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Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems

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Foreword

This standard practice presents guidelines and procedures for use during design, construction, operation, and maintenance of metallic structures and corrosion control systems used to mitigate the effects of lightning and alternating current (AC) power transmission systems. This standard is not intended to supersede or replace existing electrical safety standards. As shared right-of-way and utility corridor practices become more common, AC influence on adjacent metallic structures has greater significance, and personnel safety becomes of greater concern. This standard addresses problems primarily caused by proximity of metallic structures to AC-powered transmission systems.

The hazards of lightning and AC effects on aboveground pipelines, while strung along the right-of-way prior to installation in the ground, are of particular importance to pipeline construction crews. The effects of AC power lines on buried pipelines are of particular concern to operators of aboveground appurtenances and cathodic protection (CP) testers, CP designers, safety engineers, as well as maintenance personnel working on the pipeline.

Some controversy arose in the 1995 issue of this standard regarding the shock hazard stated in Section 5, Paragraph 5.2.1.1 and elsewhere in this standard. The reason for a more conservative value is that early work by George Bodier[1] at Columbia University and by other investigators has shown that the average hand-to-hand or hand-to-foot resistance for an adult male human body can range between 600 ohms and 10,000 ohms. A reasonable safe value for the purpose of estimating body currents is 1,500 ohms hand-to-hand or hand-to-foot. In other work by C.F. Dalziel[2] on muscular contraction, the inability to release contact occurs in the range of 6 to 20 mA for adult males. Ten mA hand-to-hand or hand-to-foot is generally established as the absolute maximum safe let-go current. Conservative design uses an even lower value. Fifteen volts of AC impressed across a 1,500 ohm load would yield a current flow of 10 mA; thus, the criterion within this standard is set at 15 volts. Prudent design would suggest an even lower value under certain circumstances.

Many are now concerned with AC corrosion on buried pipelines adjacent to or near overhead electric transmission towers. This subject is not quite fully understood, nor is there an industry consensus on this subject. There are reported incidents of AC corrosion on buried pipelines under specific conditions, and there are also many case histories of pipelines operating under the influence of induced AC for many years without any reports of AC corrosion. The members of NACE Task Group (TG) 025 agreed that criteria for AC corrosion control should not be included in this standard. However, the mitigation measures implemented for safety and system protection, as outlined in this standard, may also be used for AC corrosion control.

This standard was originally published in July 1977 by Unit Committee T-10B on Interference Problems and was technically revised in 1983 and 1995, and reaffirmed in 2000 by T-10B. NACE continues to recognize the need for a standard on this subject. Future development and field experience should provide additional information, procedures, and devices for Specific Technology Group (STG) 05, "Cathodic/Anodic Protection," to consider in future revisions of this standard. This standard was revised in 2007 and 2014 by TG 025, "Alternating Current (AC) Power Systems, Adjacent: Corrosion Control and Related Safety Procedures to Mitigate the Effects." It is sponsored by STG 03, "Coatings and Linings, Protective—Immersion and Buried Service," and STG 35, "Pipelines, Tanks, and Well Casings." This standard is issued by NACE under the auspices of STG 05.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*. The terms *shall* and *must* are used to state a requirement, and are considered mandatory. The term *should* is used to state something good and is recommended, but is not considered mandatory. The term *may* is used to state something considered optional.

Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems

Contents

Section 1: General

1.1 This standard presents acknowledged practices for the mitigation of AC and lightning effects on metallic structures and corrosion control systems.

1.2 This standard covers some of the basic procedures for determining the level of AC influence and lightning effects to which an existing metallic structure may be subjected and outlines design, installation, maintenance, and testing procedures for CP systems on structures subject to AC influence, primarily caused by proximity of metallic structures to AC power transmission systems. However, this standard is not intended to be a design guide or a "how-to" engineering manual to perform AC interference studies or mitigation designs.

1.3 This standard does not designate procedures for any specific situation. The provisions of this standard should be applied under the direction of competent persons, who, by reason of knowledge of the physical sciences and the principles of engineering and mathematics, acquired by professional education and related practical experience, are qualified to engage in the practice of corrosion control on metallic structures. Such persons may be registered professional engineers or persons recognized as being qualified and certified as corrosion specialists by NACE, if their professional activities include suitable experience in corrosion control on metallic structures and AC interference and mitigation.

1.4 This standard should be used in conjunction with the references contained herein.

Section 2: Definitions

2.1 Definitions presented in this standard pertain to the application of this standard only. Reference should be made to other industry standards when appropriate.

AC Exposure: Alternating voltages and currents induced on a structure because of the AC power system.

AC Power Structures: The structures associated with AC power systems.

AC Power System: The components associated with the generation, transmission, and distribution of AC.

Affected Structure: Pipes, cables, conduits, or other metallic structures exposed to the effects of AC or lightning.

Bond: A low-impedance connection (usually metallic) provided for electrical continuity.

Breakdown Voltage: A voltage in excess of the rated voltage that causes the destruction of a barrier film, coating, or other electrically isolating material.

Capacitive Coupling: The influence of two or more circuits upon one another, through a dielectric medium such as air, by means of the electric field acting between them.

Circular Mil: A unit of area of round wire or cable equal to the square of the diameter in mils (1 mil = 0.0254 mm = 25.4 µm).

Coating Stress Voltage: Potential difference between the metallic surface of a coated structure and the earth in contact with the outer surface of the coating.

Coupling: The association of two or more circuits or systems in such a way that energy may be transferred from one to another.

Dead-Front Construction: A type of construction in which the energized components are recessed or covered to preclude the possibility of accidental contact with elements having electrical potential.

Electric Field: One of the elementary energy fields in nature. It occurs in the vicinity of an electrically charged body.

Electric Potential: The voltage between a given point and a remote reference point.

Electrolytic Grounding Cell: A device consisting of two or more buried electrodes installed at a fixed spacing, commonly made of zinc, and resistively coupled through a prepared backfill mixture. The electrical characteristics of a grounding cell include a small degree of resistance and a subsequent reduced voltage drop across the cell during a fault condition.

Fault Shield: Shallow grounding conductors connected to the affected structure adjacent to overhead electrical transmission towers, poles, substations, etc., to provide localized protection to the structure and coating during a fault event from nearby electric transmission power systems.

Gradient Control Mat: A system of bare conductors connected to the affected structure and placed on or below the surface of the earth, usually at above grade or exposed appurtenances, arranged and interconnected to provide localized touch-and-step voltage protection. Metallic plates and grating of suitable area are common forms of ground mats, as well as conventional bare conductors closely spaced.

Gradient Control Wire: A continuous and long grounding conductor or conductors installed horizontally and parallel to the affected structure at strategic lengths and connected at regular intervals to provide protection to the structure and coating during steady-state and fault AC conditions from nearby electric transmission power systems.

Ground: An electrical connection to earth.

Ground Current: Current flowing to or from earth in a grounding circuit.

Grounded: Connected to earth or to some extensive conducting body that serves instead of the earth, whether the connection is intentional or accidental.

Grounding Grid: A system of grounding electrodes consisting of interconnected bare conductors buried in the earth to provide a common electrical ground.

Ground Potential Rise: Ground Potential Rise or Earth Potential Rise (as defined in IEEE[(1)] Standard 367)[3] is the product of a ground electrode impedance, referenced to remote earth, and the current that flows through that electrode impedance. This occurs when large amounts of electricity enter the earth. This is typically caused when substations or high-voltage towers fault, or when lightning strikes occur (fault current). When currents of large magnitude enter the earth from a grounding system, not only does the grounding system rise in electrical potential, but so does the surrounding soil. The resulting potential differences cause currents to flow into any and all nearby grounded conductive bodies, including concrete, pipes, copper wires, and people.

Inductive Coupling: The influence of two or more circuits on one another by means of changing magnetic flux linking them together.

Let-Go Threshold Current: Maximum value of electric current through the body of a person at which that person can release himself or herself.

Lightning: An electric discharge that occurs in the atmosphere between clouds or between clouds and the earth.

Load Current: The current in an AC power system under normal operating conditions.

Lumped Grounding: Localized grounding conductors, either shallow or deep, connected to the affected structure at strategic locations to provide protection to the structure and coating during steady-state and fault AC conditions from nearby electric transmission power systems.

Magnetic Field: One of the elementary energy fields in nature. It occurs in the vicinity of a magnetic body or current-carrying medium.

Over-Voltage Protector (Surge Arrester): A device that provides high resistance to direct current (DC) and high impedance to AC under normal conditions within the specified DC and AC threshold rating and "closes" or has a very low resistance and impedance during upset conditions.

Potential: See *Electric Potential*.

[(1)] Institute of Electrical and Electronics Engineers (IEEE), Three Park Avenue, 17th Floor, New York: NY 10016-5997.

Potential Gradient: Change in the potential with respect to distance.

Reclosing Procedure: A procedure that normally takes place automatically whereby the circuit breaker system protecting a transmission line, generator, etc., recloses one or more times after it has tripped because of abnormal conditions such as surges, faults, lightning strikes, etc.

Resistive Coupling: The influence of two or more circuits on one another by means of conductive paths (metallic, semi-conductive, or electrolytic) between the circuits.

Shock Hazard: A condition considered to exist at an accessible part in a circuit between the part and ground or other accessible part if the steady-state open-circuit AC voltage is 15 V or more (root mean square [rms]). For capacitive build-up situations, a source capacity of 5 mA or more is recognized as a hazardous condition. For short-circuit conditions, the permissible touch-and-step voltages shall be determined in accordance with the methodology specified in accordance with IEEE Standard 80,[4] or equivalent standard.

Solid-State DC Decoupler: A dry type of DC decoupling device comprising solid-state electronics. The electrical characteristics of a solid-state decoupler are high resistance to low-voltage DC and low impedance to AC.

Step Potential or Step Voltage: The potential difference between two points on the earth's surface separated by a distance of one human step, which is defined as one meter, determined in the direction of maximum potential gradient.

Switching Surge: The transient wave of potential and current in an electric system that results from the sudden change of current flow caused by a switching operation, such as the opening or closing of a circuit breaker.

Touch Potential or Touch Voltage: The potential difference between a metallic structure and a point on the earth's surface separated by a distance equal to the normal maximum horizontal reach of a human (approximately 1.0 m [3.3 ft]).

Varistor: A shunt mode device with a nonlinear current-voltage characteristic used to protect circuits against excessive transient voltages, and is non-conductive during normal operations when the voltage across it remains well below its clamping (i.e., let-through) voltage.

Voltage: The difference in electrical potential between two points.

Section 3: Exposures and Effects of Alternating Current and Lightning

3.1 Introduction

3.1.1 This section outlines the physical phenomena by which AC, AC power systems, and lightning can affect metallic structures.

3.2 Resistive Coupling (Electrolytic)

3.2.1 Grounded structures of an AC power system share an electrolytic environment with other underground or submerged structures. Coupling effects may transfer AC energy to a metallic structure in the earth in the form of alternating current or potential. Whenever a power system with a grounded neutral has unbalanced conditions, current may flow in the earth. Substantial currents in the earth may result from phase-to-phase-to-ground or phase-to-ground faults. A metallic structure in the earth may carry part of this current. Also, a structure in the earth coated with a dielectric material may develop a significant AC potential across the coating.

3.2.2 Resistive coupling is primarily a concern during a short-circuit condition on a power system, for example, when a large part of the current in a live conductor flows into the earth by means of the foundations and grounding system of a tower, pole, or substation. This current flow raises the electric potential of the earth near the structure, often to thousands of volts with respect to remote earth, and can result in a considerable stress voltage across the coating (see Paragraph 4.13) of a long metallic structure, such as a pipeline. This can lead to arcing that damages the coating, or even the structure itself. This difference in potential between the earth and the structure can represent an electric shock hazard. The effect of resistive coupling is usually concentrated in the vicinity of each of the first few power system poles or towers nearest the short-circuit location and near any substations involved in the short circuit. Under some circumstances, the electric potential of the structure may be raised enough to transfer hazardous potentials over considerable distances, particularly if the structure is well coated. Resistive coupling effects are strongly dependent on a number of factors, the most important of which are:

(a) The total short-circuit current;

(b) The power line overhead ground wire type and length back to the source;

(c) The size of the foundations and grounding systems of the poles, towers, or substations through which the current is flowing;

(d) The electrical resistivity of the soil as a function of depth; and

(e) Separation distance between power systems and the affected metallic structure.

The electrical layering of the soil alone can easily change resistive coupling effects by an order of magnitude or more.

3.3 Capacitive Coupling

3.3.1 The electric field associated with power conductors causes a well-defined current to flow continuously between a nearby aboveground metallic structure and the earth, whether that aboveground structure is grounded or simply suspended in the air. This current flows from the structure to the earth partially through the air as a displacement current and partially through conductive or semi-conductive paths such as deliberate grounds, wooden supports, or human beings touching the structure. The magnitude of the total current flowing from the structure is a function of the size of the structure, its proximity to the power conductors, the voltage level of the power conductors, and their geometrical arrangement. The total current flowing between the metallic structure and earth distributes itself between the different available paths to earth in direct proportion to the relative conductivity of each path. For example, a 100 ohm ground rod would carry 10 times as much current to earth as a 1,000 ohm human being, thus reducing the magnitude of the available shock current by a factor of 10. Capacitive coupling is typically a hazard during construction with respect to electric shock or arcing when the structure is on insulating supports prior to lowering in or connecting to an adjacent section. Ground rods and bonding often provide sufficient protection. The need for additional grounding may be verified with a simple voltmeter test.

3.4 Inductive Coupling

3.4.1 AC flow in power conductors produces an alternating magnetic field around these conductors, thereby inducing AC potentials and current flow in an adjacent structure. The magnitude of the induced potential depends on many factors. The most important are:

(a) The overall separation distance between the structure and the power line;

(b) The length of exposure and the power line current magnitude;

(c) Changes in the arrangement of power line conductors or in separation distance;

(d) The degree to which current flowing in one power line conductor is balanced by the currents flowing in the others because of conductor arrangement and current distribution;

(e) The type of conductor used for the lightning shield wires on the power line;

(f) The coating resistance of the structure;

(g) The grounding present on the structure; and

(h) The soil resistivity as a function of depth.

3.4.2 Grounding is usually present to some degree because of leakage across the coating or anodes of the CP system connected to the structure. Induced voltages increase in magnitude during fault conditions. The coating stress voltages caused by the inductive coupling near a short-circuit location tend to reinforce those caused by resistive coupling; therefore, both factors must be considered. The same is true for touch-and-step voltages. Hazardous induced potentials can easily extend over distances of many kilometers (miles), both within a power line corridor and beyond the extremities of the corridor. Considerable power may be transferred to a structure by means of inductive coupling and can result in currents of tens or even hundreds of amperes flowing in the structure during peak power system operating conditions, and thousands of amperes during short-circuit conditions. Potential peaks tend to occur at locations in which there are abrupt changes in the parameters. These are usually locations in which power lines and structures deviate away from or cross one another at substations or at power line phase transposition locations. Installing grounding at one location can make matters significantly worse elsewhere; therefore, the whole system should be carefully considered when designing mitigation.

3.5 Power Arc

3.5.1 During a fault-to-ground on an AC power system, the AC power structures and surrounding earth may develop a high potential with reference to remote earth. A long metallic structure, whether coated or bare, tends to remain at remote earth potential if not running parallel to the AC power lines. Worse still, if the structure runs parallel to the AC power lines, the induced potential on the structure tends to be opposite in polarity to the earth potential near the fault location at any given instance in time. Either way, if the resulting voltage to which the structure is subjected exceeds the breakdown voltage of any circuit element, a power arc can occur, damaging the circuit elements. Elements of specific concern include coatings, isolating fittings, bonds, lightning arresters, and CP facilities. If the potential gradient in the earth is large enough to ionize the soil for a finite distance, a direct arc from the power system ground to the structure may occur within that distance and result in coating damage, arc burn, or puncture/failure of the structure.

3.6 Lightning

3.6.1 Lightning strikes to the power system can initiate fault current conditions. Lightning strikes to a structure or to earth in the vicinity of a structure may produce electrical effects similar to those caused by AC fault currents. Lightning may strike a metallic structure at some point remote from AC power systems, also with deleterious effects.

3.7 Switching Surges or Other Transients

3.7.1 A switching surge or other transient may generate abnormally high currents or potentials on a power system, causing a momentary increase in inductive and capacitive coupling on the affected structures.

Section 4: Design Considerations for Protective Measures

4.1 Introduction

4.1.1 This section describes various protective measures used to help mitigate AC effects on metallic structures subject to hazardous AC conditions, minimize damage to the structures, and reduce the electrical hazard to people coming in contact with these structures.

4.1.2 The measures listed may be used to mitigate the problems of power arcing, lightning arcing, resistive coupling, inductive coupling, and capacitive coupling.[4,5,6] These measures may also be used to mitigate AC corrosion.

4.1.3 Design considerations should include steady-state conditions (including touch voltage and maximum pipe potentials during normal, emergency, and future loads) and fault conditions (including touch-and-step voltage, avoidance of pipe wall puncture and arc burns, and tolerable coating stress voltages).

4.1.4 Design mitigation objectives should be clearly defined. As a minimum, the mitigation objectives should include the maximum steady-state voltage at above-grade portions and appurtenances, maximum pipe potential (ground potential rise [GPR]) for the normally buried and inaccessible portions, touch-and-step voltage criteria at above-grade portions and appurtenances during fault conditions, and the maximum coating stress voltage during fault conditions.

4.2 Fault Shields, Lumped Grounding, and Gradient Control Wires

4.2.1 Fault shields consist of shallow grounding conductors (i.e., electrodes) connected to the affected structure adjacent to overhead electrical transmission towers, poles, substations, etc. They are intended to provide localized protection to the structure and coating during a fault event from a nearby electric transmission power system. Fault shields may reduce the possibility of damaging the coating or structure under fault conditions.

4.2.2 Lumped grounding consists of a localized conductor or conductors connected to the affected structure at strategic locations (e.g., at discontinuities). It is intended to protect the structure from both steady-state and fault AC conditions. Lumped grounding systems may be installed in shallow or deep configurations, depending on the site-specific parameters. Lumped grounding may reduce the steady-state touch voltages and the possibility of damaging the coating or structure under fault conditions; however, grounding between the lumped grounding locations may be required for complete protection.

4.2.3 Gradient control wires consist of a continuous and long grounding conductor or conductors installed horizontally and parallel to a structure (e.g., pipeline section) at strategic lengths and connected at regular intervals. They are intended to provide protection to the structure and coating during steady-state and fault AC conditions from nearby electric transmission power systems. Gradient control wires may reduce the steady-state voltages and the possibility of damaging the coating or structure under fault conditions.

4.2.4 Among the factors that influence mitigation design is the extent to which the structure is affected and the magnitude of the electrical potential between the structure and earth. These factors vary from one location to another and must be calculated or determined for each specific location. A combination of the above methods may be utilized, depending on the specific AC mitigation requirements.

4.2.5 Electrodes constructed of materials that are cathodic to the protected structure must be connected to the structure through a DC decoupling device, unless both the structure and electrode are cathodically protected as a single unit. Electrodes constructed of materials that are anodic to the protected structure may be connected directly to the structure; however, the CP design and monitoring requirements must be verified to be compatible with this type of circuitry.

4.2.6 Other types of systems may be designed for protection against faults on miscellaneous underground or aboveground structures, including measures implemented by the electric power line operator or utility.

4.3 Gradient Control Mats

4.3.1 Gradient control mats, bonded to the structure, are used to reduce electrical touch-and-step voltages in areas where people may come in contact with a structure subject to hazardous potentials. Permanent mats bonded to the structure may be used at valves, metallic vents, CP test stations, and other aboveground metallic and nonmetallic appurtenances in which electrical contact with the affected structure is possible.

4.3.2 Gradient control mats shall be large enough to extend through and beyond the entire area on which people may be standing when contacting the affected structure. They shall be installed close enough to the surface to adequately reduce touch-and-step voltages for individuals coming in contact with the structure.[6] Gradient control mats shall be engineered to provide acceptable touch-and-step voltages during both load and fault conditions, accounting for the local soil conditions.

4.3.3 Gradient control mats, regardless of materials of construction, must be bonded to the structure. Good grounding practice suggests a minimum of two (2) connections to the protected structure. If CP of the structure becomes difficult because of shielding, a DC decoupling device may be installed. Connections to the structure should be made aboveground to allow a means of testing for the effect of the gradient control mat in reducing AC potentials and its effectiveness on the CP system. Care should be taken to prevent the possible establishment of detrimental galvanic cells between the gradient control mat and structures that are not cathodically protected.

4.3.4 A bed of clean, well-drained gravel can reduce the shock hazard associated with touch-and-step voltages. Although an excellent practice, if hazardous conditions exist for pipeline applications, increasing the surface resistance should be used to augment the grounding system and not as a sole protection measure, as it may not be well maintained and kept clean. The thickness of the bed should be no less than 76 mm (3.0 in). Gravel should be a minimum of 13 mm (0.50 in) in diameter. The hazards of step voltages at the edge of a mat may be mitigated by extending the gravel beyond the perimeter of the grounding mat.

4.4 Independent Structure Grounds

4.4.1 Wherever a metallic structure subject to hazardous AC that is not electrically connected to an existing grounded structure is installed, it shall have an independent grounding system. This grounding system may consist of one or more ground rods and interconnecting wires. Care shall be taken to interconnect all components of the structure to be grounded properly. Factors considered in the design of the grounding system of an independent structure include the resistivity of the soil and the magnitude of the induced potential and current that the designer expects the structure to encounter under all possible conditions.

4.4.2 When an independent metallic structure or its grounding system is in close proximity to an existing grounded structure, an electrical hazard may develop for any person contacting both structures or their grounds simultaneously. In such cases, both grounding systems shall be connected, either directly or through a DC decoupling device, unless it is determined that such a connection is undesirable. The electrical and CP designers should both be involved with this evaluation. For more details on designing systems for independent structures, see IEEE Standard 80.[4]

4.5 Bonding to Existing Structures

4.5.1 One available means of reducing induced AC potentials on a structure involves bonding the structure to the power system ground through adequately sized cables and decoupling devices. Such bonds may, under fault conditions, contribute to increased potentials and currents on the affected structure for the duration of the fault. If the bonded structure is aboveground, or well-insulated from earth, elevated potentials may be created and exist temporarily along the entire length of the bonded structure. In such instances, additional protective devices may be required outside the immediate area of the origin of electrical effects. Close coordination should be maintained with all other utilities in the area, especially with those utilities to which bond connections are proposed. The corresponding utilities shall be notified in advance of the need to bond to their structures and shall be furnished with details of the proposed bonding arrangements. A utility may prefer to have the connection to its structures made by its own personnel. Other methods of reducing AC potentials should be considered before committing to bonding. The increased hazards during fault conditions and extra installation requirements may make this method questionable from safety and economic perspectives.

4.5.2 Whenever such a bond is installed, full consideration must be given to mitigation of hazardous AC transferred to the influenced structure.

4.6 Distributed Anodes

4.6.1 Whenever distributed galvanic anodes are used as part of the grounding system to reduce the AC potential between a structure and earth, they should be installed in close proximity to the protected structure and away from power system grounds. Connecting anodes directly to the affected structure, without test connections, may be desirable. However, the CP design and monitoring requirements must be verified to be compatible with this type of circuitry. Direct connection reduces the number of points at which people can come in contact with the structure and offers the shortest path to ground. If it is desirable for measurement purposes to open the circuit between the distributed grounding system and the structure, the test lead connection should be made in an accessible dead-front test box. When galvanic anodes are used as part of a grounding system, the useful life of the electrode material should be considered. Normal deterioration and consumption of the anode material increases the grounding system resistance.

4.7 Casings

4.7.1 Bare or poorly coated casings may be deliberately connected to a coated structure through a DC decoupling device to lower the impedance of the structure to earth during steady state and surge conditions and to avoid arcing between the structure and the casing. Any exposed and accessible portion, including metallic casing vents, should be considered as an aboveground appurtenance.

CAUTION: Choosing not to interconnect a pipeline to a casing through a DC decoupler on a pipeline subjected to AC interference could result in accelerated AC corrosion at holidays in a coating on a carrier pipe.

4.8 Connector (Electrical and Mechanical) and Conductor Sizes

4.8.1 All anodes, bonds, grounding devices, and jumpers must have secure, reliable, low-resistance connections to themselves and to the devices to which they are attached. Structure members with rigid bolted, riveted, or welded connections may be used in lieu of a bonding cable for part or all of the circuit. Steady-state conductor sizing should consider the AC load with the mitigation applied. For adequate fault sizing of conductors, refer to Table 1 and Figures 1, 2, 3, and 4. For wire gauge conversions, refer to Table A1 in Appendix A (nonmandatory). All cables, connections, and structural members should be capable of withstanding the maximum anticipated magnitude and duration of the surge or fault currents with mitigation applied.

Table 1
Maximum 60 Hz Fault Currents—Grounding Cables[A]

Cable Size	Fault Time	rms[C] Amperes		Cable Size	Fault Time	rms[C] Amperes	
AWG[B]	Cycles	Copper	Aluminum	AWG[B]	Cycles	Copper	Aluminum
1	15	10,550	6,500	3/0	15	26,500	16,500
	30	7,500	4,600		30	18,500	16,500
	60	5,300	3,200		60	13,000	8,000
1/0	15	16,500	10,500	4/0	15	30,000	21,000
	30	11,500	7,500		30	21,000	15,000
	60	8,000	5,300		60	15,000	10,000
2/0	15	21,000	13,000	250 MCM[D]	15	35,000	25,000
	30	15,000	9,000		30	25,000	17,500
	60	10,000	6,500				

[A] Based on 30 °C (86 °F) ambient and a total temperature of 175 °C (347 °F) established by the Insulated Cable Engineers Association (ICEA)[2] for short-circuit characteristic calculations for power cables. Values are approximately 58% of fusing currents.
[B] American Wire Gauge (AWG). For wire gauge conversions, refer to Table A1 in Appendix A (nonmandatory).
[C] Root mean square
[D] MCM = 1,000 circular mil

4.8.2 Mechanical connections for the installation of permanent protective devices should be avoided when practical except when they can be inspected, tested, and maintained in approved aboveground enclosures. When practical, field connections to the structure or grounding device should be made by the exothermic welding process or appropriate pin brazing methods. However, compression-type connectors may be used for splices on connecting wires. Mechanical connectors may be used for temporary protective measures, but extreme care should be taken to avoid high-resistance contacts. Soft-soldered connections are not acceptable in grounding circuits.

Figure 1 is based on the assumption that no heat is radiated or conducted from the cable to the surrounding media during a fault period. Electrical energy released in the cable equals the heat energy absorbed by the cable. This is illustrated in Equation (1):

$$I^2Rt = CFQ \tag{1}$$

where:

I = fault current in amperes
R = average AC resistance (in ohms) of conductor over temperature range T_1 to T_2 in °C (°F)
t = fault duration in seconds
Q = heat energy in kJ (BTU)
CF = conversion factor = 1,000 for SI units (1 W=J/s and 1,000 J/kJ) and 1,055 for U.S. units (1,055 W-s/BTU)

Q is calculated using Equation (2):

$$Q = CM\,(T_2 - T_1) \qquad \text{[Thermodynamics]} \tag{2}$$

where:

C = average specific heat in kJ/kg °C (BTU/lb °F) of annealed soft-drawn copper over the temperature range T_1 to T_2
M = mass of copper in kg (lb)
T_1 and T_2 = initial and final temperatures respectively in °C (°F).

[2] Insulated Cable Engineers Association (ICEA), P.O. Box 1568, Carrollton, GA 30112.

Figure 1 was developed using C = 0.104 BTU/lb °F, T_1 = 68 °F, and T_2 = 1,300 °F. Typical resistance values are shown in Table 2.

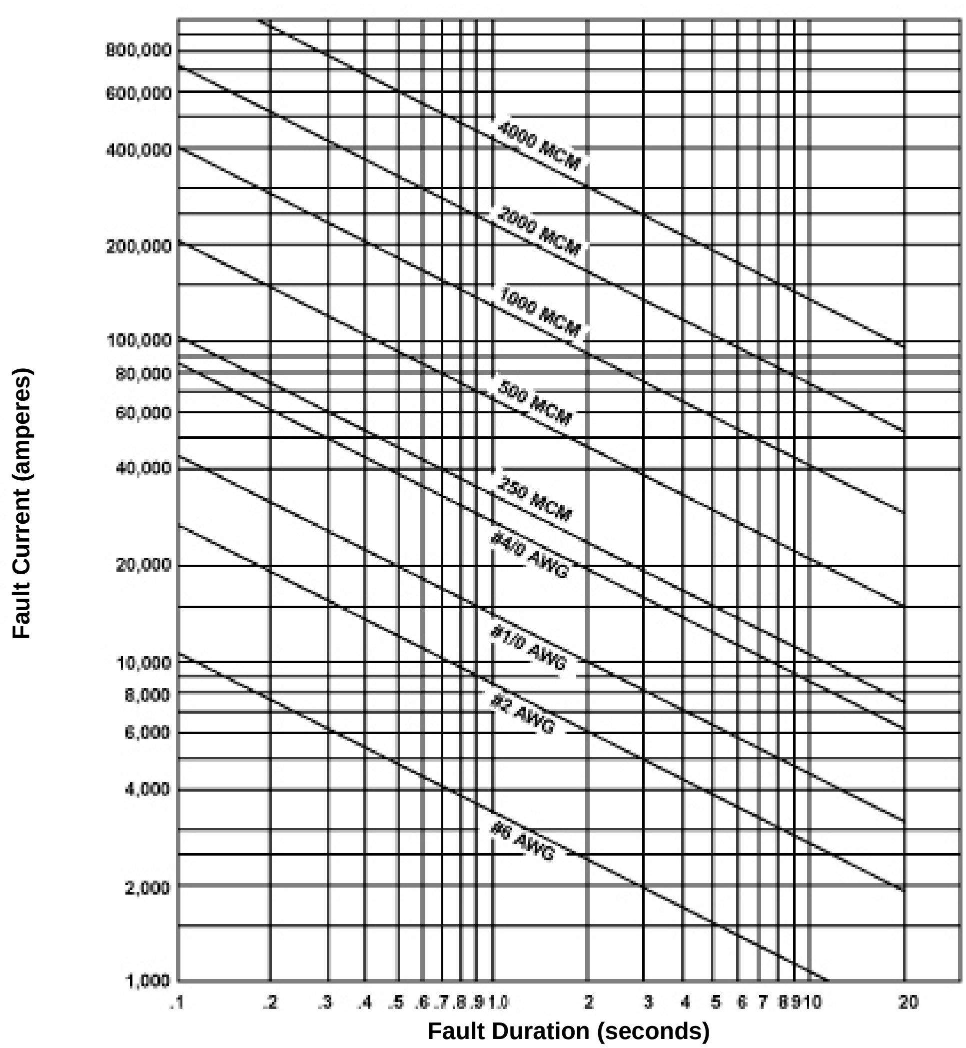


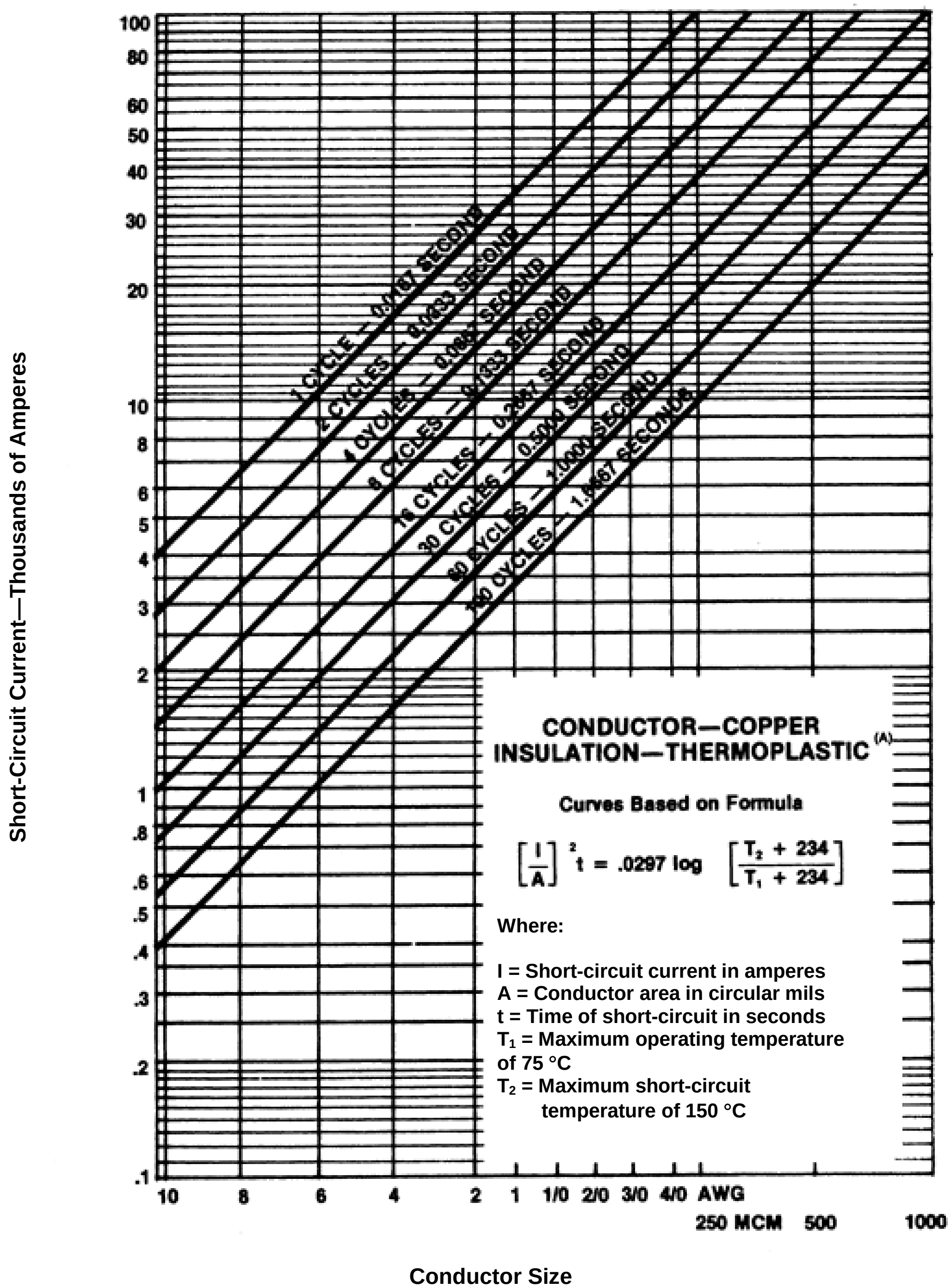
Figure 1: Approximate Current Required to Raise the Temperature of Stranded Annealed Soft-Drawn Copper Cable 684 °C (1,232 °F) Above an Ambient Temperature of 20 °C (68 °F)(3)

(3) This figure was developed by Ebasco Services, Inc. (now Raytheon Company, 870 Winter St., Waltham, MA 02451), who graciously allowed its publication in the original standard.

Table 2
Average Impedance for Various Conductor Sizes[A]

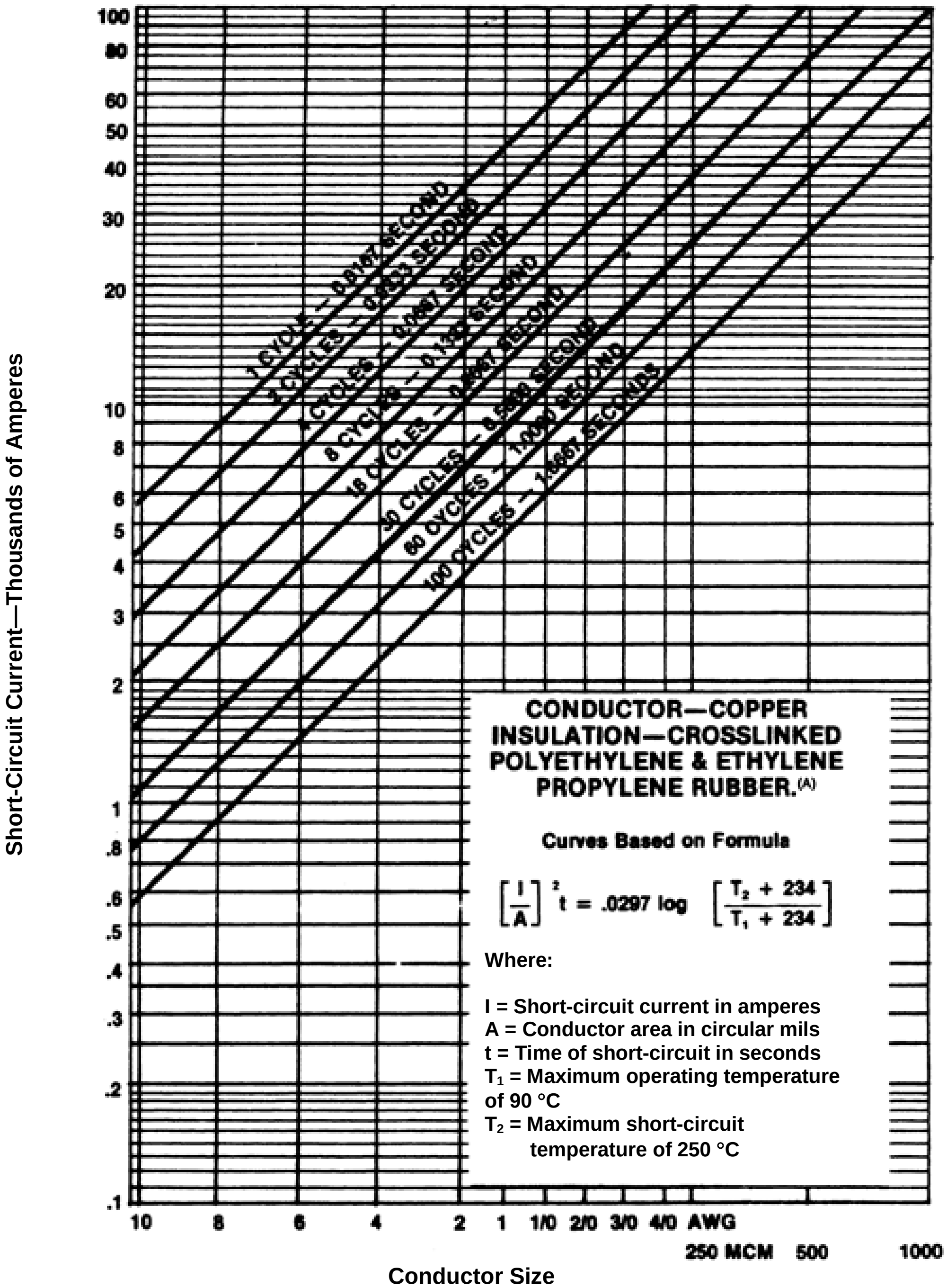
Conductor[B]	Average 60 Hz Impedance (Ohms/1,000 ft)	Average 60 Hz Impedance (Ohms/km)
#6 AWG	0.923	3.03
#2 AWG	0.366	1.20
#1/0 AWG	0.2295	0.753
#4/0 AWG	0.1097	0.360
250 MCM	0.0968	0.318
500 MCM	0.0492	0.161
1,000 MCM	0.0259	0.0850
2,000 MCM	0.0151	0.0495
4,000 MCM	0.00972	0.0319

[A] Fusing current is 10% higher than current for 684 °C (1,232 °F) temperature rise.
[B] For cable sizes in metric units, see Appendix A.



(A) To calculate this formula when the conductor sizes are in metric units, change metric values as indicated in Table A1, Appendix A to circular mil for A.

Figure 2: Allowable Short-Circuit Currents for Insulated Copper Conductors[7]



[(A)] To calculate this formula when the conductor sizes are in metric units, change metric values as indicated in Table A1, Appendix A to circular mil for A.

Figure 3: Allowable Short-Circuit Currents for Insulated Copper Conductors[7]

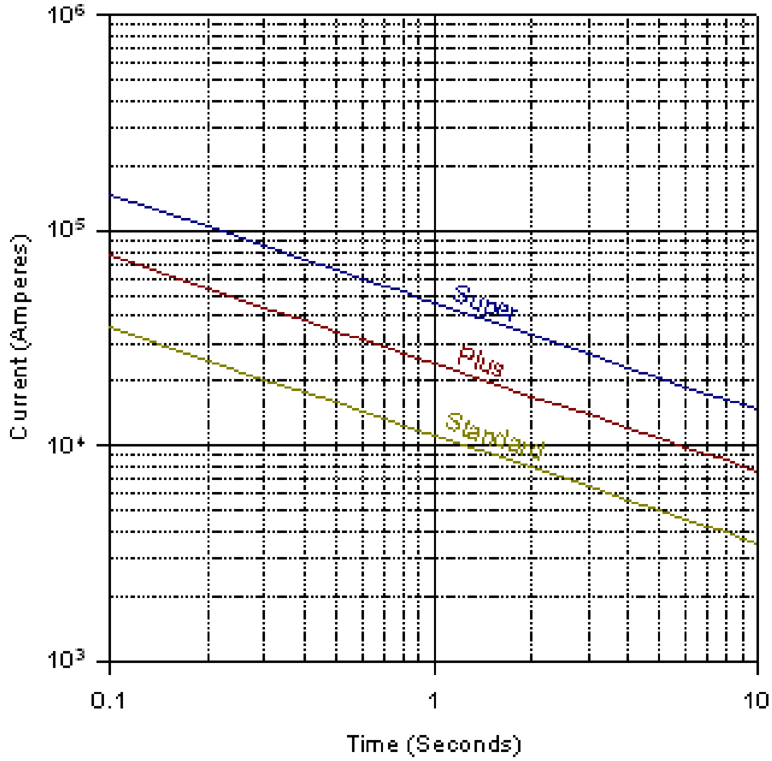


Figure 4: Zinc Ribbon Ampacity(4)
Experimental results for 60 Hz current required to raise the temperature of three sizes of cast- and rolled-zinc ribbon anode from 20 °C (68 °F) to 250 °C (482 °F).[8]

Super: 25.4 mm x 31.75 mm (1 in x 1.25 in)
Plus: 15.88 mm x 22.22 mm (0.625 in x 0.875 in)
Standard: 12.7 mm x 14.22 mm (0.50 in x 0.56 in)

Note: A design reduction factor should be determined by the user and applied in conjunction with the data in Figure 4, and connections to the ribbon steel core must be equivalent to the design ampacity requirement.

4.9 Isolation Joints

4.9.1 Although isolation joints (including flanges and fittings) can be installed to divide a structure into shorter electrical sections or to isolate a section adjacent to an AC power system from the remainder of the structure, this practice must be considered carefully for the specific application. When used to reduce the length of pipeline exposed to AC at the entrance and exit of AC right-of-ways, the beneficial grounding effect from the remaining pipeline is lost, and AC potentials may increase on the isolated section. The voltage is reduced in proportion to the length of the sections if used in the joint corridor; however, a potential hazard may exist across the isolation joint and as a minimum requires fault protection. Hazardous conditions may be transferred to the other side of isolating devices, where mitigation and protection measures may not be present during a fault even without protection devices. Therefore, the AC interference study and mitigation design shall not ignore pipe sections and appurtenances that are normally DC isolated. DC decouplers or other devices that continuously pass AC should be utilized in most cases of steady-state AC interference. In cases in which the steady-state concerns are low, but faults are a possibility, over-voltage protection devices that close during an electrical disturbance should be provided. The breakdown voltage for a typical isolation joint is in the range of 3 kV; however, arcing can occur at much lower voltages without dielectric breakdown. Arcing conditions must also be avoided in hazardous (classified) locations.

(4) Courtesy of the Platt Bros. and Company, Inc., 2670 S. Main St., Waterbury, CT 06721.

4.10 Electrolytic Grounding Cells, Solid-State DC Decouplers, Polarization Cells, and Other Devices

4.10.1 The coordinated selection and installation of electrolytic grounding cells, solid-state DC decouplers, polarization cells (2.5 V DC maximum threshold), or other devices between the affected structure and suitable grounds should be considered where arcing and induced AC potentials could develop. These devices may eliminate or greatly reduce the induced potentials resulting during normal operation or surge conditions and also reduce the possibility of arcing and structure damage. Polarization cells and solid-state DC decouplers should be considered for steady-state AC interference applications, as these devices pass AC continuously. The device and installation must be rated for the area classification, when installed in a hazardous location.

4.10.2 When polarization cells (2.5V DC maximum threshold), electrolytic grounding cells, solid-state DC decouplers, or other devices are used, they must be properly sized, located, connected, and physically secured in a manner that safely conducts the maximum amount of anticipated surge current. Cables connecting these devices to the structures shall be properly sized, as described in Paragraph 4.8.1. Cables should be kept as short and straight as possible. An adequately sized bypass circuit should be provided prior to any electrical isolation of the grounding device during testing and maintenance.

4.11 Over-Voltage Protectors

4.11.1 Surge arresters are available in many different types and for many applications. These include lightning arresters, spark gaps, and solid-state electronic devices. These devices may be used between structures and across pipeline electrical isolating devices, generally when steady-state interference is not a problem. However, one restriction to the use of arresters is that a potential difference develops before the arrester conducts. With certain types of arresters, this potential may be high enough to become hazardous to people coming in contact with the arrester. When arresters are used, they must be connected to the structure through adequately sized cables, as described in Paragraph 4.8.1. Arresters require a reliable, low-resistance ground connection. They should be located close to the structure being protected and have a short, straight ground path. Short lead length is especially important for lightning protection when the voltage build-up caused by lead induction can be significant. An adequately sized bypass circuit should be provided prior to any isolation of the grounding device during testing or maintenance.

4.11.2 Certain types of sealed, explosion-proof, enclosed, or repetitive transient arresters may be used in locations where a combustible atmosphere is anticipated, but only if it can be determined that the maximum possible power fault current does not exceed the design rating of the arrester. Open spark gaps shall not be used in these locations. The device and installation must be rated for the area classification, when installed in a hazardous location.

4.12 Stray Direct Current Areas

4.12.1 Galvanic anodes (including those in electrolytic grounding cells), grounding grids, or grounds directly connected to the structure may pick up stray DC in areas where stray direct currents are present. This current could possibly discharge directly to earth from the structure at other locations, resulting in corrosion of the structure at those points. Also, DC pickup by the structure could lead to DC discharge to earth through the galvanic anodes or grounding devices, resulting in increased consumption of the anode material or corrosion of grounding rods and an increase in their effective resistance to earth. The use of DC decoupling devices should be considered in these cases.

4.13 Coating Stress Voltage

4.13.1 External pipeline coatings can be subjected to stress voltages during a fault event on a nearby high-voltage power system. Both conductive and inductive components of a fault contribute to the stress voltage, with the conductive component acting on soil potentials and the inductive component acting on the pipeline steel potentials. Typically, the pipeline steel potential tends to be of opposite polarity to that of the earth potential so that the total coating stress voltage is on the same order as the sum of the magnitudes of the inductive and conductive components. Properly designed mitigation (i.e., grounding) can reduce the coating stress voltage to protect the coating from disbondment or damage. This, in effect, also provides some protection to the pipeline itself, as the tolerable coating stress voltages listed in Paragraph 4.13.2 do not exceed the conditions reported where there is risk of damage to the pipe.[9]

4.13.2 Limiting the coating stress voltage should be a mitigation objective. Expected threshold values for coatings differ with type and the cited reference and are generally considered to be in the range of 1 to 1.2 kV for bitumen,[10] as low as 3 kV for coal tar and asphalt,[11] and 3 to 5 kV for fusion-bonded epoxy (FBE)[11,12] and polyethylene,[12] for a short-duration fault.

4.14 Minimum Separation Distance

4.14.1 A lightning strike may initiate an arc from a power line structure ground to a nearby buried structure, which, if close enough, may sustain an ionized path for an ensuing phase-to-ground fault current. The fault current carries much more energy than the initial lightning current because of its much greater duration, and may result in severe damage to the buried structure. Laboratory testing has shown that shielding conductors connected to the buried structure cannot be relied on to intercept the power arc.[13] A minimum separation distance shall be maintained between powerline structure grounds and buried structures in order to ensure an arc initiated by lightning cannot be sustained by the fault current. The separation distance is measured from the nearest buried power system grounding conductor, which may extend beyond the tower foundation footings. Guy wire anchors that are electrically continuous with the power system grounding or shield wire shall be considered to be part of the power system grounding, as shall any buried structural steel or rebar in structural footings.

4.14.2 The sustainable arc length is a function of the GPR of the faulted power line structure and of the soil resistivity. Testing has been performed up to tower-ground-to-pipeline voltages of approximately 45 kV and power arcs were found to be sustained up to distances of up to 5.5 m (18 ft) at this voltage.[13]

4.14.3 It should be noted that it is common for power structure grounds of adjacent structures to be interconnected, with the result that the GPR value during fault conditions is only a fraction of the operating voltage of the power line. A study should be performed to determine the actual transmission line structure GPR during fault conditions and the resulting required separation distance to prevent a sustained power arc.

Section 5: Personnel Safety

5.1 Introduction

5.1.1 This section recommends practices that contribute to the safety of people who, during construction, system operation, corrosion survey, or CP maintenance of metallic structures, may be exposed to the hazards of AC potentials on those structures. The possibility of hazards to personnel during construction and system operation because of contact with metallic structures exposed to AC electrical or lightning effects must be recognized and provisions made to alleviate such hazards. The severity of the personnel hazard is usually proportional to the magnitude of the potential difference between the structure and the earth or between separate structures. The severity also depends on the duration of the exposure. Before construction work is started, coordination with the appropriate utilities in the area must be made so that proper work procedures are established and the construction does not damage or interfere with other utilities' equipment or operations. In some cases, the electric utility can shut down the electrical transmission facility or block the reclosing features. These possibilities should be explored with the electric utility.

5.1.2 The electric utility may designate a coordinator while the project is in progress.

5.1.3 Each utility should be aware of the others' facilities and cooperate in the mitigation of the electrical effects of one installation on the other. The mitigation required for a specific situation must be based on safety considerations with good engineering judgment.

5.1.4 Increasing the separation distance between facilities is generally effective in reducing the electrical effects of one installation on another.

5.2 Recognition of Shock Hazards to Personnel

5.2.1 AC potentials on structures must be reduced to and maintained at safe levels to prevent shock hazards to personnel. The degree of shock hazard and the threshold levels of current that can be tolerated by human beings depend on many factors. The possibility of shock from lower voltages is the most difficult to assess. The degree of shock hazard depends on factors such as the voltage level and duration of human exposure, human body and skin conditions, and the path and magnitude of any current conducted by the human body. The magnitude of current conducted by the human body is a function of the internal impedance of the voltage source, the voltage impressed across the human body, and the electrical resistance of the body path. This resistance also depends on the contact resistance (e.g., wet or dry skin, standing on dry land or in water), and on the current path through the body (e.g., hand-to-foot, hand-to-hand, etc.). Tables 3 and 4 indicate the probable human resistance to electrical current and current values affecting human beings.

Table 3
Human Resistance to Electrical Current[14]

Dry skin	100,000 to 600,000 ohms
Wet skin	1,000 ohms
Internal body—hand to foot	400 to 600 ohms
Ear to ear	about 100 ohms

Table 4
Approximate 60-Hz Alternating Current Values Affecting Human Beings

Current	Effects
1 mA or less	No sensation—not felt.
1 to 8 mA	Sensation of shock—not painful; individual can let go at will; muscular control not lost.
8 to 15 mA	Painful shock—individual can let go at will; muscular control not lost.
15 to 20 mA	Painful shock—muscular control lost; cannot let go.
20 to 50 mA	Painful shock—severe muscular contractions; breathing difficult.
50 to 100 mA	Ventricular fibrillation—Death results if prompt cardiac massage not administered.
100 to 200 mA	Defibrillator shock must be applied to restore normal heartbeat. Breathing probably stopped.
200 mA and over	Severe burns—severe muscular contractions; chest muscles clamp heart and stop it during shock. Breathing stopped—heart may start following shock, or cardiac massage may be required.

Source: Typical industry values

5.2.1.1 Safe limits must be determined by qualified personnel based on anticipated exposure conditions. For the purpose of this standard, a steady-state touch voltage of 15 V or more with respect to local earth at above-grade or exposed sections and appurtenances is considered to constitute a shock hazard.

5.2.1.2 It must be recognized that when touch voltages are below 15 V, the current may be dangerously high in the structure and continuity provisions and other procedures are mandatory prior to separating affected sections. All precautions must be implemented to eliminate the possibility of a person being placed in series with this current.

5.2.1.3 During short-circuit conditions, the permissible touch-and-step voltages at above-grade portions of the structure and appurtenances should be determined in accordance with the methodology specified in IEEE Standard 80[4] or other analogous methodologies, such as the International Electrotechnical Commission (IEC).[(5)]

5.2.1.4 In areas (such as urban residential zones or school zones) in which a high probability exists that children (who are more sensitive to shock hazard than are adults) can come in contact with a structure under the influence of induced AC voltage, a lower touch voltage shall be considered.

5.2.1.5 The beginning sensation of shock, which may occur at 1 to 8 mA, may not be painful or harmful to a human being, but may lead to an accident by causing rapid involuntary movement of a person.

5.2.2 In areas of AC influence, measured AC voltages between a structure and either an adjacent structure, a ground, or an electrolyte are considered an indication that further investigation is needed to determine whether AC mitigation is required.

5.2.3 When the touch voltage on a structure presents a shock hazard, the voltage must be reduced to safe levels by taking remedial measures. In those cases in which the voltage level cannot be practically reduced to a safe level on aboveground appurtenances by fault shields, gradient control wires, lumped grounding, AC continuity, etc., other safety measures shall be implemented to prevent shock to operating and maintenance personnel and to the public (see Paragraph 4.3) to satisfy the requirements in Paragraph 5.2.1. The use of dead-front construction may be utilized in lieu of gradient control mats for test stations and other CP equipment enclosures when approved by the owner; however, caution is advised, and it must be recognized that this does not reduce any hazardous voltage present.

(5) International Electrotechnical Commission (IEC), 3, rue de Varembé, P.O. Box 131, CH –1211, Geneva, Switzerland.

5.3 Construction

5.3.1 Severe hazards may exist during construction of facilities adjacent to AC power systems. A competent person shall be in charge of electrical safety. This person shall be fully aware of proper grounding procedures and of the dangers associated with inductive and capacitive couplings, fault current, lightning, etc., on aboveground and underground structures. The person must also know the hazards of the construction equipment being used as related to the "limit-of-the-approach" regulations governing them.[14] The person shall be furnished with the instrumentation, equipment, and authority required to implement and maintain safe working conditions.

5.3.2 The AC potential difference between a structure and the earth may be substantially reduced by appropriate grounding procedures. The AC potential difference between structures may be reduced by appropriate bonding procedures. The AC potential difference between separate points in the earth may be reduced through the use of appropriate grounding grids. The grounding or bonding procedure for safe construction activities depends on the type, magnitude, and duration of the AC exposure. Each situation shall be analyzed by a competent person, and safe operating procedures shall be employed during the entire construction operation.

5.3.3 During the construction of metallic structures in areas of AC influence, the following minimum protective requirements are prescribed:

(a) On long metallic structures paralleling AC power systems, temporary electrical grounds shall be used at intervals not greater than 300 m (1,000 ft), with the first ground installed at the beginning of the section. Under certain conditions, a ground may be required on individual structure joints or sections before handling.

(b) All temporary grounding connections shall be left in place until immediately prior to backfilling. Sufficient temporary grounds shall be maintained on each portion of the structure until adequate permanent grounding connections have been made.

5.3.4 Temporary grounding connections may be made to ground rods, bare pipe casing, or other appropriate grounds. These temporary grounding facilities are intended to reduce AC potentials. Direct connections made to the electrical utility's grounding system during construction could increase the probability of a hazard during switching surges, lightning strikes, or fault conditions, and may intensify normal steady-state effects if the grounding system is carrying AC; such connections should be avoided when possible.

5.3.5 Cables used for bonding or for connections to grounding facilities shall have good mechanical strength and adequate conductivity. As a minimum, copper conductor 35 mm^2 (0.054 in^2) (No. 2 AWG) stranded welding cable or equivalent should be used. See Table 1 and Figures 1, 2, and 3 for cable sizes adequate to conduct the anticipated fault current safely.

5.3.6 Temporary cable connections to the affected structure and to the grounding facilities shall be securely made with clamps that apply firm pressure and have a current-carrying capacity equal to or greater than that of the grounding conductor. Clamps shall be installed so that they cannot be accidentally dislodged.

5.3.7 All permanent cable connections shall be thoroughly checked to ensure that they are mechanically and electrically sound and properly coated prior to backfilling.

5.3.8 The grounding cable shall first be attached to the grounding facilities and then securely attached to the affected structure. Removal shall be in reverse order. Properly insulated tools or electrical safety gloves shall also be used to minimize the shock hazards. THE END CONNECTED TO THE GROUND SHALL BE REMOVED LAST.

5.3.8.1 In those instances in which high power levels are anticipated in the grounding cable, the following procedure should be used to prevent electrical arc burns or physical damage to the coating or metal on the structure.

(a) The grounding clamp shall be connected to the structure without the ground lead.

(b) The grounding cable shall first be connected to the grounding facility.

(c) Next, the grounding cable shall be connected to the grounding clamp on the structure.

5.3.9 All grounding attachments and removals shall be made by, or under the supervision of, the person in charge of electrical safety.

5.3.10 If hazardous AC potentials are measured across an isolating joint or flange, both sides of the joint or flange shall be grounded and/or bonded across. If required, a permanent bond shall be made before the temporary bond is removed.

5.3.11 Before the temporary grounding facilities are removed, provisions must be made to permanently control the effects of AC potentials on the affected structure. These provisions depend on the type of CP, the type of structure, and the anticipated magnitude of AC potentials.

5.3.12 Vehicles and other construction equipment are subject to existing electrical safety regulations, when operated in the vicinity of high-voltage AC lines.[15]

5.3.12.1 Metallic construction sheds or trailers, fences, or other temporary structures shall be grounded if subject to hazardous AC influence.

5.3.13 The person in charge of electrical safety shall communicate at least daily with the utility controlling the involved power lines to ascertain any switching that might be expected during each work period. This person may request that reclosing procedures be suspended during construction hours and may explore the possibility of taking the power line out of service. This person shall also be kept informed of any electrical storm activity that might affect safety on the work site. This person shall order a discontinuation of construction during local electrical storms or when thunder is heard.

5.3.14 The use of electrically isolating materials for aboveground appurtenances such as vent pipes, conduits, and test boxes may reduce shock hazards in specific instances. However, electrical wires permanently attached to the pipeline, such as CP test wires, may have a high possibility of a shock hazard because they cannot be isolated from the pipe (see Paragraph 7.2.6).

5.4 Operations and Maintenance

5.4.1 Maintenance of structures and CP facilities under conditions that include AC potentials may require special precautions. Warning signs shall be used as a minimum precaution. All maintenance shall be performed by or under the supervision of a person familiar with the possible hazards involved. Personnel must be informed of these hazards and of the safety procedures to follow.

5.4.2 Testing of devices intended to limit AC potentials shall be in accordance with manufacturer's recommendations and performed under the supervision of a person familiar with the possible hazards involved. In those areas in which the presence of combustible vapors is suspected, tests must be conducted before connections are made or broken to determine that the combustible vapor level is within safe limits. No more than one device intended to limit the AC potential should be disconnected at any one time. When a single protective device is to be installed, a temporary shunt bond, with or without another decoupling device, must be established prior to removing the unit for service.

5.4.3 Testing of CP systems under the influence of AC potentials must be performed by or under the supervision of a qualified person. In all cases, tests to detect AC potentials shall be performed first, and the structure shall be treated as a live electrical conductor until proven otherwise. CP records should include the results of these tests.

5.4.4 Test stations for CP systems on structures that may be subject to AC potentials shall have dead-front construction to reduce the possibility of contacting energized test leads. Test stations employing metallic pipes for support must be of dead-front construction.

5.4.5 Safe work practices must include attaching all test leads to the instruments first and then to the structure to be tested. Leads must be removed from the structure first and from the instruments last.

5.4.6 When structures subject to AC influence are exposed for the purpose of cutting, tapping, or separating, tests shall be made to determine AC potentials or current to ground. In the event that potentials or currents greater than those permitted by Paragraph 5.2 are found, appropriate remedial measures shall be taken to reduce the AC effects to a safe level. In the event this cannot be achieved, the structure shall be regarded as a live electrical conductor and treated accordingly. Solid bonding across the point to be cut or the section to be removed shall be established prior to separation, using as a minimum the cable and clamps outlined in Paragraphs 5.3.5 and 5.3.6.

5.4.7 On facilities carrying combustible liquids or gases, safe operating procedures require that bonding across the sections to be separated precede structure separation, regardless of the presence of AC.

Section 6: AC and Corrosion Control Considerations

6.1 Introduction

6.1.1 This section recommends practices for determining the level of AC influence and lightning effects to which an existing metallic structure may be subjected. This section also outlines several points for consideration regarding the effects these potentials may have on corrosion control systems and associated equipment.

6.2 Determination of AC Influence and Lightning Effects

6.2.1 A CP system design should include an evaluation to estimate the level of AC potentials and currents under normal conditions, fault conditions, and lightning surges. Because significant AC potentials may be encountered during field surveys, all personnel shall follow proper electrical safety procedures and treat the structure as a live electrical conductor until proven otherwise.

6.2.2 Tests and investigations to estimate the extent of AC influence should include the following:

(a) Meeting with electric utility personnel to determine peak load conditions and maximum fault currents and to discuss test procedures to be used in the survey.

(b) Electrical measurement of induced AC potentials between the affected structure and ground.

(c) Electrical measurement of induced AC current on the structure.

(d) Calculations of the potentials and currents to which the structure may be subjected under normal and fault conditions.[16]

6.2.3 A survey should be conducted over those portions of the affected structure in which AC exposure has been noted or is suspected. The location and time that each measurement was taken should be recorded.

6.2.3.1 The potential survey should be conducted using a suitable AC voltmeter of proper range. Contact resistance of connections should be sufficiently low to preclude measurement errors because of the relationship between external circuit impedance and meter impedance. Suitable references for measurements are:

(a) A metal rod.[(6)]

(b) Bare pipeline casings, if adequately isolated from the carrier pipe.

(c) Tower legs or power system neutrals, if in close proximity to the affected structure. (Meter connections made to tower legs or power system neutrals may present a hazard during switching surges, lightning strikes, or fault conditions.)

6.2.3.2 The presence of AC on a structure may be determined using a suitable AC voltmeter to measure voltage (IR) drop at the line current test stations. This method, however, provides only an indication of current flow, and cannot be readily converted to amperes because of the AC impedance characteristics of ferromagnetic materials. A clamp-on AC ammeter may be used to measure current in temporary or permanent bond and ground connections. Instrumentation with sufficient resolution may be used to measure current at buried coupons that are connected to the structure to provide an indication of the local AC leakage current density.

6.2.3.3 Indications of AC power levels on affected structures may be obtained by temporarily bonding the structure to an adequate ground and measuring the resulting current flow with a clamp-on AC ammeter while measuring the AC potential. Suitable temporary grounds may be obtained by bonding to tower legs, power system neutral, bare pipeline casings, or across an isolating joint to a well-grounded system. DC drainage bonds existing on the structure under investigation should also be checked for AC power levels.

[(6)] Following meter hookup, the reference rod should be inserted deeper into the earth until no further potential increase is noted. This reduces the possibility of high-resistance contact errors in the measurement.

6.2.3.4 Locations indicating maximum AC potential and current flow values during the survey discussed in Paragraphs 6.2.3 through 6.2.3.2 should be surveyed with recording instruments for a period of 24 hours or until the variation with power line load levels has been established.

6.2.3.5 These survey data should be reviewed with electric utility personnel for the purpose of considering the power line operating conditions at the time of the survey.

6.2.4 To facilitate AC interference studies and to design mitigation measures, the following data are typically required:

(a) Powerline cross-sectional dimensions, phasing, conductor types, and static wire bonding information;

(b) Powerline structure grounding details (including footings) and substation ground resistances;

(c) Substation and power plant grounding system dimensions, if close to pipelines;

(d) Single line diagrams for power lines within interference corridor;

(e) Single phase-to-ground currents for representative faults on all power lines;

(f) Load current details for all power lines, including maximum load unbalance and system operating frequency;

(g) Maximum fault clearing time for each power line;

(h) Details on nearby power plants fed by any of the pipelines in the interference corridor;

(i) Alignment drawings of pipelines and appurtenances, power lines and structures, and power line installations (substations and power plants) throughout the common corridor and up to extremities of pipelines and power lines;

(j) Pipeline characteristics, dimensions, and design information;

(k) Soil resistivity measurements up to pin (electrode) spacings of 100 m (328 ft) or more at representative locations throughout the common corridor;

(l) Drawings and locations of exposed appurtenances (scraper traps, valves, metering stations, etc.);

(m) Pipeline coating resistance and coating characteristics and thickness; and

(n) CP anode bed locations, dimensions, and design information.

6.3 Special Considerations in CP Design

6.3.1 AC influence on the affected structure and its associated CP system should be considered.

6.3.2 CP survey instruments should have sufficient AC rejection to provide accurate DC data.

6.3.3 The AC in the structure to be protected may flow to ground through CP equipment. Current flowing in the CP circuits under normal AC power system operating conditions may cause sufficient heating to damage or destroy the equipment. Heating may be significantly reduced by the use of properly designed series inductive reactances or shunt capacitive reactances in the CP circuits.

6.3.3.1 Rectifiers should be equipped with lightning and surge protection at the AC input and DC output connections. Efficiency filters appear to be of value in lightning areas.

6.3.3.2 Resistance bonds for the purpose of DC interference mitigation should be designed for the maximum normal AC and DC current flow to prevent damage to the bond. Installation of solid state DC decouplers, polarization cells, or other devices in parallel with DC resistance bonds may prevent damage to bonds. Installation of semiconductors in DC interference bonds between cathodically protected structures may result in undesirable rectification.

6.3.3.3 When bonds to other structures or grounds are used for AC considerations, the requirements as described in Paragraph 4.2.5 apply in order to maintain effective levels of CP.

6.3.3.4 Semiconductor drain switches (reverse current) for the mitigation of stray DC from transit systems should be provided with surge current protection devices.

6.3.4 In DC stray current areas, the grounding methods should be chosen to avoid creating interference problems.

Section 7: Special Considerations in Operation and Maintenance of Cathodic Protection and Safety Systems

7.1 Introduction

7.1.1 This section outlines safe maintenance and testing procedures for CP systems on structures subject to AC influence.

7.2 Operation and Maintenance of CP Systems

7.2.1 CP rectifiers that are subject to damage by adjacent electric utility systems may require inspections at more frequent intervals than rectifiers not subject to electric system influence.

7.2.2 CP testing or work of similar nature must not be performed on a structure subject to influence by an adjacent electric utility system during a period of thunderstorm activity in the area.

7.2.3 Positive measures must be taken to maintain continuous rectifier operation when repeated outages can be attributed to adjacent electric utility system influences. One or more of the following mitigation measures may be employed:

(a) Transient lightning arresters capable of repetitive operations across the AC input and DC output terminals.

(b) Heavy-duty choke coils installed in the AC and/or DC leads.

7.2.4 If galvanic anodes are used for CP in an area of AC influence, and if test stations are available, the following tests should be conducted during each structure survey using suitable instrumentation:

(a) Measure and record both the AC and DC current from the anodes.

(b) Measure and record both the AC and DC structure-to-electrolyte potentials.

7.2.5 At all aboveground pipeline metallic appurtenances, devices used to keep the general public or livestock from coming into direct contact with the structure shall be examined for effectiveness. If the devices are found to be ineffective, they shall be replaced or repaired immediately.

7.2.6 In making test connections for electrical measurements, all test leads, clips, and terminals must be properly insulated. Leads shall be connected to the test instruments before making connections to the structure. When each test is completed, the connections shall be removed from the structure before removing the lead connection from the instrument. All test connections must be made on a step-by-step basis, one at a time.

7.2.7 When long test leads are laid out near a power line, significant potentials may be induced in these leads. The hazards associated with this situation may be reduced by using the following procedures:

(a) Properly insulate all test lead clips, terminals, and wires.

(b) Avoid direct contact with bare test lead terminals.

(c) Place the reference electrode in position for measurement prior to making any test connections.

(d) Connect the lead to the reference electrode, and reel the wire back to the test location.

(e) Connect the other test lead to the instrument and then to the structure.

(f) Connect the reference electrode lead to the instrument.

(g) When the tests are complete, disconnect in reverse order.

NOTE: Close-interval pipe-to-electrolyte surveys using long lead wires require special procedures and precautions.

7.2.8 Tools, instruments, or other implements shall not be handed at any time between a person standing over a ground mat or grounding grid and a person who is not over the mat or grid.

7.2.9 Grounding facilities for the purpose of mitigating AC effects should be carefully tested at regular intervals to ascertain the integrity of the grounding system.

7.2.9.1 No disconnection or reconnection shall be allowed when a flammable or explosive atmosphere is suspected without first testing to ensure a safe atmosphere.

7.2.9.2 No one shall make contact with the structure, either directly or through a test wire, while a grounding grid is disconnected for test purposes.

7.2.9.3 Measurement of the resistance to earth of disconnected grounds shall be made promptly to minimize personnel hazards.

7.2.10 All interference mitigation devices and test equipment should be maintained in accordance with the manufacturer's instructions.

7.2.11 DC decouplers and their effects should be considered for DC pipe-to-soil voltage readings and coating holiday survey measurements. Waveform analysis may assist in determining these effects and whether corrective measures are required to obtain accurate measurements.

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Appendix A
Wire Gauge Conversions
(Nonmandatory)

This appendix is considered nonmandatory, although it may contain mandatory language. It is intended only to provide supplementary information or guidance. The user of this standard is not required to follow, but may choose to follow, any or all of the provisions herein.

Table A1 provides the nearest metric size for the conductor sizes mentioned in this standard.

Table A1
Wire Gauge Conversions[17]

Conductor Size	Diameter in mil	Nearest metric size (mm^2)	Diameter in mm of nearest metric size
4,000 MCM	2,000	2,000	50.5
2,000 MCM	1,410	1,000	35.7
1,000 MCM	1,000	500	25.2
500 MCM	707	240	17.5
250 MCM	500	120	12.4
4/0 AWG	460	120	12.4
3/0 AWG	410	80	10.01
2/0 AWG	365	70	9.44
1/0 AWG	325	50	7.98
1 AWG	290	50	7.98
2 AWG	258	35	6.68
4 AWG	204	25	5.64
6 AWG	162	16	4.51
8 AWG	128	10	3.57
10 AWG	102	6	2.76

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