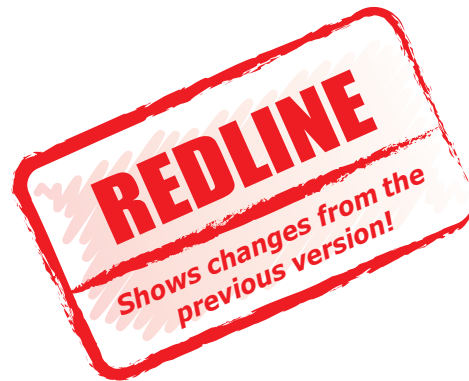


IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault

IEEE Power & Energy Society

Sponsored by the
Power System Communications Committee



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3 Park Avenue
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USA

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IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault

Sponsor

**Power System Communications Committee
of the
IEEE Power & Energy Society**

Approved 29 March 2012

IEEE-SA Standards Board

Abstract: Guidance for the calculation of power station ground potential rise (GPR) and longitudinal induction (LI) voltages is provided, as well as guidance for their appropriate reduction from worst-case values, for use in metallic telecommunication protection design.

Keywords: electric power stations, ground potential rise, IEEE 367, induced voltage, longitudinal induction voltages, power faults, power stations, telecommunication protection design, telecommunications

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Introduction

This introduction is not part of IEEE Std 367-2012, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.

Wire-line telecommunication facilities serving electric power stations often require that extraordinary protection measures be taken to protect against the effects of fault-produced ground potential rise (GPR) or induced voltages, or both. In the presence of a hostile electromagnetic environment, suitably rated protection equipment is required at the power station for personnel safety, for the protection of the serving telecommunication facilities, and to help ensure the desired continuity of telecommunication transmission at times of power system faults. There is a fundamental need, therefore, to determine the appropriate values of fault-produced GPR and induction, including considerations of their probability and duration, to be used in developing the specifications and ratings for the protection equipment to be used in any given application.

This recommended practice provides information for the determination of the appropriate values of fault-produced power station GPR and induction for use in the design of protection systems. Included are the following:

- a) The determination of the appropriate value of fault current to be used in the GPR calculation
- b) The consideration of the waveform, probability, and duration of the fault current
- c) The determination of inducing currents, the mutual impedance between power and telephone facilities, and shield factors
- d) The vectorial summation of GPR and induction
- e) The considerations regarding the power station GPR zone of influence (ZOI)
- f) The communications channel time requirements for noninterruptible services

This standard was originally prepared in 1987 by the Joint High Voltage Interface Working Group (WG) with members from the IEEE Transmission and Access Systems Committee of the IEEE Communications Society and the Power System Communications Committee of the Power Engineering Society. This WG later merged with the Inductive Coordination Electrical Protection (ICEP) Subcommittee (SC). Over time most of the members of the ICEP SC moved to the Wire-line SC, under the Power Engineering Society Power System Communications Committee. The Wire-line SC assumed ownership of this standard during the revision process in 1996.

The WG determined during this revision process (2011) that there are no international standards to determine the ground (or earth) potential rise at electric power stations or similar locations. The WG did locate, through an Internet search, two international documents that appear to deal with the subject but were not validated for harmonization purposes, as follows:

- AS/NZS 3835.1:2006, Earth potential rise—Protection of telecommunications network users, personnel and plant—Part 1: Code of practice
- AS/NZS 3835.2:2006, Earth potential rise—Protection of telecommunications network users, personnel and plant—Part 2: Application guide

Further, Volume II of the ITU-T Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines, *Calculating Induced Voltages and Currents in Practical Cases*, also appears to deal, in part, with the subject of this standard.

This standard was revised and updated by the Wire-line Working Group of the IEEE Power System Communications Committee of the IEEE Power & Energy Society.

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1. Overview

Difficulties are experienced by telecommunication, protection, and relay engineers in determining the *appropriate* values of power station ground potential rise (GPR) or the longitudinally induced (LI) voltages into wire-line telecommunication facilities including their probability, waveform, and duration, which are to be used in ~~the~~ developing the specifications for systems and component protection.

Suitably rated protection devices are required for personnel safety and for the protection and continuity of service for wire-line facilities that either enter electric power stations or that are otherwise exposed to the influence of high-voltage electric power circuits. (See IEEE Std 487™.)¹

1.1 Scope

This ~~recommended practice~~ standard provides guidance for the calculation of power station GPR and LI voltages ~~as well as~~ and guidance for their appropriate reduction from worst-case values for use in metallic telecommunication protection design. Information is also included for the determination of the following:

- a) The fault current and the earth return current. ~~(The levels; their~~ probability, waveform, and duration ~~of these currents~~; and the impedance to remote earthing points used in these GPR and LI calculations as well as the effective X/R ratio ~~are discussed.)~~
- b) The zone of influence (ZOI) of the power station GPR.
- c) The calculation of the inducing currents, the mutual impedance between power and metallic telecommunication facilities, and shield factors.
- d) The channel time requirements for metallic telecommunication facilities where non-interruptible channels are required for protective relaying.

¹ Information ~~about~~ on references can be found in Clause 2.

2.Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

~~This recommended practice shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.~~

IEEE Std 80-~~1986 (Reaff 1991)~~,TM IEEE Guide for Safety in AC Substation Grounding-~~(ANSI)~~.^{2, 3}

IEEE Std 81-~~1983~~,TM IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System-~~(Part 1) (ANSI)~~.

IEEE Std 81.2-~~1991~~,TM IEEE Guide for Measurement of Impedance and Safety Characteristics of Large, Extended or Interconnected Grounding Systems-~~(Part 2) (ANSI)~~.

IEEE Std 487-~~1992~~,TM IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations-~~(ANSI)~~.

~~IEEE Std C37.90-1989 (Reaff 1994), IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus (ANSI).²~~

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~~IEEE Std C37.93-1987 (Reaff 1992), IEEE Guide for Power System Protective Relay Applications of Audio Tones Over Telephone Channels (ANSI).~~

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary: Glossary of Terms and Definitions* [B42] should be consulted for terms not defined in this clause.^{4, 5}

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

auroral effects: Electrical voltages and currents on the earth due to emission of particle energy from the sun.

direct-current (dc) offset: The difference between the symmetrical current wave and the actual current wave during a power system transient condition. Mathematically, the actual fault current can be broken into two parts: a symmetrical alternating component and a unidirectional dc component, either or both with decreasing magnitudes (usually both). The unidirectional component can be of either polarity, but it will not change polarity during its decay period and will reach zero at some predetermined time.

⁴[IEEE Standards Dictionary: Glossary of Terms and Definitions](http://shop.ieee.org) is available at <http://shop.ieee.org>.

⁵[The numbers in brackets correspond to those of the bibliography in Annex A.](#)

direct-current (dc) offset factor: The ratio of the peak asymmetrical fault current to the peak symmetrical value.

earth resistivity: The measure of the electrical impedance of a unit volume of soil. The commonly used unit is the ohm-meter ($\Omega\cdot\text{m}$), which refers to the impedance measured between opposite faces of a cubic meter of soil.

effective X/R ratio: The value of X/R as seen from the fault location looking back into the power system far enough to include the reduction of the X/R ratio due to the effects of the terminal apparatus.

geomagnetic induced currents (GIC): Spurious, quasidirect currents flowing in grounded systems due to a difference in the earth surface potential caused by geomagnetic storms resulting from the particle emission of solar flares erupting from the surface of the sun.

geometric mean radius (GMR): Radius of a tubular conductor with an infinitesimally thin wall that has the same external flux out to a radius of 1 ft (0.3048 m) as the internal and external flux of a solid conductor, out to a radius of 1 ft (0.3048 m). GMR is a mathematical radius assigned to a solid conductor that describes in one term the inductance of the conductor due to both its internal flux and the external flux.

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

inducing current: The current that flows in a single conductor of an electric supply line with ground return to give the same value of induced voltage in a telecommunication line (at a particular separation) as the vectorial sum of all voltages induced by the various currents in the inductive exposure as a result of ground fault.

longitudinal voltage: A voltage acting in series with the longitudinal circuit.

mutual impedance: The ratio of the total induced open-circuit voltage on the disturbed circuit to the disturbing electric supply-system phase current, with the effect of all conductors taken into account.

per-unit(pu) system: The reference unit, established as a calculating convenience, for expressing all power system electrical parameters on a common reference base. One per unit (pu) is 100% of the base chosen. The pu system in power systems engineering is used to obtain a better comparison of the performance of the power system elements of different ratings, similar to the decibel system used for equating the losses and levels of different telecommunication systems.

remote earth: That distant point on the earth's surface where an increase in the distance from a ground electrode will not measurably increase the impedance between that ground electrode and the new distant point.

subtransient reactance: The reactance of a generator at the initiation of a fault. This reactance is used for the calculation of the initial symmetrical fault current. The current continuously decreases, but it is assumed to be steady at this value as a first step, lasting approximately 0.05 s after a suddenly applied fault.

susceptibility: The property of equipment that describes its capability to function acceptably when subjected to unwanted interfering energy.

synchronous reactance: The steady-state reactance of a generator during fault conditions used to calculate the steady-state fault current. The current so calculated excludes the effect of the automatic voltage regulator or governor.

telluric currents: Currents circulating in the earth or in conductors connecting two grounded points due to voltages in the earth.

transient reactance: The reactance of a generator between the subtransient and synchronous states. This reactance is used for the calculation of the symmetrical fault current during the period between the sub-transient and steady states. The current decreases continuously during this period but is assumed to be steady at this value for approximately 0.25 s.

volt-time area: The area under a curve plotted with voltage versus time with areas of positive and negative polarities added algebraically. The volt-time area that is generally of concern consists of the net accumulated volt-time area that occurs during a certain number of power frequency cycles of the ground potential rise (GPR). The area is a function of the magnitude and decay rate of the dc offset.

X/R ratio: The ratio of the system inductive reactance to resistance. It is proportional to the time constant L/R and is, therefore, indicative of the rate of decay of any dc offset. A large X/R ratio corresponds to a large time constant and a slow rate of decay, whereas a small X/R ratio indicates a small time constant and a fast rate of decay of the dc offset.

zone of influence (ZOI): An area around a ground electrode bounded by points of specified equal potential resulting from the voltage drop through the earth between the ground electrode and remote earth.

3.2 Acronyms and abbreviations

<u>2L-G</u>	<u>two lines-to-ground</u>
<u>ac</u>	<u>alternating current</u>
<u>ACSR</u>	<u>aluminum conductor, steel reinforced</u>
<u>AWG</u>	<u>American Wire Gauge</u>
<u>CT</u>	<u>current transformer</u>
<u>dc</u>	<u>direct current</u>
<u>DG</u>	<u>distributed generator</u>
<u>DS</u>	<u>distribution stations</u>
<u>EHV</u>	<u>extra high voltage</u>
<u>GIC</u>	<u>geomagnetic induced currents</u>
<u>GMR</u>	<u>geometric mean radius</u>
<u>GPR</u>	<u>ground potential rise</u>
<u>HV</u>	<u>high voltage</u>

[HVDC](#) [high-voltage direct-current](#)

[L-G](#) [line-to-ground](#)

[LI](#) [longitudinal induction](#)

[LS](#) [low-side](#)

[LV](#) [low voltage](#)

[MGN](#) [multigrounded neutral](#)

[MV](#) [medium voltage](#)

[MVA](#) [megavolt ampere](#)

[pu](#) [per unit](#)

[rms](#) [root-mean-square](#)

[ROW](#) [right-of-way](#)

[SGA](#) [System Grid Analysis](#)

[ZOI](#) [zone of influence](#)

4. Overview of technical considerations

This recommended practice considers the following:

- a) The various types of power transmission and distribution systems with respect to fault currents and fault current distribution
- b) The nature (type and location) of the faults and their determination using symmetrical component techniques
- c) The characteristics (impedances, inductances, and capacitances) of the power system and related time constants
- d) The characteristics (impedance, susceptibility, etc.) of the affected wire-line telecommunication systems
- e) The determination of the value of the station ground grid impedance to remote or true earth
- f) The determination of appropriate values of the GPR and the LI voltage and their summation and duration under varying conditions
- g) The application of probability and mitigating factors to provide more realistic and acceptable values consistent with required reliability and safety, which could affect economic decisions and trade-offs
- h) The ZOI of the GPR
- i) The rise, duration, and decay of both symmetric and asymmetric fault currents

- j) The time requirements for telecommunication channels when used for protective relaying
- k) The effects of high-voltage direct-current (HVDC), telluric, or auroral currents, or all, as well as dc power system neutral currents that can affect wire-line facilities or protective devices
- l) A few typical examples of GPR and induced voltage calculations

4.1 Telecommunication facilities

Telecommunication facilities that contain metallic components and serve electric power stations provide telecommunication circuits for a wide variety of services. Some of the telecommunication services are used for control and protective relaying purposes and are usually considered noninterruptible with respect to the occurrence of power system faults. Whenever faults involving a particular power station occur, any resulting station GPR or LI, or both, appear between the telecommunication facilities and power-station ground. Telecommunication facilities that merely pass through the ZOI of the power station may also be subject to similar interference; however, their service reliability requirements are usually not the same. The magnitude, waveform, and duration of the abnormal interfering voltages should be accurately determined to protect telecommunication facilities entering the power station or passing through the station ZOI.

4.2 Faults on power systems

Power system faults can occur at any point on a power line or in any type of power station at any voltage level. Each location has different fault characteristics. Faults can be single line-to-ground (L-G), phase-to-phase, open-phase, double line-to-ground (2L-G), or three-phase, and can progress from one to the other. These faults can theoretically be initiated at any point on the voltage or current waveform, and the resulting fault currents can attain values higher than 100 kA in North American systems. The resulting GPR or LI, or both, on adjacent telecommunication facilities can be minimal or quite high. Values of the GPR as high as 25 kV_{rms} are possible under unusual circumstances; however, most values are less than 10 kV. The waveform of the GPR voltage can vary from the symmetrical to the fully offset, as described in 5.1.5. The decay time of the direct-current component (dc offset) of the fault current may have a duration of several cycles.

Fault-current studies should be reevaluated at least every five years and more often, if required, due to the increasing MVA capacity or changing configuration of these power systems.

4.3 Power station ground grid impedance to remote earth

The power station ground grid impedance to remote earth is required in the determination of the inducing current and is used in both GPR and LI calculations.

The total power station ground grid impedance to remote earth, Z_{SGT} , is the total impedance between the power station ground and remote earth and consists of the parallel combination of [the following](#):

- a) Power station ground grid impedance itself, Z_{SG} .
- b) Combined impedance, Z_L , of all high-voltage (HV) and low-voltage (LV) ladder networks. These ladder networks are composed of overhead ground wires or neutrals with multiple tower or pole footing grounds.
- c) Incidental connected impedances, Z_i , such as rails, pipes, etc.

Z_{SGT} can be obtained by either of [the following](#) two methods:

- *Method A*—Calculations based on measurement of earth resistivity only
- *Method B*—Determinations based upon direct measurements

[Equation \(1\) summarizes the preceding sentence and all three list items \[a\), b\), c\)\]:](#)

$$\frac{1}{Z_{SGT}} = \frac{1}{Z_{SG}} + \frac{1}{Z_L} + \frac{1}{Z_i} \quad (1)$$

The choice of method will depend upon a variety of circumstances as discussed in the following subclauses.

4.3.1 Method A—Calculations based on measurement of earth resistivity only

Several mathematical models and computer methods are used by power utilities to derive the power station ground grid impedance, Z_{SG} . For example, ~~a formula~~ [an equation](#) derived from IEEE Std 80-~~2000~~ ~~1986~~, Equation (51), and good for homogeneous earth where the depth of the grid is less than 0.25 m, is [shown in Equation \(1a\)](#):

$$Z_{SG} = \rho \left(\frac{1}{4r} + \frac{1}{\ell} \right) \quad (1a)$$

where

Z_{SG} is the power station ground grid impedance (Ω)

ρ is the earth resistivity (obtained by field measurements) ($\Omega \cdot m$)

r is the equivalent radius of a power station ground grid (radius of a circle having the same area as the station ground grid) (m)

ℓ is the total length of buried horizontal ground conductors (m)

In GPR studies, calculations of the impedance of all connected overhead ground wire/tower ladder networks are required.

The impedance of a ladder for sufficiently long lines is [shown in Equation \(2\)](#):

$$Z_L = \frac{Z_s}{2} + \sqrt{\frac{Z_s^2}{4} + Z_s Z_p} \quad (2)$$

where

Z_L is the combined impedance of ladder networks (Ω)

Z_s is the per-span self-impedance of the overhead ground wire (Ω)

Z_p is the tower/pole footing impedance (Ω)

The third component, Z_i (incidental grounds) is not amenable to calculation and is omitted in this method because it can be changed without knowledge of the power utility. This omission results in an estimate of GPR that is conservative.

4.3.2 Method B—Determination based upon direct measurement

The total station ground impedance, Z_{SGT} , can be measured with the station in its operational state (all normally externally grounded metallic conductors connected). network impedance, Z_L , and incidental grounds, Z_i (for example, metallic water, gas, sewer lines, and others).

Since these connections exist when the power station is operational and since they increase the effective area of the ground grid and reduce its impedance to remote earth, they should be in place when the impedance measurement is made. Power utilities generally measure the grid impedance immediately after a new grid is constructed but before any intentional ground connections are made. This measurement is useful to check the grid against its design objective, but in itself would not be the correct value to use for GPR calculations.

The fall-of-potential method of measurement, described in IEEE Std 81.2 ~~1991~~, is appropriate for the measurement of the magnitude and phase of the impedance to earth of large grids. Refinements of this method using modern instrumentation are described in various IEEE publications (see Clause 2).

If, subsequent to the measurement, any of the incidental connections should be removed, measurements should be repeated.

4.3.3 Evaluations and applications of methods A and B

- a) *Accuracy.* Both methods require measurements, and the accuracy of each depends upon the completeness and care with which such measurements are made. Method A requires only measurements of ρ (earth resistivity). In areas of homogeneous soils a single measurement in the near vicinity of an existing or proposed station is usually all that is required; however, some utilities require that several measurements be made. In nonhomogeneous soils, where ρ may vary markedly with both horizontal displacement and depth, multiple measurements are required to categorize ρ adequately in the area of interest. This requirement is particularly true in the calculation of Z_L for long transmission lines that traverse varying terrains. Method B, on the other hand, requires measurement at an existing station with the test conductors extending outward to points beyond the influence of the station ground grid (including overhead ground wires, neutrals, and incidental grounds). Care should be exercised so that coupling between these extended ground conductors and the test leads does not introduce measurement errors.
- b) *Applications.* Method A is the only way to predict the GPR of electric power stations that have not yet been built. This method is particularly accurate for stations with relatively uncomplicated and singular grid structures. In nonhomogeneous soil earth areas, multiple measurements of earth resistivity are required to ensure accuracy. More complicated ground structures or situations require increasingly complex calculations, to the point that stations with two or more interconnected grids may be beyond the present calculating capabilities of some power utilities. Whether Method A or B is used to calculate GPR for an existing station, Method A calculation techniques are required to predict the effect of future changes in power line and grounding arrangements.

Method B can only be used on existing stations and is particularly useful for extremely complicated stations such as those that have multiple interconnected ground grids. This method is a practical way to determine the Z_{SGT} of older stations, where growth and modifications have resulted in complex ground structures or where corrosion may have reduced the effectiveness of the grounding structure. Method B ignores the effects of coupling between fault-current carrying conductors and overhead ground wires or other grounded conductors, resulting in errors in the conservative (higher GPR) direction (unless the phase conductors are used for current injection). Similarly, the test voltages used in Method B are usually too low to flashover the insulators of insulated overhead ground wires; hence, the resulting GPR values will be higher (more conservative) where insulated overhead ground wire systems are in place because such conductors do not form part of the measured circuit.

As discussed in Clause 5, the determination of the location of a line fault producing the worst-case GPR requires many of the same calculations that are used in Method A, so that Method A may be preferable, including the determination of worst-case line fault locations.

With the wide variation of conditions at different power stations, no one method of determining Z_{SGT} is best for all stations. Each power utility or substation should choose the method or methods best suited to its needs and capabilities. Larger power utilities, having more specialized engineering staffs and adequate computer capabilities, may routinely use Method A supplemented by Method B for special situations. Smaller power utilities and private substation owners may find that Method B is more suitable considering their staff and equipment. The relative costs of obtaining accurate measurements in Method B, of purchasing and operating the necessary computers for Method A, and of purchasing and operating any resulting telecommunication protection equipment are ~~all~~ among the important considerations in determining the method to be used.

Generally, in evaluating station ground impedance, both Method A and B should be used for an existing station. For a new station Method A has to be used first and when the station grounding grid is built, Method B can then be used to measure the *global (with all external ground connections)* ground impedance for verification. The fact should be pointed out that ground impedance measurement results need interpretation. Without the knowledge of the soil structure through soil resistivity measurement, correct interpretation of the ground impedance measurement cannot be achieved.

4.4 Establishing net fault current values

Power utilities, in their calculations of zero-sequence fault currents, usually do not take into account the conductive effects of the transmission and distribution line grounding network impedances (comprising overhead ground wires, neutrals, transmission tower and distribution pole footing impedances, counterpoises, and station ground grid impedances).

The net fault currents should be recalculated by including the effects of the impedances of power line ladder networks, incidental paths (pipes, rails, etc.), telecommunication cable grounds, station ground grids, and a judicious value of fault impedance.

Additional reduction of the induced voltages caused by the net fault current can be achieved by application of various shielding mechanisms available.

Care should be taken in recalculating positive sequence fault currents to include phase shifts in certain transformer windings. Substantial reduction of the net fault current can thus be achieved. The amount of reduction will depend on earth resistivity, tower/pole footing impedances, type and material of overhead ground wire or neutral conductors, span length, transmission or distribution line length, and whether or not overhead ground wire(s) are connected to the station ground grid and whether or not counterpoises and bonds are present.

4.5 Division of fault current

Generally, fault current will, at the point of fault, divide between the metallic return paths and earth. The metallic return paths will include overhead ground wires, neutrals, counterpoises, bonds, station ground grids, commonly grounded telecommunication circuits, and incidental grounds such as rail and metallic pipes. There are many factors controlling the division of power system fault current into its several paths, and calculations are usually quite complex. The determination of an accurate division of fault current requires knowledge of the earth return path impedance and the grounding system (including all other return path impedances), as shown in Clause 5.

4.6 Calculating the inducing current

The purpose for calculating the inducing current flowing in each transmission or distribution circuit connected to the power station under study is twofold:

- a) To determine the amount of fault current induced in each overhead ground wire or neutral. These currents do not cause any GPR.
- b) To determine the amount of voltage induction into nearby telecommunication circuits.

The inducing current that is used to determine the shielding action of overhead ground wires is also used to determine the LI voltage in telecommunication networks.

NOTE— The terms *overhead ground wire(s)*, *shield wire(s)*, *static wire(s)*, and *sky wire(s)* are synonymous.⁶

⁶ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

4.7 Ground potential rise ~~(GPR)~~

~~This~~ GRP is essentially the product of [the following](#):

- a) The total ground grid impedance (ZSGT) at the power system fundamental frequency to a true or remote earthing point (has to be outside the ZOI of the GPR)
- b) The total net fault current that flows through the ground grid impedance

These values should be determined by the electric power utility. See IEEE Std 80 ~~1986~~ and IEEE Std 81.2 ~~1991~~ for further information.

4.8 Sources of fault and inducing current information and impedance to remote earth information and related responsibilities of power utilities and serving telecommunication utilities

In some power utilities the necessary fault current information can be obtained from a system planning or protective relaying group. The group responsible for the determination of station ground grid impedance will usually be different from the group responsible for determining an overall impedance to a remote earthing point, including any telecommunication cable shields. Serving telecommunication utilities may be involved in this latter determination. In any event, the power utility is essentially responsible for assessing the validity of these parameters and determining the “appropriate” net fault current value to be used in the GPR calculation, its waveform and duration, and the magnitude of the inducing current. The responsibility for determining the magnitude of the GPR, the induced voltage, and their sum is that of the power utility with the cooperation of the associated telecommunication utility.

Since the electric power system originates the fault-produced interfering voltages into the telecommunication facilities serving the power station, the power utility is responsible for the accurate determination of the GPR and the induced voltage for both present and future power system arrangements by considering [the following](#):

- a) The impedance of the power station ground grid to remote earth
- b) The earth return fault current (its waveform and duration) that flows through the grid and produces the GPR
- c) The effective X/R ratio of the power system at the fault location
- d) The extent of the power station ZOI along the route of the serving telecommunication cable
- e) Fault current values and maps of the relevant power feed routes as required by a serving telecommunication utility for the computation of fault-produced induction on the serving telecommunication cables
- f) The noninterruptible channel time requirements

Since the telecommunication facilities extend into the power station to provide telecommunication service, the power utility or substation owner should advise a serving telecommunication utility of the fault-produced environment. This provision of fault-related data applies even to those cases in which the power utility or substation owner, rather than the serving telecommunication utility, provides the telecommunication protection equipment at the power station.

The telecommunication company and the power utility or substation owner should cooperate closely in determining the sum of the GPR and the induced voltage. A great deal of cooperation and trust should exist between the power utility or substation owner and the serving telecommunication company representatives, as well as with individuals within these organizations, in order to determine satisfactorily the nature of the hostile environment of the power station.

4.9 Transient voltages resulting from power system operation

Surges or transients, either unidirectional or oscillatory and usually having fast rise times, are produced by power system switching operations. These stem from switching operations involving breakers, transformer tap changers, capacitors, etc., and often result in relatively high-magnitude, short-duration voltages being induced into telecommunication wires or cables. This recommended practice is confined to the fundamental frequency and its dc offset and does not discuss surges or transients.

4.10 Types of wire-line telecommunication circuits usually requested for electric power stations as defined by some power utilities

- a) All-metallic circuits between terminals for dc and ac signals, including audio tone, that can be interrupted prior to, during, or after power system faults (noncritical channels)
- b) Nonmetallic (for example, audio tone) circuits that can be interrupted prior to, during, or after power system faults, or both (noncritical channels)
- c) All-metallic circuits between terminals for dc and ac signals, including audio tone, that cannot be interrupted (critical channels)

- d) Nonmetallic (for example, audio tone) circuits that cannot be interrupted (critical channels)

These types of services may have various requirements regarding time and fidelity of output versus input, etc.

A noninterruptible telecommunication channel usually implies that the channel be uninterrupted prior to, during, and immediately following the power fault. This document provides guidance for the time requirements of telecommunication channels relative to the various classes of power system telecommunications, including protective relaying channels prior to, during, and after the fault or circuit breaker operation.

To some degree, the assumed appropriate values of interfering voltages may well be influenced by the reliability requirements.

4.11 Service types and performance objectives for telecommunication services provided at power stations as defined in IEEE Std 487-~~1992~~

Wire-line telecommunication services into electric power stations are classified into four major types according to the following definitions:

- a) Type 1. Services requiring either dc transmission or ac and dc transmission used for
 - 1) Basic exchange telephone service, private line, or both; voice telephone service, etc.

- 2) Teletypewriter, telemetering, supervisory control, etc.
- b) Type 2. Private line services requiring ac or dc transmission, or both, used for pilot wire protective relaying or dc tripping
 - c) Type 3. Private line services requiring ac-only transmission used for telemetering, supervisory control, data, any noncritical audio tone applications, etc.
 - d) Type 4. Private line services requiring ac-only transmission used for audio tone protective relaying
 - e) [Type 5. Digital services such as DS-1 digital transmission used for T-1, ISDN, and DSL private line transport services](#)

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

- *Class A.* Noninterruptible service performance (should function before, during, and after the power fault condition)

- Class B. Self-restoring interruptible service performance (should function before and after the power fault condition)
- Class C. Interruptible service performance (can tolerate a station visit to restore service)

5. Electrical power station GPR

In order to determine the appropriate value of voltage that a station ground grid may attain relative to a remote ground point (hereafter called GPR) as a function of time, consideration should be given to at least the following:

- a) The complete data on the power system impedances, currents, and voltages for power system faults, alternate return paths such as overhead ground wire, water pipes, rails, etc.
- b) The fault locations that produce the worst combination of the GPR and the induction
- c) The duration and waveform (dc offset) of the voltages and currents for the case of the worst fault

NOTE— This assumes an evaluation of the assumed point on the voltage or current waveform for fault initiation.

- d) The ground grid impedance at the power station ground grid with respect to remote earth, and the impedance with respect to remote earth at the remote fault location

- e) The calculation of appropriate fault current values, due to the conductive effects of grounding
- f) The calculation of the GPR, induced voltages, and their vectorial sum
- g) The reduction of induced voltage due to shielding effects of transmission line conductors, overhead ground wires, and telecommunication cable shields
- h) The reduction of the GPR due to overhead ground wires

5.1 Determination of appropriate symmetrical and asymmetrical GPR

5.1.1 GPR

When a ground fault occurs, the zero-sequence fault current returns to the power system ground sources through the earth and also through alternate paths such as neutral conductors, ~~unfaulted phases,~~ overhead ground wires, messengers, counterpoises, and metallic cable shields. The ground sources are the grounded wye-connected windings of power transformers, generator grounds, shunt capacitors, frequency changers, etc. The GPR is equal to the product of the station ground grid impedance and that portion of the total fault current that flows through it. Also, the GPR is equal to the product of the alternate path impedance and that portion of the conductively coupled fault current that flows through it. The volt-time area of GPR to be determined is given in volt-seconds for the duration of the fault.

5.1.2 Ground grid impedance

Since the station ground grid impedance to remote earth is needed to calculate the GPR, the ground grid impedance shall be obtained either by the calculation or measurement methods described in 4.3.

5.1.3 Ground fault studies

A study should be made of various ground faults in order to determine the one that produces the highest GPR and volt-second area (see 5.4.4). The station ground grid impedance, as well as power overhead ground wire and telecommunication grounding networks, tend to limit the fault current and should be included in the calculations.

5.1.4 Power system generators

In the ground fault study (see 5.1.3), the power system generators are usually represented by their subtransient reactances. As the time progresses until fault clearing, their reactances increase to their transient values and possibly to their steady-state synchronous reactances. This change can be neglected in most cases and the initial subtransient reactance retained. All significant impedances should be included, such as for transmission lines.

5.1.5 DC offset

The initial magnitude of the dc offset should be calculated as a function of the voltage magnitude at the time the fault is initiated. The highest dc offset occurs when the change in current, from just before fault initiation to just after fault initiation, is maximum. Since the alternating current ([ac](#)) cannot change state instantaneously due to the inductance of the circuit, initially the dc offset counter balances the change in ac. The dc offset then decreases to zero at a rate determined from the effective reactance-~~impedance~~ [resistance, \$X/R\$](#) , ratio of the power circuit at the fault. With a highly inductive circuit, the maximum dc offset will occur when the fault is initiated close to a voltage zero crossing, a condition that is most unlikely for faults resulting from insulation breakdown. Also, a highly inductive circuit will have a prolonged dc offset. For the application of a multiplication factor for dc offset, refer to Clause 10.

Ground potentials differ from magnetically induced voltages. The transient dc component (dc offset) of the ground fault current produces a proportional but decaying ground potential. Equation (3) [is](#) used to determine the instantaneous current considering both the symmetrical and dc offset components ~~, is included in 5.4.~~

$$i = i_{ac} + i_{dc} = I \left[\sin(\omega t + \phi - \theta) - e^{-\frac{Rt}{L}} \sin(\phi - \theta) \right] \quad (3)$$

For induced voltages, the dc component is of minor importance since the induced voltage varies as $\frac{di}{dt}$. In HV networks when the fault impedance is negligible, the time constant varies; but the rate of decay of the dc component is usually within 5 ms to 40 ms and is determined by the effective power system X/R ratio. The ground fault current contains nearly a full transient or dc component if the ground fault is initiated close to voltage zero, the probability of which is very low. This [condition](#) is the instant when the resulting fault current will be at maximum. This near worst-case scenario can happen when the ground fault is caused initially by a lightning stroke or when a circuit breaker is closed into a fault. In this latter case, the pre-strike arc impedance of the breaker has the effect of reducing the initial magnitude of the dc offset. Table 1 has multiplication factors to be used on root-mean-square (rms) values to determine the total maximum peak value.

**Table 1 — Factors to be used to account for maximum effect of dc offset
on peak fault current**

<i>X/R ratio</i>	Multiplication factor
1	1.04
2	1.21
3	1.35
4	1.46
5	1.53
6	1.59
7	1.64
8	1.68
9	1.71
10	1.73
15	1.81
20	1.85
30	1.90
40	1.92
50	1.94

The shielding factor of cables for the transient dc component is poorer than the value measured at the power frequency. Moreover, a simultaneous dc component may also influence the ac shield factor of armored cables. On the other hand, the effective impedance to earth of ground electrodes containing long buried wires or cable sheaths and of lines equipped with shield wires is lower for the dc component than for the ac component.

5.1.6 Different combinations of GPR

There are four possible combinations of circumstances involving power faults that should be considered in determining the worst-case GPR at a power station. ~~With reference to~~ Figure 1, [Figure 2, Figure 3, and Figure 4 describe](#) four different ground fault conditions causing GPR at the local power station (local ground source) ~~-will be described~~. For simplicity, a single-circuit, three-phase power line with two ground sources is illustrated. A ground source at a power station is a component that can supply current to a fault and to which current returns by way of the earth and all available metallic conducting paths. Ground sources include wye-connected transformers with grounded neutrals, grounded autotransformers, and grounded generators.

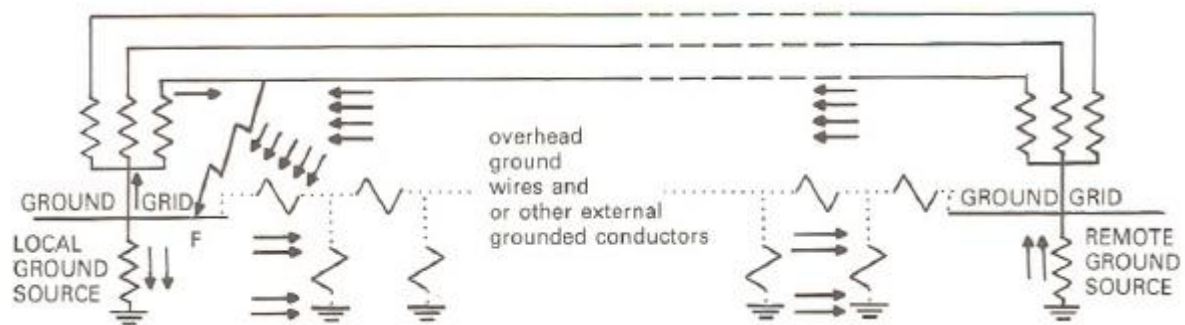


Figure 1 — Different combinations of GPR occurring at the local ground source— remote source predominates

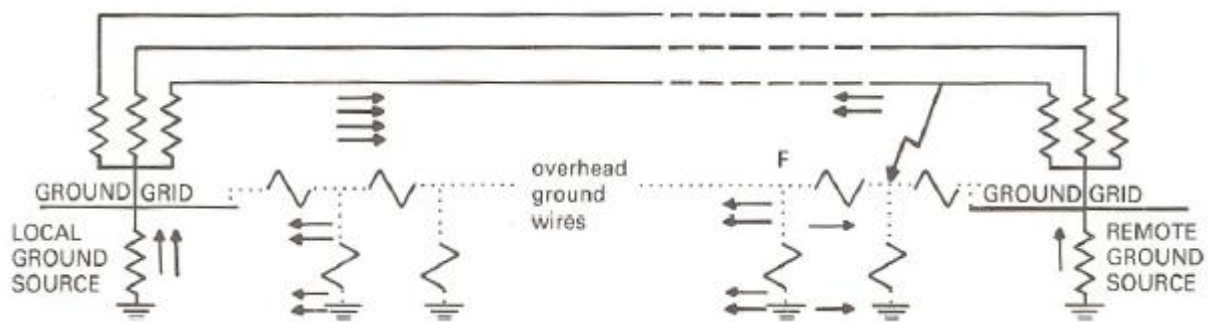


Figure 2 — Different combinations of GPR occurring at the local ground source— local source predominates

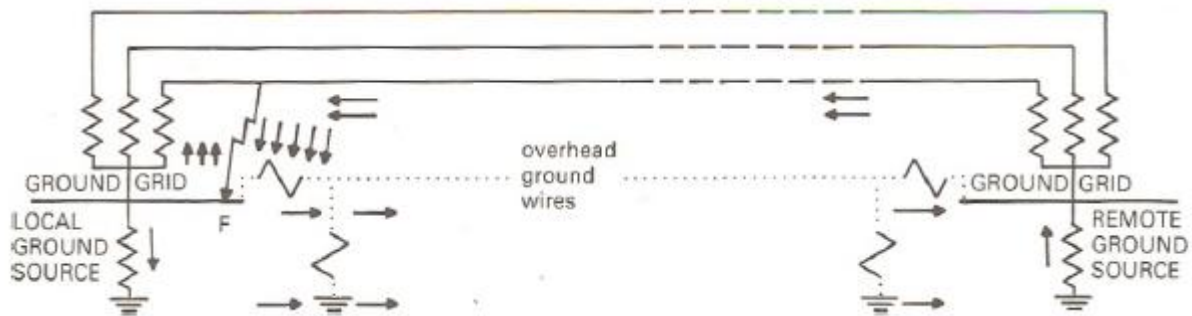


Figure 3 – Different combinations of GPR occurring at the local ground source— local source predominates

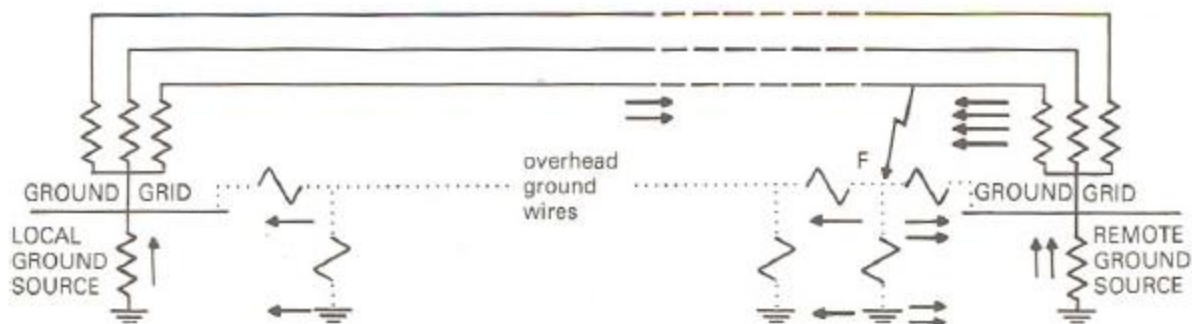


Figure 4 – Different combinations of GPR occurring at the local ground source— remote source predominates

[Notes to Figure 1 through Figure 4:](#)

NOTE 1—For simplicity, a single line with only two ground sources is illustrated.

NOTE 2—Overhead ground wires can be insulated from the towers, resulting in different values.

NOTE 3—F [is the](#) fault location.

- a) Figure 1 illustrates the situation involving a fault to the local ground grid where the remote source provides a greater amount of fault current than the local source (the remote source “predominates”). In this case, the current supplied by the local source simply circulates on the metallic grid (very little flows into the earth), therefore not producing any appreciable GPR. However, the relatively large current from the remote source returns to that source by way of the earth and all available metallic conductors, thereby producing a relatively large GPR at the local power station.
- b) Figure 2 illustrates the situation involving a line fault to remote earth (the fault location is outside the ZOI of the local power station) where the local source provides a greater amount of fault current than the remote source (the local source “predominates”). In this case, the fault currents return to their respective sources by way of the earth and all available conductors. Since the local source supplies the high-fault current, the GPR produced at the local power station will be relatively large.

- c) Figure 3 illustrates the situation involving a fault to the local ground grid where the local ground source provides a greater amount of fault current than the remote source (the local source “predominates”). The current supplied by the local source mostly does not flow into the earth and does not produce any appreciable GPR. The relatively small current from the remote source returns to that source by way of the earth and all variable metallic conductors, thereby producing a relatively small GPR at the local station.
- d) Figure 4 illustrates the situation involving a line fault to remote earth where the remote source provides a greater amount of fault current than the local source (the remote source “predominates”). The fault currents return to their respective sources by way of the earth and all available conductors. However, since the local source provides a relatively small current, this GPR produced at the local power station will be relatively small.

NOTE 4—In these examples, the cases described in items a) and b) resulted in the largest GPR at the local power station. However, all four fault conditions should be evaluated to determine the worst-case GPR at the power station of interest.

NOTE 5—Figure 1, [Figure 2](#), [Figure 3](#), and [Figure 4](#) shows a typical system, in which the externally grounded metallic conductors (including overhead ground wires) are indicated by dotted lines. Overhead ground wire systems are constructed in various configurations and may be either directly bonded to the transmission line towers or may be insulated from the towers. In addition, overhead ground wire systems may be directly connected to the station ground grid or may be terminated one or more spans out from the station. The externally grounded metallic conductors, including grounded wires, provide an alternate path for the fault current, reducing the earth return portion of the total fault current.