



BSI Standards Publication

Design of earth electrode stations for high-voltage direct current (HVDC) links — General guidelines

National foreword

This Published Document is the UK implementation of IEC TS 62344:2022. It supersedes PD IEC/TS 62344:2013, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PEL/22, Power electronics.

A list of organizations represented on this committee can be obtained on request to its committee manager.

Contractual and legal considerations

This publication has been prepared in good faith, however no representation, warranty, assurance or undertaking (express or implied) is or will be made, and no responsibility or liability is or will be accepted by BSI in relation to the adequacy, accuracy, completeness or reasonableness of this publication. All and any such responsibility and liability is expressly disclaimed to the full extent permitted by the law.

This publication is provided as is, and is to be used at the recipient's own risk.

The recipient is advised to consider seeking professional guidance with respect to its use of this publication.

This publication is not intended to constitute a contract. Users are responsible for its correct application.

This publication is not to be regarded as a British Standard.

© The British Standards Institution 2023
Published by BSI Standards Limited 2023

ISBN 978 0 30 51635 1

ICS 29 210.99

Compliance with a Published Document cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 January 2023.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------



TECHNICAL SPECIFICATION



**Design of earth electrode stations for high-voltage direct current (HVDC) links –
General guidelines**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.240.99

ISBN 978-2-8322-1035-2

Warning! Make sure that you obtained this publication from an authorized distributor.

Currently in preview, click buy full version

This page is left deliberately blank.

CONTENTS

FOREWORD.....	9
INTRODUCTION.....	11
1 Scope.....	12
2 Normative references	12
3 Terms and definitions	12
4 System conditions	16
4.1 General principles.....	16
4.2 System parameters related to earth electrode design.....	16
4.2.1 Amplitude and duration of the current	16
4.2.2 Polarity.....	16
4.2.3 Designed lifespan	16
4.2.4 Common earth electrodes.....	17
5 Design of land electrode stations.....	17
5.1 Main technical parameters	17
5.1.1 General principles	17
5.1.2 Temperature rise	17
5.1.3 Earthing resistance.....	17
5.1.4 Step voltage	18
5.1.5 Touch voltage.....	19
5.1.6 Current density.....	19
5.1.7 Field intensity in fish ponds	19
5.2 Electrode site selection and parameter measurement	19
5.2.1 General principles	19
5.2.2 Data collection survey	20
5.2.3 Distance from converter station (substation).....	20
5.2.4 Environment conditions, terrain and landform	20
5.2.5 Geophysical and geological surveys	20
5.2.6 Topographic map.....	20
5.2.7 Values selected during design	20
5.3 Earth electrode and associated components	21
5.3.1 General principles for material selection	21
5.3.2 Selection of electrode elements and characteristics.....	21
5.3.3 Chemical and physical properties of petroleum coke.....	22
5.3.4 Current-guiding system.....	22
5.3.5 Bus.....	22
5.3.6 Electrode line and its monitoring device.....	23
5.4 Electrode arrangement.....	23
5.4.1 General principles	23
5.4.2 Filling coke	23
5.4.3 Selection of earth electrode shape.....	23
5.4.4 Earth electrode corridor (right of way).....	24
5.4.5 Distance between sub-electrodes in the arrangement.....	24
5.4.6 Burial depth of the earth electrodes	24
5.4.7 Segmentation of earth electrodes	25
5.5 Minimum size of earth electrode.....	25
5.5.1 General principles	25

5.5.2	Total earth electrode length	25
5.5.3	Area of the surface of the coke-soil interface	25
5.5.4	Diameter of electrode elements	26
5.6	Current guiding system	26
5.6.1	General principles	26
5.6.2	Placement of the current-guiding wire	26
5.6.3	Connection of current-guiding wire	27
5.6.4	Selection of current-guiding wire cross-section	27
5.6.5	Insulation of the current-guiding wire	27
5.6.6	Disconnecting switch	27
5.6.7	Connection of the feeding cable	28
5.6.8	Connection of jumper cables	28
5.6.9	Selection of cable structure	28
5.6.10	Selection of cable cross-section	28
5.6.11	Selection of cable insulation	29
5.6.12	Cable welding position	29
5.6.13	Welding	29
5.6.14	Mechanical protection for cable	29
5.7	Auxiliary facilities	29
5.7.1	Online monitoring	29
5.7.2	Moisture replenishment	29
5.7.3	Exhaust equipment	30
5.7.4	Fence	30
5.7.5	Marker	30
6	Design of sea electrode station and shore electrode station	30
6.1	Main technical parameters	30
6.1.1	General	30
6.1.2	Temperature rise	30
6.1.3	Earthing resistance	30
6.1.4	Step voltage	30
6.1.5	Touch voltage	30
6.1.6	Voltage gradient in water	30
6.1.7	Current density	31
6.2	Electrode site selection and parameter measurement	31
6.2.1	General principles	31
6.2.2	Data collection survey	31
6.2.3	Distance from converter station (substation)	31
6.2.4	Environment conditions	31
6.2.5	Measurement of ground/water parameters	32
6.3	Earth electrode and associated components	32
6.3.1	General principles for material selection	32
6.3.2	Common electrode elements and characteristics	32
6.3.3	Chemical properties of petroleum coke	33
6.3.4	Current-guiding system	33
6.3.5	Bus	33
6.3.6	Electrode line monitoring device	33
6.4	Electrode arrangement	33
6.4.1	General principles	33
6.4.2	Filling coke	33

6.4.3	Selection of earth electrode shape.....	33
6.4.4	Segmentation of earth electrodes	34
6.5	Current-guiding system	34
6.5.1	Placement of the current-guiding wire	34
6.5.2	Connection of current-guiding system	34
6.5.3	Selection of cable cross-section	35
6.5.4	Insulation of the current-guiding system.....	35
6.5.5	Selection of cable structure	35
6.5.6	Mechanical protection for cable	35
6.6	Auxiliary facilities	35
7	Impact on surrounding facilities and mitigation measures	35
7.1	Impact on insulated metallic structures and mitigation measures.....	35
7.1.1	General principles	35
7.1.2	Relevant limits.....	36
7.1.3	Mitigation measures.....	36
7.2	Impact on bare metallic structures	36
7.2.1	General principles	36
7.2.2	Relevant limits.....	36
7.2.3	Mitigation measures.....	36
7.3	Impact on the power system (power transformer, grounding network, and surrounding towers)	36
7.3.1	General principles	36
7.3.2	Relevant limits.....	37
7.3.3	Mitigation measures.....	37
7.4	Impact on electrified railway.....	37
7.5	Other facilities (such as greenhouses and water pipes).....	37
Annex A (informative)	Basic concepts of earth electrodes	38
A.1	Basic concepts.....	38
A.2	Operation mode	38
A.2.1	General	38
A.2.2	Monopolar system	38
A.2.3	Bipolar system	39
A.2.4	Symmetric unbalanced system.....	41
A.2.5	Back-to-back converter station	41
A.3	Dangerous impact and accumulated impact	41
A.3.1	General	41
A.3.2	Safety risks of DC earth electrode	41
A.3.3	Accumulated effect of DC earth electrodes	46
A.4	Impact on an AC grid	47
A.4.1	General	47
A.4.2	DC current path to AC system	48
A.4.3	DC magnetic bias of AC transformer.....	48
Annex B (informative)	Earth electrode design process	50
B.1	Site selection process	50
B.2	Earth electrode design process.....	51
Annex C (informative)	Test results of human body resistance	53
C.1	Basic information of test subjects.....	53
C.2	Test method.....	54
C.3	Test results.....	54

Annex D (informative) Soil parameter measurement method	57
D.1 General requirements	57
D.2 Measurement of resistivity of shallow ground	58
D.2.1 Measurement method of resistivity	58
D.2.2 Measurement requirements	60
D.2.3 Measurement range	61
D.2.4 Data accuracy	61
D.2.5 Seasonal coefficient	61
D.2.6 Processing of measurement data	61
D.3 Measurement of resistivity of deep soil (MT method)	61
D.4 Measurement of soil volume thermal capacity	62
D.5 Measurement of soil thermal conductivity	62
D.6 Measurement of maximum natural temperature of soil	63
D.7 Measurement of soil moisture and groundwater table	63
D.8 Measurement of soil chemical characteristics	63
D.9 Geological exploration	63
D.10 Topographical map	63
Annex E (informative) Electrode line design	64
E.1 Overview	64
E.2 Main design principles	64
E.3 Selection and layout of conductor and earth wire	65
E.3.1 Selection of conductor	65
E.3.2 Selection of earth wire	65
E.3.3 Layout of conductor and earth wire	65
E.4 Insulation coordination and earthing for lightning protection	65
E.4.1 Type and number of insulator	65
E.4.2 Arcing horn gap	65
E.4.3 Earthing for lightning protection	66
E.5 Other considerations	66
Annex F (informative) Assessment of measurement method	67
F.1 General guidance	67
F.2 Experiment (testing) items	67
F.2.1 Visual inspection of the earth electrode	67
F.2.2 Current dividing system current distribution measurement	67
F.2.3 Measurement of earthing resistance	68
F.2.4 Measurement of step voltage on the ground and potential gradient in water near the earth electrode	68
F.2.5 Measurement of touch voltage	69
F.2.6 Measurement of soil surface potential profile	69
F.2.7 Measurement of earth electrode temperature rise	70
Annex G (informative) Earth electrode electrical parameter calculation method	71
G.1 General	71
G.2 Network method calculation model for DC earth electrode	71
G.3 Moment method calculation model for DC earth electrodes	71
G.4 Finite element method calculation model for DC earth electrodes	76
G.5 Calculation of earthing resistance, step voltage, touch voltage, electric field intensity and current density	78
G.5.1 General	78
G.5.2 Calculation of earthing resistance	78

G.5.3	Calculation of step voltage.....	78
G.5.4	Calculation of touch voltage.....	78
G.5.5	Calculation of electric field intensity.....	78
G.5.6	Calculation of current density.....	79
G.6	Application description.....	79
G.6.1	Original parameters.....	79
G.6.2	Example using the moment method.....	79
Annex H (informative)	Thermal time constant.....	82
Annex I (informative)	Online monitoring system.....	84
I.1	Schematic diagram of online monitoring system.....	84
I.2	Composition of online monitoring system.....	84
Annex J (informative)	Calculation method for corrosion of nearby metal structures caused by earth electrodes.....	86
J.1	Consumption of metal structure due to corrosion.....	86
J.2	Estimate of leakage current in metal pipes.....	86
J.3	Calculation of the leakage current of the metal pipe.....	87
Annex K (informative)	Calculation method for DC current flowing through AC transformer neutral near earth electrodes.....	88
Annex L (informative)	Chemical processes in sea electrodes.....	91
Annex M (informative)	Simple introduction of shore electrode.....	92
M.1	General.....	92
M.2	Beach electrodes.....	92
M.3	Pond electrodes.....	92
Bibliography	94
Figure 1	– Electrode cross-section.....	23
Figure 2	– Vertical arrangement.....	24
Figure 3	– Placement of the current-guiding wire.....	27
Figure 4	– Feeding cable.....	28
Figure 5	– Sea electrode.....	33
Figure 6	– Sea bottom electrode with titanium nets.....	34
Figure 7	– Titanium net.....	35
Figure 8	– Impact of earth electrodes on AC systems (transformer, grounding network, tower).....	37
Figure A.1	– H.VDC power transmission system structure.....	38
Figure A.2	– Schematic diagram of monopolar earth/sea water return system.....	39
Figure A.3	– Schematic diagram of monopolar dedicated metallic return system.....	39
Figure A.4	– Schematic diagram of bipolar earth/sea water system.....	39
Figure A.5	– Schematic diagram of rigid bipolar system.....	40
Figure A.6	– Schematic diagram of bipolar dedicated metallic return system.....	41
Figure A.7	– Schematic diagram of touch voltage and step voltage.....	42
Figure A.8	– Schematic diagram of single circular earth electrode.....	43
Figure A.9	– Axial distribution of step voltage of single circular earth electrode.....	43
Figure A.10	– 3-D distribution of step voltage of single circular earth electrode.....	44
Figure A.11	– Schematic diagram of double circular earth electrode.....	44
Figure A.12	– Axial distribution of step voltage of double circular earth electrode.....	44

Figure A.13 – 3-D distribution of step voltage of double circular earth electrode	45
Figure A.14 – Schematic diagram of triple circular earth electrode	45
Figure A.15 – Axial distribution of step voltage of triple circular earth electrode	46
Figure A.16 – 3-D distribution of step voltage of triple circular earth electrode	46
Figure B.1 – Flow chart of earth electrode site selection process	50
Figure B.2 – Flow chart of earth electrode process	52
Figure C.1 – Age distribution of test samples	53
Figure C.2 – Height distribution of test samples	53
Figure C.3 – Weight distribution of test samples	54
Figure C.4 – Schematic diagram of test circuit	54
Figure C.5 – Histogram of foot-to-foot human body resistance distribution	55
Figure C.6 – Cumulative probability distribution of foot-to-foot body resistance by occupation	56
Figure D.1 – Equivalent circuit of Wenner method	59
Figure D.2 – Equivalent circuit of Schlumberger method	59
Figure D.3 – Equivalent circuit of dipole-dipole method	60
Figure G.1 – π shape equivalent circuit of an individual earth electrode unit	71
Figure G.2 – Ohm’s Law applied to cylinder conductor	72
Figure G.3 – Continuity of axial component of the electric field in the soil and in the conductor	72
Figure G.4 – Spatial division of the earth electrode	72
Figure G.5 – Network for solving axis current	73
Figure G.6 – Horizontally layered soil	74
Figure G.7 – Geometrical structure of a tetra electrode unit	76
Figure G.8 – Structure of a double-circle earth electrode	80
Figure G.9 – Ground potential and step voltage distribution of a double-circle earth electrode	81
Figure H.1 – Earth electrode temperature rise characteristics	82
Figure I.1 – Schematic diagram of earth electrode online monitoring system	84
Figure J.1 – Calculation of current flowing through a metal pipe	87
Figure K.1 – Schematic diagram of ground resistance network and underground voltage source	88
Figure K.2 – Circuit model for the analysis of DC distribution of AC systems	90
Figure M.1 – Top view of shore electrode, beach type	92
Figure M.2 – Shore electrode, pond type	92
Table 1 – Composition of iron-silicon alloy electrode	22
Table 2 – Chemical composition of the petroleum coke after calcination	22
Table 3 – Physical properties of petroleum coke used for earth electrodes	22
Table 4 – Electric corrosion characteristics of different materials	26
Table C.1 – Statistical test results (foot-to-foot body resistance)	55
Table C.2 – Cumulative probability distribution of foot-to-foot human body resistance	56
Table D.1 – Soil (rock) / Water resistivity	57
Table D.2 – Soil volume thermal capacity	58

Table D.3 – Soil thermal conductivity	58
Table D.4 – Number of measurement points with different potential probes spacing.....	61
Table G.1 – Model of soil with two layers	80

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**DESIGN OF EARTH ELECTRODE STATIONS
FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) LINKS –
GENERAL GUIDELINES**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TS 62344 has been prepared by IEC technical committee 115: High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV. It is a Technical Specification.

This second edition cancels and replaces the first edition published in 2013. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- Changed the requirement of earthing resistance limit for short-time unipolar earth system in 5.1.3.
- Corrected the coefficient before ρ_s from 0,015 9 to 0,008 in touch voltage limit calculation formula (3) in 5.1.5.
- Deleted the analytical calculation formulas of earthing resistance for sea and shore electrodes in 6.1.3.
- Changed the current density limit from 100 A/m² to 40 A/m² ~ 50 A/m² for the sea electrodes that are not accessible to human beings or to marine fauna in 6.1.7.

- Extended some detailed technical requirements for the measurement of ground/water soil parameters in 6.2.5.
- Reformulated the types and characteristics of electrode element material for sea and shore electrodes in 6.3.2.
- Added an informative Annex B: Earth electrode design process.
- Added an informative Annex C: Test results of human body resistance.
- Deleted the formula for calculating the average soil resistivity using harmonic mean when processing the measurement data in D.2.6 of Annex D.
- Extended some detailed technical requirements of electrode online monitoring system in Annex H.
- CIGRE 675:2017 is added to the bibliography.
- Terminology and way of expressions are modified using more commonly used terms in the HVDC electrode design industries and English speaking countries, so as to make the readers understand the content more easily.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
115/276/DTS	115/293/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The high-voltage DC earth electrode is an important part of the DC power transmission system. It takes on the task of guiding the current into the earth under the monopolar earth return operation mode, and the unbalanced current under the bipolar operation mode. Further, it secures and provides the reference potential of converter neutral point under the bipolar/ monopolar operation mode, to protect the safe operation of the valves.

DC earth electrodes include land electrodes, sea electrodes, and shore electrodes. Today, there are around tens of DC electrodes in the world. Their influence on the nearby and far away environment is produced when there is DC current continuously leaking into the earth through DC earth electrodes.

Their influence on the surrounding environment includes:

- a) influence on humans, mainly due to step voltage, touch voltage and transferred voltage;
- b) influence on the electrode itself, mainly reflected by ground temperature rise and corrosion on the electrode;
- c) influence on nearby ponds and organisms in the sea;
- d) influence on the AC power system, mainly reflected by the DC voltage excursion of transformer neutral point;
- e) influence on buried metallic objects, mainly revealed by the corrosion of buried metallic pipelines, AC grounding grids, tower foundations for power transmission lines and armoured cables, etc.

A great deal of experience has been accumulated in the research and design work in many countries, and relevant national standards or enterprise standards have been developed. The aim of this document is to develop the design guide for DC earth electrodes, on the site selection, material selection, shape, buried depth, adoption of equipment and connection styles, etc. It can be referred to by the electrode design engineers in different countries, to ensure the safe operation of earth electrode under different modes, control the influence on the environment nearby and the environment far away to the acceptable level, and to reasonably decrease engineering costs.

To ensure this document is more scientific, precise and practical, some research results obtained in recent years are adopted.

DESIGN OF EARTH ELECTRODE STATIONS FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) LINKS – GENERAL GUIDELINES

1 Scope

This document applies to the design of earth electrode stations for high-voltage direct current (HVDC) links. It is intended to provide necessary guidelines, limits, and precautions to be followed during the design of earth electrodes to ensure safety of personnel and earth electrodes, and reduce any significant impacts on DC power transmission systems and the surrounding environment.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60479-1, *Effects of current on human beings and livestock – Part 1: General aspects*

IEC TS 61201, *Use of conventional touch voltage limits – Application guide*

IEC 61936-1, *Power installations exceeding 1 kV AC and 1,5 kV DC – Part 1: AC*

IEC TS 61936-2, *Power installations exceeding 1 kV a.c. and 1,5 kV d.c. – Part 2: d.c.*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

earth (ground) electrode

conductive part that is in electric contact with local earth, directly or through an intermediate conductive medium

[SOURCE: IEC 60050-195:2021, 195-02-01]

3.2

land electrode

earth electrode buried in the ground above the high tide water level and located away from the shore and not influenced by water bodies

3.3

shore electrode

3.3.1

beach electrode

electrode located on the shore above the low tide water level, where the active part of the electrode is in contact with the soil or with underground water, but not directly with seawater

Note 1 to entry: Compared with land electrode, beach electrode is relatively close to the shore and is influenced by water bodies.