

TECHNICAL SPECIFICATION



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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE **XC**

ICS 29.240.99

ISBN 978-2-83220-575-4

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

CONTENTS

| | |
|---|----|
| FOREWORD..... | 7 |
| INTRODUCTION..... | 9 |
| 1 Scope..... | 10 |
| 2 Normative references..... | 10 |
| 3 Terms and definitions..... | 10 |
| 3.22 current-releasing density..... | 13 |
| 4 System conditions..... | 14 |
| 4.1 General principles..... | 14 |
| 4.2 System parameters related to earth electrode design..... | 14 |
| 4.2.1 Amplitude and duration of the current..... | 14 |
| 4.2.2 Polarity..... | 14 |
| 4.2.3 Designed lifespan..... | 15 |
| 4.2.4 Common earth electrodes..... | 15 |
| 5 Design of land electrode stations..... | 15 |
| 5.1 Main technical parameters..... | 15 |
| 5.1.1 General principles..... | 15 |
| 5.1.2 Temperature rise..... | 16 |
| 5.1.3 Earthing resistance..... | 16 |
| 5.1.4 Step voltage..... | 17 |
| 5.1.5 Touch voltage..... | 17 |
| 5.1.6 Current density..... | 17 |
| 5.1.7 Field intensity in fish ponds..... | 18 |
| 5.2 Electrode site selection and parameter measurement..... | 18 |
| 5.2.1 General principles..... | 18 |
| 5.2.2 Data collection survey..... | 18 |
| 5.2.3 Distance from converter station (substation)..... | 18 |
| 5.2.4 Environment conditions..... | 19 |
| 5.2.5 Terrain and landform..... | 19 |
| 5.2.6 Measurement of soil parameters..... | 19 |
| 5.2.7 Geological exploration..... | 19 |
| 5.2.8 Topographical map..... | 19 |
| 5.2.9 Values selected during design..... | 19 |
| 5.3 Earth electrode and associated components..... | 20 |
| 5.3.1 General principles for material selection..... | 20 |
| 5.3.2 Selection of feeding rods and characteristics..... | 20 |
| 5.3.3 Chemical and physical properties of petroleum coke..... | 21 |
| 5.3.4 Current-guiding system..... | 21 |
| 5.3.5 Bus..... | 22 |
| 5.3.6 Electrode line monitoring device..... | 22 |
| 5.4 Electrode arrangement..... | 22 |
| 5.4.1 General principles..... | 22 |
| 5.4.2 Filling coke..... | 22 |
| 5.4.3 Selection of earth electrode shape..... | 22 |
| 5.4.4 Earth electrode corridor (right of way)..... | 23 |
| 5.4.5 Distance between sub-electrodes in the arrangement..... | 23 |
| 5.4.6 Burial depth of the earth electrodes..... | 23 |

| | | |
|--------|---|----|
| 5.4.7 | Segmentation of earth electrodes | 24 |
| 5.5 | Minimum size of earth electrode | 24 |
| 5.5.1 | General principles | 24 |
| 5.5.2 | Total earth electrode length | 24 |
| 5.5.3 | Side length of coke section | 24 |
| 5.5.4 | Diameter of feeding rods | 25 |
| 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 | 26 |
| 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 | 27 |
| 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 | 28 |
| 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 | Soil treatment | 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 | Temperature rise | 30 |
| 6.1.2 | Earthing resistance | 30 |
| 6.1.3 | Step voltage | 31 |
| 6.1.4 | Touch voltage | 32 |
| 6.1.5 | Voltage gradient in water | 32 |
| 6.1.6 | Current density | 32 |
| 6.2 | Electrode site selection and parameter measurement | 32 |
| 6.2.1 | General principles | 32 |
| 6.2.2 | Data collection survey | 32 |
| 6.2.3 | Distance from converter station (substation) | 32 |
| 6.2.4 | Environment conditions | 33 |
| 6.2.5 | Measurement of soil parameters | 33 |
| 6.3 | Earth electrode and associated components | 33 |
| 6.3.1 | General principles for material selection | 33 |
| 6.3.2 | Common feeding rods and characteristics | 33 |
| 6.3.3 | Chemical properties of petroleum coke | 34 |
| 6.3.4 | Current-guiding system | 34 |
| 6.3.5 | Bus | 34 |
| 6.3.6 | Electrode line monitoring device | 34 |
| 6.4 | Electrode arrangement | 34 |

| | | |
|--|--|----|
| 6.4.1 | General principles | 34 |
| 6.4.2 | Filling coke | 34 |
| 6.4.3 | Selection of earth electrode shape..... | 34 |
| 6.4.4 | Segmentation of earth electrodes | 35 |
| 6.5 | Current-guiding system | 35 |
| 6.5.1 | Placement of the current-guiding wire..... | 35 |
| 6.5.2 | Connection of current-guiding system..... | 35 |
| 6.5.3 | Selection of cable cross-section | 36 |
| 6.5.4 | Insulation of the current-guiding system | 36 |
| 6.5.5 | Selection of cable structure | 36 |
| 6.5.6 | Mechanical protection for cable | 36 |
| 6.6 | Auxiliary facilities | 36 |
| 7 | Impact on surrounding facilities and mitigation measures | 37 |
| 7.1 | Impact on insulated metallic structures and mitigation measures | 37 |
| 7.1.1 | General principles | 37 |
| 7.1.2 | Relevant limits..... | 37 |
| 7.1.3 | Mitigation measures | 37 |
| 7.2 | Impact on bare metallic structures | 37 |
| 7.2.1 | General principles | 37 |
| 7.2.2 | Relevant limits..... | 37 |
| 7.2.3 | Mitigation measures | 37 |
| 7.3 | Impact on the power system (power transformer, grounding network, and surrounding towers)..... | 38 |
| 7.3.1 | General principles | 38 |
| 7.3.2 | Relevant limits..... | 38 |
| 7.3.3 | Mitigation measures | 38 |
| 7.4 | Impact on electrified railway..... | 38 |
| 7.5 | Other facilities (such as greenhouses and water pipes) | 39 |
| Annex A (informative) | Basic concepts of earth electrodes | 40 |
| Annex B (informative) | Soil parameter measurement method | 52 |
| Annex C (informative) | Electrode line design..... | 60 |
| Annex D (informative) | Assessment of measurement method | 63 |
| Annex E (informative) | Earth electrode electrical parameter calculation method | 67 |
| Annex F (informative) | Thermal time constant | 78 |
| Annex G (informative) | Schematic diagram of online monitoring system..... | 80 |
| Annex H (informative) | Calculation method for corrosion of nearby metal structures caused by earth electrodes | 81 |
| Annex I (informative) | Calculation method for d.c. current flowing through a.c. transformer neutral near earth electrodes | 83 |
| Annex J (informative) | Chemical aspects | 86 |
| Annex K (informative) | Simple introduction of shore electrodes | 87 |
| Bibliography..... | | 89 |
| Figure 1 – Electrode cross-section | | 22 |
| Figure 2 – Vertical arrangement..... | | 23 |
| Figure 3 – Placement of the current-guiding wire | | 26 |
| Figure 4 – Feeding cable | | 28 |

| | |
|---|----|
| Figure 5 – Resistivity layers with sea or shore electrodes | 31 |
| Figure 6 – Sea electrode | 34 |
| Figure 7 – Sea bottom electrode with titanium nets | 35 |
| Figure 8 – Titanium net | 36 |
| Figure 9 – Impact of earth electrodes on a.c. systems (transformer, grounding network, tower) | 38 |
| Figure A.1 – HVDC power transmission system structure | 40 |
| Figure A.2 – Schematic diagram of the structure of a monopolar earth (sea water) return system | 41 |
| Figure A.3 – Schematic diagram of the structure of monopolar metallic return system | 41 |
| Figure A.4 – Schematic diagram of the structure of bipolar neutral grounded at both ends | 42 |
| Figure A.5 – Schematic diagram of the structure of bipolar neutral grounded at one end | 42 |
| Figure A.6 – Schematic diagram of the structure of bipolar neutral line | 43 |
| Figure A.7 – Schematic diagram of touch voltage and step voltage | 44 |
| Figure A.8 – Schematic diagram of single circular earth electrode | 45 |
| Figure A.9 – Axial distribution of step voltage of single circular earth electrode | 45 |
| Figure A.10 – 3-D distribution of step voltage of single circular earth electrode | 46 |
| Figure A.11 – Schematic diagram of double circular earth electrode | 46 |
| Figure A.12 – Axial distribution of step voltage of double circular earth electrode | 46 |
| Figure A.13 – 3-D distribution of step voltage of double circular earth electrode | 47 |
| Figure A.14 – Schematic diagram of triple circular earth electrode | 47 |
| Figure A.15 – Axial distribution of step voltage of triple circular earth electrode | 47 |
| Figure A.16 – 3-D distribution of step voltage of triple circular earth electrode | 48 |
| Figure B.1 – Equivalent circuit of Wenner method | 54 |
| Figure B.2 – Equivalent circuit of Schlumberger method | 54 |
| Figure B.3 – Equivalent circuit of dipole-dipole method | 55 |
| Figure E.1 – π shape equivalent circuit of an individual earth electrode unit | 67 |
| Figure E.2 – Ohm's Law applied to cylinder conductor | 68 |
| Figure E.3 – Continuity of axial component of the electric field in the soil and in the conductor | 68 |
| Figure E.4 – Spatial division of the earth electrode | 68 |
| Figure E.5 – Network for solving axis current | 69 |
| Figure E.6 – Horizontally layered soil | 71 |
| Figure E.7 – Geometrical structure of a tetrahedron unit | 72 |
| Figure E.8 – Structure of a double-circle d.c. earth electrode | 76 |
| Figure E.9 – Ground potential and step voltage distribution of a double-circle earth electrode | 77 |
| Figure F.1 – Earth electrode temperature rise characteristics | 78 |
| Figure G.1 – Schematic diagram of earth electrode online monitoring system | 80 |
| Figure H.1 – Calculation of current flowing through a metal pipe | 82 |
| Figure I.1 – Schematic diagram of ground resistance network and underground voltage source | 83 |
| Figure I.2 – Circuit model for the analysis of d.c. distribution of a.c. systems | 85 |
| Figure K.1 – Top view of shore electrode, beach type | 87 |

| | |
|---|----|
| Figure K.2 – Shore electrode, pond type | 87 |
| Table 1 – Composition of iron-silicon alloy electrode..... | 21 |
| Table 2 – Chemical composition of the coke after calcination..... | 21 |
| Table 3 – Physical properties of petroleum coke used for earth electrodes | 21 |
| Table 4 – Electric corrosion characteristics of different materials | 26 |
| Table B.1 – Soil (rock) resistivity..... | 52 |
| Table B.2 – Soil thermal capacity..... | 53 |
| Table B.3 – Soil thermal conductivity | 53 |
| Table B.4 – Number of measurement points with different pole distances | 56 |
| Table E.1 – Model of soil with two layers | 77 |

Withdrawn

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.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62344, which is a technical specification, has been prepared by IEC technical committee 115: High-voltage direct current (HVDC) transmission for d.c. voltages above 100 kV.

This technical specification cancels and replaces IEC/PAS 62344 published in 2007. This first edition constitutes a technical revision.

The text of this technical specification is based on the following documents:

| | |
|---------------|------------------|
| Enquiry draft | Report on voting |
| 115/53/DTS | 115/64/RVC |

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- transformed into an International Standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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

D.C. earth electrodes include land electrodes, sea electrodes, and shore electrodes. Today, there are around tens of d.c. electrodes in the world. Their influence on the nearby and far away environment is produced when there is d.c. current continuously leaking into the earth through d.c. 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 earth temperature rise and corrosion on the electrode;
- c) influence on nearby ponds and organisms in the sea;
- d) influence on the a.c. power system, mainly reflected by the d.c. voltage excursion of transformer neutral point;
- e) influence on buried metallic objects, mainly revealed by the corrosion on buried metallic pipelines, a.c. grounding grids, tower foundations for power transmission lines and armoured cables, etc.

For years, a great deal of experience has been accumulated in the research and design work in many countries, and relevant native standards or enterprise standards have been developed. The aim of this Technical Specification is to develop the design guide for d.c. earth electrodes, on the site selection, material selection, shape, buried depth, adoption of equipment and connection styles, etc. It could be referred to by the specialized employees 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 Technical Specification is more scientific, precise and practical, IEC/PAS 62344:2007 is referred to, and 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 Technical Specification 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 prevent any significant impact they may exert on d.c. power transmission systems and the surrounding environment.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC/TS 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 a.c. – Part 1: Common rules*