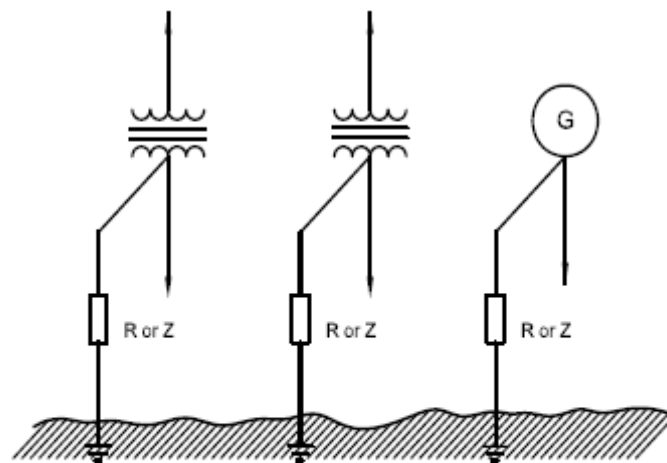
For impedance grounded systems it is acceptable to separately connect each neutral to ground through an individual impedance [part b) of Figure 1-23]. Each impedance rating should allow sufficient current to satisfy the criteria for the grounding system being used. Individual neutral switching devices (automatic or manual) are not recommended, since incorrect operation may allow a power source to operate ungrounded.

System relaying is more complex when ~~such impedance grounding is used, because of~~ there are multiple grounding points. ~~Capability of detecting a ground fault at any point in the system requires sensing at each ground point in addition to any normal feeder protection~~ sources. The fault current sensed by the feeder is variable, depending on the number of ground-fault current sources that are connected at the time of the fault.

When individual source impedances are used for low- or high-resistance grounding, circulation of third-harmonic currents between paralleled generators is usually not a problem since the impedance limits the circulating current to tolerable values. When the total ground-fault current from several individual impedances exceeds about 1000 A, a common ground point and single impedance ~~to limit the fault current~~ should be considered to provide a single acceptable value of ground-fault current [part b) of Figure 1-24]. The advantage of this connection is that the maximum fault current is known, and selective relaying can be used to open tie breakers and selectively isolate the faulted bus



(a)



(b)

**Figure 1-23—Grounding for systems with multiple power sources
(Method 1): (a) solidly grounded, (b) R or Z grounded**

The primary purpose of neutral disconnecting devices in impedance grounded systems, as shown in part b) of Figure 1-24, is to isolate the generator or transformer neutral from the neutral bus when the source is taken out of service, because the neutral bus is energized during ground faults. A generator or transformer disconnected from the power bus, but with an unbroken connection of its neutral to the neutral bus, would have all of its terminals elevated with respect to ground during a ground fault. Disconnecting devices should be metal enclosed and interlocked in such a manner as to prevent their operation except when the transformer primary and secondary switches or generator main and field circuit breakers are open. [On low-voltage systems the use of four-pole breakers may provide adequate interlocking. In this case line-to-neutral voltage should not be used for synchronizing.](#)

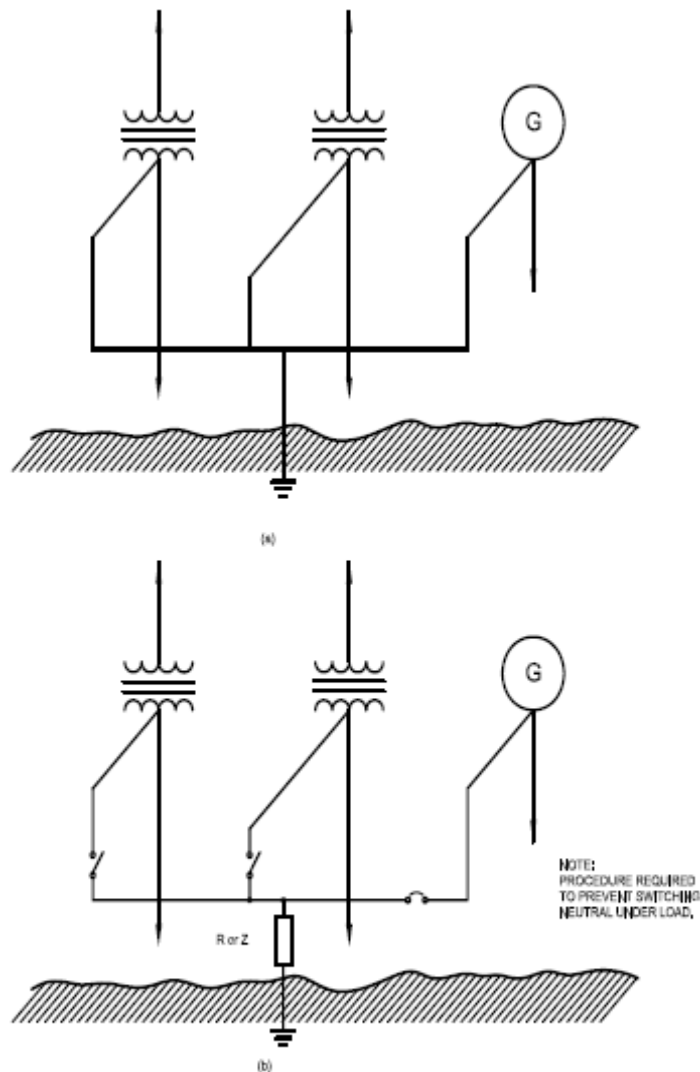


**Figure 1-24—Grounding for systems with multiple power sources
(Method 2): (a) solidly grounded, (b) R or Z grounded**