



IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Locations

IEEE Power Engineering Society

Sponsored by the
Power System Communications Committee

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IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Locations

Sponsor

**Power System Communications Committee
of the
IEEE Power Engineering Society**

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Abstract: Workable methods for protecting wire-line communication circuits entering electric supply locations are presented. This document covers: the electric supply location environment; protection apparatus; service types, reliability, service performance objective classifications, and transmission considerations; protection theory and philosophy; protection configurations; installation and inspection; and safety.

Keywords: electric supply locations, high-voltage tower, power stations, protection, wire-line communication

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Introduction

This introduction is not a part of IEEE Std 487-2007, IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Locations.

Wire-line communication facilities serving electric supply locations often require special high-voltage protection against the effects of fault-produced ground potential rise or induced voltages, or both. Some of the telecommunication services are used for control and protective relaying purposes and may be called upon to perform critical operations at times of power system faults. This presents a major challenge in the design and protection of the telecommunication system because power system faults can result in the introduction of interfering voltages and currents into the telecommunication circuit at the very time when the circuit is most urgently required to perform its function. Even when critical services are not involved, special high-voltage protection may be required for both personnel safety and plant protection at times of power system faults. Effective protection of any wire-line telecommunication circuit requires coordinated protection on all circuits provided over the same telecommunication cable.

This recommended practice presents workable methods for protecting wire-line communication circuits entering electric supply locations. It is important to note that special high-voltage protection for the purpose of personnel safety and plant protection may be required even when critical services are not involved. In the case of leased circuits mutually agreeable methods for the installation of protective equipment owned by either party are presented.

The engineering design of optical fiber communication facilities serving, or connected to, electric supply locations is addressed in IEEE Std 1590-2003,^a IEEE Recommended Practice for the Electrical Protection of Optical Fiber Communication Facilities Serving, or Connected to, Electrical Supply Locations. IEEE Std 1590 includes methods for providing telecommunication facilities serving electric supply locations using optical fiber cables extending across the zone of influence.

This recommended practice has been prepared by the Wire-Line Subcommittee of the Power System Communications Committee of the IEEE Power Engineering Society. This recommended practice represents the consensus of both power and communications engineers.

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^aThere is an approved PAR for the revision and re-titling of this recommended practice. The new title will be IEEE Recommended Practice for the Electrical Protection of Communication Facilities Serving Electrical Supply Locations Using Optical Fiber Systems.

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1. Overview

Wire-line telecommunication¹ facilities serving electric supply locations often require special high-voltage protection against the effects of fault-produced ground potential rise (GPR) or induced voltages, or both. Some of the telecommunication services are used for control and protective relaying purposes and may be called upon to perform critical operations at times of power system faults. This presents a major challenge in the design and protection of the telecommunication system because power system faults can result in the introduction of interfering voltages and currents into the telecommunication circuit at the very time when the circuit is most urgently required to perform its function. Even when critical services are not involved, special high-voltage protection may be required for both personnel safety and plant protection at times of power system faults. Effective protection of any wire-line telecommunication circuit requires coordinated protection on all circuits provided over the same telecommunication cable.

This recommended practice assumes that metallic cables are to be used to provide telecommunication services to electric supply locations. This document describes applications consisting entirely of metallic cables and of those hybrid applications where both metallic cables and fiber cables are used. The user will be referred to IEEE Std 1590™-2003² for the optical fiber portion across the zone of influence (ZOI).

1.1 Scope

This recommended practice presents engineering design practices for special high-voltage protection systems intended to protect wire-line telecommunication facilities serving electric supply locations.

The following topics are included in this document:

¹In general “wire-line telecommunication” will be referred to throughout this document as “telecommunication.”

²Information on references can be found in Clause 2.

- a) A description of the electric supply locations environment, i.e., GPR, induced voltages, lightning, and switching transients
- b) A discussion of special high-voltage protection devices
- c) Definitions of service types and service performance objectives for electric supply locations telecommunication services
- d) Special protection theory and philosophy
- e) Special protection system design guidelines
- f) Personnel safety considerations
- g) Grounding
- h) Cables with metallic members

Other telecommunication alternatives such as radio and optical fiber systems are excluded from this recommended practice.

1.2 Purpose

This recommended practice presents workable methods for the protection of wire-line telecommunication facilities serving electric supply locations. In general, special protective measures, handling procedures, and administrative procedures are necessary for personnel safety reasons and to provide protection against damage to telecommunication facilities and terminal equipment, and reliability of service. Disturbances may arise from a number of causes, including the following:

- a) Ground (earth) potential rise
- b) Longitudinal induction into the serving telecommunication facilities
- c) Electrical contact between power and telecommunication conductors
- d) Lightning surges and switching transients induced into the telecommunication system

Divided and differing opinions exist between and within the various administrations and users regarding the merits of any one protection method, voltage limits, and equipment design characteristics. This standard is not intended to supplant specific or general instructions contained in the practices of any utility, or in any agreement between a telecommunication and a power utility. Readers of this standard should evaluate all alternative procedures, methods, voltage limits, and equipment characteristics for their own use. Different administrations and users will use either peak or rms for specifying voltage levels.

In the case of leased facilities, *mutually agreeable* methods for the design and installation of protective equipment that may be owned by either party are recommended.

2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 80™-2000, IEEE Guide for Safety in AC Substation Grounding.^{3, 4}

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IEEE Std 81™-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System—Part I: Normal Measurements.

IEEE Std 81.2™-1991, IEEE Guide for Measurement of Impedance and Safety Characteristics of Large, Extended, or Interconnected Grounding Systems.

IEEE Std 367™-1996, IEEE Recommended Practice for Determining the Electric Supply Location Ground Potential Rise and Induced Voltage from a Power Fault.

IEEE Std 776™-1992 (Reaff 1998), IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communications Lines.

IEEE Std 789™-1988 (Reaff 1994), IEEE Standard Performance Requirements for Communications and Control Cables for Applications in High-Voltage Environments.

IEEE Std 1590-2003, IEEE Recommended Practice for the Electrical Protection of Optical Fiber Communication Facilities Serving, or Connected to Electrical Supply Locations.

IEEE Std C37.93™-2004, IEEE Guide for Power System Protective Relay Applications of Audio Tones Over Voice Grade Channels.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

This clause contains key terms as they are used in this recommended practice.

3.1.1 carbon block protector: An assembly of two or three carbon blocks and air gaps designed to a specific breakdown voltage. These devices are normally connected to telecommunication circuits to provide overvoltage protection and a current path to ground during such overvoltage.

NOTE—The manufacturing of carbon blocks has been largely discontinued.⁵

3.1.2 conductive (resistive) coupling: *See: coupling.*

3.1.3 coupling: The mode of propagation of disturbing energy from a power system to a telecommunications system. There are three forms of coupling between the two systems: magnetic (inductive) coupling, electric (capacitive) coupling, and conductive (resistive) coupling. In addition, coupling by electromagnetic radiation exists and is associated with propagation of radiation fields, e.g., radio frequency interference (RFI), electromagnetic pulse (EMP), and corona.

3.1.4 drainage units or drainage reactors: Center-tapped inductive devices designed to relieve conductor-to-conductor and conductor-to-ground voltage stress by draining extraneous currents to ground. They are also designed to serve the purpose of a mutual drainage reactor, forcing near-simultaneous protector-gap operation.

3.1.5 electric (capacitive) coupling: *See: coupling.*

3.1.6 electric supply locations: Any building, separate space, or site in which electric supply equipment is located that may be subjected to the effects of ground potential rise (GPR). This includes generation, transformation, conversion, switching, and delivery facilities.

⁵Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

3.1.7 fiber-optic cable: A telecommunications cable in which one or more optical fibers are used as the propagation medium. The optical fibers are surrounded by buffers, strength members, and jackets for protection, stiffness, and strength. A fiber-optic cable may be an all-fiber cable, or contain both optical fibers and metallic conductors.

3.1.8 gas-filled protector (gas tube): A discharge gap between two or more electrodes hermetically sealed in a ceramic or glass envelope.

3.1.9 ground potential rise (GPR): The product of a ground electrode impedance, referenced to remote earth, and the current that flows through that electrode impedance.

NOTE—In this recommended practice, GPR refers to ground potential rise caused by power line fault current.

3.1.10 high-dielectric cable: Cable that provides high-voltage insulation between conductors, between conductors and shield, and between shield and earth.

3.1.11 high-voltage disconnect jack: A device used to disconnect cable pairs for testing purposes. Used to help safeguard personnel from remote ground potentials.

3.1.12 high-voltage environment (HVE): A location requiring caution because it may experience a ground potential rise (GPR) from power line fault currents.

3.1.13 high-voltage interface (HVI): Protective apparatus that provides electrical isolation of wire-line communications conductive paths.

3.1.14 high-voltage isolating relay: A device that provides for the repeating of dc on/off signals while maintaining longitudinal isolation. High-voltage isolating relays may be used in conjunction with isolating transformers or may be used as stand-alone devices for dc tripping or dc telemetering.

3.1.15 horn gap: An air-gap metal electrode device, consisting of a straight vertical round electrode and an angularly shaped round electrode. In the case of a telephone pair, there is one common grounded central straight vertical electrode and two angular electrodes, one for each side of the pair. The gaps are usually adjustable. Horn gaps are used usually outdoors on open-wire lines exposed to high-voltage power transmission lines and in conjunction with isolating or drainage transformers. They are also frequently used alone out along the open-wire pair. They provide protection against both lightning and power contacts.

3.1.16 insulating transformers: *See: isolating (insulating) transformers.*

3.1.17 isolating (insulating) transformers: Transformers that provide longitudinal (common-mode) isolation of the telecommunication facility. They can be designed for use in a combined isolating-drainage transformer configuration and also can be designed for a low longitudinal to metallic conversion.

3.1.18 isolating transformer with high-voltage isolating relay: An assembly that provides protection for standard telephone service and consists basically of an isolating transformer and a high-voltage isolating relay. The transformer provides a path for voice and ringing frequencies while the relay provides a means for repeating dc signals around the transformer. A locally supplied battery or dc power supply is required for operation of the telephone and relay.

3.1.19 magnetic (inductive) coupling: *See: coupling.*

3.1.20 neutralizing transformers and reactors: Devices that introduce a voltage into a circuit pair to oppose an unwanted voltage. These devices neutralize extraneous longitudinal voltages resulting from ground potential rise, or longitudinal induction, or both, while simultaneously allowing ac and dc metallic signals to pass. These transformers or reactors are primarily used to protect telecommunication or control circuits at supply locations or along routes where exposure to power line induction is a problem, or both.

3.1.21 optic coupling device: An isolation device using an optical link to provide the longitudinal isolation. Circuit arrangements on each side of the optical link convert the electrical signal into an optical signal for transmission through the optical link and back to an electrical signal. Various circuit arrangements provide one-way or two-way transmission and permit transmission to the various combinations of voice and/or dc signaling logic used by the power industry. Single-channel optic coupling devices may be used in conjunction with other isolation devices in protection systems.

3.1.22 reliability (power system protective relaying): A combination of dependability (failure to deliver a valid trip signal) and security (delivery of a false trip or control signal.).

3.1.23 solid-state protector: A protective device that employs solid-state circuit elements that provide a combination of high speed voltage and current sensing. These protectors are a combination of voltage clamps (avalanche diodes) and crowbar devices (multilayer diodes similar to SCRs), and are designed to limit the voltage to a specific value and to reduce current flow to low values of milliamperes within nanoseconds. They are usually integrated into the terminal apparatus.

3.1.24 spark gap: An air dielectric between two electrodes that may be a combination of several basic shapes that is used to protect telecommunication circuits from damage due to voltage stress in excess of their dielectric capabilities. It may or may not be adjustable.

3.1.25 surge arrester: A device that guards against dielectric failure of protection apparatus due to lightning or surge voltages in excess of their dielectric capabilities and serves to interrupt power follow current.

3.1.26 thunderstorm day: A day during which thunder is heard at least once at a specified observation point.

3.2 Acronyms and abbreviations

ac	alternating current
ANS	American National Standard
AWG	American Wire Gauge
BIL	basic impulse insulation level
BTS	base transceiver station
C	capacitance
CO	central office
CFJ	wire-line cable–fiber cable junction
dB	decibel
dc	direct current
DS1	digital service @ 1.544 Mb/s rate
EHV	extra-high-voltage
EPRI	Electric Power Research Institute
FM	frequency modulated
FSK	frequency shift keying

GPR	ground potential rise
HVE	high-voltage environment
HVI	high-voltage interface
Hz	Hertz
ISDN	Integrated Services Digital Network
MDF	main distributing frame
MDR	mutual drainage reactor
MGN	multi-grounded neutral
NT	neutralizing transformer
OEI	optical equipment interface
OGC	overhead ground conductor
PCM	Pulse Code Modulated
PVC	polyvinyl chloride
SCADA	Supervisory Control Data Acquisition, and Automatic Control
SCR	silicon controlled rectifier
SGA	System Grid Analysis program
SPO	service performance objective
T1	1.544 Mb/s PCM Digital 4 Wire Circuit
VF	voice frequency
xDSL	(Xtype)Digital Subscriber Line
ZOI	zone of influence

4. High-voltage environment

There are two different electric supply location environments that shall be considered but the application of the recommended practice should not be limited to these:

a) Electric power stations:

These locations generally utilize an extensive ground grid designed, per IEEE Std 80, so that all grounded structures within the station can be connected to a common grid, thereby minimizing potential difference in the system during a power fault. However, the potential difference between this grounding system and other distant grounding systems may be substantial and a significant portion of these currents may be redirected to any wire-line telecommunications cables entering these locations. Ground grids in these locations help reduce surges caused by lightning strikes.

b) Power line transmission and distribution towers or poles:

These locations generally utilize a smaller grounding electrode system with a common arrangement being one ground rod per tower leg incorporated into the grounding system of the equipment placed at

the tower base. Thus, the grounding systems at towers or poles usually have a significantly higher resistance to ground than those at electric power stations. Transmission lines also have a higher probability of being struck by lightning, thereby increasing the chances of fault producing surges. A significant portion of these surge currents may be redirected to any wire-line telecommunications cables entering these locations.

At these types of locations, when a power system ground fault or lightning strike occurs, all or some of the current returns via the earth through the grounding electrode and produces a potential difference between the grounding electrode and remote earth. The fault current may be symmetrical or may have some degree of asymmetry, depending on such factors as voltage phase angle at fault initiation, location of the fault, impedance to ground and other power system characteristics. The impedance to ground depends primarily on the geometry of the grounding electrode, the connections to it and the resistivity of the soil in the vicinity of the site.

The GPR at an electric supply location may be reduced substantially because of its physical connections to remote ground points by means of overhead ground (earth, static, or sky wires) conductor (OGC), multi-grounded neutrals, counterpoises, cable shields, rail lines, etc. These connections affect the distribution of fault currents through the system grounding paths and also affect the total site impedance to remote earth.

A rigorous analysis of ground potential rise calculations at the power system fundamental frequency is presented in IEEE Std 367-1996.

4.1 Coupling

Coupling refers to the mode of propagation of disturbing energy from the power system to the telecommunications system.

Three forms of coupling between the two systems should be considered, i.e., magnetic (inductive) coupling, electric (capacitive) coupling, and conductive (resistive) coupling. In addition, coupling by electromagnetic radiation exists and is associated with the propagation of radiation fields, e.g., radio frequency interference, electromagnetic pulse, and corona.

Magnetic (inductive) coupling, particularly under power line fault conditions, is significant when several kilometers of parallel or close to parallel routing of both systems are considered. The power line fault current flowing to ground is coupled magnetically to the longitudinal circuit of the telecommunication system and results in a distributed longitudinal voltage being induced in the telecommunication circuit. The induced voltage is calculated by multiplying the inducing power line current by the mutual impedance between the two systems. The inducing current is a function of the fault location and the power system characteristics. The mutual impedance is a function of such variables as the frequency, length of parallel, separation, soil resistivity, and shielding conductors [see IEEE Std 367-1996 for methods of calculating magnetic (inductive) coupling]. Heterogeneous soil conditions, the presence of shielding conductors, and resistances to ground of shielding conductors are usually difficult to characterize accurately; however, they have a significant effect on the resulting level of induced voltage. Therefore, a large spread in values can occur between actual and estimated induced voltages because not all parameters can be assessed easily or accurately.

Capacitive coupling at power system frequencies is significant only where telecommunication lines are not shielded with a grounded metallic shield. Since most wire-line telecommunication cables are metallically shielded, capacitive coupling is minimized.

Conductive (resistive) coupling is significant where the power and telecommunications grounding systems are bonded together or where grounds are mutually coupled due to their proximity to each other. In general, for wire telecommunications facilities, resistive coupling can be minimized by avoiding joint use. If joint use

cannot be avoided, adequate bonding of the grounding systems should be ensured in situations in which the power line and its associated protective relaying circuits follow the same route.

The probability of a power conductor falling and causing a problem with a telecommunication cable in or near a substation is very low. The problem itself is no worse than any joint-use condition.

4.2 Disturbances

4.2.1 Ground potential rise

4.2.1.1 Theoretical background

With reference to Figure 1, the current causing GPR that is created by the returning fault current through the electric supply location ground grid impedance has the following form, see Equation (1) (assuming the phase currents are equal and in balance prior to the fault):

$$i_{\text{GPR}}(t) = \frac{V_{\text{pk}}}{\sqrt{(R_s + R_{\text{TG}})^2 + \omega^2(L_s + L_{\text{TG}})^2}} \left[\cos(\omega t + \alpha - \theta) - \cos(\alpha - \theta)e^{-\beta t} \right] \quad (1)$$

where

$$\begin{aligned} \beta &= \frac{R_s + R_{\text{TG}}}{L_s + L_{\text{TG}}} \triangleq \frac{R}{L}, \\ \omega &= 2\pi f = 377 \text{ rad/s at 60 Hz} \\ \alpha &= \text{angle of the power line voltage at the initiation of the fault, in radians} \\ R_s &= \text{power system equivalent resistance, in ohms} \\ L_s &= \text{power system equivalent inductance, in henries} \\ R_{\text{TG}} &= \text{total ground resistance at the point where GPR is being evaluated, in ohms} \\ L_{\text{TG}} &= \text{total ground inductance at the point where GPR is being evaluated, in henries} \\ V_{\text{peak}} &= \text{peak value of system voltage (0 } \Omega \text{ source impedance assumed)} \\ i_{\text{GPR}}(t) &= \text{GPR-producing current including the transient component, in amperes} \\ \theta &= \text{loop impedance angle, in radians,} \\ &\quad \tan^{-1}\left(\frac{\omega}{\beta}\right) = \tan^{-1}\left(\frac{\omega L}{R}\right) \\ t &= \text{time, in seconds} \end{aligned}$$

The GPR appearing across the $R_{\text{TG}} + j\omega L_{\text{TG}}$ can be calculated see Equation (2) through Equation (13), as follows:

$$V_{\text{GPR}}(t) = R_{\text{TG}} i_{\text{GPR}}(t) + L_{\text{TG}} \frac{di_{\text{GPR}}(t)}{dt} \quad (2)$$

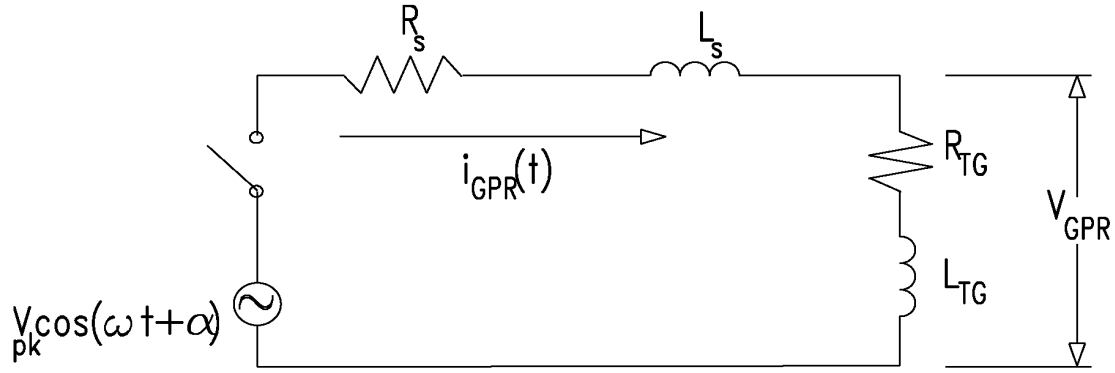


Figure 1—Simplified loop for GPR calculation

$$\frac{di_{\text{GPR}}(t)}{dt} = \frac{V_{\text{pk}}}{|Z|} \left[-\omega \sin(\omega t + \alpha - \theta) + \beta \cos(\alpha - \theta) e^{-\beta t} \right] \quad (3)$$

$$\begin{aligned} \therefore V_{\text{GPR}}(t) = \frac{V_{\text{pk}}}{|Z|} & \left[R_{\text{TG}} \cos(\omega t + \alpha - \theta) - R_{\text{TG}} \cos(\alpha - \theta) e^{-\beta t} \right. \\ & \left. + \omega L_{\text{TG}} \sin(\omega t + \alpha - \theta) + \beta L_{\text{TG}} \cos(\alpha - \theta) e^{-\beta t} \right] \end{aligned} \quad (4)$$

$$= \frac{V_{\text{pk}}}{|Z|} \left[R_{\text{TG}} \cos(\omega t + \alpha - \theta) + \omega L_{\text{TG}} \sin(\omega t + \alpha - \theta) - \cos(\alpha - \theta) (R_{\text{TG}} - \beta L_{\text{TG}}) e^{-\beta t} \right] \quad (5)$$

$$|Z| = \sqrt{(R_s + R_{\text{TG}})^2 + \omega^2 (L_s + L_{\text{TG}})^2} = \sqrt{R^2 + (\omega L)^2} \quad (6)$$

Simplifying further, let

$$|Z_{\text{TG}}| \triangleq \sqrt{R_{\text{TG}}^2 + \omega^2 L_{\text{TG}}^2}; \quad \cos \theta_{\text{TG}} \triangleq \frac{R_{\text{TG}}}{|Z_{\text{TG}}|}; \quad \sin \theta_{\text{TG}} \triangleq \frac{\omega L_{\text{TG}}}{|Z_{\text{TG}}|} \quad (7)$$

$$\therefore R_{\text{TG}} = \cos \theta_{\text{TG}} |Z_{\text{TG}}| \quad (8)$$

$$\omega L_{\text{TG}} = \sin \theta_{\text{TG}} |Z_{\text{TG}}| \quad (9)$$

$$\text{Let } \omega t + \alpha - \theta = a \quad (10)$$

$$V_{\text{GPR}}(t) = \frac{V_{\text{pk}}}{|Z|} \left[|Z_{\text{TG}}| \cos(\omega t + \alpha - \theta + \theta_{\text{TG}}) - \cos(\alpha - \theta) (R_{\text{TG}} - \beta L_{\text{TG}}) e^{-\beta t} \right] \quad (11)$$

then

$$V_{\text{GPR}}(t) = \frac{V_{\text{pk}}}{|Z|} [R_{\text{TG}} \cos a + \omega L_{\text{TG}} \sin a - \cos(\alpha - \theta) (R_{\text{TG}} - \beta L_{\text{TG}}) e^{-\beta t}] \quad (12)$$

where

$$\theta_{TG} = \tan^{-1} \frac{\omega L_{TG}}{R_{TG}} \text{ is the angle of the impedance, } Z_{TG}. \quad (13)$$

The two components of the expression for GPR are the steady-state and transient (dc offset) terms. The quantity L/R is the inverse time constant of the transient term. Multiplication of this quantity by the angular frequency, ω , yields the X/R ratio of the power system at the point of fault. The X/R ratio gives an indication of the time required for the dc transient to decay and of the volt-time area contributed by the transient term (see A.5.1.8). Looking back towards the source, under line-to-ground fault conditions, X/R ratios may range from 1 to 2 for low-voltage lines to as high as 75 for extra-high-voltage (EHV) lines. Refer to IEEE Std 367-1996 for information on the effective X/R ratio, which is not the transmission line X/R .

The initial peak amplitude of the transient term and the maximum peak amplitude of the GPR depend upon the quantity $\cos(\alpha - \theta)$. The angle, θ , is fixed by power system parameters. The phase angle of the power line voltage, α , at the initiation of the fault, therefore becomes the controlling factor. For large values of X/R , the angle, θ , approaches $\pi/2$ radians, and the power line voltage fault angle, α , which produces maximum offset, approaches zero (0) radians.

4.2.1.2 Practical implications

When a fault to ground occurs on a transmission or distribution line terminating in a grounded-neutral transformer bank at an electric supply location or substation, fault current will flow from the electric supply location ground grid to the system neutral by way of the station grounding system. Since the grounding system has a finite impedance-to-remote earth, it will experience a rise in potential with respect to remote earth because of this ground return fault current. The magnitude of the GPR depends upon such factors as the impedance-to-ground of the station grounding system, the magnitude and location of the fault, the fault impedance, the impedance of the transformers feeding the fault, the presence or absence of ground wires on the line (insulated or not), and other grounding structures in the area. Also, a fault occurring at a station without a grounded-neutral transformer or at a tower location may produce a GPR as long as there is a ground source on the system and there exists a ground current path to the fault.

This has been found to agree with certain measured data for stations not influenced by external metallic paths such as pipes, overhead ground (static or sky wires) conductors (OGC), power neutrals, etc. Where external grounds exist, this standard recommends that the fall of potential impedance measurements referenced in IEEE Std 81.2-1991 be used to generate the proper curves for a specific grid.

While the impedances of station ground grids can range from 0.01 Ω to 10 Ω or more, they are normally quite small, usually less than 1 Ω . Bus fault currents, however, may sometimes be very large, in the order of 70 000 A or higher. GPRs of several thousand volts, therefore, are possible. Ground electrodes at tower locations are generally smaller in size and have a higher grid resistance than at electric power stations.

The GPR consists of a steady-state symmetrical component and may contain a decaying dc transient component (sometimes called the dc offset, see Annex E). The magnitude of the dc transient component lies between zero and the peak value of the steady-state symmetrical component. It is dependent upon time, the ratio of the effective power system inductive reactance and resistance as determined at the point of fault (X/R ratio), and the phase angle of the power line voltage at the initiation of the fault. The rate of decay of the dc transient component is determined by the effective X/R ratio as well. The combined dc and ac components will always have a peak value below twice the peak value of the ac component. Figure 2 shows an illustration of a nonsymmetrical GPR waveform and the two components.

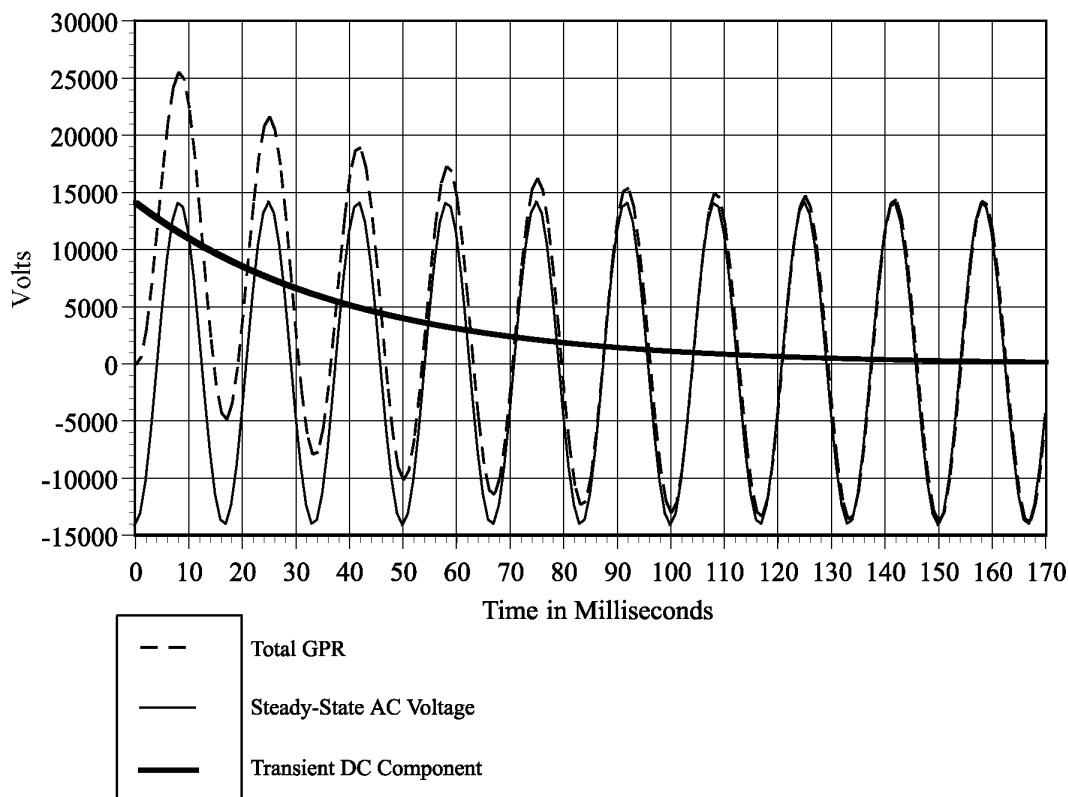


Figure 2—Illustration of a nonsymmetrical GPR waveform

The reader of this recommended practice should refer to IEEE Std 367-1996 for more detailed discussion.

For a discussion of worst-case volt-ampere area in the context of neutralizing transformers, see A.5.1.8.

NOTE 1—Power line faults are generally initiated at or close to peak voltage. For such faults, the transient dc component and the dc offset factor are minimal. Refer to IEEE Std 367-1996 and Annex E of this document. For purposes of this recommended practice, the words “asymmetrical” and “nonsymmetrical” are synonymous.

Figure 3 through Figure 6 illustrate a theoretical GPR distribution from the edge (where the protection requirements are usually specified) of four simple ground grids for a number of different earth resistivity models. These curves are easily reproduced using the EPRI⁶ System Grid Analysis (SGA) program. This has been found to agree with certain measured data for stations not influenced by external metallic paths such as pipes, overhead ground (static or sky wires) conductors (OGC), power neutrals, etc. Where external grounds exist, this standard recommends that the fall of potential impedance measurements referenced in IEEE Std 81-1983 and IEEE Std 81.2-1991 be used to generate the proper curves for a specific grid.

Two values of multilayered soils and one uniform layer soil are provided for in these curves (Figure 3 through Figure 6), 100/20 m- Ω , 100 m- Ω , and 100/1000 m- Ω .

NOTE 2—For multilayered soils, depth of the upper layer = 6 m (20 ft).

The area surrounding the electric supply location that is raised in potential above a remote (or true) earthing point is referred to as the GPR zone of influence. In practice, 300 V is often used as the boundary of this zone of influence. For a more complete discussion on this topic, refer to IEEE Std 367-1996.

⁶Electric Power Research Institute, P. O. Box 10412, Palo Alto, CA 94303, USA.

The potential of the ground around the electric supply location, with respect to remote earth, falls off with distance from the station grounding system as indicated by the equipotential lines in Figure 7. Excluding alternate return paths, this potential is roughly inversely proportional to the distance from the station grounding system. For simplicity, the equipotential lines are shown in Figure 7 as concentric circles. Due to the irregularity of the grounding system, variations in the earth resistivity around the station, and the presence of metallic underground structures such as pipes and cables, the equipotential lines will not be circular as shown.

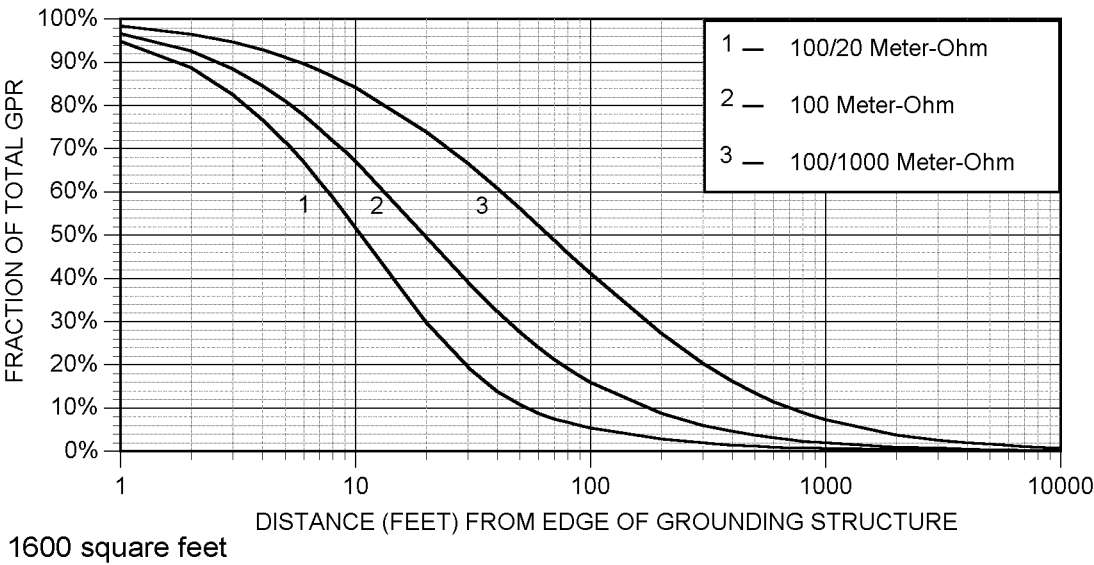
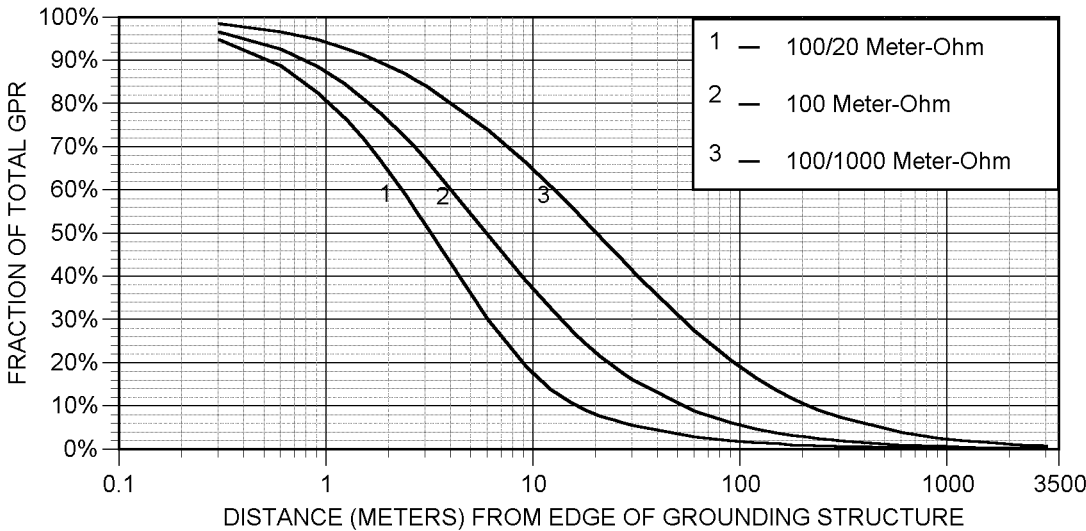
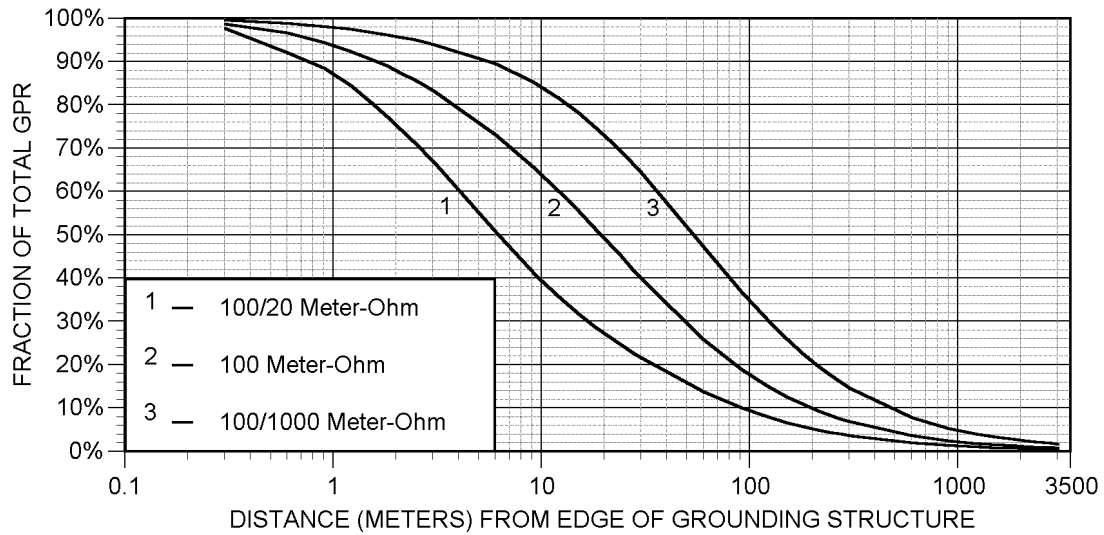
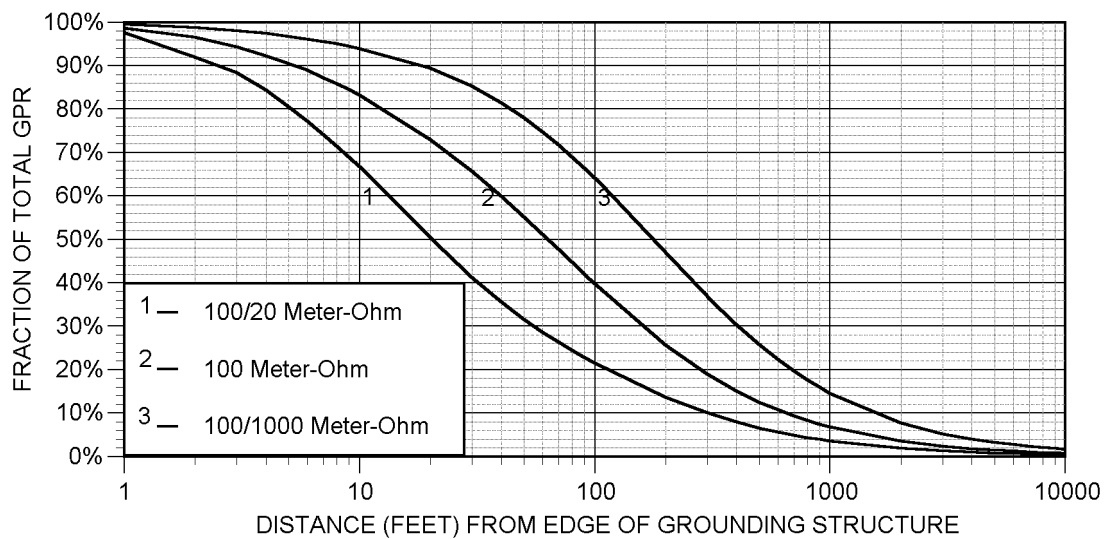


Figure 3—(Metric and inch-pound)—Earth potential distribution from edge of electric supply location grid with respect to a remote earthing point

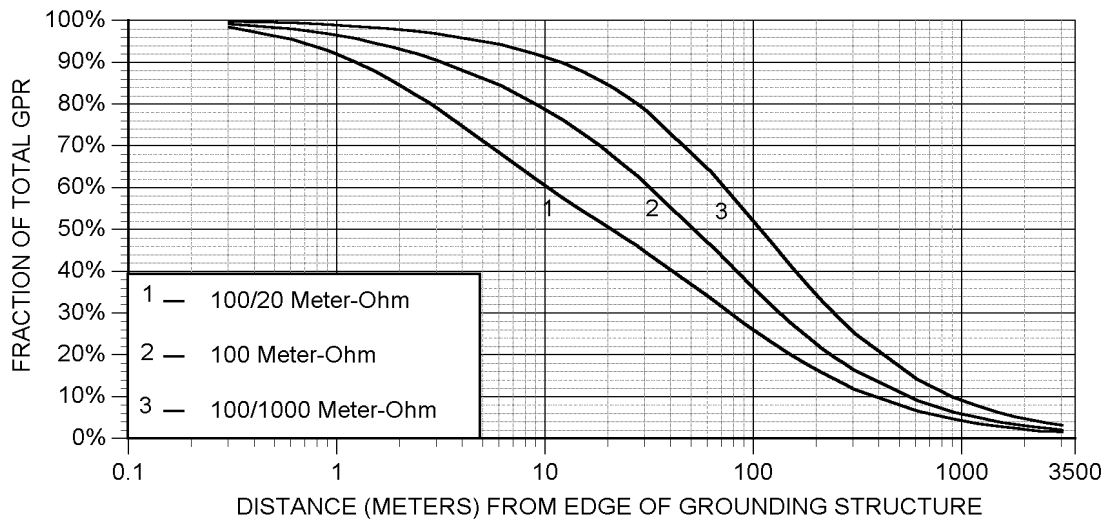


3250 square meters

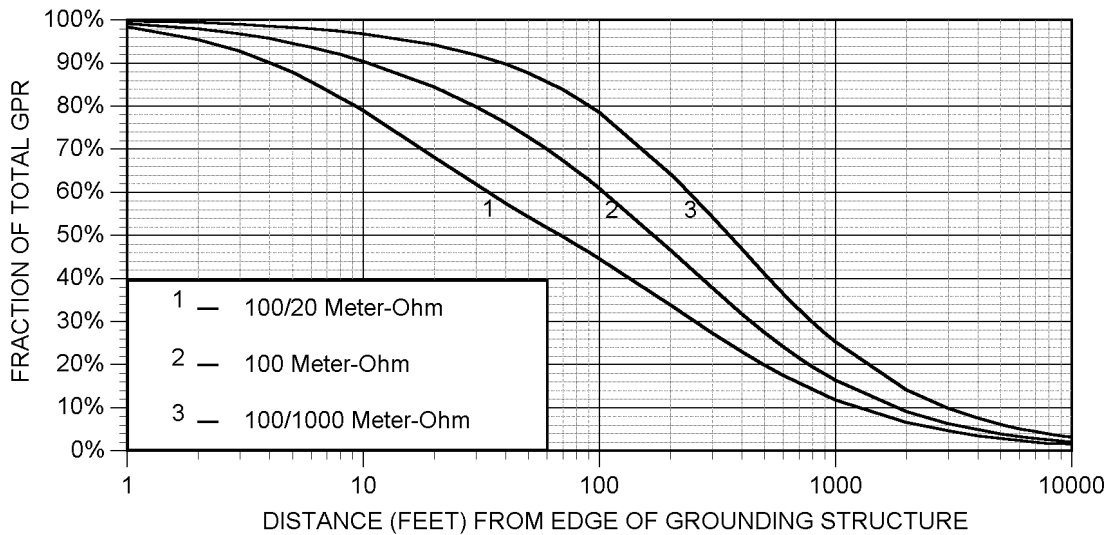


35,000 square feet

Figure 4—(Metric and inch-pound)—Earth potential distribution from edge of electric supply location grid with respect to a remote earthing point



27,000 square meters



290,000 square feet

Figure 5—(Metric and inch-pound)—Earth potential distribution from edge of electric supply location grid with respect to a remote earthing point

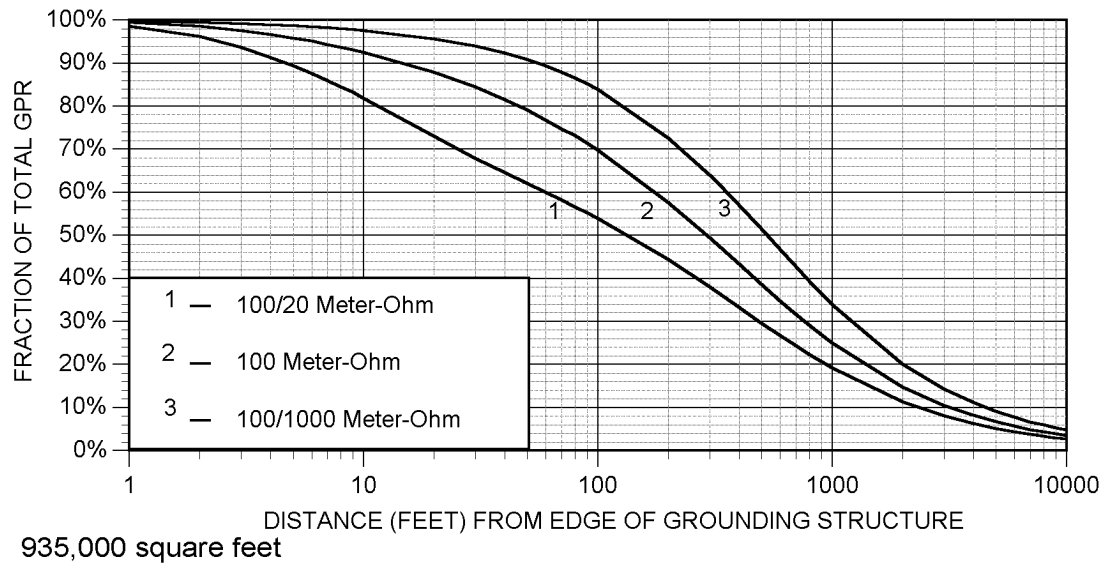
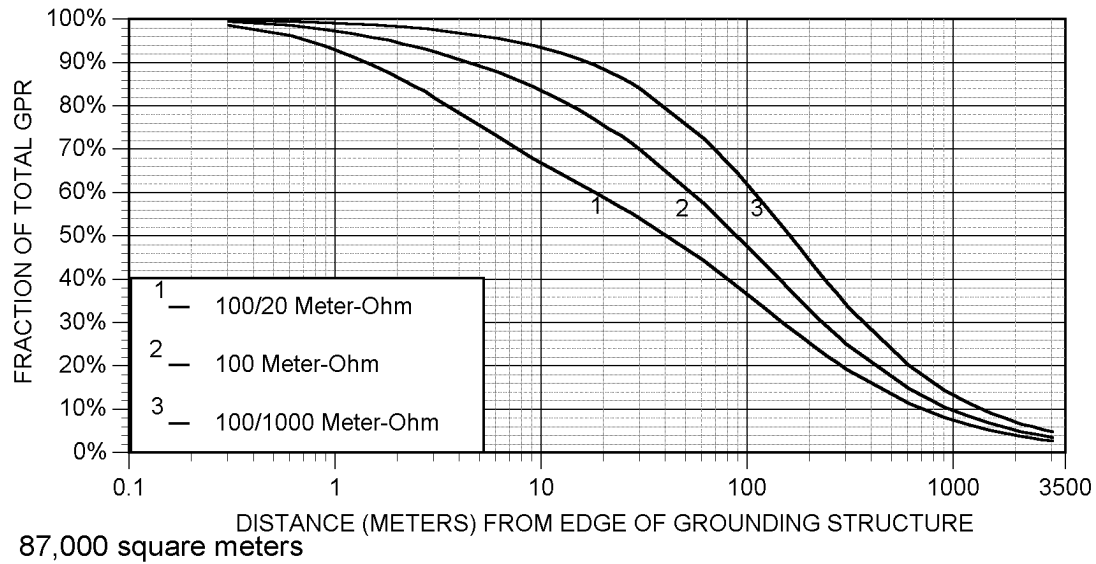


Figure 6—(Metric and inch-pound)—Earth potential distribution from edge of electric supply location grid with respect to a remote earthing point

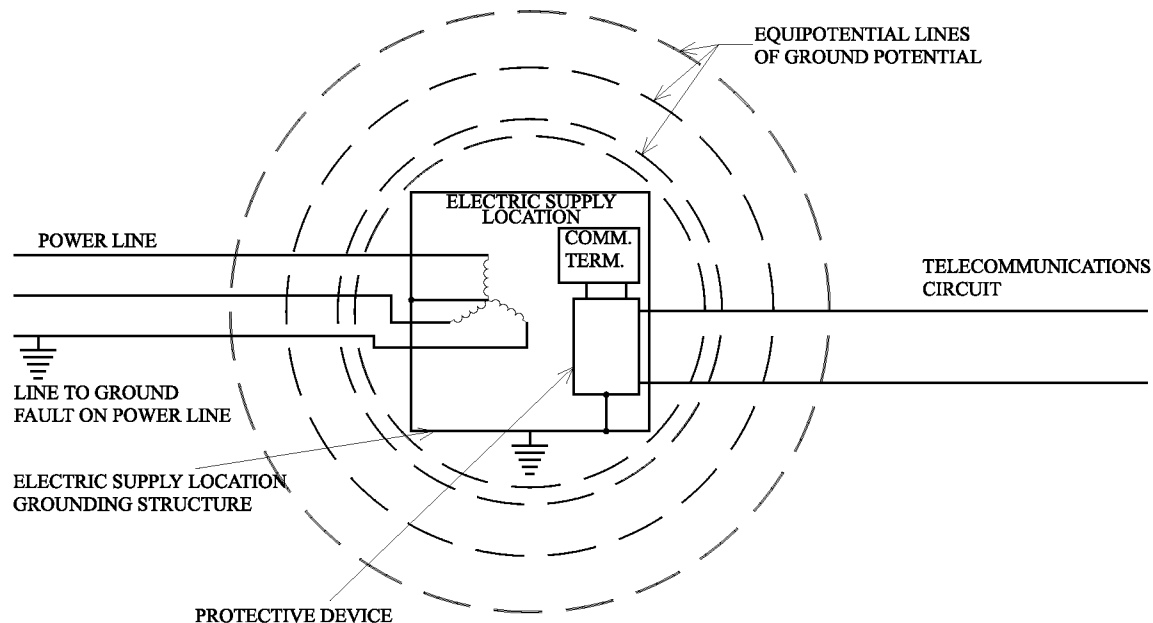


Figure 7—Theoretical illustration of electric supply location ground potential rise with conventional protection on telecommunication circuits

A telecommunication circuit, extending from the electric supply location to some remote point, is also shown in Figure 7. In this example, the protective device is installed at the electric supply location end of the telecommunication circuit, with the protector ground terminal connected to the electric supply location grounding system. At some remote point on the telecommunication circuit, such as the far end or some intermediate point, another protective device may be installed. In the latter case, the protector ground terminal is connected to what might be regarded as remote ground. These protectors serve to limit the voltage that may exist between the wire-line telecommunication circuit and local ground at the protector location. Therefore, protectors are installed to help safeguard personnel and preventing damage to property and equipment that might be caused by induction, lightning, GPR, or direct contact with power circuits.

When there is a GPR at the electric supply location, a potential difference that is equal to this rise will exist between the ground terminals of the protectors at the two locations on the telecommunication circuit. This difference in potential will cause (if of sufficient magnitude) the protectors on the telecommunication circuit to operate, possibly grounding them permanently or damage the telecommunication circuit, and cause personnel hazards.

In order to prevent this ground-return current from circulating over the telecommunication circuit and its protective devices, methods have been devised that are discussed later in this standard. In applying these methods, it is necessary to determine the expected GPR as accurately as possible.

Cables are exposed to the effects of GPR when they are entering the GPR zone to serve the electric supply location, to serve subscribers within the zone of influence, or are merely passing through the zone of influence. The metallic shield-to-core and insulating outer jacket dielectric withstand (strength) should be considered with respect to the expected GPR value at the cable location. It is important that protector and cable shield grounds not be placed in this zone without consideration of the effects of GPR at the proposed grounding location.

The dedicated cable to the substation always enters the area of highest GPR, while the general-use cable may pass through the zone of influence at some lower potential level. Refer to IEEE Std 789-1988 for a more detailed discussion on such cables. Furthermore, protector or arc noise should be more carefully avoided on

substation cables carrying protective relaying signals, see IEEE Std C37.93-2004. If protective devices are used properly and metallic members of the cable can be assured of being insulated from substation ground, then possible hazards from GPR will be greatly minimized.

The protection scheme should not be installed to cope merely with the existing fault current possibilities. Provision should also be made for future power system expansion or an increase in fault current levels, or change in station ground grid impedance. Considerations for telecommunications cables passing through the zone of influence of an electric supply location are covered in A.11.

4.2.2 Longitudinal induction

Wire-line telecommunication facilities entering supply locations are frequently routed close to power lines. Such facilities are then subject to the interfering induction effects of the power lines under both normal and fault conditions. Satisfactory electrical coordination between the two systems should be achieved under both normal and fault conditions on the power system. In addition to normal and fault conditions, longitudinal induction caused by disturbing harmonic current flow in the power system can cause interfering induction effects that should be coordinated. This effect is dealt with by other IEEE standards such as IEEE Std 367-1996 and IEEE Std 776-1992. Such coordination is particularly essential between cables containing protective relaying circuits and the power lines that are being protected by those circuits. The power line fault condition is most severe because inductive interference during this condition adds vectorially to that produced by the GPR. See IEEE Std 367-1996 for methods of calculating the vectorial summation. This may substantially increase the stress on the telecommunication facilities and the associated protection.

All-dielectric fiber-optic cables are immune to induction and other electrical effects.

4.2.3 Lightning

Transient and GPR analysis of lightning strikes is considered more complex than those for 50/60 Hz.

From the standpoint of lightning protection, the three most important parameters are the probability of lightning occurrence, its intensity, and its rate of change (see Anderson and Eriksson [B2]⁷). The first parameter is expressed in terms of lightning flash density measured as the yearly number of lightning flashes to an area of 1 km²; the second parameter is expressed as the peak amplitude of lightning current in kA; and the last parameter is expressed as the rise time in the front of the lightning current wave. In view of past records, isokeraunic levels (yearly number of thunderstorm days) rather than the flash density are readily available in many countries. Approximate empirical relations are used for conversion between the two measures. The relation is given by the following Equation (14):

$$N_g = KT_d^{1.3} \quad (14)$$

where

- N_g = ground flash density [flashes/(km² × year)]
- T_d = annual number of thunderstorm days
- K = constant that ranges from 0.023 to 0.04. On the North American continent, the value of 0.04 is used.

The incidence of lightning to most supply locations is about the same as the incidence of lightning to about 1.5 km of buried telephone cable. For example, for an isokeraunic level of 30, there were 0.7 strokes per year to a 310 × 310 m (96 000 m²) electric supply location, 0.4 strokes per year to a 225 × 225 m (50 000 m²)

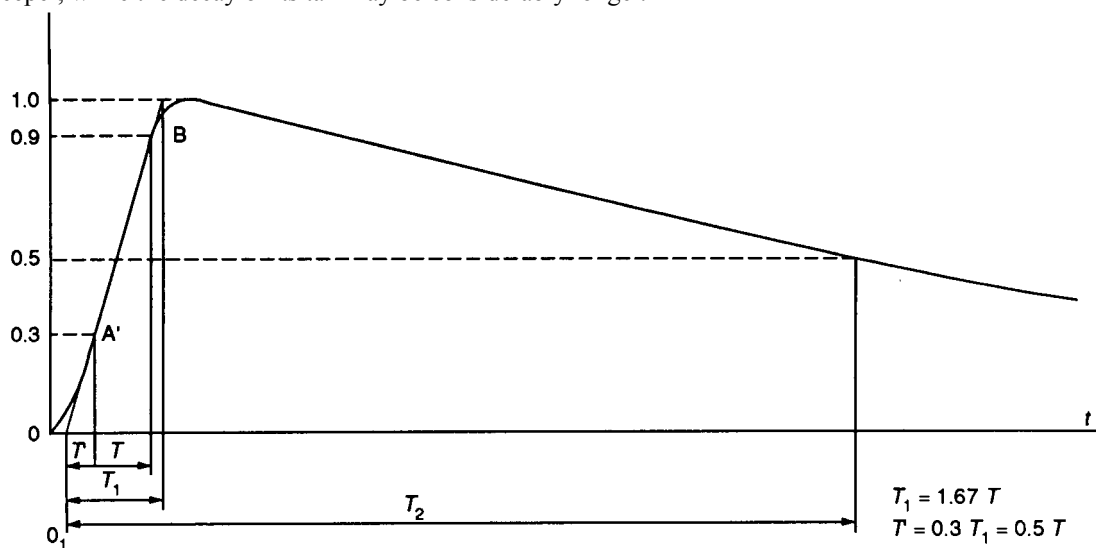
⁷The numbers in brackets correspond to those of the bibliography in Annex H.

station, and 0.07 strokes per year to a 9600 m² substation (see Sargent [B46]). The ground grids of 95% to 98% of all substations are smaller than 9600 m². This compares with 0.1 to 0.2 strokes per 1.5 km of buried cable for the same isokeraunic level (see Trueblood and Sunde [B48]).

As a general rule, large supply locations receive more strokes because of the larger area of the station; however, the effects of strokes are usually less severe than those for smaller stations. If lightning strikes or enters an electric supply location on the shielding system, the area and diversity of conduction paths of the ground grid and tower system help to readily disperse the stroke current (see IEEE Committee Report [B21]). If a shielding failure occurs, currents in the order of 2 kA to 20 kA are observed.

Current severity of lightning strokes is affected by structure height (see Eriksson [B11]). Since most electric supply location shielding systems are lower than 30 m, stroke current severity for an electric supply location and a buried cable are about the same. Thus, hazards to telecommunication facilities from lightning strokes to supply locations are about the same as from lightning strokes to a length of buried cable between 1.5 km and 3 km. Where microwave towers are located on electric supply location sites, telecommunication facilities become more exposed because tall structures are more susceptible to lightning. The reader should keep in mind that lightning strokes to tall structures have statistically smaller current crest values.

Time variations of lightning voltages and currents take place in the range of microseconds. For the purpose of testing, the wave shape of lightning stroke voltage shown in Figure 8 is normally used. The figure shows that the lightning stroke voltage is characterized by a very steep wavefront, in which the voltage rises to its maximum or crest value in a very short period of time, and by a decay period occupying a considerably longer length of time. Lightning stroke voltages and currents are usually described by two numbers. The first number is related to the time in microseconds for the wave, starting from virtual zero, to reach its crest, indicated by T_1 in Figure 8. The second number is the time in microseconds, also measured from the virtual zero, taken by the wave to decay to half its crest magnitude, as shown by T_2 in Figure 8. These times are characteristically $1.2 \times 50 \mu\text{s}$ for the “standard” voltage waveform, and $8 \times 20 \mu\text{s}$ for the “standard” current waveform (see IEEE Std 4™-1995 [B26]). In actual lightning strokes, the front of the wave may be even steeper, while the decay of its tail may be considerably longer.



NOTE— 0_1 is the virtual zero obtained as the intersection with the zero axis of a straight line through point A' and point B on the front of the voltage wave at 30% and 90% crest value (or on the front of a current wave at 10% and 90% crest value).

Figure 8—Definition of a voltage impulse wave

Time rate of change of lightning current is primarily responsible for the voltage induced by a lightning stroke in nearby apparatus. In addition, steepness of the wave determines, for the apparatus, the level of its withstand voltage. Typical values of voltage steepness used in tests lie in the range of 100 kV/ μ s to 200 kV/ μ s. Steeper wave fronts of naturally occurring lightning have been observed.

Some idea of the statistical values of crest current, collected on the basis of measurements made in different parts of the world, are shown in Figure 9. While some strokes exceed 200 kA in crest current, 50% of events have currents that do not exceed 30 kA. IEEE uses, in its work, a lightning current crest probability relation expressed by Equation (15).

$$P_I = \frac{1}{1 + \left(\frac{I}{31}\right)^{2.6}} \quad (15)$$

where

$$\begin{aligned} P_I &= \text{probability of exceeding stroke current, } I \\ I &= \text{stroke current, in kA} \end{aligned}$$

The incidence of lightning varies widely in different parts of the world and, indeed, within countries the size of the United States and Canada. This factor should be given consideration in estimating the exposure of electrical power and telecommunication plants to lightning. Data accumulated by the meteorological services of the Canadian and United States governments have been plotted on the isokeraunic map presented in Figure 10. Information contained in this map can be used with good advantage for generalized decisions regarding lightning protection. A thunderstorm day is defined as a day during which thunder is heard at least once at a specified observation point. The fact that thunder can be heard means that the storm is close enough to constitute a hazard to the electrical plant in the vicinity of the observation point.

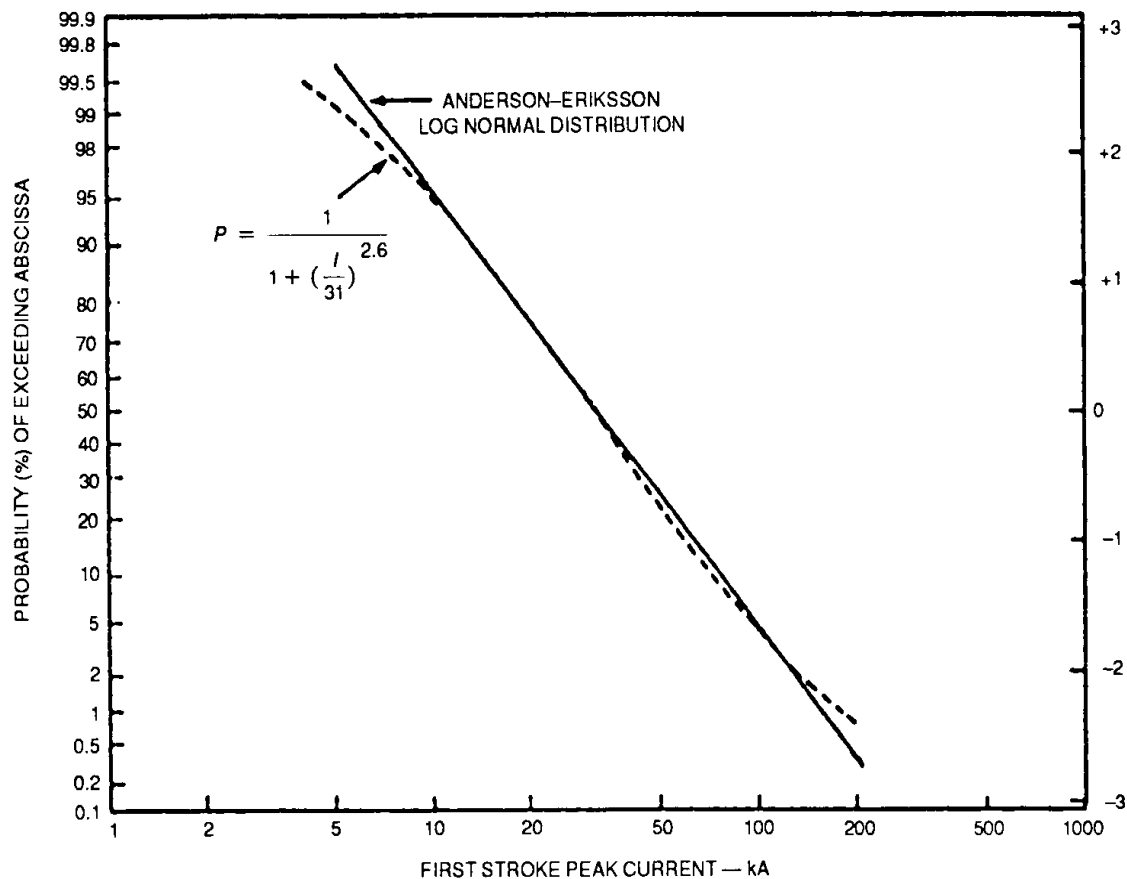


Figure 9—Cumulative probability distribution of stroke current magnitude in negative lightning flashes

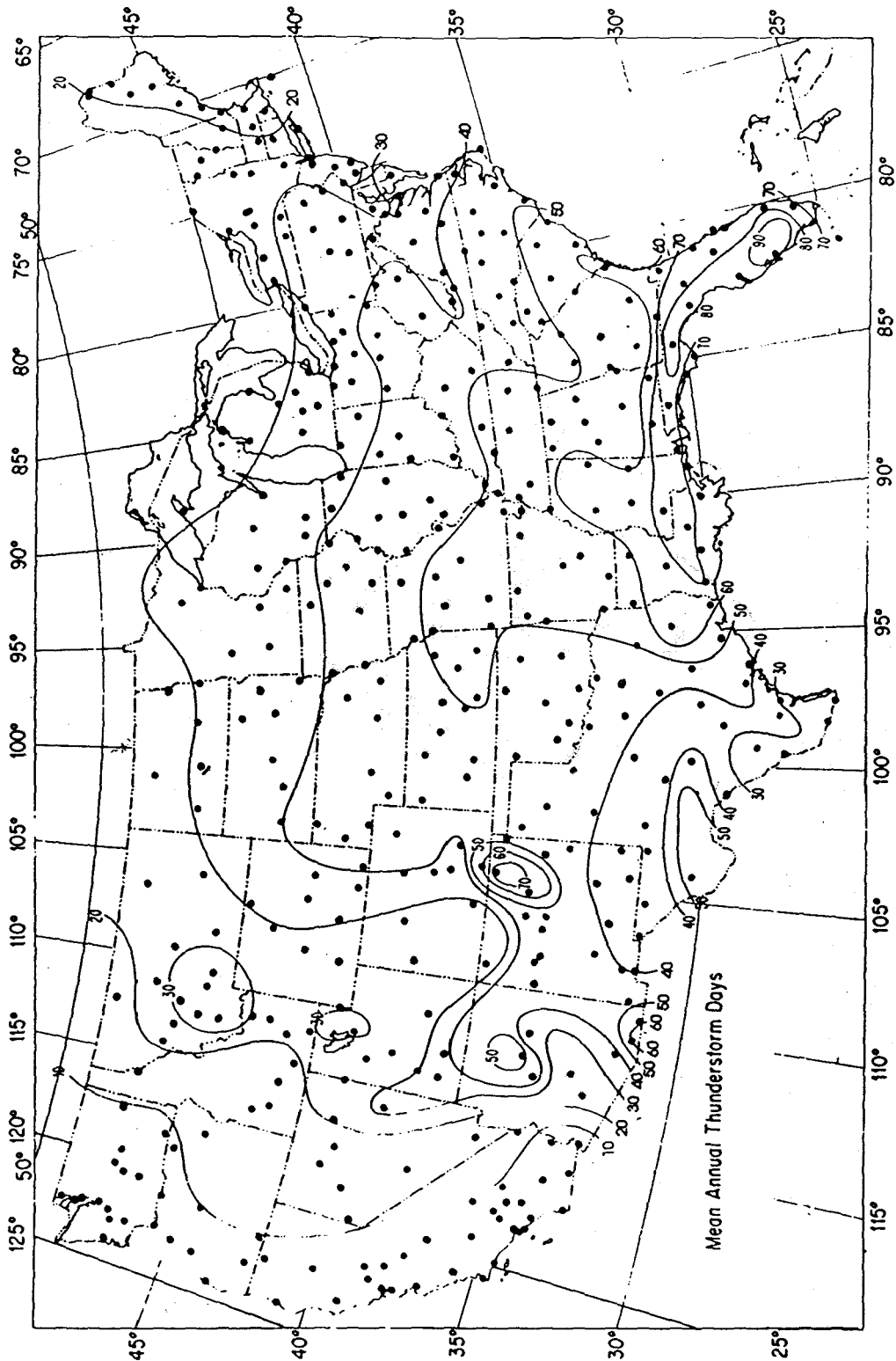


Figure 10—Isokeraunic chart for the United States
(Reprinted from IEEE Std 142™-1991 [B27])

Recent studies have found that a closer approximation to lightning flash density can be achieved by the use of thunderstorm hours per year. This measure better describes the extent and the duration of each lightning storm and, for that reason, better characterizes the number of lightning flashes per year to the area. A thunderstorm hour map for Canada is shown in Figure 11 (see CEA 077D-184A [B6]).

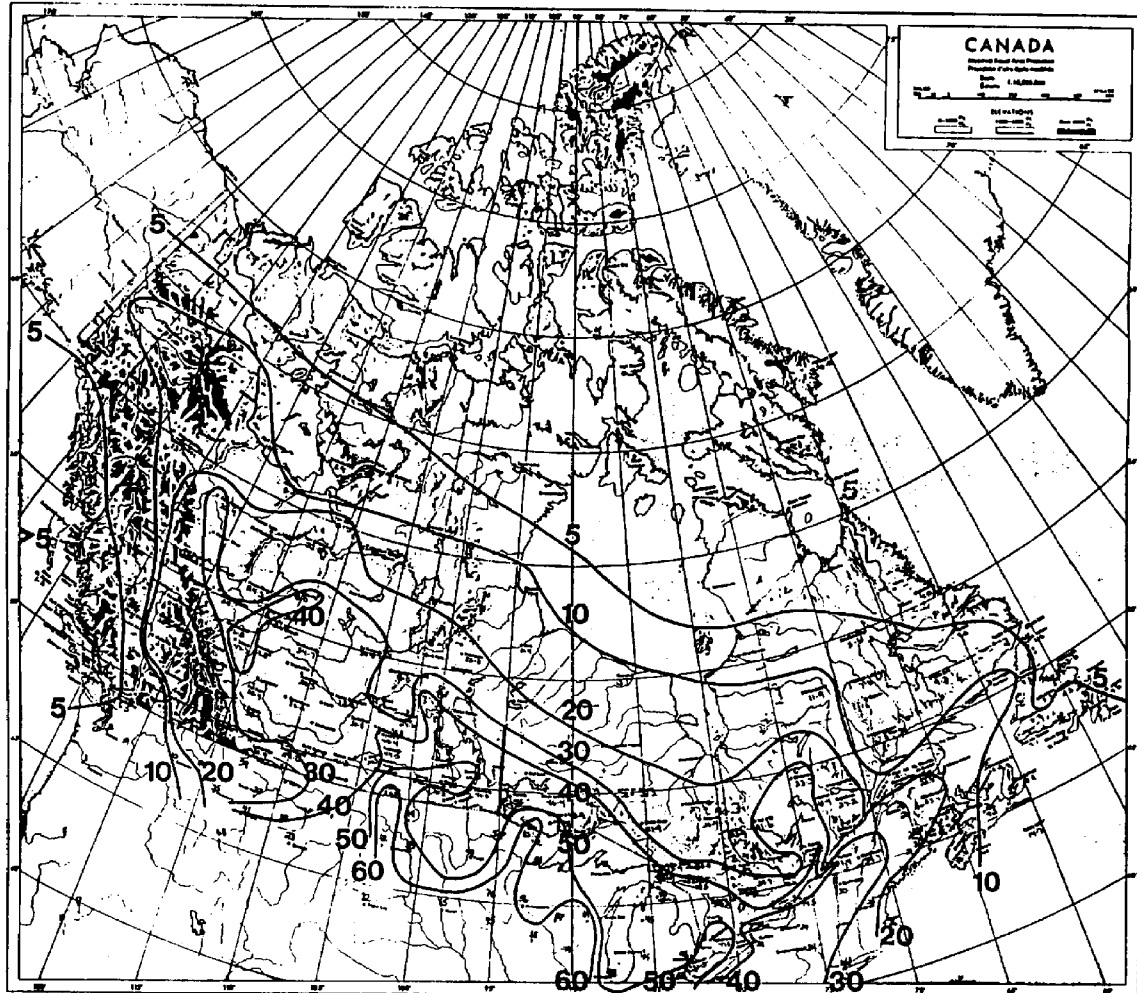


Figure 11—Annual thunderstorm-hour map of Canada
(Reprinted with permission of CEA Technologies Inc. (CEATI) from CEA Report No. 077D-184A [B6])

The relation between thunderstorm hours in a region and lightning flash density is given by Equation (16).

$$N_g = 0.054 T_h^{1.1} \quad (16)$$

where

$$\begin{aligned} N_g &= \text{ground flash density [flashes/(km}^2 \times \text{year)]} \\ T_h &= \text{annual number of thunderstorm hours} \end{aligned}$$

See IEEE Std 1410™-1997 [B29] for more recent information about lightning.

4.2.4 Switching surges

High-voltage systems can cause electromagnetic field disturbances and induce transient potentials in control and telecommunication circuits located within the electric station switchyard. These transients may be caused by the restrike characteristics of arcs that exist during the energization or interruption of a high-voltage circuit and the resonance with lumped circuit reactances within the switchyard. These reactances are attributed to potential transformers, capacitive coupling devices, power factor capacitors, reactors, power transformers, and high-voltage power cables.

Typical operations of a high-voltage electric system that cause these transient switching surges are

- a) Switching shunt capacitors
- b) Overvoltage flashover of lightning arresters
- c) Restrike of circuit breakers
- d) Switching of a section of extra-high-voltage (EHV) bus by an air-break disconnect switch

The transients are identified (see IEEE Std C37.90.1™-1989 [B23]) as high frequency, high voltage, and short time duration with a decaying amplitude characteristic. Resonant frequencies from 200 kHz to 2.9 MHz with an amplitude of 12 kV and lasting for 10 ms to 100 ms have been measured on control circuits. Pulse trains lasting up to 3 s have been observed.

Longitudinal induced voltages caused by these transient switching surges may be kept well below 1000 V if the cable is in an iron or steel conduit and is shielded and paralleled with, for example, 2/0 AWG bare wire. In this case, shield and parallel wire should be grounded at each end. The telecommunication cable should be oriented perpendicular to any high-voltage bus overhead of the cable route. All-dielectric fiber-optic cables are immune to induction and other electrical effects.

4.2.5 Other disturbances

Other higher frequency disturbances include those caused by showering arc (contact arcing), restriking faults, electrostatic discharge, and corona. These disturbances usually do not interfere with wire-line facilities but may result in distortion and scattering of radio fields and TV and radio interference.

5. Protection apparatus

Wire-line telecommunication circuits entering electric supply locations may be owned by the electric power utility or by the end user, or are leased from a telephone company. In the case of leased telecommunications circuits, the protective devices located at the high-voltage interface are considered part of the network. In some jurisdictions involving leased telephone facilities, the telco/user interface (demarcation point), by mutual agreement, would be at a point outside the ZOI; therefore, this point would not be the high-voltage protected interface. In this case, the entrance cables traversing the ZOI and the high-voltage protective interface equipment would be owned either by the power utility or by the end user. The telco/user interface shall be a protected terminal or protector block outside the ZOI. These telecommunication circuits are of various types and have different service performance objectives (SPOs), as described in Clause 6.

The type, quality, and quantity of protective devices that would be used in any particular application should be dictated by the nature, magnitude, and frequency of occurrence of the interference, the nature of the service requirements, considerations of personnel and plant safety, and by the general protective policies employed by the organizations concerned.

The protective devices recommended today range from very simple, low-cost gas tubes and small-gauge wire fuse links to sophisticated schemes involving isolating transformers, mutual drainage reactors, and optical isolation cables or systems.

Annex A provides further details, including operating characteristics, on various types of protective apparatus.

The operation of a protective device may result in a residual voltage between the telecommunication conductors and earth. The permissible magnitude of this residual voltage should be such that the requirements for personnel and plant safety are not jeopardized. In the case of circuits protected by neutralizing transformers or reactors, this residual voltage is termed the remanent or unneutralized voltage (see A.5).

The following paragraphs outline briefly the broad characteristics and application techniques of the various protective equipment in current general use.

a) Carbon block protectors

An assembly of two or three carbon blocks and an air gap designed to a specific breakdown voltage. These devices are normally connected to telecommunication circuits to provide overvoltage protection and a current path to ground during such overvoltage (see A.1).

NOTE—The manufacturing of carbon blocks has been largely discontinued.

b) Gas-filled (gas tube) protectors

A discharge gap between two or more electrodes hermetically sealed in a ceramic or glass envelope. These gaps provide protection against excessive voltage in the same manner as carbon block protectors (see A.2). The differences in operating characteristics of gas tube and carbon block protectors are discussed in B.1.

c) Solid-state protectors

These protectors employ solid-state circuit elements that provide a combination of high-speed voltage and current sensing. These protectors are a combination of voltage clamps (avalanche diodes) and crowbar devices (multilayer diodes similar to SCRs) and are designed to limit the voltage to a specific value and to reduce current flow to low values of milliamperes within nanoseconds. They are usually integrated into the terminal apparatus. Their characteristics are described in A.3, while comparisons with carbon blocks or gas tubes are described in B.2.

d) Spark gaps

Spark gaps consist of air dielectric between two electrodes that may be a combination of several basic shapes. These protectors are used to protect telecommunication circuits from damage due to voltage stress in excess of their dielectric capabilities (see A.1). They may or may not be adjustable.

e) Horn gaps

An air gap metal electrode device, consisting of a straight vertical round electrode and an angular shaped round electrode. In the case of a telephone pair, there is one common grounded, center straight, vertical electrode and two angular electrodes, one for each side of the pair. The gaps are usually adjustable.

Horn gaps are used usually outdoors on open-wire lines exposed to high-voltage power transmission lines and in conjunction with isolating or drainage transformers. They are also used frequently alone out along the open-wire pair. Horn gaps provide protection both against lightning and power contacts (see A.1).

f) Surge protective devices

Devices that guard against dielectric failure of protection apparatus due to lightning or surge voltages in excess of their dielectric capabilities and serve to interrupt power follow current. Protection of isolating and neutralizing transformers by surge arresters is covered in Annex C.

g) Isolating transformers

Isolating (insulating) transformers provide longitudinal (common-mode) isolation of the telecommunication facility. They can be designed for use in a combined isolating-drainage transformer configuration and also can be designed for a low longitudinal to metallic conversion (see A.4).

h) Neutralizing transformers and reactors

Devices that introduce a voltage into a circuit pair to oppose an unwanted voltage. These devices neutralize extraneous longitudinal voltages resulting from ground potential rise, longitudinal induction, or both, while simultaneously allowing ac and dc metallic signals to pass.

These transformers or reactors are used primarily to protect telecommunication or control circuits either at electric supply locations or along routes where exposure to power line induction is a problem, or both (see A.5).

i) Drainage units or drainage reactors

Center-tapped inductive devices designed to relieve conductor-to-conductor and conductor-to-ground voltage stress by draining extraneous currents to ground. They are also designed to serve the purpose of a mutual drainage reactor forcing near simultaneous protector-gap operation (see A.6). These devices have a high conductor-to-conductor impedance to avoid loss of signal when protectors operate.

j) High-voltage isolating relays

Provides for the repeating of dc on/off signals while maintaining longitudinal isolation. High-voltage isolating relays may be used in conjunction with isolating transformers [see item k)] or may be used as stand-alone devices for dc tripping or dc telemetering (see A.7).

k) Isolating transformers with high-voltage isolating relays

This assembly provides protection for standard telephone service and consists basically of an isolating transformer and a high-voltage isolating relay. The transformer provides a path for voice and ringing frequencies while the relay provides a means for repeating dc signals around the transformer. A locally supplied battery or dc power supply is required for operation of the telephone and relay (see A.8).

l) Optic coupling device

An isolation device using an optical link to provide the longitudinal isolation. Circuit arrangements on each side of the optical link convert the electrical signal into an optical signal for transmission through the optical link and back to an electrical signal. Various circuit arrangements provide one-way or two-way transmission and permit transmission to the various combinations of voice and/or dc signaling used by the power industry. The optical link may be either a quartz rod or a short length of optic fiber. Single channel optic coupling devices may be used in conjunction with other isolation devices in protection systems as described in 8.4.4. A multichannel protection system utilizing a cabinet with mounting arrangements for a multiplicity of optic coupling devices is described in 8.8. For further information on fiber optic isolation systems, see Annex F.

m) High-voltage disconnect jacks

Used to disconnect cable pairs for testing purposes. They help safeguard personnel from remote ground potentials (see A.10).

n) Cable in the GPR zone of influence

A high dielectric cable is one that provides high-voltage insulation between conductors, between conductors and shield, and between shield and earth (see 7.2, A.11, IEEE Std 367-1996, and IEEE Std 789-1988).

6. Service types, reliability, service performance objective (SPO) classifications, and transmission considerations

The term reliability means different things to different people. In its broadest sense, the term reliability is used with the term availability to measure system or equipment performance over a given period of time. Reliability and availability formulae and objectives are not addressed in this document.

In the context of power system protective relaying, reliability consists of a combination of dependability (failure to deliver a valid trip signal) and security (delivery of a false trip or control signal.) This subject is dealt with briefly in 6.2 and 6.2.1.

Service performance objective classifications, as used in this guide, are a function of interruptions or outages due to the effects of power system faults (see 6.2 and 6.2.1).

Telecommunication services provided to electric supply locations are of different service types and have different SPO classes in accordance with the definitions given in this clause. The responsible power utility engineer, when ordering leased telecommunication facilities within the ZOI should specify the service type and the desired SPO class for each telecommunication service provided at the electric supply location.

In addition to GPR and longitudinal induction considerations, service type, and SPO, the transmission characteristics of the channel should be considered when selecting the method of protection to be used.

6.1 Service types

For purposes of this recommended practice, wire-line telecommunication services to electric supply locations can be classified into five major types according to the following definitions and as summarized in Table 1 (see 8.9.2).

NOTE—Various other classifications may be used.

- a) *Type 1.* Services requiring either dc transmission or ac and dc transmission used for
 - 1) Basic exchange telephone service or private line, or both, voice telephone service, etc.
 - 2) Telemetry, supervisory control, etc.
- b) *Type 2.* Private line services requiring ac or dc transmission, or both, used for pilot wire protective relaying, or dc tripping.
- c) *Type 3.* Private line services requiring only ac transmission used for telemetry, supervisory control, data, etc.
- d) *Type 4.* Private line services requiring only ac transmission used for audio tone protective relaying.
- e) *Type 5.* Digital services such as DS-1 digital transmission used for T-1, ISDN, and DSL private line transport services.

6.2 Service performance objective classifications

Interruptions or outages of wire-line telecommunication circuits serving electric supply locations may occur for physical reasons such as cable damage due to extraordinarily heavy storm loading, a vehicle striking and breaking a utility pole, or a direct lightning stroke. Circuit failures caused by such events cannot be prevented but may be minimized through careful application of the appropriate construction and maintenance practices.

Interruptions or outages due to the effects of power system faults can be minimized through the installation and maintenance of special protection systems that are designed to operate in the fault-produced electrical environment (GPR and longitudinal induction) at electric supply locations. Because of the critical need for service continuity during power system faults on certain types of telecommunication services provided to electric supply locations, a system of optional service performance objective classifications, for the purpose of this recommended practice, has been established for all types of telecommunication services provided to electric supply locations (see Table 1). These objectives, with respect to the effects of power system faults, fall into the following three classifications:

- a) *Class A.* Non-interruptible service performance (shall function before, during, and after the power fault condition)
- b) *Class B.* Self-restoring interruptible service performance (shall function before and after the power fault condition)
- c) *Class C.* Interruptible service performance (can tolerate a station visit to restore service)

6.2.1 Class A service performance objective considerations

SPO Class A is the most demanding type. Service performance for this class cannot tolerate even a momentary service interruption before, during, or after a power system fault. The non-tolerable service interruptions include both loss of dependability (failure to deliver a valid trip or control signal) and loss of security (delivery of a false trip or control signal). Examples of services that may have an SPO Class A are pilot-wire protective relaying, audio-tone protective relaying, and critical supervisory (remote control) circuits.

To provide additional reliability, dual alternate routing of two SPO Class A circuits should seriously be considered. This means that critical operating circuits are duplicated, end-to-end, over two geographically separated routes, minimizing the risk of simultaneous interruption of both circuits.

In addition to the special protection employed for achieving the SPO Class A, certain other special or nonstandard physical design and administrative procedures of the plant facilities should be followed. These include

- a) The minimization of bridged taps and multiple appearances of these cable pairs.
- b) The minimization of the number of appearances on central office main frames, with special protective covers required on all appearances.
- c) These circuits should not be tested, switched, electrically contacted, or changed unless prior arrangements have been made with the appropriate group within the electric utility as to the date, time, and duration of such operations.

The use of some digital services/equipment, such as HDSL, to provide SPO Class A is not recommended due to synchronization issues that may preclude the circuit to operate before, during, and after the fault.

6.2.2 Class B service performance considerations

SPO Class B is less demanding than SPO Class A in that a service interruption can be tolerated for the duration of a power system fault, but service continuity should be restored immediately after the fault without

requiring any repair personnel activity. Examples of services that are SPO Class B (with self-restoring requirements) are storm or emergency telephone circuits, telemetering and data circuits, supervisory control circuits, and signal and alarm circuits. The telecommunications engineer may determine that, for reasons of service performance, some or all of the special, nonstandard, physical design, and administrative procedures indicated in 6.2.1 described for SPO Class A are also necessary for SPO Class B.

6.2.3 Class C service performance considerations

SPO Class C is the least demanding in that an interruption or a service outage due to a power fault that requires a station visit to restore service can be tolerated. Examples of services that are SPO Class C are basic exchange telephone service, non-critical telemetering and data circuits, and some types of signal and alarm circuits. The special nonstandard design and administrative procedures described for SPO Class A are not required to achieve SPO Class C.

6.3 Transmission considerations

The transmission characteristics of the channel should be considered in selecting the optimum protective arrangement to safeguard electric supply location telecommunication channels.

Depending upon the type of service, the transmission requirements will vary widely. For example, some services require a physical metallic pair, end-to-end. Certain channels should carry both ac and dc signals, while others are required to carry only ac signals. In the selection of protective hardware, transmission demands of the terminal equipment should be matched with the transmission capability of the channel. Transmission characteristics and SPO requirements for various types of telecommunication channels are shown in Annex D.

The following is a partial list of characteristics that should be specified by the user, if applicable, so that the transmission channel and associated protective equipment can be designed to meet the demands of the terminal equipment:

- a) Type of termination (two-wire or four-wire)
- b) Mode of operation (simplex, half-duplex, or full-duplex)
- c) Function (remote trip, supervisory control, pilot wire, etc.)
- d) Transmission (VF audio tone, dc on/off, dc pulses, etc.)
- e) Attenuation requirements
- f) Required frequency response
- g) Steady-state and impulse noise requirements
- h) End to end round trip delay
- i) Allowable harmonic distortion over frequency range of interest
- j) Envelope delay distortion requirements
- k) Shunt capacitance limitation between conductors of a single pair
- l) Maximum loop resistance, including all high-voltage interface (HVI) terminations
- m) Allowable capacitive or resistive unbalance of the pairs, or both
- n) Maximum differential mode voltage
- o) Impedance of source and load
- p) Need for metallic continuity (hardwired or derived) in the channel

7. Protection theory and philosophy

Both the telecommunications protection engineer and the power system protection relaying engineer agree that the basic objectives for the protection of wire-line telecommunication facilities serving electric supply locations are to maximize personnel safety, to protect the telecommunications plant and terminal equipment, to maintain reliability of service, and to accomplish these in the most economic way. In the design of a protection system to meet these objectives, however, the telecommunications protection engineer and the power protective relaying engineer may differ in their design approaches due to differences in their network reliability standards and protection philosophies. The design of a protection system requires a blending of the philosophies of the engineers responsible for telecommunications protection and for protective relaying in order to affect a solution that meets the primary protection objectives of both industries and the mutual customer base they serve.

The protection concepts and system designs described in this standard for leased telephone facilities have been agreed to by the power and telephone industry representatives who produced this standard. Where divergent views exist, they are covered by notes and dashed-lined boxes in the circuit diagram figures. In these cases, the telecommunications protection engineer and the power protective relaying engineer should reach a mutual agreement regarding the design to be implemented. The protection designs for telecommunications facilities to transmission line tower locations subject to GPR are generally specified by the telecommunications protection engineers with mutual agreement with other parties.

7.1 Special wire-line protection design requirements

In order to design special protective systems for wire-line facilities serving electric supply locations, the following conditions should be known. However, no single condition should be used as the sole criterion for determining the need for special high-voltage protection.

- a) The quantities, service types, and service performance objective classifications of all services at the electric supply location
- b) The transmission requirements of the terminal equipment (ac signals only, dc signals only, ac plus dc signals, signaling frequencies, transmission capabilities of the transmission facility, e.g., noise squelch levels versus expected noise performance of the facility)
- c) Factors such as the total available single phase-to-ground fault current and its distribution, maximum GPR (rms), X/R ratio, fault-produced longitudinal induction, and lightning exposure
- d) Electric supply location ground grid impedance to remote earth and the grid area
- e) The extent of the GPR zone of influence
- f) Whether the transmission parameters and service performance objectives are compatible with the available or proposed facilities
- g) Anticipated future changes in any of the above data
- h) Whether lightning protection is required
- i) Any available past trouble report history for the electric supply location in question (see IEEE Std 367-1996)

If an isolation-type protection system is to be used, drainage current capability for the isolating transformers and drainage reactors should be considered.

If a neutralization-type protection system is to be considered, the following additional information should be known:

- The required volt-second or per unit flux capability of the neutralizing transformer or reactor based on the expected GPR (including any assumed dc offset) and maximum permitted remanent voltage (see A.5)
- Wire gauge and number of pairs, based on present and future requirements
- Maximum resistance of the primary circuit conductors and remote ground resistance
- The design method to be used for design specification purposes: worst-case design, the number of good cycles approach, custom design, or standardized design
- Mechanical constraints: size, weight, type of impregnation, terminals or stub cables, etc.
- Electrical constraints: presence of additional protective devices, such as gas tubes, drainage reactors, limitations of cable and terminal dielectric strength, and remote grounding

7.2 Dedicated cable

A common feature of Voltage Level II and III circuit configurations, discussed in 8.1.3 and 8.1.4, is the use of a high dielectric withstand, dedicated cable containing only those pairs serving the electric supply location. Depending upon local agreement or authoritative regulations, the dedicated cable may be owned by either the telecommunication provider or the end user. Pairs to all other subscribers are excluded, minimizing pair-to-pair stress during a fault. A dedicated cable, if provided by a telephone company, may extend the entire distance from the electric supply location high-voltage interface location to a telecommunication center; however, it should extend at least to a point where the GPR profile has decreased to an agreed value. This point should be located so as to protect the general-use cable plant and, in the case of remote drainage, to minimize protector block operation and the resulting generation of noise, which could interrupt or interfere with critical services. See 10.3 for safety concerns related to installation and maintenance of this item.

If a remote drainage location is not used, the dedicated cable need extend only to a point on the GPR profile that is compatible with the assured dielectric of the installed, general-use cable. The reliability of the wire-line telecommunications facility is dependent, in part, upon the high-voltage integrity of the dedicated cable. Refer to IEEE Std 789-1988 for typical specifications for telecommunication cable serving electric supply locations.

Special considerations should be observed when grounding the dedicated cable. Cable pairs and shield between the high-voltage interface location and the edge of the zone of influence should not contact the ground structure at the electric supply location. The cable should be routed through a well-drained insulating conduit in the station grid area, reducing the possibility of solid or incidental contact with the station grid. If arresters are not used, the shield should be clipped and rendered inaccessible to prevent workers from erroneously connecting the shield to ground at the electric supply location.

Low-impedance grounding of the dedicated cable shield within the GPR zone of influence is likewise not permitted. Incidental, high-impedance grounding, however, can be tolerated. An incidental ground results from a small puncture or pinhole in the outer covering of the cable. Incidental grounds are assumed to have, and continue to have, sufficiently high contact impedance to limit shield current and internal cable stress.

The dedicated cable facilities are shown in Figure 13 through Figure 19. The user/telco interface is defined as a point at which the user and telco facilities meet, and to which both user and telco personnel have access. Its location is determined by local agreements or authoritative regulations. It should be noted that this point may or may not be at the same location as the high-voltage protective apparatus location referred to as the high-voltage interface (HVI).

High voltages due to GPR and induction can appear between cables, protection hardware, and the local ground at various points of an installation. It is essential that personnel accessing the installation understand the potential dangers and observe the safety practices discussed in Clause 10.

7.2.1 Aerial cable installation

The use of an aerial supported wire-line cable utilizing a metallic messenger is not recommended. Wire-line cable service to an electric supply location should be accomplished utilizing a buried PVC conduit containing the dedicated cable.

If the dedicated cable is to be aerial it should transverse the zone of influence using a pole line exclusively for the dedicated cable. Down guys and messenger attachments within the ZOI should also be isolated.

The vertical grounds and all down guys located within the zone of influence impart a portion of the GPR onto the metallic messenger and subsequently the cable shield. This situation creates a cable placement method that is difficult, at best, to protect or isolate from GPR events, and, at the same time, may endanger anyone working on this type of facility entrance.

The additional engineering methods and personnel safety measures required to minimize safety risks associated with an aerial entrance installation far outweigh the choice of placing an aerial installation over a buried or underground installation.

If hard rock soil conditions preclude the placement of buried PVC conduit, then an aerial dedicated cable may, as a last choice, be placed on a separate pole line for the exclusive use of the dedicated cable. The facilities designer has to be aware that the use of an aerial supported wire-line cable utilizing a metallic messenger is not recommended for the following reasons (not necessarily in a particular order):

- Difficulty of establishing and maintaining separate pole line to assure integrity of the protective design.
 - 1) Existing joint use agreements or contracts may preclude a separate pole line for aerial dedicated cables.
 - 2) Telecommunications Act of 1996 regulations on sharing of structural facilities may also preclude a separate pole line for aerial dedicated cables.
- Difficulty in providing for personnel safety by minimizing touch voltages between metallic members (support messengers, cable shields, etc.).
- Difficulty in assuring the integrity of the design during or after maintenance and repair activities.
- Difficulty in maintaining the designed isolation of metallic strands (support messengers) and cable shields.
- Meeting National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-2007) [B1] bonding and grounding requirements may conflict with the need to isolate metallic members.

7.2.2 Conduit containing metallic members or tracing medium

The use of any conduit containing any metallic members should not be utilized for the cable entrance facility for the electric supply location. The cable entrance facility should be all dielectric material from the HVI location to a point at least 3 m (10 ft) on the central office (CO) side of the grid or perimeter fence, whichever is closer to the CO.

These locating wires or materials violate the concept of an all dielectric cable entrance conduit and should not be used for safety reasons.

7.2.3 Resistive balance

Longitudinal current may result from an insulation breakdown of cable pairs or shield during the fault or if induced voltages are sufficient to operate the drainage mechanism provided on the pairs. This current will produce metallic voltages if the resistance of the tip and ring conductors or the drainage devices is not