

## Standard Recommended Practice

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

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## Foreword

This standard recommended 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 overhead 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 effects and alternating current effects on aboveground pipelines, while strung along the right-of-way prior to installation in the ground, is of particular importance to pipeline construction crews. The effects of overhead AC power lines on buried pipelines is of particular concern to operators of aboveground appurtenances and cathodic protection testers, 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 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.<sup>1</sup> 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 K.S. Gelges and C.F. Dalziel on muscular contraction, the inability to release contact would occur in the range of 6 to 20 milliamperes for adult males.<sup>2</sup> Ten milliamperes hand-to-hand or hand-to-foot is generally established as the absolute maximum safe let-go current. Conservative design would use an even lower value. Fifteen volts AC impressed across a 1,500-ohm load would yield a current flow of 10 milliamperes; thus the criterion within this standard is set at 15 volts. Prudent design would suggest an even lower value under certain circumstances.

This standard was originally published in July 1977 and was technically revised in 1983 and 1995. NACE International 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 to consider in future revisions of this standard. This edition of the standard was reaffirmed by Unit Committee T-10B on Interference Problems. The NACE technical committee structure changed in 2000, following the reaffirmation of this standard. This standard is issued in 2000 by NACE International under the auspices of STG 05 on Cathodic/Anodic Protection.

In NACE standard, the terms *shall*, *must*, *should* and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. *Should* is used that which is considered good and is recommended but is not absolutely mandatory. *May* is used to state that which is considered optional.

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**NACE International  
Standard  
Recommended Practice**

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

**Contents**

1. General .....	1
2. Definitions .....	1
3. Exposures and Effects of Alternating Current and Lightning .....	3
4. Design Considerations for Protective Devices .....	4
5. Personnel Protection .....	10
6. AC and Corrosion Control Considerations.....	13
7. Special Considerations in Operation and Maintenance of Cathodic Protection and Safety Systems .....	15
References.....	16
Bibliography .....	17
Appendix A—Wire Gauge Conversions.....	17

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## Section 1: General

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

1.2 This standard covers the 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 cathodic protection systems on structures subject to AC influence.

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 International if their professional activities include suitable experience in corrosion control on metallic structures.

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

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## 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 where appropriate.

**AC Exposure:** Alternating voltages and currents induced on a structure because of the alternating current (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 alternating current.

**Affected Structure:** Pipes, cables, conduits, or other metallic structures exposed to the effects of alternating current and/or lightning.

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

**Breakdown Potential:** A voltage potential in excess of the rated voltage that causes the destruction of a barrier film, coating, or other insulating material.

**Capacitive Coupling:** The association of two or more circuits with one another by means of a capacitance mutual to the circuits.

**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.

**Direct Current (DC) Decoupling Device:** A device used in electrical circuits that allows the flow of AC in both directions and stops or substantially reduces the flow of DC.

**Earth Current:** Electric current flowing in the earth.

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

**Electric Potential:** The voltage difference between two points.

**Electric Shield:** A housing, screen, or other object, usually electrically conductive, which is installed to substantially reduce the effects of electric fields on one side caused by devices or circuits on the other side of the shield.

**Electrolytic Grounding Cell:** A DC decoupling device consisting of two or more electrodes, commonly made of zinc, installed at a fixed spacing and resistively coupled through a prepared backfill mixture.

**Fault Current:** A current that flows from one conductor to ground or to another conductor due to an abnormal connection (including an arc) between the two. A fault current flowing to ground may be called a ground fault current.

## RP0177-2000

**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.

**Ground Electrode Resistance:** The ohmic resistance between a grounding electrode and remote earth.

**Ground Mat (Gradient Control Mat):** A system of bare conductors on or below the surface of the earth, so arranged and interconnected as to provide an area of equal potential within the range of step distances. (Metallic plates and grating of suitable area are common forms of ground mats.)

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

**Inductive Coupling:** The association of two or more circuits with one another by means of the mutual inductance of the circuits.

**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.

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

**Polarization Cell:** A DC decoupling device consisting of two or more pairs of inert metallic plates immersed in an aqueous electrolyte. The electrical characteristics of the polarization cell are high resistance to DC potentials and low impedance of AC.

**Potential:** See Electric Potential.

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

**Reclosing Procedure:** A procedure which 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.

**Reference Electrode:** An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

**Remote Earth:** A location on the earth far enough from the affected structure that the soil potential gradients associated with currents entering the earth from the affected structure are insignificant.

**Resistive Coupling:** The association of two or more circuits with one another by means of resistance (metallic 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 open-circuit AC potential is more than 15 V (root mean square [rms]) and capable of delivering 5 mA or more.

**Step Potential:** The voltage difference between two points on the earth's surface separated by a distance of one pace, which is assumed to be one meter, calculated in the direction of maximum potential gradient.

**Surface Potential Gradient:** The slope of a potential profile, the path of which intersects equipotential lines at right angles.

**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:** 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]).

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## 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 may 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 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 an insulating material may develop a significant AC potential across the coating.

### 3.3 Capacitive Coupling

3.3.1 The electric field associated with potentials on power conductors can develop a potential on an inadequately grounded structure in the vicinity of the power system. The potential that the structure attains because of capacitive coupling varies with the power conductor potential and depends on many factors, including the geometric configurations of the structures involved. During construction, when the structure is aboveground or in an open trench, it may reach a dangerously high potential. When the structure is buried or submerged, the capacitive coupling effect usually is not significant unless (1) the soil resistivity is high, (2) the structure is electrically isolated, or (3) the structure is very long.

### 3.4 Inductive Coupling

3.4.1 AC current flow in power conductors produces an alternating magnetic field around these conductors. Thus, an AC potential can be induced in an adjacent structure within this magnetic field, and current may flow in that structure. The magnitude of the induced potential depends on many factors including the overall geometric configuration of the structures involved, the magnitude of the current in the power circuit, and any current imbalance. If the

currents in a three-phase power system are equal (balanced) and the affected structure is equidistant from each of the conductors, the total induced voltage is zero. This, however, is seldom the case, and induced AC voltage is usually present on the affected structure. Greater electromagnetically induced potentials may occur during a phase-to-ground or phase-to-phase fault in multiphase circuits because of the higher magnitude of fault current in these systems. The leakage conductance to ground, caused by the resistive coupling of the affected structure, allows AC current to flow between that structure and earth. This phenomenon, combined with other factors, results in different values of AC structure-to-electrolyte potential along the affected structure. The higher the dielectric strength and resistance of the coating and the higher the soil resistivity, the greater the induced AC potential.

### 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 the resulting potential to which the structure is subjected exceeds breakdown potential of any circuit element, a power arc can occur and damage the circuit elements. Elements of specific concern include coatings, isolating fittings, bonds, lightning arresters, and cathodic protection facilities.

### 3.6 Lightning

3.6.1 Lightning strikes on the power system can initiate fault current conditions. Lightning strikes to a structure or to earth in the vicinity of a structure can 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.

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## Section 4: Design Considerations for Protective Devices

### 4.1 Introduction

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

4.1.2 The methods listed can be used to mitigate the problems of power arcing, lightning arcing, resistive coupling, inductive coupling, and capacitive coupling.<sup>3, 4, 5</sup>

### 4.2 Electrical Shields

4.2.1 Shields are intended to protect the structures from arcing effects that may be produced in the earth between AC power systems and affected metallic structures, thus reducing the possibility of puncturing the coating and/or structure under surge conditions.

4.2.2 Among the factors that influence the design of electrical shields are 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.

4.2.3 Shields may consist of one or more electrodes installed parallel to and/or encircling an affected structure at specific locations or along its entire length. Some types of shields, such as those made of an anodic material, must be electrically connected to the affected structure. Shields of the parallel or encircling anode type shall be connected to the structure at least at the end points of the shield. Shields constructed of materials that are cathodic to the protected structure must be connected to the structure through a DC decoupling device.

4.2.4 Other types of electrical shields can be designed for protection against surges on miscellaneous underground or aboveground structures. A long, buried, bare conductor can be used effectively as a shield.

### 4.3 Grounding Mats

4.3.1 Grounding mats, bonded to the structure, are used to reduce electrical step and touch potentials in areas where people may come in contact with a structure subject to hazardous potentials. Permanent grounding mats bonded to the structure may be used at valves, metallic vents, cathodic

protection test stations, and other aboveground metallic and nonmetallic appurtenances where electrical contact with the affected structure is possible.

4.3.2 Grounding mats should be large enough to extend through and beyond the entire area on which people may be standing when contacting the affected structure. They should be installed close enough to the surface so that step and touch potentials are adequately reduced for individuals coming in contact with the structure.<sup>6</sup>

4.3.3 Grounding mats, regardless of materials of construction, must be bonded to the structure, preferably at more than one point. If cathodic protection 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 effectiveness of the grounding mat in reducing AC potentials and of its effects on the cathodic protection system. Care should be taken to prevent the possible establishment of detrimental galvanic cells between the grounding 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 step and touch potentials. The thickness of the bed should be no less than 8 cm (3 in.). Gravel should be a minimum of 1.3 cm (0.5 in.) in diameter. The hazards of step potentials 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 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 properly interconnect all components of the structure to be grounded. 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 which 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 and/or their grounds simultaneously. In such cases, both grounding systems should be connected, either directly or through a DC decoupling device, unless it is determined that such a connection is undesirable. For more details on designing systems for independent structures, see IEEE<sup>(1)</sup> Standard 80.<sup>3</sup>

#### 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 and 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 this one. The increased hazards during fault conditions and extra installation requirements may make this method questionable from safety and economic perspectives.

#### 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. Direct connection reduces the number of points at which people can come in contact with the structure, and offers the shortest path to ground. Should it be 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. Dissipation 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 surge conditions and to avoid arcing between the structure and the casing.

#### 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. For adequate sizing of bonding cables, refer to Table 1 and Figures 1, 2, and 3. All cables, connections, and structural members should be capable of withstanding the maximum anticipated magnitude and duration of the surge or fault currents.

4.8.2 Mechanical connections for the installation of permanent protective devices should be avoided, where practical, except where they can be inspected, tested, and maintained in approved aboveground enclosures. Where practical, field connections to the structure and/or grounding device should be made by the exothermic welding process. 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):

$$I^2Rt = 1,055 Q \text{ (watt seconds = BTU)} \quad (1)$$

where I = fault current in amperes, R = average AC resistance (in ohms) of conductor over temperature range T<sub>1</sub> to T<sub>2</sub> (in degrees Fahrenheit), t = fault duration in seconds, and Q = heat energy in British Thermal Units. Q is calculated using Equation (2):

$$Q = CM (T_2 - T_1) \text{ (Thermodynamics)} \quad (2)$$

<sup>(1)</sup> Institute of Electrical and Electronics Engineers (IEEE), 3 Park Avenue, 17<sup>th</sup> Floor., New York, NY 10016-5997.

**Table 1: Maximum 60 Hz Fault Currents—Grounding Cables<sup>(A)</sup>**

Cable Size AWG <sup>(B)</sup>	Fault Time Cycles	rms Amperes		Cable Size AWG	Fault Time Cycles	rms Amperes	
		Copper	Aluminum			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	15	35,000	25,000
	30	15,000	9,000		30	25,000	17,500
	60	10,000	6,500				

<sup>(A)</sup> Based on 30°C (86°F) ambient and a total temperature of 175°C (347°F) established by Insulated Cable Engineers Association (ICEA)<sup>(2)</sup> for short-circuit characteristic calculations for power cables. Values are approximately 58% of fusing currents.

<sup>(B)</sup> American Wire Gauge (AWG)

where C = average specific heat in BTU/([lb][°F]) of annealed soft-drawn copper over the temperature range T<sub>1</sub> to T<sub>2</sub>, M = mass of copper in pounds, T<sub>1</sub> and T<sub>2</sub> = initial and final temperatures respectively in degrees Fahrenheit. Figure 1 was developed using C = 0.104 BTU/([lb][°F]), T<sub>1</sub> = 68°F, and T<sub>2</sub> = 1,300°F.<sup>(3)</sup> Typical resistance values are shown in Table 2.

#### 4.9 Isolating Joints

4.9.1 Isolating joints may be installed to divide the structure into shorter electrical sections or to isolate a section adjacent to an AC power system from the remainder of the structure. Isolating joints installed in areas where a possibility of damage exists because of induced AC potentials or fault currents should have lightning arresters, polarization cells, electrolytic grounding cells, or similar protective devices installed across the joints. The threshold voltage characteristics of lightning arresters should be considered, and installation should include personnel protection such as dead-front construction. (The AC and DC isolation provided by isolating joints is not provided during the conducting mode of some protective devices.)

#### 4.10 Electrolytic Grounding Cells, Polarization Cells, and Other Devices

4.10.1 The coordinated selection and installation of electrolytic grounding cells, 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 puncture.

4.10.2 Where electrolytic grounding cells, polarization cells (2.5-V DC maximum threshold), or other devices are used, they should be properly sized, spaced, 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 shunting circuit should be provided to permit electrical isolation of the grounding device during testing and maintenance.

#### 4.11 Lightning Arresters and Metal Oxide Varistors (MOVs)

4.11.1 Lightning arresters and MOVs may be used between structures and across pipeline electrical isolating devices. However, one restriction to the use of lightning arresters is that a potential difference has to develop 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 lightning arresters are used, they must be connected to the structure through adequately sized cables as described in Paragraph 4.8.1. Lightning arresters should always be provided with a reliable, low-resistance ground connection. They should be located close to the structure being protected and have a short, straight ground path. An adequately

<sup>(2)</sup> Insulated Cable Engineers Association (ICEA), P.O. Box 440, South Yarmouth, MA 02664.

<sup>(3)</sup> To calculate Q using metric units:

1. Find C (average specific heat) in "(cal/g)(°C)" or "BTU/([lb][°F])" from handbook tables.
2. Substitute M (mass) with "0.002205 x M<sub>(g)</sub>" where M<sub>(g)</sub> = mass of copper in grams.
3. Substitute T<sub>1</sub> = (°C<sub>1</sub> + 17.78)(1.8) and T<sub>2</sub> = (°C<sub>2</sub> + 17.78)(1.8).

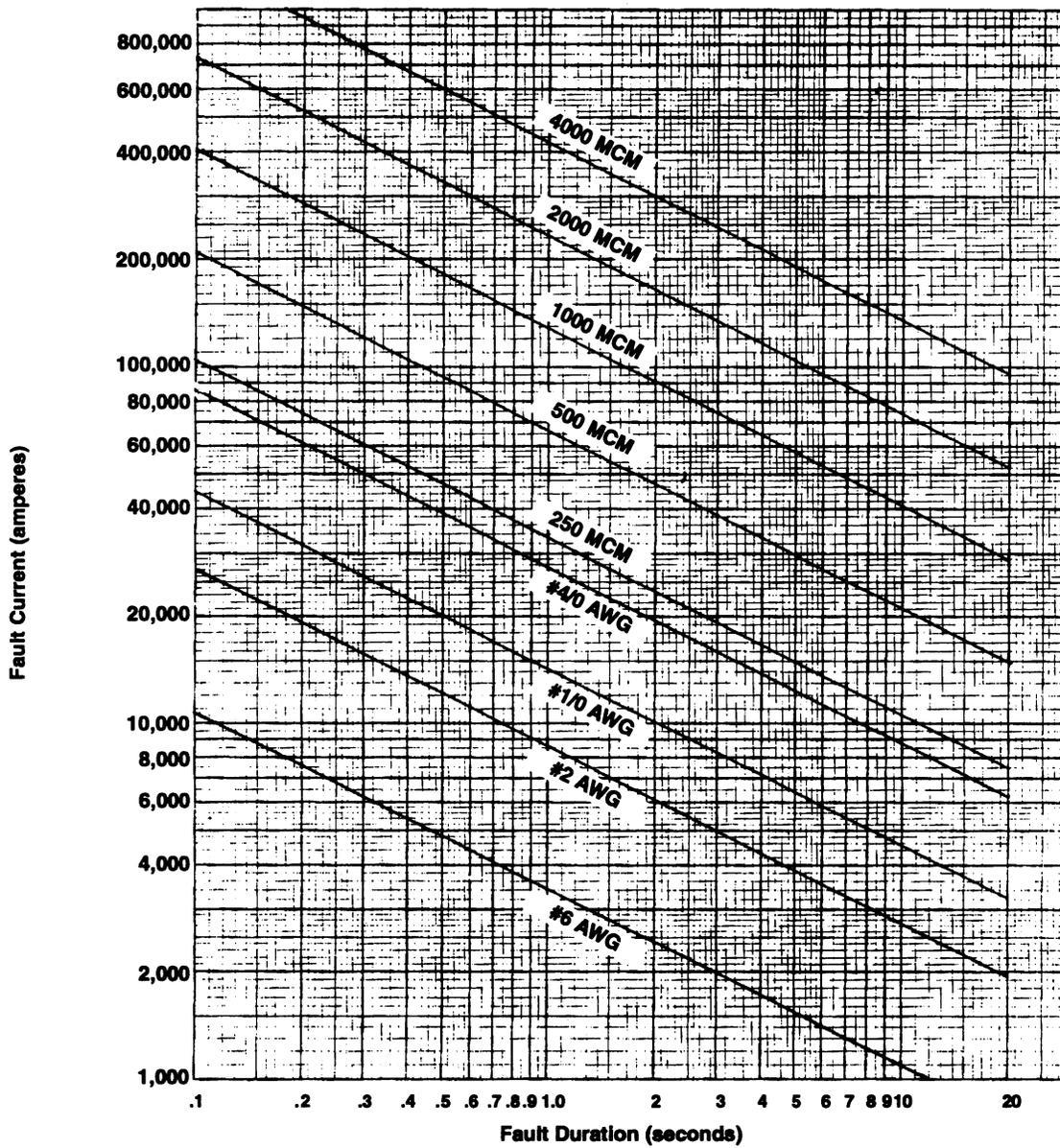


Figure 1—Approximate current required to raise the temperature of stranded annealed soft-drawn copper cable 684°C (1,232°F) above an ambient temperature of 20°C (68°F)

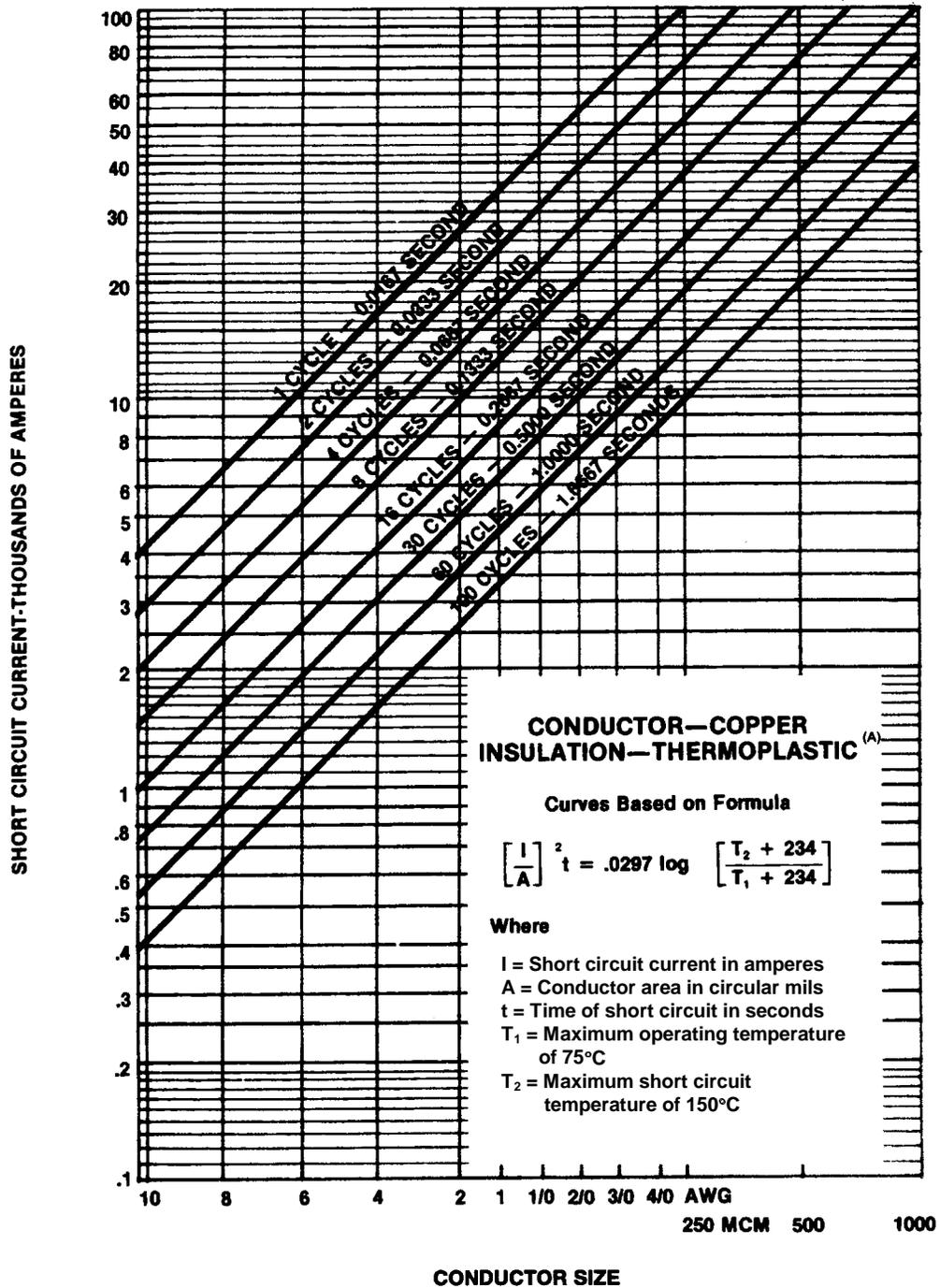
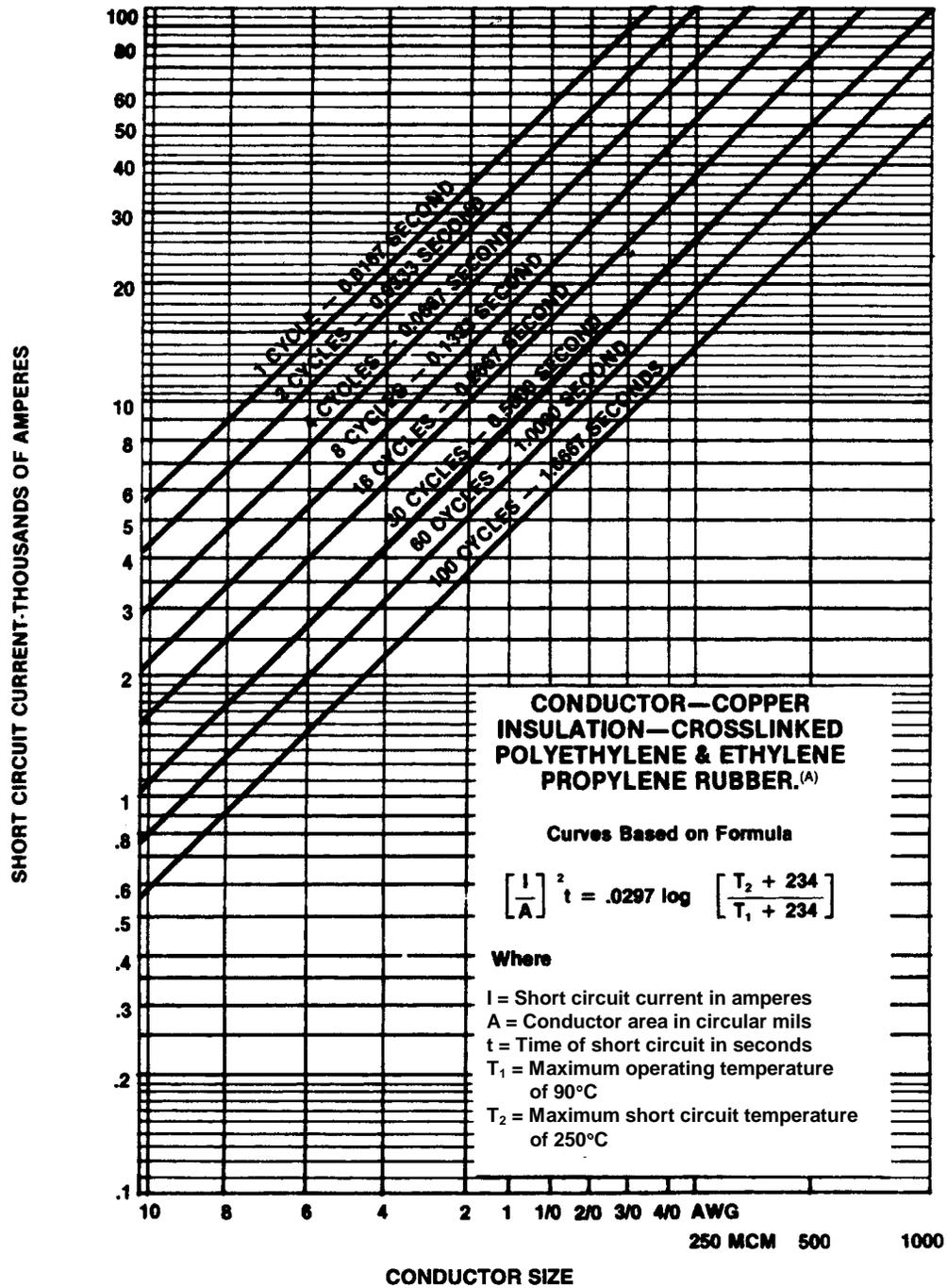


Figure 2 — Allowable short circuit currents for insulated copper conductors.

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<sup>(A)</sup> To calculate this formula using metric units, change A to metric values as indicated in Table A1, Appendix A.



**Figure 3 — Allowable short circuit currents for insulated copper conductors.**

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<sup>(A)</sup> To calculate this formula using metric units, change A to metric values as indicated in Table A1, Appendix A.

**Table 2: Average Impedance for Various Conductor Sizes<sup>(A)</sup>**

<b>Conductor<sup>(B)</sup></b>	<b>Average 60-Hz Impedance (Ohms/1,000 ft)</b>	<b>Average 60-Hz Impedance (Ohms/km)</b>
#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

<sup>(A)</sup> Fusing current is 10% higher than current for 684°C (1,232°F) temperature rise.

<sup>(B)</sup> For cable sizes in metric units, see Appendix A.

sized shunting circuit should be provided to permit isolation of the grounding device during testing or maintenance.

4.11.2 Certain types of sealed, explosion-proof, enclosed, or self-healing lightning 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.

4.12 Stray Direct Current Areas

4.12.1 In areas where stray direct currents are present, galvanic anodes (including those in

electrolytic grounding cells), grounding grids, or grounds directly connected to the structure may pick up stray direct current. This current could possibly discharge directly to earth from the structure at other locations, resulting in corrosion of the structure at those points. Also, direct current pickup by the structure could lead to direct current 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.

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**Section 5: Personnel Protection**

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 cathodic protection 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 and/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.<sup>(4)</sup>

5.1.2 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.

5.1.3 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

<sup>(4)</sup> In some cases, the electric utility can shut down the electrical transmission facility or block the reclosing features. The utility may designate a coordinator while the project is in progress. These possibilities should be explored with the electric utility.

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.).

5.2.1.1 The safe limits must be determined by qualified personnel based on anticipated exposure conditions. For the purpose of this standard, 15 V AC (rms) open circuit or a source current capacity of 5 mA or more are considered to constitute an anticipated shock hazard. 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<sup>(A)</sup>**

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

<sup>(A)</sup> Reprinted with permission from the National Safety Council. *Accident Prevention Manual for Business & Industry: Engineering & Technology*, 10th ed. Itasca, IL: National Safety Council, 1992.

**TABLE 4: 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 (possible)	Ventricular fibrillation—Death will result if prompt cardiac massage not administered.
100 to 200 mA (certain)	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 (ventricular fibrillation if prevented). Breathing stopped—heart may start following shock, or cardiac massage may be required.

Source: Unknown

5.2.1.2 In areas (such as urban residential zones or school zones) where 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 voltage shall be considered.

5.2.1.3 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, any measured AC voltages between a structure and ground (or some other adjacent structure) shall be considered an indication that further study is required.

5.2.3 When the voltage level on a structure presents a shock hazard, the voltage level must be reduced to safe levels by taking remedial measures. In those cases in which the voltage level cannot be reduced to a safe level on aboveground appurtenances, other safety measures shall be practiced to prevent shock to operating and maintenance personnel and to the public (see Paragraph 4.3).

5.3 Construction

5.3.1 Severe hazards may exist during construction of facilities adjacent to AC power systems. A responsible 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.<sup>6</sup> 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 can be substantially reduced by appropriate grounding procedures. The AC potential difference between structures can be reduced by appropriate bonding procedures. The AC potential difference between separate points in the earth can be reduced through the use of appropriate grounding grids. The grounding or bonding procedure for safe construction activities depends upon 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<sup>2</sup> (0.054-in.<sup>2</sup>) (No. 2 AWG) stranded welding cable or equivalent is recommended. 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 bonding cable, the following procedure is recommended to prevent electrical arc burns or physical damage to the coating or metal on this pipe.

(a) The pipe grounding clamp shall be connected to the pipeline.

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

(c) 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 cathodic protection, 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.<sup>6</sup>

5.3.12.1 Metallic construction sheds or trailers, fences, or other temporary structures shall be grounded if subject to 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. The person shall also keep informed of any electrical storm activity that might affect safety on the work site. The 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 cathodic protection 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 cathodic protection 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 where 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 cathodic protection 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. Cathodic protection records should include the results of these tests.

5.4.4 Test stations for cathodic protection 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.

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**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 cathodic protection 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.<sup>5</sup>

6.2.3 A survey should be conducted over those portions of the affected structure where 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.<sup>(5)</sup>
- (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 connections.

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.

6.2.3.4 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.<sup>(6)</sup>

6.2.4 In designing mitigative measures, the following power system parameters should be determined:

- (a) Maximum operating and emergency load conditions.
- (b) Maximum single line-to-ground fault current and duration.
- (c) Maximum phase-to-phase fault current and duration.
- (d) Type of grounding system used.

### 6.3 Special Considerations in Cathodic Protection Design

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

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

<sup>(5)</sup> 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.

<sup>(6)</sup> Survey data gathered in accordance with Paragraphs 6.2.3 through 6.2.3.4 should be reviewed with electric utility personnel for the purpose of correlating with the power-line operating conditions at the time of the survey.

6.3.3 The AC current in the structure to be protected may flow to ground through cathodic protection equipment. Current flowing in the cathodic protection 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 and/or shunt capacitive reactances in the cathodic protection circuits.

6.3.3.1 Rectifiers should be equipped with lightning and surge protection at the AC input and DC output connections.

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 in order to prevent damage to the bond. Installation of 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, polarization cells or grounding cells should be used, as required, in order to maintain effective levels of cathodic protection.

6.3.3.4 Semiconductor drain switches for the mitigation of stray DC from traction 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.

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## 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 cathodic protection systems on structures subject to AC influence.

### 7.2 Safety Measures for Operation and Maintenance of Cathodic Protection Systems

7.2.1 Cathodic protection rectifiers that are subject to damage by adjacent electric utility systems should be checked for proper operation at more frequent intervals than rectifiers not subject to electric system influence.

7.2.2 Cathodic protection 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 When repeated rectifier outages can be attributed to adjacent electric utility system influences, positive measures must be taken to maintain continuous rectifier operation. One or more of the following mitigative measures may be employed:

- (a) Self-healing lightning arresters 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 cathodic protection 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 currents 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:

## RP0177-2000

- (a) Properly insulate all test lead clips, terminals, and wires.
- (b) Avoid direct contact with bare test lead terminals.
- (c) Place the reference electrodes 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.

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## References

1. G. Bodier, Bulletin de la Societé Francaise Des Electriciens, October 1947.
2. C.F. Dalziel, "The Effects of Electrical Shock on Man," Transactions on Medical Electronics, PGME-5, Institute of Radio Engineers,<sup>(7)</sup> 1956. (Available from IEEE).
3. IEEE Standard 80 (latest revision), "Guide for Safety in AC Substation Grounding," (New York, NY: Institute of Electrical and Electronics Engineers Inc.).
4. NFPA<sup>(8)</sup> Standard 70 (latest revision), "National Electrical Code," (Quincy, MA: National Fire Protection Association). Also available from the American National Standards Institute (ANSI),<sup>(9)</sup> New York, NY.
5. ANSI Standard C2 (latest revision), "National Electrical Safety Code," (New York, NY: American National Standards Institute).
6. OSHA<sup>(10)</sup> Standard 2207, Part 1926 (latest revision), "Construction, Safety, and Health Regulations," (Washington, DC: Occupational Safety and Health Administration).
7. "Short-Circuit Characteristics of Insulated Cable," Insulated Cable Engineers Association Report, PR-32-382, 1994.
8. Mutual Design Considerations for Overhead AC Transmission Lines and Gas Transmission Pipelines, Volume 1: Engineering Analysis, and Volume 2: Prediction and Mitigation Procedures, AGA<sup>(11)</sup> Catalog No. L51278 (Arlington, VA: American Gas Association, 1978). Published in conjunction with The Electric Power Research Institute (EPRI).<sup>(12)</sup>

<sup>(7)</sup> The Institute of Radio Engineers (IRE) and the American Institute of Electrical Engineers (AIEE) merged in 1963 to form the Institute of Electrical and Electronics Engineers (IEEE).

<sup>(8)</sup> National Fire Protection Agency (NFPA), 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

<sup>(9)</sup> American National Standards Institute (ANSI), 11 W 42<sup>nd</sup> St., New York, NY 10036.

<sup>(10)</sup> Occupational Safety and Health Administration (OSHA), 200 Constitution Ave. NW, Washington, DC 20210.

<sup>(11)</sup> American Gas Association (AGA), 1515 Wilson Blvd., Arlington, VA 22209.

<sup>(12)</sup> Electric Power Research Institute (EPRI), 3412 Hillview Ave., Palo Alto, CA 94304-1395.

**Bibliography**

CGA<sup>(13)</sup> Standard OCC-3-1981 (latest revision). "Recommended Practice OCC-3-1981 for the Mitigation of Alternating Current and Lightning Effects on Pipelines, Metallic Structures, and Corrosion Control Systems." Toronto, Ontario, Canada: Canadian Gas Association.

Gummow, R.A., R.G. Wakelin, and S.M. Segall. "AC Corrosion – A New Challenge to Pipeline Integrity." CORROSION/98, paper no. 566. Houston, TX: NACE, 1998.

Inductive Interference Engineering Guide. Murray Hills, NJ: Bell Telephone Laboratories, March, 1974. (Available through local Bell System Inductive Coordinator.)

Lichtenstein, J. "AC and Lightning Hazards on Pipelines." *Materials Performance* 31, 12 (1992): pp. 19-21.

Lichtenstein, J. "Interference and Grounding Problems on Metallic Structures Paralleling Power Lines." Western States Corrosion Seminar Proceedings. Houston, TX: NACE, 1982.

Some Considerations During Construction Near Powerlines (latest revision), NACE Audio/Visual Presentation Prepared by Work Group T-10B-5a. Houston, TX: NACE, 1983.

Wakelin, R.G., R.A. Gummow, and S.M. Segall. "AC Corrosion – Case Histories, Field Testing and Mitigation." CORROSION/98, paper no. 565. Houston, TX: NACE, 1998.

Westinghouse Transmission and Distribution Handbook. Newark, NJ: Westinghouse Electric Corp., Relay-Instrument Div., 1950.

**Appendix A: Wire Gauge Conversions**

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

**Table A1: Wire Gauge Conversions**

Conductor Size	Diameter in mils	Nearest metric size (mm <sup>2</sup> )	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	10.04
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

Source: Fink and Carroll, Standard Handbook for Electrical Engineers, 10th ed. (New York, NY: McGraw-Hill, 1968).

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