

Australian/New Zealand Standard™

**Earth potential rise—Protection of
telecommunications network users,
personnel and plant**

Part 2: Application guide



AS/NZS 3835.2:2006

This Joint Australian/New Zealand Standard was prepared by Joint Technical Committee ET-007, Coordinating Committee on Power and Telecommunications. It was approved on behalf of the Council of Standards Australia on 10 April 2006 and on behalf of the Council of Standards New Zealand on 14 April 2006. This Standard was published on 27 September 2006.

The following are represented on Committee ET-007:

Australian Communications and Media Authority
Co-opted Member
Electrical Regulatory Authorities Council
Energy Networks Association
NZCCPTS
Telecommunications Carriers

Additional Interests:

Energex
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PREFACE

This Standard was prepared by the joint Standards Australia/Standards New Zealand Technical Committee ET-007-01, Earth Potential Rise, Coordination of Power and Telecommunications Systems. This Standard supersedes in part the EPR Code, Issue 1, 1984 (published jointly by the Australian Telecommunications Commission ATC (now Telstra Corporation) and ESAA (now ENA Energy Network Association)).

In New Zealand, this Standard supersedes the Application Guide for EPR, August 1989, published by the New Zealand Committee for the Co-ordination of Power and Telecommunications Systems (NZCCPTS).

The objective of this part of AS/NZS 3835 is to serve as an application guide for personnel responsible for safety in the application of AS/NZS 3835.1 Part 1: *Code of practice*.

Preparation of this Standard was undertaken to update the technical content of the original EPR Code and to remove those contractual and procedural matters better dealt with elsewhere.

This Standard makes reference to publications prepared by the NZCCPTS. Enquiries concerning these publications should be directed to the secretary of NZCCPTS. Contact details for the secretary and details of NZCCPTS publications are available at the web site <http://www.nzccpts.co.nz>. Some publications are available as free downloads from the above web site.

This Standard is Part 2 of a Series dealing with Earth Potential Rise (EPR). This Standard when complete will consist of the following parts:

AS/NZS	
3835	Earth potential rise—Protection of telecommunications network users, personnel and plant
3835.1	Part 1: Code of practice
3835.2	Part 2: Application guide (this Standard)
3835.3	Part 3: Isolation arrangements for paired cable telemetering telecontrol service in LV areas and HV sites
HB 219	Earth potential rise—Protection of telecommunications network users, personnel and plant—Worked examples for the application guide

The term ‘informative’ has been used in this Standard to define the application of the appendix to which it applies. An informative appendix is only for information and guidance.

Statements expressed in mandatory terms in notes to figures, are deemed to be requirements of this Standard. ‘Shall’ indicates a requirement is mandatory, while ‘should’ indicates a recommendation and good practice.

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Australian/New Zealand Standard**Earth potential rise—Protection of telecommunications network users, personnel and plant****Part 2: Application guide**

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard is a guide to the application of the EPR Code of practice for the protection of persons or plant prescribed in AS/NZS 3835.1. This Standard is intended for personnel responsible for ensuring safety in a telecommunications service environment.

1.2 APPLICATION

This Standard shall be read in conjunction with AS/NZS 3835.1:2006.

1.3 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS	
1319	Safety signs for the occupational environment
60529	Degrees of protection provided by enclosures (IP Code)
AS/NZS	
3835	Earth potential rise—Protection of telecommunications network users, personnel and plant
3835.1	Part 1: Code of practice
60479	Effects of current on human beings and livestock
60479.1:2002	Part 1: General aspects
60950	Information technology equipment—Safety
60950.1	Part 1: General requirements
HB	
101	Coordination of power and telecommunications—Low Frequency Induction (LFI): Code of practice for the mitigation of hazardous voltages induced into telecommunications lines)
102	Coordination of power and telecommunications—Low Frequency Induction (LFI): Application Guide to the LFI Code
219	Earth potential rise—Protection of telecommunications network users, personnel and plant—Worked examples for the application guide
ANSI/IEEE	
81	IEEE Guide for measuring earth resistivity, ground impedance, and earth surface potentials of a ground system
ESAA	
EG1(2000)	Substation earthing guide

IEEE

487

Recommended practice for the protection of wire-line communication facilities serving electric supply locations

SECTION 2 DEFINITIONS

2.1 DEFINITIONS

For the purposes of this Section, the definitions of Section 2 of AS/NZS 3835.1 and the following definitions apply.

2.1.1 DOG

Aluminium conductors stranded steel reinforced (ACSR) of following construction and size:

- (a) The centre wire(s) made of galvanized steel and the outer layer(s) made of aluminium.
- (b) 6 strands of 4.72 mm aluminium conductor with 7 strands of 1.57 mm diameter steel.

NOTE: This conductor is called 'DOG' and used in this Standard and in HB 219.

2.1.2 Earth grid voltage rise (EGVR)

The potential difference between the local earth grid and remote earth due to the flow of electric current into the earth grid.

SECTION 3 EPR AND GENERAL

3.1 DESCRIPTION OF EPR

At any HV station or HV earthed structure forming part of a HV power system, the possibility exists that, due to an insulation failure, an earth fault can occur which results in current flowing through the earth, and through the earthing systems at the fault location and at the source substation.

This current raises the potential of both earthing systems, with respect to remote earth potential, for the duration of the fault.

The earthing system may vary from a simple driven earth stake with a comparatively high resistance to earth (e.g. up to 100 ohms) such as at a power pole, to a complex arrangement with very low resistance to earth (e.g. less than 1 ohm), such as a buried mesh with multiple driven electrodes.

Beyond the earthing systems, the earth potential under earth fault conditions decreases with increasing distance from the earthing system. Because of this, a potential difference may exist between any two points at different distances from the earthing system (see Figure 3.1).

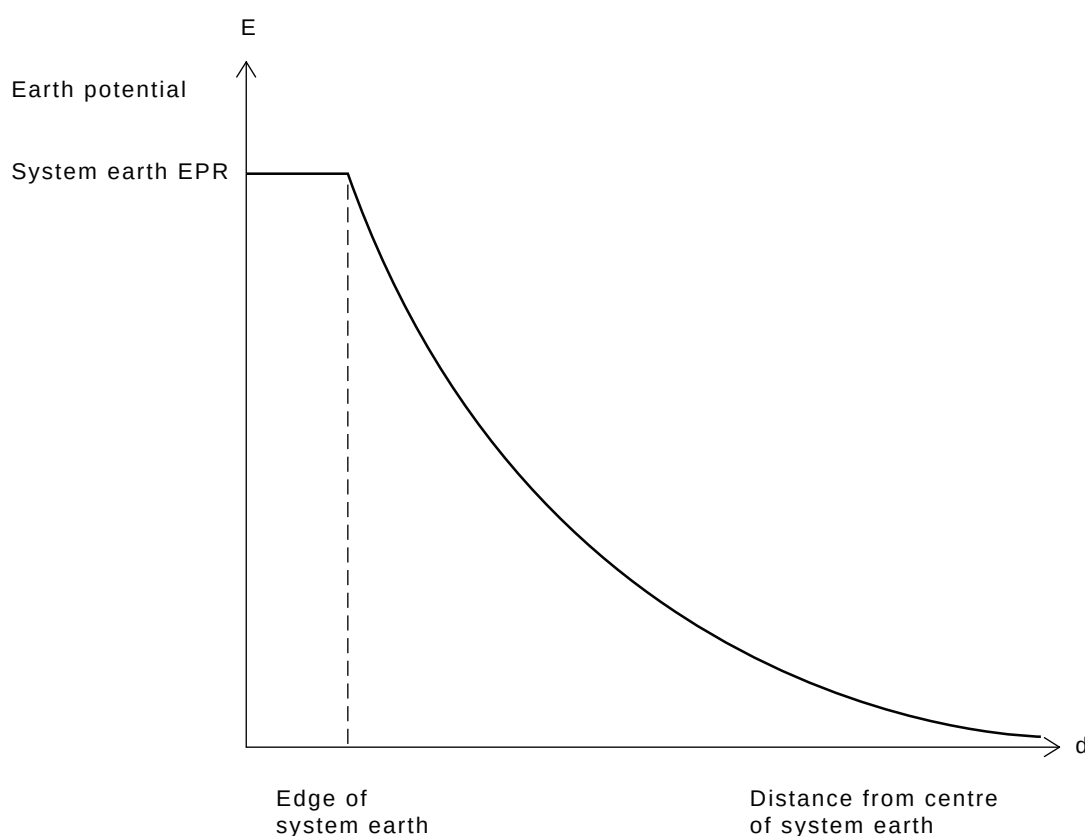


FIGURE 3.1 EARTH POTENTIAL RISE VARIATION WITH DISTANCE DURING AN EARTH FAULT CONDITION

There may exist around the earthing system, an area known as the hazard zone, in which the earth potential is of sufficient magnitude to present a hazard to members of the public, or to telecommunications personnel, users or plant. This hazard zone may extend out only a metre or two, or out hundreds of metres from the earthing system.

It is shown graphically by EPR contours (lines joining points at the same earth potential, throughout the duration of a power system fault involving the earth system).

It should be noted that any conductor connected, either directly or indirectly, to an earth inside the hazard zone, will alter the EPR contours. Examples are water pipes, metal sheathed or armoured telecommunications cables, metal sheathed or armoured power cables, power multiple earthed neutral systems, and overhead earth wires (OHEWs).

If people or equipment in this area are connected to a remote earth via an insulated conductor (e.g. all working telephone circuits in a telecommunications cable are connected, via electronic equipment in the telephone exchange, to the (remote) exchange earth), they can be subjected to the potential difference between the local EPR and the remote earth potential. Likewise, if the EPR causes insulation breakdown to conductors in a telecommunications cable, people or equipment at remote locations (at remote earth potential) could be connected via a conductor in that telecommunications cable to the hazard zone potential. These voltages may be hazardous to telecommunications personnel, users or plant.

Together with AS/NZS 3835.1 this Standard defines the conditions to be met and the procedures to be followed in the planning and design of power and telecommunications systems so as to control the level of EPR hazard to telecommunications personnel, users or plant within acceptable limits.

3.2 SOME EPR HAZARD SITUATIONS TO CONSIDER

3.2.1 Telecommunications cables passing through a hazard zone

Working conductors in a buried telecommunications cable will normally be connected to a remote earth (typically to the telephone exchange earth, via a relay set winding or electronic line circuit in the exchange). During a power earth fault, the insulation of the sheath and conductors of a telecommunications cable passing through a hazard zone will be subjected to the difference between the potential of the local earth surrounding the cable, and the remote earth potential on the conductors inside the cable.

If the insulation of the telecommunications cable sheath and conductors breaks down, this hazardous voltage will be impressed on the conductors in the cable and be transferred to locations possibly a considerable distance away from the hazard zone, where it could present a hazard to telecommunications personnel and users (see Figure 3.2).

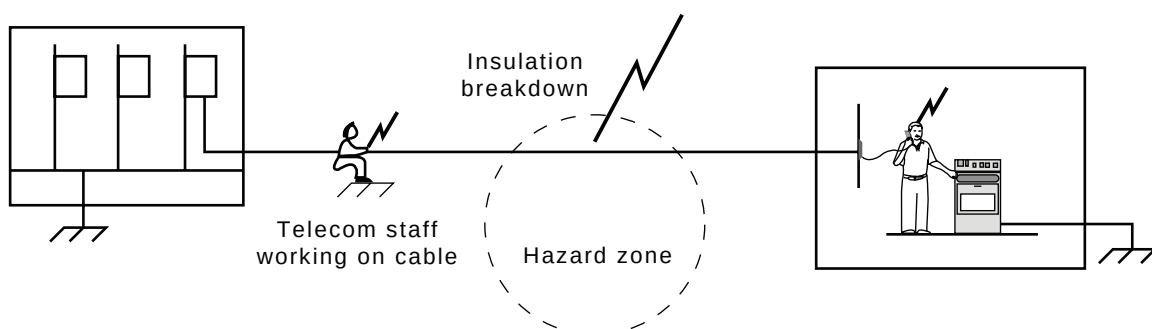


FIGURE 3.2 TELECOMMUNICATIONS CABLES PASSING THROUGH A HAZARD ZONE.

Telecommunications personnel working on telecommunications network plant inside the hazard zone could find themselves at hazard if they are simultaneously in low insulation contact with both remotely earthed telecommunications conductors and the local earth (which can rise to hazardous EPR levels during a power fault).

3.2.2 Telecommunications equipment installed inside a building which may have a hazardous EPR on its power earth

The 'effective' potential in a building is the potential of its LV (MEN) power earth. All electrical equipment in the building get their earth reference from this earth, and all exposed metalwork (e.g. kitchen sink, oven, etc.) should be bonded to this earth. If the associated distribution transformer is close and serves only that house (e.g. rural areas), the potential on the local power earth will be very close to the potential that the ground underneath the building would otherwise have.

However if the associated distribution transformer serves a number of buildings, all of whose local power earths are bonded together by the LV MEN (multiple earthed neutral) system, then all the building potentials will be approximately the same. This common MEN potential will be approximately the average of the EPRs that would otherwise appear in the ground underneath each building. Each building effectively becomes an EPR 'island' within the normal EPR contours. This effect is shown in the EPR drop-off curve diagram (see Figure 3.3).

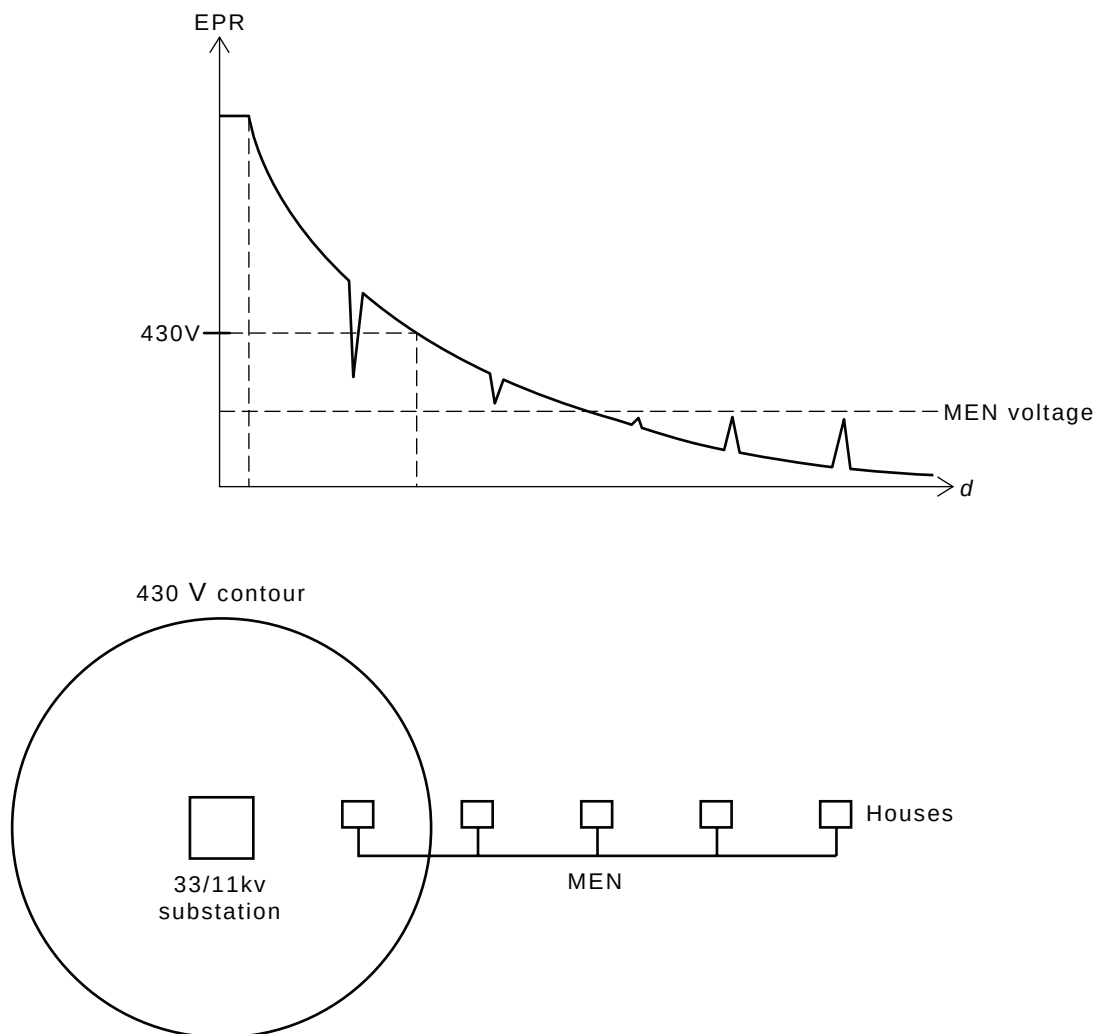


FIGURE 3.3 EFFECT OF MEN ON EPR DROP-OFF CURVE

Often, most buildings bonded to the MEN system will be outside the hazard zone. However those buildings inside the hazard zone will have disproportionately high EPRs. Unless only a few buildings are involved, the nett effect of this on the MEN potential will normally be quite difficult to model or calculate accurately—especially if the local distribution transformer MEN system is bonded to adjacent distribution transformer MEN systems. However this MEN potential can be readily measured during current injection tests.

If a building located within a hazard zone has a non-hazardous EPR on its MEN power earth, then no mitigation will be needed for the people and telecommunications plant in the house. However the possible problems with telecommunications cables passing through a hazard zone will still need to be considered (see Clause 3.2.1).

If the MEN potential that applies to a number of buildings is hazardous, all those buildings will need to be mitigated, including those outside the hazard zone.

Telecommunications equipment (e.g. telephones, PABXs, etc.) installed inside a building that can have a hazardous EPR on its MEN power earth, may give rise to a hazard to telecommunications personnel and users for the duration of the power earth fault, via the following mechanisms:

- (a) A person operating the equipment may be in contact with both—
 - (i) a remote earth potential (e.g. telephone exchange earth) brought in via a telecommunications cable or line; and
 - (ii) the local earth, typically via the body of a metallic appliance (or sink) bonded to the local power earth (see Figure 3.4).

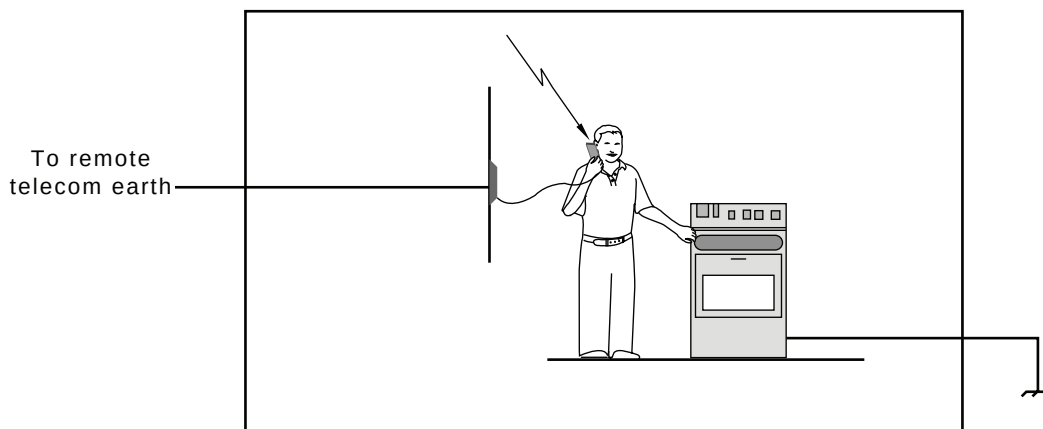


FIGURE 3.4 PERSON USING A TELEPHONE IN A BUILDING WITH HAZARDOUS EPR ON ITS POWER EARTH

- (b) During a power earth fault there may be a breakdown in the insulation within the telecommunications equipment, between the parts connected to remote earth potential via the telecommunications cable or line, and the parts connected to the local power earth, when this equipment is located in buildings that can have hazardous EPRs on their MEN power earths. This is particularly likely with mains-powered telecommunications equipment (e.g. computer modems, fax machines, answering machines), which have both these potentials present in the same piece of equipment. Any lightning protection in the equipment will ensure a relatively low insulation ‘pathway’ between the telecommunications line and the local power earth—the insulation of this pathway will depend on the firing voltage of the lightning protection electronics.

AS/NZS 60950.1 requires that any surge protection in user's mains-powered telecommunications equipment have a minimum d.c. sparkover voltage of '1.6 × upper voltage of the rated voltage range for the equipment' (normally 220 V to 240 V r.m.s.) = $1.6 \times 240 \text{ V r.m.s.} = 384 \text{ V d.c.}$ The minimum voltage needed to cause the surge protector to fire = 384 V d.c. – the exchange battery voltage of up to 52 V d.c. = 332 V d.c. This is equivalent to 235 V r.m.s.

This could result in a hazardous voltage being impressed on the telecommunications conductors and being transferred to well outside the hazard zone (see Figure 3.5).

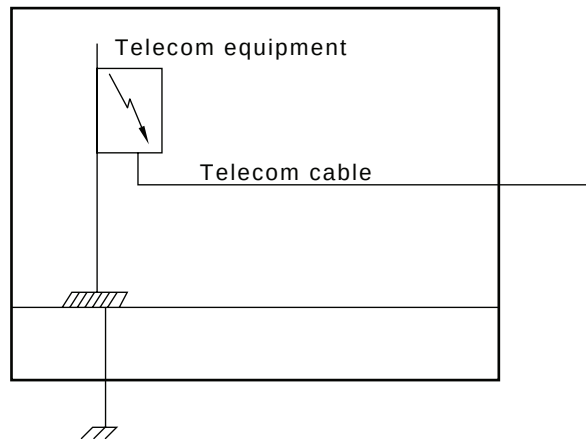


FIGURE 3.5 BREAKDOWN OF INSULATION IN TELECOMMUNICATIONS EQUIPMENT LOCATED IN A BUILDING WITH HAZARDOUS EPR ON ITS POWER EARTH

- (c) If the telecommunications equipment is connected to the local power earth for signalling purposes (e.g. earth start PABXs, 2-party telephones), the local power earth EPR hazard voltage could be transferred to well outside the hazard zone via the conductors in the telecommunications cable or line (see Figure 3.6).

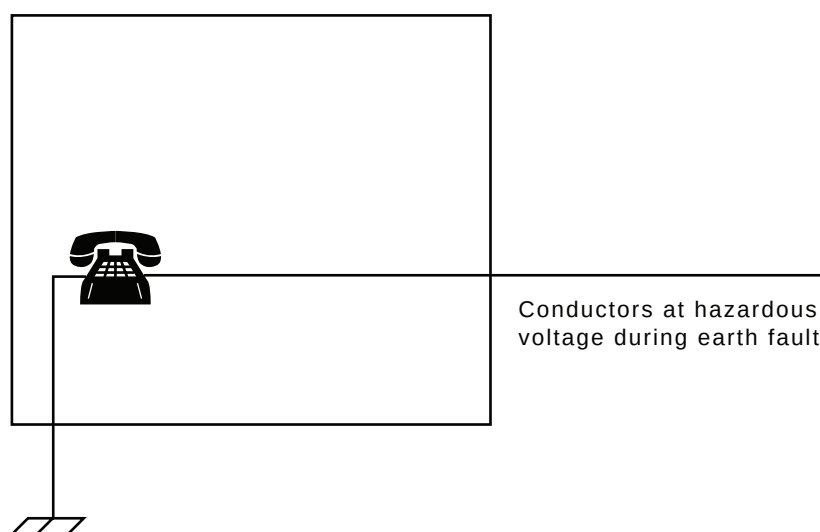


FIGURE 3.6 TELECOMMUNICATIONS EQUIPMENT WITH A LOCAL SIGNALLING EARTH CONNECTION, LOCATED IN A BUILDING WITH HAZARDOUS EPR ON ITS POWER EARTH

3.2.3 Voltage hazard relevant to telecommunications network

The voltage that telecommunications users, personnel and plant could become exposed to is the potential difference between the local (power fault) EPR level, and the potential on the telecommunications conductors (normally the potential of the local telephone exchange earthing system). Usually the local telephone exchange earthing system is effectively at remote earth potential, making the EPR level (relative to remote earth) the relevant 'hazard voltage' level.

However, in some situations, the potential on the telecommunications conductors (relative to remote earth) during the fault may be significant, and may exceed the EPR hazard voltage limit, without creating a hazardous situation. An example of this could be a telecommunications network street-mounted user's multiplex cabinet, fed from the exchange by non-metallic fibre-optic cable, powered from the local LV supply, and situated inside the hazard zone of an HV station. All the multiplex cabinet's user circuits (initial and future) could terminate in houses bonded to the same extensive MEN system to which the multiplex cabinet is bonded. In this case even though the potential on the cabinet earthing system relative to remote earth could exceed the EPR hazard voltage limit, the difference in potential between the cabinet and any of the houses may be well within the hazard voltage limit so no mitigation is required at the cabinet or in the houses. The issues relating to telecommunications cables passing through a hazard zone would still need to be checked, and if necessary, addressed.

3.3 CONSIDERATION OF POWER UTILITY CONSTRUCTION PROPOSALS

Any new proposals for HV construction, or alterations to the existing HV network need to be checked to see whether a new EPR hazard will be created or the size of the existing EPR hazard zone will increase.

Alterations to the existing network that could introduce new EPR hazards, or increase the size of existing EPR hazard zones, include the following:

- (a) Lowering the HV earth fault circuit impedance between the source and fault earthing systems. Methods of doing this include—
 - (i) increasing the line or cable conductor size; or
 - (ii) replacing the source transformer with a larger transformer.

This will increase the HV earth fault current, increasing both EPRs and low frequency induction (LFI).
- (b) Increasing the voltage of an existing HV line or cable. This may increase the HV earth fault current, increasing both EPRs and LFI.
- (c) Increasing the size of an HV earthing system. While this will reduce the resistance of the HV earthing system, and the EPR on this earthing system, it often increases the extent of EPR hazard zone. Methods of increasing the size of an HV earthing system include—
 - (i) adding new earth conductors, radials, to the HV earthing system; if done symmetrically, this will increase the EPR in the ground at virtually all points beyond the earthing system; or
 - (ii) bonding the HV earthing system to other remote earth(s) (e.g. via a HV cable sheath). This will reduce the EPR hazard zone around the HV earthing system, but at the same time will introduce new EPR hazard zone(s) around the remote earth(s).
- (d) Replacing a HV non-conductive pole (e.g. wood) with a conductive pole (e.g. concrete).

SECTION 4 EPR HAZARD VOLTAGE LIMITS

4.1 INTRODUCTION

From time to time, faults occur on power systems causing currents to flow to earth. The earthing impedance at the fault point and the magnitude of the fault current determine the local EPR. Beyond the fault point, the earth potential decreases as the distance from the fault point increases. Hence the area around the fault point may be described by equipotential contours.

Voltages may be dangerous and are classified as hazardous if they exceed a specified value for a specified time. The area within the contour (where the voltage exceeds the hazardous level for the specified time) is defined as a hazard zone.

4.2 RISK OF EPR HAZARD

Hazardous EPR occurs only during an earth fault condition on the power system. The fault duration may vary from one cycle (20 msec) to several seconds depending on the speed of operation of the power system protection equipment.

The probability that an earth fault will occur at a particular steel tower or pole or point on a power cable is very low. The probability of a fault occurring at a particular distribution substation is higher but still low. HV stations containing transformers with earthed star points offer the highest risk of occurrence of EPR because they may have many power lines radiating from them and are often interconnected with other stations. This means EPR on the HV station earthing system can be caused by either an earth fault at the HV station or by an earth fault on any of these downstream lines. However, the larger HV stations usually have a low-impedance connection to earth, so that the highest EPRs do not necessarily occur at these larger stations.

Maximum EPRs are calculated for the worst case of HV system arrangement and fault location that can reasonably occur, and should also take into account future development.

When these hazardous EPRs occur, any nearby (permanently connected) telecommunications plant will be exposed to voltage stress, and could be damaged (if its insulation is less than the EPR at that location). However when hazard to humans is considered, further probability factors must be included.

The risk of exposure to EPR is probabilistic, in that before any injury to a person can occur—

- (a) a power system fault must occur;
- (b) the magnitude and duration of the power system fault current must be sufficient to cause a hazardous EPR;
- (c) a person must be working on or using the telecommunications system in the area exposed to the hazardous EPR, and be simultaneously in contact with both the local earth and a telecommunications system conductor, during the brief duration of the fault; and
- (d) contact impedances (e.g. shoes, insulation of the telecommunications conductor/equipment) must be insufficient to limit the human body current to non-hazardous levels.

4.3 AUSTRALIAN EPR HAZARD VOLTAGE LIMITS

EPR voltage limits in Australia have been applied in practice since the early 1980s. The limits adopted were the same as those established in the early 1970s for hazardous induction, as detailed in HB 101.

The Australian limits are applicable for—

- (a) telecommunications network users; and
- (b) telecommunications personnel who are adequately trained, follow approved work practices and wear normal protective clothing.

The basic limits for safety are based on the standards to which a power line and its protection equipment are installed. The limits are specified in Table 4.1 of AS/NZS 3835.1.

The probabilistic nature of EPR hazard is factored in a simplified way into the Australian EPR hazard zone limits by means of the reliability category of the HV site (high or low).

In determining the applicable EPR hazard voltage limit for a HV site, the reliability category (high or low) is derived from the sum of all the fault risks present, e.g. taking account of multiple lines terminating at a substation or additional risk due to faults within the substation.

Australian EPR hazard zone limits are given in Table 4.2 of AS/NZS 3835.1.

NOTE: Appendix A provides an approximate guide to the extent of typical hazard zones for a range of conditions.

HV sites have been categorized according to normally expected frequency of earth fault generated EPR. HV sites such as multi-line substations and those associated with lines operating at voltages less than 100 kV can be subject to faults generating higher value EPR relatively more frequently. This increased probability of occurrence is compensated for by reducing the maximum allowable voltage limit for defining EPR hazard zones.

To select the appropriate allowable EPR voltage limit, knowledge of the earth fault clearance time and the reliability status of the line is required. The clearance time is made up of the primary protection operating time of the appropriate protection scheme and the circuit interruption time.

For complex HV sites involving more than one power system voltage level or circuits with different earth fault clearance times, it may be necessary to determine several hazard zones.

4.4 BASIS OF AUSTRALIAN EPR HAZARD VOLTAGE LIMITS

ITU-T (formerly CCITT) had for many years specified a limit of 650 V for fault durations less than 0.5 s, and 430 V for fault durations greater than 0.5 s. These values were established before research showed that as the current duration decreases from 5 s down to 50 ms, the heart can withstand much higher levels of current.

More recent work from the ITU-T Study Group 5 has reviewed this situation and has established that, provided all impedances in the 'hazard circuit' remain constant (i.e. no insulation breakdown occurs), the risk associated with each of the maximum voltage limits of the voltage limit/duration envelopes adopted by ITU-T in Recommendation K.33 (i.e. 2000 V for 0.1 s, 1500 V for 0.2 s, 1000 V for 0.35 s, 650 V for 0.5 s), is no greater than the risk associated with the maximum voltage limits of the previous ITU-T limit of 650 V for durations up to 0.5 s. (See Appendix C).

It should however be noted that if the 'hazard circuit' includes an impedance that is extremely non-linear (e.g. insulation breakdown occurs) over the voltage range 650 V to the higher limit voltages, then these new maximum voltage limits will not be 'safer' than 650 V for 0.5 s. An example of this would be an item of telecommunications equipment with an insulation breakdown voltage of say 1100 V. The hazard associated with 1500 V for 0.2 s, would now be much greater than that for 650 V for 0.5 s. For this reason, care needs to be exercised when employing any of these higher voltage limits for an EPR hazard situation, to ensure that any insulated telecommunications plant (or other key impedances) in the 'human hazard circuit', has an insulation rating in excess of the EPR hazard voltage limit to be applied.

Similarly, care needs to be exercised whenever there is a change (planned or otherwise) involving a reduction in the inherent insulation levels of new telecommunications practices or new plant (especially plant in user's premises, including telecommunications equipment). If the new inherent insulation level is below the maximum hazard voltage limit voltage (1500 V in Australia), the previous history showing that the application of these limits has not resulted in any apparent problems, may no longer be relevant to the new situation, and these limits may need to be revisited. Fortunately, virtually all new telecommunications network developments currently involve an increase in the inherent insulation level, rather than a decrease.

In Australia, research was performed to establish the sensitivity of the heart to electrical currents. From this research, a new set of voltage limits for high reliability circuits was established in the early 1970s. These were 1500 V for fault durations ≤ 0.35 s, and 1000 V for fault durations > 0.35 s but ≤ 0.5 s. For fault durations > 0.5 s, or for circuits that were not high reliability, the previous ITU-T 430 V limit still applied. These limits have been applied in Australia for induction hazard since the early 1970s, and for EPR hazard since the early 1980s. No new research has provided data to justify reducing these limits, and they have resulted in acceptably safe and economically viable coordination practices in power and telecommunications systems in Australia. Because of this history in Australia, AS/NZS 3835.1 continues the use of the existing Australian EPR hazard limits in Australia.

4.5 NEW ZEALAND EPR HAZARD VOLTAGE LIMITS

The New Zealand EPR hazard voltage limits are prescribed in the New Zealand Electricity Regulations. The key elements of the relevant regulation (ER 58) in the 1997 Electricity Regulations are—

- (a) any person constructing a power or telecommunications work (or installation), must ensure their construction does not cause any induced voltage, EPR or human shock currents that are likely to cause hazard to person, or damage to telecommunications plant;
- (b) human shock currents whose magnitude and duration fall within Zone AC-1 or AC-2 of Figure 14 of AS/NZS 60479.1:2002 are deemed not to be likely to cause hazard to persons; and
- (c) induced voltages that do not exceed—
 - (i) 430 V r.m.s. for durations > 0.5 s and ≤ 5 s; *or*
 - (ii) 650 V r.m.s. for duration ≤ 0.5 s
 are deemed not to be likely to cause damage to telecommunications plant.

Compliance with the New Zealand legislative requirements for EPR can be achieved by either—

- (i) demonstrating that both—
 - (A) the magnitude and duration of any human shock currents fall within Zones AC-1 or AC-2 of Figure 14 of AS/NZS 60479.1:2002; and
 - (B) the EPR is not likely to cause damage to telecommunications plant; *or*
- (ii) demonstrating by way of a risk study, that the EPR is not likely to cause any hazard to persons, or damage to telecommunications plant.

To ascertain the New Zealand EPR hazard voltage limits at any future time, refer to the latest version of the New Zealand Electricity Regulations.

4.6 BASIS OF NEW ZEALAND EPR HAZARD VOLTAGE LIMITS

New Zealand has a very large number of low probability EPR hazard situations where the prospective EPR is well in excess of either the Australian or the European (ITU-T) hazard voltage limits. For this reason it would be uneconomical to apply either of these sets of hazard voltage limits in New Zealand, without also allowing a risk study ‘escape clause’, which allows the option of demonstrating by way of a risk study, that the EPR is not likely to cause a hazard to persons, or damage to telecommunications plant.

A classic example of the sort of EPR problems New Zealand has is its rural distribution transformers, which typically have prospective EPRs in the range 3 kV to 6 kV. New Zealand generally has much higher prospective EPR voltages at its rural distribution transformers than comparable overseas countries (e.g. Europe, USA, Australia, Japan), because the New Zealand power system has the combination of—

- (a) a common HV/LV earthing system at the distribution transformer. This means any EPR from a HV fault at the distribution transformer will appear on the LV neutral. This conducts this EPR (virtually in full) into all houses supplied by that distribution transformer. (In Australia, separate HV and LV earths are required unless the combined HV/LV earth resistance is less than 1 Ω .);
- (b) high soil resistivity, resulting in relatively high rural distribution transformer HV/LV earthing system resistances (typically 10 Ω to 300 Ω);
- (c) a solidly earthed neutral on the zone substation 11 kV supply transformers. Virtually all European countries have isolated or impedance earthed neutrals (e.g. NERs, reactors, Petersen coils, arc suppression coils). Australia, New Zealand, USA and about 50% of the United Kingdom distribution voltage power systems are solidly earthed; and
- (d) no HV neutral. In the USA, the distribution voltage power systems are solidly earthed, and their distribution transformers have a common HV/LV earthing system, but their use of a HV neutral means distribution transformer fault EPRs are usually greatly reduced compared with the equivalent New Zealand situation.

The problem presented by high prospective EPR levels in rural New Zealand is mitigated to some degree by—

- (i) very low lightning incidence, making the probability of power faults which could cause EPR lower; and
- (ii) relatively sparse rural population density (i.e. lower number of telephone circuits and equipment).

SECTION 5 ASSESSMENT OF EPR

5.1 EPR ASSESSMENT PROCESS

The assessment process is summarized in Figure 5.1 and the steps involved in the process are explained following Figure 5.1.

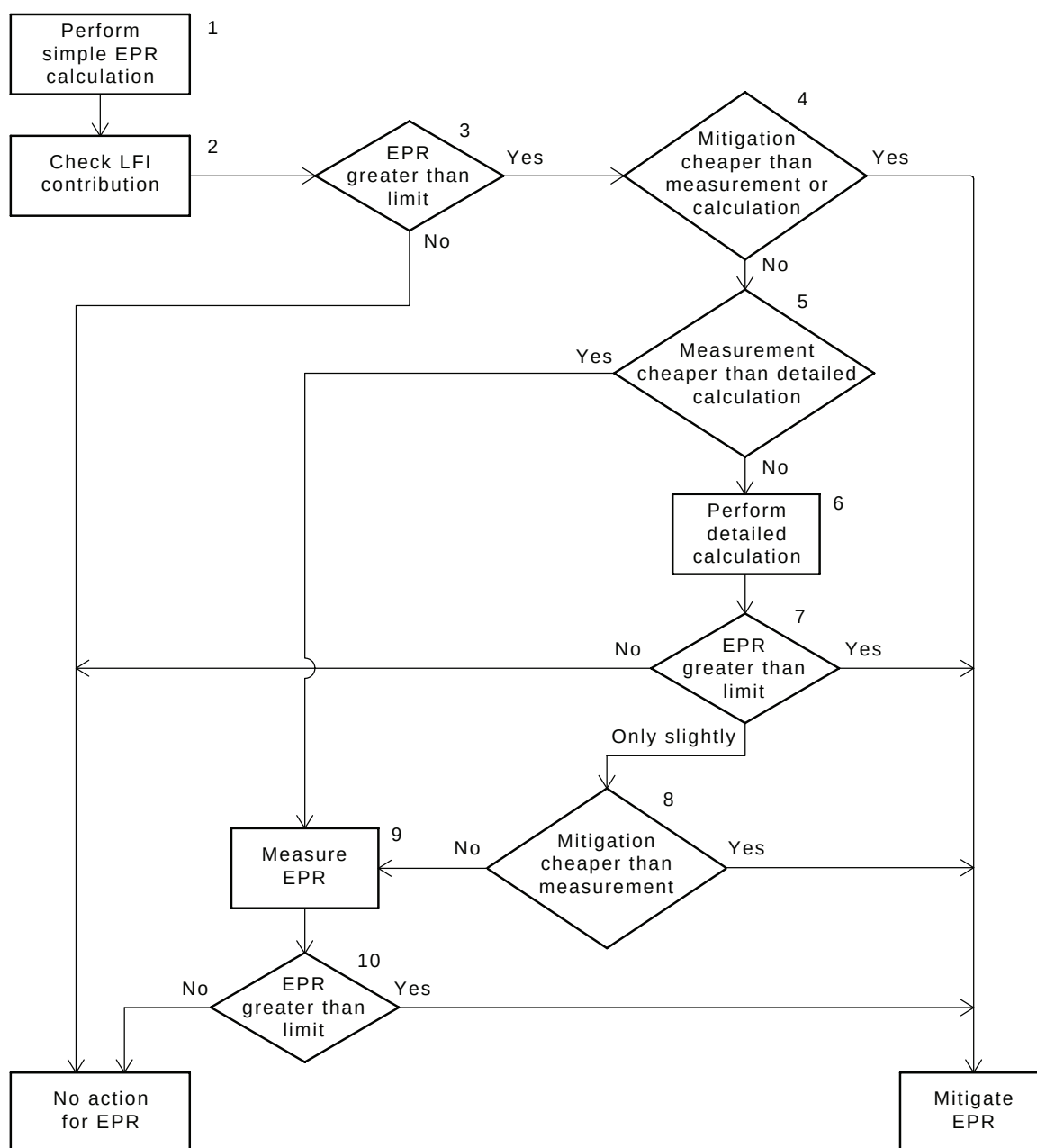


FIGURE 5.1 EPR ASSESSMENT PROCESS

- Step 1 Perform the simple calculation (Equation 5.1 in Clause 5.3.2) using readily available or easily calculated values to establish the approximate EPR at the required location.
- Conservative approximations may determine that—
- (i) the maximum prospective fault current is used rather than the earth grid current;
 - (ii) the local grid impedance is used without the inclusion of auxiliary earthing impedances (e.g. bonded by means of cable sheaths); and
 - (iii) simple EPR contour distance equations (Equations 5.5 and 5.6) are used.
- Step 2 Where an earth fault occurs on a HV power system, the fault current may induce a voltage into telecommunications lines (running parallel to power lines) due to electromagnetic coupling known as low frequency induction (LFI). If so, the LFI must be added to the EPR (see Clause 5.2). See also HB 101 and HB 102.
- The vector sum of EPR and LFI should be used in subsequent decision-making in Steps 3, 6-7 and 9-10.
- Step 3 Where the calculated EPR is less than the limit, take no further action.
- Step 4 Where the cost of mitigation (e.g. by reducing fault levels, or isolating telecommunications lines) is less than that of establishing a more accurate EPR (by measurement or by detailed calculation), implement mitigation, i.e. the cheapest solution.
- Step 5 Choose between establishing a more accurate EPR level by using more detailed calculations or by measuring the EPR (see Clause 6.4). Base the choice on the most cost-effective solution. However, in some cases, calculation may still result in the need to take measurements.
- Step 6 Obtain more accurate information on key parameters and re-calculate the EPR. It may require several iterations of this process. More accurate calculation of the EPR level may require computer modelling and/or measurement of key parameters.
- Step 7 Where the calculated EPR is less than the limit, no further action is required.
- Where the calculated EPR is above the limit, but the calculation is conservative, consider taking EPR measurements. In some situations, this will establish that the actual EPR is safe. Where the detailed calculation indicates that the EPR is well above the limit, measurements will normally confirm the need for mitigation and therefore in such a case mitigation without measurement is appropriate.
- Step 8 Before performing a measurement, compare the costs of the measurement with the costs of mitigation. A least-cost solution is usually preferred.
- Step 9 A properly performed measurement (see Clause 6.4) will normally give the best estimate of the EPR. Use maximum fault current levels and perform calculations to convert the measured values to working EPR values.
- Step 10 This is the final decision on the need to mitigate (see Section 7).

5.2 COMBINED EPR AND LFI EFFECTS

Special care should be taken when assessing hazards associated with communication lines which are exposed to both EPR (i.e. close to substation) and LFI (i.e. parallel to faulted power system conductors). Both sources of hazard should be quantified and summated.

As a first estimate, the magnitudes of both sources of hazard may be added in quadrature. To avoid overestimating the hazard, care should be taken to determine phase relationships between the two hazard voltages. Where the telecommunications line is already installed, an injection test over the power line will simulate the real fault condition. HB 101 and HB 102 provide details regarding methods for calculating induction hazard levels.

5.3 HAZARD CALCULATIONS IN SMALL INSTALLATIONS

5.3.1 General

This Clause addresses the EPR hazard calculations associated with smaller installations such as tower footings and pole top substations.

The EPR and its zone of influence, from an earthing system, will be determined by the geometry of the earthing arrangement, the variations in earth resistivity, any nearby conductive structures and the fault current magnitude. The accuracy of an analysis of any real situation is often limited because of difficulties in quantifying these influences. However, it is often possible to gain sufficient accuracy with the use of simplified formulae and, therefore, such formulae are of value in the analysis of real earthing systems for power coordination.

The important consideration with the use of any simplified formulae is the knowledge of the limitations of such formulae (see Step 1 in Clause 5.1). This Clause outlines some simplified approaches to the analysis of EPR. Clause 5.7 outlines the limitations of applying simplified calculations.

5.3.2 EPR calculation

EPR contours are more readily established if the maximum EPR V_{grid} is known. The value of V_{grid} can be calculated if the resistance of the earth and the maximum fault current is known.

The EPR (V_{grid}) from Equation 5.1 is calculated as the product of the grid impedance (Z_{grid}) and the portion of earth fault current (I_g) that flows conductively through the earthing installations to earth.

$$V_{\text{grid}} = I_g \times Z_{\text{grid}} \quad \dots 5.1$$

The parameters are determined as follows:

(a) Fault current (I_g)

The component of line-to-earth (LE) or line-to-line-to-earth (LLE) fault current entering the earthing system. As a first pass the full earth fault current may be assumed to flow conductively to earth through the metalwork comprising the earthing system. If further refinement is required, the component of fault current which is inductively coupled back to the source may be calculated. Methods for determining the value of shielding or screening factors of the overhead earthwires or cable sheath on lines feeding fault current are found in the ESAA EG1(2000).

(b) Grid impedance (Z_{grid})

Z_{grid} is the earthing system impedance composed of the combination of all connected earth impedances that may carry fault currents returning to the source(s). The value of Z_{grid} may be calculated using the empirical approximations given in Clause 5.4, or the more accurate computer modelled result discussed in Clause 5.11. The empirical approximations provide sufficient accuracy for calculations for smaller installations, provided the 'boundary' conditions are met.

Care should be taken to match calculations to actual system configurations, especially when the system is being implemented in stages.

5.4 ELECTRODES

5.4.1 General

Various forms of electrodes are used for earthing. These include electrodes installed solely for earthing purposes and other connected, buried conductive structures (installed for other purposes). These two types are called primary earth electrodes, and auxiliary earth electrodes respectively.

Earthgrids, counterpoise conductors and earth rods are typical primary electrodes.

Underground metallic structures, overhead earthwires, underground cable sheaths and reinforcing bars encased in concrete, if connected to the earthing grid, are typical auxiliary electrodes.

5.4.2 Primary electrodes

Assuming homogenous resistivity, earth resistances can be calculated using simple equations, as follows (see also Figure 5.2):

(a) For a simple vertical rod—

$$R = \frac{\rho}{2\pi L} \left[\log_e \left(\frac{4L}{r} \right) - 1 \right] \quad \dots 5.2$$

where

R	=	resistance in ohms
ρ	=	earth resistivity in ohm metres ($\Omega \cdot m$)
L	=	length of rod in metres
r	=	radius of rod in metres

(b) For a buried horizontal wire—

$$R = \frac{\rho}{\pi L} \left[\log_e \frac{2L}{\sqrt{2Dr}} - 1 \right] \quad \dots 5.3$$

where

L	=	length of buried wire in metres
r	=	radius of wire in metres
D	=	depth of burial in metres

(c) For a buried large flat plate—

$$R = \frac{\rho}{4} \times \sqrt{\left(\frac{\pi}{A} \right)} = 0.44 \frac{\rho}{\sqrt{A}} \quad \dots 5.4$$

where

A	=	area of the flat plate in square metres.
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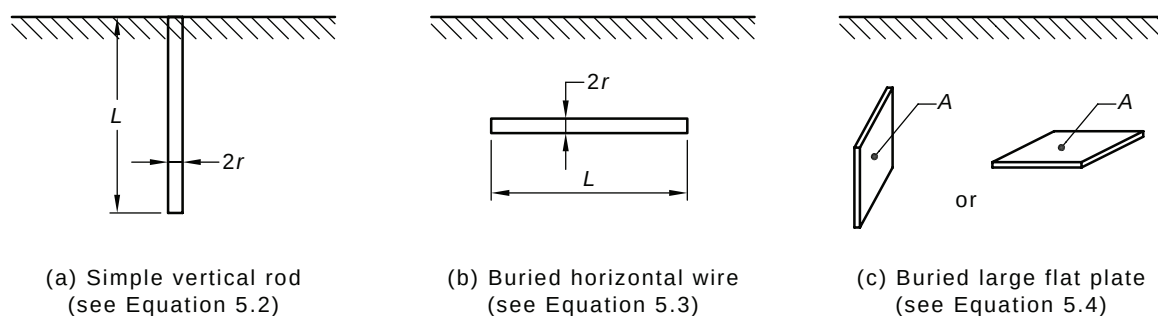


FIGURE 5.2 DETAILS OF PRIMARY ELECTRODES

For more complicated systems more detailed formulae are provided in ESAA EG1(2000). Alternatively computer programs may be used as described in Clause 5.11.

5.5 ESTIMATION OF EARTH FAULT CURRENTS

The simplest estimate of the earth fault current is the future maximum line-earth fault current at the fault point, ignoring the effect of alternative earth fault return paths. If the grid impedance is known, this should be included in the earth fault current calculation. If not, a conservative estimate can be made by assuming the grid impedance to be zero. Such a value is simple to calculate, and is usually available from fault calculation programs. Similarly, a realistic estimate of the fault impedance should be included in the earth fault current calculation to ensure a more accurate value.

5.6 SURFACE VOLTAGE GRADIENTS

5.6.1 Earth resistivity known

The simplest earthing system to analyse is a hemispherical earth electrode. A hemispherical earth electrode in a homogenous earth will radiate hemispherical contours of equipotential voltage. The resulting voltage profile for the potential (V) at a point near the earthing system with respect to remote earth is given in Equation 5.5 (see Figure 5.3).

$$V_r = \frac{\rho I}{2\pi r_x} \text{ for } r_x > r_e \quad \dots 5.5$$

where

V_r	=	voltage at distance r_x in volts
ρ	=	is the earth resistivity in ohm metres ($\Omega.m$)
I	=	earth current in amperes
r_e	=	radius of the equivalent hemispherical earth in metres
r_x	=	distance from the centre of the earth grid in metres

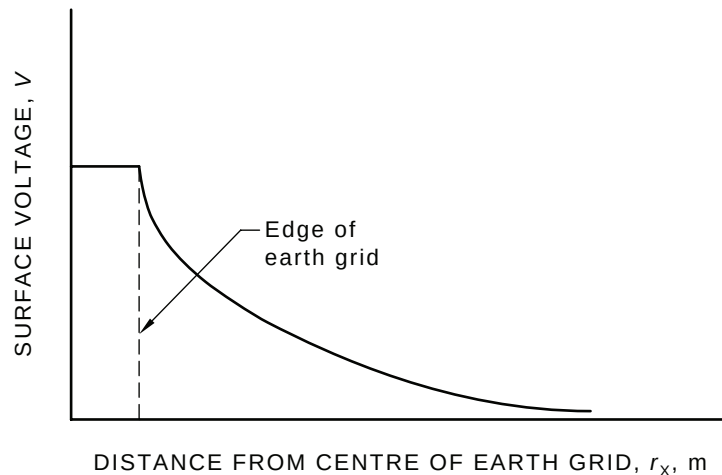


FIGURE 5.3 TYPICAL SURFACE VOLTAGE GRADIENTS

5.6.2 Uncertainties in earth resistivity

For most practical situations the earth resistivity is not known with sufficient accuracy or the earth is not uniform. Often, however, the earth resistance and dimensions may be known along with the maximum earth fault current. This enables the maximum EPR to be calculated using Equation 5.6.

$$V_x = V_{\text{grid}} \frac{r_e}{x + r_e} \quad \dots 5.6$$

where

- V_x = voltage at distance x in volts
- V_{grid} = EPR in volts
- r_e = radius of the equivalent hemispherical earth in metres
- x = distance from the edge (or corner) of the earth grid in metres

Equation 5.6 also shifts the profile so that the surface voltage equals the EPR at the edge of the grid. However this affects the accuracy slightly (the calculated EPR will be greater than the actual EPR). Inside the grid, the voltage should be close to the EPR.

In general, the radius of the equivalent hemispherical earth electrode radius (r_e) can be obtained from the equation—

$$r_e = \frac{\rho}{2\pi R} \quad \dots 5.7$$

where

- R = resistance of the earthing system

(a) for a surface plate—

Combine Equations 5.4 and 5.7 to deduce Equation 5.8

$$r_e = 0.3592 \sqrt{A} \quad \dots 5.8$$

where

- A = area of flat plate in square metres

(b) for a driven rod—

Combine Equations 5.4 and 5.7, to deduce Equation 5.9

$$r_e = \frac{L}{\log_e \left(\frac{4L}{r} \right) - 1} \quad \dots 5.9$$

where

l = length of the rod in metres

r = radius of the rod in metres

Equations 5.8 and 5.9 are appropriate for simple earthing systems. Accordingly, for more complicated structures, e.g. large substations, it is better to measure the resistance of the earthing system and the resistivity of the earth to calculate the equivalent hemispherical electrode radius from Equation 5.7.

Where the resistance of the earth grid is not known, a value of half the largest dimension of the grid may be used for r_e in Equation 5.6. However the result will probably be very conservative.

5.7 LIMITS FOR APPLYING THE SIMPLIFIED CALCULATIONS

5.7.1 General

The simplified calculations are based on an ideal situation in which a hemispherical earth is installed in an even and continuous earth (homogenous resistivity). Limitations are described in Clauses 5.7.2 to 5.7.4.

5.7.2 Non-hemispherical earthing systems

Real earths are not hemispherical, although from a distance there is little difference between the voltage contours of a non-hemispherical earth and those of the equivalent hemispherical earth. In close proximity, however, there can be significant differences between different earthing system shapes. Figure 5.4 illustrates how the equipotential contours of a single earth and a linear array vary from those for the equivalent hemispherical earth up close, and how these contours get closer to those for the equivalent hemispherical earth as the distance from the earthing system increases.

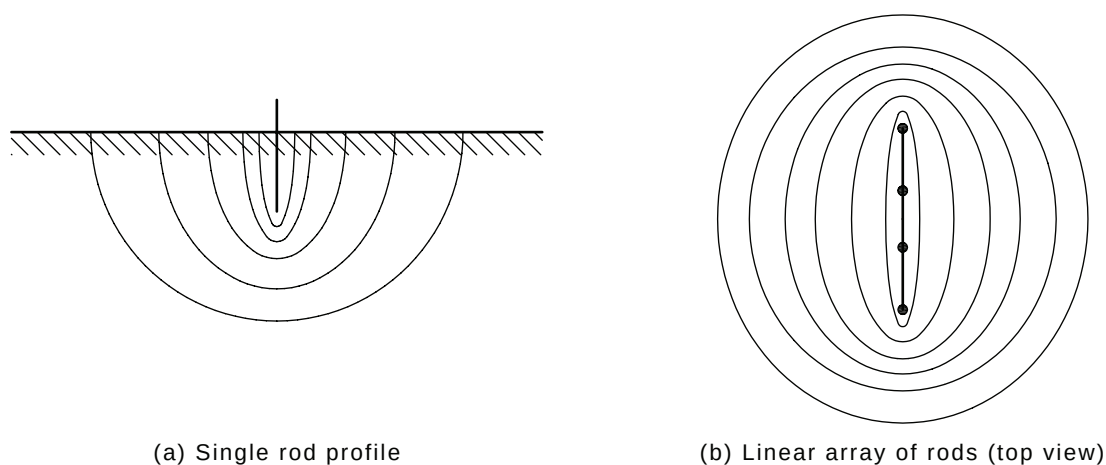


FIGURE 5.4 VOLTAGE GRADIENTS OF NON-HEMISPHERICAL EARTHING SYSTEMS

To minimize the errors from this proximity effect, the above simplified calculations should only be used for distances greater than 5 times the maximum dimension of the earth electrode. For distances less than this detailed calculations or measurements should be used to ensure that the EPR values are realistic.

5.7.3 Multilayer earth resistivity effects

The simple calculations described assume that the earth is uniform with a constant resistivity. Most soils are layered with each layer having a different resistivity. If the value of the resistivity in different layers is of the same order of magnitude then the highest value can be used to generate conservatively approximate values from the simple calculations. Where the earth system is deep enough to penetrate an area of relatively constant resistivity, that value of resistivity can be used in conjunction with the penetration depth of the earthing system into the lower layer for the purposes of simple calculations. Where the variations of resistivity are complex or very large, detailed calculations or measurements should be used to ensure the EPR values are realistic. Figure 5.5 provides an indication of the variation in voltage profile with soil resistivity changes.

NOTE: The voltage profiles are intended to be indicative only. Figure 5.5 plots the following cases for a grid that comprises four 10 m meshes with a 10 m stake at each of the four outside corners, where ρ_1 = top layer resistivity to a depth of 5 m, and ρ_2 = lower layer resistivity:

- (a) Case I Equation 5.6
- (b) Case II $\rho = 100 \Omega.m$, $R = 2.04 \Omega$
- (c) Case III $\rho_1 = 10 \Omega.m$ (5 m depth), $\rho_2 = 100 \Omega.m$, $R = 0.64 \Omega$
- (d) Case IV $\rho_1 = 100 \Omega.m$ (5 m depth), $\rho_2 = 10 \Omega.m$, $R = 0.41 \Omega$

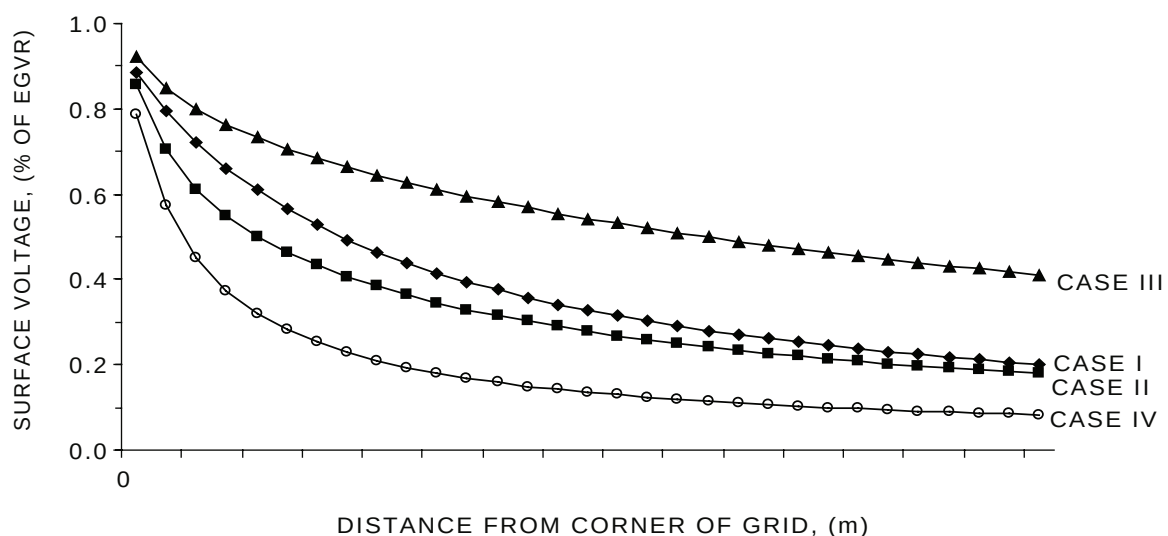


FIGURE 5.5 EFFECT OF SOIL RESISTIVITY ON SURFACE POTENTIAL GRADIENTS

5.7.4 Conductors extending the EPR

For locations where other underground services exist there is a risk that the EPR zone will be distorted by conductive services running through or near the site. See Figure 5.6 for an example of this effect.

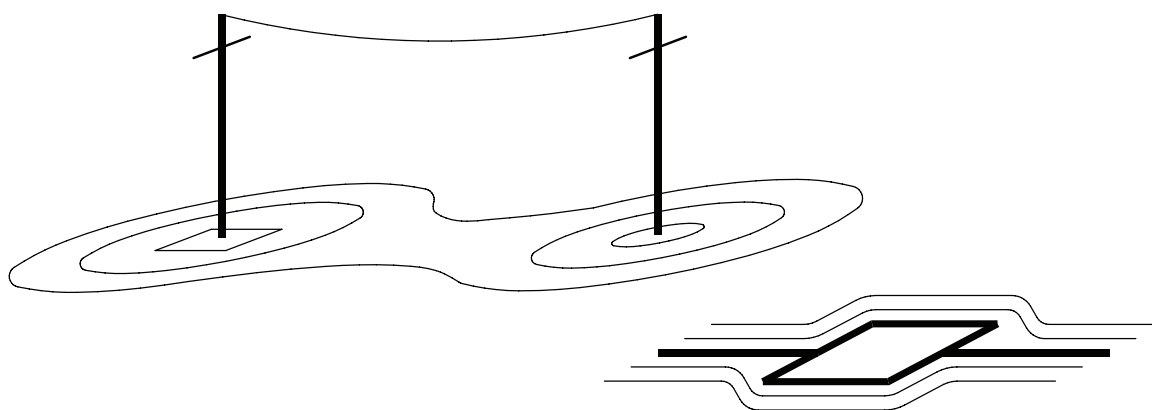


FIGURE 5.6 DISTORTION OF EPR CONTOURS

In addition, where underground services (e.g. cable sheaths, buried conductors), OHEW conductors, connect adjoining earths the EPR may be transferred to the adjoining structures without a fault occurring on them. Where other services are concerned, details of the coupling to these services or the earthing effect of them might be unknown. In these cases the resulting EPR effect can only be established by measurement. Where the EPR is transferred on overhead conductors, the effect can normally be calculated and the combined effect of the connected structures needs to be considered to establish a realistic EPR value.

5.8 EPR IN LARGE SUBSTATIONS

5.8.1 General

Due to the interconnection of substations in a power system, the task of working out a localized EPR for a particular substation site can be quite involved. This can be done manually where the situation is not overly complicated, or via the use of computer modelling, which generally yields quicker results. The following sections address the additional issues involved in analysing large systems.

5.8.2 EPR calculation

As for smaller systems the EPR is simply defined as the multiplication of system impedance by the fault current flowing through that impedance. For larger systems such a calculation is not trivial, and 'conservative' simplified estimations are often not useful in the light of the very large prospective fault currents. Clauses 5.9 and 5.10 briefly introduce the issues to be addressed in such a calculation, with Clause 5.11 addressing the application of computerized analysis packages to the problem.

5.9 EARTH SYSTEM IMPEDANCE

5.9.1 General

The total grid impedance is often calculated as the parallel combination of all connected earth system impedances as in Equation 5.10.

$$Z_{grid} = \left[\frac{1}{R_c} + \left(\frac{1}{Z_{ia}} + \dots \right) + \left(\frac{1}{Z_{ic}} + \dots \right) \right]^{-1} \quad \dots 5.10$$

where

- R_c = primary electrode resistance in ohms
- Z_{ia} = aerial conductor input impedance in ohms
- Z_{ic} = buried cable input impedance in ohms

Equation 5.10 is approximate in that it ignores the following:

- (a) The mutual resistance effects between individual auxiliary earth components, such as adjacent conductively oversheathed cable sheaths (e.g. jute served), which will increase total Z_{ic} . For PVC oversheathed cables terminated remote from the grid, Equation 5.10 is appropriate.
- (b) More current will return via conductors that lie in the direction of the fault current source.
- (c) The effect of conductive structures such as pipelines which, although not bonded directly to the grid, will reduce the return current path impedance.

Unfortunately, ignoring the effects of these approximations is not conservative.

In many instances the total grid impedance is primarily determined by the auxiliary earth system. Including the effect of this auxiliary earth system in the total impedance calculation is especially vital in urban or city indoor substations where grid area is severely limited. To do this, analytical calculations are required as described in Clause 5.11.

5.9.2 Aerial conductors

For aerial lines the paralleling effect of feeder tower footing impedances with the grid impedance of the substation is modelled by showing the OHEW of each incoming (or outgoing) transmission line circuit connected to its tower footings at both ends of each span. This can be represented by a ladder network such as the one shown in Figure 5.7. It is assumed that the transmission circuit has spans of equal length, with the OHEW self impedance per span Z_s , and equal tower footing resistances R . Assuming uniform spacing, impedances and earth resistivity, the total resistance can be calculated from Equation 5.11.

$$Z_{ia} = \frac{Z_s}{2} + \sqrt{\left(RZ_s + \frac{Z_s^2}{4}\right)} \quad \dots 5.11$$

where

Z_s = OHEW self impedance per span in ohms

R = footing resistance in ohms

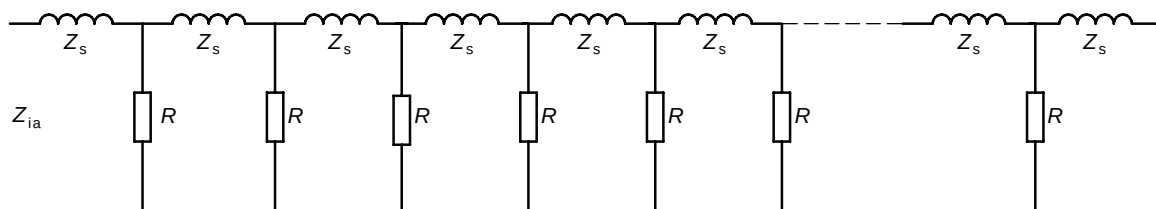


FIGURE 5.7 EQUIVALENT LADDER NETWORK

5.9.3 Underground cables

The input impedance of PVC oversheathed power cables is simply calculated using the series impedance of the sheath armouring and the terminating impedance. For conductively oversheathed cable (e.g. jute served) the input impedance is often not simple to calculate. Close to the earthgrid the proximity effect makes the calculation non-conservative (see ESAA EG1(2000)). If the problem still requires more accurate consideration of the cable sheaths, computer modelling is often used in conjunction with injection testing.

5.10 DETERMINATION OF PROSPECTIVE FAULT CURRENT (Initial estimate)

The simplest estimation of fault current is that of the total phase to earth fault current at the fault point ignoring the effect of alternative current paths. Thus, normal equations concerning symmetrical components, may be used and the grid and fault impedances are often assumed to be zero. If this 'conservative' estimate yields acceptable, or workable, EPR results then there is little point in making further current distribution calculations (apart from inductive interference calculations). Fault calculation programs are often used to provide this maximum current value.

The following guidelines are commonly adopted when calculating the initial maximum grid current:

- (a) Substation primary faults—
 - (i) ignore grid impedance and use future ultimate fault level for a first estimate of EPR; and
 - (ii) use realistic future (staged development) current calculations for personnel safety/voltage gradient hazard determination.

- (b) Substation secondary faults—

Consider likely fault impedance scenarios when determining personnel hazard levels. The assessment of fault impedance for cable-fed or overhead lines is important (e.g. cable-fed, pad-mounted substation where $R_{\text{fault}} \leq 5 \Omega$). Such analysis reduces the prospective fault current significantly.

- (c) Detailed calculations—

In many cases such a simplified approach is not workable. For each major voltage level and its associated bus-to-earth fault current, the effects of current splits caused by the interconnection of substations by OHEWs and/or underground cable sheaths need to be taken into account. The effect of interconnection is the inductive re-channelling of part of the fault currents via the interconnecting OHEWs, resulting in less overall current returning via the general earth paths. Only the current flowing into the earth at a specific location contributes to the EPR of that location.

In general, for the case of a single feeder, I_e is related to I_f as in Equation 5.12.

$$I_e = K I_f \quad \dots 5.12$$

where

K = shielding factor of the OHEW or cable sheath.

The results of such analysis often yield EPR reductions of 10% to 50% for overhead lines, and 50% to 95% for cable fed systems.

The issue of d.c. offset is significant when considering the EPR of systems close to generating plant (up to 40% increase in EPR). ESAA EG1(2000) shows how to calculate this.

5.11 COMPUTER ANALYSIS

The use of computerized analysis is often done in two stages (using different packages):

- (a) Earthing system modelling:

The distribution of currents in the earthing system and voltages created on metalwork and the earth is calculated.

- (b) Power system current distribution:

The inductive and conductive distribution of fault energy in the power system phase and neutral (i.e. OHEW and cable sheaths) conductors are calculated.

The obvious advantage of using computer methods is the number-crunching capability for dealing with difficult situations, which would otherwise require a large amount of manual and tedious computational work. Computer simulation can easily solve current split problems resulting from complicated interconnection of networks and analyse effects of fault current flow in multi-layer soil models. The latter feature is especially worthwhile as most 'formulae based' hand calculation methods assume a uniform/homogeneous soil model, which is normally arrived at by taking the arithmetic mean of test soil resistivity data to various depths. Some case studies have found that the EPR values of substations derived using a uniform soil model analysis can differ from those arrived at using a multi-layer soil model approach by anywhere from 10% to 50% and more, depending on the actual composition of the soil structure.

Computer methods are not without their pitfalls. It should be kept in mind that the accuracy of any non formula based modelling exercise depends very much on how well the model simulates the real situation. This is in turn dependent on a number of factors such as the following:

- (i) The simplifying assumptions made, and their effect on the model as a whole (e.g. some packages assume constant voltage on grid conductors).
- (ii) The accuracy of the input data used and the sensitivity of the answer to variations in input data.
- (iii) The algorithm adopted by the program, which determines the level of accuracy achievable by the software.
- (iv) The experience and expertise of the person carrying out the modelling works.

Figures 5.8 and 5.9 illustrate the surface EPR at a substation.

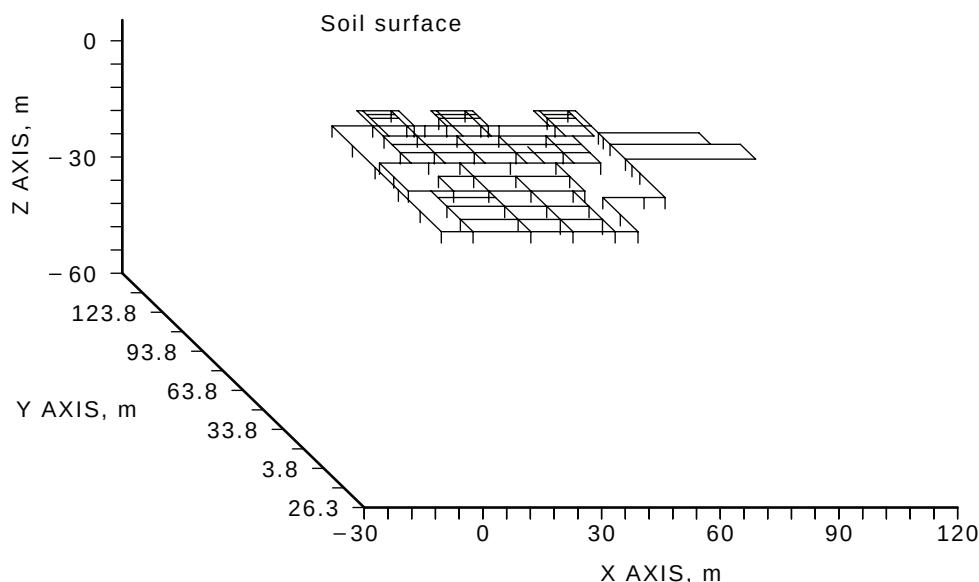


FIGURE 5.8 SUBSTATION EARTHING SYSTEM

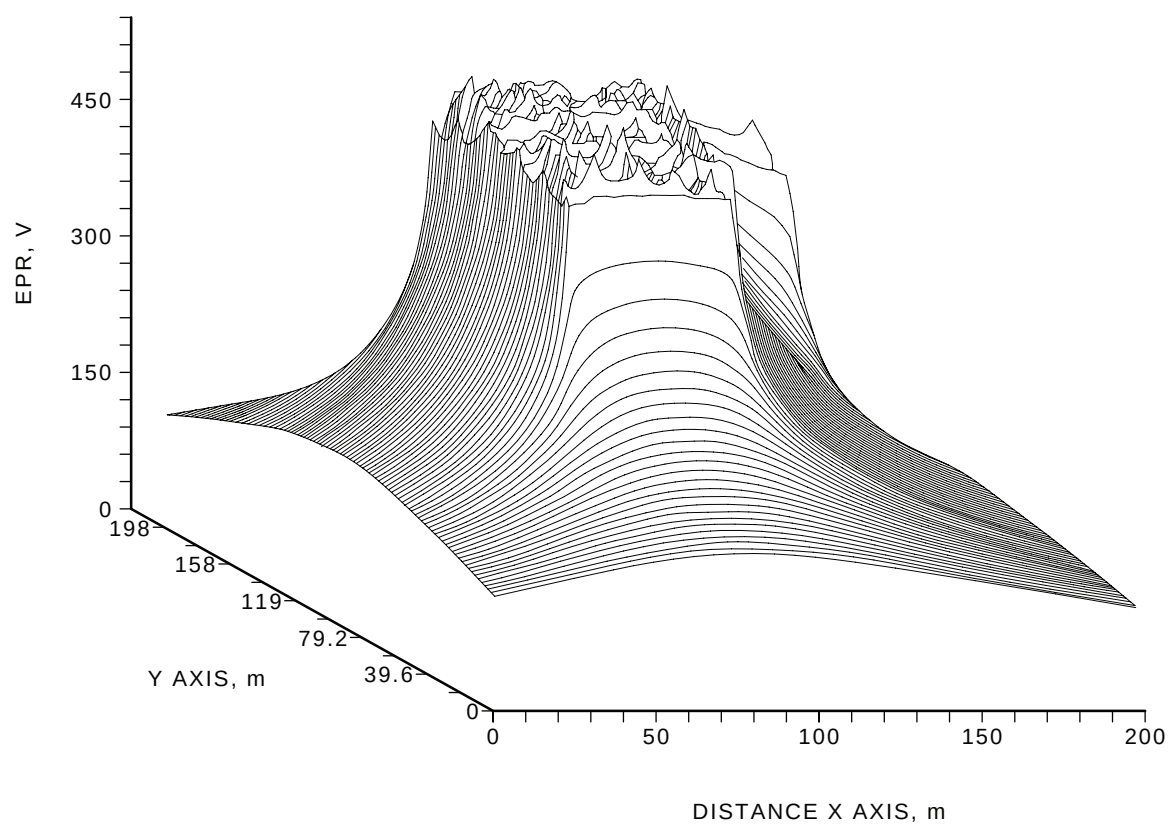


FIGURE 5.9 SUBSTATION SURFACE VOLTAGE GRADIENT

SECTION 6 FIELD TESTS AND MEASUREMENTS

6.1 INTRODUCTION

EPR is created by the component of fault current that enters the HV earthing system, as calculated in Section 5. However, when simple methods of calculation are used and when it is difficult to obtain precise information on the parameters involved, the calculated results are just an estimate of the probable values, and field tests may become necessary.

6.2 OBJECTIVES OF FIELD TESTS

The three main reasons for conducting field tests for EPR are as follows:

- (a) Measurement of a grid impedance and/or confirmation of the calculations, especially when the calculations have indicated the need for expensive protective measures for telecommunications plant; and also for complicated situations (e.g. where the effect of HV cable sheaths or MEN systems and the like are difficult to precisely model or calculate).
- (b) Determination of the extent of the actual hazard zone(s) surrounding a HV site especially to assist in the selection of proposed routes for telecommunications cables; and vice versa when the status quo of an existing HV site, which may be surrounded by telecommunications plant, needs to be changed. All new HV sites should be checked and tested, if possible, prior to commissioning.
- (c) Ascertain that the requirements for isolation of telecommunications systems are adequate. The maximum EPR of an installation is usually used for that purpose.

6.3 METHODOLOGY

In some cases it is prudent to determine the HV site EPR using accurate analytical methods (see ESAA EG1(2000)). However, less accurate results can be expected for large interconnected earthing systems which comprise distributed earthing such as the LV MEN system. Therefore, measurement of the earthing system impedance once a grid is interconnected with a larger network is desirable.

The methodology for determining the HV site EPR for systems involving large interconnected earthing systems requires the earthing system of the installation to be tested and modelled. The verification of an earthing model through testing allows the accuracy of the model for the single fault condition examined to be verified. A verified earthing model can then be used to consider all realistic fault conditions to determine the maximum EPR for the installation, which is the HV site EPR.

Hence it is very important to recognize the importance of using modelling to analyse test results to accurately estimate HV site EPR. The remainder of this section discusses recommended methods for performing and analysing earthing system testing. The level of analysis required depends on the complexity of the HV earthing system and the systems that interact with it.

6.4 CURRENT INJECTION TESTS

6.4.1 General

Unless a special method of measurement is employed, the presence of the d.c. current, stray 50 Hz and harmonic currents, and other standing voltage effects are likely to introduce errors.