

IEEE Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV through 500 kV

IEEE Power and Energy Society

Sponsored by the
Insulated Conductors Committee

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USA

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IEEE Power and Energy Society**

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Abstract: The most common shield/sheath-bonding systems now in use on medium through extra high-voltage (5 kV to 500 kV) single-conductor shielded power cables and the methods of calculating the corresponding shield/sheath voltages and currents, when the cables are operated as part of a three-phase system, with the neutral grounded directly or through an impedance, are described in this guide.

Keywords: bonding, cross bonding, distribution cable, grounding, high-voltage cable, IEEE 575™, medium-voltage cable, power cable, sheath, sheath bonding, sheath voltage limiters, shield, shield bonding, shield voltage limiters, single-point bonding, special bonding, SVL, transmission cable

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Introduction

This introduction is not part of IEEE Std 575™-2014, IEEE Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV through 500 kV.

This document is a revision of IEEE 575-1988, which had been reaffirmed multiple times without change in years past. The current revision changes the document title to more appropriately reflect the intent of the guide. Most clauses of the guide were revised and updated to better clarify recommendations and procedures. Advances in computer technology now allow many of the equations to be programmed and solved rapidly using software that can analyze the corresponding circuit configuration and make recommendations for application of specialized bonding. Considerations for shield/sheath optimization have been included in Clause 5. A major addition is Annex F, which provides new information on current and voltage distribution on cable shields/sheaths in situations involving installations with multiple cables per phase.

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1. Overview

Large investment costs, generally associated with the installation of underground transmission circuits, typically mandate optimizing cable operation from the standpoint of efficiency and power throughput capacity. With the popularity of single-conductor cables and the use of low loss, high dielectric-strength insulating materials and improved cable jackets in the mid-1960s, and their application at sub-transmission and transmission voltages, there is significant interest in the use of single-conductor cables and the problems of the induced voltages and currents associated with their use. Many of these problems (for example, failure of shield/sheath insulators, failure of cable jackets, and shield/sheath corrosion) have been recognized since metallic-sheathed cables were first used, and the fundamentals of calculating shield/sheath voltages and currents have been defined for many years. However, increasingly, ampacity requirements and short-circuit capabilities of modern power systems have accentuated some problems, while improvements in shield/sheath insulations have virtually eliminated others.

Thus it is evident that there is a need for some guidelines whereby the cable engineer can select the shield/sheath-bonding method that best fits the needs of a particular installation.

1.1 Scope

This guide describes the most common special shield/sheath-bonding systems now in use on high-voltage single-conductor shielded power cables and the methods of calculating shield/sheath voltages and currents, particularly as applied to three-phase systems operating at 60 kV and above, with the cable neutral grounded directly or as part of a special bonding system as described in the guide.

Although special bonding has been used predominantly in the past on higher voltage cable systems, more recent attention to shield and sheath losses on distribution class cables has prompted users to consider special bonding on lower voltage class cable systems as well. This is particularly applicable on the collector systems for wind farms, where long cable runs interconnect the individual wind turbines. While this guide on induced voltages and currents in metallic shields and sheaths is written largely around high-voltage cables operating at 60 kV and above, the fundamental principles in this document apply equally to single-conductor medium-voltage shielded power cables when installed and operated as outlined in this guide.

The user is cautioned to make sure that the installation/operating design does not contravene any local or national regulations.

1.2 Purpose

The purpose of this guide is to provide the cable engineer with recommendations for consideration when designing new power cable delivery systems as well as evaluating existing cable systems. This guide addresses the reduction of cable operational losses and increase in cable current carrying capacity through use of special cable bonding and grounding methods. The guide will also assist the user in calculating the standing shield/sheath voltages for various bonding and grounding methods.

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.

AEIC CS9, Specification for Extruded Insulation Power Cables and their Accessories Rated above 46 kV through 345 kV ac.¹

ANSI/ICEA S-108-720, Standard for Extruded Insulation Power Cables Rated above 46 kV through 345 kV.²

ICEA Publication P-32-382, Short-Circuit Characteristics of Insulated Cables.³

IEC 60287-1, Electric cables—Calculation of the current rating—Part 1: Current rating equations (100% load factor) and calculation of losses.⁴

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.⁵

¹ AEIC publications are available from the Association of Edison Illuminating Companies (<http://www.aeic.org/>).

² ANSI publications are available from the American National Standards Institute (<http://www.ansi.org/>).

³ ICEA publications are available from the Insulated Cable Engineers Association (<http://www.icea.net/>).

⁴ IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch/>). IEC publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org/>).

⁵ *IEEE Standards Dictionary Online* subscription is available at:
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

bonding lead: The insulated conductor connecting the shield/sheath of a shielded cable segment to an adjacent cable segment or bonding accessory for the purpose of providing a fault current path. A bonding lead may connect the shield/sheath of a cable segment or cable accessory to: (1) the shield/sheath on another cable segment, (2) a cable accessory, such as a joint casing, a termination bell, or a link box, or (3) a grounding point, such as a grounding bus, a ground rod, or a ground continuity conductor (GCC).

continuous cross bonding: A form of cross bonding applicable to circuits consisting of at least four minor sections in which the cable metallic shields/sheaths are successively cross-bonded at each junction between adjacent minor sections throughout the cable route. At each end of the route the shields/sheaths are solidly bonded and grounded.

cross bonding: The form of special bonding in which the metallic shields/sheaths of different phase cables in successive minor sections are cross connected in such a way so as to attain partial or full cancellation of induced currents on the metallic shields/sheaths.

flat formation: Three cables laid in one plane with normally equal spacing between adjacent cables.

ground continuity conductor (GCC): A conductor laid parallel and in close proximity to a cross-bonded or single-point bonded cable circuit to provide a continuous metallic ground connection between the grounding systems at the ends of the cable route and along the run.

impedance bonding: A bonding scheme in which an impedance, such as a reactor or a resistance, is inserted into the shield/sheath current path for the purpose of limiting fault currents or load losses.

insulated shield/sheath system: A cable system in which the metallic shield/sheath of each cable is individually insulated throughout its length except where any necessary grounding or inter-shield/sheath connections are made.

joint sleeve insulation: The external insulation applied over the metallic sheath/shield of a cable joint.

link box: A box in which bonding and grounding connections are made through removable links. The box may also contain shield/sheath voltage limiters.

major section: A set of consecutive minor cable sections between solidly bonded shields/sheaths that are connected in such a way so as to minimize cable shield/sheath current losses on each phase cable. For three-phase systems, three consecutive minor sections are required to form a major section to minimize shield/sheath currents on all three phases.

minor section: The length of cable between shield/sheath sectionalizing insulators, and between sheath insulators and sheath end-bells at the cable terminations.

multiple single-point bonding: The form of special bonding in which the three cable shields/sheaths are solidly bonded and grounded to a ground continuity conductor (GCC) at one end of a section, and connected to ground through shield/sheath voltage limiters at the other end; done at multiple locations along a route.

power frequency: The operating frequency of the ac power cable system.

NOTE—The basic principles presented in this guide apply to 50 Hz and 60 Hz systems once appropriate adjustments of constants are made. Examples in this guide assume either a 50 Hz or 60 Hz frequency as indicated.⁶

⁶ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

screening conductor: A conductor laid in parallel with a current-carrying loop and itself forming part of a closed circuit in which induced currents can flow whose magnetic field will oppose the field of the current-carrying loop.

sectionalized cross bonding: The form of cross bonding in which three consecutive minor sections are taken to form a single cross-bonded unit (see **major section**). The three shields/sheaths are solidly bonded at both ends of a major section and may be grounded at these points. At the two intermediate positions the cables are transposed and the shields/sheaths are interconnected in such a way so that each continuous shield/sheath circuit through the major section occupies the same geometrical position in the cable formation. For long cable routes there will usually be a number of major sections.

sheath: Historically the term implied an extruded lead sheath that provided a moisture impervious barrier for the inner cable core while simultaneously providing the requisite metallic shielding for the cable. More recently extruded aluminum sheathing and copper foil laminates have been employed in order to provide moisture tightness.

sheath interrupt: A break or interruption, incorporated into the metallic shield/sheath and semiconducting shield of a cable at a joint in order to provide electrical isolation between adjacent cable shield sections.

sheath sectionalizing insulator: An insulating member inserted into the joint and metallic joint casing (if present) in order to electrically isolate the shields of adjacent cable lengths, of the same phase, from each other; typically this insulating member is a ring made of epoxy or porcelain.

sheath sectionalizing joint: A joint in which the metallic screen and metallic casing, if present, are electrically interrupted by means of a shield/sheath sectionalizing insulator.

sheath standing voltage: The voltage to ground appearing on the metallic shield/sheath of a specially bonded cable when balanced full-load currents are flowing in the cable conductors; typically specified at the point along the cable length at which it is a maximum (that is, at the ungrounded extremity of a minor section in the case of single-point bonding and at a cross-bonding point in the case of cross bonding). When the voltages differ for the three-phase cables, the highest value is typically specified.

sheath voltage limiter (SVL): A surge protective device connected between the metallic shield/sheath and ground on specially bonded cables to limit shield/sheath overvoltages during system transients.

shield: A non-moisture impervious metallic outer conductor of single conductor power cables, such as concentric wires and concentric copper tapes, that provide grounding and a fault current path for the cable.

shield/sheath: See 3.1.

single-point bonding: The form of special bonding in which the three cable shields/sheaths of a minor section are solidly bonded together and grounded at one point only. For long cable routes this may be repeated a number of times. *See also:* **multiple single-point bonding**.

solid bond: A metallic connection between shields/sheaths or between shields/sheaths and ground.

special bonding: Methods of bonding and grounding the metallic shields/sheaths of single-conductor cables so as to minimize the shield/sheath circulating currents resulting from induction of conductor currents.

transposition of power cables: The practice of laying single-conductor cables so that each phase cable successively occupies, optimally over equal lengths of the route, each of the three geometric lay positions in the formation.

transposition of the parallel ground continuity conductor (GCC): The practice of laying a parallel ground conductor alongside a minor section of untransposed power cables so that the conductor occupies over half of the section's length one position and over the other half occupies a symmetrically opposite position.

trefoil: The formation of three cables positioned so that the cable centers are equidistant (when viewed in cross section, lines drawn through the cable centers form an equilateral triangle).

uniform major section: A section consisting of three similar uniform minor subsections having equal lengths.

3.1 Special terms

shield/sheath: For the purpose of this guide and in order to simplify the discussion, the terms *sheath* and *shield*, as used in the context of this document, are intended to refer to the metallic, electrically conducting portion of the cable sheath or shield and as such both terms are used interchangeably when referring to the outer conductor of a single conductor medium- or high-voltage power cable.

4. Background

Single conductor medium- and high-voltage power cables employ a coaxial design essentially consisting of a metallic center conductor surrounded by insulation and an outer metallic shield or sheath (outer conductor). Semiconducting layers are provided at the interface between the conductor and the insulation, and between the insulation and the metallic shield or sheath in order to provide a smooth electrical interface for the insulation and thus establish a uniform electrical stress pattern within the insulation. Cable core conductors are normally comprised of aluminum or copper wires but can be of solid construction.

Present day cable insulation materials generally consist of impregnated paper, ethylene propylene rubber (EPR), or cross-linked polyethylene (XLPE). The cables are constructed with an outer metallic shield or sheath, which is primarily comprised of one of the following:

- Concentrically applied copper wires, aluminum wires, or helically applied copper tapes
- Extruded lead or aluminum sheaths
- Longitudinally applied corrugated copper tapes sealed at the overlap
- Longitudinally applied thin copper or aluminum foil laminates sealed at the overlap
- Combination of wires with any of the above copper tapes

NOTE—Since this document deals primarily with the electrical aspects of shields and sheaths, and to simplify the discussion, the cable metallic shields or sheaths will be referred to interchangeably as the *shield* or *sheath* unless otherwise indicated.

Covering the metallic shield/sheath is normally an insulating jacket typically consisting of extruded polyethylene (PE) or comparable electrically insulating jacketing material, which protects the underlying metallic shield/sheath from electrolysis.

The magnetic field resulting from current flow through the core conductor couples the metallic shield/sheath and any other adjacent conductors. If the shield is also part of a continuous closed loop electric path, transformer action induces a current flow in the coupled shield/sheath and other adjacent conductors. Resistive losses due to the circulating currents in the shield then contribute to the temperature rise of the cable, limiting the amount of current that can be carried by the cable and reducing cable

efficiency. Conversely, if the electric path is interrupted through use of special bonding techniques, the shield/sheath circulating currents will be reduced or eliminated resulting in greater loading capability for the cable but at the disadvantage of developing a rise in shield/sheath voltage. Consequently, special bonding and grounding arrangements have been developed to limit the magnitude of sheath voltages and to minimize the flow of circulating currents.

To assure proper performance of specially bonded systems, the jacket's electrical integrity should be checked as part of factory testing and upon installation. To ensure that an adequate ground is available for field testing of the cable jacket in the field, the outer surface of the jacket is either coated during manufacture with a graphite coating or alternatively a semiconducting layer is extruded overall during manufacture. Typical field practices include testing the jacket's integrity by subjecting the jacket to a 10 kV dc test for one minute as follows:

- a) After delivery and prior to installation
- b) Immediately after laying each cable length
- c) After cable jointing (splicing)
- d) As part of final commissioning of the circuit
- e) Periodically thereafter as part of a routine maintenance program as recommended by the manufacturer

CAUTION

It is essential with specially bonded cable systems to ensure that all disconnecting links are properly reconnected after completion of the jacket tests or any other related testing. Operation of cables with shields/sheaths improperly connected (grounded) will often result in cable failure. To obviate this potential risk, formal link box commissioning, inspection, certification, and link box locking procedures should be established.

Safety and cost considerations often do not justify application of special bonding for cable operation below transmission voltage class. Many distribution cable installations are also multipoint grounded because they are installed in random lay with communication cables and the installations are governed by Accredited Standards Committee C2-2012, National Electrical Safety Code[®] (NESC[®]) [B1] Rule 354D.⁷ Conversely, on higher voltage power cable systems that carry large bulk of power, it is often economical and practical to employ special bonding in order to limit shield/sheath losses and thus maximize loading capability.

For distribution class cables, the metallic shield is for the most part normally installed multipoint solidly grounded. This is due to safety concerns associated with making sure that all shield components of a specially bonded distribution cable would remain effectively insulated in the field after installation/during operation. The initial installation cost and additional maintenance associated with specially bonded installations makes this option often also less economically attractive for distribution class feeders, which have relatively lower power transfer requirements as compared to their transmission class counterpart. Thus special bonding techniques may be justified in some instances on distribution class feeders once safety aspects have been adequately addressed and the additional initial installation and subsequent maintenance costs have been effectively considered.

5. Shield optimization

For distribution class cables, shield losses can sometimes be reduced by increasing the shield impedance through a reduction of the metal content of the shield. However, this approach is generally limited by fault current magnitude and duration requirements for the shield. The fault duration requirement will need to

⁷ The numbers in brackets correspond to those of the bibliography in Annex A.

consider any delay introduced by failure of the primary circuit protection and dependence on a backup protection scheme. Cable designs typically specify a maximum temperature on the shield under this worst-case condition. The required amount of metal in the shield is then specified as a fraction of the cross-sectional area of the core conductor. For example, the shield can be full, 1/2, 1/3, 1/6, or even 1/12 the cross-sectional area of the core conductor. Designs with large surface areas compared to the volume of metal allow for increased heat dissipation into surrounding materials through thermal conduction. Thin corrugated shields tend to incorporate the highest shield to core conductor ratios because of the very large surface area presented for the minimum amount of metal present. The design results in some of the highest heat dissipation for the amount of metal included in the shield while reducing resistive losses by exhibiting high impedance. The most commonly used shield configuration for distribution class cables is concentric wires.

Incorporating an impervious moisture barrier into the design of a transmission class cable is an important requirement. For this reason, transmission cables have historically employed tubular lead sheaths because these could be readily extruded as a continuous, uninterrupted layer over the cable core while simultaneously providing the requisite metallic shield. More recent moisture-tight designs have often replaced lead with extruded corrugated aluminum sheaths and various combinations of corrugated and flat copper tapes in conjunction with copper wires. Where extruded metallic sheaths are not part of the design, metallic shields are supplemented with moisture-tight alternative polymeric and other designs in order to assure the high degree of operational reliability required of a transmission cable. Balancing the choices between designs, materials, electrical properties, and economics in the selection of the cable metallic shields/sheaths is referred to as *shield optimization*.

In many early cable designs, the shield was exposed and in direct contact with the earth, water, mud, and conduit. This resulted in corrosion problems caused by ac electrolysis, leading to shield damage. Early efforts to limit such damage placed restriction on the maximum magnitude of shield/sheath voltage, limiting these voltages to the range from about 12 V to 17 V. Newer cable designs generally include an outer jacket that is insulating and the likelihood of corrosion is thus effectively eliminated as long as the jacket remains intact. Since application of special bonding results in the build-up of significant voltage levels on the shield during faults and other abnormal operating conditions, designs take advantage of the state-of-the-art electrical insulating properties for the jacket to meet needed voltage withstand requirements. A graphite coating or an outer semiconductive layer is usually applied over the jacket at the factory to allow for testing of the jacket's electrical integrity.

6. Special bonding techniques

With heavier loads on single conductor cable circuits, shield circulating current losses resulting from multipoint solidly bonded and grounded systems can be excessive for the intended application. To mitigate these losses, alternative shield grounding methods are available, and these are collectively referred to as *special bonding techniques*. Because long circuits and high currents tend to be more common on transmission class circuits, special bonding techniques tend to be more applicable on these types of circuits. However, special bonding techniques can be applied on distribution circuits when operating conditions dictate a reduction in circuit losses.

Shield losses also increase with the spacing between cables, particularly when multiple point grounded, single-conductor cables are installed with wide spacing, such as when cables are placed in separate ducts or when they are direct buried in spaced configurations. When cables are spaced apart, significantly higher currents flow on the shield of solidly grounded systems, resulting in higher induced shield circulating current losses. Increased spacing decreases the effects of mutual heating but increases the effect of magnetic coupling and therefore, increases shield circulating current losses resulting in lower current ratings. The purpose of special shield bonding is to eliminate or significantly reduce shield circulating current losses on single-conductor cables.

Some special bonding options include the following:

- Single-point bonding
- Multiple single-point bonding
- Impedance bonding
- Sectionalized cross bonding
- Continuous cross bonding

The simplest and most effective method of special shield bonding is single-point bonding, in which one end of the circuit is grounded and the other end is isolated from ground. The maximum cable section length is governed by the permissible shield standing voltage allowed at the isolated end. For typically permitted shield voltage rise levels (i.e., no higher than about 200 V), this method is generally employed on line lengths of up to about 2 km (1.2 mi).

For longer line lengths or when shield voltages become excessive due to very high fault currents, cross bonding is generally preferred and is the most widely used form of special bonding. (Note, however, that most ac submarine cable circuits are solidly bonded because it is not practical to install shield break insulators along their run). The shields of cross-bonded cables are generally expected to be nominally at ground potential, but specially bonded systems can have appreciable voltages with respect to ground, even under normal load conditions. Under some circumstances, even solidly bonded and grounded shields can develop voltages well above ground potential along the circuit run. With present day jacketing materials and appropriate jacket thicknesses, some utilities have allowed shield standing voltages as high as 600 V under normal operation on specially bonded transmission class cable systems. See Annex B for additional information.

An alternative scheme that can be applied to long line lengths is multiple single-point bonding. Single-point bonding should always employ a separate ground-return conductor, except for the case where a circuit is installed totally within a station area having a ground grid that provides a low impedance return ground path.

In all cases, special shield bonding designs must effectively address the following functions:

- Provide grounding for the cable
- Maintain a continuous fault-current return path either through the shield/sheath and/or a ground continuity conductor (GCC)
- Limit normal steady-state shield voltages to acceptable and safe levels
- Significantly reduce or eliminate shield losses
- Limit transient overvoltages to acceptable levels in combination with surge protective devices

To meet these requirements, special bonding techniques are used that divide the cable shield into a number of sections along the cable run, using shield sectionalizing joints. The length of each section is determined by the permissible shield voltage under normal and fault conditions. Shield sectionalizing is normally accomplished at joint and termination locations where access to the shield is readily available. The ability to site joints and terminations at a particular location affects the system shield voltages and currents that will develop, and can affect the type of shield bonding selected. Complete suppression of circulating shield currents may not always be possible because of practical limitations imposed on cable lengths by the spacing of manholes and other access points. In these cases, it may be necessary to calculate the residual shield currents and assess their effect on the cable rating.

Special bonding designs depend in part on the insulating properties of a cable jacket to withstand induced voltages. Jackets for specially bonded cable systems typically incorporate an outer conductive layer, such as a graphite coating, to allow periodic testing of the jacket integrity and thus assure proper in service performance. However, the jacket is only part of the bonding system and proper design and coordination with other components, such as shield interrupts, link boxes, and shield voltage limiters (SVLs) is necessary in order to arrive at the proper design for a specially bonded system. The design and ratings of these components is determined based on factors such as the following:

- Maximum allowable magnitude of steady-state shield voltage
- Maximum allowable magnitude of transient shield voltage under fault conditions
- Dielectric breakdown voltage (puncture voltage) of the cable jacket under fault conditions
- Flashover voltage of the shield joint insulator (shield interrupt) under fault conditions

6.1 Design

In the design of special sheath-bonding arrangements, consideration must be given to the following aspects:

- a) Cable sheaths on short transmission cable circuits and most distribution circuits are usually expected to be nominally at ground potential. However, in a specially bonded system the shields/sheaths can have appreciable voltages with respect to ground and shields/sheaths should never be assumed to be at ground potential. Appropriate precautions must be taken to ensure that personnel are aware of the potential hazard and proper safety procedures. Consideration should be given to effective installation of appropriate barriers, warning devices, etc., as warranted by expected shield/sheath voltages.
- b) Complete suppression of circulating shield/sheath currents may not always be possible because of practical difficulties in the choice of cable lengths and cable spacing. It is then necessary to calculate the residual sheath currents and assess their effect on the cable rating.
- d) The use of special bonding gives rise to sheath overvoltages during system transients and faults, and the magnitudes of those overvoltages must be considered in the design of the cable system. For higher voltage systems, a shield/sheath voltage limiter will be generally needed and in all cases consideration must be given to the coordination of the jacket insulation levels, the voltages to which the jacket will be subjected, and the characteristics of surge voltage protective devices.
- e) Failure of a part of the jacket or of a sheath voltage limiter (SVL) can result in excessive shield/sheath currents and losses and cause overheating of the cables. Consideration must therefore be given to the duty imposed on the shield/sheath voltage-limiting device and to the monitoring and maintenance of the complete systems.

For single-conductor cable circuits carrying currents in excess of about 500 A, special bonding is often economically desirable as the reduction in losses allows an appreciably smaller conductor size to be used. Very often, employing special bonding will permit the use of a single cable per phase installation where, otherwise, multiple cables per phase would be required with the use of solid bonding. There is no clear-cut load level at which special bonding should be introduced and the extra cost of the larger conductor cable or multiple cables per phase system needed for a solidly bonded system must be weighed against the cost of the additional equipment and the maintenance cost arising from the greater complexity of a specially bonded system.

The use of special bonding gives rise to high shield overvoltages during system transients and faults. Failure of components employed in special bonding systems can result in significant shield currents and losses leading to cable overheating. The magnitude of overvoltages must be considered during system design and the protective capabilities of SVLs properly coordinated with the expected shield insulation

levels. Prudent circuit design requires that consideration be given to the duty imposed on the shield-voltage-limiting device and to periodic monitoring and maintenance of the complete system during operation

6.2 Safety considerations for specially bonded cable systems

WARNING

Potentially hazardous voltages can be present on the exposed portions of the metallic shields/sheaths of high-voltage cables, the outer surface of conducting cable jackets, the conductor of bonding cables, the conductor of grounding leads, across exposed shield/sheath interrupts, the SVLs, and various hardware connections within the link boxes and other equipment connected to or associated with specially bonded cable systems. Appropriate precautions must be taken to provide access control to these areas to ensure that safety procedures are followed in order to protect both personnel and equipment.

Exposed portions of the metallic shield, sheath, bond cable, or other conductive connections in electrical contact with the cable's shield/sheath, or bond cable of a specially bonded cable system, should never be assumed to be at ground potential. The allowable shield/sheath voltage at full load varies considerably among utilities and among countries. The shield/sheath voltage will be significantly higher during system transients and short circuit conditions. As a consequence, appropriate protection and precautions must be taken to ensure that personnel who may come into contact with any of the above conductive components are familiar with the design, take adequate protection against potentially related hazards, and follow proper safety procedures.

6.3 Single-point bonding

The simplest form of special bonding consists in grounding the sheaths of the three cables at only one common point (for all three cables) along the cable run. In these types of installations, a voltage is induced on the sheath of the cable during operation, progressively increasing with distance away from the grounded point and reaching a maximum at the farthest point away from the grounded end. The sheaths must therefore be adequately insulated from ground by means of an effective insulating jacket. Since there is no continuous closed loop electrical path for the shield/sheath, current does not flow longitudinally along the shields/sheaths and shield circulating current losses are thus eliminated (sheath eddy losses will still be present).

SVLs should always be used if the expected surge voltage level exceeds 75% of the BIL of the jacket or of the shield/sheath sectionalizing insulator.

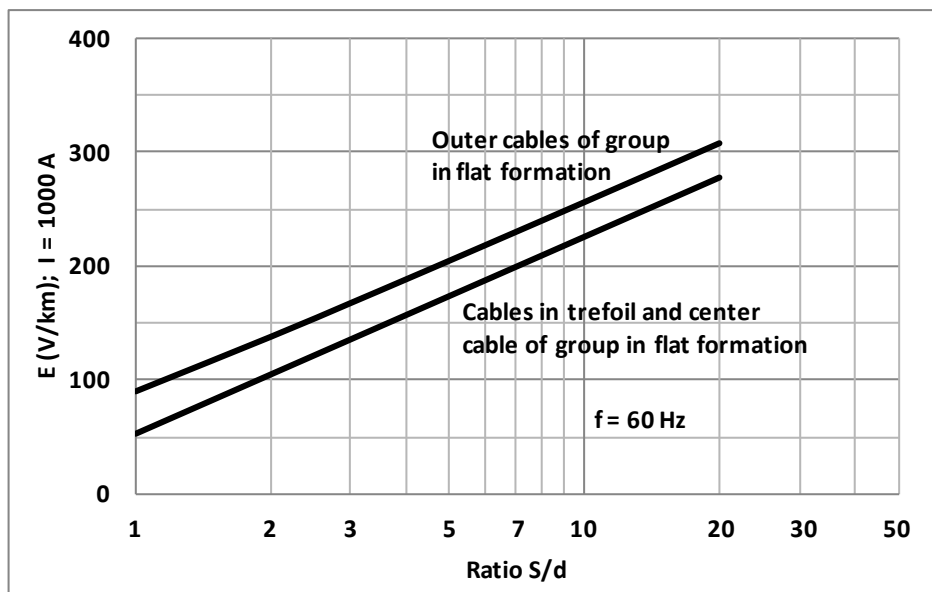


Figure 1—Induced shield/sheath voltage gradient for a conductor current of 1000 A

6.3.1 Shield/sheath standing voltages

Values of sheath standing voltage can be found using Figure 1.

As an example, for a typical circuit having a conductor current $I = 1000$ A and $S/d = 2$

where

S is the center-to-center cable spacing
 d is the mean sheath diameter

The shield/sheath voltage will be 103 V/km (166 V/mi) and 138 V/km (222 V/mi) for trefoil and flat formations, respectively, under normal three-phase operation. It should be also recognized that the shield/sheath voltages will be significantly higher during system transients and short circuit conditions.

6.3.2 Multiple lengths

When the circuit length is such that the sheath-standing voltage limitation is exceeded when the ground is connected at one end of the circuit, the ground connection may be moved to some other location along the circuit run, for example, the center of the length. The shield/sheath standing voltage on each of the two sections thus formed is then correspondingly reduced. When the circuit is too long to be dealt with by this means, it may be sectionalized by the use of shield/sheath sectionalizing joints (multiple single-point bonding) so that the shield/sheath standing voltage for each minor section is within the limitation imposed.

6.3.3 Parallel ground continuity conductor

During a ground fault on the power system, the zero-sequence current carried by the cable conductors returns by whatever external paths are available. Since a single-point, bonded cable shield/sheath is grounded at one position only, it cannot, except in the case of a cable fault, carry any of the returning current. This being so, unless some parallel external conductor is available or is provided to serve as an alternative path, the return current can flow only by way of the ground itself. Because the resistivity of the

ground is very high compared with that of good conductors, the return current is widely diffused through the ground and the mean effective depth of the current is hundreds of meters deep. Because the returning current path is significantly remote from the cable, the voltage induced along parallel conductors, including the cable shields/sheaths, tend to be very high.

Furthermore, in the absence of a parallel GCC, the occurrence of a ground fault in the immediate vicinity of a cable could cause a major difference in potential to arise between the two ends of a cable system. Depending to some extent on the particular design of the voltage limiters employed, hazards could then ensue to personnel or equipment.

Accordingly, it is recommended that single-point bonded and multiple single-point bonded cable installations be provided with a parallel GCC that is grounded at both ends of the route as shown in Figure 2. The spacing of this conductor from the cable circuit should be sufficiently close to limit the voltage rise of the shield/sheath to an acceptable level during a single-phase fault. The size of this conductor must be adequate to carry the full, expected fault current for the cable system.

Although a GCC is not required for cross-bonded systems since the cable shields/sheaths form an end-to-end path for fault currents, many utilities, especially those in the U.S., do install GCCs to insure a solid end-to-end conductor, and to give a low impedance connection point for grounding the shield/sheath voltage limiters and cable shields/sheaths in vaults. Note that circulating currents can be induced in the GCCs, especially in imbalanced cross-bonded systems, and the resulting losses should be considered when calculating cable ampacity.

The parallel GCC is usually insulated so as to avoid any corrosion risk since it will be subjected to voltage induction from the power cables in the same way as any other parallel conductor. To avoid circulating currents and losses in this conductor, it is preferable, when the power cables are not transposed, to transpose the parallel GCC as shown in Figure 2, using the methods described in Annex D, D.3.

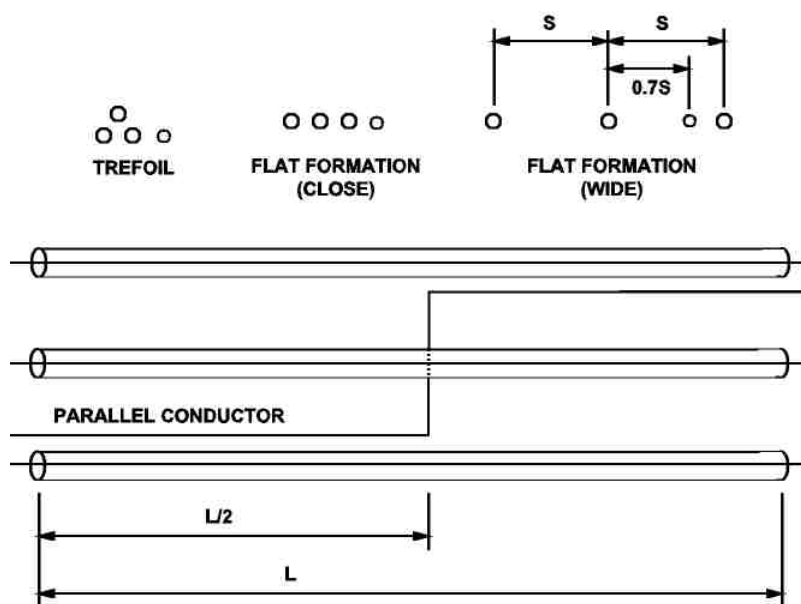
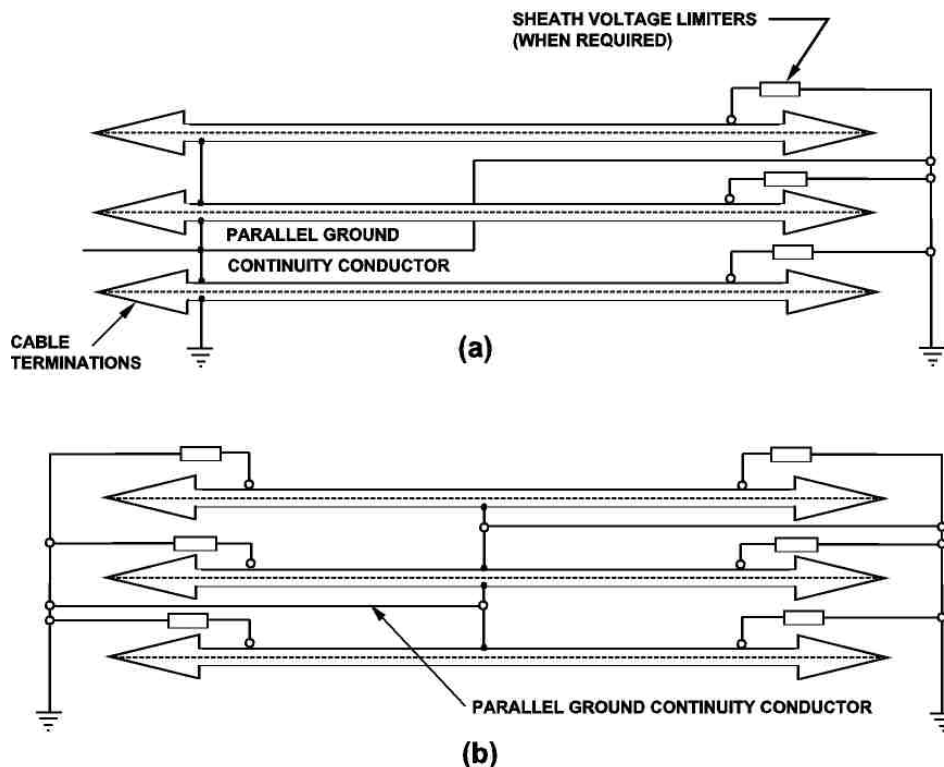


Figure 2—Transposition of parallel ground continuity conductor to reduce induced shield/sheath voltages on power cables in flat or trefoil formation

6.3.4 Circuit arrangements

The application of single-point bonding to single length circuits is shown in Figure 3 and to multiple length circuits in Figure 4. These diagrams do not show the disconnecting boxes to permit testing of the shield/sheath insulation.



(a) End-point bonding

(b) Midpoint Bonding

NOTE—Other patterns of ground conductor transposition may be used. See Annex D, D.4.

Figure 3—Single-point bonding diagrams for circuits comprised of only one cable length

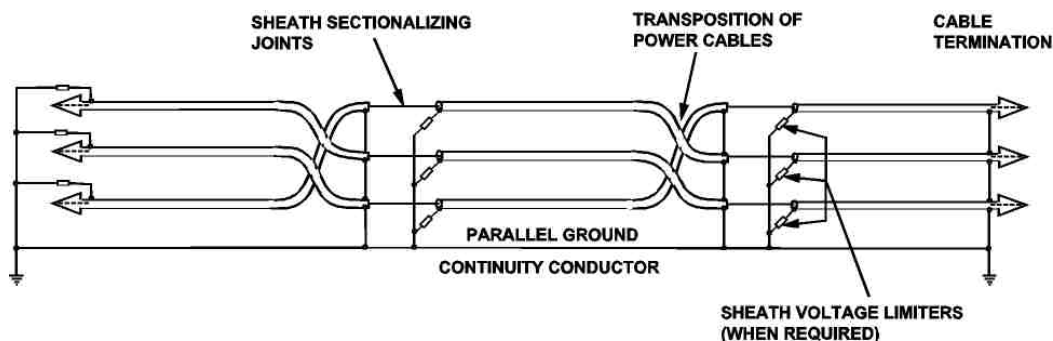


Figure 4—Single-point bonding diagram for a circuit comprised of three cable lengths