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142™

IEEE Recommended Practice for

Grounding of Industrial and Commercial Power Systems

Published by the
Institute of Electrical and
Electronics Engineers, Inc.

IEEE Std 142™-2007
(Revision of
IEEE Std 142-1991)

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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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Print: ISBN 0-7381-5639-2 SH95700
PDF: ISBN 0-7381-5640-X SS95700

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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 70[1] particular needs of service and the experience and training of the workforce should also be considered.

[1]Information on references can be found in 1.16.

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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

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.

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 not greater than 3, and the ratio of zero-sequence resistance to positive-sequence reactance (R_0/X_1) is positive and not greater 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.

[2]The numbers in brackets correspond to those of the bibliography in 1.17.

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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 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 $R_0 < X_{co}$, 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.

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.

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.

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,

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

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,

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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 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 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 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.

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

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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 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.

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