

IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations

Sponsor
**Power Systems Communications Committee
of the
IEEE Power Engineering Society**

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

Keywords: wire-line communication, protection

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Foreword

(This foreword is not a part of IEEE 487-1992, IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations.)

Wire-line telecommunication facilities serving electric power stations 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 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 standard has been prepared by the Wire-Line Subcommittee of the Power Systems Communications Committee of the IEEE Power Engineering Society with the assistance of the Telco/User Interface Working Group of the Inductive Coordination and Electrical Protection (ICEP) Subcommittee of the Transmission Systems Committee (TRANSYSCOM) of the IEEE Communications Society. This standard represents the consensus of both power and telecommunications engineers.

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IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations

1. Scope

This document presents recommended engineering design practices for special high-voltage protection systems intended to protect wire-line telecommunication facilities serving electric power stations.

The following topics are included in this document:

- 1) A description of the power station environment, i.e., ground potential rise (GPR), induced voltages, lightning, and switching transients
- 2) A discussion of special high-voltage protection devices
- 3) of service types and service performance objectives for power station telecommunication services
- 4) Special protection theory and philosophy
- 5) Special protection system design guidelines
- 6) Personnel safety considerations
- 7) Grounding

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

2. Introduction

Wire-line telecommunication¹ facilities serving electric power stations 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.

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

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

- 1) Ground (earth) potential rise (GPR)
- 2) Longitudinal induction into the serving telecommunication facilities
- 3) Electrical contact between power and telecommunication conductors
- 4) 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.

3. References

The following documents shall be used in conjunction with this recommended practice.

[1] IEEE C37.93-1987, IEEE Guide for Power System Protection Relay Applications of Audio Tones Over Telephone Channels (ANSI).²

[2] IEEE Std 80-1986 (Reaff 1991), IEEE Guide for Safety in AC Substation Grounding (ANSI).

[3] IEEE Std 81-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System (ANSI).

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

[5] IEEE Std 367-1987, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault (ANSI).

[6] IEEE Std 776-1987, IEEE Guide for Inductive Coordination of Electric Supply and Communication Lines (ANSI).

[7] IEEE Std 789-1988, IEEE Standard Performance Requirements for Communications and Control Cables for Applications in High-Voltage Environments (ANSI).

4. Definitions

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.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

conductive (resistive) coupling: *See coupling.*

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.

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.

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

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

grounding relays: *See: short-circuiting relays.*

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

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

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.

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.

hot-line protectors: *See: open-wire protectors.*

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

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.

isolating transformers with high-voltage isolating relays: 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.

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

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 power stations or along routes where exposure to power line induction is a problem, or both.

open-wire protectors: Combined isolating and drainage transformer-type protectors used in conjunction with, but not limited to, horn gaps and grounding relays are used on open-wire lines to provide protection against lightning, power contacts, or high values of induced voltage. *Syn: hot-line protectors.*

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 signalling 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.

radiated coupling: Propagation of a wave through free space at radial distances greater than $\lambda/6$ from the power line carrying the disturbing energy. *See:* **coupling**.

reliability (power system protective relaying): A combination of dependability and security.

short-circuiting relays: Telecommunication circuit grounding relays are used to ground an exposed telecommunication or telephone pair, usually on open-wire “joint-use” facilities during periods of severe power system disturbance. *Syn:* **grounding relays**.

sky wire-coupling protector: *See:* **static wire-coupling protector**.

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.

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.

static wire-coupling protector: A device for protecting carrier terminals that are used in conjunction with overhead, insulated ground wires (static wires) of a power transmission line. *Syn:* **sky wire-coupling protector**.

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.

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

5. Electric Power Station Environment

5.1 General

Electric power stations utilize a ground grid so that all grounded structures within the station can be connected to a common grid, thereby minimizing potential difference in the system during a lightning stroke or a power system fault. When a power system ground fault occurs, all or some of the fault current returns via the earth through the ground grid and produces a potential difference between the ground grid and remote earth. This potential difference is defined as power station ground potential rise (GPR). 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 ground grid, the connections to the ground grid, and the soil resistivity in the vicinity of the station.

Connections to the ground grid from remote points by means of overhead ground (earth, static, or sky) wires, multigrounded neutrals, cable shields, rail lines, etc., affect the distribution of fault currents through the system grounding paths and also affect the total station impedance to remote earth. Since the above factors can vary significantly, the GPR can vary over a wide range.

A rigorous analysis of ground potential rise calculations is presented in IEEE Std 367-1987 [5]³.

³The numbers in brackets correspond to those of the references in Section 3.

5.2 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 (RFI), electromagnetic pulse (EMP), 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 [B15]⁴). 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 all parameters cannot 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, electric 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 or by ensuring adequate bonding of the grounding systems in situations in which the power line and its associated protective relaying circuits should 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.

Radiated coupling refers to the propagation of a wave through free space at radial distances greater than $\lambda/6$ from the power line carrying the disturbing energy. This form of coupling is not discussed further in this document.

5.3 Disturbances

5.3.1 Ground Potential Rise (GPR)

5.3.1.1 Theoretical Background

With reference to Fig 1, the current causing GPR that is created by the returning fault current through the power station ground grid impedance has the following form (assuming that the zero sequence current prior to the fault is zero):

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

⁴The numbers in brackets, when preceded by the letter “B,” correspond to the bibliographical entries in Section 14.

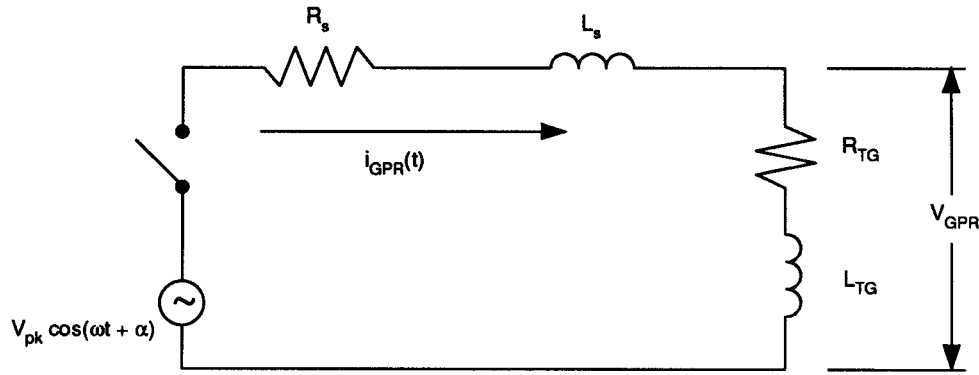


Figure 1—Simplified Loop for GPR Calculation

where

$$\beta = \frac{R_s + R_{TG}}{L_s + L_{TG}} \triangleq \frac{R}{L}$$

$\omega = 2\pi f = 377 \text{ rad/s}$ at 60 Hz

α = phase angle of the power line voltage at the initiation of the fault, in radians

R_s = power system equivalent resistance, in ohms

L_s = power system equivalent inductance, in henries

R_{TG} = total ground resistance at the point where GPR is being evaluated, in ohms

L_{TG} = total ground inductance at the point where GPR is being evaluated, in henries

V_{pk} = peak value of system voltage (0 ω source impedance assumed)

$i_{GPR}(t)$ = GPR producing current including the transient component, in amperes

$$\theta = \text{loop impedance angle} = \tan^{-1}\left(\frac{\omega}{\beta}\right) = \tan^{-1}\left(\frac{\omega L}{R}\right), \text{ in radians}$$

t = time, in seconds

The GPR appearing across the $R_{TG} + j\omega L_{TG}$ can be calculated as follows:

$$V_{GPR}(t) = R_{TG} i_{GPR}(t) + L_{TG} \frac{d i_{GPR}(t)}{dt}$$

$$\frac{d i_{GPR}(t)}{dt} = \frac{V_{pk}}{|Z|} [-\omega \sin(\omega t + \alpha - \theta) + \beta \cos(\alpha - \theta) e^{-\beta t}]$$

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

$$+\beta L_{\text{TG}} \cos(\alpha - \theta) e^{-\beta t}]$$

$$= \frac{V_{\text{pk}}}{|Z|} [R_{\text{TG}} \cos(\omega t + \alpha - \theta) + \omega L_{\text{TG}} \sin \omega t + \alpha - \theta$$

$$-\cos(\alpha - \theta)(R_{\text{TG}} - \beta L_{\text{TG}}) e^{-\beta t}]$$

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

Simplifying further, let

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

$$\therefore R_{\text{TG}} = \cos \theta_{\text{TG}} |Z_{\text{TG}}|$$

$$\omega L_{\text{TG}} = \sin \theta_{\text{TG}} |Z_{\text{TG}}|$$

$$\text{Let } \omega t + \alpha - \theta = a$$

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

then

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

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

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

where

$$\theta_{TG} = \tan^{-1} \frac{\omega L_{TG}}{R_{TG}}$$

is the angle of the impedance, Z_{TG} .

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 Annex A.5.1.6). 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 367-1987 [5] 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, α , approaches $\pi/2$ radians, and the power line voltage phase angle, α , which produces maximum offset, approaches $\pi/2$ radians.

5.3.1.2 Practical Implications

When a fault to ground occurs on a transmission or distribution line terminating in a grounded-neutral transformer bank at a power station or substation, fault current will flow from the power station 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 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.

While the impedances of station ground grids can range from 0.01 to 10 Ω or more, they are normally quite small, usually less than 1 Ω . 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.

The GPR consists of a steady-state symmetrical component and may contain a decaying dc transient component (sometimes called the dc offset, see Appendix A). 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. Fig 2 shows an illustration of a nonsymmetrical GPR waveform and the two components.

The reader of this document should refer to IEEE Std 367-1987 [5] for more detailed discussion.

For a discussion of worst case volt-ampere area in the context of neutralizing transformers, see Annex A.5.1.9.

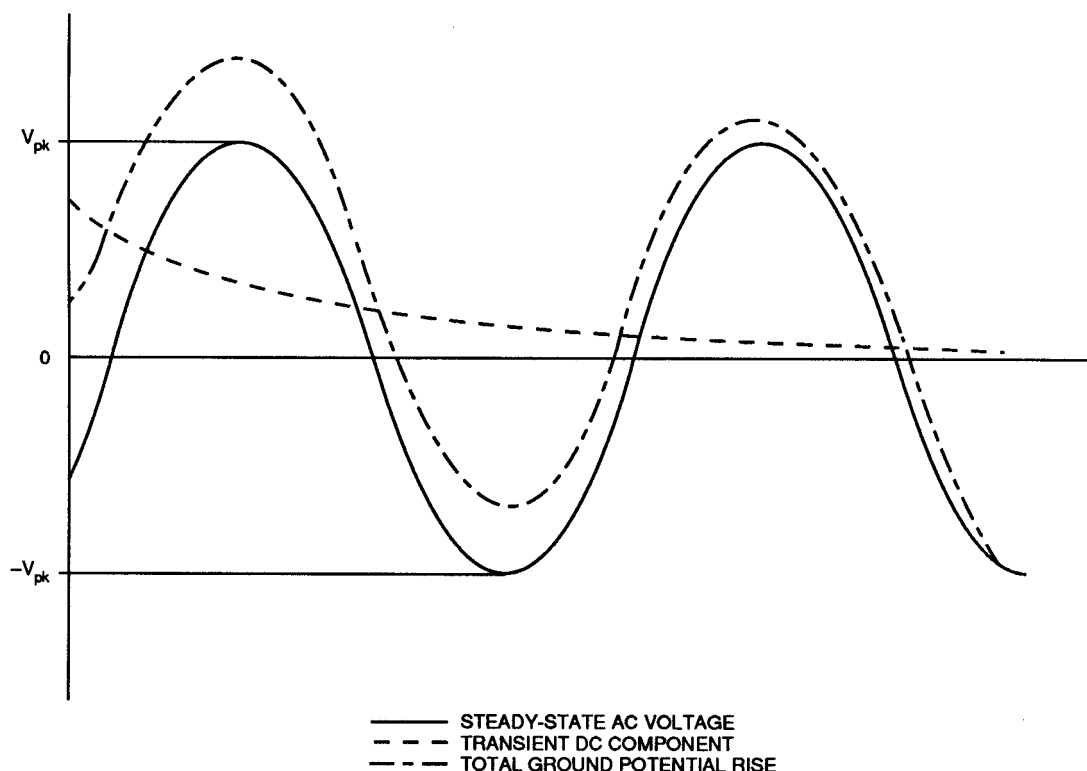


Figure 2—Illustration of a Nonsymmetrical GPR Waveform

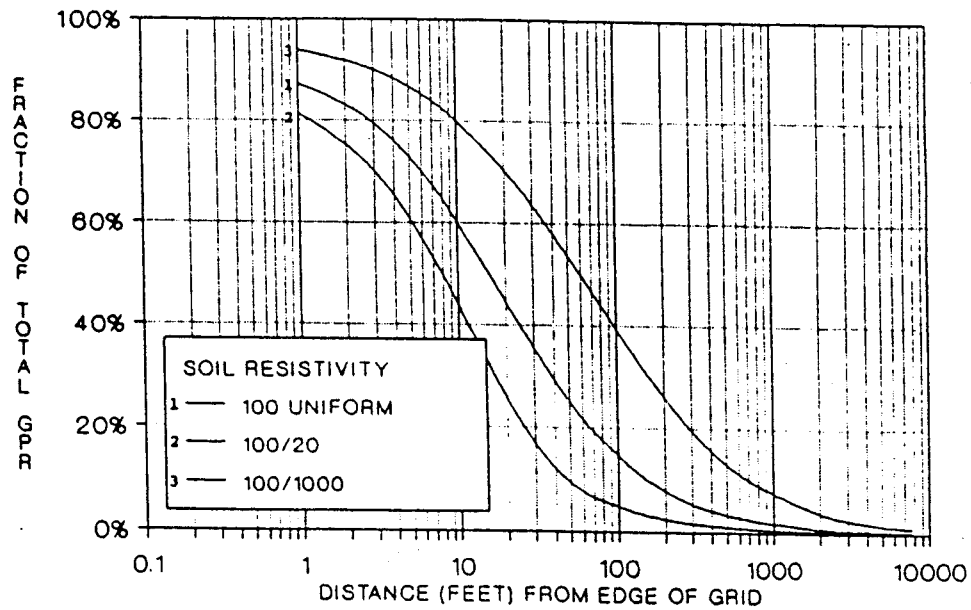
NOTE — Power line faults are generally initiated at or close to peak voltage. For such faults, the transient dc component and the dc offset factor are minimal. Refer to IEEE Std 367-1987 [5] and Appendix A of this document. For purposes of this recommended practice, the words “asymmetrical” and “nonsymmetrical” are synonymous.

Figs 3(a) and 3(b) illustrate a theoretical GPR distribution from the edge (where the protection requirements are usually specified) of two simple ground grids for a number of different earth resistivity models. These curves are easily reproduced using the EPRI⁵ program Station Grounding Workstation (SGW). 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, power neutrals, etc. Where external grounds exist, this practice recommends that the fall of potential impedance measurements referenced in IEEE Std 81-1983 [3] and IEEE Std 81.2-1991 [4] be used to generate the proper curves for a specific grid.

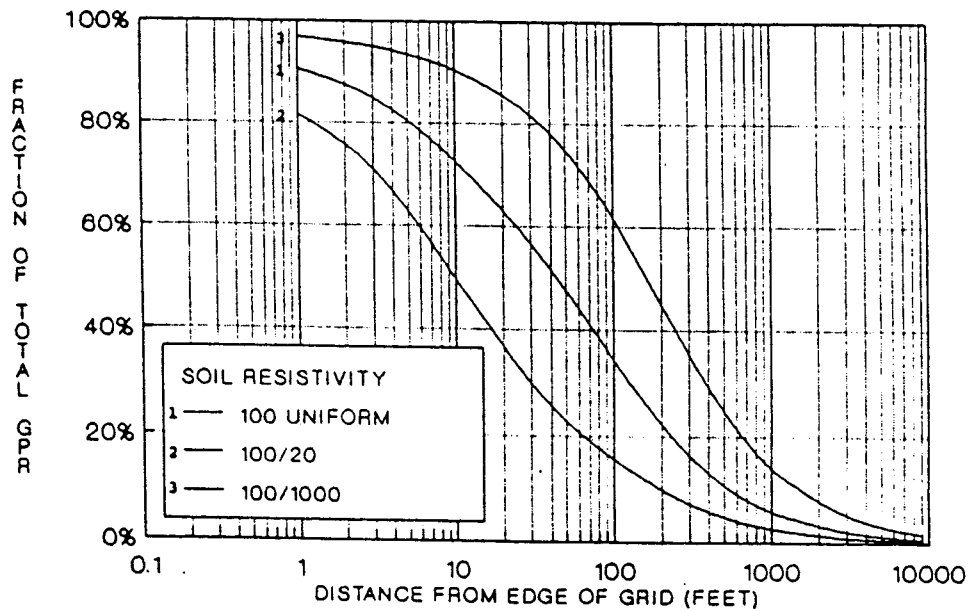
The area surrounding the electric power station that is raised in potential above a remote (or true earthing point) is referred to as the GPR zone of influence. In practice, 300 V (see 8.3 and 9.2) is often used as the boundary of this zone of influence. For a more complete discussion on this topic, refer to IEEE Std 367-1987 [5].

The potential of the ground around the power station, with respect to remote earth, falls off with distance from the station grounding system as indicated by the equipotential lines in Fig 4. 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 Fig 4 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.

⁵Electric Power Research Institute, P. O. Box 10412, Palo Alto, CA, 94303, USA.

A - 1800 SQUARE FOOT GRID

Note: For non-uniform soil, depth of upper layer = 20 feet.

B - 35000 SQUARE FOOT GRID

Note: For non-uniform soil, depth of upper layer = 20 feet.

Figure 3—Earth Potential Distribution From Edge of Power Station Grid With Respect to a Remote Earthing Point

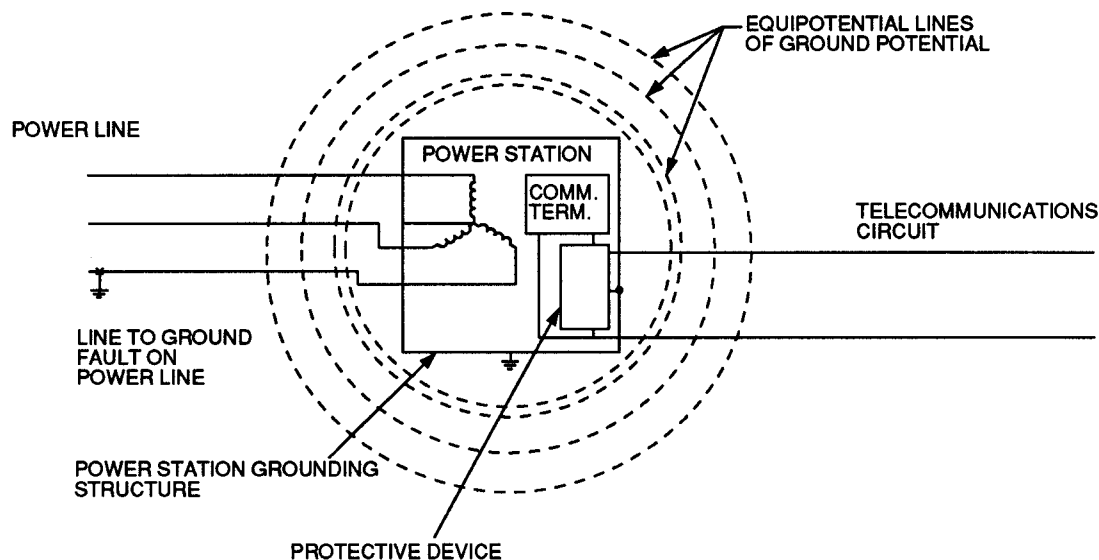


Figure 4—Theoretical Illustration of Power Station Ground Potential Rise With Conventional Protection on Telecommunication Circuits

A telecommunication circuit, extending from the power station to some remote point, is also shown in Fig 4. In this example, the protective device is installed at the power station end of the telecommunication circuit, with the protector ground terminal connected to the power station 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 for the purpose of safeguarding 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 power station, 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 ground 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 whether they are entering the GPR zone to serve the power station, to serve subscribers within the zone of influence, or are merely passing through the zone of influence. In each case, 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 difference between hazard to a cable serving a substation and hazard to a nearby cable serving the general public is one of degree. The cable to the substation always enters the area of highest GPR, while the other cable may pass through the zone of influence at some lower potential level. Refer to IEEE Std 789-1988 [7] 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 C37.93-1987 [1]. 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.

This practice emphasizes that no protection scheme should 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.

5.3.2 Longitudinal Induction

Wire-line telecommunication facilities entering power stations 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 776-1987 [6]. 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 [B15]). This may substantially increase the stress on the telecommunication facilities and the associated protection.

5.3.3 Lightning

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 [B12]). 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:

$$N_g = KT_d^{1.3} \quad (1)$$

where

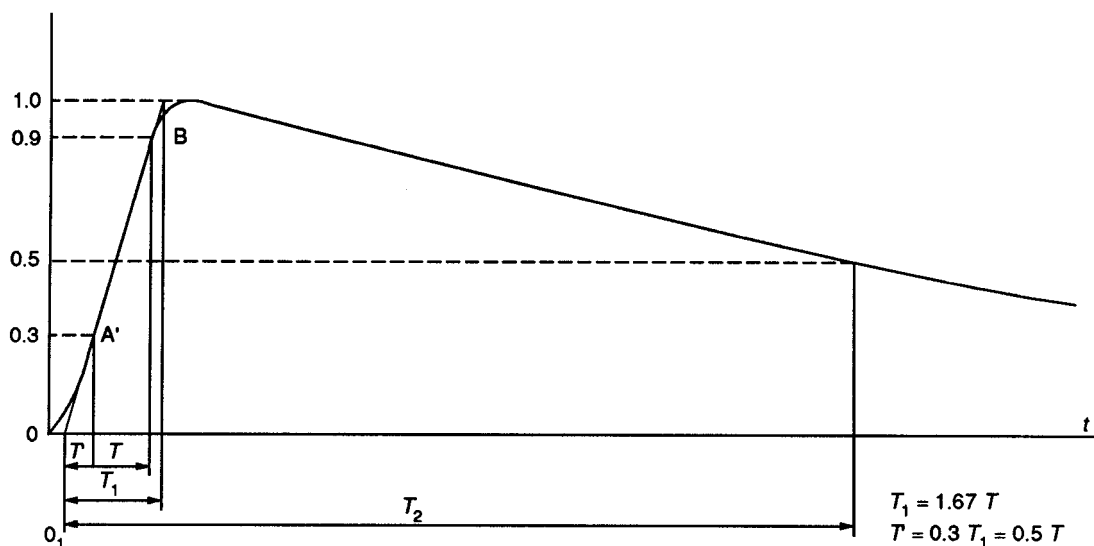
- N_g = ground flash density (flashes/km²/year).
- T_d = annual number of thunderstorm days.
- K = constant that ranges from 0.023 to 0.04. On the North American continent, the value of 0.04 is used.

The incidence of lightning to most power stations 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) power station, 0.4 strokes per year to a 225 × 225 m (50 000 m²) station, and 0.07 strokes per year to a 9600 m² substation (see [B21]). The ground grids of 95–98% 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 [B23]).

As a general rule, large power stations receive more strokes because of the larger area of the station; however, in view of large stations' increased capacitance, the effects of strokes are usually less severe than those for smaller stations. If lightning strikes or enters an electric power station on the shielding system, the massive area and diversity of conduction paths of the ground grid and tower system help to readily disperse the stroke current (see [B18]). If a shielding failure occurs, currents in the order of 2 to 20 kA are observed.

Current severity of lightning strokes is affected by structure height (see [B16]). Since most power station shielding systems are lower than 30 m, stroke current severity for a power station and a buried cable are about the same. Thus, hazards to telecommunication facilities from lightning strokes to power stations are about the same as from lightning strokes to a length of buried cable between 1.5 and 3 km. Where microwave towers are located on power station 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 Fig 5 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 Fig 5. 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 Fig 5. 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 wave form (see [B10]). 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 points A and 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 5—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 to 200 kV/ μs . 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 Fig 6. 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 Eq 2 (see [B22]).

$$P_I = \frac{1}{1 + \left(\frac{I}{31}\right)^{2.6}} \quad (\text{pu}) \quad (2)$$

where

P_I = probability of exceeding stroke current, I
 I = stroke current, in kA

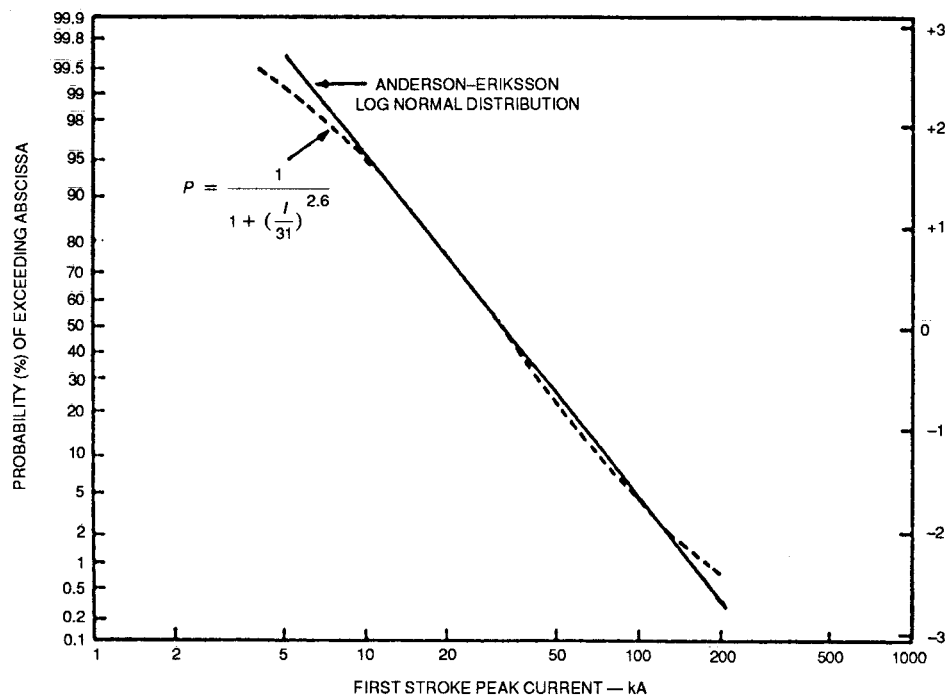


Figure 6—Cumulative Probability Distribution of Stroke Current Magnitude in Negative Lightning Flashes

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 Fig 7. 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.

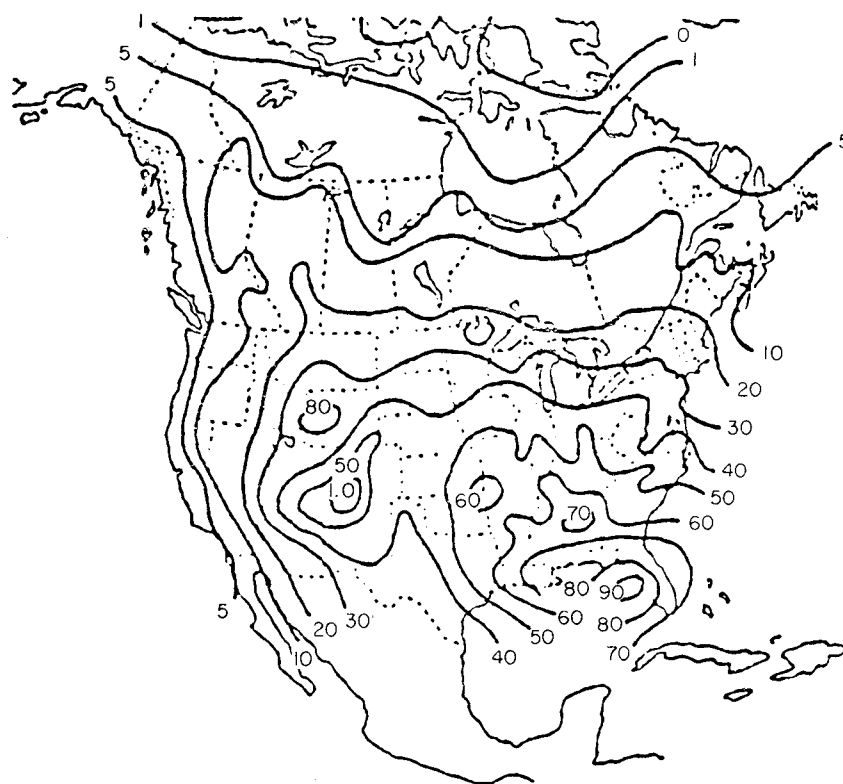


Figure 7—Isokeraunic Chart for US and Canada

Recent studies have found that a closer approximation to lightning flash density can be achieved by the use of thunderstorm hours per year (see [B19]). 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 Fig 8 (see [B13]).

The relation between thunderstorm hours in a region and lightning flash density is given by Eq 3, which is taken from [B19].

$$N_g = 0.054T_h^{1.1} \quad (3)$$

where

N_g = ground flash density (flashes/km²/year)
 T_h = annual number of thunderstorm hours

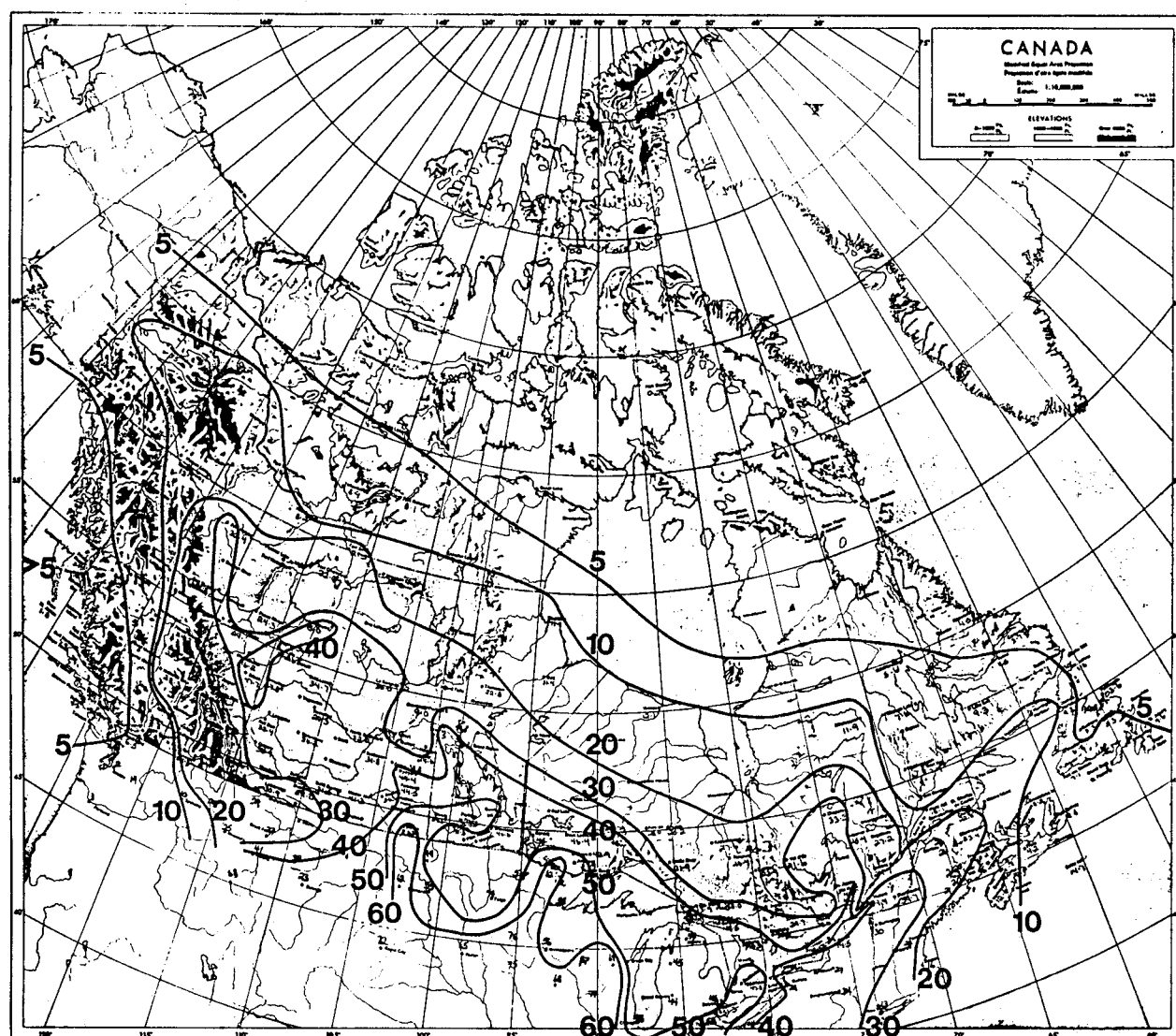


Figure 8—Annual Thunderstorm-Hour Map of Canada

5.3.4 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

- 1) Switching shunt capacitors
- 2) Overvoltage flashover of lightning arresters
- 3) Restrike of circuit breakers

4) Switching of a section of extra-high-voltage (EHV) bus by an air-break disconnect switch

The transients are identified (see [B7]) 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 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 can be kept well below 1000 V if the cable is shielded and paralleled with, for example, 2/0 bare copper wire. Both shield and parallel copper wire should be grounded at each end. Telecommunication cable should be oriented perpendicular to any high-voltage bus overhead of the cable route.

5.3.5 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.

6. Protection Apparatus

6.1 General

Wire-line telecommunication circuits entering power stations are either owned by the electric power utility or 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 may be owned by either utility. In some jurisdictions, the ownership of the protective interface by one party may require agreement by the other party. In some jurisdictions involving leased telephone facilities, the telco/user interface, by agreement, would be at a point outside the GPR zone of influence; therefore, this point would not be the high-voltage protected interface. In this case, the entrance cables traversing the GPR zone of influence and the high-voltage protective interface equipment would be power utility or end user owned. The telco/user interface could be a simple terminal or protector block outside the GPR zone of influence. These telecommunication circuits are of various types and have different performance objectives, as described in Section 7.

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 in service today range anywhere from very simple, low-cost, carbon-block protectors or gas tubes and small gauge wire fuse links to the most sophisticated schemes involving neutralizing transformers or reactors, isolating and drainage transformers, mutual drainage reactors, relays, filters, and the use of optical couplers.

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 Annex A5).

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

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

6.2 Carbon Block Protectors

A carbon block protector is 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 Annex A1).

6.3 Gas-Filled Protectors

A gas-filled protector is 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 Annex A2). The differences in operating characteristics of gas tube and carbon block protectors are discussed in Annex B.1.

6.4 Solid-State Protectors

Solid-state 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 Annex A3, while comparisons with carbon blocks or gas tubes are described in Annex B2.

6.5 Spark Gaps

Spark gaps consist of air dielectric between two electrodes that may be a combination of several basic shapes. Spark gaps are used to protect telecommunication circuits from damage due to voltage stress in excess of their dielectric capabilities [see Annex A1(2)]. They may or may not be adjustable.

6.6 Horn Gaps

A horn gap is 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 Annex A1(3) and A9].

6.7 Surge Protective Devices

Surge arresters are 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.1.

6.8 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 Annex A4).

6.9 Neutralizing Transformers and Reactors

Neutralizing transformers and reactors are 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 power stations or along routes where exposure to power line induction is a problem, or both (see Annex A5).

6.10 Drainage Units or Drainage Reactors

Drainage units or drainage reactors are 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 Annex A6).

6.11 High-Voltage Isolating Relays

A high-voltage isolating relay 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 6.12) or may be used as stand-alone devices for dc tripping or dc telemetering (see Annex A7).

6.12 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. Alocally supplied battery or dc power supply is required for operation of the telephone and relay (see Annex A8).

6.13 Short-Circuiting or Grounding Relays

Telecommunication circuit grounding relays are used to ground an exposed telecommunication or telephone pair, usually on open-wire “joint-use” facilities during periods of severe power system disturbance (see Annex A10).

6.14 Special Combination Protective Devices (Open-Wire or Hot-Line Protectors)

Combined isolating and drainage transformer type protectors used in conjunction with, but not limited to, horn gaps and grounding relays, are used on open-wire lines to provide protection against lightning, power contacts, or high values of induced voltage (see Annex A9).

6.15 Optic Coupling Device

An optic coupling device is 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 signalling 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 9.4. A multichannel protection system utilizing a cabinet with mounting arrangements for a multiplicity of optic coupling devices is described in 9.8. For further information on fiber optic isolation systems see Appendix B.1.

6.16 High-Voltage Disconnect Jacks

High-voltage disconnect jacks are used to disconnect cable pairs for testing purposes. They help safeguard personnel from remote ground potentials (see Annex A12).

6.17 Overhead Insulated Ground (Static or Sky) Wire-Coupling Protector

A device for protecting carrier terminals that are used in conjunction with overhead, insulated, ground wires (static wires) of a power transmission line is described in 9.10.

6.18 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 Annex A13, subsection 8.3, IEEE Std 367-1987 [5], and IEEE Std 789-1988 [7]).

7. Service Types, Reliability, Service Performance Objective (SPO) Classifications, and Transmission Considerations

7.1 General

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 and security. This subject is dealt with briefly in 7.3 and 7.4.

Service performance objective (SPO) classifications, as used in this guide, are a function of interruptions or outages due to the effects of power system faults (see 7.3 and 7.4).

Telecommunication services provided to electric power stations are of different service types and have different SPO classes in accordance with the definitions given in this section. The responsible power utility engineer should specify the service type and the desired SPO class for each telecommunication service provided at the power station.

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.

7.2 Service Types

For purposes of this recommended practice, wire-line telecommunication services to electric power stations can be classified into four major types according to the following definitions and as summarized in Table 1.

NOTE — Various other classifications may be used.

- 1) *Type 1.* Services requiring either dc transmission or ac and dc transmission used for
 - a) Basic exchange telephone service or private line, or both, voice telephone service, etc.
 - b) Teletypewriter, telemetering, supervisory control, etc.
- 2) *Type 2.* Private line services requiring ac or dc transmission, or both, used for pilot wire protective relaying, or dc tripping.

- 3) *Type 3.* Private line services requiring only ac transmission used for telemetering, supervisory control, data, etc.
- 4) *Type 4.* Private line services requiring only ac transmission used for audio tone protective relaying.

7.3 Service Performance Objective (SPO) Classifications

Interruptions or outages of wire-line telecommunication circuits serving electric power stations 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 power stations. Because of the critical need for service continuity during power system faults on certain types of telecommunication services provided to power stations, 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 power stations (see Table 1). These objectives, with respect to the effects of power system faults, fall into the following three classifications:

- 1) *Class A.* Noninterruptible service performance (should function before, during, and after the power fault condition)
- 2) *Class B.* Self-restoring interruptible service performance (should function before and after the power fault condition)
- 3) *Class C.* Interruptible service performance (can tolerate a station visit to restore service)

7.4 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 nontolerable 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 meet SPO Class A using wire-line facilities, dual alternate routing should be seriously considered. This means that critical operating circuits are duplicated, end-to-end, over two geographically separated routes such that an interruption on one route will not result in an interruption on the other.

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

- 1) The minimization of bridged taps and multiple appearances of these cable pairs.
- 2) The minimization of the number of appearances on central office main frames, with special protective covers required on all appearances.
- 3) 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.

7.5 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 7.4 described for SPO Class A are also necessary for SPO Class B.

7.6 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, noncritical 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.

7.7 Transmission Considerations

The transmission characteristics of the channel should be considered in selecting the optimum protective arrangement to safeguard power station 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 B.

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:

- 1) Type of termination (two-wire or four-wire)
- 2) Mode of operation (simplex, half-duplex, or full-duplex)
- 3) Function (remote trip, supervisory control, pilot wire, etc.)
- 4) Transmission (VF audio tone, dc on/off, dc pulses, etc.)
- 5) Attenuation requirements
- 6) Required frequency response
- 7) Steady-state noise requirements
- 8) Impulse noise requirements
- 9) Allowable harmonic distortion over frequency range of interest
- 10) Envelope delay distortion requirements
- 11) Shunt capacitance limitation between conductors of a single pair
- 12) Maximum loop resistance, including the neutralizing transformer (NT), if used
- 13) Allowable capacitive or resistive unbalance of the pairs, or both
- 14) Maximum differential mode voltage
- 15) Impedance of source and load
- 16) Need for metallic continuity in the channel

8. Protection Theory and Philosophy

8.1 Introduction

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 power stations are to ensure 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 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 effect a solution that meets the primary protection objectives of both.

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.

8.2 Special Wire-Line Protection Design Requirements

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

- 1) The quantities, service types, and service performance objective classifications of all services at the power station
- 2) The transmission requirements of the terminal equipment (ac signals only, dc signals only, ac plus dc signals, signalling frequencies, transmission capabilities of the transmission facility, e.g., noise squelch levels versus expected noise performance of the facility)
- 3) 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, lightning exposure
- 4) Power station ground grid impedance to remote earth and the grid area
- 5) The extent of the GPR zone of influence
- 6) Whether the transmission parameters and service performance objectives are compatible with the available or proposed facilities
- 7) Anticipated future changes in any of the above data
- 8) Whether lightning protection is required
- 9) Any available past trouble report history of the electric power station in question (see IEEE Std 367-1987 [5])

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:

- 1) 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 Annex A5)
- 2) Wire gauge and number of pairs, based on present and future requirements
- 3) Maximum resistance of the primary circuit conductors and remote ground resistance
- 4) The design method to be used for design specification purposes: worst case design, the number of good cycles approach, custom design, or standardized design
- 5) Mechanical constraints: size, weight, type of impregnation, terminals or stub cables, etc.
- 6) Electrical constraints: presence of additional protective devices, such as carbon blocks, drainage reactors, limitations of cable and terminal dielectric strength, and remote grounding

8.3 Dedicated Cable

A common feature of Voltage Level II and III circuit configurations, discussed in 9.2.1.2 and 9.2.1.3, is the use of a high dielectric withstand, dedicated cable containing only those pairs serving the power station. Depending upon local

agreement or authoritative regulations, the dedicated cable may be owned by either the telecommunication provider or by 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 power station 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 as to protect the general-use cable plant and to minimize protector block operation and the resulting generation of noise, which could interrupt or interfere with critical services. Some administrations use 300 V peak (see 9.2) as the agreed value, while others use 300 V rms. Other administrations use other values.

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. Refer to IEEE Std 789-1988 [7] for typical specifications for telecommunication cable serving power stations.

The reliability of the wire-line telecommunications facility is dependent, in part, upon the high-voltage integrity of the dedicated cable. To ensure the high-voltage capability, this facility should be high-potential tested prior to and subsequent to installation completion and after any repair-splice operation that has been performed. Even a slight repositioning of previously spliced pairs in a splice case may be sufficient to degrade high-voltage performance. Periodic high-voltage testing may be performed to ascertain that the high-voltage integrity is being maintained.

High-potential testing of the dedicated cable consists of an application of the test voltage between a single pair and the remaining pairs and shield, which have been temporarily strapped together. The process is repeated for all pairs in turn until the complete pair complement has been tested. A further test may be conducted between all pairs strapped together and the shield, depending on the magnitude of the anticipated voltage stress. High-voltage disconnect jacks or switches will be required at one end of the dedicated cable to apply the test potential and at the other end to disconnect pairs from service and properly terminate them so that arcing does not occur during testing. Lastly, a cable jacket insulation voltage withstand test to earth should be conducted.

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 power station. 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 station ground.

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 Figs 11, 12, 13, 14, 15, and 16. 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 Section 10..

8.4 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 balanced. This longitudinal-to-metallic (L/M) conversion can produce sufficient metallic noise levels to disrupt sensitive critical services. The effect

of L/M conversion should be minimized by checking the resistance balance of pairs for power station use and assigning critical services to the pairs with the best resistive balance. Effects of capacitance unbalance are relatively negligible when direct drainage longitudinal currents flow; thus, only normal tests for noise are required for this parameter.

When determining resistive balance, the entire pair length between the power station and the telecommunication center should be considered. Where the dedicated cable extends only a short distance from the power station and joins with the general-use plant, the general-use telephone cable may form an appreciable section of the cable run and will have the greatest contribution to resistive unbalance. If this cable is exposed to induction, strategically placed drainage along the cable route may be used to maintain the voltage within acceptable limits; however, drainage current will be converted to metallic noise on poorly balanced pairs. Presently, resistive balance is considered acceptable when the difference in resistance between tip and ring conductors does not exceed 1%.

8.5 Concepts and Concerns

A fundamental concept regarding the protection of wire-line telecommunication facilities serving power stations is the concept of a coordinated protection system design. This refers to a system of protection in which special protection measures are applied to SPO Class C services, as well as to SPO Class A and B services, that are provided in the same cable so that a circuit interruption or outage on an interruptible service will not cause a circuit failure or interruption on a noninterruptible service. The protection devices used on the various services should, therefore, be coordinated with each other with respect to the environment and the service performance objectives of the services on which they are employed. The object of the coordination is to minimize the likelihood of cable failure, protector operation, failure of special protection devices, failure of terminal equipment, or other similar occurrences that could create hazards to personnel and plant and result in interruptions or outages of critical and noncritical services alike. The various special protection systems described in Section 9. of this document are examples of coordinated systems of protection.

In situations in which the only telecommunication services at a power station are of an interruptible type (SPO Class C) and in which the electrical environment is judged to be hazardous to personnel or equipment, responsible protection philosophy requires that special protection measures be taken. This situation is of concern because of the need to provide special protection for personnel and plant safety when uninterrupted service performance is not a requirement. Instead, only ordinary station protection is sometimes installed and this results in an inadequate or potentially unsafe condition. The power utility personnel and, in the case of a leased telecommunications facility, the telephone company personnel are cautioned to not overlook this situation.

8.6 General-Use Telecommunication Cable in the Power Station GPR Zone of Influence

When the general-use telecommunications cable to which the dedicated cable is connected passes through an area subject to GPR, dielectric breakdown in that cable may compromise the reliability of the power station circuits. Additional protection may be required on the general use cable to avoid such degradation. The case of a general-use cable passing through the zone of influence beyond the junction with the dedicated cable is discussed in Annex A13. Routing the power station circuits through another power station zone of influence between the remote drainage point and the central office is undesirable and should be avoided.

Telephone type cables suitable for this type of installation are covered in IEEE Std 789-1988 [7].

9. Protection Configurations

9.1 General

The application of protective devices such as carbon blocks, gas tubes, isolating and drainage transformers, neutralizing transformers or reactors, optical couplers, etc., involves both the physical and electrical planning of the protection installation to ensure both personnel safety and operating reliability. The configuration may range from no protection to a simple carbon block or gas tube protection plan to a very complex configuration involving the use of neutralizing transformers or reactors and isolating transformers. This section provides recommended practices on the use of the various protection schemes and the reasons for their selection.

9.2 Ground Potential Rise (GPR) Plus Induced Voltage Levels

9.2.1 Voltage Level Quantification

Voltage protection levels in this document are given in terms of peak values because communication cable dielectric, bare spots on wires, and air gaps essentially break down on close to the peak of the voltage waveform and because some degree of a dc offset may be superimposed on the sinusoidal wave form. As a result of the non-symmetrical wave shape, the relationship between the rms and peak values is not usually $\sqrt{2}$. The user may specify values in terms of rms if the user wishes to choose his or her own offset factor for the first half cycle of the wave shape.

For purposes of this protection standard, protection options are given for three voltage levels: I, II, and III.

9.2.1.1 Voltage Level I

For Voltage Level I, a power station is considered to have virtually no GPR or induction and no zone of influence; therefore, no special protection (neutralizing or isolating transformers, etc.) is required. Even in Voltage Level I, however, special protection arrangements on highly critical services may be used and may differ from those on less critical services. Descriptions of figures and options are covered later in the protection table and protection schematic chart.

Voltage Level I is the voltage level at which virtually no pair-to-pair or pair-to-shield dielectric failure would occur in cables serving the power station that had not been specifically installed and tested as a dedicated high dielectric cable. If service should be continuous during the fault (SPO Class A) or restored immediately after the fault (SPO Class B), then consideration of the dielectric withstand capabilities of the elements of the plant is important. Experience has shown that the general-use telephone cable may fail in the pair-to-pair and pair-to-shield modes at the splices at voltages that exceed 300 V peak. Similarly, some 3 mil carbon blocks may fire as low as 300 V peak. When determining the peak value of the voltage in meeting this criteria, adding an appropriate value of dc offset of the transient and the longitudinally induced voltage (expressed by V peak) to the steady-state GPR (expressed in V peak) is necessary (see Section 5.).

NOTE — Many administrations have chosen a value of 300 V, either rms or peak, as the upper limit for Voltage Level I. Other administrations have chosen values such as 420, 430, or 650 V rms or peak. Some administrations have chosen even higher voltages on the Basis of their higher cable and equipment dielectric withstand capabilities.

9.2.1.2 Voltage Level II

The upper limit for Voltage Level II is 1000 V peak. It is based on experience and is considered to provide a suitable safety margin below voltage and current levels that would cause telephone-type protectors to fuse, explode, or cause fire hazards. In Voltage Level II, special protective devices are not required on power station services, provided that momentary interruption of service can be tolerated during a power system fault. If certain services require isolation or neutralization for reliability reasons, however, then all other services should be isolated or neutralized, or the dielectric capability of the dedicated cable should be coordinated to withstand the conductor-to-conductor voltage stresses that can occur.

A dedicated, high dielectric cable should be used for Voltage Level II, unless the only service involved in that cable is a service that can be interrupted and not automatically restored after a fault (SPO Class C), in which case the voltage can be allowed to rise to 1000 V peak or higher before special protective measures should be used. The Voltage Level II upper limit is the point at which experience has shown that

- 1) Protectors may operate and recover after a fault to restore the circuit to normal.
- 2) The current through the conductors will not cause damage to the conductors or the insulation.

An upper limit of 1500 V peak is suggested if remote protection is used at the junction of the dedicated and general-use cables. An upper limit of 1000 V peak is suggested if the remote protection is not used. For specific stations, some administrations establish an upper limit for Voltage Level II based upon the time-current characteristics of the protectors and the power station parameters.

In the case of leased or rented telecommunication facilities, the choice of the magnitude of the voltage should be by agreement between the local power utility or end user and its serving telephone company. Power utilities regularly use rms values as the basis for their own facilities and calculations.

9.2.1.3 Voltage Level III

Voltage Level III begins at the upper limits of Voltage Level II and requires special high-voltage protection such as isolation or neutralization, or both, for the protection of plant, personnel, and circuit integrity for all types of services and SPO classes.

9.3 Basic Protection System

Depending upon the service performance objective requirements and the GPR plus induced voltage level (see 9.11) requirements, basic wire-line communication protection, as shown in Figs 9 and 10, may be used. The basic protection illustrated in Fig 9 may be used on all power station services, provided that the interfering voltage is calculated not to exceed the Voltage Level I range, as discussed previously. Administrations, power utilities or telephone companies, and end users who so choose will permit this limit to be higher. Above the chosen voltage, basic protection, as illustrated in Fig 10, may be used on certain services in the Voltage Level II range (see 9.11). Noninterruptible service requires special protection, i.e., neutralization or isolation in both Voltage Level II and III ranges.

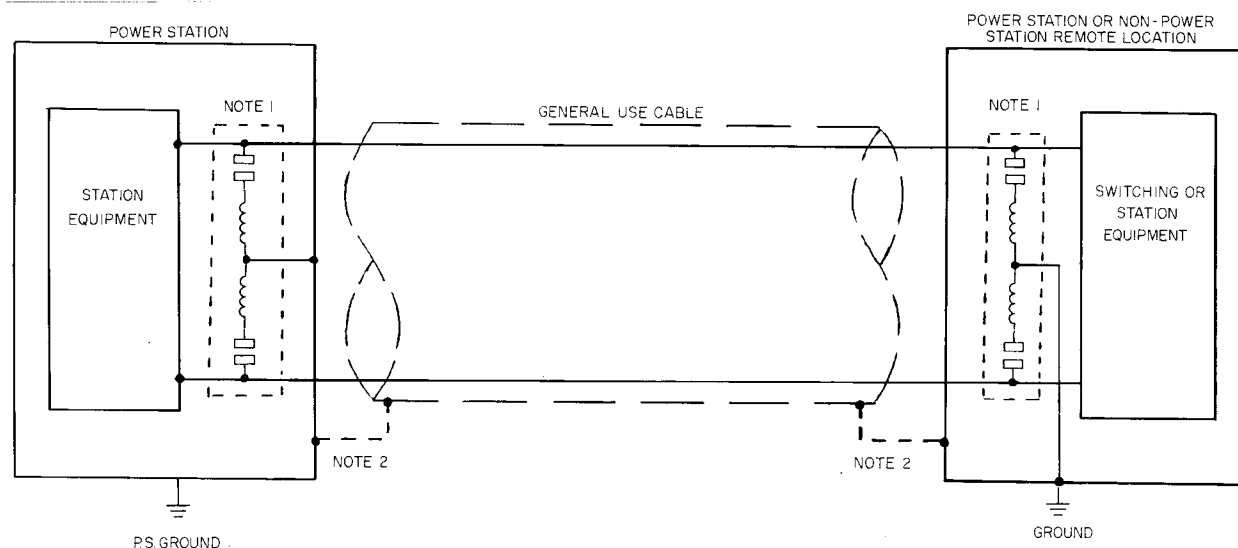


**Figure 9—Basic Protection for Voltage Level I
All Service Classifications**

NOTES:

- 1 — See Table 1 and Fig 21 for applicable options.
- 2 — Some telephone administrations may require that shields of all general use cables be grounded at power stations. Current carrying capability of the shield under power system fault conditions should be considered.

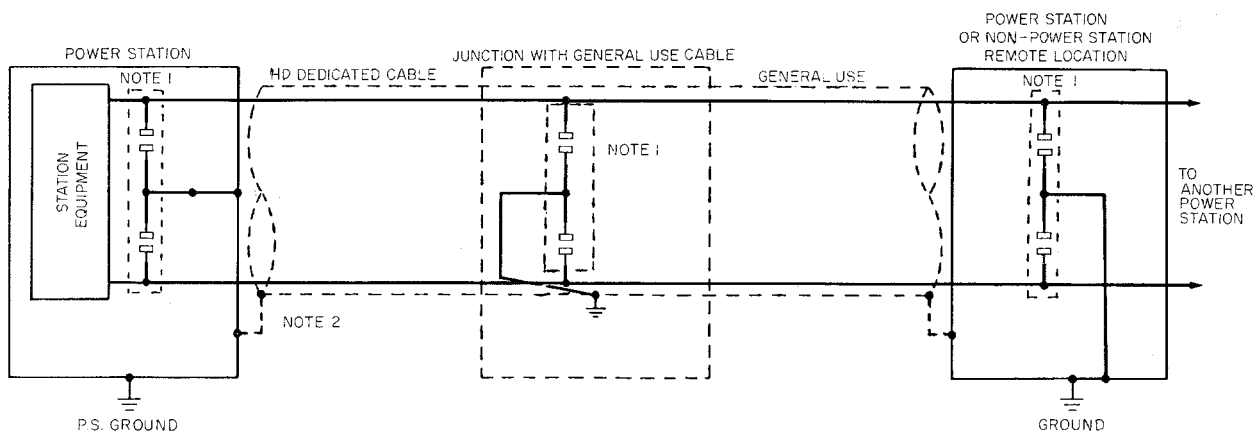


**Figure 10—Basic Protection for Voltage Level II Range
Class B or Class C Services Only**

NOTES:

- 1 — See Table 1 and Fig 21 for applicable options.
- 2 — Although this guide recommends that the dedicated cable shield be isolated from the power station ground grid, some administrations may require that shields of all dedicated cables be grounded at power stations. Current carrying capability of the shield under power system fault conditions should be considered.

9.4 Protection Configurations Employing Isolation Devices

9.4.1 General

Circuit configurations range from the simple, consisting basically of the isolation device at the power station and dedicated cable to a remote location, to the more elaborate, when distance to the remote location or distance between the isolation device and terminal equipment at the power station is increased. A remote location is defined as another power station or dispatch office, telephone central office, or other remote communications terminal. Fig 11 illustrates the simplest situation. Figs 12 and 13 illustrate the more elaborate situations in which extended distance between the power station and the remote location may make routing of dedicated cable for the entire distance impracticable. The dedicated and general-use cable plant are normally interconnected, and remote drainage protection may be required at the junction point. The decision to use remote drainage protection should be by mutual agreement between the administrations involved. When the cable length between the isolation device and terminal equipment at the power station becomes significant, protection is further complicated by the shielding required for the interconnecting cable. Where the remote location is another power station, a high-voltage interface may also be provided at the remote location (see Fig 13).

9.4.2 Basic Isolation Protection Configuration

A very simple and effective protection system can be realized with high-dielectric isolation transformers, relays or optical couplers, high-voltage disconnect jacks, surge (lightning) arresters, and high-dielectric dedicated cable. In some cases, the dielectric of these devices will coordinate satisfactorily with GPR and the dielectric rating of the dedicated cable, thereby eliminating the need for a lightning arrester, drainage device, and spark gap at the power station location (see Fig 11).

9.4.3 Protection at the Power Station

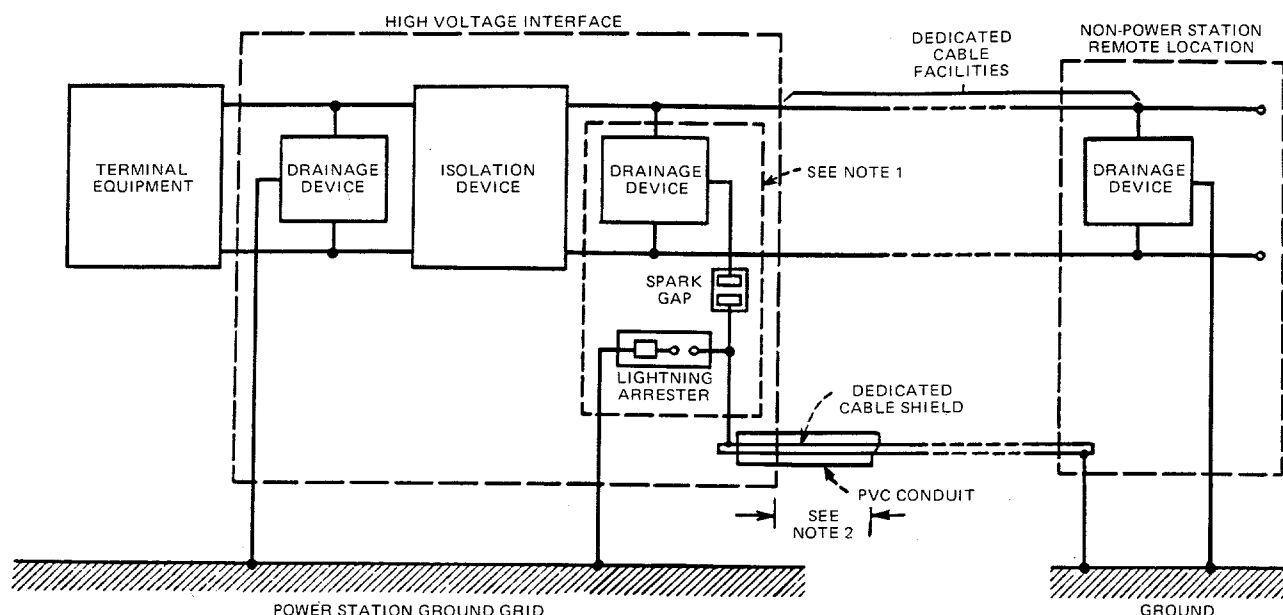
Protection at the interface between the power station and the incoming communications cable, (i.e., the isolation or neutralization device) is intended to keep the ground potential rise from appearing on the incoming cable. The power station communications cable interface will, therefore, be referred to as the high-voltage interface (HVI). This point is not necessarily the telco/user interface.

The HVI could be located at either the edge of the station ground grid or at the control building. Wiring between the HVI and terminal equipment should be short to minimize exposure to inductive interference, switching transients, or differential ground grid voltages; or measures as shown in Fig 12 and 13 should be taken to protect against such interference. Drainage to the power station ground is provided on the station side of the isolation device.

For a totally ac class of service, direct drainage may be applied. When ac and dc signals will both be present on the pair, a drainage reactor with a gap protector in each leg, termed a mutual drainage reactor, should be used because the drainage reactor presents a low bridging impedance to dc signals. Blocking capacitors could be used in place of the gap protectors; however, resonant conditions should be considered (see [B12]).

Drainage provided on pairs assigned to Class C service performance (see 7.3) may consist only of carbon protector blocks, gas tubes, or solid-state protectors. Pairs assigned to Class A service performance (see 7.3) should always be equipped with direct drainage or mutual drainage reactors to minimize noise interference.

The isolation device may also be an isolation transformer with a well balanced center tap serving the dual function of isolation and drainage. The center tap on the power station side may be connected to the ground grid to provide direct drainage, as shown in Fig 14, as long as a ground loop is not created. The center tap of the line or central office (CO) side winding should have a specified minimum drainage capability.



NOTES:

(1) Use of drainage device, spark gap, and lightning arrester to be by mutual agreement between protective relay and communications engineer.

(2) Conduit, 3 m minimum from grid or fence, whichever is further out.

NOTES:

1 — Use of drainage device, spark gap, and lightning arrester to be by mutual agreement between protective relay and communications engineer.

2 — Conduit, 3 m minimum from grid or fence, whichever is further out.

Figure 11—Basic Isolation Protection Configuration

If the dielectric of the isolation devices and cable may be exceeded, cable protection can be provided on the remote location side of the isolation device to the dedicated cable shield through a spark gap intended to limit pair-to-shield stress. This cable protection will not be effective for longitudinally induced voltages, as both the pair and shield are in the same field. When isolation devices other than well-balanced, center-tapped isolation and drainage transformers are used, separate drainage coils with direct, capacitor-blocked, or protector drainage connections should be provided for Class A services and may be provided for Class B services. Class C services utilize only carbon protector blocks or equivalents. The spark gap does not normally operate except as a safety measure to prevent cable damage in the event that an isolation device fails or the dedicated cable shield contacts the station ground.

The surge (lightning) arrester shown in Fig 14 protects the isolation device in the event of a lightning stroke to the power station ground structure or communications facility that exceeds the isolation device's basic impulse insulation level (BIL). The arrester may be eliminated if the dielectric (BIL) of the isolation device is capable of withstanding the voltage from a lightning stroke.

The dedicated cable is routed in a well drained insulating conduit, e.g., polyvinylchloride (PVC), within the station ground grid area.