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IEEE Recommended Practice for Grounding of DC Equipment Enclosures in Traction Power Distribution Facilities

IEEE Vehicular Technology Society

Sponsored by the
Rail Transportation Standards Committee

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New York, NY 10016-5997
USA

IEEE Std 1653.6™-2018
(Revision of IEEE Std 1653.6-2013)

IEEE Recommended Practice for Grounding of DC Equipment Enclosures in Traction Power Distribution Facilities

Sponsor

Rail Transportation Standards Committee of
the
IEEE Vehicular Technology Society

Approved 23 October 2018

IEEE-SA Standards Board

Abstract: The grounding of dc equipment enclosures installed in dc traction power distribution facilities as well as related insulation treatments required for solid and resistance grounding methods are covered in this standard. Guidelines are also given for material, installation, and testing of insulation used in dc traction facilities and further recommended criteria for acceptability are provided. System grounding, though related, is not covered in this document.

Keywords: 64, 64GS, 64HS, 64M, 64MR, bonding, building enclosure, dc, dc circuit breakers, device 64, diode ground, direct current, distribution facilities, electric trolley bus, enclosure ground, equipment enclosure, equipment ground, ETB, floor insulation, ground, ground protection, ground relay, grounded structure, grounding, GS, heavy rail, high resistance, high-resistance grounding, hot structure, HS, IEEE 1653.6™, insulation dielectric test, insulation testing, light rail, low resistance, low-resistance grounding, low-voltage equipment, negative return, rail transit, rectifier, single-point grounding, switchgear, system grounding, traction power,

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The Institute of Electrical and Electronics Engineers, Inc.
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PDF: ISBN 978-1-5044-5308-0 STD23407
Print: ISBN 978-1-5044-5309-7 STDPD23407

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Introduction

This introduction is not part of IEEE Std 1653.6™-2018, IEEE Recommended Practice for Grounding of DC Equipment Enclosures in Traction Power Distribution Facilities.

This document contains recommended practices for grounding and bonding of dc equipment enclosures installed within traction power distribution facilities where the conventional practice in most dc traction power systems is to isolate both the positive and negative poles from ground. There exists a variety of system grounding methods, including single-point grounding, positive- or negative-pole grounding, resistive grounding, diode grounding, etc; however, details on system grounding and related applications, e.g., stray current control, rail-to-ground protective relay devices, are not covered by the scope of this document. For additional information regarding transit power systems grounding, refer to IEEE Std 142™, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.[a, b, c]

The necessity of this recommended practice stems from the lack of uniformity of enclosure grounding practices in the dc traction industry. Furthermore, grounding of dc traction equipment enclosures is not covered in the National Electric Code® (NEC®) [B4][d] or the National Electrical Safety Code® (NESC®) [B1]. As such, the goal of this document is to provide users with the various grounding methods used specifically for grounding dc traction equipment enclosures and preparing dc traction distribution facilities when implementing these grounding methods.

The organization of this document follows a typical equipment layout within a dc traction distribution facility. The main clauses include ac equipment enclosures, dc equipment enclosures, floor insulation, and wall insulation. Refer to Figure a.

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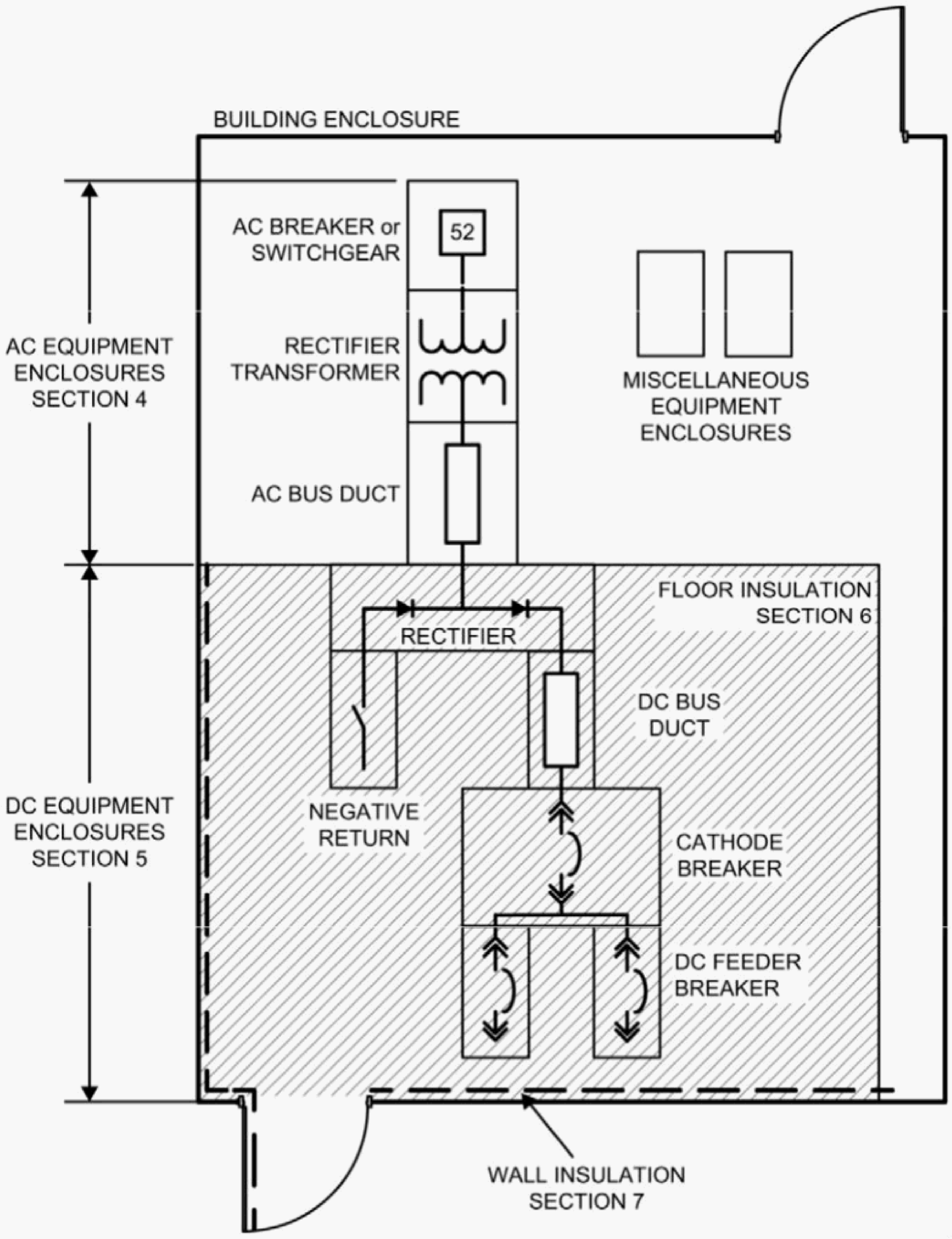

Figure a—Typical dc traction power distribution facility

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IEEE Recommended Practice for Grounding of DC Equipment Enclosures in Traction Power Distribution Facilities

1. Overview

1.1 Background

Grounding of dc equipment enclosures in dc traction power substations include many features not found in ac power distribution systems. The practices and methods vary throughout the industry in the United States and other parts of the world. It is appropriate that the practices be documented with input from the designers, users, and manufacturers as grounding practices and methods are essential for the protection of equipment and proper operation of dc traction power substations.

1.2 Scope

This document includes recommended practices for grounding of dc equipment enclosures installed in dc traction power distribution facilities. DC distribution facilities may include, but are not limited to, traction power substations, tie breaker stations, gap breaker stations, section huts, cross-tie substations, circuit breaker houses, and equalizer houses.

1.3 Purpose

This document provides recommended practices for grounding dc equipment enclosures to system designers, transit authorities, system operators, and manufacturers of dc traction power distribution facilities.

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.

IEEE Std 142™, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.[1, 2]

IEEE Std 80™, IEEE Guide for Safety in AC Substation Grounding.

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.[3]

building enclosure: A built-in-place or prefabricated structure composed of walls, roof, floor, and structural base in which distribution equipment is typically installed.

earth ground: Reference potential as in a driven ground rod.

equipment enclosure: Box-like structures that in traction power distribution facilities may contain electrical equipment such as switchgear, circuit breakers, transformers, rectifiers, communication equipment, busbar, and switches.

transfer trip: A protective trip function initiated by local devices that sends a trip command to breakers located at adjacent traction facilities for purposes of de-energizing circuit breakers feeding into the same power section as the local breakers where the trip command originated.

4. AC equipment enclosures

The enclosures of all metal-clad or metal-enclosed ac switchgear and transformers in traction power distribution facilities should be grounded in accordance with IEEE Std 142 and IEEE Std 80.[4] The enclosures of all other metallic objects that contain ac power wiring, such as bus enclosures, battery chargers, ac panelboards, and light fixtures should be grounded, except for those installed in dc equipment enclosures discussed in the clauses to follow.

5. DC equipment enclosures

5.1 Background on dc equipment enclosures

DC equipment in traction power substations, which commonly consists of the rectifier enclosure, dc bus enclosures, and dc switchgear, can be solidly grounded, high-resistance grounded, or low-resistance grounded. Each method is described in this clause.

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5.2 NEC requirements

In accordance with NEC Article 90.2(B)(1), installation for railways for generation, transformation, transmission, and distribution of power used exclusively for the operation of rolling stock are not covered by the NEC® [B4].[5]

5.3 Solid grounding

Solidly grounded dc enclosures are connected to earth ground through the bonding of neighboring equipment, building structure, and grounded electrodes with no intentional impedances installed between the enclosure and ground.

The operation of solidly grounded equipment relies on the presence of very low-impedance connections between equipment enclosures and ground in order to minimize voltage potentials during normal operation and during fault conditions.

Due to the low operating voltage and correspondingly high operating current, particular attention must be paid to providing an adequate earthing system and bonding conductor size. Insufficiently sized conductors may simply fuse (open circuit) and allow the affected equipment enclosure to elevate to the system voltage. An earthing system that exhibits excessive resistance may raise an entire building to the system voltage. If the fault is remote from the supply, as is often the case in transit systems, conductor resistance may limit currents below feeder breaker trip settings and the fault may continue indefinitely.

An enclosure fault to railway negative may go almost totally unnoticed. Over time, the fault may cause earthing electrodes to be rendered ineffective by stray current corrosion. A negative fault may also cause enough current to flow to ground such that equipment bonds melt unnoticed and inadvertently isolate the equipment from safety grounds.

As a result, it is generally not recommended to solidly ground positive polarity dc equipment enclosures due to the high-energy nature of dc faults and the fact that some ground faults can be low in magnitude and not detectable by overcurrent protective devices.

Freestanding negative polarity equipment enclosures and negative bus duct enclosures may or may not be grounded.

5.4 High-resistance enclosure grounding

5.4.1 Background on high-resistance enclosure grounding

High-resistance grounding is performed by isolating dc equipment enclosures from ground through the use of insulation and connecting the equipment chassis to ground through a high-resistance protective relay device. This is shown in Figure 1.

[5] The numbers in brackets correspond to those of the bibliography in Annex B.

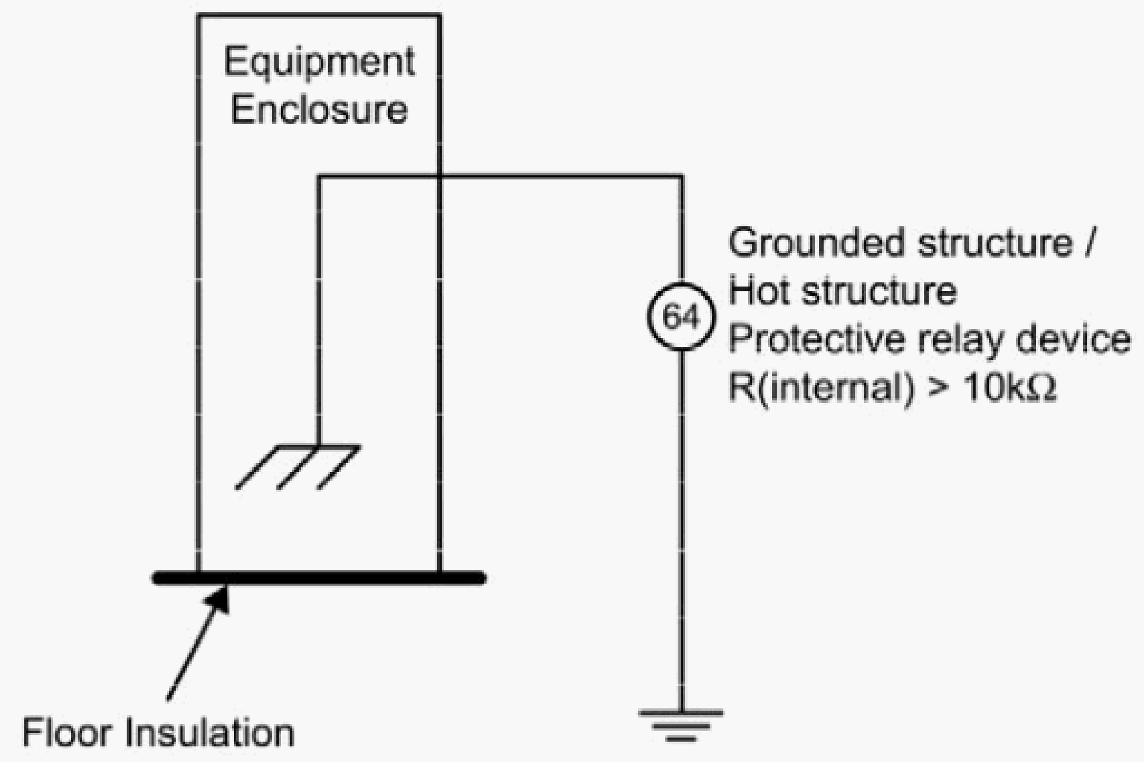

Figure 1—High-resistance grounding schematic

Protective relays function by applying a small dc voltage on the structure at all times and continuously monitoring the voltage on the enclosure. In the event that the measured voltage rises above its high-voltage trigger during a hot structure fault or diminishes below the low-voltage trigger during a grounded structure fault, the 64 device initiates output signals in accordance with protective schemes implemented for the device.

High-resistance grounding was developed when the industry recognized that injury to personnel and damage to equipment due to faults could be minimized by not grounding dc enclosures. Since fault currents in high-resistance grounded enclosures are limited to below 1 A or less during a positive-to-enclosure fault, there is little to no damage to wiring, components, or equipment. Repairs can be made at very little cost, and equipment can be quickly restored to service once the fault condition has been removed. However, the potentially high voltages necessitated the development of methods to protect personnel by designing equipment that could tolerate being energized to full system voltage during an enclosure fault. These methods also included the development of relay schemes that could detect an energized structure as well as unintentionally grounded structures in the event of a fault. Refer to 5.4.2 for recommended protection schemes.

As with any grounding design and installation, special care must be taken when high-resistance grounding is used as the insulation may be subjected to rated voltage. An accidental bridging of the insulation, due to metallic artifacts such as metal debris, is capable of bypassing the protective circuit.

5.4.2 Protection

Protection practices for high-resistance grounding depend primarily on the operating procedures of a transit agency. Some agencies may decide to only monitor hot or grounded structure faults and trigger an alarm. Others may decide to trip traction power ac and dc breakers upon a hot structure fault event. Regardless of the protection scheme, the protective device should feature outputs that indicate when a hot or grounded structure fault occurs. These outputs should then be used to employ the preferred protection scheme of the agency.

The recommended protection scheme for high-resistance grounding is to trip the ac breaker feeding the rectifier transformer, dc cathode breaker, and dc feeder breakers upon a hot structure fault. Some systems also employ transfer tripping of dc breakers located at adjacent substations because of the possibility that an enclosure fault may be fed from the load side of a local feeder breaker. For grounded structure faults, an alarm should be annunciated to a local alarm panel at minimum. Protective relaying should be applied to dc-positive switchgear enclosures, dc-negative enclosures not solidly grounded, and dc-bus duct enclosures.

5.4.3 Device number and nomenclature

IEEE Std C37.2 [B3] defines the ground detector relay as device number 64. This device number has been adopted by the transit industry for the high-resistance ground protective relay but is typically used in conjunction with a variety of different suffixes. Common suffixes include 64M for "Monitoring," which provides only annunciation of a grounded structure or hot structure fault; 64MR for "Monitoring/Relay," which provides not only annunciation but also trips feeder breakers; 64HS for "Hot Structure," and 64GS for "Grounded Structure." For purposes of standardization, the recommended nomenclature for high-resistance ground protective relays is to use an "HS" or "GS" suffix with the 64 device for "hot structure" or "grounded structure" respectively.

5.5 Low-resistance enclosure grounding

5.5.1 Background on low-resistance enclosure grounding

Low-resistance grounding is performed by bonding enclosures through a bidirectional diode current sensing device with a ground protective relay monitoring the fault status of the enclosure. In addition, dc equipment enclosures are isolated from ground to reduce the chance of inadvertent bridging of the ground detection circuit, as shown in Figure 2.

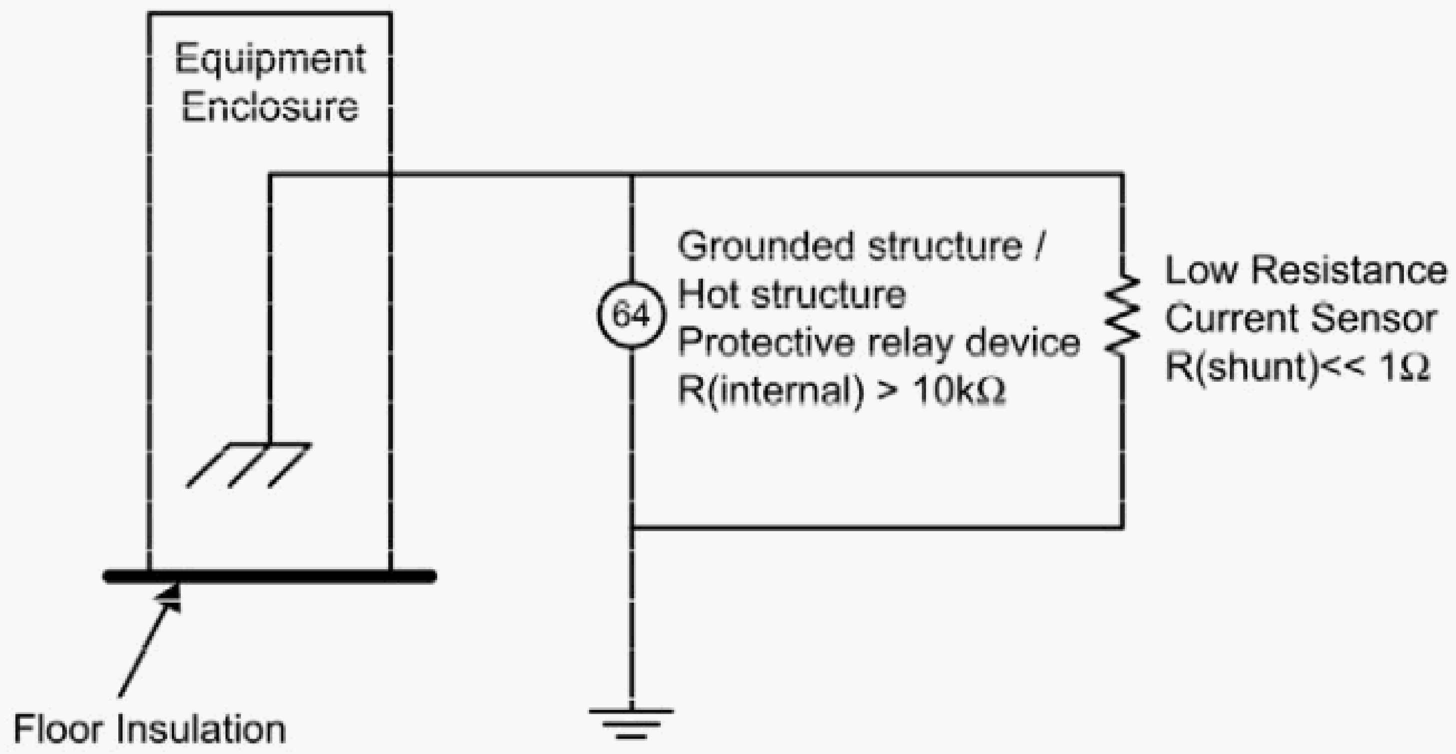

Figure 2—Low-resistance grounding schematic

Fault detection in a low-resistance grounding scheme is similar to high-resistance grounding in that a small voltage is maintained on the structure at all times and continuously monitored by the protective relay. But unlike the high resistance scheme, the voltage from a hot structure fault only elevates to the voltage drop across the current sensing device, and the voltage potential on the structure is typically less than five volts to ground. In the event that the measured voltage rises above its voltage trigger during a hot structure fault or diminishes below the low-voltage trigger during a grounded structure fault, the 64 device initiates alarms and sends trip signals to circuit breakers in accordance with the protective scheme implemented for the device.

Low-resistance grounding has the benefit of limiting voltage potential on equipment enclosures for personnel, but the high-fault currents that result can cause damage to equipment, including steel panels, structural members, and copper bars. Ground conductors should be sized to sustain the maximum dc fault for 0.25 s while maintaining a continuous ground path to allow for protective devices to clear the fault.

5.5.2 Protection

The protection scheme as described in 5.4.2 can also be applied for low-resistance ground protective relays.

5.5.3 Device number and nomenclature

The device number described in 5.4.3 can also be applied for low-resistance ground protective relays.

6. Floor insulation practices

6.1 Background on floor insulation practices

Facilities utilizing either high- or low-resistance grounding methods should employ insulated floors under and surrounding dc equipment. Floors are insulated for the purpose of isolating ungrounded (low- or high-resistance grounded) equipment within the proximity of the equipment from ground. In masonry and prefabricated type substations, epoxy is commonly used for insulating material, although fiberglass laminates and rubber mats have also been used.

The dielectric properties of floor insulation material should be capable of withstanding the voltage limits indicated in 6.2. Mechanical properties of the insulation should have compressive, tensile and impact strengths suitable for the equipment being installed. Particular consideration should be made for abrasion resistance to withstand steel-wheeled traffic from breaker trucks and other switchgear equipment that frequently roll across the floor. Insulation should also be non-porous and have little moisture absorption to limit electrical tracking across the floor.

As for installation, insulation should extend horizontally at a minimum 1.83 m (6 ft) beyond insulated enclosures. In cases where open space clearances are obstructed by surrounding equipment enclosures, such as walls, doors, or other equipment enclosures, the application of wall insulation as described in Clause 7 is recommended for all grounded surfaces and enclosures within the clearance area.

6.2 Dielectric withstand test

Dielectric withstand tests should be conducted to determine the integrity of floor insulation. Ground detection protective relay devices must be disconnected from ground prior to commencing the test. The recommended test voltage for insulation used in 1500 Vdc systems is 3500 Vdc and should be applied between the enclosure and ground for 1 min. The recommended test for voltage for insulation used in 1000 Vdc systems or less is 2500 Vdc and should be applied between the equipment and ground for 1 min. The test is successful if there is no breakdown in the insulation and the leakage current does not exceed 50 µA. Ground detection relaying devices/systems should be re-connected and tested after dielectric tests of flooring are completed.

Dielectric tests of flooring should be conducted before and after installation of dc equipment on insulated floors. The test area can be reduced to the exposed floor around the equipment for tests conducted after equipment is installed. Insulated floors in prefabricated distribution facilities should be retested in the field after delivery to verify the integrity of the insulation.

6.3 Metal plate method

This method utilizes a metal plate as an electrode to apply voltage across insulation-in-test using a hipot device. The positive lead from the hipot is connected to the metal plate and the negative lead to the building ground. The test is generally performed over the entire area of the insulation at 1-m intervals and at specific locations where imperfections are visible. Additional tests may be performed as required by the owner. The use of conductive gels or ionized water with the plate is recommended to reduce the resistance between the plate and insulation.

The recommended material for the metal plate is carbon steel manufactured in accordance to ASTM A36/A36M standards [B2], although, metal plates with higher conductivity may be used. The dimensions of the plate should be a minimum of 30.48 cm × 30.48 cm (12 in × 12 in) with a minimum thickness of 3.18 mm (11-gauge). In addition, a minimum weight of 10 kg (22 lb) should be applied to the metal plate to enhance contact with the surface being tested.

7. Wall insulation practices

7.1 Background on wall insulation practices

Wall insulation is recommended in dc traction facilities where clearances to grounded walls, doors or other grounded structures are within close proximity of insulated equipment enclosures. Insulation should be installed on the grounded surfaces using nonmetallic hardware. Suitable wall insulation can be made of polyester fiberglass laminates, rubber matting or other dielectric material.

The dielectric properties of wall insulation material should be capable of withstanding the voltage limits indicated in 7.2. Mechanical properties of the insulation should have compressive, tensile, and impact strengths suitable for the equipment being installed. Insulation should also be nonporous and have little moisture absorption to limit electrical tracking across surfaces where the insulation is installed.

Walls, doors, and other grounded structures within 1.83 m (6 ft) of isolated dc equipment should be insulated to a height of 2.44 m (8 ft) to minimize potential personnel contact with grounded enclosures.

The use of nonmetallic raceways within 1.83 m (6 ft) of isolated dc equipment enclosures is recommended; however, raceways installed above 2.44 m (8 ft) may be metallic if a minimum clearance of 0.61 m (2 ft) is maintained from isolated equipment.

For grounded equipment enclosures installed in the same lineup as insulated dc enclosures, insulation barriers should be installed between the enclosures and extend horizontally such that the sum of the lengths A and B, as shown in Figure 3, is a minimum of 1.83 m (6 ft). In addition, insulation barriers should extend vertically to a minimum of 15.25 cm (6 in) above the tallest enclosure, whether grounded or insulated, as in Dimension C in Figure 3.

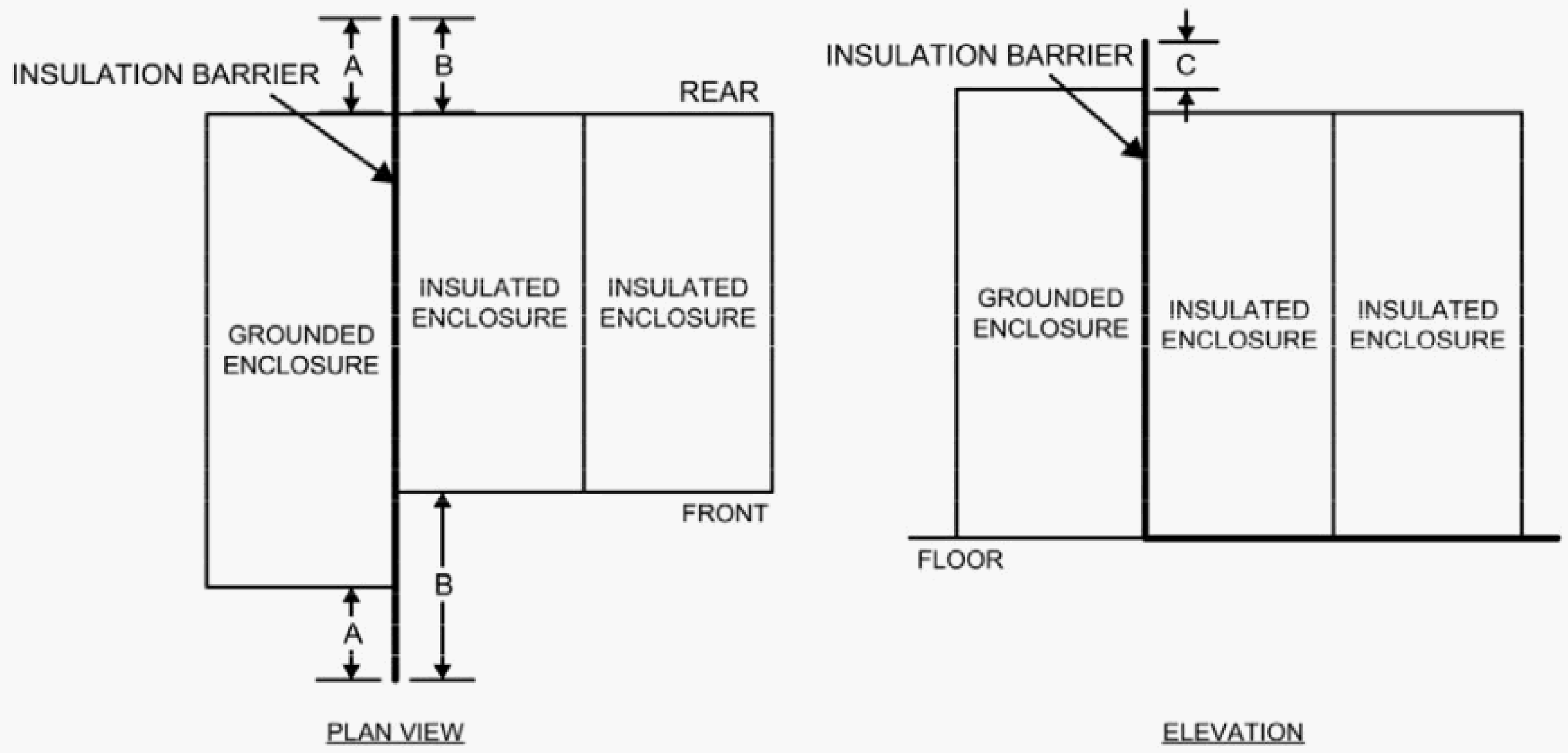

Figure 3—Insulation barrier between grounded and insulated enclosures

7.2 Dielectric withstand test

Wall insulation should be tested similarly to insulated floors to determine the integrity of the insulation. Ground detection protective relay devices must be disconnected from ground prior to commencing the test, should be re-connected, and tested after testing of the wall insulation integrity. The recommended test voltage for insulation used in 1500 Vdc systems is 3500 Vdc and should be applied between the enclosure and ground for 1 min. The recommended test for voltage for insulation used in 1000 Vdc systems or less is 2500 Vdc and should be applied between the equipment and ground for 1 min. The test is successful if there is no breakdown in the insulation and the leakage current does not exceed 50 µA.

Dielectric tests of wall insulation should be conducted before and after installation of dc equipment against insulated walls. The test area can be reduced to the exposed wall around the equipment for tests conducted after equipment is installed. Insulated walls in prefabricated substations should be retested in the field after delivery.

7.3 Test methods

The metal plate method as described in 6.3 should also be used for wall insulation testing.

Annex A

(informative)

Grounding design considerations

Special consideration should be given to designing and implementing grounding systems for ancillary equipment and systems associated with dc traction distribution facilities. Some design considerations are provided in Table A.1.

Table A.1—Design considerations for grounding dc equipment enclosures

Equipment or system	Type of dc equipment enclosure grounding	
	Low resistance	High resistance
Grounded conductors	Leads should be made as short as possible and be fully insulated from the enclosure.	Leads should be made as short as possible and be fully insulated from the enclosure.
AC control power	Special provision is not generally required.	The 120 Vac or 240 Vac control power source should be supplied from an ungrounded ac power system. This can be accomplished by use of an isolating transformer.
Insulation collar	Insulation should be rated for the maximum voltage that can potentially be voltage. developed during a fault condition.	Insulation should be rated for the maximum system
Bonding	All conductive materials within the protective zone of the 64HS/GS relay should be bonded. When multiple zones are implemented, conductive materials should not be bonded between zones.	All conductive materials within the protective zone of the 64HS/GS relay should be bonded. When multiple zones are implemented, conductive materials should not be bonded between zones.
Anchoring	Insulated anchors should be used.	Insulated anchors should be used.

Annex B

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] Accredited Standards Committee C2-2017, National Electrical Safety Code® (NESC®).[6]

[B2] ASTM A36/A36M, Standard Specification for Carbon Structural Steel.[7]

[B3] IEEE Std C37.2, IEEE Standard Electrical Power System Device Function Numbers, Acronyms, and Contact Designations.

[B4] NFPA 70®, National Electric Code® (NEC®), National Fire Protection Association[8, 9]

[6] National Electrical Safety Code and NESC are both registered trademarks and service marks of the Institute of Electrical and Electronics Engineers, Inc.

[7] ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

[8] National Electrical Code and NEC are both registered trademarks and service marks of The National Fire Protection Association.

[9] The NEC is published by the National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169, USA (http://www.nfpa.org/). Copies are also available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

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