Guidelines on earthing/grounding/bonding in the oil and gas industry

energy institute
Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

GUIDELINES ON EARTHING/GROUNDING/BONDING IN THE OIL AND GAS INDUSTRY

First edition

September 2016

Published by
ENERGY INSTITUTE, LONDON
The Energy Institute is a professional membership body incorporated by Royal Charter 2003
Registered charity number 1097899

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

The Energy Institute (EI) is the chartered professional membership body for the energy industry, supporting over 23 000 individuals working in or studying energy and 250 energy companies worldwide. The EI provides learning and networking opportunities to support professional development, as well as professional recognition and technical and scientific knowledge resources on energy in all its forms and applications.

The EI's purpose is to develop and disseminate knowledge, skills and good practice towards a safe, secure and sustainable energy system. In fulfilling this mission, the EI addresses the depth and breadth of the energy sector, from fuels and fuels distribution to health and safety, sustainability and the environment. It also informs policy by providing a platform for debate and scientifically-sound information on energy issues.

The EI is licensed by:
– the Engineering Council to award Chartered, Incorporated and Engineering Technician status;
– the Science Council to award Chartered Scientist status, and
– the Society for the Environment to award Chartered Environmentalist status.

It also offers its own Chartered Energy Engineer, Chartered Petroleum Engineer and Chartered Energy Manager titles.

A registered charity, the EI serves society with independence, professionalism and a wealth of expertise in all energy matters.

This publication has been produced as a result of work carried out within the Technical Team of the EI, funded by the EI's Technical Partners. The EI's Technical Work Programme provides industry with cost-effective, value-adding knowledge on key current and future issues affecting those operating in the energy sector, both in the UK and internationally.

For further information, please visit **http://www.energyinst.org**

The EI gratefully acknowledges the financial contributions towards the scientific and technical programme from the following companies

BP Exploration Operating Co Ltd
BP Oil UK Ltd
Centrica
Chevron
CLH
ConocoPhillips Ltd
DCC Energy
DONG Energy
EDF Energy
ENGIE
ENI
E. ON UK
ExxonMobil International Ltd
Kuwait Petroleum International Ltd
Maersk Oil North Sea UK Limited
Nexen
Phillips 66
Qatar Petroleum
RWE npower
Saudi Aramco
Scottish Power
SGS
Shell UK Oil Products Limited
Shell U.K. Exploration and Production Ltd
SSE
Statkraft
Statoil
Talisman Sinopec Energy (UK) Ltd
Tesoro
Total E&P UK Limited
Total UK Limited
Tullow Oil
Valero
Vattenfall
Vitol
World Fuel Services

However, it should be noted that the above organisations have not all been directly involved in the development of this publication, nor do they necessarily endorse its content.

Copyright © 2016 by the Energy Institute, London.
The Energy Institute is a professional membership body incorporated by Royal Charter 2003.
Registered charity number 1097899, England
All rights reserved

No part of this book may be reproduced by any means, or transmitted or translated into a machine language without the written permission of the publisher.

ISBN 978 0 85293 924 6

Published by the Energy Institute

The information contained in this publication is provided for general information purposes only. Whilst the Energy Institute and the contributors have applied reasonable care in developing this publication, no representations or warranties, express or implied, are made by the Energy Institute or any of the contributors concerning the applicability, suitability, accuracy or completeness of the information contained herein and the Energy Institute and the contributors accept no responsibility whatsoever for the use of this information. Neither the Energy Institute nor any of the contributors shall be liable in any way for any liability, loss, cost or damage incurred as a result of the receipt or use of the information contained herein.

Hard copy and electronic access to EI and IP publications is available via our website, **https://publishing.energyinst.org**.
Documents can be purchased online as downloadable pdfs or on an annual subscription for single users and companies.
For more information, contact the EI Publications Team.

e: **pubs@energyinst.org**

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

CONTENTS

Page

Acknowledgements **7**

Foreword **8**

1 Introduction, scope and application **9**
1.1 Introduction 9
1.2 Scope 10
1.3 Application 10

2 Background **11**

3 Functional performance requirements of earthing/grounding/bonding systems **13**

4 Principles **14**
4.1 Electrical power earthing/grounding arrangements 14
4.1.1 TT systems 15
4.1.2 TN-C systems 15
4.1.3 TN-S systems 16
4.1.4 TN-C-S (PME) systems 16
4.1.5 IT (unearthed) systems 18
4.1.6 Ship's systems earthing/grounding 21
4.1.7 Summary of LV system supply features 21
4.2 AC substations 22
4.3 HV/LV interfaces 22
4.4 Electrical equipment classification 24
4.5 Static electricity 25
4.6 Lightning 27
4.6.1 The likelihood of a strike, and risk management 27
4.6.2 Earth/ground-terminations 28
4.6.3 Physical damage and life hazard 29
4.7 Circulating currents 29
4.8 Cathodic protection 30
4.9 Electromagnetic interactions between systems 31
4.9.1 Lightning 31
4.9.2 Power lines 33
4.9.3 RF induction 34
4.10 Earthing/grounding/bonding interconnections as a system 34
4.11 Hazardous areas, Ex certified apparatus and ignition sources 36
4.12 Earth/ground electrode resistance requirements 36
4.13 Touch and step voltages 37
4.14 Temporary installations 38

5 Applications **39**
5.1 Electrical machines and power systems 39
5.2 Machine sets with non-electric drives 41
5.3 Ex I systems and apparatus 41
5.4 Above ground tanks and fixed storage units 42
5.4.1 Note on cathodic protection (CP) of tanks 45
5.5 Cross-country pipelines 45

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

Contents continued

Page

5.6 Tankers and fuel transfer/dispensing systems . . . 46
5.6.1 Road tanker loading and unloading facilities . . . 46
5.6.2 Bulk railcar loading and unloading facilities . . . 47
5.6.3 Sea tanker loading jetties . . . 47
5.6.4 Aircraft fuelling facilities . . . 49
5.6.5 Filling Stations . . . 51

6 Detailed design/constructional requirements . . . 54
6.1 Field cables . . . 54
6.2 Protective conductors . . . 55
6.2.1 CPCs . . . 56
6.2.2 Power supply system earthing/grounding conductors . . . 57
6.2.3 Bonding conductors . . . 57
6.2.4 Instrument and telecommunications systems, and intrinsically safe system cables . . . 58
6.2.5 Lightning protection system earth/ground conductors and down conductors . . . 58
6.2.6 Static electricity . . . 58
6.3 Cable tray . . . 60
6.4 Earth/ground electrode design . . . 60
6.5 Above ground floating roof storage tanks . . . 63
6.6 Steel structures (onshore) . . . 64
6.7 Vessels . . . 64
6.8 Metallic stacks and towers . . . 64
6.9 Non-metallic structures . . . 65
6.10 Metallic guy ropes . . . 65

7 Operations . . . 66
7.1 Portable container filling . . . 66
7.2 Tank cleaning . . . 66
7.3 Scaffolding . . . 67
7.4 Connecting/disconnecting conductive paths . . . 68
7.5 Operations during lightning storms . . . 68
7.6 Radio silence during product transfer . . . 68
7.7 Welding . . . 69
7.8 Tank dipping . . . 69

8 Maintenance and inspection . . . 70
8.1 Permanently installed earthing/grounding/bonding connections . . . 70
8.2 Portable earthing/grounding equipment for power system maintenance . . . 70

9 Testing . . . 72
9.1 Current tests (using clamp meters) . . . 72
9.2 Earth/ground fault loop impedance testing . . . 72
9.2.1 Example method . . . 74
9.2.2 Measurement of R_{main} – see Figure 22 . . . 75
9.2.3 Measurement of R_1 – see Figure 24 . . . 75
9.2.4 Measurement of $R_1 + R_2$ – see Figure 25 . . . 75

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

Contents continued

Page

9.2.5 Determination of R_{total} – see Figure 23 76
9.2.6 Completion of test protocol 76
9.2.7 Alternate methodology 76
9.2.8 Existing installations (with MV transformers) where Z_e is not known 76
9.2.9 Existing installations (without MV transformers) where Z_e is not known . . 77
9.2.10 Modifications/additions to existing installations 77
9.2.11 Example method using a conductivity meter 83

Annexes

Annex A Glossary of terms (adapted from various EI publications and British standards) and acronyms 84
A.1 Terms 84
A.2 Acronyms 86

Annex B Touch and step voltage limits 88

Annex C Functional performance of earth/ground electrodes 90
C.1 Soil characteristics 90
C.2 Electrode geometry 90
C.2.1 Annular current distribution 90
C.2.2 Hemispherical current distribution 91

Annex D Measurement of earth/ground electrode resistance 93

Annex E Legal requirements in Britain 95
E.1 Electricity safety, quality and continuity regulations 95
E.2 Electricity at work regulations 96
E.3 Summary of British legal requirements 97

Annex F References 98

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

LIST OF FIGURES AND TABLES

Page

FIGURES

Figure 1 Earthing/grounding system conductors . . . 12
Figure 2 Earthing principles onshore . . . 15
Figure 3 PME supplies and diverted neutral current (DNC) . . . 17
Figure 4 Conversion of PME supply or public TN-S to local TT supply . . . 17
Figure 5 Conversion of PME or public TN-S to local TN-S supply . . . 18
Figure 6 Petersen coil-fault on blue phase . . . 19
Figure 7 Typical leakage current route to trigger RCD . . . 21
Figure 8 HV/LV Interface – separate earth/ground electrodes . . . 23
Figure 9 HV/LV Interface – combined earth/ground electrodes . . . 24
Figure 10 Typical earthing/grounding/bonding system for instruments . . . 32
Figure 11 Surge protection of signal processing equipment . . . 33
Figure 12 Typical example of earthing/grounding system interconnections . . . 34
Figure 13 Example of the surface potential profile and resulting touch and step voltages . . . 38
Figure 14 Earthing principles offshore . . . 39
Figure 15 Typical earthing/grounding arrangements . . . 40
Figure 16 Typical floating roof tank installation . . . 43
Figure 17 Typical arrangement of CP for shore systems, jetty and ship . . . 48
Figure 18 Some typical filling station earth/ground/bond interconnections . . . 51
Figure 19 Earthing/grounding system design flow chart . . . 61
Figure 20 Earth/ground loop impedances . . . 73
Figure 21 Layout of a TN-S system with the earth/ground fault loop resistances identified . . . 78
Figure 22 Measurement of R_{main} at the distribution board . . . 79
Figure 23 Measurement of R_{total} at the field device . . . 80
Figure 24 Measurement of R_1 at the distribution board . . . 81
Figure 25 Measurement of $R_1 + R_2$ at the distribution board . . . 82
Figure D1 'Fall of potential' electrode resistance measurement . . . 93
Figure D2 Wenner method of soil resistivity measurement . . . 94

TABLES

Table 1 Supply system features . . . 22
Table 2 Summary of earthing/grounding/bonding conductor sizes . . . 59
Table B1 Permissible body currents depending on duration of exposure . . . 88
Table B2 Limiting values for severe conditions . . . 89

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

ACKNOWLEDGEMENTS

This publication was prepared at the request of the EI's Electrical Committee by Bernard Emery. It was subsequently reviewed and developed by members of the Electrical Committee.

At the time of publication the Electrical Committee comprised:

Jim Adams	BP
Neville Harris	Valero Energy Limited
Terry Hedgeland	Consultant
Gary Holcroft	Health and Safety Executive
Justin Mason	BP Exploration
Toni Needham	Energy Institute
Ian Neve	Total Lindsey Oil Refinery
Zaur Sadikhov	Shell
Jonathan Slark	Valero Energy Limited
John Stevens	BPA
Chris Turney	F.E.S
Steve Wilkinson	Phillips 66

The EI wishes to record its appreciation of the work carried out by the members of the Electrical Committee and to recognise the contribution made by those individuals, companies and organisations that provided comments during technical review of earlier drafts.

Project coordination was undertaken by Toni Needham (EI).

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

FOREWORD

Earthing/grounding and bonding are of major importance for the safety of personnel and the protection of material assets in the energy industry, wherever electrical energy is present. This applies not only where electricity is generated, distributed, stored or used, but also includes the natural phenomena of lightning and static electricity. It is a subject that is often misunderstood and considered to have 'grey areas'.

As a 'safety critical' feature of installations in the energy industry, onshore and offshore, the effectiveness of earthing/grounding and bonding is a prime factor in the protection of personnel against electric shock, fire and burns due to the presence of electricity and the prevention of ignitive sparks in hazardous areas associated with potentially explosive atmospheres. This ranges from protection against static electricity to minimising the possible effects of lightning strikes.

Within the industry there are many discrete activities or locations having specific earthing/grounding and/or bonding requirements relating to them. It can happen that earthing/grounding or bonding provided to satisfy one set of requirements may be incompatible with requirements satisfying other purposes, creating an unforeseen potential hazard. The provision of a connection allowing undesirable current to pass to earth/ground from an installation also provides a route for undesirable current from elsewhere to pass into the installation, with possibly serious consequences.

The EI has an extensive portfolio of codes of practice and other guidance publications for a range of topics, many of which include provisions for earthing/grounding and bonding relevant to the topics concerned. This guidance publication brings together, from that portfolio, the essential requirements relating to earthing/grounding and bonding for installations in hazardous areas in the oil and gas industry. Whilst providing an overview to show a 'bigger picture', this publication does not replicate all the detailed requirements contained in individual publications in the portfolio, which should, in any event, otherwise be referred to. Within this guidance publication the terms 'earth' and 'ground' mean the same thing, as do 'earthing' and 'grounding'.

This publication embodies relevant recommendations in the EN 60079 series; BS 7671 Requirements for electrical installations – IEE Wiring Regulations; relevant aspects of the UK statutory Electricity at Work Regulations and the Electrical Safety, Quality and Continuity Regulations; and gives cognizance to the relevant aspects of the recommendations from IEEE 80 Guide for Safety in AC Substation Grounding.

The contents of this publication are provided for information only and while every reasonable care has been taken to ensure the accuracy of its contents, the EI cannot accept any responsibility for any action taken, or not taken, on the basis of this information. The EI shall not be liable to any person for any loss or damage which may arise from use of the information contained in any of its publications.

The above disclaimer is not intended to restrict or exclude liability for death or personal injury caused by own negligence.

Suggested revisions are invited and should be submitted to the Technical Department, Energy Institute, 61 New Cavendish Street, London W1G 7AR.

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

1 INTRODUCTION, SCOPE AND APPLICATION

1.1 INTRODUCTION

This code is aimed at providing an overview of electrical 'earthing', 'grounding' and 'bonding' to address the following phenomena:

- electrical power system earth/ground faults;
- touch and step voltage hazards;
- lightning electrical and ignition hazards;
- ignition hazards associated with Ex apparatus;
- ignition hazards associated with the interruption of currents;
- ignition hazards associated with electrostatic discharges, and
- disturbance of signal transmission.

Earthing/grounding/bonding practices consist of interconnecting certain conductive parts of a system by engineered electrically conductive paths, primarily for the following personnel safety and asset protection purposes:

- To provide a path for power system fault currents to flow back to the source of supply, and to mitigate arc flash hazards.
- The elimination of electric shock hazards (touch and step voltages).
- To provide a path to dissipate lightning currents into the general mass of the Earth.
- The elimination of ignition hazards, whether related to Ex certified apparatus or the prevention of the interruption of stray currents.
- The dissipation of electrostatic charges that could cause potentially incendive sparking.
- To ensure the integrity of signal return paths, and to minimise electrical interference with such signals.

Earthing/grounding/bonding systems are important for electrical safety, lightning safety, and the control of sources of potential ignition. They contribute to the operability of process control systems and to the integrity of active safety functions; hence these systems make a vital contribution to continuity of operation and to ongoing asset integrity.

Note: A protective function, and the system that implements that function, may be regarded as 'safety critical' if a purpose of that function/system is to reduce the likelihood, or the consequences, of an accidental event which may result in major injuries to personnel; earthing/grounding/bonding systems will often meet that definition of safety criticality, and indeed may be subject to specific regulatory requirements (further information is given in the EI *Guidelines for the management of safety critical elements)*. However, earthing/grounding/bonding systems that are designed, maintained, tested and operated in accordance with this document and the underlying standards should normally meet both personnel safety and commercial objectives.

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

The overall structure of this document includes discussions of

– the underlying processes;
– the functional requirements and performance standards of earthing/grounding/bonding systems;
– some specific applications, and
– detailed design and construction issues.

1.2 SCOPE

This publication covers earthing, grounding and bonding practices in the upstream and downstream oil and gas industry, most notably in hazardous areas, but including adjacent areas classified as non-hazardous. The petroleum industry is distinctive because of the flammable nature of the product; this requires the control of sources of potential ignition of flammable product, e.g. the prevention of the interruption of stray currents that could result in an incendive spark. This publication does not cover earthing/grounding/bonding practices in other industrial sectors. References to current international, British and EI standards and guidance are provided.

1.3 APPLICATION

This publication is intended for global application to oil and gas facilities such as upstream production installations, storage facilities, terminals, refineries, filling stations and product transfer, but not downstream gas facilities. It covers the design, operation, inspection, test and maintenance of both new and existing facilities, portable/temporary equipment, and to operational interactions with bulk fuel tankers and aircraft refuellers (but no other aspect of tankers or aircraft). This publication creates no general requirement to upgrade a legacy installation designed to obsolete standards, providing that it remains safe, operable and in compliance with legal requirements. However, if a significant modification is required, it should meet current standards where possible.

Note: The legal requirements described in this publication are specific to Britain, and any reference to regulations in this publication refers only to British legislation; other jurisdictions may have different requirements. Metric units are used throughout.

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

2 BACKGROUND

This publication embodies and builds on relevant recommendations from the standards listed in Annex F (note, some of these standards do not apply offshore). It is consistent with the British *Electricity at Work Regulations 1989* and the *Electricity Safety, Quality and Continuity Regulations 2002*, and provides some additional guidance.

Note: There can be differences between standards, e.g. between those intended for offshore installations and those intended for ships such as floating production, storage and offloading installations (FPSOs). For example, the requirements for offshore installations in BS IEC 61892 differ from the requirements for ships (as applied to FPSOs) in BS IEC 60092-502, which itself is not in full concurrence with the system earthing/grounding requirements of the IMO *International Convention for the Safety of Life at Sea (SOLAS).* However, this publication makes no general attempt to identify inconsistencies between standards, or to resolve them. Where there is a conflict between standards, the chosen arrangement should be agreed with the insurer, classification society, regulator, and any other interested parties such as commercial partners.

The characteristics of, and distinctions between, earthing, grounding and bonding are best understood by reference to their functions. However, any given earthing, grounding or bonding conductor may provide more than one of those functions. Earthing/grounding/bonding connections may be achieved by specifically installed conductors, but in many cases there will be other incidental or fortuitous paths in parallel, e.g. cable armour, cable tray, metallic structures, stray capacitance, or the body of the Earth itself.

The terminology in various publications is not necessarily consistent. The term 'earthing' often indicates a protective conductor intended to carry power system fault currents (often called 'earth faults' or 'ground faults') from exposed conductive parts (such as electrical apparatus housings) back to the source of supply, but this function may also be called 'grounding'. However, although in some cases fault current may flow through the body of the Earth back to the return side of the source of supply, the body of the Earth serves simply as a conductor in the flow path of the fault current, not as a 'zero' potential reference point. Alternatively, the term 'earthing' may refer to a connection from certain conductive part(s) to the general mass of the Earth (considered to be a zero potential reference point), sometimes called 'ground' but which may be water, e.g. the sea, but this function may also be called 'grounding'. The terms 'earth(ing)' and 'ground(ing)' are used interchangeably in the literature.

Note: 'Exposed conductive parts' are defined as parts of an electrical installation that are not normally live, but which may become live under fault conditions (e.g. the exposed metallic housing of electrical apparatus); 'extraneous conductive parts' are not part of an electrical installation, and so are not normally live, but may similarly become live under fault conditions (e.g. structural steelwork, metallic pipework or conductive cable tray).

This and other publications make general use of such terms as protective earth, protective conductor, earth/ground conductor, etc. but the following terms have specific meanings (defined in Annex A) and are used in a consistent way in this publication:

– *Circuit protective conductors* (CPCs): provide the primary route for currents due to a fault between live and conductive parts of the apparatus not intended to carry normal functional current (e.g. the housing of electrical apparatus) to flow back to the main earthing/grounding terminal, and hence to the return side of the supply (generally the supply transformer star point).

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

– *Main bonding conductors:* provide a connection between extraneous conductive parts, or the lightning down conductor, to the main earthing/grounding terminal of the electrical installation.
– *Supplementary bonding conductors:* make a local connection between exposed or extraneous conductive parts.

Figure 1 illustrates some possible layouts for the main and supplementary bonding conductors, CPC etc.

'Bonding' in the sense of main or supplementary conductors is employed to deal with power system fault currents, stray current or lightning currents, and is different from 'bonding' applied to prevent electrostatic charges from accumulating; see 4.5 for further guidance on electrostatic charges.

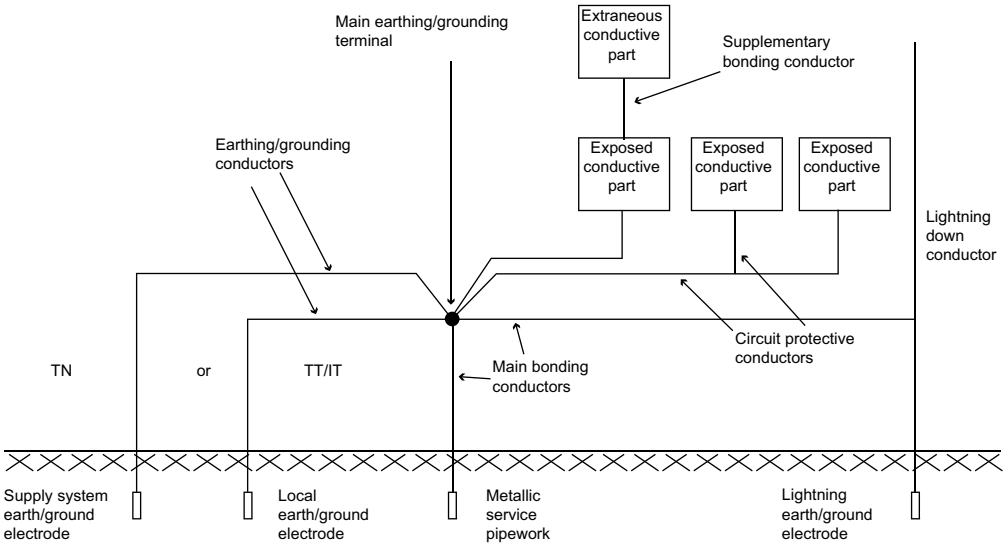


Figure 1: Earthing/grounding system conductors

CPCs, main bonding conductors and supplementary bonding conductors are not intended to carry electrical system operating currents.

Note: Sometimes, adjacent systems require some degree of separation from each other, for example, where it is necessary to isolate cathodic protection systems so as to confine the cathodic protection current to the steelwork intended to be protected. In this case, the protected steel is at a finite potential with respect to the general mass of the Earth, and the anode is the earth/ground reference point.

Low resistance paths provided for earthing/grounding and bonding purposes provide a fortuitous current path for stray currents; these can arise from a number of sources, some inherent in the situation (e.g. galvanic currents resulting from corrosion of buried metallic objects), some introduced deliberately (e.g. cathodic protection), and some due to faults (e.g. in electrical power supply circuits). Where a current path is interrupted or reconnected, a potentially incendive arc or spark may result. Therefore, the management controls of earthing/grounding/bonding arrangements are particularly demanding in the oil and gas industry, given the need to avoid the risk of ignition of potentially flammable atmospheres.

Documents
Document Sharing Hub
This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

3 FUNCTIONAL PERFORMANCE REQUIREMENTS OF EARTHING/GROUNDING/BONDING SYSTEMS

The design and operation of functional systems such as earthing/grounding/bonding are best understood by reference to the defined function and the required performance of that function. The functions and performance requirements of earthing/grounding/bonding systems in the oil and gas industry are as follows:

– Electrical protection is designed to operate rapidly in the event of a power system fault between the live circuit conductor(s) and exposed or extraneous conductive parts (this is commonly called an 'earth/ground fault'); protection is designed to mitigate the risk of damage to apparatus or harm to personnel from arcs, under single fault conditions in otherwise normal operation. This protective function relies on a low impedance circuit protective conductor (CPC) in order to allow a sufficiently high current to flow so as to initiate the disconnection function within an acceptable time. Recommended minimum conductor sizes for the CPC and maximum isolation times to achieve satisfactory performance are given in BS 7671, and see 6.2.

– Accessible exposed conductive parts are earthed/grounded, and extraneous conductive parts are bonded, in order to reduce 'touch voltages' and 'step voltages' to a non-hazardous level (see Annex B for a discussion of tolerable touch and step voltages).

– Lightning strikes can cause direct damage or injury. Some degree of protection is provided if the earthing/grounding system impedance is low enough to limit the voltage rise of the lightning protection conductors. BS EN 62305-3 recommends low earth/ground resistance, if possible lower than 10 Ω.

– A spark can result if a current is interrupted or reconnected. BS EN 60079-11 indicates that for gas subdivisions IIA, IIB and IIC, in a circuit with no reactance, a voltage below 10 V appears not to be able to create an incendive spark, and for voltages below 20 V, a current below 100 mA cannot create an incendive spark. Earthing/grounding/bonding conductors are considered to have little reactance. For petrol filling stations earthed via a TN-C-S system it is considered that currents below 100 mA may not present an ignition hazard if interrupted or reconnected. However, currents (including stray or diverted neutral current) above 100 mA in CPCs or bonds in hazardous areas should be investigated in case the operational situation changes and the current rises to a potentially incendive level.

– Electrostatic charges can reach incendive levels in certain conditions, but are readily dissipated to a non-incendive level by bonding paths of less than 1 MΩ resistance (see 4.5).

– Reliable functionality of instrument and telecommunications signals cannot be assured in the presence of significant signal interference, so signal return paths (especially safety system signal paths) may require protection. Voltages and currents that can interfere with correct circuit operation can be determined only on a case-by-case basis.

  Note: e.g. that many instrument signals use 4 – 20 mA, so that levels of interference in the range of a few mA or less, are likely to cause a malfunction in instrumentation applications (this may be a relatively high level of signal interference, but is normally much less than a potentially incendive level).

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

4 PRINCIPLES

4.1 ELECTRICAL POWER EARTHING/GROUNDING ARRANGEMENTS

For low voltage (LV) systems, the IEC 60364 series of standards distinguishes three classes of earthing/grounding arrangements for power supplies, using the two-letter codes TT, TN and IT. These apply equally to three-phase AC and single-phase supplies.

The first letter indicates the connection between earth/ground and the power supply generator:

– T: direct connection of a point (often the generator star point) with earth/ground (the letter T is derived from the Latin, terra).
– I: no point is connected to earth/ground (except through a high impedance or stray impedances).

The second letter indicates the connection between earth/ground and the electrical apparatus being supplied:

– T: direct connection with earth/ground, independent of any earth/ground connection in the supply system.
– N: connection with earth/ground via the supply system.

There are three variants of TN systems:

– TN-S: the protective earth/ground and neutral are separate conductors, joined together at or near the power source.
– TN-C: a single conductor functions as a combined neutral and protective earth/ground; this conductor may be earthed/grounded at several points.
– TN-C-S: supplier's part of the system uses a combined protective earth/ground and neutral conductor, but this is split at some point, usually on entry to the consumer's facility, into separate protective earth/ground and neutral conductors connected to the electrical load apparatus; the protective earth/ground conductor is earthed/grounded at several points, typically at each consumer's site. This variant is also known as protective multiple earth (PME) or multi-grounded neutral (MGN).

There are advantages to both unearthed/ungrounded and earthed/grounded neutral systems, and both systems are widely used. Protection through earthing/grounding will only be effective if the earth/ground path impedance is sufficiently low so that there is no danger from any voltage developed due to any prospective fault current flow. Earthing/grounding of the neutral via an impedance designed to limit fault current may be undertaken provided there will be an effective earth/ground fault protection arrangement, the neutral is insulated from earth/ground to the requirements of phase voltage and in all other respects is regarded as a potentially live conductor.

For high voltage (HV) applications, generator neutrals will generally be earthed/grounded via neutral earthing/grounding resistors so as to limit the earth/ground fault current and to prevent overvoltages that may otherwise occur on electrical systems. The neutral earthing/grounding resistor should be rated for the short-term fault current, but should also be rated for the continuous circulating current where generators with earthed/grounded neutrals are intended to run in parallel with the neutrals interconnected (especially with generators of different rating or winding pitch).

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

HV distribution systems are usually earthed/grounded at the transformer in order to control phase to earth/ground voltages and avoid overstressing the insulation by keeping neutral voltages as close to earth/ground potential as possible. The LV neutral is usually earthed/ grounded at the switchboard. Figure 2 shows typical arrangements.

DC supplies are widely used in well drilling and well control power supply applications, switchgear tripping supplies and in power supplies to control and safety systems. These applications usually use unearthed/ungrounded supplies, as they generally require the associated improved availability of supply.

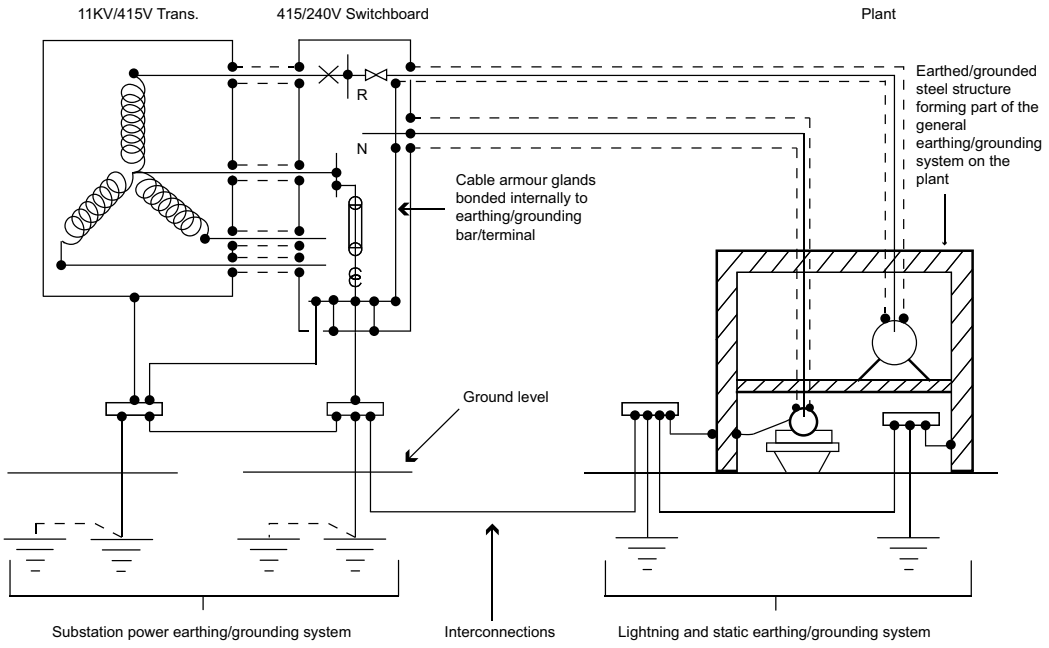


Figure 2: Earthing principles onshore

4.1.1 TT systems

TT systems require electrically independent earth/ground electrodes at the supply and at the consumer's installation. This may be a costly option, and the earth/ground loop impedance will be high, so protection against earth/ground faults is typically provided by residual current device (RCD.)

4.1.2 TN-C systems

TN-C systems are the least safe because a failure of the combined neutral and earth/ground conductor results in the neutral side of the load apparatus rising towards line potential. This problem can be reduced if the system has multiple earth/ground connections in addition to the low impedance earth/ground at the source (see 4.1.4 for a discussion of the effects of a broken combined neutral and earth (CNE) conductor in this situation, and on the effects of diverted neutral currents).

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

4.1.3 TN-S systems

TN-S systems can be costly because of the requirement for a separate protective conductor from source to load. Also note that failure of this conductor is not revealed, and if the protective earth (PE) conductor is open circuit, the potential of exposed conductive surfaces may become hazardous in the event of an earth/ground fault in the apparatus.

4.1.4 TN-C-S (PME) systems

The TN-C-S system is often known as the PME system, but is sometimes known as the MGN system. The protective earth and neutral (PEN) conductor, also referred to as the CNE conductor, should have earth/ground connections at a number of points in order to mitigate the risk of a broken neutral conductor. In PME systems, the protective earth/ground (PE) conductor within a given facility is connected to the incoming CNE conductor near the boundary of the site; all exposed conductive parts (e.g. electrical apparatus housings) and extraneous conductive parts (e.g. steelwork) in that facility then are bonded to the site-specific PE conductor, therefore providing a connection to the supply system combined neutral/earth (CNE) conductor. The PE is also connected to service pipework (e.g. conductive utility pipework such as water mains) to provide *de facto* earth/ground connections at every facility supplied by the PME supply; however, the resistance and the integrity of these earth/ground connections are unknown. In simple terms, for a self-contained facility, PME systems should not create a shock hazard in the event of a failure of the CNE conductor (when the CNE conductor may be at a significant potential with respect to the general mass of the Earth in spite of the local 'earth/ground' connection provided by connections to service/utility pipework), because comprehensive main and supplementary bonds should eliminate potentially hazardous touch voltages; this situation is likely to be revealed by unacceptable voltage variations. Similarly, the failure of the PE conductor or a main bonding conductor should not create a shock hazard if the CNE conductor remains connected to the protective earthing/grounding system and exposed conductive parts remain insulated from live circuit conductors. However, this PE or bonding conductor failure is not revealed, so a subsequent earth/ground fault may create a shock hazard. Therefore periodic tests should be conducted on PE and main bonding conductors to confirm the integrity of the protective function, but PME systems generally will tolerate any single fault condition. However, if it is possible to touch a conductive surface at CNE potential and 'true' earth/ground, e.g. by standing on a (wet/conductive) surface in contact with the general mass of the Earth, there is indeed a potential electric shock hazard under single fault conditions, e.g. failure of the CNE conductor. Therefore PME systems cannot be recommended for oil and gas industry applications, even in areas classified as non-hazardous.

Furthermore, even in fault-free PME systems, some proportion, called the 'diverted neutral current' (DNC), of the load return/neutral current will flow through any conductor that is connected to the CNE conductor and is in effective contact with the general mass of the Earth - this could, for example, be any extraneous conductive part, e.g. metallic cable tray (see Figure 3). The accidental making or breaking of joints in such conductors, or their deliberate making or breaking, e.g. in maintenance work, could result in a potentially incendive spark. Therefore these systems should not be used in classified hazardous areas, except where a risk assessment determines that such use cannot be hazardous, e.g. if the DNC (including the effects of DNCs from other consumers on the same supply) can be shown to be below potentially incendive levels.

Note: It is possible to convert PME or public TN-S supplies to local TT or local TN-S, and that this eliminates the DNC problem (see Figures 4 and 5).

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

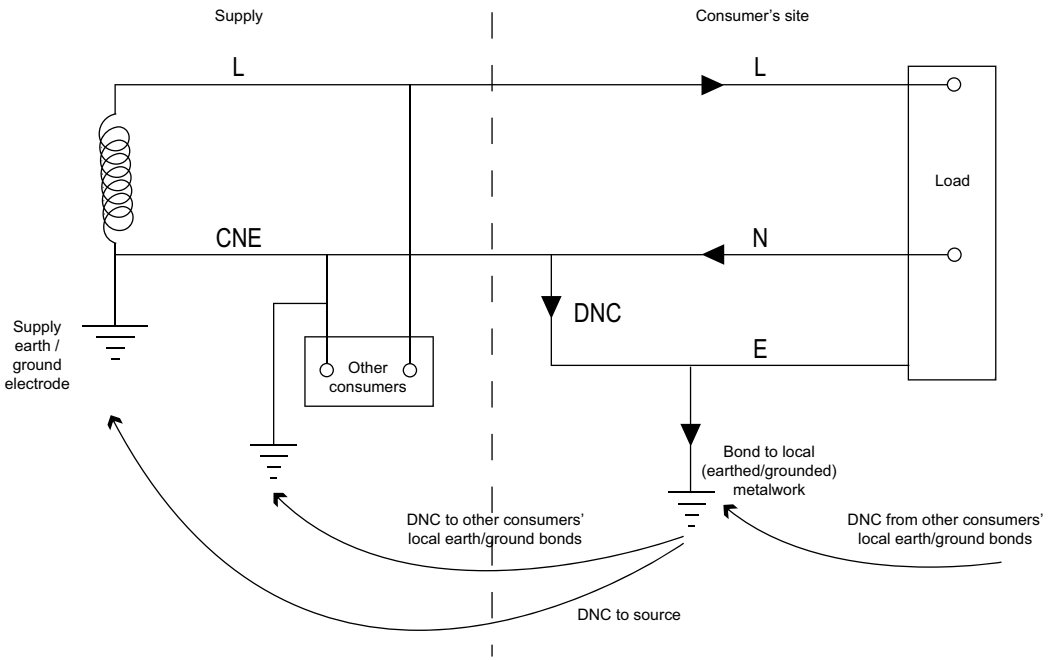


Figure 3: PME supplies and diverted neutral current (DNC)

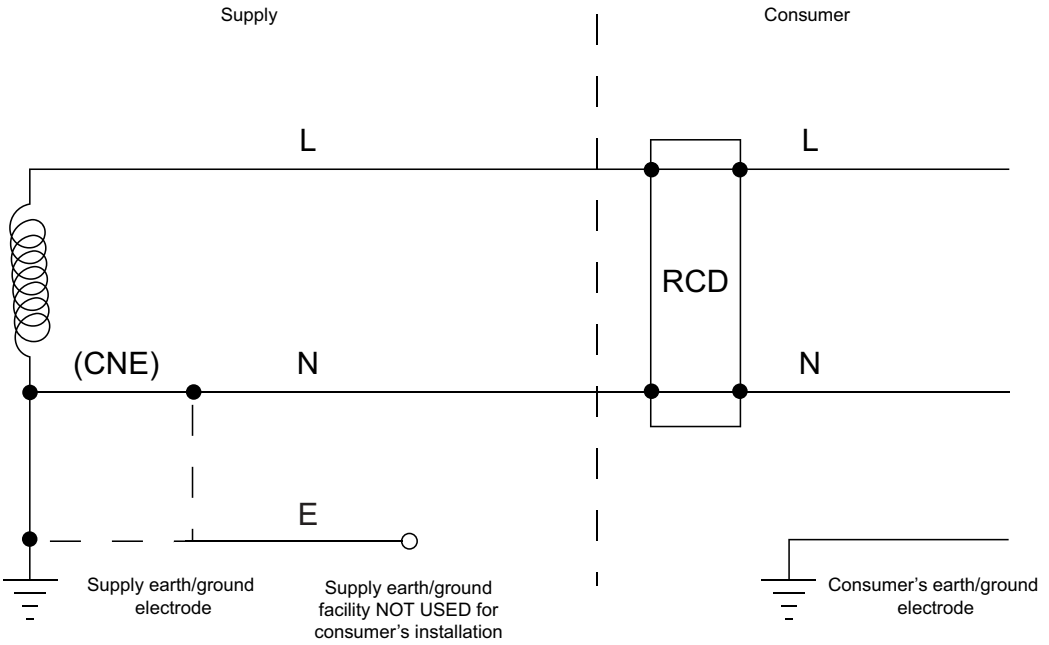


Figure 4: Conversion of PME supply or public TN-S to local TT supply

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

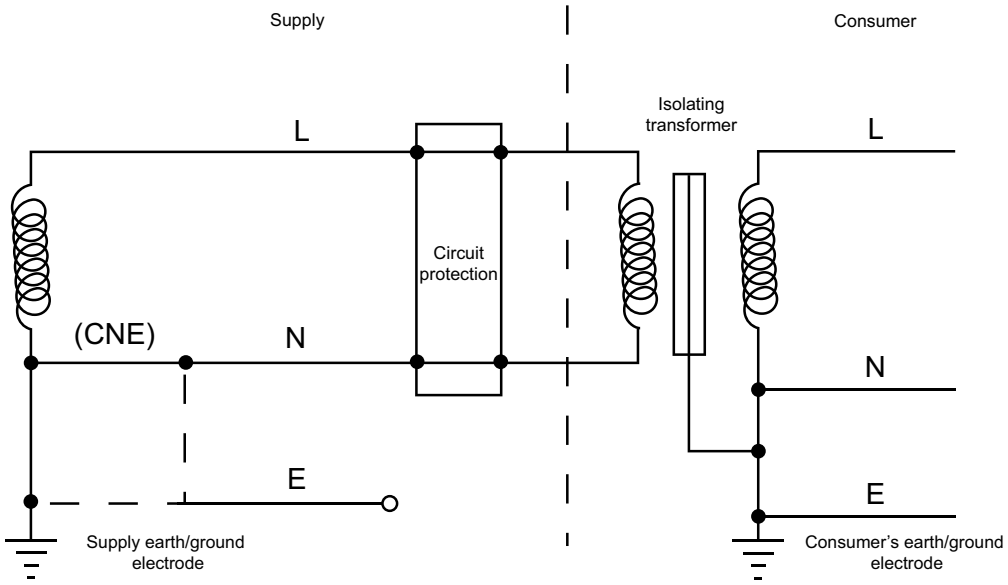


Figure 5: Conversion of PME or public TN-S to local TN-S supply

4.1.5 IT (unearthed) systems

The IT system is generally used for high reliability of electrical supply, especially in safety critical applications, e.g. in marine stability applications, drill rigs and DC supplies to control and safety systems. In these applications, the loss of equipment availability owing to one earth/ground fault might have adverse safety implications or adverse effects on the operability or survivability of the installation. IT systems might also be used to reduce the possibility of earth/ground fault currents flowing in hazardous areas, e.g. cargo tanks. IT systems are best suited for small electrical systems (e.g. a ship's electrical system in relatively dry, below-deck conditions), and are less suited to systems situated in a damp environment (e.g. the electrical systems associated with process plant on the deck of an FPSO).

An appropriate risk assessment needs to balance the above risks together with the possibility of low arcing faults going undetected. Where a mixture of earthed/grounded and unearthed/ungrounded electrical distribution systems is to be implemented on the same installation, an appropriate risk assessment should be undertaken to ensure that the systems are compatible and to identify any essential control measures. There is a balance of risk between, on the one hand, the control of high energy electrical faults, and on the other hand, major accident risks, such as the ignition of flammable atmospheres or loss of availability of safety critical systems.

Where unearthed/ungrounded systems are installed, it should be recognised that the power system phase conductors could constitute an electric shock hazard or potential ignition hazard as a result of contact between them and an extraneous conductive part, notwithstanding the apparent lack of a current route to earth/ground. This arises because of stray capacitive coupling between the power system phase conductors and the local mass of adjacent conductive material, usually at or near earth/ground potential. It is this capacitance that is the basis for Petersen coils; these coils connect the star point of the IT supply to the local mass of conductive material via a relatively high inductive impedance (so preserving the IT property, i.e. that a single earth/ground fault is tolerated). The coil and

Documents
Document Sharing Hub
This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

stray capacitances are tuned to the power frequency so that in the event of an earth/ground fault, much of the fault current flows back to the star point through the Petersen coil, rather than through the fault itself. The result is that any arc at the site of the fault may be less intense and extinguish more easily. Figure 6 illustrates the operation of Petersen coils; note when the Petersen coil is activated, an alarm should be given.

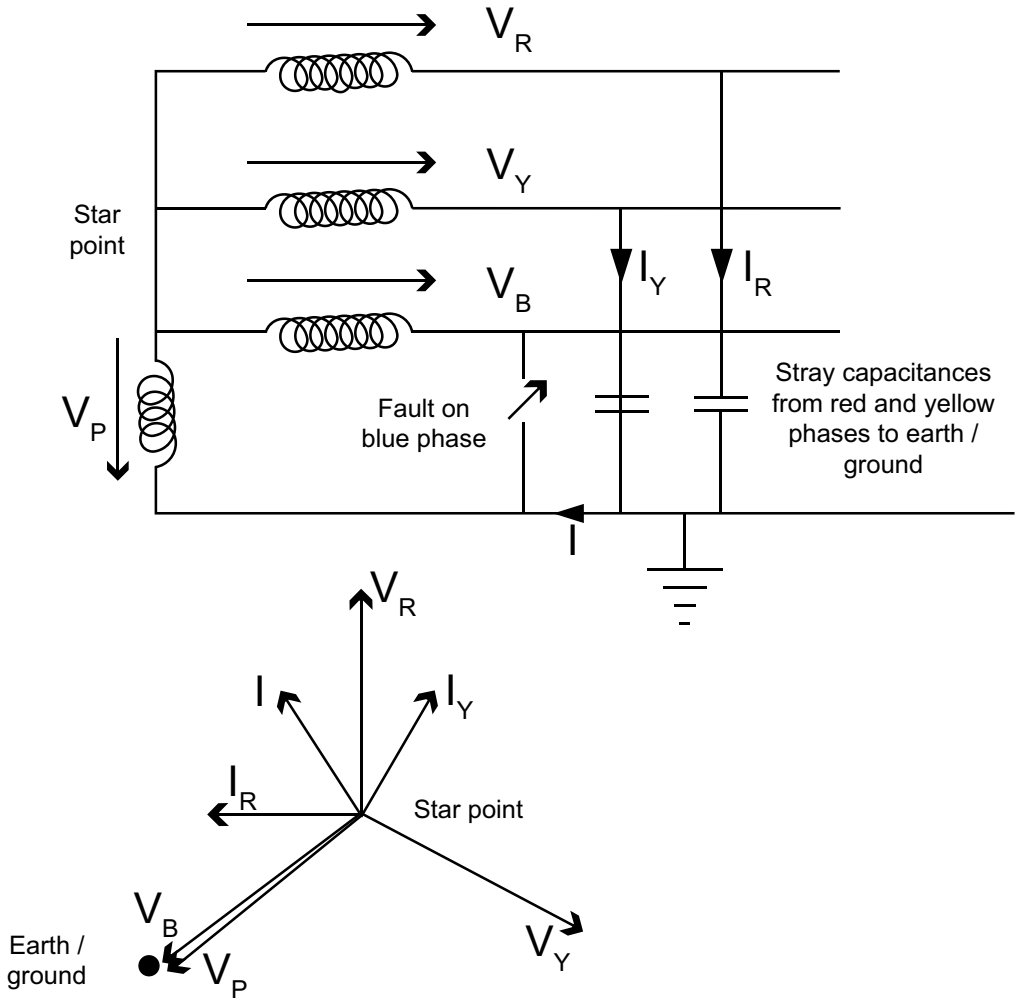


Figure 6: Petersen coil – fault on blue phase

IT system integrity relies upon there being no power system earth/ground contact; if an earth/ground fault occurs then it becomes earthed/grounded via the fault impedance, but without the earth/ground fault detection or the neutral earthing/grounding resistor that play an important role in electrical protection arrangements in earthed/grounded systems. Therefore, any fault is potentially at full load current, i.e. there is a risk of arc flash faults. By contrast, incomers on a conventional earthed/grounded system would typically have earth/ground fault protection with settings (say at 10 to 15 % full load current) designed to clear the fault before damage could occur. The occurrence of a second earth/ground fault on IT systems may not cause the overcurrent protection to operate if the fault impedance restricts the fault current below that required to initiate the protection. When other earth/ground

Documents
Document Sharing Hub
This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

faults occur, a situation can develop that results in an IT electrical distribution system having multiple earth/ground faults present. There is a risk of low-arcing faults, greatly in excess of normal load currents, and the upstream overcurrent protection may not be able to clear the fault(s) sufficiently quickly to prevent damage or danger. The risks of such faults occurring on an IT system should be assessed and, where necessary, appropriate action should be taken to reduce the risks.

When using IT systems, the designers need to pay particular attention to the need for earth/ground fault monitoring and ease of tracking and rectifying the first earth/ground fault as soon as practicable. Designers should therefore structure the system so that switchboards are not too large, and should consider the use of isolation transformers for the supplies to electronic and electrical equipment that might have low impedance networks (i.e. filter circuits) which, inherently in their design, will cause leakage to earth/ground.

Insulation monitoring arrangements play a crucial role in assisting with the tracing of earth/ground faults. The three lamp system and the basic insulation level monitor system provide only limited assistance to maintenance technicians. More sophisticated systems are now available that facilitate the rapid tracing of earth/ground faults. As well as reducing the time that a fault remains present, the use of these systems minimises the requirement for supply disconnection and technician intervention on energised electrical equipment.

Residual current devices (RCDs) can have a role in protecting against electrical shock, and can assist with the tracing of earth/ground faults when used on IT electrical distribution systems. The IT electrical distribution system stray impedance to earth/ground will often be at a value low enough to allow an RCD to function when an earth/ground fault occurs. This is particularly so with electrical distribution systems that incorporate harmonic line filters. Where continuity of supply is required, it will be appropriate to detect the fault by means of a residual current monitor (RCM), but not to trip.

For protection against electrical shock, it is recommended that 30 mA rated RCDs (detect and trip) be incorporated in IT electrical supplies to portable electrical tools and equipment, unless other risk reduction measures have been taken, e.g. the use of a reduced voltage. The use of 30 mA rated RCDs on unearthed/ungrounded systems should also be considered in non-industrial areas such as accommodation on offshore installations, because if two earth/ground faults occur (on separate phase conductors), such protection could provide better protection against electric shock. Also, where the distribution system stray impedance to earth/ground upstream of the RCD is low (e.g. where there are harmonic line filters), the RCD may provide protection if a person comes into contact with a live conductor. An RCD that is sensitive to an imbalance between live and neutral circuit currents is more likely to disconnect a circuit that has developed an earth/ground fault than a fuse or circuit breaker. Incorporation of RCDs into final circuits that are susceptible to earth/ground faults, such as deck lighting, can therefore assist in the tracing and clearing of faults. Figure 7 illustrates typical imbalanced current routes that can be detected by RCDs.

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

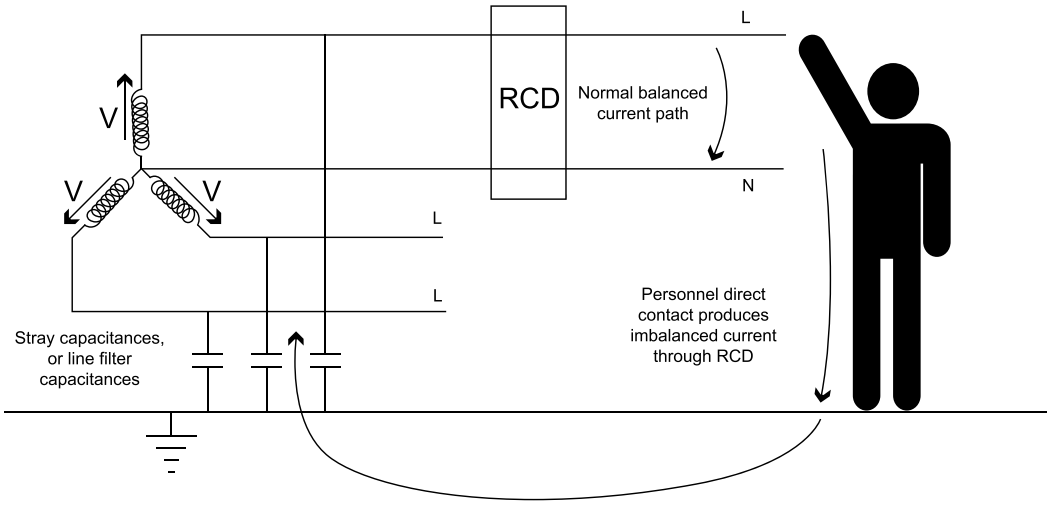


Figure 7: Typical leakage current route to trigger RCD

For unearthed/ungrounded systems on offshore installations, further guidance is given in IEC 61892-1 *Mobile and fixed offshore units. Electrical installations. General requirements and conditions,* and in BS IEC 61892-2 *Mobile and fixed offshore units. Electrical installations. System design.* The requirements for unearthed/ungrounded systems on floating production storage and offloading installations (FPSOs), which are different, are given in BS IEC 60092-502.

4.1.6 Ship's systems earthing/grounding

BS IEC 60092-502 and IEC 61892 discuss four classes of neutral earthing/grounding arrangements; any of these is permitted on ships:

- three-phase, three-wire high impedance earthed/grounded neutral;
- three-phase, three-wire low impedance earthed/grounded neutral;
- three-phase, three-wire directly earthed/grounded neutral, and
- three-phase, three-wire insulated neutral.

On systems with an insulated neutral, the fault could last a relatively long time, so the system should be rated this condition. For system with a high resistance earthed/grounded neutral, the system should incorporate a trip, so the system requires only a short-term rating. In either case, the insulation of the neutral should be designed for the phase-to-phase voltage.

4.1.7 Summary of LV system supply features

The TN-S system has the disadvantage that a broken PE conductor is unrevealed, and the user installation is not earthed/grounded. Then if an earth/ground fault occurs, the exposed conductive surfaces may be at a hazardous potential. The TN-C three-phase system is similarly susceptible to a broken CNE conductor, depending on the imbalance between the three phases; in TN-C single phase systems, the potential of the neutral conductor can rise to the line potential if the CNE conductor fails. The TN-C-S (PME) system has a significant earth/ground loop impedance under fault conditions (higher than the impedance of a normal CNE conductor), and this may lead to unacceptable load voltage variations. Some other features of the various supply types are shown in Table 1.

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

Table 1: Supply system features

	TN-S	TN-C	TN-C-S	TT	IT
PE conductor cost	Highest	Least	High	Low	Low
Earth loop impedance	Low	Low	Low	High	Highest
Risk of broken neutral	High	Highest	High	No	No
Safety	Safest	Least safe	Safe	Safe	Less safe
Needs site electrode	No	No	No	Yes	Yes
EM interference on the earth/ground system	Low	High	Low	Least	Least
Advantages	Safest	Cost	Cost and safety	Safe and reliable	Availability and cost

4.2 AC SUBSTATIONS

An AC substation requires a low resistance earth/ground electrode, usually implemented by a buried earth/ground plate, mesh or grid which covers the whole footprint of the substation; this provides a route to the general mass of the Earth and hence back to the source of supply (see 6.2 for a discussion of conductor sizing, and 6.4 and Annex C for a discussion of earth/ground electrode design). During earth/ground fault conditions in a substation, the current flow via this earthing/grounding system will result in a rise in the system potential relative to the general mass of the Earth, i.e. a ground potential rise (GPR) or earth potential rise (EPR). The sub-station earthing/grounding system should be designed to have a low enough resistance to limit the GPR such that touch and step voltage limits are not exceeded (see 4.13 for a discussion of touch and step voltages). This GPR will be fairly uniform across the area covered by the earthing/grounding system so that the gradient and step voltages are small, but where a grid is used, the GPR will undulate across the site between conductors of the grid, creating local gradients that cause higher step voltages. Around the periphery of the earth/ground electrode system, the gradient will be higher, generating high step voltages; earth/ground potential grading rods may also be included around the electrode periphery to control these step voltages. For a discussion of touch and step voltage limits, see Annex B.

4.3 HV/LV INTERFACES

HV and LV systems associated with a ground mounted HV/LV substation or transformer may either share a common earth/ground electrode or have a separate electrode for each system. For a system where HV metalwork (transformers, associated switchgear and cable armour) and LV neutral-earthing/grounding share a common electrode, the earth/ground resistance should not exceed 1Ω. Where this cannot be achieved, separate electrodes should be provided for the HV and LV systems, with a minimum separation distance of three metres. Depending on earth/ground resistance, it may be necessary to increase the separation distance to avoid electrode area overlap. Where LV equipment is located within metalwork connected to the HV earth/ground electrode, care must be taken to adequately insulate the LV neutral-earthing/grounding bars and LV cable armour from the HV metalwork.

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

Where HV and LV systems have their own earth/ground electrodes whose spheres of influence do not overlap, there is no interaction between the two earthing/grounding systems, but a touch voltage can exist between the two earthing/grounding systems, as shown in Figure 8. Where HV and LV systems share a common earth/ground electrode, the temporary overvoltage of the HV earth/ground electrode (which occurs on a HV system during a fault condition) is transferred into the (common) LV system earth/ground and there is no such touch voltage, as shown in Figure 9. Where the separate HV and LV electrodes have spheres of influence that overlap, part of this earth/ground potential rise is transferred into the LV system.

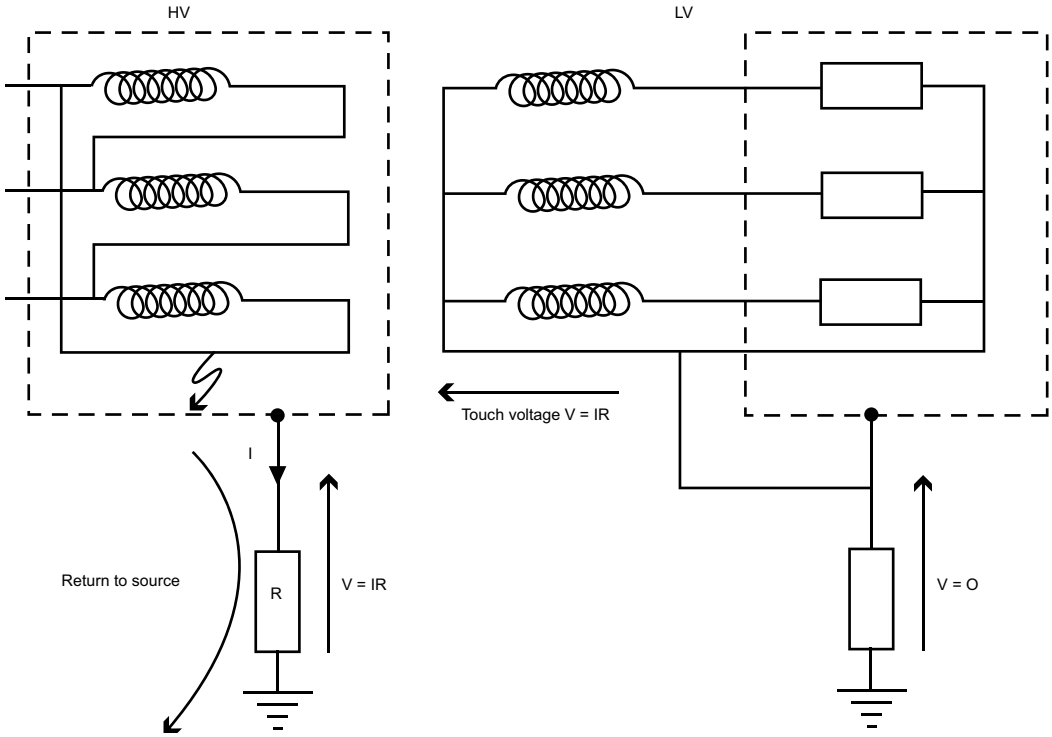


Figure 8: HV/LV interface – separate earth/ground electrodes

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

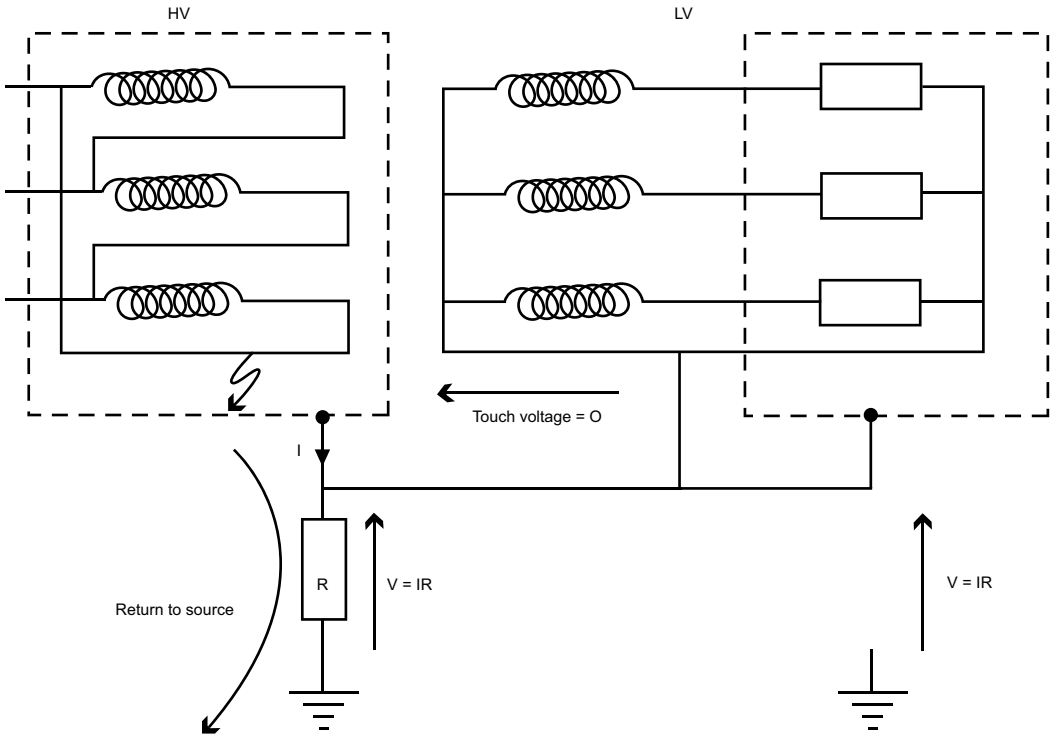


Figure 9: HV/LV interface – combined earth/ground electrodes

An interconnected earthing/grounding system (i.e. global earthing/grounding system) should be used where practicable because the fault current returns directly to the supply star point, and the global earthing/grounding arrangement limits touch voltages between exposed conductive surfaces of HV apparatus and exposed conductive surfaces of LV apparatus (touch voltages between HV apparatus exposed conductive surfaces and extraneous conductive surfaces may exist; whichever configuration is chosen). In a global earthing/grounding system, the earth/ground fault current divides between the various local earthing/grounding systems, and this results in a reduction in the earth/ground potential rise at the local earthing/grounding system where the fault current originates. This may make for a more economical design than individual local earthing/grounding systems.

Note: The current sharing process may result in other local earthing/grounding systems being overloaded, depending on their current rating and earth/ground resistance. Where the global earthing/grounding concept is applied, the entire system should be designed as such; in-service system performance can be verified by either calculation or by test.

For further information on HV/LV interfaces and on the protection of LV installations against overvoltages due to faults in their HV supply, see BS 7671 (Chapter 44, Section 442), and BS 7430; for HV installations including substations, see BS EN 61936-1 and BS EN 50522 Fig. NA 7 (none of these standards applies on ships or offshore installations).

4.4 ELECTRICAL EQUIPMENT CLASSIFICATION

LV electrical equipment is classified in IEC 60364 according to its insulation characteristics and any protective earthing/grounding arrangements, and this classification determines the practical uses to which the equipment may be put.

Documents
Document Sharing Hub
This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

Class I equipment has live parts surrounded by basic insulation (which may be air), and exposed conductive parts have a means of connection to a circuit protective conductor (CPC) that is part of the fixed wiring of the installation; if the equipment develops an internal fault between a live part and exposed conductive part(s), a path is available for the fault current to flow back to the source and operate the circuit protection, which should be designed to disconnect the power supply within the defined disconnection time. Much fixed equipment is Class I.

Class II equipment has live parts surrounded by basic insulation and supplementary insulation (or has reinforced insulation that meets the requirements for double insulation), but has no provision for any exposed conductive part to be earthed/grounded; this arrangement is commonly called 'double insulation' or 'all insulation'. Class II protection is often used for smaller items of equipment whose casings lend themselves to construction from non-conductive material. Class II equipment remains safe with failure of one layer of insulation (or degradation of the reinforced insulation), and is usually used with circuit protection by RCD. Class II equipment has the advantage of simple installation, and cannot have the possible adverse effects of diverted neutral current, and can have no touch voltage under single fault conditions.

Class III equipment operates at separated (or 'safety') extra-low voltage (SELV) and relies on protection against electric shock by using an ELV supply of no greater than 50 V ac or 120 V dc. Exposed conductive parts may be earthed/grounded, or may be unearthed/ungrounded (e.g. for electromagnetic compatibility purposes). Portable equipment often relies on the SELV concept, and inherently cannot give rise to a hazardous touch voltage. ELV limits are defined in IEC 61201.

4.5 STATIC ELECTRICITY

Whenever two dissimilar materials come into contact, charge separation occurs at the interface. If one (or both) of the materials is a very poor conductor, recombination of these charges is impeded and a charge accumulates – this is static electricity. Unless relaxed (i.e. conducted away), charge may build up on, for example, isolated conductive surfaces, on any particulates in a flow stream, or on the internal surfaces of a pipe wall. The conditions that cause static charges to be separated are present in many working situations, including processes that rub surfaces together or agitate fluids. Examples include: sampling from live hydrocarbon lines into sample containers, product loading, steam cleaning, grit blasting, water jetting, pouring of fuels, decanting of chemicals, and product flow through a nozzle (see 7.1 and 7.2 for further comments).

Charge separation is substantial in a two-phase flow due to agitation of the mixture and the increased surface area of the phases, and downstream of fine filters due to extensive agitation of the fluid.

Note: Where the fluid has significant conductivity (typically greater than 50 pS/m), charge will relax quickly, rather than accumulating; conductivity may be a natural property of the fluid, or may result from anti-static additives; static relaxation tanks may be used to allow sufficient time for the relaxation process to occur.

Equally, personnel and their clothing and boots can become charged, and this charge could persist unless relaxed, e.g. by contact with secondary structures such as conductive flooring.

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

The energy dissipated by the discharge of static electricity generated in typical oil and gas industry applications is unlikely to cause any direct damage, or to harm personnel, but greatly exceeds the minimum ignition energy of some common oil or gas products (see the EI *Model Code of Safe Practice Part 1: The selection, installation, inspection, and maintenance of electrical and non electrical apparatus in hazardous areas*). Therefore, electrostatic charge may create an incendive spark when brought into close proximity with a conductor at a different potential.

Note: An aircraft in flight will typically acquire an electrostatic charge. However, most of the parts of the aircraft will be bonded (either explicitly, or incidentally, in some cases via paths of high resistance), and the occupants of the aircraft will be in contact with the aircraft body. The aircraft itself will be unaffected by the electrostatic charge, as this does not cause a potential difference between aircraft parts, and similarly the occupants will be unaffected by (and indeed unaware of) the charge. When the aircraft lands, the electrostatic charge will generally be dissipated into the general mass of the Earth via (semi) conductive tyres and the runway/apron/helideck, with no observable effects on the aircraft or its occupants (but the aircraft may need a bonding conductor during refuelling, to avoid ignition of fuel vapours, see 5.6.4).

The generation of static charge may be a continuous process; the charging current depends on numerous factors, but practical experience in the oil and gas industry indicates that the current will be 10^{-4} A or less, and tests indicate that in normal oil and gas applications, at least 300 V are required to initiate an incendive discharge from an electrostatic source (see the EI *Model Code of Safe Practice Part 1: The selection, installation, inspection, and maintenance of electrical and non electrical apparatus in hazardous areas*). Therefore, it is recommended that an electrostatic potential of 100 V should not be exceeded, but static electricity is easily relaxed via conductive or dissipative bonds (sometimes called semi-conductive bonds) with a resistance not normally exceeding $100V/10^{-4}$ A, i.e.1 MΩ (bonding assists in the relaxation of static charges i.e. bonding prevents the build-up of a dangerous electrostatic voltage, but does not prevent charge separation and the creation of static electricity). Therefore, where conductors are required to be effectively isolated for other reasons, they may nonetheless be bonded via high resistance paths in order to relax static electricity.

Note: Vehicle and aircraft tyres can provide a suitable dissipative path to the general mass of the Earth (though tarmac may have too high a resistance to allow this process, see the EI *Model Code of Safe Practice Part 1: The selection, installation, inspection, and maintenance of electrical and non electrical apparatus in hazardous areas*).

Earthing/grounding/bonding conductors provided for electrical or lightning protection have very low resistance values in relation to the requirements for static electricity. Consequently, where such conductors are provided, there will also be protection against electrostatic energy.

A mixture of conductive and non-conductive components in one installation should be avoided, as this may result in isolated conductive sections that may acquire a potentially incendive electrostatic charge; such an arrangement can also create difficulties in the periodic verification of the earthing/grounding/bonding functionality. For example, insertion of a section of non-conductive pipe into a conductive pipe run breaks the continuity along that run; it is then necessary to ensure that the conductive parts at both ends are reliably connected to earth/ground, or to install a bonding conductor to bridge the non-conductive pipe section. Alternatively, the use of semi-conductive/dissipative pipe should ensure that a continuous conductive path is maintained throughout the length of the pipe run (provided that electrical contact is maintained at interfaces).

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

Where an open-ended pipe discharges into a vessel or where a line incorporates an electrically discontinuous flexible coupling to a vessel, bonding between the end of the pipe and the vessel is required in order to prevent the accumulation of potentially incendive electrostatic charges during product flow.

Further advice on the control of hazards arising from static electricity is given in EI *Model code of safe practice Part 21 Guidelines for the control of hazards arising from static electricity.*

4.6 LIGHTNING

Lightning is the discharge of static electricity generated within clouds by the charge separation mechanism described in 4.5, but on a very large scale. It results from collisions between water droplets, ice/water slush or ice crystals, driven by air circulation or wind within the cloud. Negative charge tends to accumulate on the base of the cloud, whereas the top of the cloud becomes positively charged. Ionised 'leaders' reach down from the cloud, and leaders reach up from ground level or from tall structures. Eventually, a massive discharge occurs via a conductive plasma that 'attaches' to some point on the surface of the Earth or to an earthed/grounded structure. Following the initial fast strike, a lower current may flow for a longer period. The lightning current flows into the general mass of the Earth, where it need be considered no further (unlike the situation with electrically powered systems, where currents always return to the source of supply, typically the transformer star point). Most cloud-to-ground lightning is a discharge from the negatively charged base of the cloud. Positive lightning arises from the positively charged top of the cloud, and may travel a considerable distance away from the cloud before forming a large bolt of lightning which can be more severe than negative lightning, by about a factor of 10; only about 10 % of strokes are positive.

Lightning strikes have currents and voltages that might be capable of damaging unprotected structures, process apparatus or electrical/electronic apparatus, as well causing ignition of flammable inventories. However, the structures of large oil and gas installations are generally made of conducting materials such as steel, and are generally in contact with the soil or the sea. Larger items of process plant are generally made of steel and are in contact with the basic structure of the facility, and machinery is generally in metallic casings, once again in contact with the structure. The sizes and thicknesses of these structures and casings may exceed the BS EN 62305-3 requirements for thickness and cross-sectional area (e.g. 4 mm for steel sheets, 25 mm^2 for copper conductors not prone to mechanical damage), and so offer adequate protection; bonding to the site earth-termination electrode is required.

The energy of a strike is sufficient to cause injury to personnel; a stroke near a facility, or a stroke on a service connected to a facility (e.g. a pipeline, power cable, signal cable, or other conductive structure), can also cause injury. Because soil is not a perfect conductor, large voltage gradients can appear adjacent to the immediate site of the strike, and cause hazardous 'step voltages' between the feet of personnel (see 4.13).

4.6.1 The likelihood of a strike, and risk management

Maps of the world showing lightning flash density ('isokinauric maps') are available and give the average number of lightning flashes per square kilometre per year. Data are available from many sources, for example, the National Lightning Safety Institute (891, N. Hoover Avenue, Louisville, CO, USA) and the Council on Large Electrical Systems (CIGRE, 21 rue d'Artois, FR-75008, Paris, France). The number of flashes in some parts of the world may exceed

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

10 per square kilometre per year, and in others is less than 0,1. For small facilities (say 10 m x 10 m) in benign locations with an annual probability of a strike of e.g. 0,1 per square km, the annual probability of a strike is 10^{-5}, the threshold of risk to human life or permanent injuries suggested in BS EN 62305-2 as requiring consideration. However, in general the likelihood of a hazardous strike and resulting losses should be assessed.

The methodology defined in BS EN 62305 is to identify the lightning protection zone (LPZ) which requires protection by a lightning protection system (LPS). BS EN 62305-1 defines four lightning protection levels (LPL), I, II, III and IV, I being the most onerous, and defines the specific lightning parameters which the LPS should be designed to withstand (i.e. in terms of cross section area of bonding conductors, thickness of shielding, etc.).

Note : BS EN 62035-2 indicates that at least class II should be adopted for facilities with an explosion risk, but the need to define a performance standard for the lightning protection function is self-evident for oil and gas facilities, as these contain a significant inventory of flammable fluids which could be ignited by a strike. The parameters of individual lightning strikes vary greatly, but their statistical distribution is given in BS EN 62305-1; for LPL II there is a 98 % probability that the parameters of individual lightning strikes will be within the values given (so only 2 % of strikes will be more severe than the values given, see BS EN 62305-1 Table 5), and LPL II systems give a good degree of lightning risk reduction.

The mechanical effects of lightning are related to the peak value of the current (for LPL II, 150 kA), the thermal effects are related to the specific energy, (for LPL II 5,6 MJ/Ω where resistive coupling is involved) and to the charge (for LPL II, 75 coulombs) in cases when arcs develop. Overvoltages and sparking caused by inductive coupling are related to the average steepness of the lightning current front (for LP II, 20 kA/μs).

The functions of the external LPS are (a) to intercept the lightning flash via an air-termination system (not addressed in this publication), (b) to provide a conductive path via a down-conductor system (not addressed in this publication) therefore bypassing the protected facility and ideally routing the lightning current away from hazardous areas, and (c) to disperse it into the general mass of the Earth via an earth/ground-termination system, usually a system of earth/ground electrode(s), though the underground metallic structures of the facility such as foundation steelwork may form an effective earth/ground-termination.

Surge protection systems may be required to intercept surges resulting from resistive and inductive coupling, transmitted by lines connected to the structure, or magnetic fields directly coupling with apparatus, and to provide protection against the failure of internal systems, see 4.9.1.1.

4.6.2 Earth/ground-terminations

The lightning earth/ground termination, and related conductors and bonding bar(s) generally used to interconnect extraneous conductive parts, etc, should be of sufficient strength and current carrying capacity to tolerate the peak current and heating effect. BS EN 62305-3 gives recommended minimum conductor sizes (which are independent of LPL).

Earth/ground-termination conductors should also have low inductance so as to reduce overvoltages caused by the steep edges of the lightning current pulses. The inductance (L) of a linear conductor in free space is approximately (see EB Rosa):

$$L = 2.l.[\ln(2l/r)-1]x10^{-7}\ H$$

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

Where:

l = length

r = radius

= 5 μH for a conductor of radius 10 mm and length 5 m

So on this basis, for the maximum di/dt of 20 kA/μs defined for LPL II, the voltage generated is 100 kV for a 5 m conductor; however, di/dt can be up to 10 times higher for positive lightning, and the voltage generated correspondingly higher. Stray capacitance reduces these overvoltages, and in practice an inductance up to 100 μH may not be a problem (see CuI/LT-0373 *Lightning simulation testing to determine the required characteristics for roof bonding cables)*. Nonetheless, earth/ground-termination conductors should be kept as short as possible, and bends should be avoided as they increase inductance.

The resistance of copper earth/ground-termination conductors is of order 0,005 Ω/m, so for the peak current defined for LP II (150kA), the voltage generated is around 3,75 kV for a 5 m conductor. This voltage is dwarfed by the inductive component, but since side flashes may occur at potential differences of 5 kV or more, structures adjacent to earth/ground-termination conductors should be bonded to the earth/ground-termination conductor at intervals of no more than 5 m.

To disperse the lightning current into the general mass of the Earth, so minimising potentially hazardous overvoltages, the earth/ground electrode system should have a low resistance. BS EN 62305-3 recommends as low a resistance as practicable and where possible a maximum resistance of 10 Ω (measured at low frequency). On this basis, the LPL II peak current of 150 kA gives a voltage of 1 500 kV, so the earth/ground electrode resistance is a significant contributor to overvoltages.

4.6.3 Physical damage and life hazard

For loss of human life or permanent injuries, BS EN 62305-2 gives a representative value for tolerable risk of 10^{-5} per year (a suitably small share of the 10^{-3} widely applied as the maximum tolerable risk in workplaces). The risks in a particular situation should be compared with the tolerable risk, and where the risk is higher than the tolerable risk, an LPS should always be provided. Health and safety legislation and practice in Britain have a second requirement, i.e. 'grossly disproportionate' expenditure to reduce the residual risk to a level which is 'as low as is reasonably practicable' (ALARP.) This final level of residual risk may be lower than the limit of tolerability (10^{-5}), if cost-effective risk reduction measures are available.

For economic loss, a straightforward cost-benefit analysis may be adopted, as discussed in BS EN 62305-2; in general, this requires the identification of all types of loss and the evaluation of the risk associated with each. The cost-effectiveness of each possible protective measure is evaluated by comparison of its costs with the economic value of losses averted by that protection measure (see BS EN 62305-2 Annex D).

4.7 CIRCULATING CURRENTS

Circulating currents may occur in any loop, for example, induced by nearby power transmission conductors, RF radiation, CP currents, galvanic currents, etc. See 4.1 for comments on circulating currents between generators.

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry

Where practicable, loops should be avoided and radial layouts are preferred, i.e. a single conductive earthing/grounding/bonding path should be used, although there are special cases (e.g. Zener barrier systems) where two or more conductors are required to provide a sufficiently low impedance path, or a path of high integrity that will withstand a conductor failure; in these cases, the conductors may need to run side-by-side in order to have the lowest practicable mutual inductance.

4.8 CATHODIC PROTECTION

Steel structures in contact with the sea, and underground steel tanks and structures, are often protected from corrosion by a combination of external protective coatings and cathodic protection (CP). There are two types of CP, (a) a sacrificial anode system, and (b) an impressed current system. The anodes of either type are inherently in direct/intimate contact with the general mass of the Earth and form the 'reference potential point' for bonding purposes; the steel cathode is protected against corrosion by the current which flows from the anode.

Any structure residing in the same electrolyte, and in electrical contact with the structure intended to be protected, may divert part of the cathodic protection current by acting as an alternative conductive path. This current detracts from the effectiveness of the CP scheme, and may create an incendive spark if interrupted or reconnected. Therefore structures such as connected pipework or cable armour that could divert the CP current should be electrically isolated from the protected structure, e.g. by means of isolation bushes. A method of testing to confirm the continued effectiveness of the isolation(s) should be incorporated. Isolations allow potential differences to appear between conductive parts, which should therefore be placed far enough apart that they cannot be touched simultaneously (to create a 'touch voltage' hazard, or a potentially incendive spark). Where electrical power is supplied to systems on a CP protected structure, the supply system and structure should not share earth/ground connections; for example, the power supply system on a CP protected jetty should be a local TT (with RCD protection) or a local TN-S system, as shown in Figures 4 and 5.

The design of CP for a new facility should include isolating joints or insulating gaskets between flanges to ensure that new steel pipework and storage tanks are electrically isolated from the site earth/ground bar, but will not isolate these structures from any static earth/ground electrode required. All sections of buried steelwork and pipework to be protected should be made electrically continuous by the use of a separate insulated and sheathed bonding conductor.

On retrofitted CP systems it should be noted that it may not be possible to isolate every unintended earth/ground connection. For example, CP current may be diverted by the armouring/screening of instrument cables, and this could also interfere with the instrument function. Where possible, instrument cable connections to the protected steelwork should be electrically isolated from that steelwork, and should have the cable armouring/screening earthed/grounded at one point only.

Isolated flanges and the pipework on each side of the flange should be protected with an insulating material (e.g. for a distance of 1 metre from the flange) by wrapping with a cold applied PVC tape. The aim is to avoid unintentional potentially incendive discharge between earth/ground and the cathodically protected structure in the event of accidental contact, e.g. tools short-circuiting the flange. The wrap will also prevent ingress of moisture and debris which could result in a reduction in the electrical insulation properties of the insulated flange.

Documents
Document Sharing Hub

This document is issued with a single user licence to the EI registered subscriber: Shell. It has been issued as part of the Corporate access Technical Partner membership of the Energy Institute.
IMPORTANT: This document is subject to a licence agreement issued by the Energy Institute, London, UK. It may only be used in accordance with the licence terms and conditions. It must not be forwarded to, or stored, or accessed by, any unauthorised user. Enquiries: e:pubs@energyinst.org t: +44 (0)207 467 7100
Full document details: Guidelines on Earthing/Grounding/Bonding in the Oil and Gas Industry