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Guidance on Practice for Earthing/Grounding

GP 12-25

BP GROUP
ENGINEERING TECHNICAL PRACTICES

Foreword

This is the first issue of Engineering Technical Practice (ETP) GP 12-25. This Guidance on Practice (GP) is based on the following heritage documents from merged BP companies:

Amoco ACES

EL-GR-00-G	Electrical—Grounding—Guide
EL-GR-00-E	Electrical—Grounding—Engineering Specification
EL-GR-00-C	Electrical—Grounding—Installation Specification

ARCO APCES

ES 401-90	Electrical Grounding
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BP GOMDW

EL-SP-4056	Neutral Grounding Resistor
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BP Chemical-US

CP 17-10-1	Neutral Grounding Resistor
CP 17-15-1	Equipment Grounding Details

BP RPSE

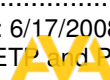
RP 12-16	Electrical Systems and Installations Earthing and Bonding
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1. Scope

This GP document provides guidance for design, application, and installation of earthing/grounding.

2. Normative references

The following normative documents contain requirements that, through reference in this text, constitute requirements of this technical practice. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this technical practice are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

American Petroleum Institute (API)

RP 2003	Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents
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British Codes and Standards

BS 7430	Code of Practice – Earthing
BS EN 1474	Installation and equipment for liquefied natural gas – Design and testing of loading/unloading arms

Institute of Electrical and Electronic Engineers (IEEE)

IEEE Std. 80	Guide for Safety in AC Substation Grounding
IEEE Std. 141	Recommended Practice for Electric Power Distribution of Industrial Plants
IEEE Std. 142	Recommended Practice for Grounding of Industrial and Commercial Power Systems

International Electrotechnical Committee (IEC)

IEC 60364-5-54	Electrical installations of buildings - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements, protective conductors and protective bonding conductors
IEC 61892	Mobile and fixed offshore units - Electrical installations - All parts

National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code (NEC)
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3. Power system earthing/grounding philosophy

3.1. General

- a. Earthing/grounding and/or bonding for electric power distribution systems should be designed and installed in accordance with relevant parts of IEC 60364-5-54, IEC 61892, API RP2003, NFPA 70, IEEE Standards 80, 141, and 142 or BS 7430.

Additional earthing/grounding details are given in PIP ELIGD000 and Appendix A of this GP. Typical earthing and bonding installations for both onshore and offshore are shown in Fig 1A, 1B, 2A, and 2B.



- b. Earthing/grounding of each part of a power system operating at a specific voltage should be considered individually. If such systems are required to be earthed/grounded solidly, or via an impedance, the neutrals should be connected to a common plant earthing/grounding system. This system should have a resistance to earth that ensures operation of protective devices in the various circuits and should not be in excess of 4-ohms. If connected to a Public Utility supply HV system earth, the combined earth resistance of the Public Utility earth and this earthing/grounding system should be less than 1-ohm.

The selection of 4 Ohms as power system resistance to earth is relatively arbitrary and therefore this value may vary depending upon the basic design and safety requirements). However, the possibility of earthing/grounding system resistance variation due to varying soil conditions through time needs to be considered also. The requirement for 1-ohm resistance of a combined Public Utility HV system earth and the interconnected earth for solidly earthed neutrals arises from the need to minimise neutral potentials under Public Utility HV earth fault conditions.

A 1-ohm earthing/grounding resistance is not considered mandatory if HV and LV distribution systems are both owned and operated by BP and are earth bonded together with negligible probability of HV faults giving rise to LV system neutral potential rise with respect to 'true' earth. (If true earth represents the potential of the earth's core. This may be transferred to structures if these are not bonded to the site earthing/grounding system).

- c. The neutral connections for earthing/grounding equipment should be provided at generators, transformers or both, which have their neutral brought out, and which are the source of power to the distribution system. If such power sources are delta connected, and do not have neutrals brought out, neutral earthing/grounding may be carried out at other star connected power transformers on the system or by the provision of earthing/grounding transformers.
- d. Power systems operating at a common voltage, which may be normally or abnormally run un-paralleled, should have a neutral earthing/grounding connection facility provided for each system. The neutral earthing/grounding system should be designed to ensure that there is no possibility of inadvertently operating a system with an isolated neutral.

Under some circumstances, an alarm for the condition of power system in operation without neutral earthing/grounding should be satisfactory. Typical of such circumstances is the condition whereby a single earthed neutral is desirable (perhaps in order to limit circulating currents between power generators) and there would be a complex and difficult automatic system for earthing/grounding switching in the event of power system disconnection.

- e. The potential between immediate metalwork and a 'true earth' (which may be transferred to the immediate locale typically by telephone services) should be calculated for all representative single phase to earth conditions. Calculations should be presented as support to earthing/grounding system design.

The earthing/grounding arrangements of a site are a fundamental feature of safety and it is therefore necessary that the operator is assured that no dangerous potentials can be obtained. It is important that touch potentials be less than 430 V under any single phase-earth fault if there is overcurrent protection arranged to de-energise the live conductor. The 430 V level relates to telephone system limits of exposure. Fundamental safety to personnel should be considered separate to this requirement. IEEE 80 is a useful document for this.

If communications and/or protection cables run outside the earthing/grounding system to another remote site, the need for voltage isolation measures at all termination sites should be considered.



It is common for Control Systems to demand 'clean' or 'reference' earth points which are associated with earthing/grounding electrodes not connected to the general site earthing/grounding system. This practice can give rise to dangerous situations under HV system faults and should be avoided.

3.2. Un-earthed/grounded (isolated) neutral

- a. An un-earthed/grounded or isolated neutral system should be used only subject to specific design approval.

Such systems may be used if the highest integrity against faults is required. (e.g. Unearthed systems are often used for oil well drilling power supplies and for d.c. shutdown system power supplies).

If unearthed/grounded systems are installed it should be recognised that the power system conductors (phase conductors) could constitute a danger of electrical shock or fire as a result of contact with them and earth. The danger is a result of capacitance coupling of the power system conductors and earth.

- b. Unearthed/ungrounded power systems should be provided with an earth fault detection system and operator action to clear any earth faults that occur as a matter of priority.

3.3. Solidly earthed/grounded neutrals (for systems below 1000 V)

Low voltage systems should have their neutrals solidly connected to the plant earthing/grounding system. Impedance earthing/grounding of systems with a voltage below 1000 V should only be used subject to design approval.

Impedance earthed LV systems may be considered if the system will be 3 wire without neutral connections and there is benefit in limiting damage during earth fault conditions. (E.g. If a special voltage 690 V may be used in preference to say 3.3 kV and in effect replaces the HV system in its application).

If single-phase supplies are taken from LV systems, the neutral should be solidly earthed at the supply point only in accordance with IEC 60364-5-54.

If PME (Protective Multiple Earth) power supplies are taken from a Public Utility it is considered that there should be no need for isolation transformers to achieve the TN-S arrangement within the premises, however, the design should conform to national legislation and this may require that under certain circumstances, isolation transformers are required.

3.4. Impedance earthed/grounded neutrals (for systems rated 1000 V and above)

- a. Neutral earthing/grounding equipment to limit earth fault currents should be provided in the neutral connection to the plant earth system on all high-voltage power systems.

Such provision limits the overall transient system disturbance caused by earth faults and also limits the amount of damage caused by this most common type of fault.

- b. If the power system at the specific voltage contains no direct connected generators under any mode of operation, the provision of the earthing/grounding resistor and its earth/ground connection should consider the following possibilities:
1. At the source star connected transformers.
 2. At other star connected power transformers.
 3. At earthing/grounding transformers.
- c. Neutral earthing/grounding equipment should comprise a resistor with a minimum 10-second fault rating selected to reduce the fault current to the full load rating of the



power source transformer. The use of reactors to earth/ground neutral systems should only be used subject to design approval

Systems employing reactor earths are uncommon but have been used in some countries or under special circumstances. One special circumstance is if a 'Petersen Coil' is used to avoid a circuit trip due to a transient earth fault e.g. lightning induced flashover in overhead lines. Such special circumstances are unlikely in industrial installations.

If reactance earthing/grounding is considered, its use should be tested against the cost/benefit compared with resistance earthing/grounding. Special attention should be taken of the possible tuning effects between the earthing/grounding reactor and the power system.

- d. If direct connected generators may be operated in parallel with source transformers, the neutral earthing/grounding arrangements should provide for either system operating independently. Neutral earthing/grounding equipment should be identically rated for all power sources. If resistors are provided, these should comprise 10-second fault rated, solid resistors. Resistors should reduce the fault current to a convenient level one half to full load rating of the lowest rated power source, provided this fault current is sufficient to operate the distribution system earthing/grounding protection and provide suitable discrimination. If normal ratings of the source transformer and parallel running generators are significantly different, the resistor rating selection should be dictated by the requirement to ensure that the most insensitive earth/ground fault protection on any incoming or outgoing circuit operates positively with the smallest possible source of earth/ground fault current connected to the system.

If there is a 4-wire supply system, solid earthing/grounding will be provided in order to keep neutral voltages as close to earth as possible. In this case the neutral earthing/grounding arrangement should be simplified by arranging for the neutral to be earthed at the switchboard.

3.5. Earthing/grounding resistors

Earthing/grounding resistors should be provided with insulation suitable for the phase-to-phase voltage of the systems to which they are connected. They should be designed to carry their rated fault current for the times specified in the preceding clauses, without any destructive effect to their component parts.

It is expected that resistors will be located in an outdoor environment where transformer earthing/grounding is involved but could be indoors for generators. There is no mandatory requirement for locating these devices indoors other than normal economic factors.

3.6. Generators

- a. Neutrals of generators directly connected to the distribution switchgear in 3-wire systems (i.e. HV systems or special LV systems) may be solidly or resistance earthed/grounded. However, solid earthing/grounding should be limited to generators if the earth/ground fault capacity of the generator is approximately equal to the current level required to operate the distribution system protection.

If solid earthing/grounding of the neutral is applied to a system with a (relatively) low capacity generator in parallel with a larger power source, which has resistance earthing/grounding, the generator should have a neutral circuit breaker, which should be automatically controlled. However, where the influence of the fault on other equipment is not unduly compromised by too high an earth/ground fault current, the generator neutral could be allowed to remain solidly connected.



- b. Resistor earthing/grounding should be used for generators directly connected to distribution switchgear. Resistor should be of the 10-second (minimum) fault rated, solid type, and its resistance should be selected to reduce the fault current to a level between the half and full load current rating of the machine, provided this is sufficient to operate the distribution system protection system selectively.
- c. If generators directly connected to the distribution switchgear are operated in parallel and earthed/grounded either solidly or through resistors, the provision of neutral switchgear for each generator should be considered to avoid third harmonic current flows and their heating effect. If such neutral switchgear is provided, it should be connected and operated in a manner to ensure that only one generator neutral switch is always closed at a time. Neutral switchgear may comprise contactors on resistor-earthed/grounded schemes instead of circuit breakers. The provision of neutral switchgear schemes may be avoided if identical pitch generators are paralleled, or if the provision of neutral earthing/earthing resistors sufficiently reduces the prospective third harmonic currents to acceptable levels. A 1% or less de-rating as a result of third harmonic currents should be considered acceptable.

A possibility would be for the neutral of each generator to be permanently earthed/grounded via a resistor where the resistance thus installed would limit the circulating currents to acceptable levels. However, this type of earthing would mean that earth/ground fault current levels on the power system would vary depending upon how many power generators were operating. Such an installation would be acceptable if it showed economic advantages.

- d. If generators are connected to the distribution switchgear system via unit transformers, the generator neutral should be connected to earth/ground via the primary winding of a single-phase distribution transformer. Secondary winding of this transformer should be shunted by a resistor with a resistance value, which is calculated to be approximately the same as the zero sequence capacitance for the generator winding system.
- e. Manufacturers standard arrangements for high impedance earthing/grounding systems for these types of generators will be acceptable. It is expected that the arrangements will be aimed at raising 5 to 10 A under earth/ground fault conditions. Selection of a resistance equal to the system-to-earth/ground capacitance under earth/ground fault conditions will ensure that the system capacitance will discharge energy reasonably and over voltages will be eliminated even for arcing earth/ground faults.
- f. Rated primary voltage of generator earthing/grounding transformers should be taken as the generator phase voltage although voltages of at least 1.5 times generator line to neutral voltages will be acceptable to obtain standard transformers. Transformer ratings should be the product of the primary current and rated primary voltage using a 30-second (6 times overload factor) duty cycle.

Conservative sizing of the transformer is preferred as its reactance has little effect on the earthing system. The secondary resistor should have a continuous duty as its size and cost will not normally be significant.

3.7. Substations

- a. Substation safety criteria are different in different countries, with two main approaches. American and European methods assess “step” and “touch” voltages, while the UK, focus is given to evaluating the Rise of Earth Potential.

UK method is based on the fact that if the rise of earth potential is within specific safety limits, then the maximum ‘step’ and ‘touch’ voltages are also sufficiently low not to yield any hazard.

UK maximum permissible substation potential rise is 430 V. On systems protected by high-speed protection (typically transmission lines), this limit may be increased



to 650 V, provided that protection intervention is guaranteed to be of 200 ms or faster.

These values, although derived from experience and common practice, are universally adopted by the electricity supply industry in the UK, and are included in EA TS 41-24 and EA S.34.

In the UK, sheath to earth voltages at sealing ends and joint positions should be limited to 50 V. Doing so, the system safety is enhanced by complying with the provisions of a functional extra low voltage system.

Step and touch potential requirements for American practices are covered in IEEE Std 80.

- b. For onshore sites, earth electrodes should be installed in ground below each main substation.

Although their main functions are related to electrical safety, the earth electrodes are also used in this case to create a reference point for the supply system. They are not generally required to carry full fault currents, as all power circuits entering and emanating from the substation will have earth continuity provided (i.e. by sheaths/armours and/or separate earth conductors). This screening effect reduces the ground return current and therefore the rise of substation potential, which shall however be assessed and within the safety limits for all soil conditions likely to occur clause.

- c. At least one more than the required minimum number of electrodes shall be installed. By this means, each electrode can be disconnected one at a time for testing without affecting the integrity of the power earthing/grounding system.
- d. A bar of high conductivity hard drawn (hchd) copper should be used as main earthing/grounding terminal, to which earth/ground bars of switchboards and metallic enclosures of low-voltage ancillary equipment (e.g. battery charger, lighting distribution board, etc.) should be connected.
- e. Main switchboards should be connected to substation earthing/grounding system at two separate points.
- f. Main substation earth/ground bar should be connected to one or more earthing/grounding busbars to form a complete ring. Alternatively, stranded copper cable may be used to connect each item to the earthing/grounding busbars.
- g. Earth/ground bars and earthing/bonding conductors should be “sized” respective of minimum sizes prescribed in standards.
- h. Star points of delta-star and similarly connected transformers and all alternator windings should be connected to earthing/grounding system (either directly, via a current limiting impedance and/or earthing/grounding switchgear). Either hard-drawn high-conductivity copper bar or stranded copper cable with green/yellow PVC covering should be used.
- i. Transformer tanks should be connected directly to an earthing/grounding bus-bar.
- j. The neutral of low-voltage three phase four wire systems shall be connected to earth/ground via the relevant main switchboard earth/ground bar. A bolted link should be provided between the neutral bar and the earth/ground bar.
- k. Armouring and metallic sheath of multi-core cables should be bonded to switchboard earth/ground bar, via the termination or gland and gland plate.
- l. Armours and/or metallic sheaths on single-core cables should be bonded together and earthed/grounded at each termination unless cable de-rating is unacceptable. A metallic gland plate provides an adequate bonding connection between sheaths/armours of three phases, but care must be taken to reduce eddy current effects.



In single-core cable installations, the terminating gland plate surrounds each of the three cable cores. The load current in each of the three phases generates a magnetic field which extends into the volume external to the cable core and therefore into the gland plate. If a ferrous material is used alternating magnetic field induces hysteresis and eddy current effects, which heat the gland plate, with possible insulation stress. Insulation stress effects are reduced by introducing an air gap between adjacent cables (or other means of producing high magnetic reluctance). This reduces the magnetic field intensity and the magnitude of eddy currents. Alternatively, a non-ferrous gland plate could be employed, however, corrosion due to dissimilar metals and the method of sheath earth bonding/grounding need to be carefully considered.

Problems associated with eddy currents and hysteresis in single core cables also affect ferrous armour. Therefore single core cables should always have a non-ferrous armour applied.

- m. If single point (or cross) bonding is required, unearthed/ungrounded terminations must be insulated and shrouded. Earthed/grounded end should be at the hazardous area end (when applicable). Maximum permissible sheath voltages to earth/ground are specified in referenced industry standards for both sealing ends and joint positions.

3.8. High-voltage motors

- a. Enclosures of high-voltage motors should be connected directly to local static and lightning earthing/grounding system, or to local earth/grounding electrodes. A common earth/ground electrode system may be used for several motors in same area. When high-voltage motors are in permanent electrical contact with steelwork forming part of common earthing/grounding system, no additional copper bonding connections are required.
- b. Metallic enclosures of local control stations and other associated electrical devices local to the motor, should be bonded to motor enclosure or to earthing/grounding system to which motor is connected. This may be achieved through the mounting bolts and earthed/grounded steelwork.

3.9. Low-voltage equipment

- a. Enclosures in permanent direct metallic contact, e.g. via pump bedplates, vessels, piping, structures, etc., with earthed/grounded plant steelwork require no further connection to earthing/grounding system.
- b. Enclosures not in direct metallic contact with earthed/grounded plant steelwork or pipe-work should be bonded to static and lightning earthing/grounding systems or to the adjacent earthed/grounded steelwork by means of a copper conductor.

3.10. Offshore installations

- a. Earthing/grounding should comply with local, national, and international industry standards.
e.g. the IEE Recommendations for the Electrical and Electronic Equipment of Mobile and Fixed Offshore Installations, Section 2.
- b. Enclosures of each main generator, transformer and switchboard should be solidly bonded to steel structure.
- c. Location of earthing/grounding connections should be visible, easily accessible and protected against corrosion.
- d. Additional bonding connections should be made at welded bosses local to equipment to avoid long cable runs.



- e. Low-voltage electrical equipment in contact with earthed/grounded steelwork and protected in accordance with IEE Recommendations for the electrical and electronic equipment of mobile and fixed offshore installations or equivalent standard do not require additional bonding connections.
- f. Parts of the plant not in metallic contact with an earthed/grounded structural steelwork should be bonded to platform steelwork. A separate earthing/grounding system for lightning and static protection is not required.
- g. A reel of single core flexible cable, of suitable size, should be installed in an area classified as non-hazardous by helideck, for bonding helicopters to platform during refuelling. Reel should incorporate a slip ring to pick up connection to earth/ground.

4. Earthing/Grounding methodology

4.1. General

- a. Earthing/grounding conductors may consist of one or a parallel combination of:
 - 1. Dedicated earthing/grounding conductor
 - 2. Cable armouring or metallic sheath
 - 3. Rigid screwed conduit
 - 4. Earth core within a multi-core cable
 - 5. Structural steelwork.
- b. Sole reliance on cable armouring and/or metallic sheathing should only be made if it is adequately fault rated as a protective conductor.

This is a fundamental requirement, which should be met in case of faults within electrical equipment. In the case of faults within cable, it may not be possible to have armour which is fully fault-rated, particularly if armour is steel braid type. However, the advantages of steel braid armour over steel wire armour on cables used offshore are considered to outweigh this possible disadvantage.

- c. Structural steelwork may be considered as a protective conductor provided it is part of the common static and lightning earthing/grounding system and there is a permanent metallic path for fault current via such steelwork and other earthing/grounding conductors back to the power supply.

Use of structural steelwork as part of earthing/grounding system and as a path for fault current is acceptable practice, particularly offshore where welded steel structure of platform is regarded as 'earth'. The term only applies to permanent structures such as an offshore platform or an onshore process plant. Connection points should be made available for periodic testing of electrical integrity and current carrying capacity of steelwork alone.

When a complex structure is used as (one of) the protective conductors, its impedance cannot be readily calculated. However, it can be assumed that a very large structure such as an offshore platform has negligible impedance compared with that of cable armouring. For the purpose of calculations, the impedance of the return path through such a structure can be assumed to be zero.

A consistency in choice of protective conductors for a particular plant should be maintained when extensions to the plant are designed.

- d. Cross sectional area of earthing/grounding conductors and bonding connections between exposed and extraneous conductive parts should be capable of carrying earth fault current, or an appropriate fraction of total fault current, for the duration of the fault without damaging conductor or associated insulation.

