

IEEE Std 3003.1™-2019

Recommended Practice
for System Grounding of
Industrial and Commercial
Power Systems

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IEEE Recommended Practice for System Grounding of Industrial and Commercial Power Systems

Developed by the

Industrial and Commercial Power Systems Standards Development Committee
of the
IEEE Industry Applications Society

Approved 13 June 2019

IEEE SA Standards Board

Abstract: Discussed in this recommended practice is the system grounding of industrial and commercial power systems. The recommended practices in this document are intended to provide explanations of how electrical systems operate. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Keywords: effectively grounded, ground, grounding system, high resistance ground, IEEE 3003.1™, neutral

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Introduction

This introduction is not part of 3003.1–2019, IEEE Recommended Practice for System Grounding of Industrial and Commercial Power systems.

IEEE 3000 Series®

This recommended practice was developed by the Industrial and Commercial Power Systems Standards Development Committee of the IEEE Industry Applications Society as part of a project to repackage IEEE's popular series of "color books." The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material included in the 13 "color books" will be included in a series of new standards. Approximately 60 "dot" standards, organized into the following categories, will provide in-depth treatment of many of the topics formerly covered in the color books:

- Power Systems Design (3001 series)
- Power Systems Analysis (3002 series)
- Power Systems Grounding and Bonding (3003 series)
- Protection and Coordination (3004 series)
- Emergency, Stand-By Power, and Energy Management Systems (3005 series)
- Power Systems Reliability (3006 series)
- Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a "dot" standard comes from a particular chapter of a particular color book. In other cases, material from several color books has been combined into a new "dot" standard. The material in this recommended practice largely comes from Chapter 1 of IEEE Std 142™-2007.

IEEE Std 3003.1™

This recommended practice covers the system grounding of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

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IEEE Recommended Practice for System Grounding of Industrial and Commercial Power Systems

1. Overview

1.1 Scope

This recommended practice covers the system grounding of industrial and commercial power systems. The basic reasons for grounding or not grounding the electrical system and the various types of system grounding, as well as the practices commonly used to ground electrical systems are discussed.

1.2 Purpose

Grounding of an electrical system is a decision that must be faced by 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 recommended practice to assist the engineer in making decisions 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, institutional, and/or commercial 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. In addition to the general technical considerations in the practice of grounding as discussed in this recommended practice, pertinent codes or standards imposed by local regulatory authorities, the particular needs of service, and the experience and training of the workforce should also be considered. Where an industrial or commercial 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 or commercial setting, conditions of service may be altered by the following:

- a) Location within the power system
- b) Individual generator characteristics
- c) Manufacturing process requirements
- d) Emergency/life safety requirements of the local codes

The standards listed in [Clause 2](#) 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, IEC, or any other location-specific regulatory codes.

The recommended practices in this document are intended to provide explanations of how electrical systems operate. A better understanding of the electrical principles will assist the engineer in implementing the recommendations in a manner that best provides for the needs of a specific design function.

1.3 Covered—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.

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 Not covered—equipment grounding and bonding

The terms grounded and bonded are defined in the CEC, IEC, NESC, and NEC. “Bonding” is the electrical interconnecting of non-current carrying conductive parts designed to achieve a low impedance conductive path. This definition is self-explanatory and implies that the conductive path should be adequately sized, and connections properly installed, in order to maintain a path with impedance as low as possible. The term bonding obviously is not exclusive to grounded systems. “Grounded” means connected to, or in contact with, the earth, or connected to some extended conductive body that serves in place of the earth, whether the connection is intentional or accidental. The earth or the other conductive body is known as the “ground” in North America and areas of the world that use the CEC or NEC, and “earth” in the areas of the world that use the IEC. When used as a verb, “grounding” is the act of establishing the aforementioned connection to ground or the conductive body. When used as an adjective, grounding describes the conductor or metal part that is used to make the connection to ground.

Equipment grounding and bonding is covered in IEEE Std 3003.2™, IEEE Recommended Practice for Equipment Grounding and Bonding in Industrial and Commercial Power Systems.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 60364-1, Electrical Installations of Buildings.

IEEE Std C37.101™, IEEE Guide for Generator Ground Protection.

IEEE Std 367™, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.

IEEE Std 3003.2™, IEEE Recommended Practice for Equipment Grounding and Bonding in Industrial and Commercial Power Systems.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹

3.1 Grounding terminology as used worldwide

earth: *See:* **ground.**

earthed: *See:* **grounded.**

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

equipment grounding conductor (EGC): *See:* **protective conductor.**

exposed-conductive-parts (ECP): A conductive part, forming part of electrical equipment, which can be touched (even if out of reach) and not live, but likely to become live when basic insulation fails. ECPs are required to be connected to the same earthing system individually, in groups or collectively, via a protective conductor.

extraneous-conductive-part (EXCP): A conductive part, not forming part of the electrical installation, and liable to introduce an electric potential, generally the electric potential of a local earth/ground.

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. This term is considered equivalent to the term “earth”.

ground (earth) electrode: Conductive part, which may be embedded in a specific conductive medium (e.g., concrete or coke) in electric contact with the earth.

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

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.

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.

high-resistance grounded: A resistance grounded system designed to limit ground-fault current to a value that can be allowed to flow for an extended period of time, 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.

¹IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>.

local ground (local earth): Part of the ground (earth) which is in electric contact with a ground (earth) electrode, whose electric potential is not necessarily equal to zero.

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.

neutral point: Common point of a star-connected polyphase system or earthed mid-point of a single-phase system.

neutral conductor: The conductor connected to the neutral point of a system that is intended to carry current under normal conditions.

per-phase charging current (ICO): The current (V_{LN}/X_{C0}) that passes through one phase of the system to charge the distributed capacitance per phase-to-ground of the system.

protective conductor: The conductor provided for protective functions, such as providing a path for fault current to flow back to the source, for connecting exposed-conductive-part ECPs, such as non-current carrying metal parts of equipment, raceways, and other enclosures to earth, etc. There are often specific names for this conductor, such as “equipment grounding conductor (EGC)” in the NEC, “protective earth conductor (PE)” in the IEC, and “bonding conductor (BC)” in the CEC.

protective earth neutral (PEN): A conductor that combines the functions of the protective conductor and the neutral conductor, used in some IEC grounding systems.

R_0 : The per phase zero sequence resistance of the system.

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

remote (or reference) ground (earth): Part of the ground (earth) considered as conductive, whose electric potential is conventionally taken as zero, being outside the zone of influence of any earthing arrangement.

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

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” by the parallel circuit consisting of inductance (L) and capacitance (C). This happens when,

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

R_G : Value of the resistance-to-earth of an electrode that grounds a point of the electrical source of a system (e.g., the neutral point of a transformer). It is not a resistance intentionally inserted. *See also: solidly grounded.*

R_N : Value of the resistance-to-earth of a neutral grounding resistor.

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.

solidly grounded: System in which at least one neutral point is grounded (earthed) directly, with no intentional device having a resistance/impedance designed to limit the line-to-ground short-circuit current.

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

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

system charging current: The total distributed capacitive charging current ($3 V_{LN}/X_{C0}$) of a three-phase system.

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 for the purpose of conducting load current.

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.

touch voltage: The difference in potential between metallic objects or structures within the substation site that may be bridged by direct hand-to-hand or hand-to-feet contact.

transient overvoltage: The temporary overvoltage 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.

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

V_{LN} : The line-to-neutral voltage.

X_{C0} : The distributed per-phase capacitive reactance to ground of the system.

X_0 : Zero-sequence reactance of the system.

X_1 : Positive-sequence reactance of the system.

X_2 : Negative-sequence reactance of the system.

3.2 IEC system grounding terminology

Rather than using dual terminology throughout this recommended practice, basic system grounding nomenclature from the International Electrotechnical Commission (IEC) as found in IEC 60364-1, is provided in this section for relation to the concepts presented in the remainder of this document.

When discussing what in North America is called grounding, of primary importance is the understanding that the term for ground in much of the world is earth (E). Translated to French, earth is terre (T) and for system definitions equates to a solidly grounded system. Systems without a direct connection to earth (ungrounded) or connected through a sufficiently high impedance are called isolated (I). T or I may be used in the first of two positions of an IEC system grounding configuration to indicate source grounding. T may also be found in the second position indicating a direct connection to earth at the device being supplied. Neutral (N) in the second position indicates connection to ground via the supply network.

3.2.1 TT systems

TT (Terre-Terre) systems are defined as the electrical systems whose devices being supplied are connected to ground electrodes electrically independent of the ground electrodes of the source (e.g., the local utility) [Figure 1](#).

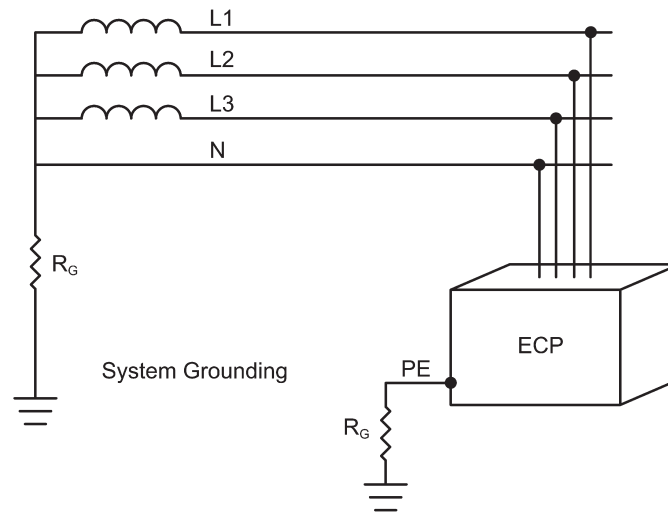


Figure 1—TT system

This is the grounding method adopted for low-voltage systems (i.e., not exceeding 1 kV) supplying dwelling units in several countries, to list a few: Algeria, Belgium, Denmark, Egypt, France, Greece, Italy, Japan, Kenya, Luxemburg, Morocco, Tunisia, Spain, Portugal, Turkey, United Arab Emirates, etc.

3.2.2 TN system

TN (Terre-Neutral) systems are defined as the electrical systems whose ECPs are directly connected by a protective conductor to the solidly grounded point of the source (e.g., the neutral point [Figure 2](#)). Of note; connection of the PE to individual ECPs may intentionally or unintentionally provide additional connections to earth throughout the system. The different arrangements of neutral and protective conductors determine three types of TN system. In TN-S systems [Figure 2](#), also as in typical industrial and commercial applications, two separate wires are used as protective and neutral conductors, throughout the system.

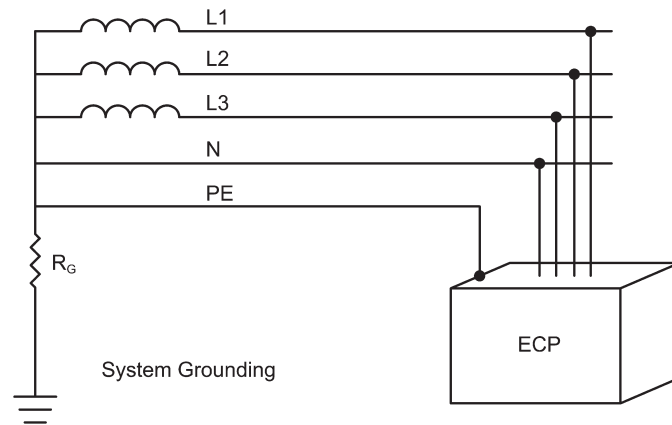


Figure 2—TN-S system

In TN-C systems, the functions of the neutral conductor and of the PE are combined in the PEN conductor throughout the system [Figure 3](#). This is a configuration typical of utilities in North America, but not a recommended practice for industrial and commercial power systems.

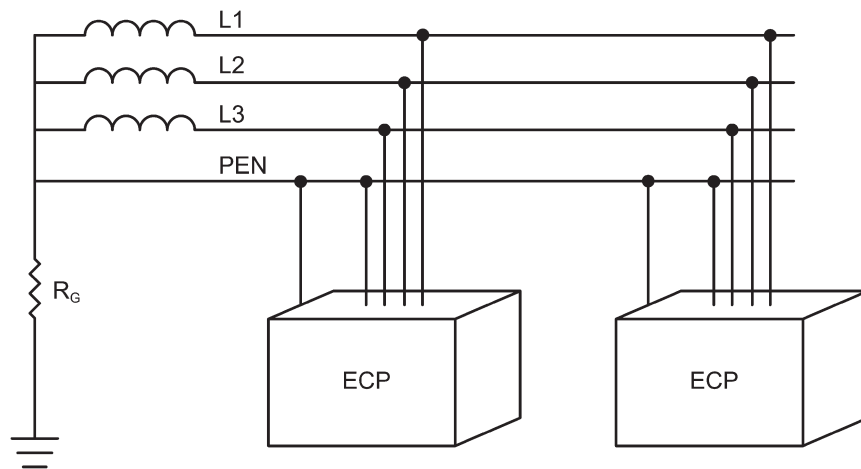


Figure 3—TN-C system

In TN-C-S systems, the functions of the neutral conductor and of the PE are combined in a single conductor in a part of the system. Such conductor is referred to as protective earthed neutral (PEN). When the earthing point is provided to low-voltage users by a utility network, the TN-C-S system is also referred to as protective multiple earthing (PME) as shown in [Figure 4](#). In North America, the transition point from PEN to PE is typical of the utility to user interface with inclusion of an electrode for an intentional connection to earth at the service entrance.

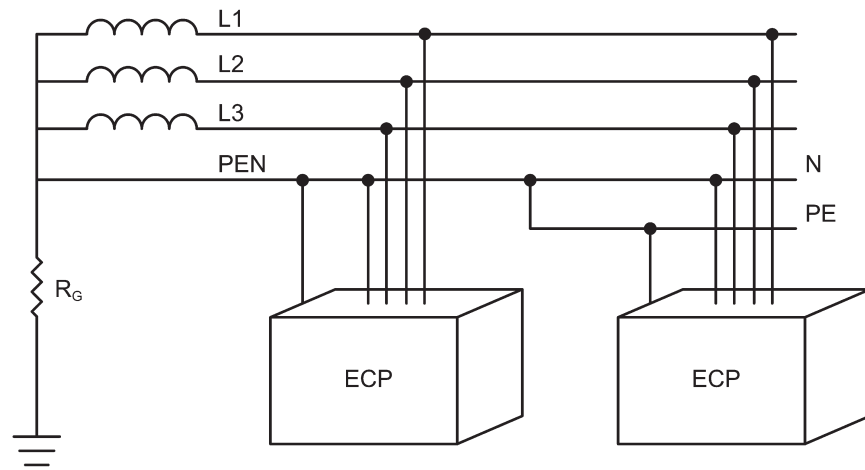


Figure 4—TN-C-S system

3.2.3 IT system

Isolation terre (IT) systems are defined as the electrical systems whose source is insulated from ground or connected to it through sufficiently high impedance. In this arrangement it is advisable, although not prohibited, to omit the neutral wires to loads in order to safeguard its isolation from ground.

In the event of a first fault between a line conductor and an ECP, or earth, fault currents can still flow due the distributed capacitance to ground of the electrical system. Such currents are relatively low in intensity, but may be sufficient to cause harmful touch voltages. Thus, in order to limit such hazard, ECPs are required to be earthed individually, in groups, or collectively as shown in [Figure 5](#) and [Figure 6](#).

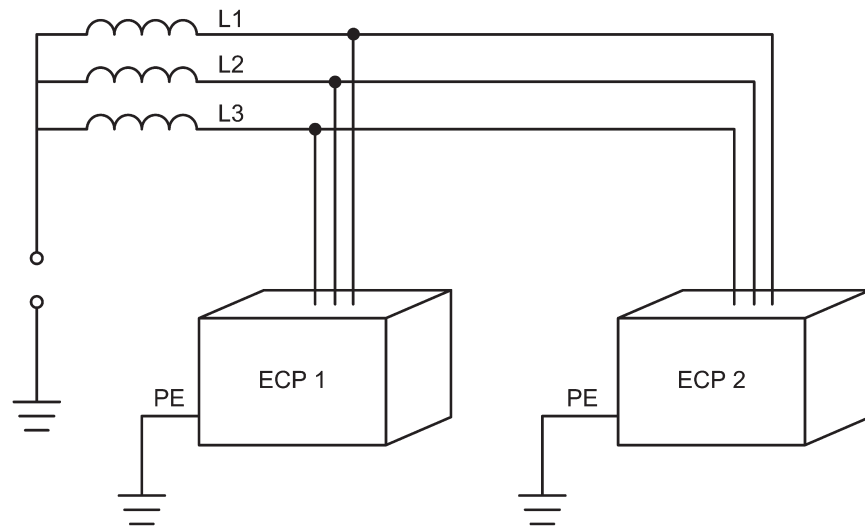


Figure 5—ECPs earthed individually in IT systems

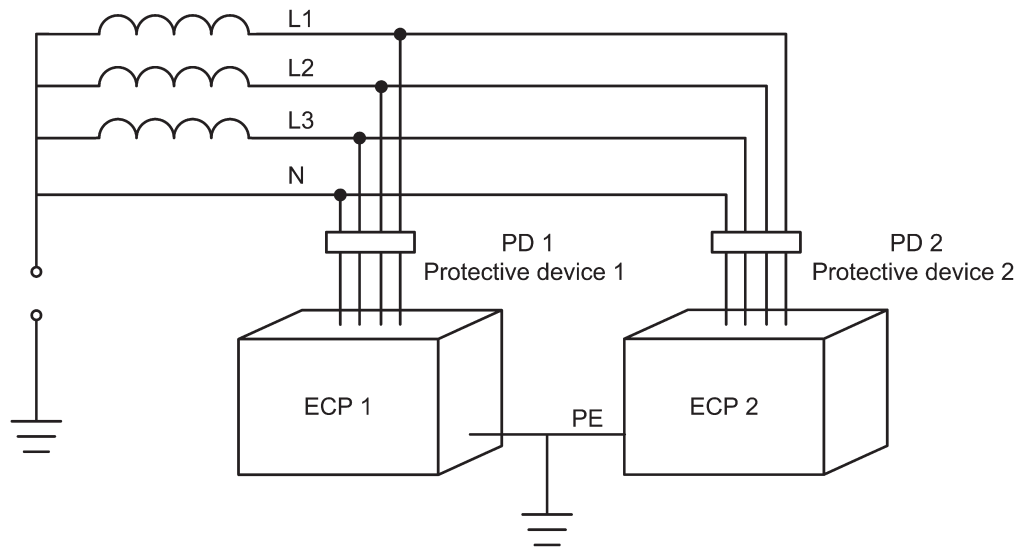


Figure 6—ECPs earthed collectively in IT systems

4. Methods of system neutral grounding

4.1 Introduction

Most electrical systems employ some method of grounding the system neutral at one or more points. Similar to the IEC T and I designations, 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 7 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. For additional clarity, see the definition of “effectively grounded.”

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 a text on symmetrical components for power systems, several of which are listed in the bibliography.

Molded-case circuit-breaker interrupting capabilities can be affected by the method of grounding. If other than solidly grounded wye systems are used, the circuit breakers’ single-pole interrupting ratings should be evaluated for the application [B20].

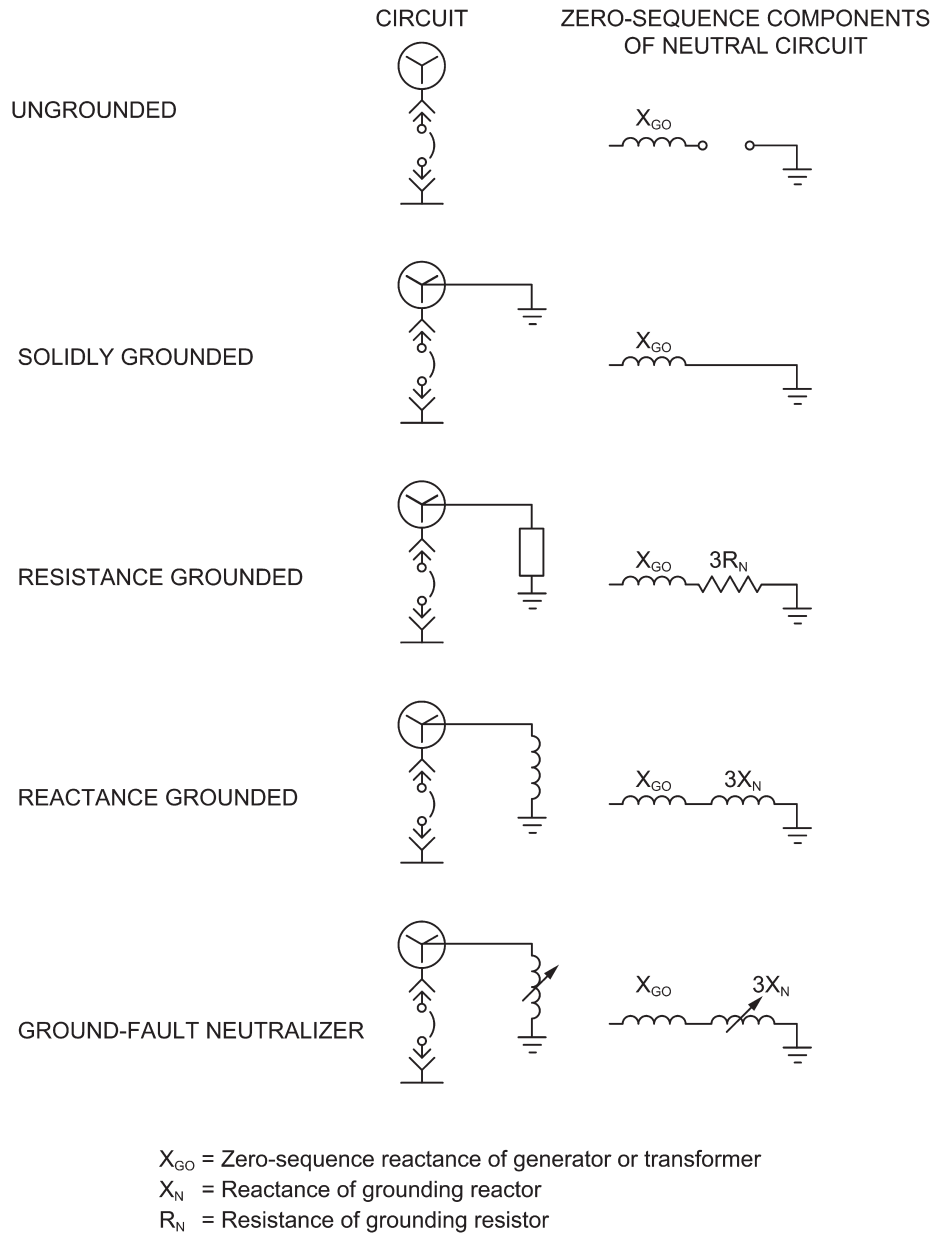


Figure 7—System neutral circuit and equivalent diagrams for ungrounded and grounded systems

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 8, there always exists a capacitive coupling between one system conductor and another, as well as between system conductors and ground. By virtue of the distributed capacitance from the system conductors to ground, the so-called ungrounded system is in reality a capacitance grounded system. 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_{C0} , is assumed to be balanced.

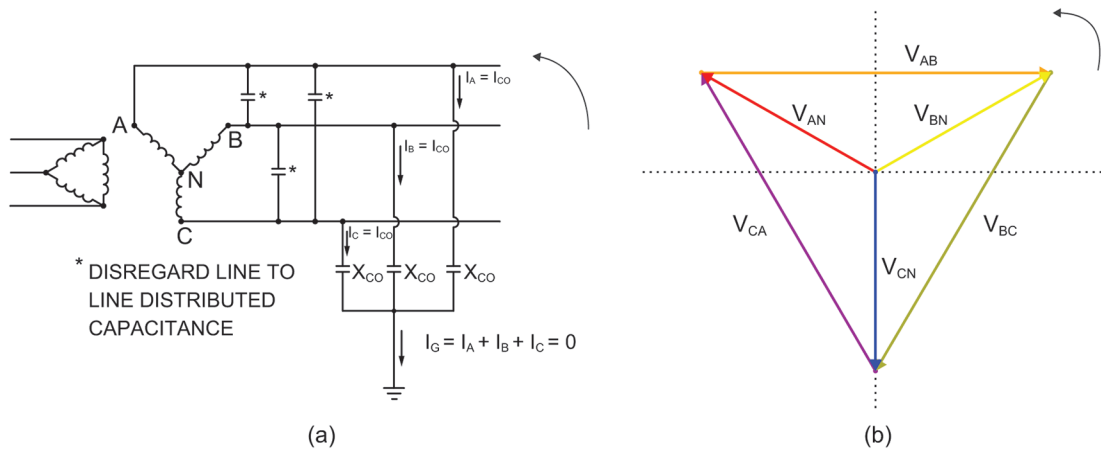


Figure 8—a) Ungrounded system circuit configuration, b) Voltage phasor diagram

In normal operating conditions, with balanced three-phase voltages applied to the lines, the capacitive charging current, I_{C0} , in each 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 phasor relationships can be determined. 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 increase from line-to-neutral to line-to-line. The capacitive charging current, I_{C0} , in the two phases without a fault will therefore increase by the square root of 3. As shown in Figure 9, the line-to-ground voltages are no longer 120° , but 60° apart. This causes the excessive terminal voltages during faults, along with the absence of a neutral conductor, precludes support of line-to-neutral loads on an ungrounded system.

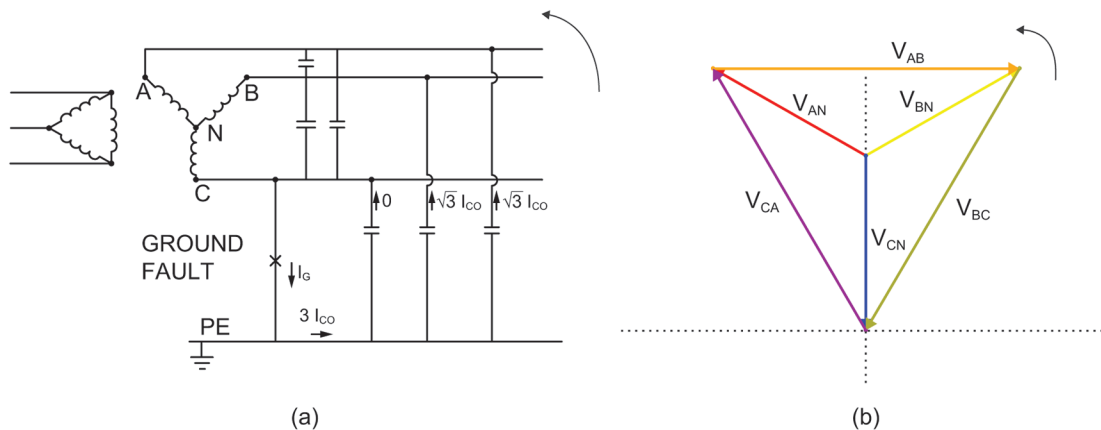


Figure 9—a) Single line-to-ground fault on an ungrounded system, b) Voltage phasor diagram

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° .