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ELECTRICAL PROTECTION OF COMMUNICATION FACILITIES SERVING POWER STATIONS

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APPENDICES

1. GENERAL

1.01 Wireline and wireless communications facilities serving electric power stations, switching stations, cogeneration stations, and high voltage towers often require special high voltage protection against the effects of Ground Potential Rise (GPR) and induction caused by faults in the electric power system. In the presence of a hostile fault-produced electrical environment, special protection is intended to protect customers and telephone company personnel and facilities from injury or harm and to provide the desired continuity of telecommunications transmission as specified by the power utility customer.

1.02 Communications services provided to power stations can form an integral part of the operation and control of the electric power system. These services range from ordinary voice telephone service to highly critical telemetering and protective relaying services which must operate without interruption at times of fault conditions. In general, special protection measures as well as special handling and administrative procedures are necessary to provide for personnel and plant safety and to provide the desired continuity of telecommunications service.

1.03 This practice is being revised to update special protection concepts and methods, and to provide engineering guidelines applicable to the recently merged SBC Local Exchange Carriers. Major additions or changes of special note in this revision include the following: Due to current disuse of the technology Special Protection Devices and Systems, Neutralizing Transformers, has been integrated into Appendix VI. At the time of the next revision of this document, Appendix VI should be reviewed for deletion. The Ground Distribution Potential charts on pages 13 and 14 are now based on IEEE Std 487 Ground Distribution Potential charts.

A. Objectives of Special Protection at Power Stations

1.04 Three fundamental objectives of special protection at a power station are:

(a) To minimize electrical hazards to customers and personnel engaged in the construction, operation, maintenance, and use of the telecommunications system.

(b) To prevent electrical damage to telecommunications equipment and cable facilities.

(c) To provide the desired service performance and continuity of telecommunications transmission at times of power faults as specified by the customer.

With regard to objective (c) a discussion of the system of Service Performance Objective Classifications is contained in 2.08 through 2.15.

B. Power System Description

1.05 To appreciate the significance of special services to power stations, an overall understanding of what constitutes a typical power system is helpful. Electric power systems consist of two large divisions: the bulk power source and the distribution system [1]. The bulk power source includes generating stations, bulk power substations and the transmission lines interconnecting them. In general, the power distribution system can be subdivided into six parts which are subtransmission circuits, distribution substations, distribution or primary feeders, distribution transformers, secondary circuits (called secondaries), and customers' service connections. Fig. 1 is a simplified block schematic of a typical power system showing these components. There may be many interconnected power generating sources and bulk power substations on a power network; therefore, during a fault, current may flow in either direction on the power facilities from several of these sources to the fault location.

1.06 Power system economics usually dictate that power generating stations be located where hydraulic energy or fuel is most economically obtainable. Site locations may require extensive transmission lines to the load centers. As the transmission distances and the amounts of bulk power to be transmitted increase, higher transmission voltages are advantageous to avoid excessive line losses and to limit conductor gauge. To date, the highest ac transmission voltage in commercial use is in the order of 765 kV. However, experiments are being conducted at voltages as high as 1.5 MV.

1.07 Operation of a power network is controlled from a highly centralized decision-making center called the dispatch center. This center and subordinate dispatch centers strategically located on the system maintain supervision and control of the entire system.

1.08 The types of power stations listed below may require special protection arrangements for telecommunication circuits serving them.

(a) Generating stations are the source of bulk power. The prime mover of the generator is usually a hydraulic turbine or a steam turbine supplied with steam by either a fossil or nuclear fueled boiler.

(b) Switching stations are switching and/or transforming stations generally located at one or both ends of a transmission line. At the generating end these stations interconnect the various generators to several outgoing lines and at the receiving end they tie one or more transmission lines to branches serving various parts of a service area.

(c) Transformer stations are stations which interconnect high voltage transmission lines with subtransmission lines. In systems involving long lines, the transformation may be from 700, 500, 345, or 230 kV nominal to 115 or 69 kV nominal. In systems involving shorter distances, the transformation is usually from 138 or 115 kV nominal down to 69, 34.5, 23, or 13.2 kV nominal. These are illustrative values and may vary in practice.

(d) Distribution substations are particular types of transformer stations designed to transform a medium transmission voltage ranging from 69 to 13.2 kV nominal down to a distribution voltage of 34.5 to 2.4 kV nominal.

(e) Industrial service installations are transformer or distribution-type substations located close to a large industrial complex or other load center requiring large amounts of power. Occasionally, power demands are such that these installations will combine the functions of a transformer and distribution substation in one voltage step-down.

2. TELECOMMUNICATIONS SERVICES TO POWER STATIONS

2.01 Telecommunications circuits are used extensively in a power system to conduct routine work, to collect data, and to transmit manual and automatic control functions. These circuits are also essential for communication between interconnected power systems, not only to coordinate system operation, but also to coordinate system and communication network maintenance. Voice circuits are also used extensively to bring a far-reaching mobile radio system control into a center of operation.

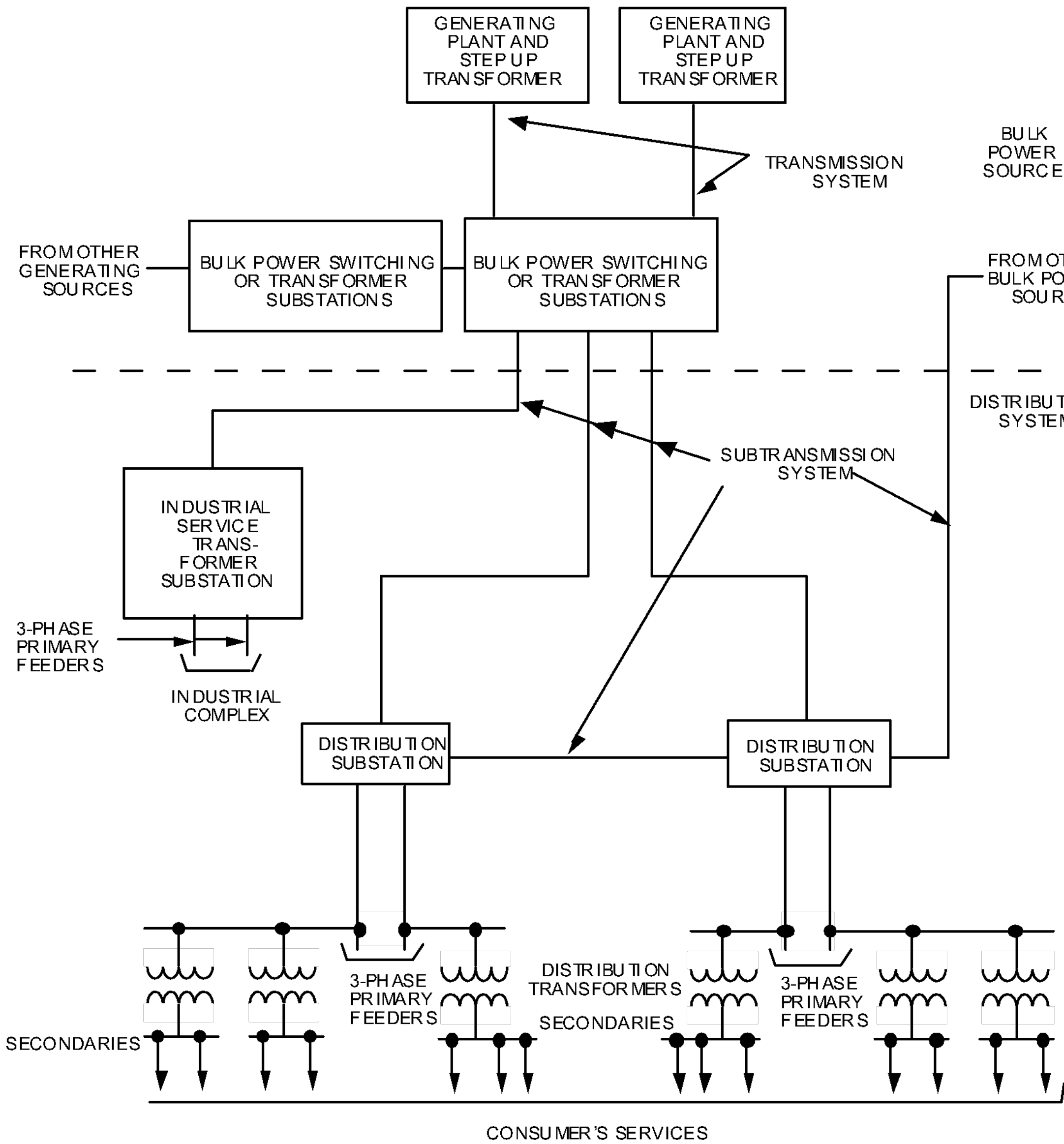


Figure 1 - Simplified Electric Power System Showing Component Pars

2.02 Telemetry circuits are used for such purposes as:

(a) Centralized general station data logging. For example, in an interconnected extra high voltage (EHV) transmission system, telemetry is employed between the dispatch center and all stations and includes such quantities as kva and kvar (reactive power) flow, direction of flow, bus voltages, transformer loadings, phase angles, frequency, and exchange of energy between power systems.

(b) Remote measurement of water levels, weather information, and water content of the snow pack in hydrogeneration areas.

2.03 Control or status circuits are used for monitoring and general supervisory control of the power system where remote unmanned generating plants or substations require this type of operation. Supervisory Control and Data Acquisition (SCADA) circuits are typical of these types of circuits (see 2.05). In addition, in large interconnected systems where EHV transmission is involved, the status of oil circuit breakers and series compensating capacitors is required at a dispatch center to provide an overall picture not only of that system but also of the neighboring systems. This information is used to determine when power circuits are at a critical stage of operation and to provide the dispatch center with information which will minimize time lost in deciding what action should be taken to correct a problem. Alarm status is used extensively to inform staffed stations of problems that occur in automatic stations under their jurisdiction. Control circuits for an automatic dispatch computer are essential, and they connect the center to all generating plants and switching substations under the control of a computer.

2.04 Protective relaying systems that require communication circuits are those that involve phase comparison, directional comparison, transfer trip, and pilot wire relaying [2,3]. The protective relays will operate in the event of a power system fault or overload condition. The relay operation initiates signals to local and distant circuit breakers which function to de- energize or isolate a fault and thus prevent equipment damage and general service interruption. Fault isolation is accomplished by dividing the system into protective zones separated by circuit breakers. These zones may be divided into four classes: (1) generator, (2) bus, (3) transformer, and (4) line. During a fault, the zone which includes the faulted apparatus is de-energized and disconnected from the system.

2.05 The Supervisory Control and Data Acquisition (SCADA) system is a computer-based supervisory control and data acquisition system that has been developed to provide direct control and supervision of the power utilities' distribution and transmission lines. Using this system, power problems can be traced and acted upon promptly, thereby reducing power downtime for customers. The SCADA system today normally consists of two master computers, one as the central processing unit (CPU) and the other as a backup unit which takes over completely if the CPU fails. In addition to the many automatic control features of the SCADA system, the system is designed for future growth and expansion using peripheral equipment such as microprocessors, etc. Some of the basic functions of the SCADA system in a power utility include detection of emergency load situations, load transfer, fault location and isolation, routine switching and control for electrical equipment at remote, unattended locations.

2.06 Circuits for more specialized services are occasionally required depending on operational needs. These circuits may provide a large variety of services, the more common of which are automatic fault location, relay check-back schemes, and slow-scan TV. Automatic fault location is a system which prints out the distance to the fault as it occurs, thus pinpointing the location to within a line span. Relay check-back schemes are used on directional comparison relay circuits for a remote check of the power line carrier system to ascertain its operating status. Slow-scan TV, which can be transmitted via a standard voice bandwidth channel, has been used where a large number of telemetered quantities are required at a distance.

A. Service Types

2.07 The telecommunication services to power stations as described briefly in 2.01 to 2.06 are classified into four basic types according to usage and transmission requirements [4]. The Service Types are defined as follows:

Type I - Services requiring either dc transmission or ac and dc transmission and used for:

(1a) basic exchange telephone service and/or private line voice telephone service, etc.

(1b) teletypewriter, telemetering, supervisory control, etc.

Type 2 - Private line services requiring either dc transmission or ac and dc transmission and used for pilot wire protective relaying or dc tripping.

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

Type 4 - Private line services requiring only ac transmission and used for audio tone protective relaying.

B. Service Performance Objective Classifications

2.08 Interruptions or outages of telecommunications 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.

2.09 Interruptions or outages of telecommunications circuits due to the effects of power system faults can be minimized through the use of special high voltage protection systems which are designed to operate in the fault-produced electrical environment (GPR and longitudinal induction) at electric power stations. Because of the customer's need for service continuity during power system faults on some types of telecommunications services provided to power stations, a system of Service Performance Objective (SPO) classifications has been established for the purpose of permitting the customer to specify the performance objectives for all types of telecommunications services provided to power stations [4]. These objectives, *with respect to the effects of power system faults*, fall into three classifications which are listed below and are described in the following paragraphs:

- Class A: Non-interruptible service performance (must function before, during, and after the power fault condition)

- Class B: Self-restoring interruptible service performance (must function before and after the power fault condition)

- Class C: Interruptible service performance (can tolerate a station visit to restore service).

2.10 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 usually have a Class A SPO are pilot-wire protective relaying, audio-tone protective relaying, and critical supervisory (remote control) circuits.

2.11 To achieve SPO Class A using wire-line facilities, dual alternate routing should be 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.

2.12 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 should be considered. These include:

(a) The minimization of bridge taps and multiple appearances of these cable pairs

(b) The minimization of the number of appearances on central office main frames, with special protective covers required on all appearances

(c) These circuits should not be tested, switched, electrically contacted, or changed unless prior arrangements have been made with the appropriate group within the electric utility as to the date, time, and duration of such operations.

2.13 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 usually have Class B SPOs (with self-restoring requirements) are storm or emergency telephone circuits, telemetering and data circuits, supervisory control circuits, and signal and alarm circuits.

2.14 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 usually have Class C SPOs are basic exchange telephone service, noncritical telemetering and data circuits, and some signal and alarm circuits.

2.15 The above SPO classifications are used only to indicate the customer's desired telecommunication service performance at times of power system faults. They are not intended to represent guarantees of fault-related service performance by the telephone company.

3. POWER STATION ELECTROMAGNETIC ENVIRONMENT

A. General

3.01 The power station electromagnetic environment is unique in that it often presents a variety of unusual and difficult protection problems (sometimes in combination) which must be properly addressed if telecommunication services are to be provided reliably and safely. Cable and wire facilities entering electric power stations may be subjected to the effects of Ground Potential Rise (GPR) and longitudinal induction during power system fault conditions. Even during normal power system operation, the facilities may be subjected to the effects of lightning and radiated power system switching transients. These four environmental factors are described in 3.05 through 3.21.

B. Power System Faults

3.02 Power system faults are caused by mechanical and electrical failures occurring in power system components, by weather-related causes and man-made accidents, and by lightning strokes to the power system. They may occur at any location on a power line or within generating, switching, or distribution stations. Faults can be phase-to-ground, phase-to-phase, two phase-to-ground, or three phase and can progress from one to the other. Faults due to lightning tend to be initiated randomly in the ac cycle. Faults due to insulation failure and most mechanical causes are usually the result of dielectric breakdown which occurs near a peak of the alternating power system voltage.

3.03 The duration of power system faults is highly variable and is primarily dependent upon the type of power circuit disconnect apparatus employed by the utility. Various types of circuit breakers and fuses having significantly different operating times are used by utilities for disconnecting faults. In general, the higher voltage power systems employ the fastest operating circuit breakers, while lower voltage systems often use slower operating breakers or even fuses. The shortest overall fault clearing time that can be expected on high voltage power systems using modern protective relaying schemes and fast operating breakers is about 50 milliseconds. This overall fault clearing time includes fault detection time, delay associated with the communications channel and the protective relaying terminal equipment, and the operating time of the circuit breaker. The most significant of these factors is the operating time of the circuit breaker because of the mechanical movement required for its operation. Lower voltage power systems that employ slower operating devices may have overall fault clearing times ranging from about 150 milliseconds when circuit breakers are used up to about 3 seconds when fuses are used. On either high or low voltage power systems, where backup protective relaying must operate because of some failure in the primary protective relaying system, the overall fault clearing time can be as long as 2 or 3 seconds [5].

C. Power Station Ground Grid

3.04 A power station ground grid is a system of ground electrodes consisting of interconnecting bare conductors buried in the earth to provide a common ground for electrical devices and metallic structures. Electric power stations employ a ground grid so that structures and equipment within the station can be connected to the grid to minimize potential differences during a lightning stroke or a power system fault. A grid is typically an arrangement of heavy conductors, e.g., 4/0 bare copper cables, buried 12 to 18 inches below grade and spaced in a grid pattern of about 10 by 20 feet. At each junction, the cables are securely bonded together and are often also connected to a ground rod, e.g., an 8 foot copper clad steel rod, which has been driven at the point of intersection. In very high resistivity soils, longer rods are often driven to much greater depths. The grid usually underlies the entire station yard and sometimes extends beyond the fence which encloses the buildings and electrical equipment.

D. Power Station Ground Potential Rise

3.05 Power station Ground Potential Rise (GPR) is the potential difference between the power station ground grid and remote earth. Power station GPR occurs when a fault to ground on the power system causes fault current to flow through the impedance of the power station ground grid. In the example shown in Fig. 2, a ground on a phase wire of a grounded neutral wye-connected power system has resulted in current flow into the ground at the fault location which then returns via earth to the neutral ground connection of the station transformer. The potential of the power station ground grid with respect to remote earth is raised by fault current returning through the station ground grid impedance. This potential also appears in the earth surrounding the power station, its magnitude decreasing with increasing distance from the power station as described in 3.13.

3.06 Figure 2 also illustrates the effects of GPR on conventionally protected wireline telecommunications facilities between the power station and the serving central office. Assuming that the central office is at remote earth with respect to the power station, approximately 3000 volts will appear between the power station and central office grounds during the fault condition. This potential appears across the grounded midpoints of the two sets of protectors and is sufficient to cause the protectors to operate, thereby enabling the flow of longitudinal current on the conductors as shown. At the time of protector operation, communications will be disrupted and, depending on the magnitude and duration of current flow, the protectors may become permanently grounded or the communications facility may be damaged due to thermal effects or arcing. Conventional protection measures, therefore, cannot be used to protect telecommunications facilities at a power station where a hostile fault- produced GPR is predicted. Instead, special high voltage protection devices (i.e., isolation or neutralization devices) must be used on the facilities serving the power station (see Part 4).

3.07 At a power station, the GPR produced by various fault conditions increases as a function of the amount of fault current returning through the station ground grid impedance. When a power system fault-to-ground occurs such that the fault current circuit is completed through the earth and the station ground grid, GPR with respect to remote ground will occur at the station. Sky wire and neutral conductors, when connected to the ground grid, provide an alternate return path for fault current and result in reduced GPR. In urban areas where the ground grid is connected to a large network of underground metallic pipes, the grid impedance is effectively reduced due to its many connections to ground, the earth return fault current is reduced due to the many alternate metallic return paths, and therefore the GPR is reduced.

3.08 Under fault conditions, the power system may be approximately represented as a simple series RL circuit. The GPR waveshape is identical to the fault current waveshape and is simply the product of the grid impedance and the earth return fault current through that impedance. The ground potential rise waveshape is composed of two components: a steady- state sine wave, and an exponentially decaying transient component sometimes called the "dc offset". The instantaneous values of these components, when added, constitute the total GPR. The steady-state 60 Hz component, the decaying dc transient, and total ground potential rise waveshapes are shown in Fig. 3.

3.09 The time constant τ of the transient component of the fault current is equal to the L/R ratio of the power system impedance at the point of fault. The X/R ratio, where $X = \omega L$ ($\omega = 2\pi f = 2\pi 60 = 377$) is the reactance to resistance ratio of the power system, and is often used instead of the time constant in power system discussions. The higher the X/R ratio at the point of fault, the longer the decay time of the transient component. Note that inductance L is a common element in both ratios; accordingly, by definitions and analysis, it can be shown that $\omega\tau = X/R$ or $377\tau = X/R$. Therefore, given either τ or X/R for a power system, conversion is made by $377\tau = X/R$. The X/R ratio is influenced by such factors as the type of transmission line and distance from the fault location to generating stations or transformer stations. The higher voltage transmission lines have greater inductance and, therefore, exhibit a larger X/R ratio than low voltage lines. When a fault occurs near a power generating station, the added inductance of the generators and step-up transformers will increase the X/R ratio. Typical values of X/R for all types of power lines range from approximately 2 to 27 which correspond to L/R time constants of approximately 5 to 70 milliseconds. The waveshapes in Fig. 3 are shown for a transient time constant of 37 milliseconds.

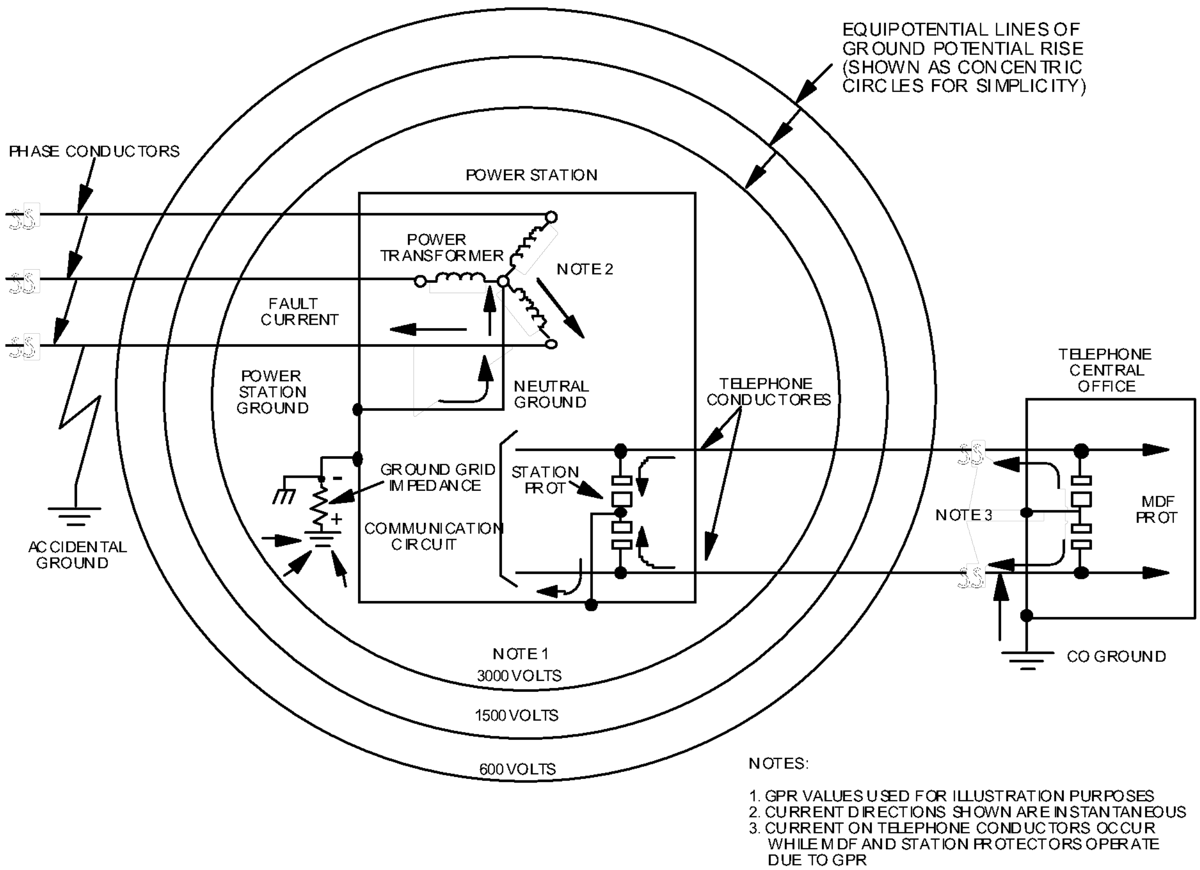


Figure 2 - Rise Potential of Power Station Ground Resulting from a Fault on the Power Line

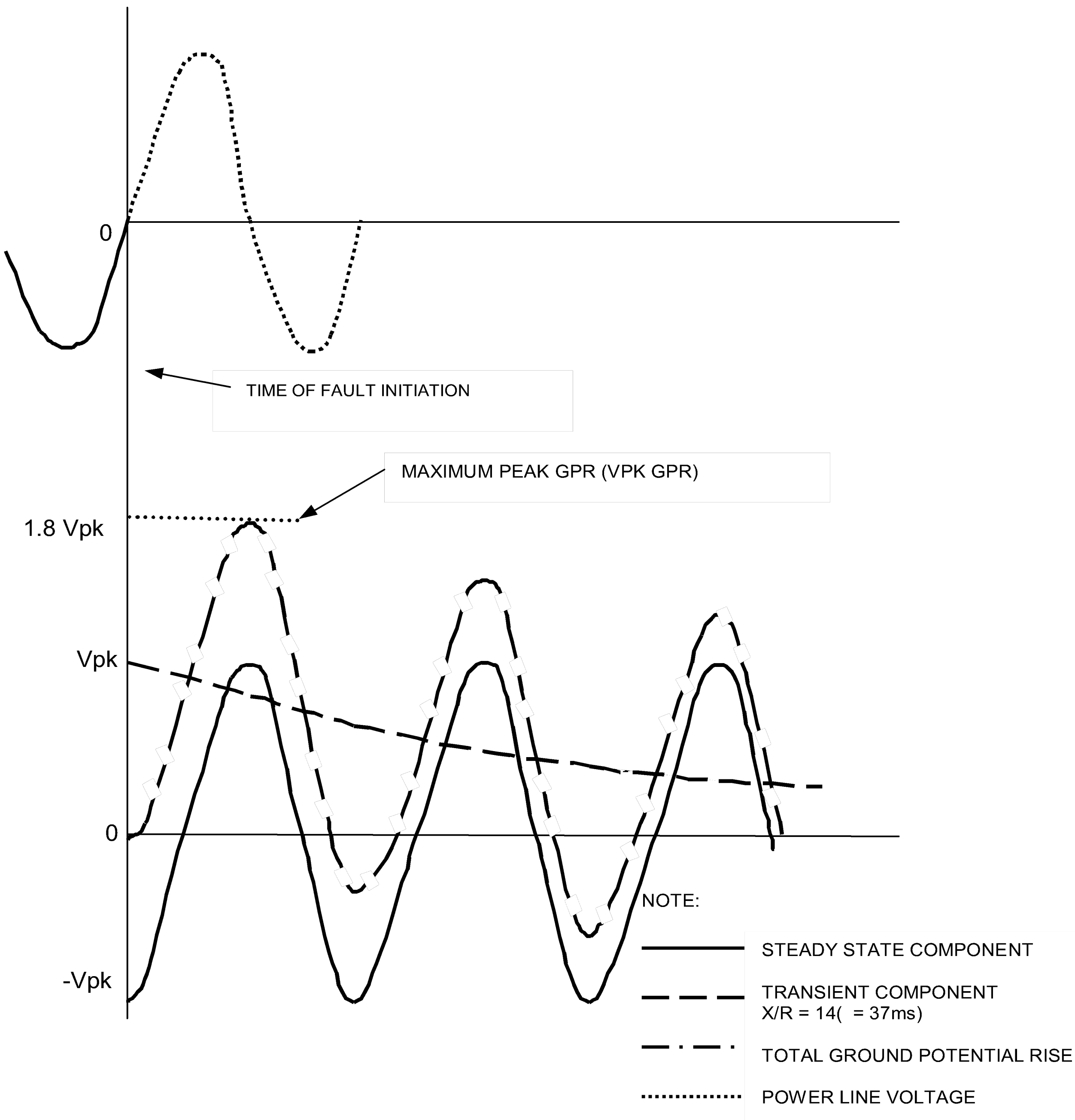


Figure 3 – Ground Potential Rise Composite Waveshape Due to Worst-Case Fault Initiation

310 The initial value of the dc transient component of the GPR waveform depends on the phase angle of the power line voltage at the initiation of the fault, and is maximum (worst case) if the fault occurs as the line voltage wave is near or passing through zero. This angle of fault initiation is likely to be caused only by a lightning stroke or by the closing of a breaker to re-energize a line, both of which can occur at random at any point on the line voltage wave. The transient component of Fig. 3 is shown for such a condition. The phase relationship between the power line voltage and steady-state component of the GPR is due to the voltage- current phase relationship in the power line and approaches 90 degrees for a highly reactive power system.

3.11 For a single phase fault to ground initiated at the time when the power line voltage is at or near zero, the peak GPR occurs approximately one-half cycle after initiation of the fault. Addition of the steady-state and transient components yields a peak GPR that is substantially greater than would be anticipated by the product of the steady-state earth return current and the ground grid impedance, and may approach twice the peak value of the steady-state ac component. If the fault occurs as the power line voltage is passing through a maximum, there will be no dc offset (transient component), and the peak GPR in this case will simply equal the product of the peak steady-state earth return current and the ground grid impedance.

3.12 The ratio of the maximum peak asymmetrical ground potential rise to the peak value of the steady-state component is called the "peak factor", and is a function of the X/R ratio of the power system. Fig. 4 shows the maximum peak factor (for worst case faults occurring at or near line voltage zero crossings) as a function of power system X/R ratio. Fig. 4 may be used by the telephone company protection engineer to determine worst case peak factor and worst case peak GPR voltage when engineering protection for telephone facilities serving power stations. Engineering procedures are detailed in the discussions of Part 6 and in Appendix VI.

E. Power Station Zone of Influence

3.13 When GPR occurs at a power station, not only the ground grid but also the earth surrounding the power station is raised in potential with respect to remote earth. This area around the power station which is raised in potential with respect to remote earth is known as the zone of influence. The ground potential is at a maximum at the ground grid and decreases with increasing distance from the station. The decrease in potential as a function of distance is not linear, but is somewhat exponential in nature. The area beyond the zone of influence, i.e., where the ground potential has dropped to a negligible value, is considered to be at remote earth with respect to the power station. The fraction of the station ground potential which may be present at a specific distance and direction from the station depends on such variables as the area and configuration of the station ground grid and the presence of grounded metallic structures such as multigrounded neutrals, power line static wires, pipe lines, metal sheath cables, etc., but is not affected by specific earth resistivity. These variables and structures determine the actual shape of the equipotential lines around the power station which are shown idealized as circular in Fig. 2.

3.14 Assuming a simple ground grid in homogeneous earth with no connections to external grounded metallicstructures, the extent of the earth potential gradient is a function of the station grid area as shown in Fig 5 [6]. Fig. 5 indicates that, regardless of the actual potential rise of the grid with respect to remote ground, the potential gradient is significantly related to grid area. Any external metallic ground connection such as a power system neutral, a water pipe or a cable shield will extend some portion of the voltage rise from the power station along the route of the grounded conductor. The curves of Fig. 5 may, therefore, be considered to represent the minimum distance which the ground potential rise will extend and may be useful in isolated, or rural undeveloped areas. However, in developed suburban and urban areas, GPR profile measurements should be made instead of using Fig. 5[7,8].

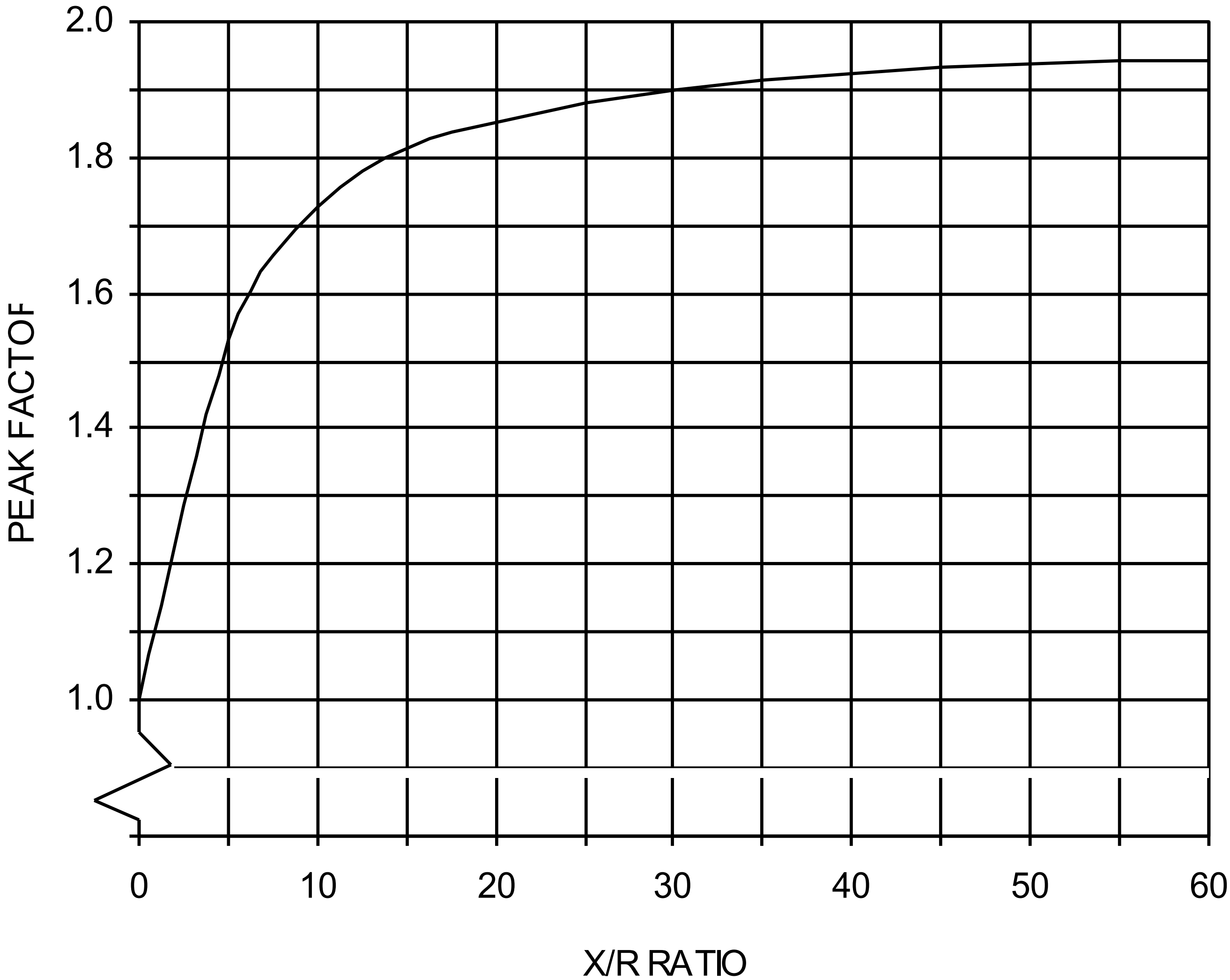


Figure 4. – Maximum Peak Factor vs. Power System X/R Ratio For Worst-CaseFault Initiation

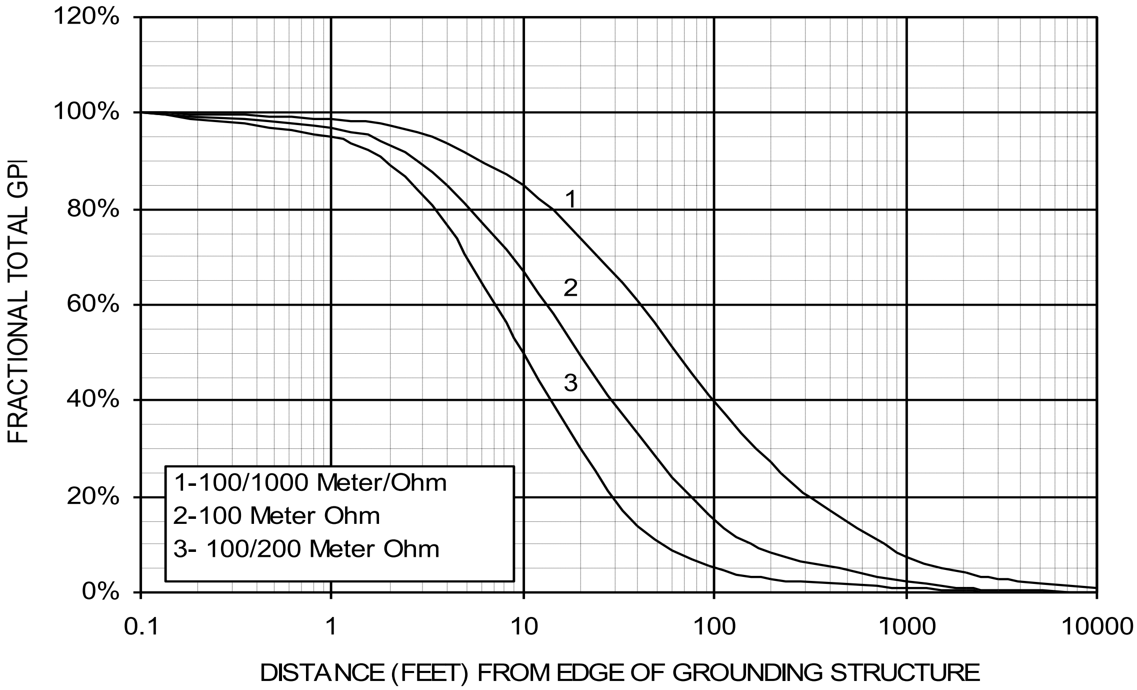


Figure 5a – 16,000 Square Feet: Ground Potential Distribution From Edge of Power Station Ground Grid With Respect to Remote Earth

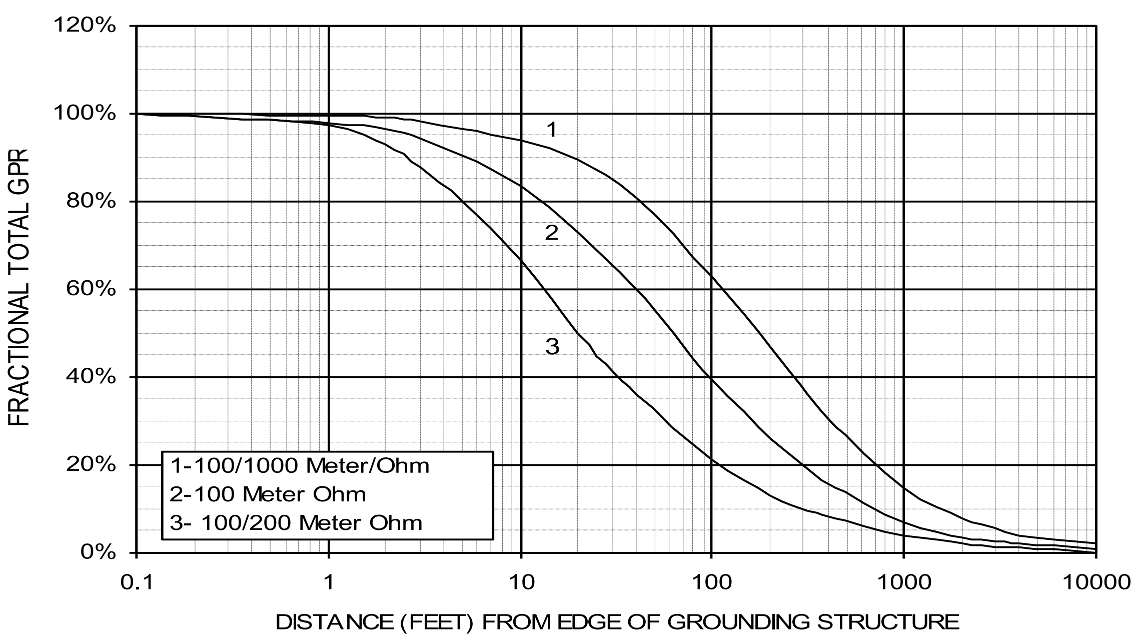


Figure 5b – 35,000 Square Feet: Ground Potential Distribution From Edge of Power Station Ground Grid With Respect to Remote Earth

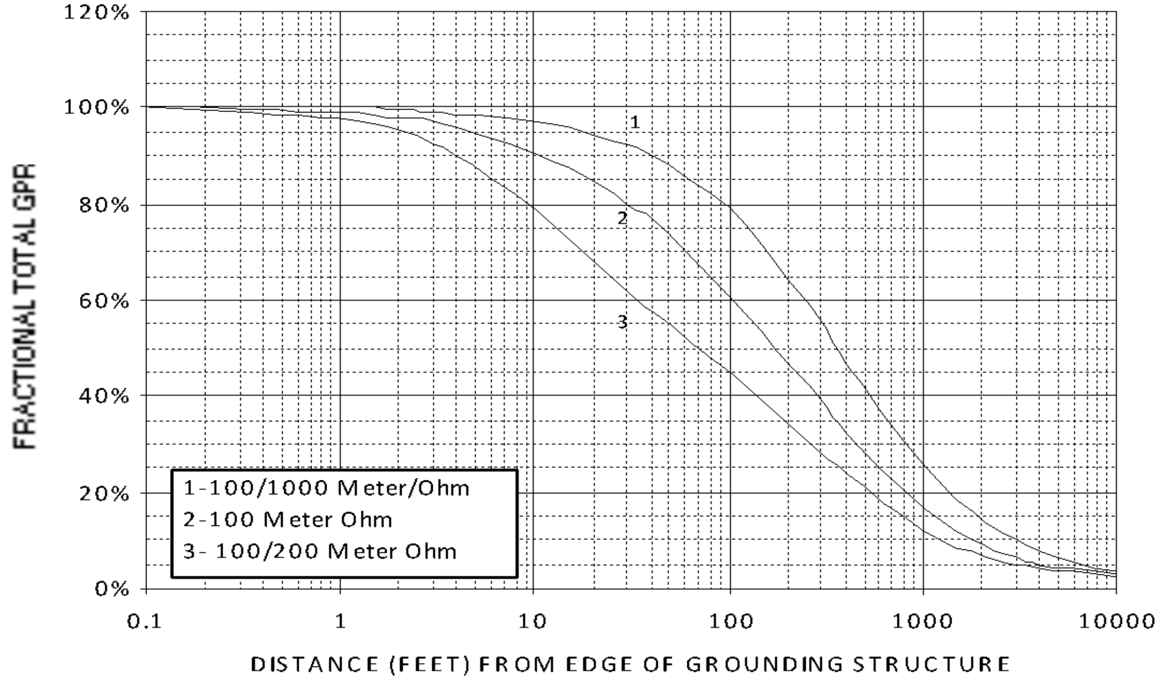


Figure 5c – 290,000 Square Feet: Ground Potential Distribution From Edge of Power Station Ground Grid With Respect to Remote Earth

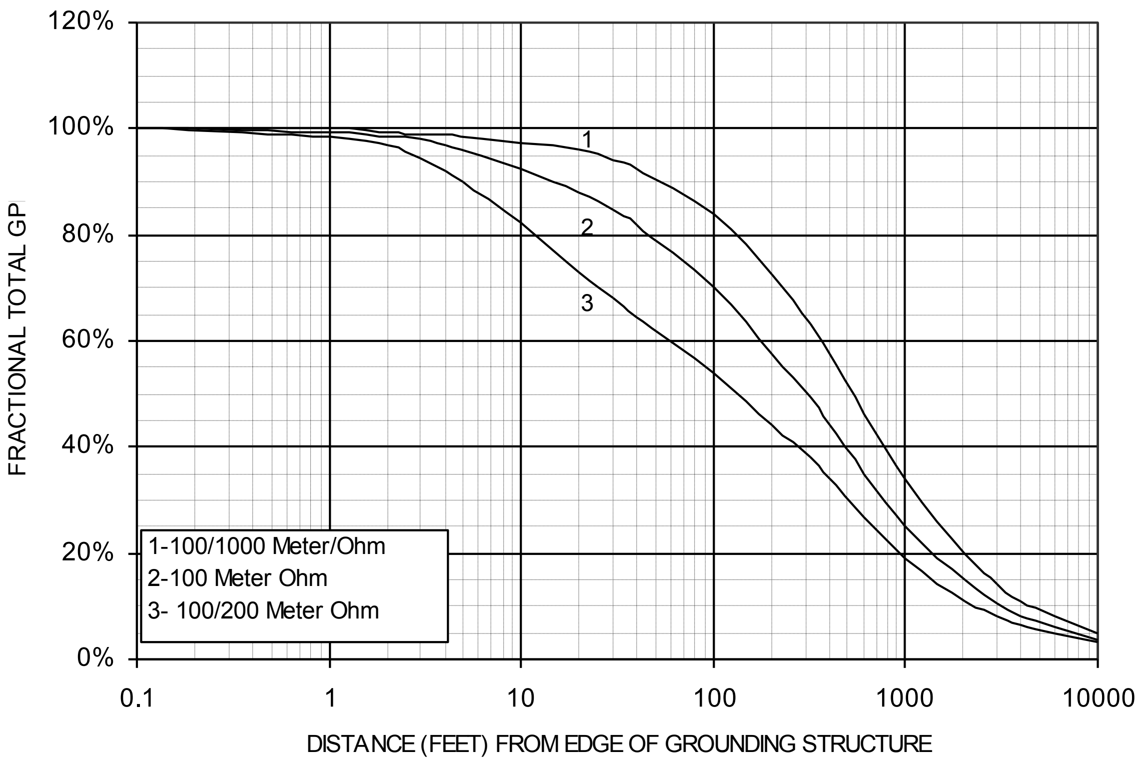


Figure 5d – 935,000 Square Feet: Ground Potential Distribution From Edge of Power Station Ground Grid With Respect to Remote Earth

F. Longitudinal Induction

3.15 Mutual coupling between telephone and power lines may, under power fault conditions, result in a substantial longitudinal voltage impressed on the communication facility. When the power lines and telephone lines are connected to the same power station, the total stress to which the facility is exposed is the vector sum of the longitudinally induced voltage and the power station GPR. This condition is illustrated in Fig. 6, in which a power line parallels a cable pair from the power station for part of the distance to the central office. One of the phase wires is shown faulted to ground, and fault current I_f is flowing into the fault. The earth return portion of the fault current, I_g, flows through the earth from the fault location to the power station ground grid and the power transformer neutral. Fault current I_g produces a rise in potential at the power station ground, magnetic coupling between the faulted line and the serving telephone cable, and results in longitudinally induced voltage on the communication cable. It is not uncommon for the fault produced longitudinal induction at a power station to exceed the GPR there. It is important, therefore, thatboth GPR and induction (including the effects of shielding) be evaluated thoroughly so that the power station electrical environment can be completely and accurately characterized. The addition of GPR and induced longitudinal voltages is covered in 6.30 to 6.32.

3.16 In addition to the partial induction exposure illustrated in Fig. 6, exposures to fault induction may exist for the entire distance between the power station and the central office. The telephone company protection engineer should fully examine the routing of the serving telephone cable with respect to the power lines entering or leaving the power station so that the total mutual impedance can be determined. The power utility should be requested to provide fault current data for the lines in question. Mitigative measures for longitudinal induction are discussed in the protection engineering designs of Part 6. (Refer to the 873 Division for general considerations of coupling factors and the computation of low frequency induction.)

3.17 Faulted power lines have been known to cause interruptions on distant interoffice carrier facilities either through high voltage induction causing repeater protector operations, or through low voltage induction (below the sparkover level of protectors) with the resulting longitudinal current causing deregulation of the repeater regulator diodes. Although serious problems in this area are considered to be uncommon, the protection engineer should be aware of the possibility of such occurrences and of mitigative measures which can be taken. Practice 873-406-101 provides guidance in reducing the effects of inductive interference to various types of carrier systems.

G. Lightning

3.18 Lightning incidence in the area must also be taken into consideration. A lightning arrester may be required at an electric power station to protect the High Voltage Protection Devices. In general, lightning arresters are recommended, however, they may not be required in all locations especially in the Pacific Region. The ICEP Engineer should consider the following factors:

(1) Number of Thunderstorm Days

(2) Lightning Exposure Classification of Telephone Plant

(3) Lightning Exposure Classification of Electric Supply Facilities

(4) Operating Experience within a Given Geographical Area

Special lightning protection is described in 4.14 through 4.17. (Refer to Practices 876-300-100 and 876-400-100 on customer premises and cable protection, respectively, which include information on lightning exposure that will help define the meaning of “negligible” or “high” lightning incidence from a practical standpoint applicable to the power station environment.)

H. Switching Transients

3.19 High voltage power system switching operations can cause electromagnetic field disturbances which induce transient potentials and currents in communication circuits located within an electric power station. These switching transients may be caused by the electrical characteristics of arcs that exist during the energization or interruption of high-voltage circuits and the resonance of lumped circuit constants within the switch-yard.

3.20 Events on high-voltage power systems which cause these induced transients are: (1) the switching of shunt capacitors, (2) overvoltage flash over of lightning arresters, (3) operations (closures and reclosures) of circuit breakers, and (4) switching a section of extra-high-voltage (EHV) bus by an air break disconnect switch.

3.21 The transients are identified as high frequency, high voltage, and having a 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 μs have been measured on control circuits in power stations. Pulse trains lasting up to 3 seconds, have been observed [4]. Mitigative measures for switching transients occurring within the power station are described in 6.24.

4. SPECIAL PROTECTION DEVICES AND SYSTEMS

A. Device Use and Reliability

4.01 The safety and reliability of the telecommunications circuits serving an electric power station are dependent, in part, on the special high voltage protective devices used there. If required protection devices are omitted or improperly chosen and applied, hazards to personnel, interruptions to transmission continuity and possible dam age to plant and terminal equipment could result during power fault conditions. Safety and reliability are determined largely by the proper selection and application of special protective devices, or, in short, by the proper engineering of the protection system. Special protection devices for power station applications include isolation transformers, isolation devices which provide for dc signaling, neutralizing transformers, mutual drainage reactors, high voltage isolating relays, spark gaps, lightning arresters, carbon blocks and gas tubes. Descriptions and performance specifications for such devices are available from the manufacturers. One example of a listing of many of the above devices is found in AT&T Product Evaluation Report #449, Issue 2, dated September 20, 1983.

4.02 Choice of protective devices depends on combinations of such considerations as (1) the quantity of telecommunication services requested at a given location, (2) the mix of Service Types and the Service Performance Objective Classification designated for each type, (3) the magnitude of the fault-produced GPR and induction, (4) the availability and type of existing telecommunications facilities nearby. The overall engineering of special protection systems which takes the above factors into account is covered in Part 6.

B. Isolation Transformers

4.03 The isolation transformer is basically a 2-winding transformer with suitable insulation and impedance ratio characteristics to allow its insertion into the communications pair serving an electric power station. This arrangement effectively isolates the power station cabling and terminal equipment from the outside plant transmission facilities. The isolation transformer allows the station cabling and terminal equipment to remain at the potential of the power station ground, while any fault-produced potential difference between the station ground and remote earth appears between the windings of the isolation transformer. There is no dc path through the transformer; therefore, it cannot be used in circuits which require dc continuity. Some isolation transformers have center-tapped windings on one or both sides of the transformer and thereby provide a path for the drainage of longitudinal currents to ground. transformers designed to drain longitudinal currents should be capable of handling specific minimum amounts of both continuous 60 Hz currents and also lightning surge currents. Isolation transformers are not subject to core saturation from longitudinal current.

4.04 A typical isolation transformer connection at a power station is shown in Fig. 7. In this example,both primary and secondary windings are center-tapped. The station side center-tap is connected to the ground grid to maintain the station side wiring at or near ground grid potential. This connection eliminates any potential difference between the station wiring and terminal equipment and the station side of the isolation transformer. The center-tap on the central office side is connected through a gas tube protector to a spark gap and lightning arrester. A gas tube on each center tap provides transmission separation between pairs carrying unrelated communications services. The spark gap provides high voltage isolation between the shield and isolated pairs to prevent service interruptions in the event of inadvertent grounding of the shield. It also protects the cable by operating during severe abnormal voltage stress between the cable shield and the pairs protected by the isolation transformers. It does not operate under normal conditions. The lightning arrester protects the isolation transformer from excessive surge voltages caused by lightning. During a power system fault, the station wiring and terminal equipment will assume ground grid potential and the potential difference between the station ground grid and a remote ground point will appear harmlessly across the primary-to-secondary insulation of the isolation transformer.

C. Mutual Drainage Reactors

4.05 A mutual drainage reactor is a noise mitigation device which provides a path to ground for extraneous longitudinal currents on a pair of communication conductors without significantly disturbing the metallic signal path. The drainage reactor, or drainage transformer as it is frequently called, consists of two electrically identical windings mutually coupled by a magnetic core. These windings are so connected that inductively they are series aiding for metallic currents and parallel opposing for longitudinal currents. Consequently, the device presents a high bridging impedance to metallic circuit alternating currents between the tip and ring of a pair and, at the same time, provides a low impedance path to ground for longitudinal currents. Mutual drainage reactors are used only on SPO Class A services.

4.06 Drainage reactors may be used in direct, single protector, or double protector drainage applications. Direct drainage (Fig. 7) is the simplest application and is restricted to circuits requiring ac transmission only. This is because the direct drainage connection provides a low resistance dc path from tip to ring of the pair, and from tip or ring to ground. Hence, its use also precludes the application of sealing current and the use of dc testing methods on the circuit. Single protector drainage consists of a single carbon block protector between the center-tap of the drainage reactor and ground. Because single protector drainage provides a low resistance dc path from tip to ring, it is also restricted to circuits requiring ac transmission only. Its use may also preclude the application of sealing current and the use of dc test methods. Single protector drainage is used so that longitudinal current flows only after protector operation, thus eliminating any steady state metallic noise that could possibly occur with direct drainage through longitudinal-to-metallic noise conversion. However, when all factors are considered, single protector drainage is generally inferior to direct drainage due to noise generated when the protector does operate.

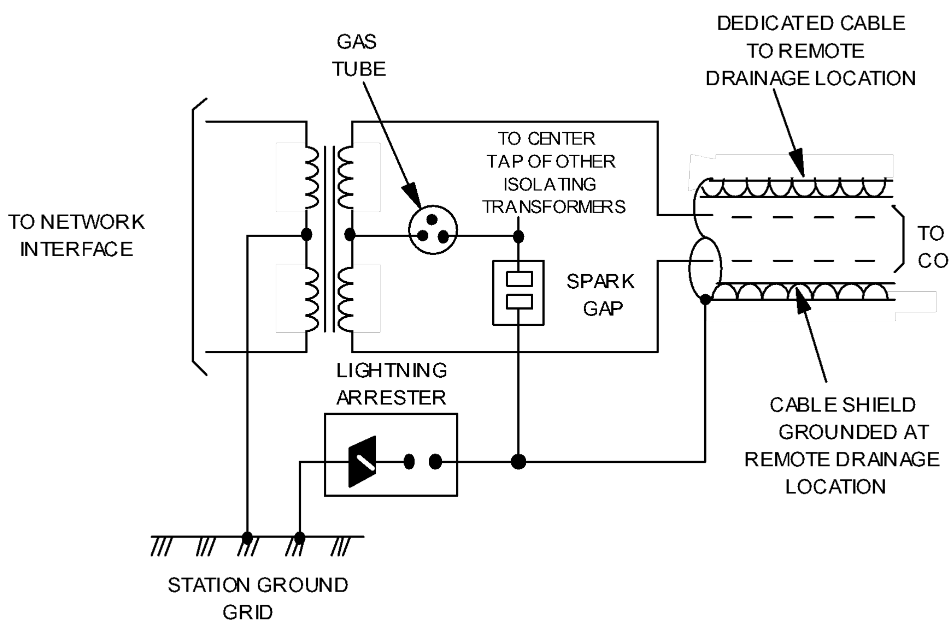


Figure 6 – Isolation Transformer – Typical Application

4.07 When a combination ac and dc transmission path is required, or when dc sealing current is to be applied to the pair being protected, double protector drainage consisting of 3-mil carbon block protectors in series with each winding of the drainage reactor should be used as shown in Fig. 8. The protectors prevent any undesired dc current flow from tip to ring, or from tip or ring to ground except when the protectors operate. The mutual drainage reactor serves a dual purpose when used in a double protector drainage application. First, longitudinal current drainage is provided when voltage levels are sufficient to operate the protectors. Second, where the protectors have different sparkover values, mutual coupling forces simultaneous protector operation at the spark-over value of the lower voltage protector (provided the spark- over level of the higher voltage unit is less than twice that of the lower voltage unit), thereby minimizing metallic noise voltage resulting from unsymmetrical protector operation. The forced simultaneous operation takes place as follows: when the lower voltage protector, P1, operates, longitudinal current to ground through winding #1 induces, through mutual coupling, a potential in winding #2 in a manner that supplements the voltage across P2. As shown in Fig. 8, the sum of the two voltages is now adequate to operate the higher voltage protector. This entire operation takes place so rapidly that any metallic voltage which might be produced is of extremely low magnitude and short duration.

4.08 Fig. 12 illustrates how unsymmetrical transformer protector operation can produce undesirable metallic noise voltages when the drainage reactor is not present to force simultaneous operation. Protector P1 fires at T1 when the longitudinal voltage reaches 300 volts. Protector P2 has not fired; therefore, approximately 275 volts is applied across the termination. The 25-volt discharge drop across protector PI is not effective across the termination. The metallic voltage continues to be applied to the termination until at T2, the longitudinal voltage increases to 500 volts and P2 fires. Consequently, for the period T2 - T1, a metallic noise voltage ranging from 275 to 475 volts is introduced into the communications channel. Use of a mutual drainage reactor virtually eliminates the longitudinal to metallic conversion of noise occurring as a result of unsymmetrical protection operation.

D. Isolation Devices Which Provide for DC Signaling

4.09 Isolation devices which provide for dc signaling are those devices which perform their protection function by means of isolation, rather than neutralization, and which effectively enable the transmission of dc type signals across a high dielectric strength insulating barrier either through pulsing or regeneration. There are presently two types of such devices. The first is the electromechanical type, which is used for voice telephone service with loop start, metallic ring-up circuits. It consists of a high dielectric strength isolation transformer combined with a highly insulated reed relay. With the relay coil on one side of the dielectric barrier and the relay contacts on the other side, capability is provided for transmitting switch hook position information and rotary dial pulses. Voice, ringing, and dual tone multifrequency dialing signals are transmitted through the high voltage isolation transformer. The high voltage protection rating of this first type of isolation device is the rating of the high voltage isolation transformer used in the assembly. Like the isolation transformer described in 4.03, this device allows the power station terminal equipment and associated cabling to remain at power station ground potential while the fault-produced potential difference between station ground and remote ground appears between the windings of the transformer.

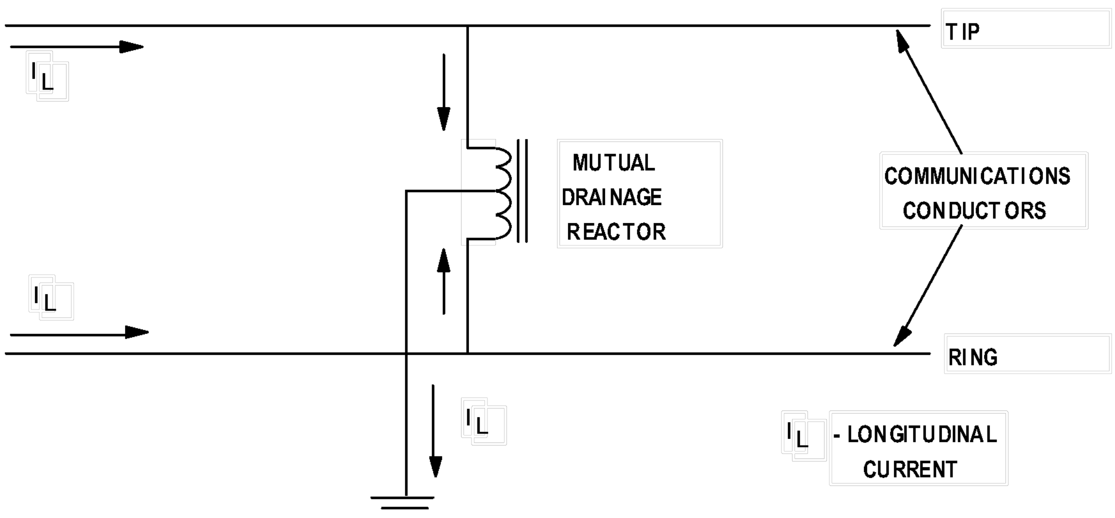


Figure 7 – Direct Drainage Connection of Mutual Drainage Reacto

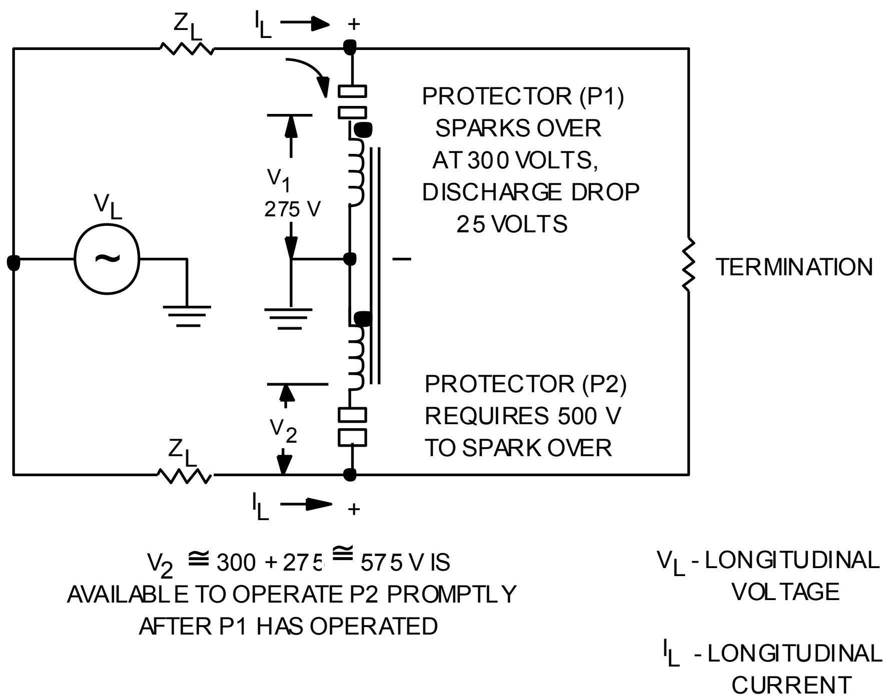


Figure 8 - Mutual Drainage Reactor - Reduction of Unsymmetrical Protector Operation by Mutual Coupling

4.10 The second type of isolation device which provides for dc signaling is the optical type which employs an air gap or glass rod as the high dielectric strength insulating barrier and optical-electronic components for the transmission, detection and regeneration of various types of signals ordinarily requiring a dc path. Depending upon the type and configuration of optical-electronic components used, these isolation devices are available for a variety of applications including voice telephone service with manual or automatic PBXs and either loop start or ground start circuits, dc signaling or continuous dc transmission, telegraph service (up to 300 baud) and pilot wire with dc supervision. The high voltage protection rating of these devices is basically a function of the dielectric strength between the power station side and the Central Office side.

4.11 All isolation devices which provide for dc signaling are active and require a source of local power on the power station side of the device to operate either the relays or the electronics and to provide voltage and current to the terminal equipment, e.g., microphone current to the telephone set. Manufacturers of the isolation devices generally also provide power supplies for this purpose. Such power supplies require a local power source at the power station, such as 117 Vac, or a dc voltage from the station battery. Where uninterruptible telecommunications services are involved, power supplies are available with battery backup in case of failure of the local power source.

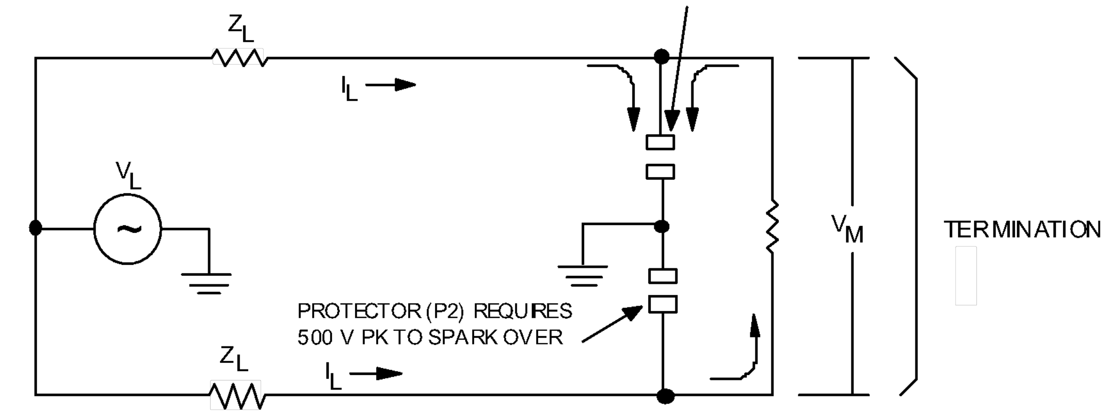
E. High Voltage Isolating Relays

4.12 High voltage isolating relays are isolation devices which perform their protection function by means of isolation, rather than neutralization, and which provide a means of transmitting contact closures or slow speed "on-off" type signals across the high dielectric strength insulating barrier. Although similar to the electromechanical type of isolation devices which provide for dc signaling described in 4.10, the high voltage isolating relays have a more limited field of application.

4.13 The high voltage isolating relay consists of a highly insulated coil surrounding a center well into which a highly insulated reed contact assembly is mounted. When current is passed through the coil, the magnetic field causes the contacts to operate. A high dielectric strength insulating barrier separates the coil from the contact assembly. High voltage isolating relays may be connected either to transmit contact closures or pulses from the power station toward the central office, or to relay contact closures or pulses from the central office toward the customer equipment at the power station. When installed on a communications circuit, the device allows the power station terminal equipment and associated cabling to remain at power station ground potential, while the fault-produced potential difference between station ground and remote ground appears across the insulating barrier between the coil and the relay contacts.

F. Lightning Arresters

4.14 Lightning arresters are used in special high voltage protection systems to protect the isolating or neutralizing devices from insulation failure due to excessive surge voltages caused by lightning strokes to the power station ground structure or to the dedicated cable. Lightning arresters also prevent 60 Hz follow-through current due to GPR produced by a lightning-initiated power system fault. This function protects the dedicated cable from possible damage due to 60 Hz current flow. The type of arrester to be used in special protection systems is the gapless, metal oxide distribution class arrester. The low impulse sparkover (RM) type arrester having gapped silicon carbide construction is no longer recommended due to the superior operating characteristics of the metal oxide type arrester.



NOTES:

1. METALLIC VOLTAGE (V_M) ACROSS TERMINATION VARIES FROM ABOUT 275 TO 475 VOLTS PK FOR THE PERIOD T_2-T_1
2. SPARKOVER VALUES SHOWN ARE POSSIBLE VALUES FOR BLOCKS WHICH HAVE EXPERIENCED SOME SERVICE DUTY

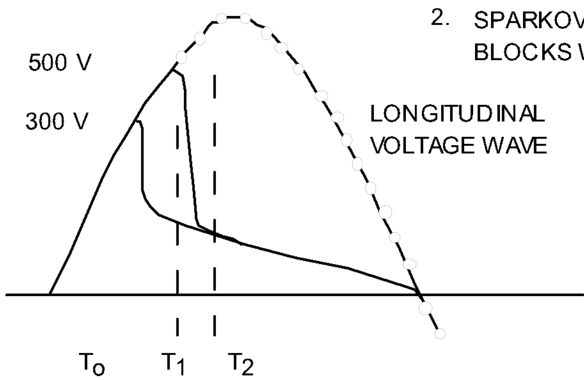


Figure 9 - Unsymmetrical Operation of Protectors

4.15 The protective characteristics of metal oxide type lightning arresters are described by several parameters which are of interest and should be understood:

(a) Maximum continuous operating voltage (MCOV) - This value, in kV rms, is the maximum power frequency voltage which may be applied across the arrester on a continuous basis. For electric power utilities, this is the primary application consideration since the arrester MCOV must coordinate with the continuous line-to-ground system operating voltage.

(b) Rated voltage - This value, in kV rms, is typically 15 to 20 percent higher than the MCOV value. It is the power frequency voltage which may be applied to the arrester on a temporary basis, e.g., for thirty minutes, to accommodate temporary overvoltage conditions which occur during normal power system operation.

(c) Equivalent Front-of-Wave Protective Level - This value, in kV peak, is defined as the maximum discharge voltage for a 10 kA impulse current wave which produces a voltage wave cresting in 0.5 μsec. With the gapless metal oxide arrester, there is no longer an actual "front-of-wave impulse sparkover" value such as with the gapped silicon carbide arresters formerly used. This is because there are no gaps in the metal oxide arrester to spark over. However, for arresters having the same rated voltage, the "equivalent front-of-wave protective level" (also known as the 0.5 μsec 10kA maximum IR) is numerically similar to the former "front-of-wave impulse sparkover value."

(d) Maximum discharge voltage - This value, in kV peak, is the maximum discharge voltage across the arrester produced by various values of impulse currents having a standard 8 x 20 μsec impulse current waveform. This parameter has the same meaning with either the gapless metal oxide type arrester or the gapped silicon carbide type arrester. It is in this area of arrester performance that the metal oxide arrester is greatly superior to the silicon carbon type. With the silicon carbide arrester, the maximum discharge voltage across the arrester often exceeded the front-of-wave impulse sparkover voltage of the arrester with impulse currents of only moderate to high value. However, with the metal oxide type arrester, the maximum discharge voltage generally does not exceed the equivalent front-of-wave protective level even with extremely high values of discharge current.

4.16 The recommended selection procedure is to choose an arrester having an rms voltage rating equal to the 60 Hz rms voltage rating of the isolating or neutralizing device to be protected. Manufacturers of special protection devices design them to have insulation surge withstand levels based on coordination with the equivalent front-of-wave protection level (formerly the maximum front-of-wave impulse spark-over value) of a distribution class lightning arrester having the same rms voltage rating as the device to be protected. The surge withstand level of a protection device is known as its basic impulse insulation level (BIL). Typically, isolating and neutralizing devices are designed to have BILs which are approximately 120 percent of these front-of-wave impulse values. This ensures that a lightning surge will cause the arrester to operate prior to the BIL rating of the protective device being exceeded, thereby preventing insulation damage to the device. Descriptions and performance specifications of gapless, metal oxide distribution class lightning arresters are available from the manufacturers.

4.17 As an example of lightning arrester selection, suppose it is desired to protect a 9 kV rms rated isolation transformer which has a BIL rating of 40 kV. A typical 9 kV rms rated lightning arrester has an equivalent front-of-wave protective level of approximately 33.5 kV. One hundred twenty per cent of this value is 40 kV; therefore, the arrester properly coordinates with the insulation withstand capability of the isolation transformer. A typical arrester's maximum IR discharge voltage is about 34.5 kV even with the discharge current as high as 20 kA. This value of discharge voltage is well below the transformer BIL of 40 kV.

G. Spark Gaps

4.18 A spark gap is an overvoltage protection device with a calibrated gap between two electrodes which can be connected to a circuit to limit the voltage on that circuit to the breakdown voltage of the gap. In high voltage protection systems, spark gaps maintain pair-to-pair and pair-to-shield voltages within acceptable limits for the cable serving the power station and prevent arcing within the cable should abnormal voltage stresses develop. Typical spark gaps consist of two metal electrodes sealed in a gas-filled ceramic or glass cylindrical envelope. Envelopes are typically one to three inches long and approximately one half inch in diameter. Breakdown voltages (dc or surge) can range from several hundred volts to greater than 20,000 volts.

H. Carbon Blocks and Gas Tubes

4.19 Carbon blocks and gas tubes protect wire-line facilities, connected equipment, and personnel against overvoltages due to lightning surges and power system longitudinal voltages. Both types of protectors are used in special high voltage protection systems. Practice 876-101-100 contains comprehensive descriptions and operating characteristics of both carbon block and gas tube protectors.

4.20 The specific use of either carbon blocks or gas tubes in various protection situations is detailed in the engineering designs of Part 6. In general, gas tubes should be used instead of carbon blocks in protection installations at the power station premises and at any intermediate locations between the CO and the power station. The use of gas tubes should result in reduced maintenance visits to these locations. At the CO, except for services having Class B SPOs, the general recommendation is for the use of 3-mil carbon blocks to be consistent with conventional CO main distributing frame protection. Gas tubes approved for CO use should be used for services having Class B SPOs.

4.21 At any protection location where mutual drainage reactors with double protector drainage are to be applied, 3-mil carbon blocks should be used instead of gas tubes. Whereas carbon blocks produce tolerably low circuit noise in this application, the circuit noise generated by various types of presently available gas tubes operating in conjunction with drainage reactors has not been characterized.

4.22 The gas tubes employed at the power station premises and at intermediate locations between the CO and the power station should meet the requirements of TR-TSY-000070. Gas tubes employed at the CO should meet the TR-TSY-000072. In addition to meeting the stated requirements of the documents cited, for maximum service life all gas tubes should also pass as many of the life objective tests as possible.

5. REQUIRED PROTECTION ENGINEERING INFORMATION

A. Power Station Data File

5.01 The protection engineering of facilities serving a power station is greatly facilitated by having a data file on the power station of interest. It is suggested that an information file similar to the five-part arrangement shown in Appendix I be maintained for each power station where telecommunication services are provided.

B. Power Utility-Provided Information

5.02 Much of the information needed for high voltage protection engineering can be provided only by the power utility. The telephone company protection engineer is not in a position to determine the power station fault-produced electrical environment or to know the characteristics of any individual station. The telephone company engineer must rely on the power utility engineer in this area. Since the power system is the source of interfering voltages into the serving telecommunications facilities, it is the responsibility of the utility to provide to the telephone company the technical information needed to determine any special protection requirements for those facilities. This provision of technical data should apply even in those cases in which the power utility owns the protection equipment at the power station.

5.03 It is recommended that the telephone company and the power utility cooperate fully in the compiling of information which accurately characterizes the power station and defines its fault-produced environment. Appendix I contains a sample of a form (see reduced Exhibit of Form EO-615) which was designed to facilitate the transfer of both technical data and service request information from the power utility to the telephone company. This form is available from the Forms Management Group in each BOC.

C. Evaluating Power Utility Data

5.04 When the power utility provides the technical data needed to determine the fault- produced power station environment, the telephone company protection engineer should not simply accept the data without examining it and subjecting it to certain tests for reasonableness. Although this may appear to be an unnecessary assumption of responsibility, the evaluation of utility-provided data is highly useful since it can preclude serious technical, economic, and business problems which could result from extreme overestimates or underestimates of the fault-produced power station environment.

5.05 The utility-provided data which have the greatest and most direct impact on the ratings and requirements of the special protection system are:

(a) the value of the ground grid impedance to remote earth (across which the GPR appears),

(b) the value of the total fault current and that portion of it which produces GPR,

(c) the value of fault-produced GPR,

(d) the value of the X/R ratio of the power system at the worst case fault location.

5.06 Appendices II through V contain guidelines to aid the telephone company engineer in evaluating the reasonableness of the technical data provided by the power utility. The technical areas covered by the appendices are as follows:

Appendix II - Ground Grid Impedance
Appendix III - Fault Current
Appendix IV - Ground Potential Rise
Appendix V -X/R Ratio

D. Transmission Considerations

5.07 With the exception of protective relaying channels, the telecommunications channels provided to electric power stations are the same as channels provided to other business customers at locations not having a fault-produced electrical environment. The transmission characteristics of various types of telephone channels are described both in technical documents (e.g., Technical References, Bellcore Practices, etc.) and in telephone company tariffs. Technical parameters for either switched services or dedicated channels are the same for all customers regardless of whether the customer location is a power station or a typical business location.

5.08 Channels specific to electric power stations are those that are used for power system protective relaying, i.e., audio tone protective relaying (Service Type 4), and dc tripping and pilot wire protective relaying (Service Type 2). These types of channels are also described in various technical literature and are provided for in telephone company tariffs. Protective relaying channels are those which carry signals indicative of the operational status of the power system, e.g., “guard” type signals when the power system is operating normally, and “trip” type signals when the power system experiences a fault and a “trip” signal is transmitted to operate power utility circuit breakers which de-energize or sectionalize the faulted portion of the power system. Power utilities consider protective relaying channels to be among the most important types from a reliability standpoint and ordinarily assign to such channels a Class A Service Performance Objective (SPO).

5.09 The transmission characteristics of the telecommunications channels must be considered in the selection of the special protection devices to be used on the serving facilities. It is essential that the transmission capabilities of the protective apparatus be compatible with the channel characteristics, and that the transmission performance of the channel not be impaired by the application of the protective apparatus. Typical channel transmission parameters which must be considered when selecting compatible protection devices are:

(1) characteristic impedance

(2) bandwidth

(3) frequency response (attenuation distortion)

(4) insertion loss

(5) envelope delay distortion

(6) signal power

(7) need for metallic continuity (dc transmission).

E. Forecast of Future Developments

5.10 Power utility plans for future power system modifications may affect the design of the protection system; therefore, these effects should be anticipated to the extent possible in the original protection system planning. Information needed for this purpose must be obtained from the power utility engineer. Typical examples of changes in the power system which can affect the protection design are: (1) increases in available system fault current due to new system inter-ties or to increased generating capability, (2) changes in the connections of the station grid to externally grounded metallic structures, (3) changes in grid size or design, (4) new line construction which can change induction exposures.

6. PROTECTION ENGINEERING OF FACILITIES SERVING POWER STATIONS

A. Determination of Need

6.01 To determine whether or not special high voltage protection equipment is required at the power station for the serving telephone facilities, the following guidelines are set forth:

(a) Special protection equipment should be used when the fault-produced GPR and/or induction at the power station is 1000 volts peak or greater.

(b) Special protection equipment should be used when the fault-produced GPR and/or induction at the power station is 300 volts peak or greater and at least one telecommunication service has been assigned a Class A SPO by the customer.

(c) Special protection equipment is not required when the conditions in (a) or (b) above are not met. Some utilities, however, may request and pay for special protection on services considered to be critical (SPO Class A) even when the fault-produced environment is less than 300 volts peak.

6.02 When special protection apparatus based on the above guidelines is used at the power station, a high dielectric dedicated cable should always be used to traverse the hostile GPR zone of influence surrounding the power station (see 3.13). Also, depending upon the type of special protection apparatus employed at the power station and upon the SPO classification of the services there, additional special protection equipment may be required at the serving central office and at the point where the dedicated cable joins the general use cable.

B. Dedicated Cable

6.03 When a special protection system is used at the power station, a high dielectric dedicated cable containing only those pairs serving the power station should also be used. The dedicated cable is an integral part of the special protection system because it helps ensure the dielectric integrity of the serving facilities in the immediate vicinity of the power station. Detailed information pertaining to the dedicated cable is contained in Appendix VII. The dedicated cable may be considered to begin at the power station and extend through the zone of influence to a point where the GPR voltage has diminished to a level which is compatible with the expected dielectric strength and protectors of general use cable plant. The location at which the dedicated cable joins the general use cable is called the “remote drainage location”. It is the point at which the power station GPR has fallen off to 300 volts peak or less. The name derives from the fact that, in some types of special protection systems, drainage reactors and overvoltage protectors are used at this location to provide remote “backup” protection with drainage capability to protect the general use cable plant in the event of a protection failure at the high voltage interface.

6.04 Special precautions must be observed with regard to grounds on the dedicated cable shield. It is absolutely essential that the metallic shield remain isolated from ground within the power station and throughout the zone of influence. Deliberate, low impedance grounding of the cable shield in the power station and in the zone of influence must be avoided in order not to circumvent protective measures at the power station. Low impedance grounds could cause interruptions of services and possible damage to the cable from excessive currents on the shield and pairs. It is recognized that pinholes in the outer jacket will provide incidental grounding to the shield, particularly in buried plant, but such incidental grounds have sufficiently high impedance to preclude the problems described above.

C. Coordination of Protection

6.05 A fundamental concept in high voltage protection of wire line facilities serving a power station is the concept of a "coordinated" system of protection. This means a system of protection in which comparable protection measures are applied to both non-critical and highly critical services that are provided in the same cable so that a circuit interruption or failure of a highly critical service will not be caused by a protection failure on a non-critical service. The protection system must, therefore, be coordinated with the expected fault-produced environment, and the protection devices must be coordinated with each other with respect to their protection ratings and performance. For example, if the serving telephone cable carries both ordinary voice services and highly critical protective relaying channels, it would not be appropriate to protect the voice services with ordinary carbon block protectors and the protective relaying channels with high voltage isolation transformers. This could result in protector block operation during a severe power fault condition, excessive current on the voice pairs between the power station and the central office, and potentially harmful voltage differences within the cable between the voice pairs and the isolated protective relaying pairs. Interruption of critical services due to arcing from the voice pairs could occur, along with possible permanent damage to the cable.

6.06 The objective of coordination is to minimize the likelihood of protector operation, cable failure due to excessive pair-to-pair and pair-to shield voltages, failure of a special protection device, or other similar occurrences which can create hazards to personnel and plant and result in interruptions to critical and non-critical services alike. The special protection systems described in this practice are examples of "coordinated" systems of protection.

PROTECTION LOCATIONS

D. High Voltage Interface Location

6.07 The heart of any high voltage protection system is the arrangement of protective apparatus at the High Voltage Interface (HVI) location on the power station premises. It is at the HVI location where appropriately rated isolating or neutralizing devices are installed in a coordinated system designed to protect the serving telephone facilities from the expected fault-produced GPR and/or induction. The special protection apparatus at the HVI is considered to be telephone network equipment, and it is always located on the telephone company side of the Network Interface. Even if the protection equipment is owned by the utility, it is still considered network equipment and must be located on the telephone company side of the Network Interface. It is not considered to be terminal equipment, and thus is not subject to registration under FCC Part 68 rules. Depending upon the type of protective apparatus used at the HVI, and upon considerations of lightning, other devices which may also be used at the HVI are mutual drainage reactors, spark gaps, carbon blocks, gas tubes and a lightning arrester.

6.08 The HVI should be located on the power station ground grid and a direct connection to the grid for grounding the protection system should be made available there by the utility. A 6-gauge solid, bare copper conductor, well bonded to the grid and as short as practical, is recommended. There are essentially two choices available regarding the physical location of the HVI on the ground grid and there are special considerations associated with each. It is suggested that the telephone company protection engineer and the power utility engineer mutually agree on the most favorable location in each instance.

6.09 One choice of HVI location is near the edge of the station ground grid and about 10 feet inside the station fence. The exact location should be chosen so that personnel cannot simultaneously contact both the grounded HVI cabinet and the station fence or any metal structures which may not be well grounded (some utilities do not bond the station fence to the grid). When the HVI is located near the edge of the grid, a weatherproof cabinet must be used to house the protection apparatus. Depending upon the physical dimensions of the station, there could be a considerable distance between the HVI and the Network Interface (NI), and a lengthy exposure to inductive interference or switching transients could necessitate the use of special shielding measures (e.g., iron or steel conduit, supplemental 4/0 conductor) along the exposure or additional protection measures at the NI. If active protective apparatus is used at the HVI, it will need to be powered from the power station building or control house. This will involve the application of dc power over metallic conductors in the cable between the HVI and the NI. As with other pairs in that cable, these dc power pairs are also subject to inductive interference and switching transients. When the HVI is located on the grid perimeter, special insulating protection using PVC electrical conduit to isolate the dedicated cable from the grid is required only for the short distance between the HVI and a point 10 feet beyond the edge of the grid or fence (see 6.10).

6.10 Another choice of location for the HVI is inside the power station building or control house. This location precludes the need for a weatherproof cabinet and, since the distance from the HVI to the NI is greatly reduced, the exposure of communications pairs and any dc power pairs to inductive interference and switching transients is minimized. A major precaution which must be taken with the HVI inside the control house is that extreme care be taken to isolate the dedicated cable from the ground grid. This necessitates the placement of the dedicated cable inside PVC conduit for the entire distance between the control house and the edge of the grid. This isolation must also be maintained as the cable enters the control house and is extended to the HVI location inside. A further consideration here, when the dedicated cable is a filled, waterproof type cable, is the need to change to a high dielectric interior type cable after entering the control house in accordance with BOC construction standards (see Appendix VII). Regardless of the HVI location on the power station premises, the dedicated cable on the CO side of the HVI should be placed in PVC conduit when routed across any portion of the power station grid and for a minimum of 10 feet beyond the grid or the station fence, whichever is further out.

6.11 There may be occasions when the power utility insists that the HVI be located immediately outside the power station fence. If this location causes the HVI to be situated off the ground grid, and if there are no other alternatives, then special construction measures to effectively extend the grid mustbe taken by the utility to make the proposed location as safe as possible for personnel and facilities. The main grid must be extended to the HVI location so that step and touch potentials around the HVI are no greater than on the main grid itself. A mini-grid of appropriate electrical design must underlie the HVI and extend at least 8 feet beyond it in all directions. The mini-grid must be connected to the main grid by at least three buried 4/0 bare copper conductors which are coplanar and parallel to each other with 18 inch spacings between adjacent conductors. The purpose of these heavy conductors is to minimize, to the extent possible, potential difference between the two grids for purposes of safety and service reliability. If the fence or other metallic structures are within about 10 feet from the mini-grid, they must be bonded to the mini-grid. The cable between the HVI and the NI in the control house should be contained in an iron or steel conduit with a separate 4/0 conductor as described in 6.09 to minimize longitudinal induction and switching transients. This iron or steel conduit should be routed along the center line of the conductors joining the mini-grid to the main grid. The metallic conduit, along with the 4/0 supplemental conductor, will also help minimize potential differences between the HVI and the NI. As described in 6.08, a direct connection to the mini-grid should be made available for telephone company use by the utility.

E. Network Interface

6.12 Protection requirements at the Network Interface (NI) are dependent upon the protection system in place at the HVI and upon the exposure status of the cable between the HVI and the NI with regard to induction, lightning, and localized GPR effects. In general, with properly designed and installed systems of protection at the HVI, no protection is required at the NI if the cable between the HVI and the NI can be considered unexposed. Guidelines pertaining to the exposure status of this cable is contained in 6.24 for isolation systems of protection, and in 6.33 for systems containing neutralizing transformers. Where protection measures at the NI are indicated, such measures would typically consist of the application of drainage reactors and gas tube protectors as a function of Service Type and SPO Class.

F. Remote Drainage Location

6.13 Protection recommendations at the Remote Drainage Location (RDL) are primarily based on the type of special high voltage protection apparatus used at the HVI. Since the basic purpose of protection at the RDL is to protect the general use cable from excessive voltages and currents in the event of a protection failure at the HVI, protection at the RDL is unnecessary when the probability of protection failure at the HVI is considered extremely low. One exception to this general rule, however, is the case where significant fault-produced induction occurs in the general use cable between the CO and the RDL. In this case, when the induction exceeds 300 volts peak and Class A services are present, or when induction exceeds 1000 volts peak and no Class A services are present, then protection measures should be taken at the RDL to limit induced voltages to tolerable levels. Such measures would include the use of drainage reactors on Class A services and gas tubes on the other services.

6.14 When the protection system at the HVI uses only appropriately rated isolation-type devices (no neutralizing transformers), and a high-dielectric dedicated cable is used between the HVI and the RDL, and induction per 6.13 is not present, then special protection at the RDL is not required. In this case, the RDL is simply the location at which the dedicated cable is joined to the general use cable. No special protection measures or special grounding measures at the RDL are needed. The Service Performance Objective Classifications (A, B, or C) of the services are not a factor.

6.15 When the protection system at the HVI uses a neutralizing transformer, either in an all neutralization system or in combination with isolation-type devices, protection at the RDL is recommended. This is to protect the general use cable from the effects of excessive current and voltage which could result from ineffective neutralizing transformer action due to core saturation or to problems associated with the primary circuit during a power fault. The use of protection measures at the RDL will also protect the general use cable between the RDL and the CO should there be fault induction as described in 6.13. For services having a Class A SPO, mutual drainage reactors should be used at the RDL. For services having a Class B or Class C SPO, gas tube protectors should be used.

G. Central Office

6.16 Protection for power station services at the serving Central Office is a function of the SPO Class for the individual service under consideration. For services having a Class A SPO, mutual drainage reactors, in either a direct drainage or protector drainage configuration, should be used in place of conventional main distributing frame (MDF) protection. Considerations pertaining to the use of either direct drainage or protector drainage at the Central Office are covered in 6.26. The application of mutual drainage reactors in a Central Office Terminating Unit (COTU) is covered in

Practice 201-211-101. The COTU is a prewired cabinet specifically designed for the mounting of drainage reactors and for their connection to power station circuits in a Central Office. For services having a Class B SPO, gas tubes approved for CO use should be employed instead of conventional 3-mil carbon block protectors. For services having a Class C SPO, conventional CO protection using either 3-mil carbon protector blocks or gas tubes can be used.

H. Technical Considerations Regarding Isolation-Type Systems of Protection

6.17 The simplest, most reliable system of high voltage protection is one which uses only isolation transformers and/or isolation devices which provide for dc signaling at the HVI. This type of system when used in conjunction with a high dielectric dedicated cable, offers both technical and economic advantages over systems which use neutralizing transformers. The high reliability of the isolation devices, in combination with the high dielectric strength of the serving cable, permits a simplified protection design that does not require any type of special protection or special grounding measures at the RDL. The isolation devices at the HVI, in conjunction with the isolated dedicated cable shield, prevent fault-produced power station GPR from appearing on the dedicated cable and from being conducted from the dedicated cable to the general use cable.

6.18 There are essentially two configurations of isolation-type protection systems which may be implemented at the HVI using presently available apparatus. The first configuration is the system composed of an arrangement of discrete, components at the HVI for each pair being protected. these components, such as isolation transformers and other isolation-type devices, are selected to satisfy both the transmission requirements of the service and the protection requirements of the fault-produced environment. They are typically mounted on a wooden backboard and located within an outdoor weatherproof cabinet or in a cabinet inside the power station control house. A lightning arrester, spark gap, and gas tubes are added as needed. When protection apparatus is mounted on the backboard, care must be given to the physical spacing between the power station and central office sides of the devices, and cross-connect wiring must be carefully routed so that adequate separations always exist between wiring on the power station and central office sides of the protection system. This configuration of discrete components is the type of locally engineered protection system which has been most often designed and implemented by telephone company protection engineers.

6.19 The second isolation-type configuration is the modular component type in which isolation devices are contained on printed circuit boards which are usable only when installed in an insulated, prewired shelf. Several models of isolation-type plug-in boards having different transmission capabilitiesare presently available; and several sizes of shelves are also available. Together, the boards and shelves constitute a flexible modular-type protection system which may be mounted either in an outdoor weatherproof cabinet or installed inside the power station control house.

6.20 Advantages and disadvantages of the two configurations of isolation-type protection systems are:

(a) **Discrete Component Configuration**

Advantages

- A variety of isolation transformer voltage ratings allows the selection of transformers closely matched to the fault-produced environment.
- Isolation transformers having wide bandwidth capabilities are available and may be used in protection applications for a variety of analog or digital carrier systems.

Disadvantages

- Each system must be almost custom designed based on the quantity and types of services, SPOs, considerations of future growth, etc.
- Significant engineering time is involved in planning the layout of devices, routing of cross-connect wiring, allowing for expansion, etc.
- The integrity of the protection system may be easily compromised by inadvertent wiring errors or by deliberate bypassing of the protection devices.

(b) **Modular Component Configuration**

Advantages

- Certain plug-in boards effectively allow the transmission of dc (which otherwise requires a neutralizing transformer).
- All boards have a uniform high dielectric strength rating.
- Rearranging circuits or adding new circuits is eased by rearranging boards or by plugging in additional boards.
- There is reduced engineering and labor effort through the use of standardized shelves and plug-in boards.
- Prewired shelves eliminate potential breakdown problems associated with incorrectly routed cross-connect wiring.
- It is more difficult to deliberately bypass the protection system by wiring around the shelf.

Disadvantages

- Most boards are active and require a source of local power, possibly with battery backup (neutralizing transformers, which some of the boards replace, do not require power).
- The high voltage rating of the modular system does not permit a close match with lower voltage environments needing only a low dielectric withstand capability.

I. Engineering A Discrete Component Isolation System

6.21 Fig. 10 illustrates the special protection measures taken to protect power station services in an isolation system of protection using discrete components. The isolation components shown at the HVI are isolation transformers for Service Types 3 or 4 and an isolation device which provides for dc signaling for Service Type 1A. Other devices in the overall protection system at the HVI are gas tubes, a spark gap and a lightning arrester. The station sides of the isolation components are held at or near ground grid potential by the grounded center taps of the isolation transformers, and by the gas tubes connected to isolation device D1. In addition to maintaining all station side wiring at or near ground grid potential these station side connections form part of the path by which lightning protection is provided to the isolation components.

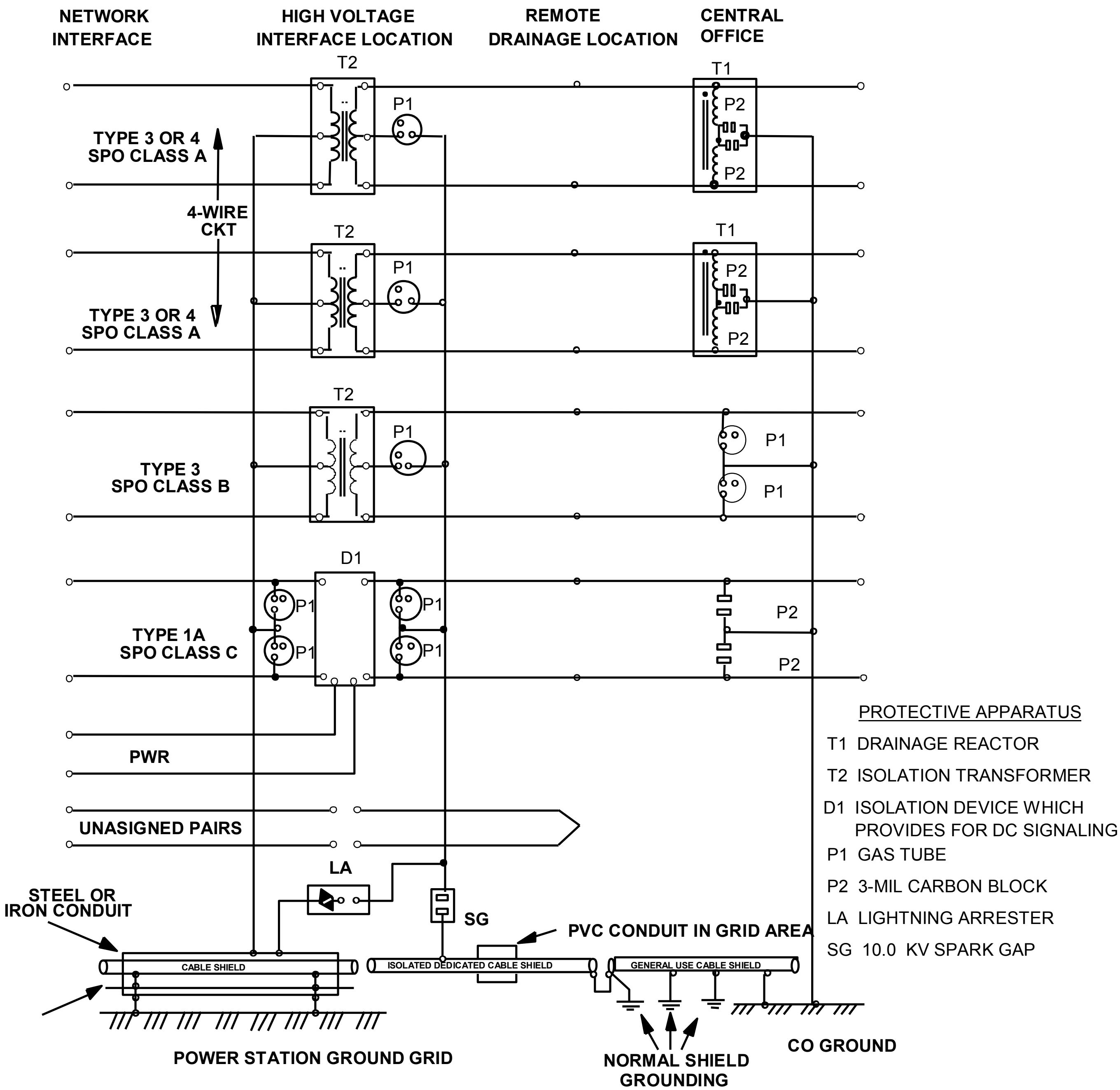


Figure 10 - Isolation System of Protection Using Discrete Components

6.22 On the CO side of the isolation components, gas tubes are connected to the transformer center taps and are added across D1. The common connection from these gas tubes is connected, in turn, to the junction of the lightning arrester and spark gap. The spark gap is then connected to the isolated dedicated cable shield. The purpose of these various components is as follows. The gas tubes maintain transmission separation between isolated pairs so that a circuit problem on one pair will not affect another pair. Center taps on unrelated pairs should not be directly connected together, although in the case of a 4-wire circuit, the two center taps may be directly connected for the application of simplex sealing current. The common connection of the gas tubes to the lightning arrester forms another part of the path by which lightning protection is provided to the isolation components. The lightning arrester, effectively shunted across the isolation components, protects them from insulation damage due to excessive surge voltages appearing from power station side to CO side. In the event of a lightning strike which causes a high surge voltage between the power station and CO sides of the HVI, the lightning arrester and the gas tubes will operate to limit the surge voltage across the isolation components to a safe level. If the surge voltage due to the lightning strike is sufficiently high, the spark gap will also operate when the lightning arrester and gas tubes operate. This will place comparable surge potentials on the isolated cable shield as well as on the isolated pairs. If the spark gap does not operate when the lightning arrester and the gas tubes operate, then a surge potential difference not exceeding 10 kV will exist between the pairs and the isolated shield. In a high dielectric cable, this potential difference is safely accommodated. Aside from its lightning related function, the spark gap also prevents interference to the isolated pairs from voltages which may somehow appear on the dedicated cable shield due to inadvertent grounding of the shield near the power station or from pin hole connections to earth.

6.23 The breakdown value of the spark gap is chosen to coordinate with the core-to-shield dielectric strength of the dedicated cable. The breakdown value should be sufficiently high so that operations are minimized, yet low enough that it operates before the core-to-shield dielectric strength of the cable is exceeded. Pairs in the dedicated cable which are unassigned and unterminated should be turned back and kept well isolated from shield and ground at the HVI location.

6.24 With an isolation system of protection at the HVI, protection requirements at the NI are dependent on the length and shielding treatment of the cable between the HVI and the NI. In those installations in HVI is located inside the control housee and is adjacent to the NI, no further protection measures are required at the NI. When the HVI and the NI are separated, such as in installations where the HVI is located near the edge of the ground grid, protection at the NI is not required when the cable is contained in a steel or iron conduit with a 4/0 supplemental copper conductor as shown in Fig. 13. With these shielding measures in place, the cable between the HVI and the NI may be considered to be unexposed. However, in installations where the HVI and the NI are separated, and the above shielding measures are not employed, then the exposure of the cable to lightning, induction, and localized GPR effects should be evaluated by the protection engineer on an individual case basis and appropriate protective measures at the NI should be taken. Such measures would include the application of drainage reactors on services with Class A SPOs and gas tubes on other services.

6.25 As shown in Fig. 10 and described in 6.13 and 6.14, there are no special protection requirements orspecial grounding measures at the Remote Drainage Location (RDL) when an isolation system of protection is used at the HVI, when induction into the general use cable is below threshold values, and a high dielectric dedicated cable is employed. The dedicated cable pairs and shield should be joined to the general use cable at the RDL using conventional methods. The two shields should be bonded to the lowest impedance ground attainable, such as a multigrounded neutral (MGN). If an MGN is not available, a ground rod should be used. Spare pairs in the dedicated cable should be turned back and isolated from working pairs and from ground at the RDL.

If special protection is necessitated at the RDL because of induction in the general use cable, the measures described in Appendix VI for neutralizing transformers should be used.

6.26 Referring again to Fig. 10, at the serving CO, drainage reactors in a double protector drainage configuration are shown on the Type 3 or 4, SPO Class A services. Drainage reactors should always be used in the CO on Class A services. It should be recognized that, for Service Types 3 or 4, direct drainage is preferable to protector drainage from the standpoint of noise generation since there are no arcing devices (carbon blocks or gas tubes) used which could inject broadband noise directly onto the circuit. However, direct drainage precludes the use of circuit test methods using dc voltages, nor can sealing current be applied to circuits using direct drainage. Telephone companies commonly apply dc sealing current to "dry" (no dc signals present) special service circuits such as Service Types 3 and 4 to prevent corrosion- caused deterioration of connectors. It is recommended, therefore, that direct drainage be employed only on those circuits most susceptible to noise from arcing protectors and only when practicable from an overall plant design and maintenance standpoint, otherwise use double protector drainage with 3-mil carbon blocks. Refer to Section 201-211-101 for information on the application of Central Office drainage reactors using a Central Office Terminating Unit (COTU). The COTU should be used only where Class A services requiring drainage reactors are involved. When the COTU is used because of the presence of services with Class A SPOs, it may also be used to terminate and protect services with Class B or C SPOs as well. Gas tubes approved for CO use should be used on SPO Class B services, and either 3-mil carbon blocks or gas tubes can be used on Class C services.

J. Engineering a Modular Component Isolation System

6.27 Fig. 11 illustrates the special protection measures taken to protect power station services in an isolation system of protection using modular components. All isolation components at the HVI are contained on printed circuit boards which plug into prewired, insulated shelves. Most boards are active, employing optical-electronic components, and require a source of local power. Other devices in the overall protection system at the HVI are gas tubes, a spark gap and a lightning arrester. Because the isolation devices (DI) have no center taps, protectors must be added to both sides of the devices as shown to provide a path by which lightning protection is provided. The gas tubes, the spark gap, and the lightning arrester perform the same function here as described in 6.21 and 6.22 for the discrete component system. Treatment of unassigned and unterminated pairs at the HVI is the same as in 6.23.

6.28 For any isolator boards which require a connection to remote ground for any reason, such as for the operation of a ground start feature, a separate pair (or pairs) back to the CO should be used for this purpose rather than using the metallic shield of the dedicated cable. Using the shield as the remote ground conductor may result in reduced pair-to-shield dielectric strength inside the shelf where the dedicated cable pairs and a connection to the shield are terminated. Furthermore, the dedicated pair is more likely to maintain continuity to remote ground than the shield. It is essential to maintain high dielectric strength between pairs and shield, not only throughout the length of the dedicated cable, but also at the end of the cable at the HVI. Fault-produced potentials on the isolated shield due to inadvertent grounds can result in arcing to isolated pairs inside the shelf if the pair-to-shield dielectric strength is degraded.

6.29 Protection requirements at the NI are dependent upon the exposure status of the cable between the HVI and the NI as described in 6.24. Protection considerations at the RDL and CO for the modular component system are the same as described in 6.25 and 6.26 for the discrete component system.

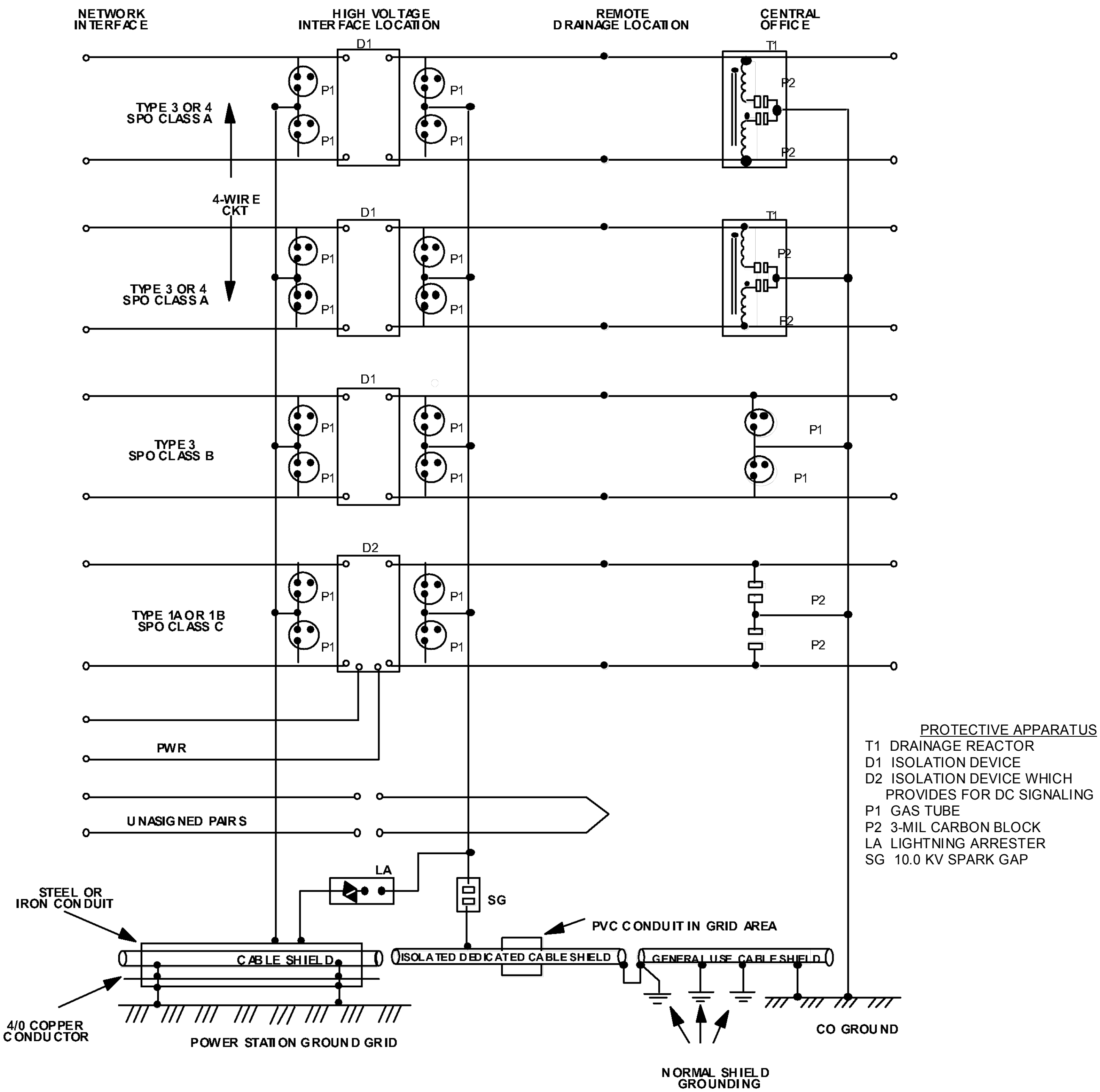


Figure 11 – Isolation System of Protection Using Modular Components

K. Determining the Total Fault-Produced Environment and Required Protection Equipment Ratings

6.30 To determine the total fault-produced environment at a power station, both the GPR at the power station and the fault induction on the serving telephone facilities must be determined. The vector sum of these two quantities yields the 'total stress to which the serving facility is exposed at the HVI. The following paragraphs provide guidelines for combining the GPR and induction in order to determine first the total fault-produced environment and then to determine the minimum ratings of special protection equipment

6.31 Power station ground grid impedances at 60 Hz are composed of both a resistive and a reactive component. For grid impedances of about 0.5 ohms or greater, the reactive component is exceedingly small and the impedance is essentially resistive. For grid impedances less than 0.5 ohms, the reactive component may be more appreciable, but the impedance is still primarily resistive. Because grid impedances are primarily resistive, the GPR voltages developed across them are approximately in phase with the fault current producing the GPR. However, the induction in the serving telephone cable produced by the same fault current is about 90 degrees out of phase with the fault current because the mutual impedance between power and telephone systems is predominately inductive. Therefore, the GPR and induction voltages produced by the same fault current should be added vectorially at 90 degrees to determine the total stress to which the serving telephone facility will be exposed at the HVI. It is recognized that this simplified approach may, in some instances, produce a small los of accuracy when compared to a more rigorous analysis. However, the simplified approach yields sufficiently accurate results and is considered appropriate in light of the fact that the fault-related GPR and induction values being combined are themselves derived through inexact means and are subject to significant error. Moreover, the data provided by the utility can be given only broadest tests for reasonableness by the telephone company protection engineer.

6.32 The following is an example of the combining of GPR and induction at a power station such as shown in Fig. 6. Assume that the data below has been provided by the utility:

Grid Impedance	0.2 ohms
X/R Ratio of Power System	3
GPR	1750 volts (rms)
Return current which causes GPR	8750 amperes (rms)
Inducing current	8750 amperes (rms)

Following an evaluation of the induction exposure between the power station and the RDL, the telephone engineer determines:

Total mutual impedance	0.30 ohms
Shield Factor	0.9
Induction (8750 amps x 0.30 ohms x 0.9)	2363 volts (rms)
Peak factor (from Fig. 4)	1.4

To determine the combined fault-produced GPR and induction, it is necessary to convert the rms values of GPR and induction to peak values and then add them vectorially at 90 degrees. The conversion to peak values is necessitated by the fact that the GPR in the example is an asymmetrical waveform with a 1.4 peak factor and it must be described in peak terms. Although the longitudinal induction has little or no asymmetry, its rms value is also converted to a peak value so that it can be added to the peak value of GPR. To convert GPR (rms) and induction (rms) values to peak:

Vpk GPR = GPR (rms) x $\sqrt{2}$ x peak factor
Vpk GPR = 1750 volts x $\sqrt{2}$ x 1.4
Vpk GPR = 3465 volts peak

Vpk induction = Induction (rms) x $\sqrt{2}$
Vpk induction = 2363 volts $\sqrt{2}$
Vpk induction = 3342 volts peak

To combine the peak values of GPR and induction to yield the total stress on the facilities at the HVI:

Vpk Total = (Vpk GPR^2 + Vpk $\text{induction}^2)^{1/2}$

Vpk Total = $(3465^2 + 3342^2)^{1/2}$

Vpk Total = 4814 volts peak

6.33 To determine the voltage ratings of protection equipment to be used in a given fault-produced environment, some additional considerations are necessary. Manufacturers commonly rate their equipment in terms of rms voltage values, not peak values. For example, in AT&T Product Evaluation Report 449, Issue 2, September 20, 1983, a voltage rating system which was agreed to by all manufacturers was used. In this system, the rated "continuous" rms voltage of a device was set by either of two one-minute dielectric withstand tests. For 60 Hz tests, the rated rms voltage was determined by the following relationship:

Rated rms voltage = [Test voltage (Vrms) – 1000] ÷ 2.

For dc dielectric tests, the rated rms voltage of a device was determined by the following relationship:

$$\text{Rated rms voltage} = \left[\frac{\text{Test voltage (Vdc)} \div \sqrt{2} - 1000}{2}\right]$$

As an example, in this rating system, for a device to have a "continuous" rms voltage rating of 9,000 Vrms, it must have been successfully tested for one minute at 19,000 Vrms (60 Hz) or 27,000 Vdc. This rating system for high voltage protection apparatus is still applicable and should be used. Telephone protection engineers should ascertain the basis of the ratings of any protection equipment which they intend to use.

6.34 To determine the rms voltage rating of protection equipment to be used in the power station example of 6.32, use the vector sum of the rms values of GPR and induction. This will yield the value of voltage on which to base the minimum rms voltage rating of protection equipment to be used:

rms rating = $[\text{GPR (rms)}^2 + \text{Induction (rms)}^2]^{1/2}$

rms rating = $(1750^2 + 2363^2)^{1/2}$

rms rating = 2940 volts rms

Assuming that the rating system described in 6.33 was used to determine the rms voltage rating of the equipment to be used in the power station example, then equipment rated at 2940 volts rms would satisfy the requirement to protect against the combined GPR and induction total of 4814 volts peak. Equipment rated at 2940 volts rms would have been successfully tested for one minute at 6880 volts rms (9730 volts peak) or 9730 volts dc.

6.35 The considerations described in 6.30 to 6.34 for the determination of equipment voltage ratings apply to isolation transformers, other types of isolation devices, and neutralizing transformers. When neutralizing transformers are used, however, another critical parameter, the transformer's core flux (volt second) requirement must be determined. This subject is covered in detail in Appendix V1.

L. Protection of Carrier Systems on Metallic Facilities

6.36 When greater than ordinary service requirements at a power station make the protection of many individual voice-frequency circuits either impractical or excessively costly, the use of analog or digital carrier systems directly-into the power station should be considered. Protection engineering and apparatus costs can be substantially reduced through the use of wideband protection equipment capable of carrier signal transmission. Because of the large numbers of circuits which could be involved in a protection-related carrier system failure, it is recommended that only isolation-type protection i.e., isolation transformers or other isolation devices, be implemented for the protection of carrier systems.

6.37 The special protection concepts previously described for protecting voiceband telephone circuits are generally applicable to carrier systems as well. Fig. 12 illustrates the special protection measures for a T1-type digital carrier system on metallic facilities serving a power station directly from a central office. In this system, all Service Types are served over the same carrier system without any distinctions between them. The objective of the special protection is to isolate the serving telephone facilities from the power station environment for reasons of plant and personnel safety and to enable uninterrupted carrier system transmission at all times. There are a number of fundamental transmission and protection considerations which are described in the following paragraphs.

6.38 At the HVI, isolation transformers and other isolation-type devices should be used on all working pairs. Wideband transformers having appropriate transmission characteristics and high voltage protection capabilities should be used to protect the digital line pairs. The wideband transformer loss at 772 kHz (for T1 carrier) will have to be considered by the span design engineer when calculating the end section maximum design loss. For the two transformers protecting the two pairs of the T1 system, the CO side center taps should be connected together to provide a simplex path for looping the dc powering current from the first repeater location out from the power station. The protection engineer should ensure that the wide band transformers are capable of handling the dc powering current through their center taps on a continuous basis. If they are not, then the power should be looped at the last repeater from the CO and soldered connections should be considered for the "dry" section between the last repeater and the HVI. Where more than one T1 system is involved, similar protection should be provided for each digital line pair, however, the simplex connections for one system should not be directly connected to the simplex connections of another system. They should be separated by gas tube protectors as shown in the abbreviated illustration of Fig. 17.

6.39 For the fault locate and order wire circuits, and for any other voiceband circuits, appropriate voiceband isolation devices should be used as shown in Fig. 12. Neutralizing transformers should not be used in this application due to the possibility of carrier system interruptions should core saturation occur during power system faults. The voltage ratings of the wideband isolation transformers and the voiceband isolation devices should be appropriate for the fault-produced environment. If one set of devices has a lower voltage rating than the other, then the overall rating of the protection system is dictated by the lower rating. The lightning arrester should be selected to coordinate with the lower rated isolation devices. The gas tubes, the lightning arrester, and the spark gap have the same function as described in 6.21 and 6.22 for voiceband systems.

6.40 The remote digital carrier terminal and the active isolation devices at the HVI should be powerered from an uninterruptible source at the power station. The reliability of the communications system will be directly dependent on the reliability of the local power source.

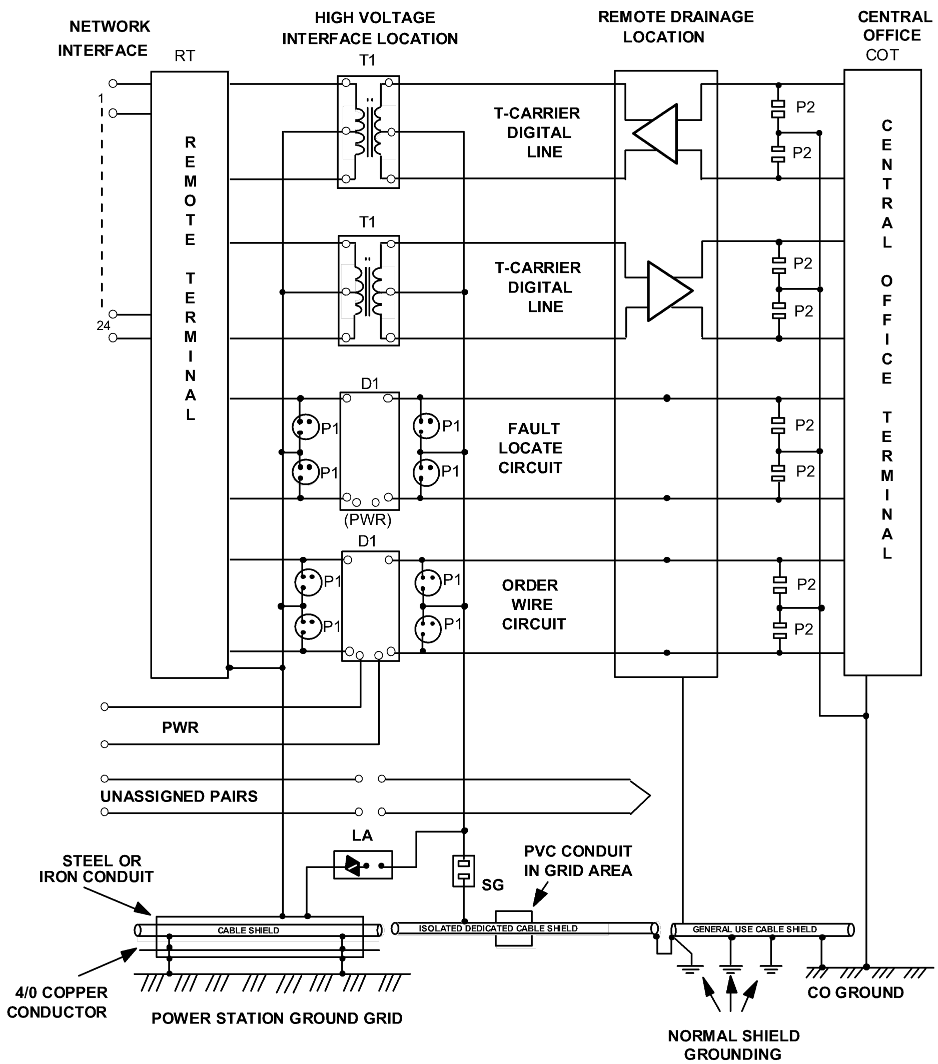
6.41 A high dielectric dedicated cable should be used between the power station and the remote drainage location. Its shield should be isolated at the power station and remain isolated until it joins the general use cable at or beyond the 300 volt peak point. Unassigned pairs in the dedicated cableshould be turned back and kept isolated from other pairs and from ground at the RDL.

6.42 The first repeater location out from the power station should be beyond the 300 volt peak point, but may be dictated by the end section maximum design loss. If the first repeater location is well within the zone of influence, there is the risk of repeater protector operations and service interruptions at times of power system faults. Such protector operations would be due to the potential difference between the repeater ground and the carrier system cable pairs which would be at some distant ground potential. If the extent of the power station zone of influence is not accurately known, then the first repeater location should be placed as far from the power station as transmission considerations will permit.

6.43 The Central Office Terminal will provide power to all line repeaters, up to and including the last repeater out from the CO. If the dc power feed is looped back on the CO side of the isolation transformers at the HVI, the power feed will serve as sealing current for the entire cable run from the CO to the HVI.

6.44 Standard carrier design and cable grounding practices are to be followed between the RDL and the CO. The carrier system is considered to be "exposed" with regard to repeater and CO main frame protection.

6.45 The protection concepts described in 6.36 through 6.44 should satisfactorily provide both high voltage protection and carrier system service continuity at time of power station GPR and fault induction which occurs between the power station and the RDL. However, if there is significant fault induction along the cable exposure between the RDL and the CO, interruptions to services may occur due to induced current affecting the regulator diodes in the repeaters or during operations of repeater protectors. Practice 873-406-101 provides guidance in reducing the effects of inductive interference on various types of carrier systems. Mitigative measures include improved shielding, the use of hardened repeaters, and the application of multipair induction type neutralizing transformers. Application of one or more of these measures should be adequate to preclude interruptions in most cases. However, in the event that the effects of fault induction in the general use plant cannot be sufficiently mitigated to preclude fault-related interruptions, and if power station services having Class A SPOs are involved, than the Utility should be advised that the telephone company is unable to meet its objectives for uninterrupted (Class A SPO) service.



PROTECTIVE APPARATUS

T1 WIDEBAND ISOLATION TRANSFORMER
D1 VOICEBAND ISOLATION DEVICE WHICH PROVIDES FOR DC SIGNALING
P1 GAS TUBE
P2 3-MIL CARBON BLOCK
LA LIGHTNING ARRESTER
SG 10.0 KV SPARK GAP

NOTE: THE FIRST REPEATER LOCATION OUT FROM THE POWER STATION SHOULD BE AT OR BEYOND THE 300 VOLT PEAK POINT

Figure 12 – Isolation System of protection Using Modular Components

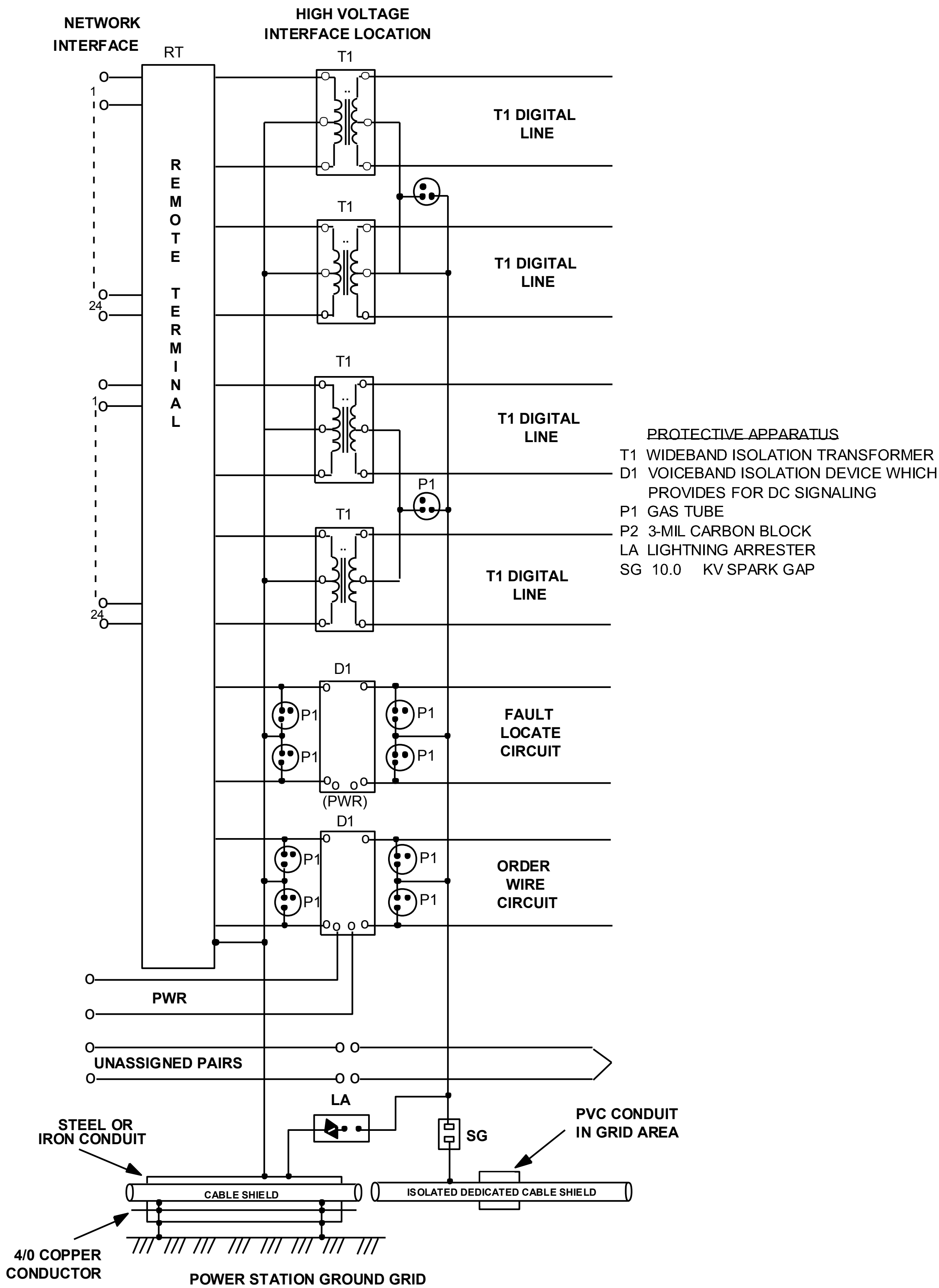


Figure 13 – Isolation System of Protect;ion for Carrier Systems – Connections at HVI for Multiple Digital Lines

M. Service to Power Stations using Optical Fibers

6.46 The use of an optical fiber transmission system to serve an electric power station should be seriously considered either when the pair/bandwidth requirements are high or when the fault-produced GPR and induction at the station are too high for conventional methods. In the power station environment, an optical fiber system may be viewed as both a broadband transmission medium and a high voltage protection strategy. Fiber optics provides high channel capacity and, depending upon the construction of the optical fiber cable, has varying degrees of immunity to electrical disturbances such as lightning and fault-produced GPR and induction. Given the right combination of circumstances, the use of carrier operating over optical fibers may be the most cost-effective engineering solution to the problem of providing and protecting power station services.

6.47 Special protection considerations pertaining to optical fiber systems serving power stations are primarily a function of the presence or absence of metallic components in the optical fiber cable. The use of all-dielectric cable provides immunity from the effects of fault-produced GPR and induction at the power station. However, the use of optical fiber cable containing metallic strength members, a metallic foil vapor barrier, or talk pairs raises several protection considerations. In the case where an optical fiber cable is employed between the power station and the edge of the zone of influence, the metallic elements of the cable must be isolated from the power station ground and from grounds within the zone of influence. This isolation is necessary to prevent the fault-produced GPR from being introduced directly onto the metallic components. Am intentional low impedance ground connection to the metallic components will allow potentially damaging currents to flow on the cable from the grounded point to remote earth at times of power faults. Since the optical fiber cable must traverse the GPR zone of influence, it must have sufficient dielectric strength in its outer jacket to preclude any break down between earth (or a grounded support strand in aerial construction) and its inner metallic components.

6.48 With regard to longitudinal induction in the zone of influence, when the metallic members are isolated from ground, induced voltages will be developed on the metallic members and will appear between the metallic members and ground. If all metallic elements in the cable are isolated, all will have the same voltage induced on them and there will be no stress between metallic members in the cable. There will be stress, however, between the metallic components and ground. Therefore, the dielectric strength of the cable's outer insulating jacket must also be sufficient to withstand the expected fault-produced longitudinal induction. Where both power station GPR and induction in the zone of influence are present, the vector sum of the two voltages will be at a maximum at the power station and will appear between the ground grid and the isolated metallic components of the optical fiber cable. The most critical need for isolation, therefore, is at the power station proper and in the nearby zone of influence.

6.49 The protection considerations described in 6.47 and 6.48 pertain to the optical fiber cable between the power station and the edge of the zone of influence (the RDL). At the power station, a remote terminal for signal conversion (electrical to optical and vice versa) would have to be powered from a reliable local source . At the RDL, the fiber cable from the power station could be terminated in another optical-electrical signal conversion terminal which, in turn, is connected to a digital carrier system operating on optical fibers or metallic facilities back to the CO. Alternatively, the fiber cable from the power station could be routed the entire distance to the CO without connection to another carrier system. Regardless of the design and makeup of the digital carrier system, it is important that equipment such as carrier terminals, optical- electrical conversion terminals, and optical repeaters not be located within the GPR zone of influence. As with other protected apparatus, there is the risk of protector operations and service interruptions due to GPR during power fault conditions. For optical fiber cable or metallic digital carrier facilities between the RDL and the CO, normal grounding practices should be applied.

7. SERVICE TO SUBSCRIBERS SUBJECT TO GROUND POTENTIAL RISE

A. Protection at Nearby Subscriber Premises

7.01 Telephone subscribers in close proximity to electric power stations may require special high voltage protection on their serving facilities if they are exposed to the effects of high power station GPR. However, unless field measurements and a detailed analysis of the available GPR is conducted for each nearby subscriber location, there is no way to know if a problem exists except through experience. The trouble report history at each subscriber location is the most practical indicator of GPR related problems. For example, if there are repeated customer complaints or service interruptions resulting from the operations of carbon block station protectors, replace the carbon blocks with gas tube station protectors. Minor GPR-related problems may be reduced or eliminated with this simple step. If the problems persist, or if there are service outages due to permanent grounding of the station protectors, it is likely that there is a high percentage of the power station GPR present at the subscriber's premises and that a more serious problem exists. Of course, grounded station protectors coupled with evidence of damage (overheating, arcing, fusing, etc.) to the subscriber's serving facilities is the strongest indication of the need for special protection measures on that subscriber's facilities.

7.02 The experience-related approach outlined in 7.01 necessarily puts the telephone company protection engineer in the position of waiting for trouble to occur and then correcting it. At the present time, however, there are no known methods of accurately predicting (without extensive field measurements) the percentage of power station GPR present at a nearby subscriber location. Field measurements at each nearby location are, from both a practical and an economic standpoint, unsupportable. There is a need for field investigation and research in this area; however, until more is known, the preceding approach is both practical and reasonable.

7.03 It should be noted that, even when the GPR related problems described in 7.01 occur, the telephone subscriber and the station equipment are not endangered as long as the station protector is properly grounded in accordance with principles in BR 876-300-100. When the protector is properly grounded, voltages at the subscriber premises are effectively equalized and the protector ground, the power service ground, and the interior metallic water pipes rise and fall in potential together.

7.04 When special protection equipment is required for a nearby subscriber, it takes the place of the conventional station protector. The measures to be taken and the choice of protective apparatus are dependent upon the subscriber's service requirements and the severity of the problem being treated. The protection engineer should determine the approach to be taken in each individual case.

B. Protection of General Use Cable in the Zone of Influence

7.05 There may be occasions when a protection strategy is needed to reduce or eliminate damage to cables within the GPR zone of influence caused by pair-to-pair or pair-to- shield stresses during power faults. Because it would be extremely difficult to predict accurately the nature and severity of such problems in advance, the analytical and mitigative procedures which follow should be used only when there is a clear indication of fault-related troubles.

7.06 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 power station services are contained in a general use cable that is routed through the GPR zone as shown in Fig. 14 and a voltage profile is developed along the shield of the general use cable as indicated in Fig. 15. This profile, drawn with the aid of Fig. 5, assumes a homogeneous earth and no metallic conductors to distort the voltage profile. Similar profiles along the route of an existing cable can be derived from actual field measurement data. Power station pairs are shown at or near central office potential due to the special protection applied to these pairs at the power station. Pair C is also shown at or near potential because Subscriber C is outside the GPR zone and 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. Significant pair-to-pair and pair-to-shield potential differences can be observed at various points along the cable. These could result in insulation breakdown within the cable and possible disruption of services to the power station and to Subscribers A, B, and C.

7.07 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, full count protection with gas tubes should be applied to pairs in the general use cable not serving the power station at the cable junction near the remote drainage location. When pair-to-pair voltage differences exceed 300 volts peak, regardless of the type of general use cable, full count gas tube protection should be applied to all pairs not serving the power station at the cable junction. Placement of these protectors will reduce both pair-to-pair and pair-to-shield stress in the common use cable between the central office and the remote drainage location. It is important that this protection not be applied to pairs serving the power station. Fig. 16 shows the voltage profile with full-count protection on the pairs not serving the power station at the cable junction. As described in 7.06, 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. It is seen from Fig. 16 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.

7.08 To reduce the potential differences in the cable passing through the GPR zone, strategically placed full count protection should be used at additional location(s) along the cable route. Two approaches regarding this additional protection are as follows:

(1) When pair-to-pair or pair-to-shield voltage differences exceed 1000 volts peak, apply strategically located full count gas tube protection.

(2) When experience indicates that cable damage is resulting from excessive pair-to-pair or pair-to-shield voltage differences, apply strategically located full count gas tube protection.

7.09 The selection of a location for the strategically placed protection can be made using the voltage profiles. Fig. 17 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. 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 gas tube station protectors were strategically placed at the Subscriber A location to reduce the stresses shown in Fig. 16. In placing this additional protection at Subscriber A, stresses have been sufficiently reduced so that further overvoltage protection along the cable route is unnecessary.

7.10 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. 17) to the additional subscriber locations and the unassigned pair termination locations. Pair-to-pair and pair-to-shield voltage differences could then be observed and excessive differences reduced by the use of a second strategically placed full-count protection location at or near Subscriber C.

C. Current Carrying Capacity of Telephone Plant

7.11 The application of full-count protection as described in 7.07 through 7.10 creates paths for longitudinal currents on cable pairs between protection locations whenever a significant GPR occurs. Longitudinal currents flow on cable pairs when protectors, grounded at different locations within the GPR zone, operate. The current waveshape is that of the station GPR, and the magnitude is a function of the voltage and total impedance between the ground locations. Usually, a power fault to ground will be cleared within 10 to 12 cycles of the 60 Hz wave or about 200 milliseconds. The longitudinal current surge in cable pairs is therefore of significantly short duration that the process may be assumed adiabatic (no heat gain or loss) and the relationship which states I^2t is a constant applies.

7.12 The I^2t product in a conductor between two ground points at different potentials due to GPR can be approximated given the power system X/R ratio and the following equation:

$$I^2t = (Vpk / R)^2 \times [(T+\tau)/2]$$

where

Vpk = peak value of the steady-state voltage between the two ground points

R = total resistance between ground points including conductor and earth resistance

T = time to clear fault in seconds

τ = $(X/R) \times 1/\omega$

and

ω = 377 at 60 Hz

7.13 To evaluate the possibility of cable damage due to excessive longitudinal currents between protector locations, computations according to 7.12 should be made to determine the value of I^2t on the conductors between protector locations which are at different potentials during sparkover. The I^2t ratings for telephone distribution wire and for 24- and 26-gauge cable may be found from the fusing and protective characteristics contained in Practice 876-101-100. The I^2t values obtained from these characteristics are valid for fusing times of several hundred milliseconds or less. It is estimated, however, that conductor insulation damage occurs at I^2t values which are significantly smaller than the fusing values. Therefore, where computations indicate that one-fourth of the conductor I^2t rating will be exceeded during conditions of GPR, fuse links or fusible stub cables should be installed at the protector locations to prevent cable damage. A 24-gauge fuse link or stub cable should be' used to protect 19- and 22- gauge cable, and a 26-gauge fuse link or stub cable should be used to protect 24- and 26-gauge cable. In the case of a new cable being routed through the GPR zone, an alternative to providing fusing protection would be to employ cable conductors having adequate I^2t capability in that portion of the route where the stresses occur.

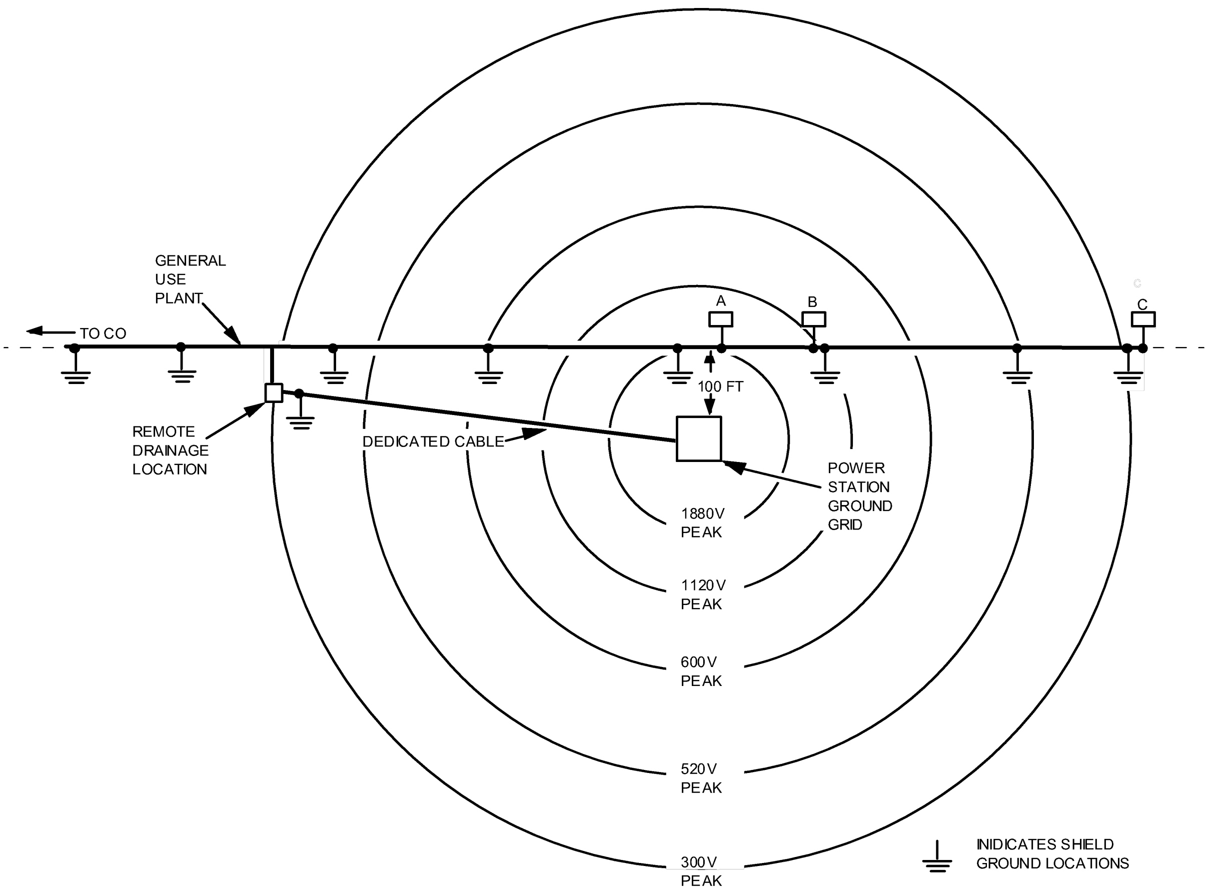


Figure 14 – GPR Voltage Gradient

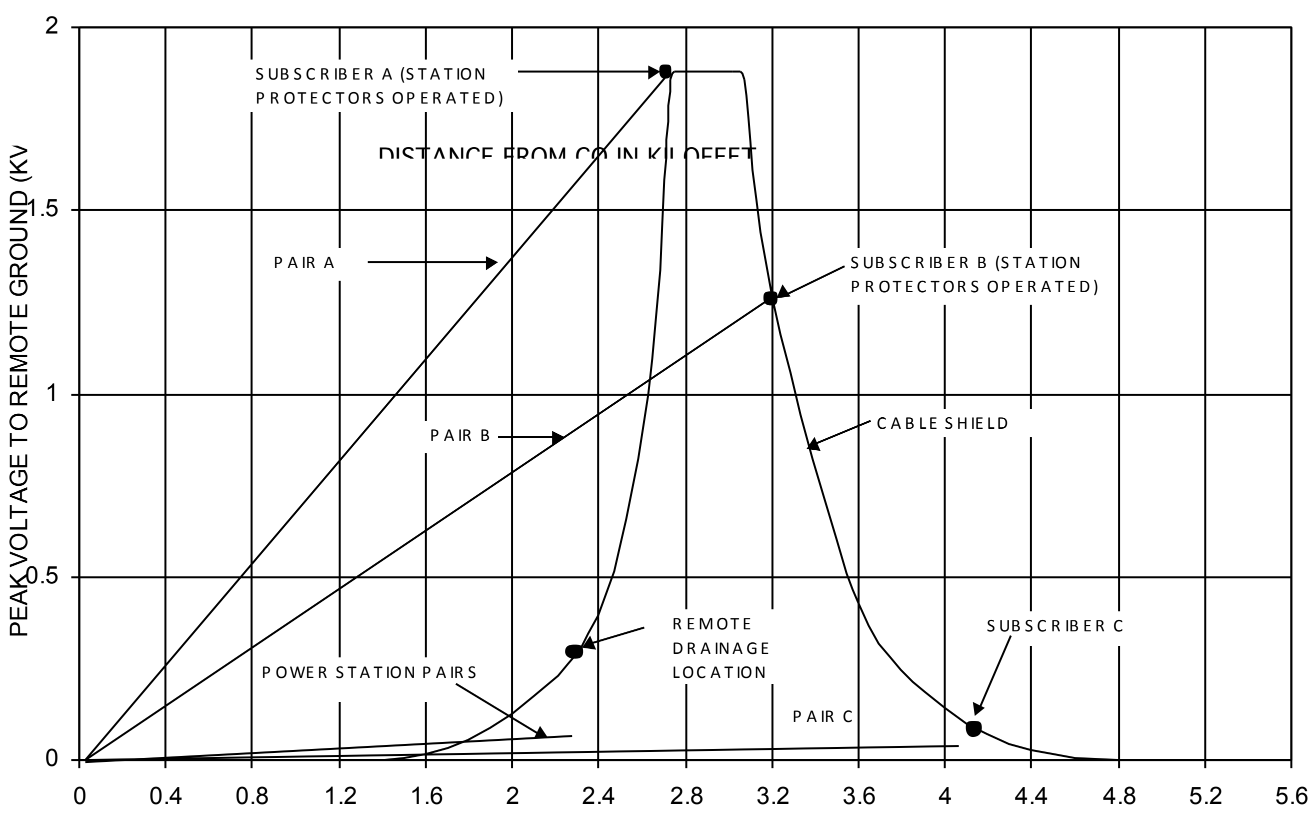


Figure 15 – Voltage Gradient Along General Use Cable

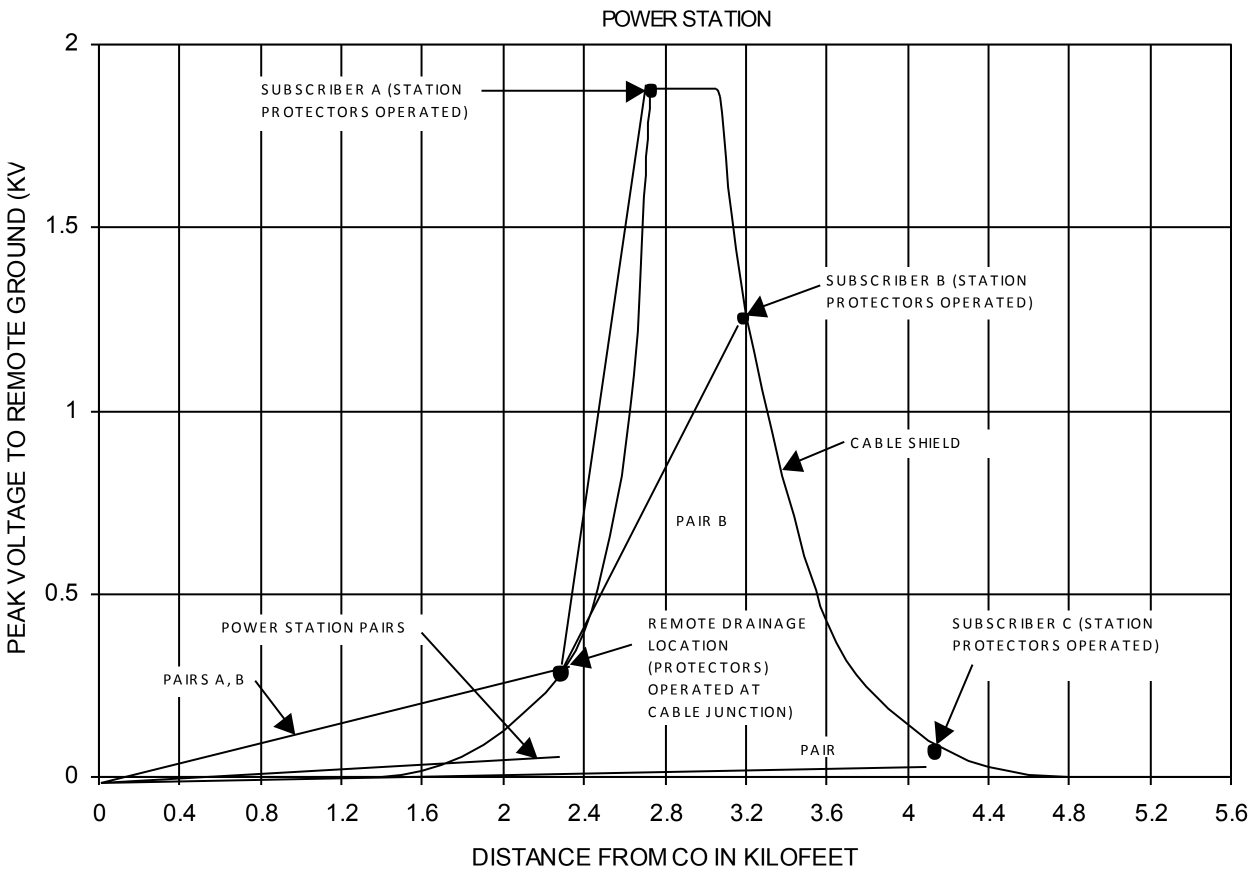


Figure 16 – Voltage Gradient Along General Use Cable With Full Count Protection Applied At the Remote Drainage Location

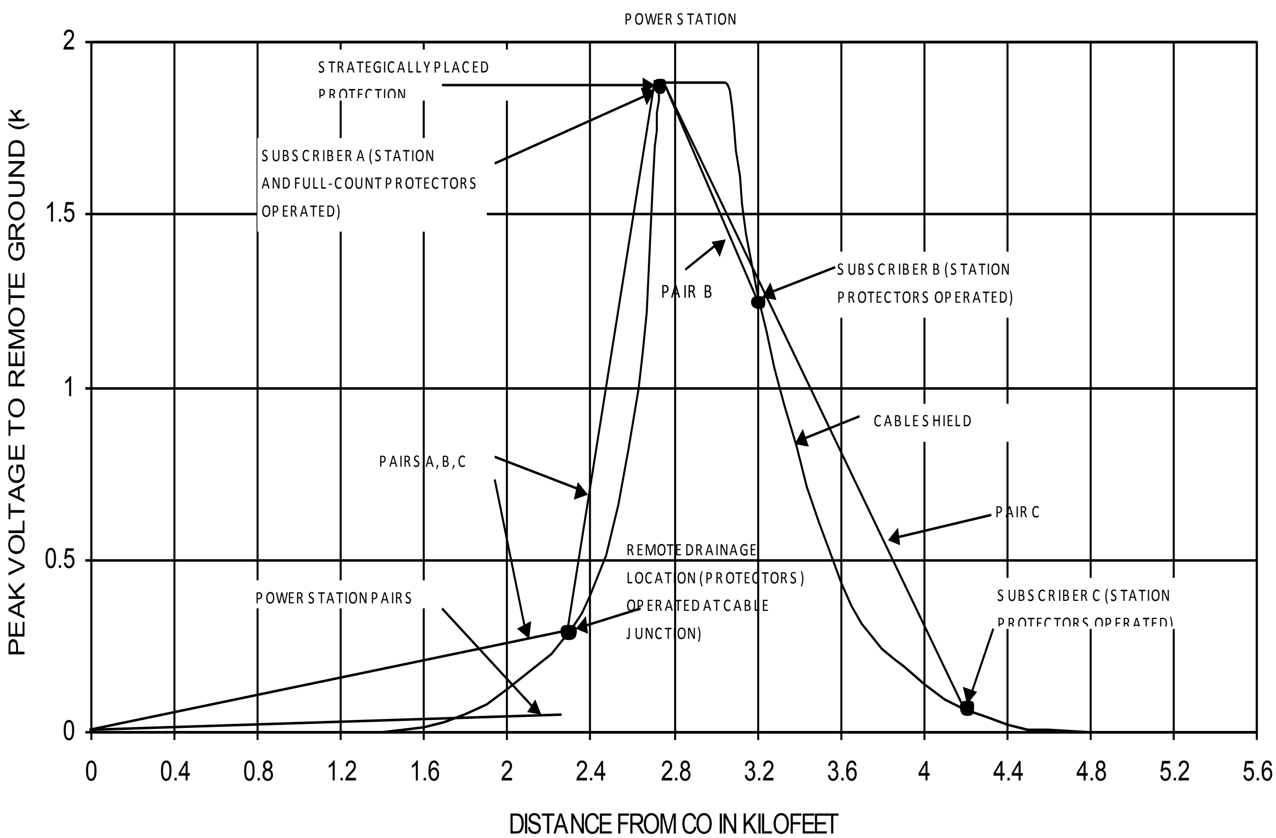


Figure 17 – Voltage Gradient Along General Use Cable With Full Count Protection Applied At the Remote Drainage Location and Strategically Along Cable Route

8. SAFETY

A. General

8.01 Hazards of both a mechanical and an electrical nature can exist at power stations. It is important, therefore, that telephone company personnel working on power station premises comply with all personnel safety requirements that have been established there by the utility (e.g., wearing of hard hats). It should also be recognized that in the power station environment, hazardous voltages with respect to local ground may appear suddenly and without warning on the serving telephone facilities (e.g., cable shields and pairs, metallic members of fiber optic cables) and on associated protective apparatus at times of power system faults. The fundamental safety measure, therefore, is for personnel to avoid simultaneous contact with power station ground and with any metallic conductors which are grounded at or extended to remote earth. The following paragraphs provide guidance for maximizing personnel safety in various aspects of power station communications and protection.

B. Safety During Installation

8.02 In placing the dedicated cable, keep the shield and pairs well isolated (at least 6 inches away) from grounds at both ends until the cable is fully in place and the pairs are ready to be terminated. In the event of a power fault, this precaution will prevent a potential to ground due to GPR from appearing at a cable end where a craftsperson may be working. With the RDL end still isolated, terminate the pairs and shield at the HVI end onto a terminal strip and an insulated standoff which are well isolated from power station ground. Then, at the RDL, connect the dedicated cable to the general use cable.

8.03 In the wiring of the protective apparatus at the HVI, all wiring of the equipment and associated devices should be completed before connections to the dedicated cable are made. Wiring and devices on the station side of the protection equipment should be adequately separated (4 inches minimum) from wiring and devices on the CO side. The final connections to be made at the HVI are those which join the protective apparatus to the dedicated cable pairs and shield. These should be made while using insulating gloves and blankets.

8.04 Cable and equipment installation work should not be performed when electrical storms are in the vicinity. See Practice 010-110-009 for additional information on safe work practices.

C. Safety During Disconnection

8.05 Safety precautions similar to those described above should also be taken when disconnectingor rearranging power station circuits or when removing special protection equipment. If changes are to be made at both the HVI and the RDL, the work at the HVI should be completed first. As described in 8.01, personnel working at the power station should avoid simultaneous contact with power station ground and with metallic conductors that extend to distant earth. If it is necessary to remove or rearrange the protection equipment, the wiring connections on the CO side of the equipment should be disconnected first while using insulating gloves and blankets. With the metallic connections to distant earth thus removed, it is then safe to remove and rearrange the protection equipment. Whenever it is necessary to disconnect or rearrange wiring on the CO side of the protection equipment, such work should be done while using insulating gloves and blankets. Dedicated cable pairs taken out of service at the HVI should either remain terminated on the insulated terminal strip or they should be tied back, taped, and kept well insulated from the cable shield and from power station ground.

8.06 At the RDL, if it is necessary to rearrange dedicated cable pairs or to disconnect dedicated cable pairs from general use cable pairs, it should first be determined that the dedicated cable pair appearances at the HVI are well isolated from power station ground. Such pairs should either be terminated on the insulated terminal strip at the HVI or be tied back and isolated from power station ground as described in 8.05. With the dedicated cable pairs thus isolated at the HVI, it is safe to make the necessary changes or disconnections at the RDL. Dedicated cable pairs taken out of service at the RDL should either be isolated as shown for unassigned pairs in Figures 10, 11, and 12, where no RDL protection is used

8.07 Cable and equipment disconnections and rearrangements should not be done when electrical storms are in the vicinity. See Practice 010-110-009 for more details.

D. Safety in Protection System Design

8.07 All conducting surfaces and parts exposed to touch at the power station must be maintained at ground grid potential. Exposed metallic transformer cases and equipment cabinets must be well grounded to the grid.

8.08 The physical design should protect against inadvertent simultaneous contact between points which are at local and remote potentials. Substantial insulating barriers or insulated closures should be used over all open terminals and exposed non-grounded metallic parts of protection apparatus and its associated hardware or wiring.

9. SPECIAL ADMINISTRATIVE CONSIDERATIONS AND PERIODIC INSPECTIONS

A. General

9.01 Due to the uniqueness of the power station environment and the critical nature of some power station services, there are a number of special considerations regarding the administering and handling of power station services which should be noted:

(a) Utility requests for service to electric power stations should be made in writing using a form such as that shown in Appendix I and they should be made only to the BOC Marketing Account Representative. Requests for services should not be made to the BOC local business office. BOC internal processes should ensure coordination between the Marketing Account Representative and the Protection Engineer so that all power station service requests can be reviewed with regard to the need for special high voltage protection. Service requests to the business office may result in the installation of circuits without the required special protection, or in the case where special protection is already in place, a circuit installed without protection may bypass and thereby negate existing protection measures.

(b) Power station services having Class A or Class B SPOs should be given Special Safeguarding Measures and Special Service Protection in accordance with local BOC practice and the guidelines contained in Practices 660-200-300 and 660-200-301. See 2.11 and 2.12 for other special considerations pertaining to SPO Class A services.

(c) It is suggested that plant records show that the protection engineer is to be notified when any maintenance work is required on the high dielectric dedicated cable. Similarly, the protection engineer should be advised when protective apparatus at the power station, at the remote drainage location, or at the CO is believed to be causing a service problem.

B. Periodic Inspections

9.02 Because the special protection concepts and methods for facilities serving power stations are so different from those used on general use facilities, and because the protection installations are often accessible to both power and telephone personnel, periodic inspections of the protection installations should be performed to ensure that the special protection measures are still intact and have not somehow been diminished or negated. It is possible, for example, for personnel of either company to negate the isolation of the dedicated cable shield by deliberately connecting the shield to ground at the power station without realizing the possible consequences. Similarly, over a period of time, connections can corrode or become loose and devices can begin to deteriorate physically or mechanically. In the operating areas of some telephone companies, power utilities own significant amounts of the special protection apparatus used to protect telephone facilities, and thus utility personnel have virtually unlimited access to the protection installation. In view of the many possibilities for changes in the protection system, inspections should be performed at intervals mutually agreed to by power and telephone representatives. Annual inspections are suggested for the most hazardous locations from a GPR/induction standpoint and for those locations considered most critical from an operational standpoint by the utility. Somewhat longer intervals may be considered for more nominal circumstances. Because protection systems are quiescent, defects will not become apparent until a protection system failure occurs under fault conditions. Periodic inspections are intended to prevent these problems before they can occur.

10. REFERENCES

10.01 The following reference sources are identified in the text by the corresponding number shown enclosed in brackets [ ].

[1] *Electric Utility Engineering Reference Book-Distribution Systems,* Westinghouse Electric Corp., East Pittsburgh, PA, 1965, Chap 1, pp. 1-18.

[2] *The Art of Protective Relaying,* GET 7206A, General Electric Co., Philadelphia, PA, 1964.

[3] *Guide for Protective Relay Applications of Audio Tones Over Telephone Channels,* IEEE Std. 305-1976, ANSI C37.93-1976, IEEE, New York, NY, 1976.

[4] *IEEE Guide for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations,* IEEE Std. 487-1980, IEEE, New York, NY, 1980.

[5] *IEEE Guide for Determining the Maximum Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault,* IEEE Std. 367-1979, IEEE, New York, NY, 1979.

[6] *Earth Potential Distributions Associated With Power Grounding Structures, D. W.* Bodle, AIEE Conference Paper CP 62-205, AIEE, New York, NY, 1962.

[7] *IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System,* IEEE Std. 81-1983, IEEE, New York, NY, 1983.

[8] *A Practical Ground Potential Rise Prediction Technique for Power Stations,* F. P. Zupa and J. F. Laidig, IEEE Transactions on Power Apparatus and Systems, Volume PAS-99, No. 1, January/February 1980.

10.02 The following Practices contain information related to the content of this practice:

PRACTICE	TITLE
201-211-101	Central Office Terminating Unit for Integrated Protection System Description, Installation, and Maintenance
310-540-100	Protective Relaying Channel Description
660-200-300	Special Services-Special Safeguarding Measures-Description
660-200-301	Special Services-Special Service Protection-Description
851-201-101	Protective Relaying Channel Transmission Specifications and Considerations

10.03 The following Technical Reference contains information related to the content of this practice:

TECHNICAL REFERENCE	TITLE
PUB 41011	Transmission Specifications for Voice Grade Private Line Audio Tone Protective

POWER STATION DATA FILE

1. GENERAL

1.01 This Appendix lists the items of information that should be contained in the data file for each power station that has communication service. Much of the information needed for the data file can be provided only by the power utility.

1.02 When this Appendix is reissued, the reason for reissue will be included in this paragraph.

2. POWER STATION DATA FILE

Part 1: *Power Utility Contacts*

A. Power Utility

B. Communication Engineer

(1) Business address

(2) Business telephone

C. Systems Planning engineer

(1) Business address

(2) Business telephone

Part II: *Power Station Characteristics*

A. Name of Station

B. Location (address) of station

C. Type of station (generation, switching, distribution, industrial, etc.)

D. Bus voltages

E. Ground grid type

F. Ground grid area

G. Is ground grid connected to:

(1) MGN circuits

(2) Metallic water lines

(3) Metallic sewer lines

(4) Metallic gas lines

(5) Metallic pipe-type power cables

(6) Sky-wires

(7) Rail lines

H. Earth resistivity (if known)

I. Grounded neutral transformers present

J. Grounded auto-transformers present

K. Station layout showing

(1) Transformer locations

(2) Power line routing at station and in vicinity

(3) Serving telephone cable (or wire) routing at station and in vicinity

(4) Control house location

(5) Telephone facility protection (High Voltage Interface) location

Part III: *Power Station GPR/ Induction Environment*

A. GPR (rms) for worst case single phase fault both for existing conditions and anticipated future changes

B. X/R ratio of power system at worst case fault location

C. Fault current data - both total fault current and that portion which produces GPR

D. Ground grid impedance to remote earth (and how it was determined - by measurement or calculation)

E. GPR profile data (along route of serving telephone cable)

F. Fault current diagrams showing sources and magnitudes of all fault currents

Computed fault-produced induction based on items II K(2), II K(3), and III F above

H. Any past history of fault effects such as known GPRs, plant damage, service interruptions, etc.

Part IV: Telecommunications Services

A. For Each Service

(1) Service Type

(2) Service Performance Objective (SPO) Class

(3) Date installed

(4) Circuit number

(5) 2 wire or 4 wire

(6) Function (telemetry, voice, data, pilot wire, etc.)

(7) Forecast of future requirements

(8) Amy fault related trouble history

Part V: Special High Voltage Protection Data

A. For Each Service

(1) Protection devices used at High Voltage Interface (HVI), Remote Drainage Location (RDL), Central Office (CO)

(2) Make, model, rating, date installed

(3) Any trouble history

B. For Each Protection Location (HVI, RDL, CO)

(1) Layout diagram of devices, wiring, cabling, pair assignments

(2) Special construction (e.g., conduit in place, mounting arrangements, grounding or isolation arrangements, etc.)

C. Dedicated Cable

(1) Type sheath, conductor gauge, number of pairs

(2) Aerial, buried, underground

(3) When placed

(4) Amy splices

(5) High potential tested

(6) Amy trouble history

A. If Neutralizing Transformer(s) in Place

(1) Single-pair

(2) Multi-pair

(3) Make-up of external primary circuit (number of cable pairs)

(4) Where primary is remotely grounded and how ground is achieved (CO ground, RD ground, rod array, etc.)

E. If Active Protection Devices are in Place

(1) Powering arrangements at station

(2) Battery backup

(3) Remaining capacity of power supplies

(4) Trouble history, if any.

GUIDELINES FOR DETERMINING REASONABLENESS OF GROUND GRID IMPEDANCE DATA

1. GENERAL

1.01 This Appendix provides guidance for judging the reasonableness of ground grid impedance data quoted by the Power Utility.

1.02 When this Appendix is reissued, the reason for reissue will be included in this paragraph.

1.03 All values of ground grid impedance (Z_G) quoted by the Power Utility should be examined to determine whether or not they are "reasonable" for use in the calculation of GPR. First ask the utility representative if the value of Z_G is a computed or a measured value.

2. Computed Value

2.01 Computed (unmeasured) values of Z_G may not be appropriate for the determination of GPR. Computed values may be subject to significant error since they are often based on estimates, on assumptions which may be incorrect and on factors which are not fully known. Calculated values are approximations unless a method of calculation is used which accounts for every pertinent factor affecting the end result. Further, the input data to the mathematical process must be the most accurate attainable.

2.02 The 0.5 ohm value is always suspect. Many times, prior to construction, a new grid is designed to have a Z_G not to exceed a specified design objective (often 0.5 ohms). After construction , Z_G may never actually be measured but the design objective of 0.5 ohms is carried in the Utility records as the value of Z_G. To use this value of Z_G in the calculation of GPR can be *highly* erroneous. If the GPR is unreasonably high, request the Utility to properly measure Z_G explaining the probable cost saving (for a special protection system) that may accrue from an accurate measurement of Z_G.

3. Measured Value

3.01 If the quoted Z_G is a measured value, determine if it has been measured with the station grid in its operational state (all normal externally grounded metallic conductors connected). Such conductors include grounded sky wires, muligrounded neutrals, metallic water, gas, and sewer lines, rail lines, etc. Since these connections exist when the power station is operational and since they increase the effective area of the grid and reduce its impedance to remote earth, they should be in place when the Z_G measurement is made. Utilities some times measure Z_G immediately after a new grid is constructed but before any connections to external grounds are made. This measurement would be useful to check the grid against its design objective, but would not be appropriate for GPR calculations.

3.02 Determine if Z_G has been measured using the fall-of-potential method. This is the appropriate method (see IEEE Std. 81) for measuring power station ground grids. Considerations are:

(a) probe wires long enough to reach remote earth,

(b) no coupling between current and voltage probes,

(c) use of ac signal (or periodically reversed dc as in Megger[1] or Vibroground[2] test sets). See (d) below for information on Meggers and Vibrogrounds,

(d) use of appropriate instrumentation capable of measuring the 60 Hz impedance - Meggers and Vibrogrounds measure resistance only (not the reactive component of impedance) and are not generally sensitive enough to accurately measure resistance values below one ohm. These instruments would be suitable for measuring resistances above one ohm.

4. Guidelines on Actual Z_G Values

4.01 Nearly all properly measured power stations will have values of Z_G less than 0.5 ohms.

4.02 Stations that either serve multigrounded neutral (MGN) distribution circuits or are connected to a metallic pipe system often have Z_G values less than 0.2 ohms.

4.03 Stations having both MGN and metallic water pipes or many externally grounded metallic conductors often have Z_G values less than 0.1 ohms.

4.03 Stations located in high resistivity soil (1000 meter-ohms or higher) and with few exter nally grounded metallic conductors can have values of Z_G exceeding 1.0 ohm. Small distribution substations are particularly likely to have higher values of Z_G., sometimes well in excess of 1.0 ohm.

[1] Megger is a trade name of the James G. Biddle Co
[2] Vibroground is a trade name of Associated Research, Inc.

GUIDELINES FOR DETERMINING REASONABLENESS OF FAULT CURRENT DATA

1. GENERAL

1.01 This Appendix provides guidance for judging the reasonableness of fault current data quoted by the Power Utility.

1.02 When this Appendix is reissued, the reason for reissue will be included in this paragraph.

1.03 All values of fault current I_F (see Note) quoted by the Power Utility should be examined to determine whether or not they are "reasonable" for use in the calculation of GPR. Accurate fault current values are also required for the calculation of fault-produced induction into the serving telephone cable when that cable is exposed to power lines carrying all of, or part of, the total fault current. The following discussion addresses various considerations regarding fault current values.

NOTE: Throughout this discussion, the I_F referred to is the fault current from a single-phase to-ground fault which produces the maximum worst-case GPR at the power station of interest. Two-phase-to-ground faults, which could produce even higher GPRs, are considered to be uncommon occurrences and are not usually evaluated.

2. I_F to be Used In Determining GPR

2.01 In the determination of GPR at a power station, the I which must be used in the GPR calculation is the current which actually flows through the station ground grid impedance to remoteearth (Z_G). Only this fault current, flowing through Z_G, produces the GPR. It is essential that the Power Utility engineer understand this fundamental point when providing fault current data. Many utility engineers are not well versed in determining the appropriate fault current for use in GPR calculations because it usually isn't a part of their job. An excellent way for the utility engineer to evaluate and understand the fault current which causes GPR is through the use of a fault current diagram. Such a diagram, which can be constructed manually or by computer, should indicate the total current flowing into a fault, the source(s) of this current from the power system network, the individual current contributions from each source, and the amount of current flowing through the Z_G of interest.

2.02 In order to arrive at a realistic GPR, factors which limit or reduce fault currents should always be taken into account by the utility engineer. These factors include generator, transformer, and line impedances, the station grid impedance to remote earth (Z_G), and the fault impedance to ground at the fault location if it can be evaluated (it is often assumed to be zero). If auto-transformers are in place at the power station, the utility engineer should take care to analyze the direction of flow of fault current through the windings. Past experience has shown that currents of opposing phases in an autotransformer can result in some current cancellation which, in turn, results in reduced current for the production of GPR.

2.03 One common mistake in determining the fault current to be used in calculating GPR occurs in the case of a generating station. If a fault to the station ground grid occurs at a generating station, the fault current supplied by the local generator does not flow into the earth (it simply circulates on the metallic grid) and therefore does not produce GPR. However, if the generator is connected in a power system network, currents flowing to the fault from other sources in the network will flow through the generating station grid impedance to return to their sources, thereby producing a GPR at the generating station.

2.04 GPR at the generating station can also be produced by a distant fault on the transmission line being supplied by the local generator. In this case, generator current will flow over the transmission line to the fault location, into the earth at that location, and then return to the generator by way of the generation station Z_G This return current flowing through the generating station Z_G produces GPR at the generating station.

2.05 The above discussion is covered by IEEE Standard 367 which describes four basic fault circuit configurations that should be evaluated when determining the maximum GPR at a power station. The standard contains simplified illustrations showing local and remote power stations, each with a fault current "ground source", and in which either the local or remote ground source "predominates" (supplies the greatest fault current). The fault current paths and the resulting GPRs explained by these basic illustrations should be studied and understood. A ground source at a power station is a component which can supply current to a fault and to which current returns by way of the power station $Z_{G.}$ Ground sources include a wye-connected transformer with its neutral grounded, a grounded autotransformer, or a grounded generator. Stations without ground sources (switchyards with no transformers, or transformers with only delta connections) are not affected by GPR for faults which occur off the ground grid, but would experience GPR if a fault directly to the station grid occurred.

2.06 The general guidelines outlined above are intended to acquaint the telephone company protection engineer with some important fundamental considerations involved in determining the appropriate fault currents to be used in calculating GPR. The protection engineer should be familiar with such considerations so that he or she, in turn, can make the utility engineer more aware of the relevant factors which affect fault current values so that realistic and accurate determinations of GPR can be made.

GUIDELINES FOR DETERMINING REASONABLENESS OF GROUND POTENTIAL RISE DATA

1. GENERAL

1.01 This Appendix provides guidance for judging the reasonableness of ground potential rise (GPR) data quoted by the Power Utility.

1.02 When this Appendix is reissued, the reason for reissue will be included in this paragraph.

1.03 All values of GPR (see Note) quoted by the Power Utility should be examined to determine whether or not they are "reasonable" and can be used with confidence in the design of a special high voltage protection system. Historically, GPR values have often been overstated due to errors in grid impedance values or in appropriate fault current values, or both. To the greatest extent possible, GPR values should be examined to determine that they are neither greatly overstated, nor greatly understated, but are reasonably accurate in order to make any resulting protection system cost-effective, reliable, and safe.

NOTE: Throughout this discussion, the GPR referred to is the maximum worst-case GPR at the power station of interest which would be produced by a single-phase-to-ground fault which affects that station. Two-phase-to-ground faults, which could produce even higher GPRs, are considered to be uncommon occurrences and are not usually evaluated.

2. EVALUATING GPR DATA

2.01 GPR data values can best be evaluated by examining the quoted values of ground grid impedance (Z_G) and fault current (I_F) for reasonableness using the guidelines (Appendices II and III) which have been drawn up for those quantities. Once those two quantities have been examined and accepted, and in the absence of any other information, there is little else one can do to determine the reasonableness of the calculated GPR which results.

2.02 Occasionally, a situation will arise in which it is a required to determine the GPR of an older power station with a long, trouble-free history of telephone service. Following careful measurements, the newly calculated GPR is found to be much greater than the service history would indicate and greater than the original protection system would be effective against. Should this situation occur, first ask the Power Utility if a worst-case fault causing GPR at that station has ever occurred (perhaps the old protection system has never been fully stressed). Also, determine if any factor (such as increased available fault current) has been changed to cause the newly calculated GPR to be so high. If it is found that a worst-case fault has occurred in the past, and if other factors affecting GPR have not changed, then it seems likely that the newly calculated GPR figure is incorrect. Reexamine the Z_G and I_F values to determine if some error was made.

3. GUIDELINES ON QUOTED GPR VALUES

3.01 Quoted GPR values in excess of 10kV rms are *highly* suspect. Such values may indeed exist in unusual cases, but they are uncommon and should be evaluated thoroughly, not simply accepted at face value. Assuming a peak factor of 1.8, the maximum first peak value of GPR would exceed 25 kV peak. This is considered to be an unusually high value for protection design purposes.

3.02 It is believed that the great majority of properly determined GPRs will be less than 5 kV rms, with most of the remainder between 5 and 10 kV rms.

3.03 Stations located in urban areas or in well developed suburban areas will often have GPRs less than 1000 V rms, and sometimes less than 300 V peak.

GUIDELINES FOR DETERMINING REASONABLENESS OF X/R RATIO DATA

1. GENERAL

1.01 This Appendix provides guidance for judging the reasonableness of X/R Ratio data quoted by the Power Utility.

1.02 When this Appendix is reissued, the reason for reissue will be included in this paragraph.

1.02 All values of X/R quoted by the Power Utility should be examined to determine whether or not they are "reasonable" for use in calculating maximum worst-case peak GPR and for establishing the core flux (volt-second) requirement for a neutralizing transformer in the event that a neutralizing transformer must be used in a special (1) high voltage protection system.

1.04 The X/R ratio of interest is the ratio of the 60 Hz inductive reactance (X L) to the resis tance (R) of the power system as observed from the fault location (see Note). The X/R ratio is influenced by such factors as the type, design, and configuration of the power line and the distance from the fault location to highly inductive components such as generators and transformers. Higher voltage transmission lines, for example, due to the size and configuration of conductors, have greater inductance than lower voltage power lines and, therefore, have a larger X/R ratio. Typically, the range of X/R ratios for high voltage to extra high voltage transmission lines might be from about 10 to 25, while the X/R ratio for lower voltage distribution lines might be only 2 or 3. Intermediate voltage lines might have X/R values ranging from about 3 to 10. For faults taking place near generating stations and transformer locations, the added inductance from these components will increase the X/R ratio above that of the power line itself.

NOTE: The fault location referred to here is the location at which a single-phase-to-ground fault would occur to produce the maximum worst-case GPR at the power station of interest. Two-phase-to-ground faults, which could produce even higher GPRs, are considered to be uncommon occurrences and are not usually evaluated.

2. The Importance of X/R Ratio

2.01 From a protection standpoint the X/R ratio is important in two respects:

(1) It determines the "peak factor" (see Figure 4 of Practice 876-310-100) by which the worst-case symmetrical GPR is multiplied to determine its maximum first peak value. Protection devices must be able to withstand this maximum first peak value of voltage.

GPR (max. first peak) = GPR (peak) x peak factor = GPR (rms) x $\sqrt{2}$ x peak factor

(2) The X/R ratio is critically important in establishing the core flux (volt-second) requirement for a neutralizing transformer. Specifying a neutralizing transformer in terms of its voltsecond requirement is the only way to ensure the satisfactory performance of the transformer when it is subjected to the symmetrical and asymmetrical GPR waveforms experienced during power fault conditions. (Refer to Appendix VI which discusses the design of neutralizing transformer installations in terms of volt-second requirements.)

DESIGN OF NEUTRALIZING TRANSFORMER INSTALLATIONS

1. GENERAL

1.01 This Appendix describes the operation of the neutralizing transformer and the design of protection systems employing neutralizing transformers.

1.02 The major disadvantage of the neutralizing transformer is that it must be placed in series with the GPR or longitudinally induced voltage and is subject to core saturation. Core aturation may occur in the neutralizing transformer when the exciting current in the primary is in a transient mode, in which case the "remnant" or unneutralized voltage can assume a value substantially larger than that which results during steady-state conditions. In addition, longitudinal direct current through any winding can cause a serious degree of core saturation even at relatively low current magnitudes.

1.03 Other important disadvantages of the neutralizing transformer are its size, weight, and cost relative to comparable protection capabilities of other devices. In addition, there is the ongoing need to maintain and administer the primary circuit connection to remote ground. In view of the shortcomings inherent to neutralizing transformers, these devices should be used only where there is no other practical alternative.

1.04 Isolation transformers and other types of isolation devices are not subject to the core saturation effects experienced by neutralizing transformers and do not require a remote ground connection. Further, service reliability does not depend upon maintenance of a remote ground connection. Much higher levels of ground potential rise (including dc offset) can be tolerated by isolation transformers and other types of isolation devices with no cost penalty. Engineering designs for neutralizing transformer installations are described in detail in Appendix VI.

1.-05 This appendix is being revised to transfer technical information on neutralizing transformers from the body of the BSP to this index. Neutralizing transformer technology is not used within the SBC Local Exchange Carriers at this time. If the technology has not changed, or the technology is still not utilized in the field at the time of the next review of this appendix, consideration should be given to eliminating this appendix.

2. Neutralizing Transformer Operation

2.01 The neutralizing transformer is intended to protect the communications facility from fault-produced GPR and induced longitudinal voltage while providing a low-loss path for both ac and dc metallic signals. The neutralizing transformer consists of closely coupled windings on a ferromagnetic core structure. A single winding, designated the primary winding, is connected between the power station ground and remote ground. A secondary winding is placed in series with each conductor of the communication wire pair (or pairs) to be protected by the neutralizing transformer. The metallic impedance of the secondary windings is low due to mutual coupling and provides a low impedance path for metallic signals. When GPR occurs, the power station ground structure is elevated in potential with respect to remote ground. This potential appears across any protector blocks on the communication pairs entering the power station and across the neutralizing transformer primary winding whose reactance is large relative to the external primary circuit impedance. The primary voltage is induced into each secondary winding through transformer action in a direction to equalize the GPR voltage appearing across the protector blocks. The protector blocks do not spark over and the connecting circuit remains operational during periods of GPR. A typical single pair neutralizing transformer installation is shown in Fig. 8.

2.03 When the number of circuits to be protected requires the use of more than one single-pair neutralizing transformer, a multipair transformer may be used or a number of single pair transformers may be connected with their primary windings paralleled. A typical multipair neutralizing transformer installation is shown in Fig. 9. Paralleled neutralizing transformers must have matched electrical characteristics (see Appendix VI). If the electrical characteristics are mismatched, the level of protection will be dictated by the transformer with the least favorable characteristics.

2.03 Neutralizing transformers should not be connected in series to achieve a higher voltage rating or a higher flux (volt-second) rating to avoid exceeding the individual transformer capabilities. A series connection will expose one of the transformers to excessive winding-to-case voltage unless the case is permitted to float. The case will then assume an unknown potential and may prove to be a personnel safety hazard.

2.04 Fig. 1 illustrates neutralizing transformer operation during a power fault which has produced a ground potential rise (V_{GPR}) at the power station. The rise in potential is applied across the neutralizing transformer primary which is connected between the station ground grid and remote ground as shown in Fig. 1. In some unit type transformers, terminals 1, 3 and 5 have lower dielectric strength with respect to the case than the other terminals and are therefore the terminals associated with station ground in Fig. 1. The neutralizing transformer usually has a turns ratio of one. As long as the primary winding inductive reactance remains high relative to primary winding and external circuit resistance, the majority of the rise in potential will be transformed into each secondary, as shown in Fig. 1, to equalize or neutralize the longitudinal voltage appearing between the grid and the communications conductors. (For purposes of explanation, instantaneous polarities are shown.) Fig. I shows that the voltage polarities across Z_G. and the neutralizing transformer primary and secondary windings are in a direction to produce equalization. Negligible voltage is developed across the gas tube protectors on either the station or central office side of the neutralizing transformer and they do not operate.

2.02 The neutralizing transformer functions in exactly the same manner to neutralize longitudinally induced voltages. In this case, the undesirable longitudinal voltage arises from magnetic coupling with power lines and is distributed along the communications wire pairs and neutralizing transformer primary ground conductors rather than applied to the cable end at the power station. The series impedance of each secondary winding is low and provides a low impedance path for metallic signals.

2.03 That portion of the ground potential rise which appears across the primary winding resistance Rp, the external circuit resistance R_{EXT}, and the remote ground resistance R_G, is not transformed into the secondary and hence, is not neutralized. The unneutralized portion of the longitudinal voltage, or remnant voltage, is shown as V_{REM} in Fig. 1. Peak remnant voltage is equal to the product of the peak primary current (I_P) and the sum of the primary winding resistance (Rp), external circuit resistance (R_{EXT}), and remote ground resistance (R_G,). The equation is:

$$V_{REM}\ pk = Ip\ pk\ (Rp + R_{EXT} + R_G)$$

The maximum allowable remnant voltage should be limited to 150V peak. If the applied GPR is too great or contains a dc component, the capability of the transformer may be exceeded. If this occurs, primary winding reactance is decreased, primary circuit current Ip is increased, and remnant voltage increases. If this condition is severe, remnant voltage may increase to a level sufficient to protectors and service will be disrupted.

2.04 Nameplate data and transformer excitation characteristics which have been used in the past to design neutralizing transformer installations are steady-state condition ratings. When considering the neutralizing transformer for protection against ground potential rise and/or induced voltage during a power fault, steady-state characteristics alone are inappropriate. Choice of a neutralizing transformer must also depend on its satisfactory transient performance when subjected to the symmetrical and asymmetrical GPR waveforms experienced during power system faults. The analysis which follows describes the transient performance of the neutralizing transformer in terms of the accumulated volt-time area of the applied voltage waveform and the resulting primary circuit current.

2.05 Under power fault conditions, the neutralizing transformer may be subjected to an asymmetrical transient voltage similar to that shown in Fig. 3 of Practice 876-310-100. Application of this type of waveform may result in varying degrees of core saturation depending upon transformer volt-time capability, phase angle of the power line voltage at the initiation of the fault, and the X/R ratio of the power system at the location of the fault. Saturation may also occur when a symmetrical voltage is applied, but is most likely to occur under the asymmetrical ground potential rise conditions of Fig. 3 in Practice 876-310-100.

2.06 The remnant voltage resulting from the experimental application of an asymmetrical transient voltage to the primary winding of a 4 kv rms steady state rated neutralizing transformer is shown in Fig. 2. The peak factor of this simulated ground potential rise, as shown in Fig. 2, is approximately 1.4. Under this type of excitation, severe core saturation results and a remnant voltage peak (V_{REM}) of approximately 1200 volts peak is observed. This oscillogram was obtained in laboratory tests. Essentially comparable results have been observed with both single pair and multipair transformers during staged tests on 345-kV and 500-kV power systems under maximum fault current conditions. These data indicate conclusively that remnant voltages during the first few cycles of a fault can substantially exceed the steady-state design values.

2.07 Saturation causes large unneutralized voltages, protector operation, and possible elevation of remote ground points to dangerous voltage levels due to excessive, longitudinal currents. Saturation means that the transformer core material is unable to support the accumulated volt-time area under the applied voltage waveform without exceeding the acceptable level of exciting current. A neutralizing transformer subjected to a steady-state 60Hz voltage will be required to support the volt-time area under a quarter cycle of the applied voltage waveform. This is equal to 3.75 volt-seconds per 1000 volts rms of the applied wave or Vpk/w voltseconds. (Volt-time area under the positive and negative quarter cycles of the steady-state voltage are equal, but opposite in sign, yielding a net accumulated volt-time area under each successive positive and negative quarter cycle of zero. Therefore, during any given cycle, the maximum volt-time area which can accumulate before the voltage waveform changes polarity and begins to subtract volt-time area is that under a quarter-cycle.)

2.08 When considering a transient voltage which is symmetrical about the zero axis such as a longitudinally induced voltage or ground potential rise without dc offset, the transformer must be required to sustain the volt-time area under a full half-cycle of the applied ac (2Vpklw

V-sec or 7.5 volt-seconds per 1000 volts rms). If the voltage applied to the transformer initiates at or near a zero crossing, the volt-time area will accumulate for a full half cycle before the voltage again passes through zero and volt-time area is subtracted. In this application, twice the volt-time capability of steady-state is required or in other words, for a given transformer, its steady-state voltage rating must be derated by a factor of 2.

2.09 The composite waveshape (Fig. 3 in Practice 876-310-100), due to its asymmetry, results in the application of a large unipolar volt-time area to the transformer. The total volt-time area is a function of the steady-state portion of the waveshape, the initial offset of the transient component, and the X/R ratio of the power system. The relative volttime area for any given X/R ratio is a function of the phase angle of the power line voltage at the initiation of the fault as shown in Fig. 3. For maximum offset and small values of X/R, (X/R less than 2) the neutralizing transformer must be able to sustain 2Vpk/w volt-see; i.e., the area under 1/2 cycle of the ac component of the GPR. As the X/R ratio increases, the accumulated volt-time area per 1000 volts rms asymptotically approaches (V/& (1+X/R) , which very closely approximates the accumulated volt-time area for values of X/R of 2 or greater. For an X/R ratio of 2, such as might be encountered on a low voltage line distant from a generating station, the maximum applied volt-time area is three times the steady state value. For an X/R ratio of 14 (typical of a fault on an EHV line), the required volttime capability maximum is 15 times the steadystate requirement. The transient component of the ground potential rise adds significantly to the magnitude of the applied volt-time area and results in a derating factor from the steady-state rating in the range of 2 to 15 and greater. Fig. 4 shows the relationship between the X/R ratio and the maximum accumulated volt-time area per 1000 volts ground potential rise for several angles of fault initiation.

2.10 The "maximum accumulated volt-time area of Fig. 4 for zero degree angle is the value shown in Fig. 5 after sufficient time has elapsed to permit the accumulated volt-time area to reach an asymptotic value. The zero degree curve of Fig. 4 is therefore a plot of asymptotic values for various X/R ratios of Fig. 5. The sinusoidal component of the ground potential rise alternately adds and subtracts from the accumulated volt-time area during each cycle. Therefore, the transformer is required to support the peak volt-time area that occurs during each positive half-cycle of the sinusoidal component. Fig. 6 is obtained by eliminating the volt-time area which is subtracted on each negative half cycle, and is a plot of the accumulated volt-seconds per 1000 volts rms which the transformer will be required to support as a function of elapsed time since the initiation of the fault. If, for a given X/R ratio, the curve has reached its asymptotic value, the transformer will be required to support the maximum volt-time area as shown in the zero degree curve of Fig. 4.

3. Analyzing Neutralizing Transformer Performance

3.01 There are three distinct operational conditions which can result when neutralizing transformers are used.

(a) When accumulated volt-time area does not exceed transformer capability, remnant voltage remains within limits, protectors on secondary pairs do not operate and all services function properly.

(b) When accumulated volt-time area does exceed transformer capability, the resulting increase in primary current may increase the remnant voltage in secondary pairs enough to cause protector operation and the service on a neutralized pair may be disrupted with the introduction of noise into the circuit.

(c) When accumulated volt-time area greatly exceeds transformer capability, primary winding inductive reactance is reduced by several orders of magnitude from the maximum and the transformer core is said to be saturated. This results in a large longitudinal current flow, possible elevation of local ground potential at the remote ground point and a significant aggravation of the conditions described in (b)

3.02 Excitation characteristics representative of two commercially available neutralizing transformers are illustrated in Fig. 7 and 8. Fig. 7 shows the relationship between applied volt-time area and peak exciting current for a more modern transformer rated at 52 volt-seconds. Fig. 8 shows the characteristics of an older transformer rated at 4500 volts steady state. The latter transformer illustrates a condition referred to as "remnent flux", which affects the saturation characteristic and hence remnant voltage. Application and removal of a voltage with a net dc component will leave the transformer core biased or "set" at some remanent flux value. If the next fault occurs such that the remanent and applied flux add, fewer volt-seconds are required for saturation, resulting in premature saturation of the transformer. The 4500 volt steady-state rating of the transformer (Fig. 8) implies a volt-second rating of approximately 16. This is true when no remanence is present. However, a maximum remanence of 8 volt-seconds causes the effective volt-second capability of this transformer to vary between 8 and 24, depending on the amount and relative polarity of the remanent flux and the polarity of the applied voltage waveform.

3.04 Remanent flux is reduced significantly when the transformer design uses a gapped core structure. The transformer in Fig. 7 has such a core and has a maximum remanence of less than 1 volt second. Transformers with gapped core structure are therefore recommended. The saturation region for multipair transformers in Fig. 7 and 8, and for single-pair transformer KS16076 L1 (shown in Fig. 9) is the region where transformer current becomes more a function of primary winding and total external circuit resistance and less a function of accumulated volt-time area. Total transformer current under conditions of full saturation is determined by dividing the peak ground potential rise by the parallel combination of primary and secondary circuitresistances (assuming the secondary circuit protectors have operated).

4. Designing Neutralizing Transformer Installations

4.01 The following design procedure is a departure from techniques based on steady-state conditions alone. The procedure described herein provides the means to predict the performance of the transformer under transient conditions as well. The major function of neutralizing transformers when used in connection with service to a power station is usually the neutralization of ground potential rise. Choice of transformer type, single pair or multipair, should be based on service requirements, future growth, and economics in addition to technical requirements.

4.02 The remote ground connection for the neutralizing transformer primary may be obtained either at the Remote Drainage Location (RDL) or at the Central Office. Where fault induction is experienced between the RDL and the CO, the remote ground should be obtained at the CO. Wherelittle or no fault induction occurs between the RDL and the CO, the remote ground should be obtained at the RDL. The number of pairs required is determined by the transformer steady-state excitation current, pair resistance, and allowable remnant voltage. Obtaining ground for the primary at the central office offers no advantage over grounding at the remote drainage location when protecting against GPR and fault induction into the dedicated cable. A practical advantage of grounding at the remote drainage location is the release, for other purposes, of common use cable pairs. Fewer pairs are required in the dedicated cable due to the decrease in resistance of the shorter run. Maintenance and reliability are improved because primary pairs are no longer accessible in the general use cable. Accordingly, when protecting against ground potential rise and/or induced voltage in the dedicated cable caused by a power fault, the remote ground connection for neutralizing transformer primaries should be at the remote drainage location (see Fig. 15, Practice 876-310-100)

4.02 Transformer excitation characteristics similar to those shown in Fig. 7 through 9 must be obtained from the manufacturer in order to design a neutralizing transformer installation. The data must show the performance of the neutralizing transformer well beyond the nominal rating and should be in the form of exciting current as a function of applied volt-seconds. If the information is not available, then Fig. 8 can be used as explained in the example calculations beginning at 4.04.

4.04 Two basic approaches for the design of neutralizing transformer installations will be examined. The first is the worst-case design in which every parameter affecting the transformer volt-second requirement is taken at its worst possible value regardless of the probability of occurrence. For example, the point on the power system voltage waveform at the initiation of the fault is 'assumed to be near a zero crossing a condition which results in maximum dc offset of the GPR. The second approach is a less-than-worst-case approach in which the worst values of parameters are reduced by the application of valid statistical data. For example, a transformer volt-second requirement may be significantly reduced if it can be shown that fault initiation virtually always takes place at a more favorable phase angle on the power system voltage waveform. In the absence of valid power company fault data, the worst-case design approach should be followed in order to ensure protection integrity. Fig. 10 presents a design procedure for neutralizing transformer installations in flow-chart form. The example calculations which follow are numerically keyed to the applicable steps in the flow chart by the preceding number in parentheses.

Example 1: Worst Case Design-Accumulated Volt-time Area Under GPR Waveform Is Within Capability of Transformer

(1) GPR 2000 Vrms
X/R = 5

(4) From the zero degree curve of Fig. 4 for X/R = 5, the accumulated volt-time area = 22 V-sec per 1000 Vrms GPR

(5) Maximum accumulated volt-seconds
= 22 x (2000/1000)
= 44 V-sec

(6) The 52 volt-second rated transformer of Fig. 7 is chosen for the example

(7) From Fig. 7, 44 V-sec results in a peak primary current of 0.75 amperes.

(8) Compute peak remnant voltage
V_{REM} pk = Ip, pk $(R_P + R_{EXT} + R_G)$

Assume R_P = 27 ohms
*RExT*10 ohms (resistance of 4 paralleled 19-gauge conductors, one mile in length)

RG = 10 ohms

Vrem pk = 0.75 (27 + 10 + 10)
=35.2V pk

(9) Compute GPR at the remote drainage location due to primary current flow

V_G pk = I_P pk $X\ R_G$
= 0.75 x 10
= 7.5 V pk

In this example, the accumulated volt-time area of the GPR waveform was well within the capability of the transformer. Remnant voltage remained low, protectors did not operate, personnel safety was maintained, and services were not interrupted**.**

4.05 When data, such as shown in Fig. 7 and 8 are unavailable, the curve of Fig. 8 may be used as representative of neutralizing transformers designed to steady-state ratings. To adapt Fig. 8 to the transformer at hand, multiply the "applied volt-seconds-unfavorable remanence" scale by the transformer steady-state voltage rating and divide by 4500. The design obtained in this manner may be overly conservative. The transformer of Fig. 8 possesses very high remanence and makes maximum use of volt-second capability of core material at the Steady-state rating. Transformers of lower remanence and conservative design will, under fault conditions, have more volt-second capability. Therefore, this approach should be used only when it is impossible to obtain the required information from the manufacturer.

4.06

Example 2: Worst Case Design-Accumulated Volt-Time Area Under GPR Waveform Exceeds Capability of Transformer

(1) GPR = 2500 Vrms
X/R = 5

(4) From the zero degree curve of Fig. 4 for X/R = 5, the accumulated volt-time area = 22 V-sec per 1000 Vrms GPR

(5) Maximum accumulated volt-seconds = 22 x (2500/1000) = 55

(6) The 52 volt-second rated transformer of Fig. 7 is chosen for the example

(7) From Fig. 7, 55 V-sec results in a peak primary current of 12 amperes

(8) Compute peak remnant voltage
Vrem pk = I_P pk $(R_P + R_{EXT} + R_G)$ = 12 (27 +10+10)
=564 Vpk

(9) Compute GPR at the remote drainage location due to primary current flow
V_G *pk* = I_P *pk x* R_G
= 12 X 10
= 120 Vpk

This example illustrates the drastic results of exceeding the transformer volt-second capability by only a small margin (55 V-sec applied, 52 V-sec rating). Has greatly exceeded the 150-volt limit, protectors on the secondary pairs may have operated on the power station side of the transformer and possibly at the remote drainage location, and services protected by the neutralizing transformer may have been disrupted. To satisfy the criteria for a worstcase design, a 55 V-sec rated transformer is required.

4.07

Example 3: Less than Worst Case Design-Accumulated Volt-Time Area Under GPR Waveform is Within Capability of Transformer

(1) GPR 1500 Vrms
X/R 6

(2) From available power company fault data, it is determined that virtually all faults on the power systems entering the substation occurred at points on the voltage waveform at least 45 degrees from a zero crossing.

(3) From the 45 degree curve of Fig. 4 for X/R = 6, the accumulated volt-time area = 19 V-sec per 1000 Vrms GPR

(4) Maximum accumulated volt-seconds
= 19 x (1500/1000)
= 28.5

(5) The KS-16076 transformer of Fig. 9 is chosen for the example

(6) From Fig. 9, the application of 28.5 V-sec, with unfavorable remanence, results in a peak primary current of 0.55 amperes

(7) Compute peak remnant voltage

$V_{REM}\ pk – I_P\ pk\ \ R_P + R_{EXT} + R_g)$
R_p. = 63 ohms
R_{EXT} = 10 ohms
R_G = 10 ohms
V_{REM} = 0.55 (63 + 10 + 10)
= 45.6 Vpk

(8) Compute GPR at the remote drainage location due to primary current flow

$V_G\ pk = Ip\ pk \times R_G$
= .55 x 10
= 5.5 Vpk

This example illustrates the use of power company fault data to reduce the volt-time requirement of the transformer. Had the design been for worst-case (zero degree fault initiation), the volt-second requirement would have been (26 x 1500/1000 = 39 V-sec (see Fig. 4). The application of 39 V-sec, even with favorable remanence, would greatly exceed the transformer's V-sec capability and core saturation would result (see Fig. 9). The remnant voltage, under these conditions might approach the full GPR. This transformer, therefore, could not be used in the worst-case design but will operate satisfactorily in the less than worst-case application shown.

5. Paralleling Neutralizing Transformers

5.01 Paralleled neutralizing transformers must have the same volt-time rating and have approximately the same remanent flux characteristic. For a given level of ground potential rise and transformer type, the total primary current and remnant voltage are proportional to the number of paralleled units. Paralleling has the effect of increasing remnant voltage or, for a given remnant voltage, decreasing the number of volt-seconds which may be applied. To maintain remnant voltage within acceptable limits, transformers of greater volt-time capability may be required, or the number of primary pairs must be increased. The number of units that may be paralleled must be practically determined based on remnant voltage, volt-second capability of the transformers, external impedance, and number of primary pairs required.

5.02 The following examples illustrate neutralizing transformer paralleling:

Assume that the total accumulated volt-time area of the GPR waveform is 52 volt-sec.

A transformer with exciting current characteristic as shown in Fig. 7 is chosen.

Primary resistance Rp = 27 ohms
Primary pairs = 19 gauge, two pairs in parallel
Distance to remote-drainage location = 1 mile
R_{EXT} 10 ohms
R*g*10 ohms

From Fig. 7 for 52 V-sec. applied, peak primary current = 2.5A

Remnant voltage = Vrem pk = Ip pk (Rp + R_{EXT} + Rg)

Vrem pk = 2.5 (27 + 10 + 10)
Vrem pk = 2.5 x 47 = 117.5 V pk

Two transformers in parallel:

Vrem pk = Ip pk [Rp + n (R_{EXT} + R*g*)]
where n = number of transformers in parallel
Vrem pk = 2.5 [27 + 2 (10 + 10)]
Vrem pk = 2.5 x 67 = 167.5V pk

The increase in remanent voltage may be negated by increasing the number of primary pairs or by using transformers of greater volt-time capability.

6. Neutralizing Transformer Tests

6.01, Neutralizing transformers may be tested (out of service) to determine internal shorts or opens in the primary and secondary windings, internal shorts from the windings to the case, and proper polarization of the windings with respect to each other. Test instruments required are a standard ohmmeter and a 4-terminal ground resistance test set such as the Megger[1] Test Set, the Vibroground[2] Test Set, or equivalent.

6.02 Table A provides a step-by-step procedure for performing the tests (Fig. 11) and describes the nature of the trouble as indicated by the various readings. Where trouble is indicated, further investigation or consultation with the transformer manufacture is recommended. In tests requiring the use of a ground resistance test set, the Megger is used in the test descriptions for illustrative purposes. Due to the hazards involved, in-service testing of neutralizing transformers should not be performed.

[1] Megger is a trade name of the James G. Biddle Co
[2] Vibroground is a trade name of Associated Research, Inc.

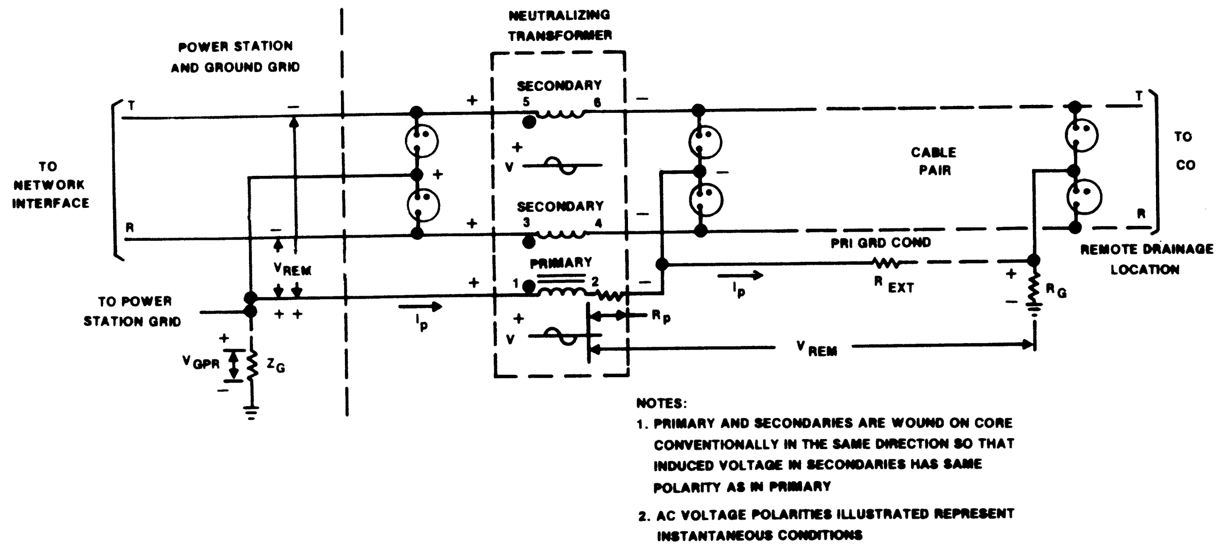
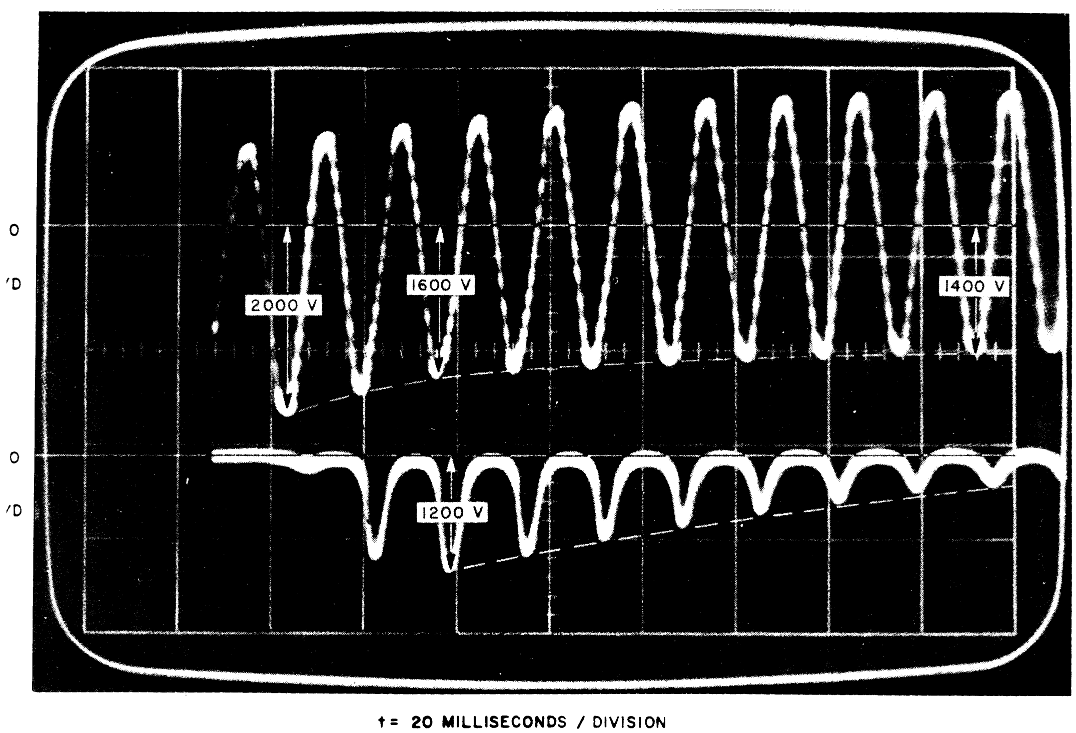


Figure 1 – 3-Winding Neutralizing Transformer – Neutralizing Ground Potential Rise at Power Station



V/D = VOLTS/DIVISION
V_P = PRIMARY VOLTAGE
V_{REM} = SECONDARY REMNANT VOLTAGE TO GROUND

Figure 2 – Oscillogram Showing Typical Effect of 60 Hz Asymmetrical Voltage on a 4kV rms Rated Neutralizing Transformer

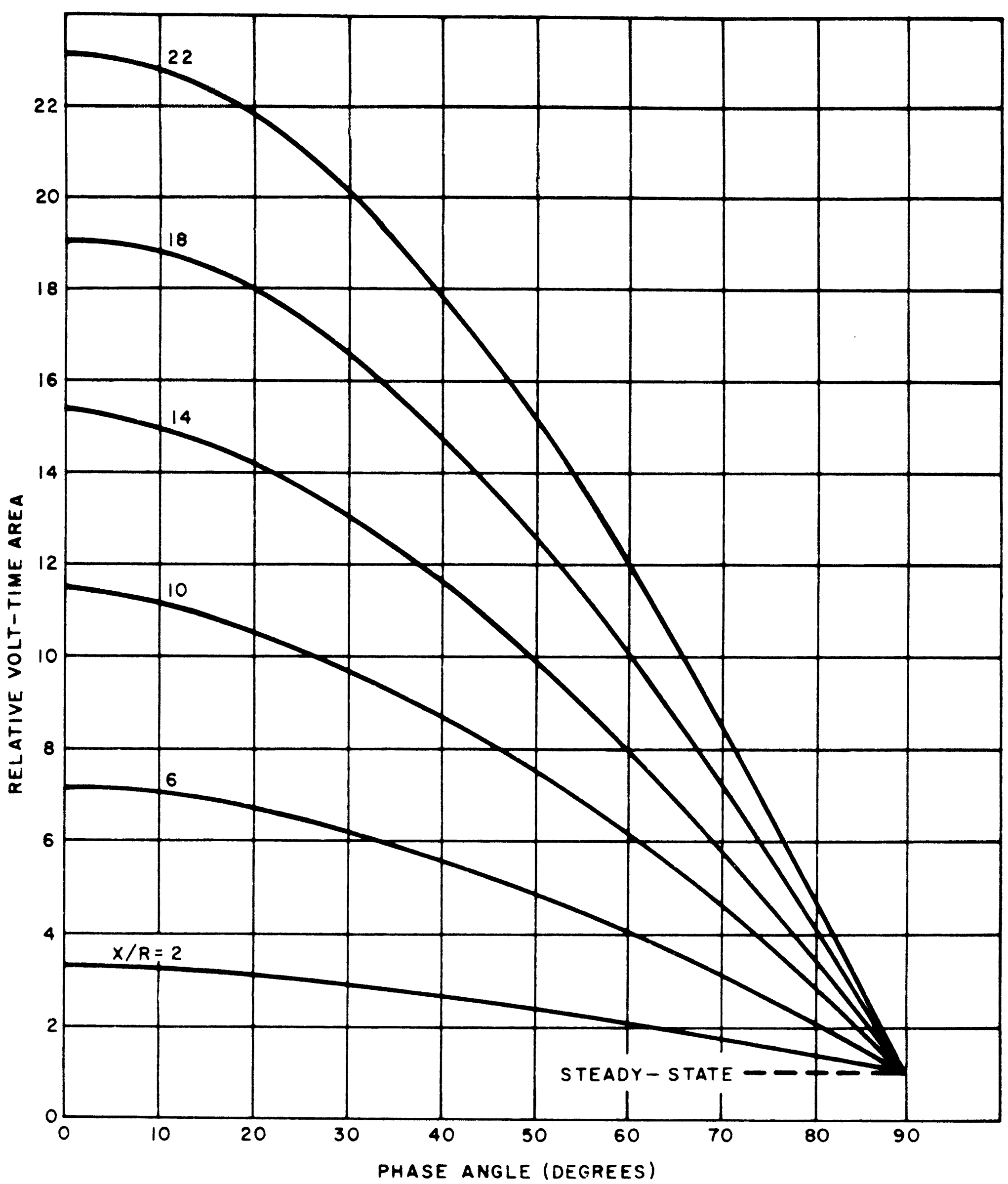
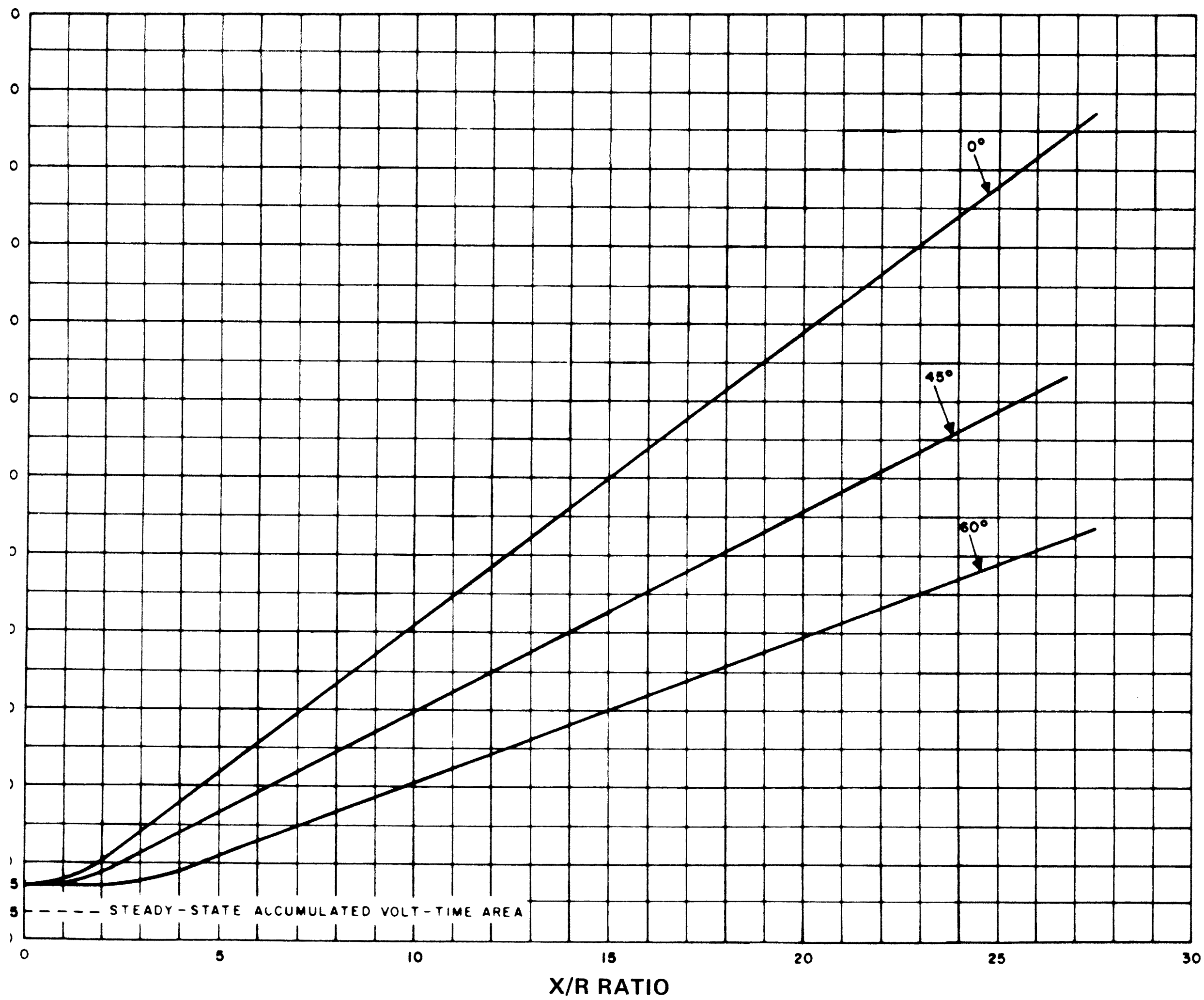


Figure 3 – Relative Volt-Time Area (Asymptotic Value) For Various X/R Ratios As a Function of Power Line Voltage Phase Angle at Initiation of Fault



NOTE: NUMBER OF DEGREES ON CURVE INDICATES PHASE ANGLE OF POWER SYSTEM VOLTAGE AT FAULT INITIATION

Figure 4 - Maximum Accumulated Volt-Seconds Per 1000 Volts RMS Ground Potential Rise Versus X/R Ratio of Power System For Different Fault Initiation Phase Angles

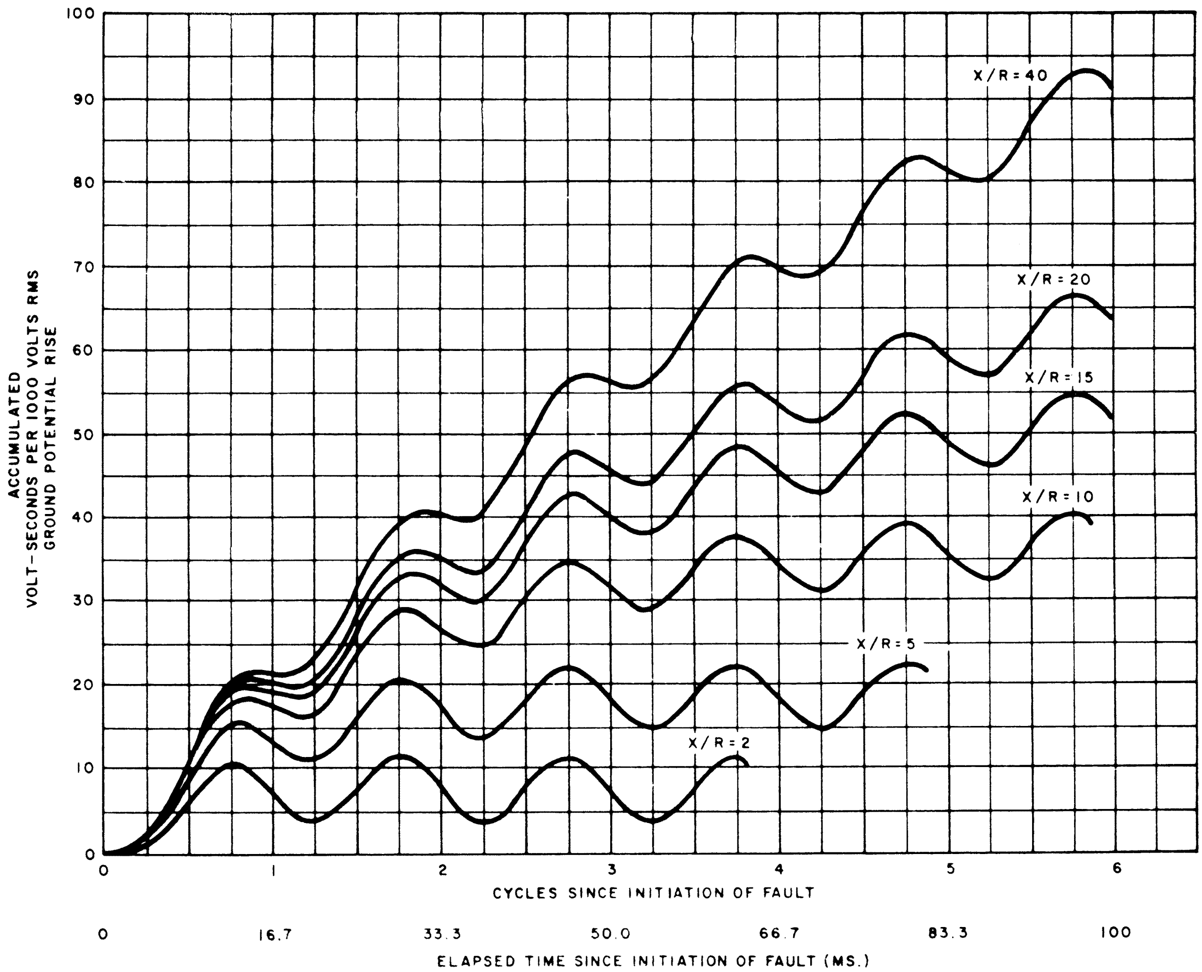


Figure 5 – Accumulated Volt-Time Area Per 1000 Volts RMS Ground Potential Rise Versus Elapsed Time Since Initiation of Fault For Various X/R Ratios

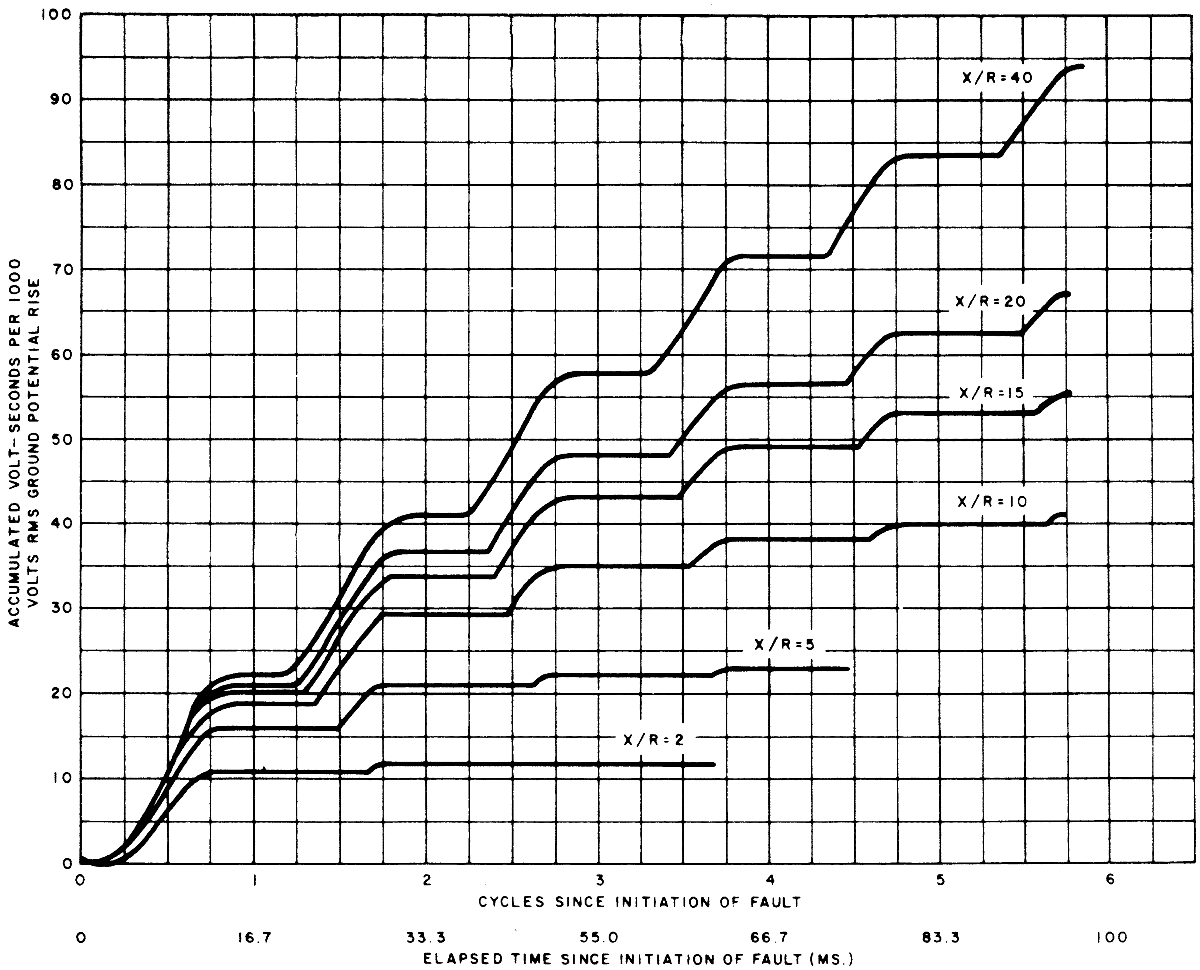


Figure 6 – Required Transformer Capability in Volt-Seconds Per 1000 Volts RMS Ground Potential Rise

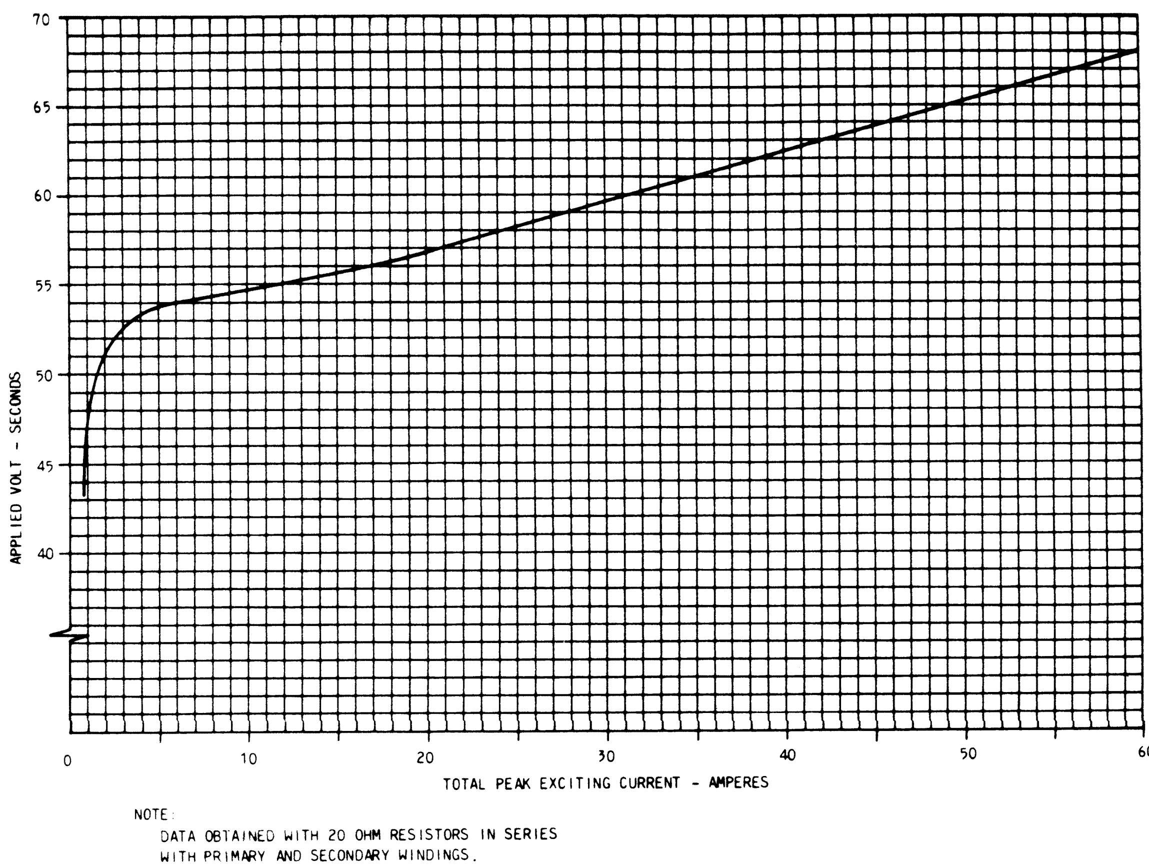
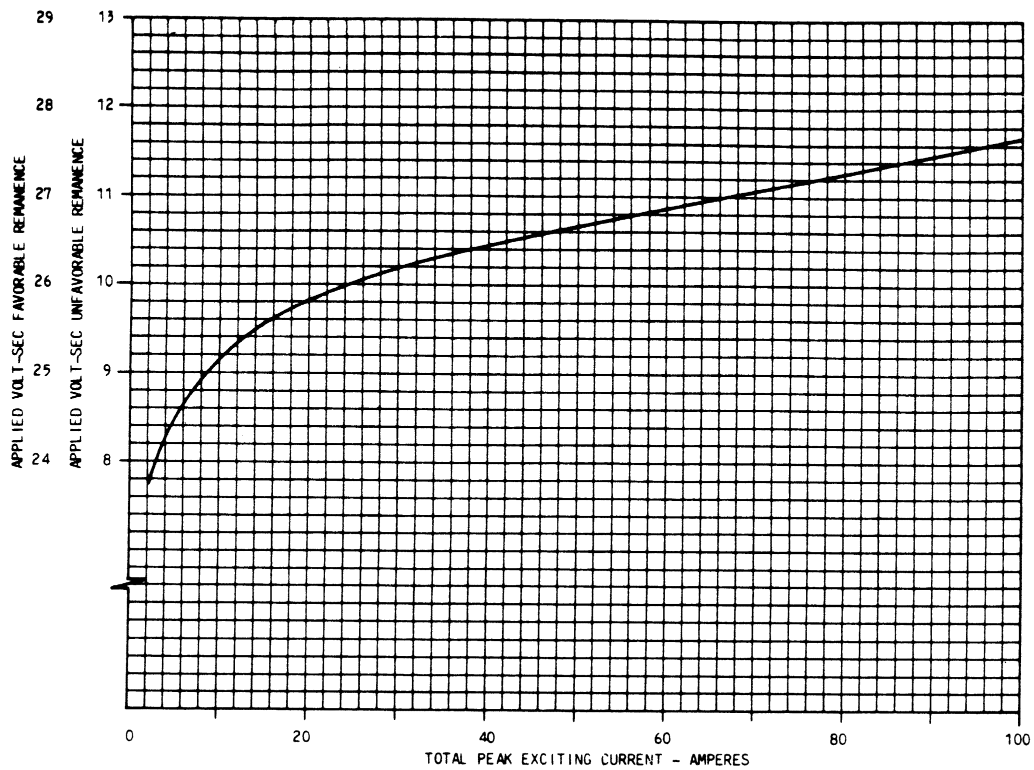


Figure 7 – 52-Volt-Second Rated Neutralizing Transformer Excitation Characteristic



NOTE:
DATA OBTAINED WITH 20 OHM RESISTORS IN SERIES WITH PRIMARY AND SECONDARY WINDINGS.

Figure 8 – 4500-Volt RMS Steady-State Rated Neutralizing Transformer Excitation Characteristic

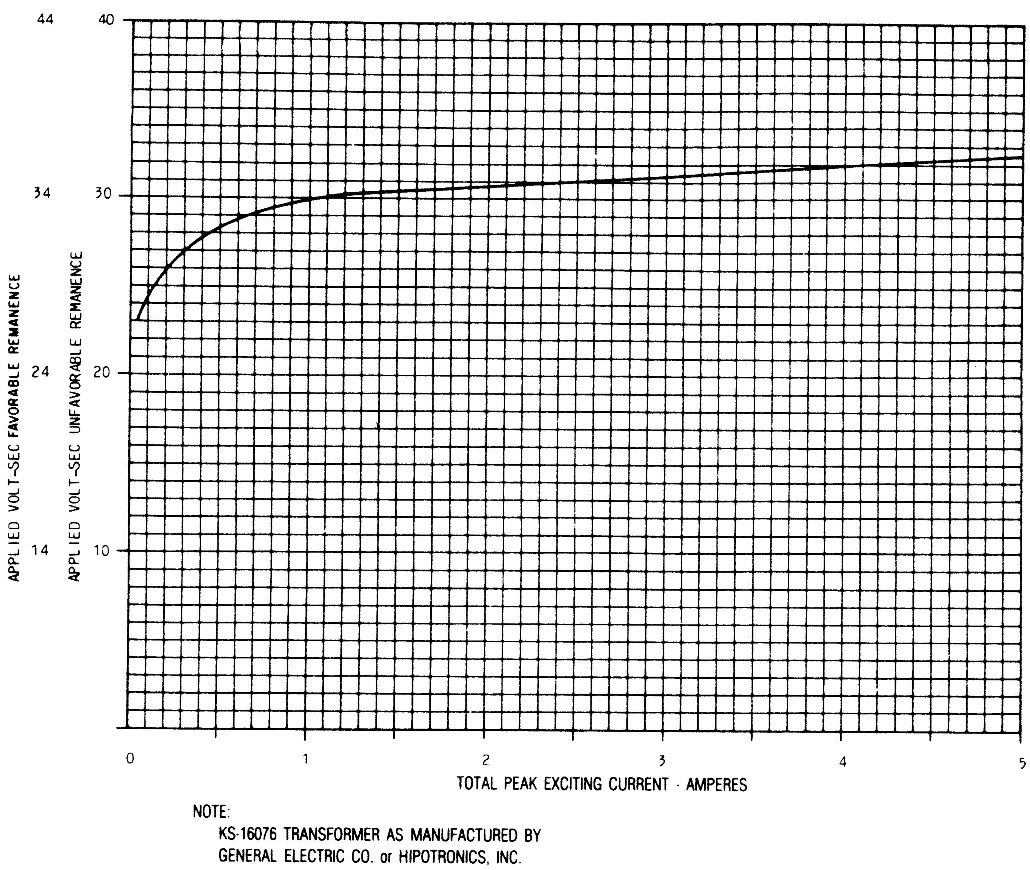


Figure 9 – KS-16076 (Gapped Core) Neutralizing Transformer Excitation Characteristic

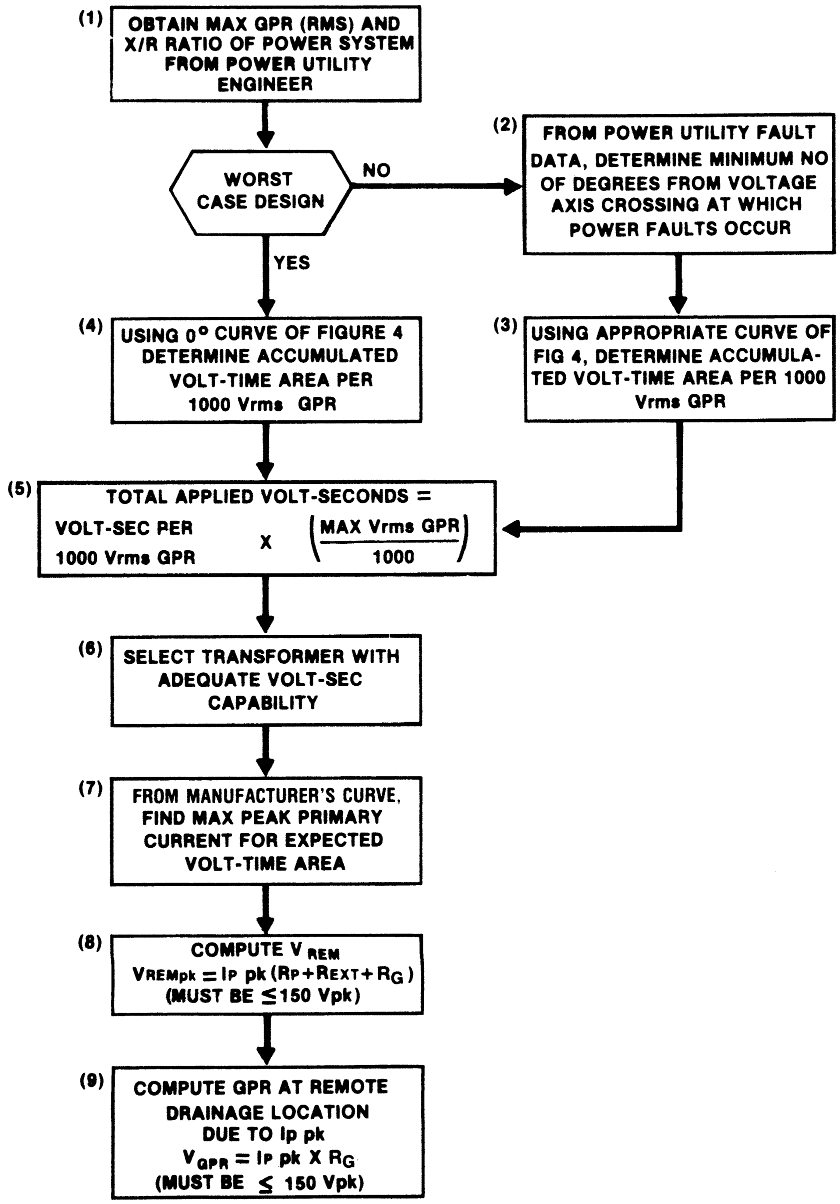
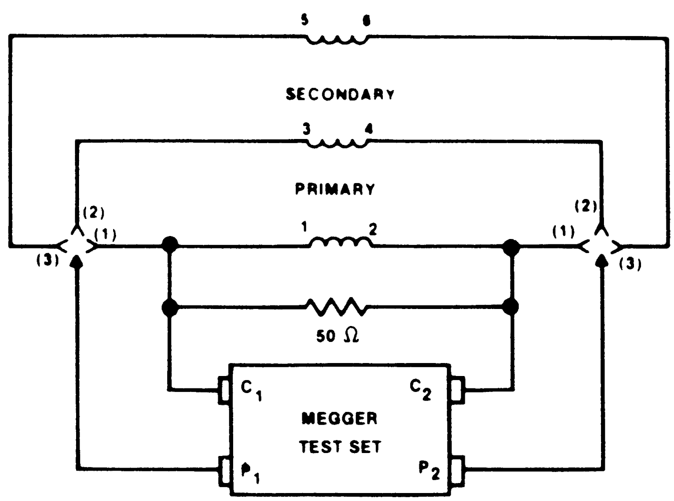


Figure 10 - Recommended Design Procedure For Neutralizing Transformer Installations



( ) INDICATES NUMER OF TEST AND ASSOCIATED
LEAD CONNECTIONS TO MEGGER TEST SET

Figure 11 - Testing Out-of-Service Neutralizing Transformer

TABLE A
NEUTRALIZING TRANSFORMER TESTS

STEP	TEST	METER READING	INDICATED TROUBLE
1	All transformer leads should be free of connections to each other and ground. Set ohmmeter to highest resistance range and check for shorts from each winding to case and from each winding to all other windings.	(a) Very high resistance (greater than 500K)	No trouble indicated. Proceed to Step 2.
		(b) Low resistance.	Short indicated. Do not install transformer.
2	Using appropriate resistance range, use ohmmeter to measure dc resistance of primary and secondary windings.	(a) Manufacturer's specified resistance value (allow 5 percent tolerance).	No trouble indicated. Proceed to Step 3.
		(b) Less than (a) - zero ohms.	Partially or completely shorted winding. Do not install transformer.
		(c) Greater than (a) - infinite ohms.	High resistance internal connection or open winding. Do not install transformer.
3	Connect leads of Megger test set as shown in Fig. 11 for test [1], and operate test set.	(a) 50 ohms.	No trouble indicated. Proceed to Step 4
		(b) Reversed (reading off low end of scale).	P_1 and P_2 leads reversed.
4	Connect leads of Megger test set as shown in Fig. 11 for test [2], and operate test set.	(a) 50 ohms.	No trouble indicated. Proceed to Step 5.
		(b) Reversed (reading off low end of scale).	P_1 and P_2 leads reversed, or 3-4 secondary polarity reversed with respect to primary. Do not install.
5	Connect leads of Megger test set as shown in Fig. 11 for test [3], and operate test set.	(a) 50 ohms.	No trouble indicated. Transformer is satisfactory.
		(b) Reversed (reading off low end of scale).	P_1 and P_2 leads reversed, or 5-6 secondary winding polarity reversed with respect to primary Do not install.
6	For multipair transformers, repeat Steps 4 and 5 for each secondary pair.		

DEDICATED CABLE ENGINEERING CONSIDERATIONS

1. General

1.01 When a dedicated cable is used between the power station and the remote drainage location, the choice of cable type, construction, and related safety practices for the dedicated cable are different from those for general use cables. With regard to dielectric strength, cables having factory test ratings as high as 20 kV dc core-to-shield and 5 kV dc pair-to-pair are available and should be used. Such cables typically have either 19- or 22-gauge copper conductors with solid plastic conductor insulation. Cable shield continuity should be tested in the factory. For aerial construction, double jacketed air core cables with PAP or PASP sheaths are appropriate. For buried or underground construction, a filled high dielectric strength waterproof cable should be used. Regardless of the type of dedicated cable construction (aerial, buried, underground), the outer plastic jacket will be relied upon to maintain the isolation of the metallic shield from earthand all other external ground conductors between the High Voltage Interface (HVI) and the Remote Drainage Location (RDL). *The shield must remain isolated and ungrounded throughout its length.*

1.02 Considerations regarding the three types of construction are as follows:

Buried - Buried construction, where possible, is the preferred type of construction for the dedicated cable. All splices should be buried so that aboveground appearances are eliminated. Where aboveground appearances cannot be avoided, the cable should be identified there and tagged as described in *1.05.* Once installed, the cable will be virtually free of necessary work activity, and since it will be inaccessible, circuit reliability and personnel safety will be enhanced because the likelihood of inadvertent work activity will be precluded.

Underground – Where underground construction is required, the dedicated cable ‘should be identified and tagged in each manhole as described in *1.05.* Within the manholes, the shield must not be bonded to other cable shields nor to the manhole grounding ribbon or to the cable support rack. Non-metallic, waterproof splice cases should be used.

Aerial – Where aerial construction is required, the dedicated cable should be identified and tagged at each pole as described in *1.05.* The support strand and associated lashing wire must be bonded and grounded to other cable strands, vertical grounds, and power neutrals according to normal construction practice. The outer plastic jacket of the cable will be relied upon to maintain the required isolation between shield and grounded strand. Non-metallic splice cases will maintain the isolation from the strand at splice locations.

1.03 The dedicated cable should be free of splices if possible. Where splices are necessary, they should be located as far from the power station as possible. In either new construction or in repair work, in-line splices using individual self-sealing plastic connectors in non-metallic closures should be used. For splices in buried or underground construction, the non-metallic splice closure should accommodate the sealed plastic connectors and should be filled with an encapsulant which allows reentry. For aerial construction, a non-metallic closure which accommodates a double jacketed air core cable should be used. Shield continuity must be maintainedthrough the splices by using the bonding hardware provided, but the provision for grounding the shield *must be omitted.* Special care should be exercised in handling the cable pairs to avoid cuts, nicks,scratches, abrasions and sharp bends in the conductor insulation. The insulating layer between the core and the shield should extend into the splice opening at least one inch beyond any sheath members and care must be exercised that the core wraps are not damaged in any way during installation of the bond clamps. It is important that no wire work come in contact with uninsulated portions of the bonding ribbons, bond clamps or any metallic part within the closure.

1.08 The metallic shield of the dedicated cable must be kept insulated from the power station ground grid. The dedicated cable should be mechanically secured on insulators near its entry point into the HVI cabinet. The shield is connected to one side of the lightning arrester. Care should be exercised to assure that undamaged core wraps extend at least two inches beyond the shield. The dedicated cable shield is further protected from contact with the power station ground by running the cable in PVC electrical conduit across the grid from the HVI to a point at least ten feet outside the power station ground grid or fence, whichever is farther. The PVC conduit is typically installed by the customer.

1.08 Identification tags should be placed on the dedicated cable as described below. The tags should bear words such as: “CAUTION. This cable serves an electric power station. Momentary HIGH VOLTAGES are possible. The cable shield IS and MUST REMAIN UNGROUNDED. DO NOT work on or in this cable in electrical storms.”

- Buried construction—Use tags at above ground appearances.
- Underground construction—Use tags in each manhole where the dedicated cable appears.
- Aerial construction—Use tags at each pole.

1.06 A non-conductive backboard shall be provided at the HVI that does not have any exposed attachment devices that contact metallic surfaces. A method to accomplish this requirement is to use two 1” backboards. The first backboard is attached to the wall or frame, the second backboard is attached to the first backboard with attachment devices that DO NOT penetrate the first backboard or touch any metallic surfaces. Other methods are acceptable.

1.07 Unused cable pairs from the dedicated cable should be cleared and capped at the HVI.

1.08 When the High Voltage Protection Device is provided by the customer an ADC[1] Telephone Line Isolation Panel will also be installed to provide access to the phone lines/circuits for testing.

2. High Potential Testing

2.01 Previous protection guidelines (Practice 876-310-100, Issue 2) recommended that the dedicated cable be high potential tested after its initial installation and after any subsequent repair activities. The use of a dc high potential test set to produce test voltages as high as 12 kV was recommended. Such tests are no longer considered applicable on a general basis when a splice-free high dielectric cable is used and caution is exercised at the HVI in properly terminating the cable pairs and shield and in keeping both pairs and shield fully separated from each other and well isolated from ground. Even when the dedicated cable contains a splice, high potential tests may be unnecessary when the splice location is well removed from the power station, when the splice is made per the instructions in 1.03, and when

[1] ADC is a trade name for products from ADC Telecommunications

the cable shield and pairs are carefully terminated in the HVI.

2.02 Considerations leading to a relaxing of previous high potential testing recommendations are as follows:

a) Field experience has shown that virtually all dielectric breakdowns in cable occur at splices and access points where standard splicing methods developed for general use cable have been employed. Use of a splice-free dedicated cable, therefore, will eliminate all such splicerelated causes of breakdown.

b) Where a splice is required, the diligent application of the methods and hardware described in 1.03 will retain the high dielectric integrity of the cable without degradation. In addition, locating the splice some distance from the power station will place it at a point where the fault-produced environmental stresses are greatly reduced from their maximums.

2.02 It is recognized that the dedicated cable may be damaged during installation, or it may experience damage subsequent to installation. In buried plant, for example, settling and crushing against rocks or other objects can reduce the dielectric strength of the outer jacket and degrade the pair-to-pair and core- to-shield dielectric strength as well. Based on field experience, however, occurrences of breakdown due to this type of damage are extremely few in comparison to occurrences of breakdowns which are related to standard splicing methods. In view of the various considerations of dielectric breakdown which have been described here, the telephone company protection engineer should determine the need for high potential testing of the dedicated cable on an individual case basis. For example, testing may be considered when highly critical services having Class A SPOs are involved, when the fault-produced environment is unusually severe, or when the power utility specifically requests such tests. Core-to-shield test values should be at least as high as the combined worst case GPR and induction which could be imposed on the cable, but should not exceed 12 kVdc. Pair-to-pair test values should not exceed the pair-to-pair factory test value for the cable being tested. It should be noted here that the objective of high voltage testing is not to determine the dielectric strength of the cable, but it is to reveal abnormal deficiencies of dielectric strength. Practice 634-020-504 covers dc high potential test methods.

3. Terminating Buried or Underground Dedicated Cables

3.01 Waterproof cables containing flammable filling compounds are considered unsuitable for use inside buildings or for entering indoor equipment or cross-connection enclosures. Rules have been established for splicing such cables to non-filled extensions on customer premises, but a modified set of rules is required to meet the special needs of power station dedicated cables. The filled cable shall be spliced to approved indoor cable as close as practicable to the point of entrance into the building, but in no case more than 50 feet from the entrance. An exception to the length limitation may be made if the filled cable is contained in a continuous PVC electrical conduit all the way from the building entrance to the splice. For splicing to a filled22-gauge high dielectric dedicated cable, the recommended indoor cable is a 22-gauge, dual plastic insulated cable with an Alvyn (aluminum-polyvinylchloride) sheath. A 24-gauge cable of similar construction is not recommended, both because the finer gauge would make it act as a fuse cable for the 22-gauge filled cable and because the thinner insulation on the wires has inadequate dielectric strength. Flame-resistant cables for indoor use are described in Practice 626-107-005**.**

3.02 The splice closure used should be non-metallic to avoid possible dielectric breakdown problems and should be made of a suitable flame resistant material for use inside buildings. One closure which meets these requirements is described in Practice 633-560-101. The conditions which led to the prohibition against use of this closure on cables smaller than 400 pairs inside buildings do not apply to this usage, so it may be used for all cable sizes. The splice should be made as described in Practice 633-560-101 for subscriber building cable splices, with the following additional precautions. The conductors should be spliced in-line using individual self-sealing plastic connectors. Special care should be exercised in handling the cable pairs to avoid cuts, nicks, scratches, abrasions and sharp bends in the conductor insulation. The ends of the sheaths should be prepared, and appropriate bond clamps should be attached to the shields of both cables. Note: The core wrap of the cable shall extend at least one inch beyond any bare metal part of the bond clamp. Bonding leads are not to be attached at this time. After the pairs have all been joined, protect the spliced core with two layers of half lapped polyethylene tape wrapped as tightly as possible and lapped over the cable core wrap. Secure the end turn with vinyl tape. Connect the bonding clamps with a bonding strap of appropriate length. Place a length of polyethylene tape longitudinally between the bonding ribbon and the wrapped core, and cover the entire splice by wrapping a halfwrapped layer of polyethylene tape around the splice. Secure the end turn with vinyl tape.

3.03 When the high voltage interface is in an outdoor cabinet, filled cable may be brought directly upward into an opening in the bottom of the cabinet. The cable sheath should be terminated near the bottom of the cabinet while still pointed upward, and the length of the pair conductors to the terminating block where they are attached should be kept as short as practicable.

4. Terminating Aerial Dedicated Cable

4.01 If aerial dedicated cable is used, the air core cable can be brought directly into a terminating cabinet either indoors or outdoors. Since the outer jacket of these cables is polyethylene, they should not be run exposed for extended distances inside an occupied building. A maximum of 50 feet is considered acceptable. If a longer run is required, the cable may be enclosed in continuous PVC electrical conduit from the building entrance point to the high voltage interface location. Caution with respect to conductor gauge must be exercised when splicing from an aerial dedicated cable to an indoor cable. A splice from a 19-gauge aerial cable to a 22-gauge indoor cable would not be acceptable because the gauge change would cause the indoor cable to act as a fuse cable in the unlikely event of heavy current flow in the dedicated cable.