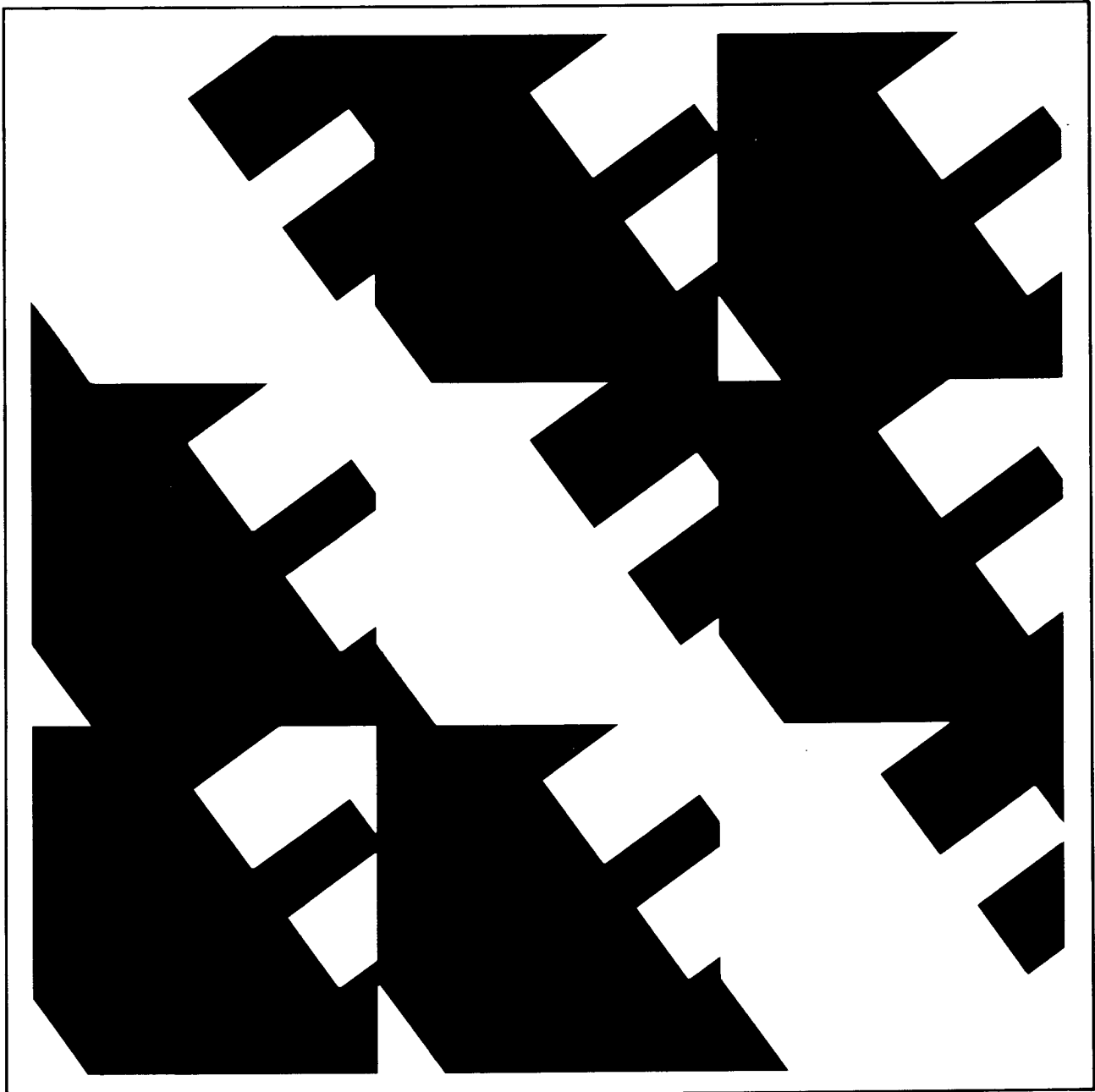


IEEE Guide for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations



ANSI/IEEE Std 487-1980



Published by The Institute of Electrical and Electronics Engineers, Inc 345 East 47th Street, New York, NY 10017, USA

August 8, 1980

SH07807

An American National Standard

**IEEE Guide for the Protection of
Wire-Line Communication Facilities
Serving Electric Power Stations**

Sponsor

**Transmission Systems Committee
of the
IEEE Communications Society**

and

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

Approved June 7, 1979

IEEE Standards Board

Approved April 20, 1981

American National Standards Institute

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Foreword

(This Foreword is not a part of IEEE Std 487-1980, IEEE Guide for the Protection of Wire-Line Communication Facilities Serving Power Stations.)

Wire-line communication facilities serving electric power stations often require special high-voltage protection against the effects of fault-produced ground potential rise or induction voltages, or both. Some of the communication services are used for control and protective relaying purposes which may be called upon to perform critical operations during periods of these faults. This constitutes a major problem in the design of the communications system since power system faults usually result in the introduction of interfering voltages and currents into the communication circuit just at the time when the latter is most urgently required to perform its function. Effective protection of any wire-line communications circuit requires coordinated protection on all circuits.

This guide presents workable methods for protecting wire-line communication circuits entering power stations. 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.

This guide has been prepared by a working group which is jointly sponsored by the Power Systems Communications Committee of the IEEE Power Engineering Society and by the Transmission Systems Committee of the Communications Society. The guide represents a consensus of opinion by both power and communications engineers.

At the time of approval of this standard, the membership of the working group was:

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The assistance of the members of the Inductive Coordination, Electrical Interference and Protection Subcommittee, the Wire-Line Subcommittee, and the Relaying Channels Subcommittee is gratefully acknowledged.

Contents

SECTION	PAGE
1. Introduction	9
2. Electric Power Station Environment	10
2.1 General	10
2.2 Ground Potential Rise (GPR)	10
2.3 Longitudinal Induction	12
2.4 Lightning	14
2.5 Switching Surges	16
3. Protection Apparatus	16
3.1 General	16
3.2 Carbon Block Protectors	16
3.3 Gas Filled Protectors	16
3.4 Spark Gaps	17
3.5 Horn Gaps	17
3.6 Surge (Lightning) Arresters	17
3.7 Isolating Transformers	17
3.8 Neutralizing Transformers	17
3.9 Drainage Units	17
3.10 High-Voltage Isolating Relays	17
3.11 Isolating Transformers with High-Voltage Isolating Relays	17
3.12 High-Voltage Telephone Repeaters	17
3.13 Short Circuiting or Grounding Relays	17
3.14 Special Combination Protective Devices (Open-Wire or Hot Line Protectors)	17
3.15 Optical Coupler	18
3.16 High-Voltage Disconnect Jacks	18
3.17 Overhead Insulated Ground (Static or Sky) Wire Coupling Protector	18
3.18 Cable in the Zone of Influence	18
4. Service Types, Reliability, Service Performance Objective (SPO) Classifications and Transmission Considerations	18
4.1 General	18
4.2 Service Types	18
4.3 Service Performance Objective (SPO) Classifications	18
4.4 Class A Service Performance Objective Considerations	19
4.5 Class B Service Performance Considerations	19
4.6 Class C Service Performance Considerations	19
4.7 Transmission Considerations	19
5. Protection Theory and Philosophy	20
5.1 Introduction	20
5.2 Special Protective System Design Requirements	20
5.3 Dedicated Cable	21
5.4 Resistive Balance	21
5.5 Concepts and Concerns	22
5.6 Other Telephone Subscribers in the Power Station Zone of Influence	22
6. Neutralizing Transformer Theory and Design Concepts	25
6.1 NT Operation — The 3-Winding Neutralizing Transformer	25
6.2 Neutralizing Transformer Concept — Design Alternatives	31
7. Protection Configurations	35
7.1 General	35
7.2 Ground Potential Rise (GPR) Plus Induced Voltage Levels	35

SECTION	PAGE
7.3 Basic Protection System	37
7.4 Protection Configurations Employing Isolation Devices	37
7.5 Protection Configurations Employing Neutralizing Transformers	42
7.6 Protection Configuration Employing Neutralizing in Parallel with Isolation on Separate Pairs	43
7.7 Protection Configuration Employing Neutralization in Tandem with Isolation	44
7.8 Protection Configuration Employing Short-Circuiting or Grounding Relays and Open Wire	45
7.9 Description of a Protection Scheme for Carrier on Overhead Insulated Ground Wires	45
7.10 Protection Guide for Power Station Services	47
8. Installation and Inspection Considerations	51
8.1 Installation Considerations Related to Neutralizing Transformers	51
8.2 Periodic Inspection	52
9. Safety	53
9.1 General Safety Considerations	53
9.2 Safety Considerations in Equipment Design	53
9.3 Safety Related to Installation and Maintenance	54
10. Activities of Other Standards Writing and Other Technical Organizations	54
11. Summary	55
12. References and Bibliography	56
FIGURES	
Fig 1 Example of Asymmetrical GPR Waveform	11
Fig 2 Earth Potential Distribution from Edge of Power Station Ground Grid with Respect to Remote Earth	12
Fig 3 Schematic Illustration of Power Station Ground Potential Rise	13
Fig 4 Lightning Surge Representation	14
Fig 5 Distribution of Lightning Stroke Currents	15
Fig 6 Isokeraunic Chart for US and Canada	15
Fig 7 GPR Voltage Gradient	23
Fig 8 Voltage Gradient Along General-Use Cable	23
Fig 9 Voltage Gradient Along General-Use Cable with Full Count Protection Applied at the Remote Drainage Location	24
Fig 10 Voltage Gradient Along General Use Cable with Full Count Protection Applied at the Remote Drainage Location and Strategically Along Cable Route	25
Fig 11 3-Winding Neutralizing Transformer	26
Fig 12 Straight Line Approximation to a Saturation Characteristic for Typical Neutralizing Transformer	28
Fig 13 Maximum Worst-Case Accumulated Volt·Seconds per 1000 V rms GPR as a Function of the X/R Ratio of the Power System	29
Fig 14 Relative Volt-Time Area (Asymptotic Value) for Various X/R Ratios as a Function of Power-Line Voltage Phase Angle at Initiation of Fault	30
Fig 15 Worst Case Accumulated Volt·Seconds per 1000 V rms GPR as a Function of X/R Ratio and Elapsed Time Since Fault Initiation	30
Fig 16 A Particular 52 Volt·Second Rated Transformer Exciting Current as a Function of Applied Volt·Seconds	32

Fig 17	A Particular 4500 V rms Rated Transformer Exciting Current as a Function of Applied Volt-Seconds	32
Fig 18	Typical Excitation Characteristics	35
Fig 19	Basic Protection for Voltage Level I All Service Classifications (See 7.3)	36
Fig 20	Basic Protection for Voltage Level II Range Class B or Class C Services Only (See 7.3)	37
Fig 21	Basic Isolation Protection Configuration	38
Fig 22	General Isolation Protection Configuration	39
Fig 23	General Isolation Protection Configuration Between Two Power Stations	39
Fig 24	Composite Protection System	40
Fig 25	Neutralizing Transformer Installation Protection	42
Fig 26	Typical Isolated and Neutralized Services in Parallel or Separate Pairs	44
Fig 27	2-Winding Capacitor Excited Neutralizing Reactor in Tandem with an Isolating Transformer	45
Fig 28	3-Winding Neutralizing Transformers in Tandem with an Isolating Transformer	46
Fig 29	Coupling Protectors	47
Fig 30	Simplified Protection Schematic Chart for a Power Station	49
Fig 31	Foundation and Grounding Diagram	51

TABLES

Table 1	Typical Protection Table for Power Station Services	48
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ANNEXES

Annex A	Protection Apparatus	57
A1.	Air Gap Protectors	57
A2.	Gas Tube Characteristics	58
A3.	Surge (Lightning) Arrester Characteristics	61
A4.	Isolating or Combined Isolating and Drainage Transformers	61
A5.	Neutralizing Transformers	63
A6.	Telephone-Type Drainage Units	66
A7.	Typical Specification for a High-Voltage Isolating Relay	67
A8.	Isolating Transformer with High-Voltage Isolating Relay	68
A9.	High-Voltage Telephone Repeater	69
A10.	Special Combination Protective Devices (Open Wire or Hot Line Protector)	70
A11.	Grounding Relays	71
A12.	Typical Specification for Optical Coupler	72
A13.	Typical Specification for High-Voltage Disconnect Jacks	72
A14.	Cable in the Zone of Influence	73
Annex B	Comparison of Protector Gap Characteristics (Carbon Blocks and Gas Tubes)	75
Annex C	Protection of Isolating and Neutralizing Transformers by Lightning Arresters	76
Annex D	Transmission Characteristics and SPO Requirements for Various Communication Channels	78
Annex E	Typical Interface Requirements and Transmission Characteristics for Voice Band Telephone Channels Used for Power Station Communications	79
Annex F	User Information Required for Preparing a Neutralizing Transformer Design Specification	80
Annex G	Neutralizing Transformer Installation Design Examples	82

ANNEX FIGURES		PAGE
Fig A1	Spark-Gap Break Down Voltages	58
Fig A2	Schematic of a Typical Fuseless Protector or Terminal Equipped with Two Element Gas Tube Protectors Only	59
Fig A3	Schematic of a Typical Fuseless Protector or Terminal Equipped with a Three Element Gas Tube Protector Only	59
Fig A4	Typical Voltage Characteristics of a Two-Electrode Gas Tube Protector	59
Fig A5	Typical Maximum Exciting Current Versus Percentage of Rated Voltage at 60 Hz	65
Fig A6	Sample Circuit Diagram of an Isolation Device for Telephone Service	68
Fig A7	Typical Specifications for an Open-Wire Line Telephone Protector	70
Fig A8	A — Typical Grounding Relay	71
	B — Schematic of Grounding Relay	71
	C — Light-Duty Grounding Relay in a Typical Protective Circuit	72
	D — Heavy-Duty Grounding Relay Protecting a Combined Isolating and Drainage Transformer	72
Fig A9	The Optical Couple	72
Fig A10	Types of Bantam Plugs	73
ANNEX TABLES		
Table A1	Carbon Electrode Protector Units Typical Sparkover Values	57
Table A2	Typical Operating Characteristics of a 3-Electrode Gas Tube	60
Table A3	Sparkover Characteristics of Discharge Gaps in Argon Gas at 0.1 Atmosphere	60
Table A4	Typical Operating Characteristics of a 2-Electrode Gas Tube	60
Table A5	Typical Characteristics for Distribution Class, Low Impulse Sparkover Type (RM) Surge Arresters	61
Table A6	Typical Specifications for Grounding Relays	71
Table A7	Dielectric Rating Factor Test Levels	74
Table A8	Intrinsic Surge Dielectric Capability	74

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

1. Introduction

Wire-line communication facilities serving electric power stations often require special high-voltage protection against the effects of fault-produced ground potential rise or induction voltages, or both. Some of the communication services are used for control and protective relaying purposes which may be called upon to perform critical operations during periods of these faults. This constitutes a major problem in the design of the wire-line communications system since power faults usually result in the introduction of interfering voltages and currents into the communication circuit just at the time when the latter is most urgently required to perform its function. 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. Effective protection of any wire-line communications circuit requires coordinated protection on all circuits.

In general, extraordinary protective measures and special handling and administrative procedures are necessary in order to provide for personnel safety, protection against damage to communication facilities and terminal equipment, and to provide for reliability of service. Disturbances in communication circuits may arise from a number of causes, the major ones are:

- (1) Ground potential rise at the power station
- (2) Longitudinal induction
- (3) Electrical contact between power and communication conductors
- (4) Lightning and switching surges affecting the communication system

This guide presents workable methods for protecting wire-line communication circuits entering power stations. It draws heavily on the content of the following three IEEE papers, their discussions and closures.

(1) Paper No T75160-7, *The Isolation Concept for Protection of Wire-Line Facilities Entering Electric Power Stations*, outlines a combination of existing and improved isolation techniques for protecting ac interruptible and noninterruptible communication services.

(2) Paper No F76379-8, *The Neutralizing Transformer Concept for Protection of Wire-Line Facilities Entering Electric Power Stations*, presents the history, theory of operation, and information for the application of the neutralizing transformer for ac or dc service, or both, using neutralization alone, neutralization in parallel with isolation, and neutralization in tandem with isolation.

(3) Paper No 31TP66-35, *A Guide for the Protection of Wire-Line Communications Facilities Serving Electric Power Stations*.

It is recognized that there are divided and differing opinions between and within the various administrations regarding the merits of any one protection method, voltage limits, and equipment design characteristics. This guide is not intended to supplant specific or general instructions contained in the practices of any utility, or in any agreement between a telephone and a power utility. Users of this guide should evaluate all suggested procedures, methods, voltage limits, and equipment characteristics for their own use.

In the case of leased facilities *mutually agreeable* methods for the installation of protective equipment owned by either party are presented.

2. Electric Power Station Environment

2.1 General. Electric power stations utilize a ground grid so that all grounded structures in the station can be connected to the grid as a safety measure to minimize potential differences in the system during a lightning stroke or a power system fault. When a power system fault to ground occurs, 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 referred to 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, and power system characteristics. The GPR has the same wave shape as the fault current. The impedance to ground depends primarily on the geometry of 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, (static or sky) wires, multi-grounded neutrals, cable shields, rail lines, etc affect the distribution of fault currents through the station grounding grid and also affect the impedance of the grid to remote earth. Since the above factors can vary significantly, the GPR can vary over a wide range.

IEEE papers are referenced to help the reader understand the hazards involved in serving the power station, and, from these, the effects and magnitude of the hazards can be equated to those with which communication engineers are already familiar. Hazards in the power station area are outlined in Ground Potential Rise (GPR), 2.2; Longitudinal Induction, 2.3; Lightning, 2.4; and Switching Surges, 2.5.

2.2 Ground Potential Rise (GPR). 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 ground to the system neutral by way of the station grounding system. Since the grounding system has a finite impedance-to-ground, 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 impedance of the transformers

feeding the fault, the presence or absence of ground wires on the line, and other grounding structures in the area. It should be noted also that 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.

While the impedances of station ground grids can range from 0.01 to 100 Ω or more they are normally quite small, frequently 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 voltage, which is of the same wave shape as the fault current, consists of a steady-state component and a transient component (sometimes called the dc offset). The magnitude of the transient component lies between zero and the peak value of the steady-state component and is dependent on the phase angle of the power line voltage at the initiation of the fault. The rate of decay of the transient components is determined by the power system inductive reactance and resistance (a function of the X/R ratio) looking back toward the source(s) of generation. Figure 1 shows an example of an asymmetrical GPR waveform and of the two components. A discussion of this waveform is given in Section 6.

Figure 2 illustrates a theoretical GPR distribution from the edge of a simple ground grid in homogenous earth for a number of ground grid areas with no external metallic ground paths.¹ 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 it is recommended that the fall of potential impedance measurements referenced in IEEE Std 81-1962 should be used to generate the proper curves for a specific grid.

The area surrounding the electric power station that is raised in potential is referred to as the *zone of influence*.

The potential of the ground around the power station, with respect to remote earth, falls off with distance from the station ground-

¹ Additional studies in the determination of GPR distributions are presently being conducted by various authorities, administrations and technical organizations.

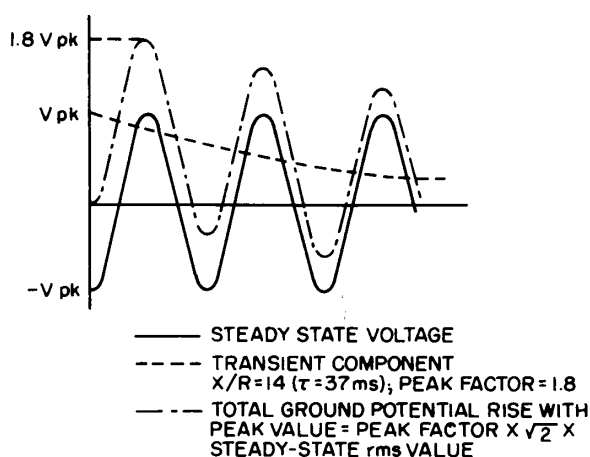


Fig 1
Example of Asymmetrical GPR Waveform

ing system as indicated by the equipotential lines in Fig 3. This potential is inversely proportional, roughly, to the distance from the station grounding system. For simplicity the equipotential lines are shown in Fig 3 as concentric circles. Due to the irregularity of the grounding system, however, 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 as regular as indicated.

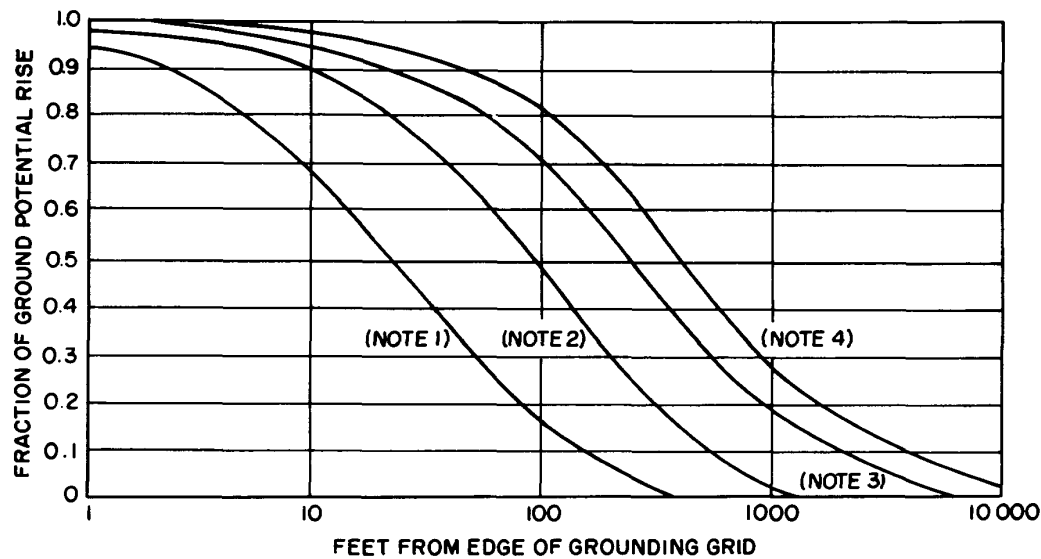
A typical communication circuit, extending from the power station to some remote point, is also shown in Fig 3. In this example the protector blocks are installed at the power station end of the communication circuit, with the protector ground terminal connected to the power station grounding system. At some remote point on the communication circuit, such as the far end or some intermediate point, other protector blocks are installed. In the latter case, the protector ground terminal is connected to what may be regarded as remote ground. These protectors serve to limit the voltage which may exist between the wire-line communication circuit and local ground at the protector location, and are, therefore,

installed for the purpose of safeguarding personnel and preventing damage to property and equipment that might be caused by induction, by lightning, or by direct contact with power circuits.

It is apparent that when there is a GPR at the power station, a potential difference, equal to this rise, will exist between the ground terminals of the protectors at the two locations on the communication circuit. This difference in potential will, if of sufficient magnitude, cause the protectors on the communication circuit to operate, and possibly ground permanently or damage the communication circuit.

In order to prevent this ground-return current from circulating over the communication circuit and its protector gaps, methods have been devised which are discussed later in this guide. 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 substation, to serve subscribers within the zone of influence, or merely passing through the zone of influence. In each case,



NOTES:

- (1) Approximate grid area 1600 ft² (150 m²)
- (2) Approximate grid area 35 000 ft² (3350 m²)
- (3) Approximate grid area 290 000 ft² (27 000 m²)
- (4) Approximate grid area 935 000 ft² (87 000 m²)

Fig 2
Earth Potential Distribution from Edge of
Power Station Ground Grid with Respect to Remote Earth

the shield-to-core dielectric strength must be higher than the GPR at the point where the cable goes through the zone. It is important that protector and cable shield grounds not be placed in this zone without special consideration. The difference in hazard to a cable serving a substation and 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 voltage level. Furthermore, protector or arc-over noise must be more carefully avoided on substation cables carrying protective relaying signals. If isolation devices are used and conductors of the cable core can be assured of being free of substation ground and its potential rise, then no hazard will exist.

It should be emphasized that no protection scheme should be installed to cope merely with the existing fault current possibilities.

Provision must also be made for future power system expansion.

A rigorous analysis of the ground potential rise calculation is presented in IEEE Std 367-1979, IEEE Guide for Determining the Maximum Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.

2.3 Longitudinal Induction. Wire-line communication facilities entering power stations are frequently routed parallel to power lines. Such facilities are then subject to interfering induction effects of the power lines under both normal and fault conditions. Satisfactory electrical coordination between the two systems must be achieved under both normal and fault conditions on the power system. Such coordination is particularly essential between cables containing protective relaying circuits and the power lines which are being protected by those circuits. The power line fault condition is most

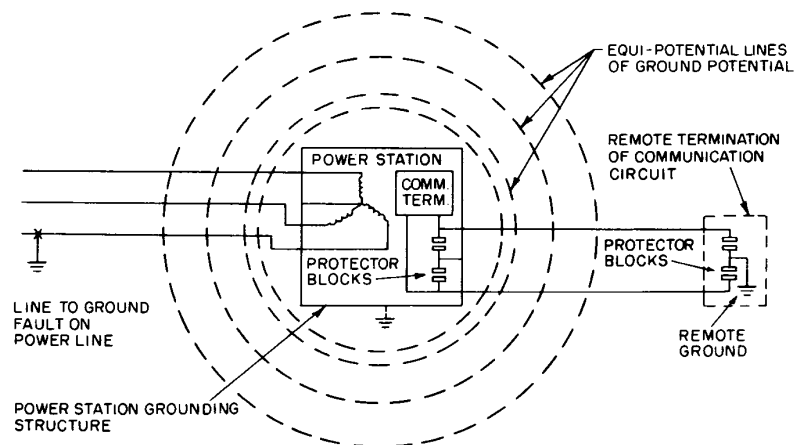


Fig 3
Schematic Illustration of Power Station
Ground Potential Rise

severe since inductive interference during this condition adds vectorially [1] to that produced by the GPR. This may substantially increase the stress on the communication systems and their associated protection.¹

Three forms of coupling between the two systems must be considered, that is, magnetic (inductive) coupling, electric (capacitive) coupling, and conduction (resistive) coupling.

Magnetic (inductive) coupling, particularly under power line fault conditions, is significant when several kilometers of parallel routing of both systems are constructed. The power line fault current flowing to ground is coupled magnetically to the longitudinal circuit of the communication system and results in a distributed longitudinal voltage being induced on the communication circuit. The induced voltage is calculated by multiplying the inducing power line current by the mutual impedance of 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 inducing current, frequency, length of parallel, separation, soil resistivity, and shielding conduc-

tors [2]. Heterogenous 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. Thus, one must recognize that a large spread in values can occur between actual and estimated induced voltages because all parameters cannot be assessed accurately.

Electric (capacitive) coupling at power system frequencies is significant only where communication lines are not shielded with a grounded metallic shield. Since most wire-line communication cables are metallically shielded electric coupling is minimized.

Conductive (resistive) coupling is significant where the power and communications grounding systems are bonded together or where grounds are mutually coupled due to their proximity to each other. In general, for leased telecommunications facilities, resistive coupling can be minimized by avoiding joint use and by ensuring adequate separation of the grounding systems in situations where the power line and its associated protective relaying circuits must follow the same route.

The probability of a power conductor falling and causing a problem with a communication cable in or near a substation is very low. The

¹Numbers in brackets correspond to those of the Bibliography, Section 12 of this guide.

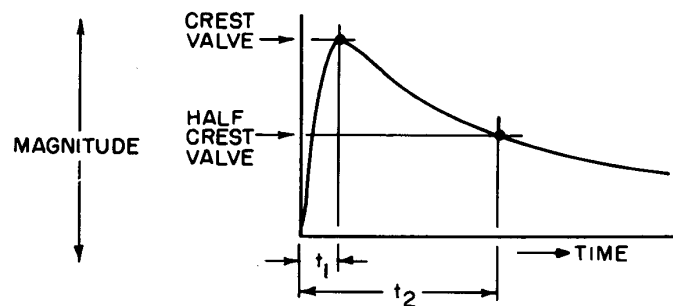


Fig 4
Lightning Surge Representation

problem itself is no worse than any joint-use condition.

2.4 Lightning. The occurrence of lightning strokes to power stations is about the same as those to about 1.6 km (about 1 mi) of buried telephone cable. For an iskeraunic 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 [3]. The ground grids of 95 to 98% of all substations are smaller than 9600 m². This compares with 0.1 to 0.2 strokes/1.5 km of buried cable for the same iskeraunic level [4]. As a general rule, large power stations receive more strokes because of the area of the station and the surges entering on transmission lines, but because of reflections, the effects of the strokes are less severe than for the small station [5]. If lightning strikes or enters an electric power station on the shielding system, the massive area of the ground grid and tower system disperses the effect of the stroke current [5]. If a shielding system failure occurs and results in a stroke to the ground grid itself, currents in the order of 2 to 20 kA can be realized. Current severity of lightning strokes is largely a function of structure height [6]. 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 communica-

tion facilities from lightning strokes to power stations are about the same as those for 1.5 to 3 km of buried cable. High microwave towers located on power station sites will also localize the introduction of lightning currents of all magnitudes.

The generalized wave shape of lightning stroke current is indicated in Fig 4. The figure shows that the lightning stroke current is characterized by a very steep wavefront, where the current rises to its maximum or crest value in a very short period of time and a decay interval occupying a considerably longer length of time. Lightning stroke voltages and currents are usually described by two numbers separated by an X; the first number shows the time in microseconds for the wave to reach its crest, indicated by t_1 in the diagram. The second number is the time in microseconds, also measured from the initiation of the discharge, taken for the wave to decay to half its crest magnitude, shown by t_2 in the diagram. These times are usually very short, and may be in the order of 1.2 X 50 μ s for voltage wave form, or 8 X 20 μ s for current wave form. In some strokes the decay tail may be considerably longer.

Some idea of the values of crest current experienced may be obtained from the distribution curve of Fig 5. While some strokes exceed 200 000 A in crest current, 50% of the strokes have crests not exceeding 20 000 A.

The incidence of thunderstorms varies widely

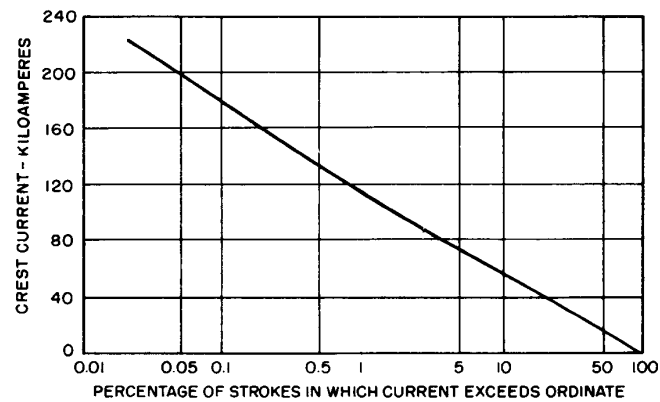


Fig 5
Distribution of Lightning Stroke Currents

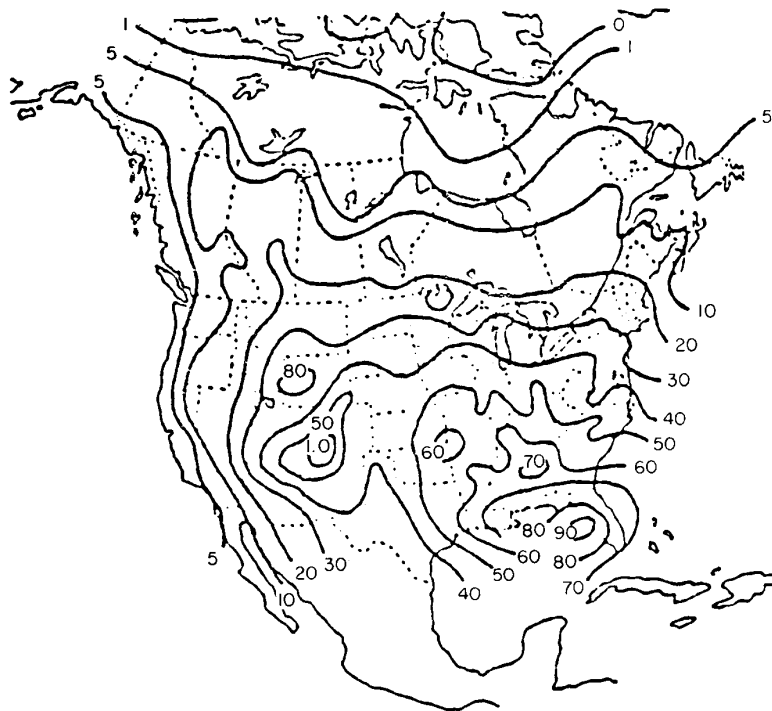


Fig 6
Isokeraunic Chart for US and Canada

in different sections of the country, and this factor must be given consideration in estimating the exposure of electrical power and communication plant to lightning. Data accumulated by the Meteorological divisions of the United States and Canadian Governments have been plotted on an isokeraunic map, Fig 6 which shows the average annual thunderstorm-day expectancy in any part of those countries. 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.

2.5 Switching Surges. High-voltage systems can cause electromagnetic field disturbances and induce transient potentials in control and communication 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 of lumped circuit constants within the switchyard, for example, potential transformers, capacitive coupling devices, power factor capacitors, reactors, power transformers, and high-voltage power cables.

Typical operations of a high-voltage electric system which cause these transient switching surges are: (1) switching shunt capacitors, (2) overvoltage flashover of lightning arresters, (3) restrike of circuit breakers, and (4) switching a section of extra-high-voltage (EHV) bus by an air break disconnect switch.

The transients are identified [7] 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 μ s 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 must be grounded at each end. Communication cable should be oriented perpendicular to any high-voltage bus overhead of the cable route.

3. Protection Apparatus

3.1 General. Wire-line communication circuits entering power stations are usually either owned by the electric power utility or leased from a telephone company. In the case of leased telephone circuits, the protective devices located at the high-voltage interface may be owned by either utility. These communication circuits are of various types and have different performance objectives as described in Section 4.

The type, quality, and quantity of protective devices which would be used in any particular case would 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 to the most sophisticated schemes involving neutralizing, isolating, and drainage transformers, relays, and filters. The following paragraphs will 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.

3.2 Carbon Block Protectors. A carbon block protector is an assembly of two carbon blocks and an air gap designed to a specific breakdown voltage. These devices are normally connected to communication circuits to provide overvoltage protection and a current path to ground during such overvoltage. (See Annex A1)

3.3 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.

3.4 Spark Gaps. Spark gaps consist of air dielectric between two electrodes which may be a combination of several basic shapes. Spark gaps are used to protect communication circuits from damage due to voltage stress in excess of their dielectric capabilities. [See Annex A1(3)]

3.5 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 will be one common grounded, center straight, vertical electrode and two angular electrodes, one for each side of the pair.

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 both against lightning and power contacts. (See Annex A1(3) and A10.)

3.6 Surge (Lightning) Arresters. Surge arresters are devices which guard against dielectric failure of protection apparatus due to lightning or surge voltages in excess of their dielectric capabilities, and serve to interrupt power following current. Protection of isolating and neutralizing transformers by surge arresters is covered in Annex C. (See Annex A3 for specifications).

3.7 Isolating Transformers. Isolating (insulating) transformers provide longitudinal (common mode) isolation of the communication facility. They can also be designed for use in a combined isolating-drainage transformer configuration. (See Annex A4.)

3.8 Neutralizing Transformers. The neutralizing transformer is a device which introduces a voltage into a circuit pair to oppose an unwanted voltage. It neutralizes extraneous longitudinal voltages resulting from ground potential rise, or longitudinal induction, or both, while simultaneously allowing ac or dc metallic signals to pass.

These transformers are primarily used to protect communication circuits at power stations, or along routes where exposure to power line induction is a problem, or both. (See Annex A5 and F.)

3.9 Drainage Units. Drainage units 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 simultaneous protector-gap operation. (See Annex A6.)

3.10 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 3.11) or may be used as stand-alone devices for dc tripping or dc telemetering. (See Annex A7.)

3.11 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. A locally supplied battery or dc power supply is required for operation of the telephone and relay. (See Annex A8.)

3.12 High-Voltage Telephone Repeaters. A high-voltage telephone repeater provides high-voltage longitudinal isolation, while permitting voice and signalling to pass. This is accomplished by using a short span, carrier transmission system and high-voltage, isolation capacitors or transformers. The repeater is intended to provide ordinary telephone service in a power station environment without interference to other non-interruptible, critical circuits. (See Annex A9.)

3.13 Short Circuiting or Grounding Relays. Communication circuit grounding relays are used to ground an exposed communication or telephone pair, usually on open-wire joint use during periods of severe power system disturbance. (See Annex A11.)

3.14 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 A10.)

3.15 Optical Coupler. An optical coupler provides isolation using a short length, optical path. Annex A12 contains optical coupler specifications for transmission of dc *on-off* signals. Other forms of optical isolation techniques for all types of transmission modes are presently in the developmental stage.

3.16 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 A13.)

3.17 Overhead Insulated Ground (Static or Sky) Wire-Coupling Protector. A device for protecting carrier terminals which are used in conjunction with overhead, insulated, ground wires (static wire) of a power transmission line is described in Section 7.

3.18 Cable in the Zone of Influence. A high dielectric cable which provides high-voltage insulation between conductors and between conductors and shield. (See Annex A14 and Section 5.)

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

4.1 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 guide.

In the context of power system protective relaying, *reliability* consists of a combination of dependability and security. This subject is dealt with briefly in 4.3.

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 4.3).

Communication 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 must 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 must be considered when selecting the method of protection to be used.

4.2 Service Types. For purposes of this guide, wire-line communication services to electric power stations can be classified into four major types according to the following definitions.

NOTE: Various other classifications may be used.

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.

Type 2: Private line services requiring ac or dc transmission, or both, used for pilot wire protective relaying, or dc tripping

Type 3: Private line services requiring only ac transmission used for telemetering, supervisory control, data, etc

Type 4: Private line services requiring only ac transmission used for audio tone protective relaying

4.3 Service Performance Objective (SPO) Classifications. Interruptions or outages of wire-line communication 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, a direct lightning stroke, or acts of God. 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 which 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 guide, has been established for all types of communication services provided to power

stations. These objectives, with respect to the effects of power system faults, fall into three classifications. They are:

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

4.4 Class A Service Performance Objective Considerations. SPO Class A is the most demanding type. It is service performance which 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, certain other special or nonstandard physical design and administrative procedures of the plant facilities must be followed. These include:

- (1) The minimization of bridge 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 must 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

4.5 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 must be restored immediately after the fault without requiring any repair personnel activity. Examples of services which 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 communications engineer may determine that, for reasons of service performance, some of the special, nonstandard, physical design, and administrative procedures indicated in 4.4 described for SPO Class A are also necessary for SPO Class B.

4.6 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 which requires a station visit to restore service can be tolerated. Examples of services which are SPO Class C are basic exchange telephone service, noncritical telemetering and data circuits, and some signal and alarm circuits. The special nonstandard design and administrative procedures described for SPO Class A are not required to achieve SPO Class C.

4.7 Transmission Considerations. The transmission characteristics of the channel must be considered in selecting the optimum protective arrangement to safeguard power station communication 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 must 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 must be matched with the transmission capability of the channel. Transmission characteristics and SPO requirements for various types of communication channels are shown in Annex D. Typical interface requirements and transmission characteristics for voice band channels used for power station communications are shown in Annex E.

The following is a partial list of characteristics which 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 terminating equipment:

- (1) Type of termination (2-wire or 4-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

5. Protection Theory and Philosophy

5.1 Introduction. Both the communications protection engineer and the power protective relaying engineer agree that the basic objectives for the protection of wire-line communication facilities serving power stations are to ensure personnel safety, protect the communications plant and terminal equipment, 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 communications 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 communications protection and for protective relaying in order to effect a solution which meets the primary protection objectives of both.

The protection concepts and system designs described in this guide have been agreed to by the power and telephone industry representatives on the joint working group which produced this guide. Where divergent views exist, they are covered by notes and dashed-lined

boxes in the circuit diagram figures. In these cases, the communications protection engineer and the power protective relaying engineer must reach a mutual agreement regarding the design to be implemented.

5.2 Special Protective System Design Requirements. In order to design special protective systems for wire-line facilities serving electric power stations, the following conditions should be known:

(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 demands of terminal equipment related to the transmission capabilities of the transmission facility, for example, 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

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

(1) Whether lightning protection is required for the isolation devices

(2) Drainage current capability for the isolating transformers and drainage reactors, if required

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 based on the expected GPR (including dc offset if required) and maximum permitted remanent voltage (see 6.1.2).

(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, 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

5.3 Dedicated Cable. A common feature of all circuit configurations, discussed in Protection Configurations (Section 7), is the use of a high dielectric, dedicated cable containing only those pairs serving the power station. Pairs to all other subscribers are excluded, minimizing pair-to-pair stress during a fault. A dedicated cable provided by a telephone company may extend the entire distance from the power station high-voltage interface location to a communication center, but it should extend at least to a point where the GPR profile has decreased to an ineffective value. This point should be the 300 V peak point in order 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.

If a remote drainage location is not used, the dedicated cable need extend only to a point on the GPR profile compatible with the assured dielectric of the installed, general-use cable. In some cases, this may be only 300 V peak. Annex A14 lists typical specifications for communication cable serving power stations.

The reliability of the wire-line communications facility is dependent, in part, upon the high-voltage integrity of the dedicated cable. To ensure the high-voltage capability, it should be high potential tested prior to, and subsequent to, installation completion and after any repair-splice operation which 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 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 withstand test should be conducted.

Special considerations must be observed when grounding the dedicated cable. Cable pairs and shield between the high-voltage interface location and the remote drainage location *must not* contact the ground structure at the power station. The cable should be routed through 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.

5.4 Resistive Balance. Longitudinal current will result if cable pairs contact the station potential 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 of the drainage devices is not balanced. This longitudinal-to-metallic conversion can produce sufficient metallic noise levels to disrupt sensitive critical services. It 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 so only normal tests for noise are required for this parameter.

When determining resistive balance, the en-

tire pair length between the power station and the communication center must 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 excellent when the difference in resistance between tip and ring conductors does not exceed 1%.

5.5 Concepts and Concerns. A fundamental concept regarding the protection of wire-line communication 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 non-interruptible service. The protection devices used on the various services must, 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 which 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 7 of this guide are examples of *coordinated* systems of protection.

In situations in which the only communication services at a power station are of an interruptible type (SPO Class C) and where the electrical environment is judged to be hazardous, 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 in-

stalled and this results in an inadequate or potentially unsafe condition. The telephone company and the power utility personnel are cautioned not to overlook this situation.

5.6 Other Telephone Subscribers in the Power Station Zone of Influence. When a general-use cable with a grounded shield is routed through an area subject to GPR, supplemental protection measures may be necessary to preclude cable damage due to pair-to-pair and pair-to-shield potential differences at times of GPR. This situation is illustrated in the following example in which the power station services are contained in a general use cable that is routed through the GPR zone as shown in Fig. 7. The voltage profile in the earth and developed along the grounded shield of the general-use cable is indicated in Fig 8. This profile assumes a homogeneous earth, a hemispherical model interpreted for a square station grid, and no metallic conductors to distort the voltage profile. Power station pairs are shown at or near central office potential, due to the special protection at the power station and because the protectors on the power station pairs at the remote drainage location have not operated (pairs A,B, and C have no protectors at the cable junction near the remote drainage location). Pair C is also shown at or near central office potential because subscriber C is outside the GPR zone and the station protectors at location C have not operated. Station protectors at subscribers A and B have operated, raising the potentials on pairs A and B to the values shown. The voltage drop due to resistance in all the ground connections has been neglected, and it is further assumed that protectors at subscriber locations are metallically connected to the general-use cable shield in these diagrams (Figs 7, 8 and 9). Significant pair-to-pair and pair-to-shield potential differences can be observed at various points along the cable. These potential differences could result in insulation breakdown within the cable and possible disruption of services to the power station. Thus, special protection applied at the power station high-voltage interface may possibly be circumvented.

To reduce the pair-to-pair and pair-to-shield stresses within the general-use cable between the central office and the remote drainage location, protection may be applied to all pairs not serving the power station at the cable junction. If permanent grounding of the carbon

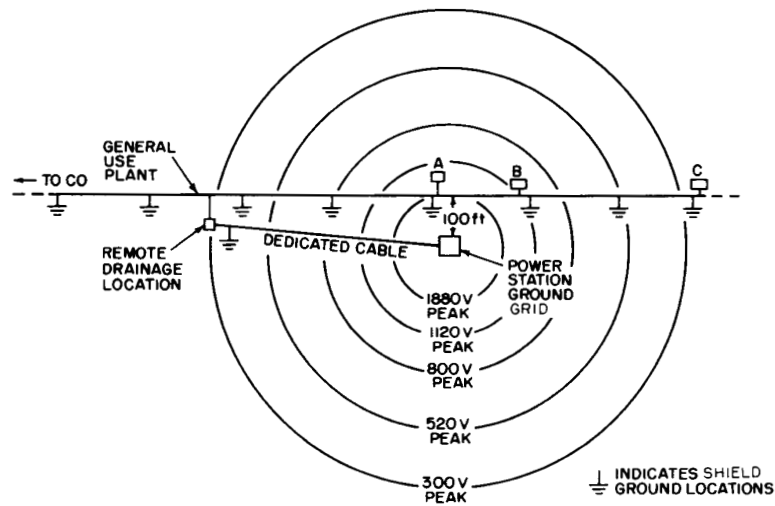


Fig 7
GPR Voltage Gradient

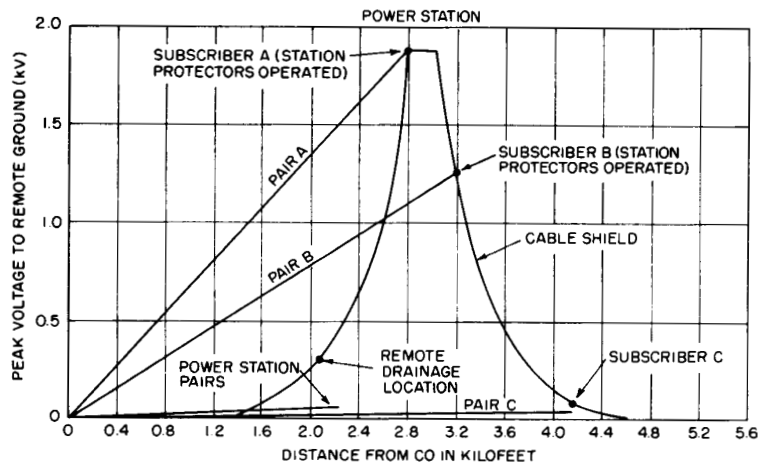


Fig 8
Voltage Gradient Along General Use Cable

protectors presents a maintenance problem, gas tube protector units may be used in place of the carbon blocks. Placement of these protectors will reduce both pair-to-pair and pair-to-shield stress in the general-use cable be-

tween the central office and the remote drainage location. It is important that this protection *not* be applied to pairs serving the power station. Pairs in the general-use cable that serve the power station are protected at the

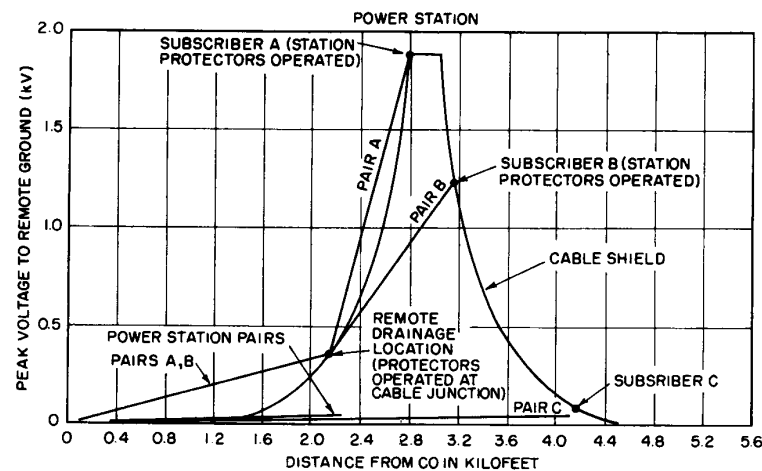


Fig 9
Voltage Gradient Along General Use Cable with
Full Count Protection Applied at the Remote Drainage Location

remote drainage location as part of the system of protection for circuits entering the power station. Figure 9 shows the voltage profile with full-count protection (all pairs protected) on the pairs not serving the power station at the cable junction. As described earlier, the power station pairs and pair C are at or near central office potential. Station protectors at subscribers A and B have operated, and the protectors on pairs A and B at the cable junction have also operated, causing the pairs to assume the potential of the shield at those locations. Figure 9 shows that pair-to-pair and pair-to-shield stresses have been reduced between the central office and the remote drainage location, but that significant voltage differences still exist within the cable passing through the GPR zone.

To reduce the potential differences in the cable passing through the GPR zone, strategically placed full-count protection may be necessary at additional location(s) along the cable route. Considerations regarding this additional protection are as follows:

- (1) When pair-to-pair voltage differences exceed 600 V peak, regardless of the type of general-use cable, consider applying full count 6 mil carbon block protection.
- (2) When pair-to-shield voltage differences exceed 850 V peak for cables having paper core insulation, or 2000 V peak for PIC cables, con-

sider applying full count 6 mil carbon block protection.

The selection of a location for the strategically placed protection can be made using the voltage profiles. Figure 10 shows the results of placing full-count protection at the subscriber A location. As before, the power station pairs are at or near central office potential because the protectors on the power station pairs at the remote drainage location have not operated. However, other protectors have operated as shown, creating the indicated voltage profiles. Excessive pair-to-pair and pair-to-shield stresses have been eliminated and it is seen that the voltage profiles of the pairs generally follow the profile of the shield. In the example, full count 6 mil carbon protection was strategically placed at the subscriber A location to reduce the stresses shown in Fig 9. In placing this additional protection at subscriber A, stresses have been sufficiently reduced so that further overvoltage protection along the cable route is unnecessary. If additional subscribers had been located, or unassigned pairs terminated beyond subscriber C, the voltage profiles of these pairs could be obtained by drawing straight lines from the full-count protection location at subscriber A (Fig 10) to the additional subscriber locations and the unassigned pairs termination locations. Pair-to-pair and pair-to-shield voltage differences could then be

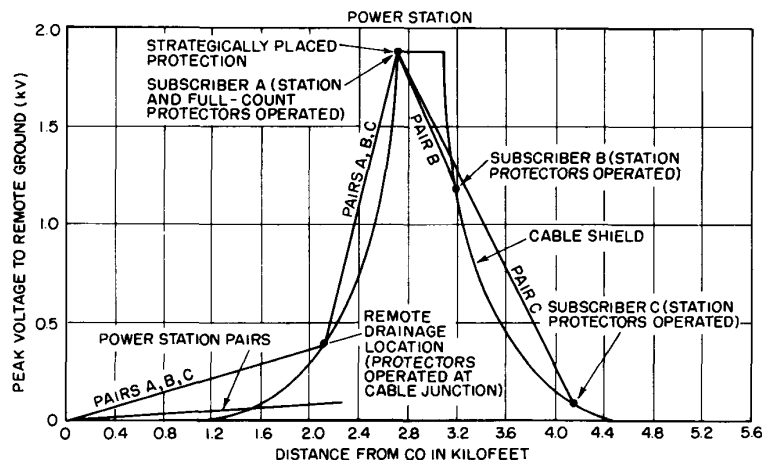


Fig 10
Voltage Gradient Along General Use Cable with
Full Count Protection Applied at the Remote
Drainage Location and Strategically Along Cable Route

observed and excessive differences reduced by the use of a second strategically placed full-count protection location at or near subscriber C.

NOTE: The models and graphs are for illustrative purposes only. Each installation should be engineered to include all ground resistances and customer drop (entrance wiring) impedances as these can have a significant effect on pair and shield potentials. Conductor and shield currents should be evaluated to determine possible thermal damage and the need for special protective apparatus. A further consideration is the effect on power station communication services of possible protector operation at the remote drainage location due to the subscriber zone protective measures. Because shield and core potentials can differ from that of the surrounding earth, safe working practices are required.

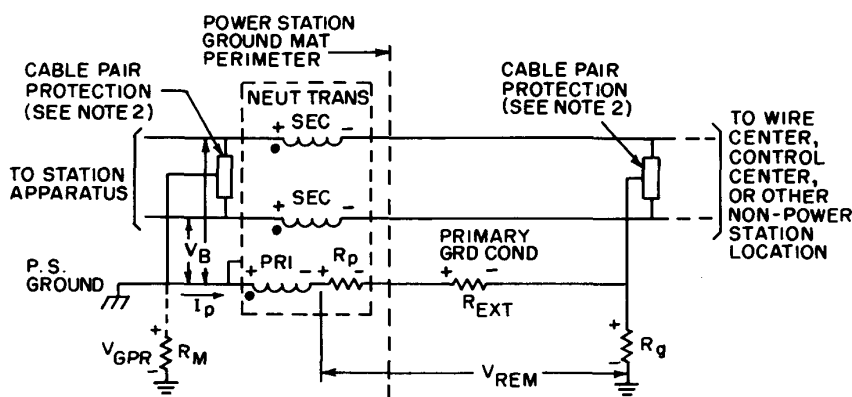
6. Neutralizing Transformer Theory and Design Concepts

6.1 NT Operation — The 3-Winding Neutralizing Transformer

6.1.1 General. Protection of the communications facility by a neutralizing transformer is accomplished by introducing a voltage of the proper magnitude and polarity into a cable pair to cancel or neutralize undesirable common

mode voltages arising from power station GPR, longitudinal induction, or both. A basic 3-winding neutralizing transformer configuration is illustrated in Fig 11. A primary circuit is established between the power station ground grid and a remote ground point which is outside the zone of influence of the GPR and its induction. During a power fault to ground, the current returning to the power system neutral through R_m , the resistance of the power station ground grid with respect to reference ground, will produce an increase in potential on the power station side of the neutralizing transformer with respect to remote ground. As long as primary reactance remains high relative to primary winding and external circuit resistance, the majority of the rise in ground potential will be developed across the primary winding and will be coupled into each secondary winding with the proper magnitude and polarity to neutralize the common mode voltage applied to the communication conductors by the power station GPR.

The communication pairs are virtually grounded at the end distant from the power station either through impedance to ground of connected equipment or through cable capa-



NOTES:

- (1) Instantaneous voltage polarities are shown.
- (2) Protection such as carbon protector blocks or drainage reactors are usually incorporated on leased communications facilities to protect cable dielectric from damage due to excessive voltage stress.

$$V_{REM} \approx I_p(R_p + R_{EXT} + R_g) = \frac{V_{GPR}(R_p + R_{EXT} + R_g)}{|Z_{PRI}|}$$

where

$$Z_{PRI} = [(R_p + R_{EXT} + R_g)^2 + (W_{LPRI})^2]^{1/2}$$

Fig 11
3-Winding Neutralizing Transformer

citance to ground. Fig 11 shows that the instantaneous voltage polarities across R_m and the NT primary and secondary windings are in a direction to provide cancellation. Thus, negligible voltage is developed from communication conductors to ground or across cable-pair protection devices at the power station location.

The NT functions in the same manner to neutralize longitudinally induced voltage. In this case, the undesirable common mode voltage arises from coupling with power lines and is distributed along the communication wire pairs and NT primary circuit conductor(s). Neutralization will occur only if the NT primary conductors are exposed to the same magnetic induction as the communications conductors. Thus, the NT primary conductor(s) must be within the same communications cable or must follow the same routing as the communication conductors.

Unlike the isolation transformer in which the disturbing voltage is applied across the primary-to-secondary dielectric and no longitudinal

(common mode) current flows through the transformer windings, the NT primary winding is placed in series with the disturbing voltage. Significant longitudinal current does not normally flow in the NT secondaries. Therefore, the primary winding may be viewed as a longitudinal choke or reactor.

Primary exciting current is a function of the applied voltage and the volt-time area accumulated under the applied voltage waveform. The excitation characteristic of a typical NT is a monotonically increasing relationship between exciting current and accumulated volt-time area. The characteristic may be varied, that is, the value of excitation current which results for a given accumulated volt-time area may be changed by altering either the number of turns, the core area or the air gap within the core, or a combination of these parameters.

6.1.2 Remanent Voltage. Primary winding resistance R_p , primary external conductor resistance R_{EXT} , and remote ground resistance R_g are illustrated in Fig 11 along with cable-pair protection at the power station and the remote