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TECHNICAL SPECIFICATION

colour inside

Power transformers –
Part 23: DC magnetic bias suppression devices

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INTERNATIONAL
ELECTROTECHNICAL
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CONTENTS

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POWER TRANSFORMERS –

Part 23: DC magnetic bias suppression devices

FOREWORD

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- 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 TS 60076-23, which is a technical specification, has been prepared by IEC technical committee 14: Power transformers.

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

Enquiry draft	Report on voting
14/924/DTS	14/943/RVDTS

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

A list of all parts in the IEC 60076, published under the general title *Power transformers*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://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- withdrawn,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.

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

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INTRODUCTION

In some cases, abnormal direct current (DC) is introduced into the AC power network and has adverse effects upon neutral grounded power apparatuses such as power transformers.

- Case 1

  Direct current flows into the AC power network through grounded neutral points of transformers when an HVDC transmission system operates in monopole ground return mode or in bipolar unbalanced mode.

- Case 2

  Quasi-DC is induced in the AC power network by geo-magnetically induced current (GIC) during the period of a solar magnetic storm.

- Case 3

  Electric traction locomotives and some large capacity power electronic equipment may cause DC current in AC power network.

DC current flowing through transformer windings may cause DC magnetic bias of the transformers, presenting a safety risk for both the transformers and the power system. The mechanism and harmful effects of DC bias are shown in Annex A and Annex B.

Two techniques for suppressing the transformer DC bias current are presented in this document, respectively to limit or block the transformer bias current produced by the HVDC transmission system.

The two techniques can also be used to suppress transformer DC bias caused by GIC, electric traction locomotives and some large capacity power electronic equipment. However, these issues are not included in this document due to their complexity.

This document defines the technical requirements for the two types of DC current suppression devices that are connected to neutral points of power transformers and converter transformers.

POWER TRANSFORMERS –

Part 23: DC magnetic bias suppression devices

1 Scope

This document specifies requirements for devices for the suppression of DC magnetic bias of power transformers and convertor transformers. It includes requirements for service conditions, structures, testing, packing, transport and storage.

The devices are connected to neutral points of power transformers and converter transformers to suppress DC bias current in the case an HVDC system is operated in monopole ground return mode or bipolar unbalanced mode. In the case of dedicated metallic return HVDC system, the devices are useful to mitigate DC stray current flowing through power transformers and converter transformers during transient conditions such as DC line fault.

This document applies to DC magnetic bias suppression devices for operation at frequencies of 50 Hz and 60 Hz on power systems having voltages above 110 kV.

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 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60068-3-3, *Environmental testing – Part 3-3: Guidance – Seismic test methods for equipments*

IEC 60076-3, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

IEC 60076-5, *Power transformers – Part 5: Ability to withstand short circuit*

IEC 60137, *Insulated bushings for alternating voltages above 1000 V*

IEC 60168, *Tests on indoor and outdoor post insulators of ceramic material of glass for systems with nominal voltages greater than 1000V*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 61071, *Capacitors for power electronics*

IEC 62271-1, *High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear*

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
DC magnetic bias suppression device
electric device connected between the transformer neutral point and the earth to limit or to block the DC bias current flowing through the transformer windings

3.2
DC current-limiting device
electric device connected between the transformer neutral point and the earth to limit the DC bias current flowing through the transformer windings

Note 1 to entry: It normally consists of a resistor and a protection gap. For more information, see Annex C.

3.3
DC current- blocking device
electric device connected between the transformer neutral point and the earth to block the DC bias current flowing through the transformer windings

Note 1 to entry: It normally consists of a capacitor, a mechanical bypass switch, a high speed bypass switch, AC and DC sensors, and control devices. For more information, see Annex D.

3.4
mechanical bypass switch
mechanical switch connected in parallel to the capacitor in DC current-blocking device for the purpose of bypassing the capacitor persistently

3.5
high speed bypass switch
high speed switch connected in parallel to the capacitor in DC current-blocking device for the purpose of bypassing the capacitor quickly

3.6
DC bias current
DC current flowing through transformer windings which causes drift of the excitation characteristic curve of transformer

4 Service conditions

4.1 General

This document gives detailed requirements for the DC current-limiting or blocking devices under the following conditions.

a) Altitude

Height above sea-level not exceeding 1 000 m (3 300 ft).

b) Climate conditions

- Maximum ambient temperature: +40 °C.
- Minimum ambient temperature: −25 °C.
- Maximum daily temperature difference: 25 °C.
- Maximum relative outdoor humidity: 90 % at 40 °C.

- Maximum wind speed: 35 m/s.
- Ice thickness: 10 mm.
- Sunshine intensity: ≤1 000 W/m^2 (wind speed of 0,5 m/s).

4.2 Seismic conditions

Devices for operation under seismic conditions shall be qualified in accordance with IEC 60068-3-3, subject to agreement between the manufacturer and the purchaser.

4.3 Unusual conditions

Any unusual service conditions, which can lead to special consideration in the design of the device, shall be stated in the inquiry and order. These can be factors such as high altitude, extreme high or low temperatures, tropical humidity, severe contamination. They can also concern conditions for shipment, storage and installation, such as weight or space limitation.

5 Selection principle

5.1 Classification and features of the devices

DC magnetic bias suppression devices can be installed at the neutral points of the transformers to suppress the DC bias current. These devices are divided into two categories: DC current-limiting devices and DC current-blocking devices.

Resistor-type DC current-limiting devices limit the DC current flowing through transformer windings by increasing the resistance between neutral points of transformers and earth, without completely blocking the DC current. The installation of such a device at one substation has little effect on the DC current flowing through transformer windings in other substations.

Capacitor-type DC current-blocking devices completely block the DC current from flowing through the transformer windings when connected between neutral points of transformers and earth. The installation of such a device changes the distribution of DC current flowing in the earth and through transformer windings in other substations.

5.2 Selection principle for DC current-limiting devices

To determine the resistance, capacity and other electrical properties of the DC current limiting devices, several factors shall be taken into consideration. These factors include the tolerance of the transformers to magnetic bias current, the short-circuit current level of the grid, the insulation level of the neutral points, and the simulation result of the effect of installing current-limiting devices.

In addition to selecting the appropriate resistance, the protection configuration of transformers shall be assessed, to verify their compatibility with the resistor type DC current-limiting devices.

Normally, no relay protection is required for DC current-limiting devices. However, an overvoltage protection unit shall be included.

In the case where both short-circuit current and DC bias current need to be suppressed, the serially connected reactor and resistor shall be used as the current-limiting component of the device.

5.3 Selection principle for the DC current- blocking device

Normally, a low-voltage capacitor together with a high-speed bypass switch and a mechanical bypass switch is adopted for the current-blocking devices to ensure that the capacitor is bypassed during unsymmetrical faults.

The capacitance shall not introduce an overvoltage condition. Installation of the capacitor shall not affect the function of the protection relays of the transformers.

In the case when both the short-circuit current and the DC bias current need to be suppressed, a current-blocking capacitor in series with a reactor shall be installed. Verification shall be made concerning the suppression effect of the short-circuit current, the configuration of the relay protection and resonance condition.

5.4 Calculation and verification

Before the design and installation of the DC magnetic bias suppression devices, DC current distribution in the earth shall be calculated by setting up calculation models. The type selection of DC magnetic bias suppression devices shall be based on the calculation results. The effect of installing the devices and the influence on transformers in other substations shall be evaluated.

An electric field simulation method is recommended to set up the calculation model of the DC magnetic bias current caused by monopole ground return operation of HVDC systems. A resistor network method is recommended for quick assessment for engineering purposes. For more information on calculation models, see Annex E and Annex F.

The calculation results of DC current distribution in transformer windings shall be compared with the data of DC bias current of transformers collected in field measurements in all substations within the distance of 50 km from the grounding electrode of the HVDC system before the installation of the devices. Special attention should be paid to the transformers within the distance of 10 km from the electrode in the measurements. The calculation model should be used for engineering purposes only after verification and modification.

The examples of application of two types of suppression devices are shown in Annex G.

6 DC current-limiting device

6.1 Functional requirements

6.1.1 General

DC current-limiting device consists of a resistor and an overvoltage protection unit to protect the resistor when a fault occurs in a power grid. A graphite ball protection gap is recommended as the overvoltage protection.

The device normally works in the current-limiting mode, with the resistor connected directly to the neutral of the transformer to limit the DC bias current.

6.1.2 Resistance

The resistance shall be determined by field technical conditions of the installation site through comprehensive technical evaluations. Electrical ratings and characteristics of the DC current-limiting devices should be evaluated to coordinate with the system conditions of the power grid.

Normally, resistors made of stainless steel or cast iron should be used.

Long-term normal alternating currents should not be less than 50 A.

The recommended range of resistance is 1,5 Ω to 5 Ω.

The tolerance of resistance for DC current-limiting devices is ±5 % at 25 °C.

If tapped resistors are utilized, 0,5 Ω per tap is recommended.

6.1.3 Overvoltage protection

Normally, a graphite ball discharge gap should be used as the overvoltage protection, and should meet the following requirements:

- current carrying capacity of 10 kA/1 s, or determined by short-circuit current analysis of the grid;
- the discharging voltage of switching impulse shall not be higher than 10 kV;
- the power frequency breakdown voltage is 3 kV to 5 kV RMS.

6.1.4 Structure

The internal structure of current-limiting devices shall meet the requirements of electrical, thermal and mechanical stability.

The resistive elements shall be made of materials that have a high melting point, stable resistance, low temperature coefficient, and large thermal capacity.

If the device exploits a cabinet structure, it shall be designed to make installation and maintenance convenient. The ingress protection level shall not be less than IP54, as specified in IEC 60529. Ventilation should be considered to prevent overheating of the device.

If a graphite gap is used as overvoltage protection, an independent enclosure shall be used that should enable the graphite gap to be observed from outside.

For a principle diagram of DC current-limiting devices, refer to Annex C.

6.2 Ability to withstand effects of short-circuit current

6.2.1 Ability to withstand thermal effects of short-circuit current

DC current-limiting devices shall have the capability to withstand thermal effects of short-circuit current in accordance with the short-circuit capacity of the grid at the installation location, which can be obtained through short-circuit current analysis of the power grid. The thermal equivalent short-circuit current of no less than 8 kA for a duration of 2 s is recommended as the lowest limit. In addition, the maximum temperature rise shall not exceed the specified heat tolerance of the insulation.

6.2.2 Ability to withstand dynamic effects of short-circuit current

DC current-limiting devices shall have the capability to withstand dynamic effects of short-circuit current in accordance with short-circuit capacity of the grid at the installation location. A peak value of asymmetrical current of no less than 20 kA for a duration of 0,20 s is recommended as the lowest limit. The asymmetrical factor to assess the peak current under short circuit condition shall be calculated according to IEC 60076-5.

6.3 Temperature rise

6.3.1 Metal chip resistors

The temperature rise limits for metal chip resistors of stainless steel are the following:

- 385 K for long-term current flow;
- 760 K for a short-circuit current of 10 kA RMS for a duration of 1 s.

6.3.2 Dry-type non-inductive epoxy-resin insulated resistors

The heat-resistant grade of insulating material shall be of class F and above. The temperature rise limits for long-term current flow are the following:

- the average temperature rise of windings shall be lower than 75 K;
- the highest temperature rise allowable shall be 100 K.

6.3.3 Other types of resistors

For other types of resistors, the temperature rise limit for long-term current flow shall not exceed the temperature tolerance of the insulating materials.

6.4 Insulation level

The insulation level of the DC current-limiting device shall correspond to the insulation of the neutral of the power transformer to which the device is to be installed.

If the resistor is of a multiple-cell structure, the rated power-frequency withstand voltage between adjacent units should be:

$$V \times 2{,}5 + 2\ \text{kV}$$

where

V is the rated voltage per cell, in kV.

7 DC current-blocking device

7.1 Functional requirements

7.1.1 General

The device consists of a capacitor, a high-speed bypass switch and a mechanical bypass switch connected in parallel. The device normally works in the DC-blocking mode, with the capacitor connected directly to the neutral of transformers to block the DC bias current. When a fault occurs in the power grid, the high-speed bypass switch is closed to bypass the capacitor quickly and then the mechanical bypass switch is closed to bypass the capacitor persistently. The device may also work in direct-grounding mode. In direct-grounding mode, the transformer neutral is grounded directly through bypass switches. If the DC current reaches the configured level and duration, the device switches to operate in DC-blocking mode automatically.

7.1.2 Capacitance

Capacitance shall be determined by field technical conditions of the installation site through comprehensive technical evaluations. Electrical ratings and characteristics of the DC current-blocking device shall be evaluated to coordinate with system conditions of the power grid.

The impedance of a capacitor connected to the neutral point is recommended to be less than 1,2 Ω.

Power frequency withstand voltage (RMS) should be no less than 3 kV.

Long-term normal alternating currents should not be less than 50 A.

For information on other requirements pertaining to capacitors, see IEC 61071.

7.1.3 Bypass switches

A mechanical bypass switch should have a life cycle of not less than 8 000 times of operation. A high-speed bypass switch should have a life cycle of not less than 10 000 times.

The closing time of a high-speed bypass switch should be less than 200 μs. The closing time for a mechanical bypass switch should be less than 50 ms.

The action voltage of the bypass switch shall be higher than the peak voltage determined jointly by the unbalanced AC current in normal operation and DC current at the neutral points.

When the bypass switch is closed, the hold time shall be longer than the trip time of the backup failure protection of transformers for a single-phase grounding fault.

All bypass switches, no matter whether electronic or mechanical switches, shall be able to withstand the full making currents of installation locations.

7.1.4 Function of device

The requirements for the operation of the DC current-blocking devices are the following.

- The time to switch DC current-blocking devices from the direct-grounding state to the DC-blocking state should be less than 1 s. The time to switch devices from the DC-blocking state to the direct-grounding state should be less than 200 μs.
- For the device to switch from direct-grounding state to DC-blocking state, the set value of DC current level should be in the range of 0 A to 100 A, and can be adjusted continuously with a resolution of 1 A. The set value of startup time should be in the range of 0 s to 30 s, and can be adjusted continuously with a resolution of 1 s.
- For the device to switch from DC-blocking state to direct-grounding state, the set value of DC voltage should be in the range of 0 V to 100 V and can be adjusted continuously with a resolution of 1 V. The set value of AC current through the transformer neutral should be in the range of 0 A to 500 A and can be adjusted continuously with a resolution of 1 A.

7.1.5 Structure

The requirements for the structure of the DC current-blocking devices are the following.

- The device should be of cabinet structure, and be designed to make installation and maintenance convenient.
- The ingress protection level of enclosure shall not be lower than IP54, as specified in IEC 60529.
- The devices shall operate on redundant DC power supplies to avoid the possibility of power supply failure.
- For supporting post insulators, requirements in IEC 60168 apply.
- For bushings, requirements in IEC 60137 apply.
- For principle diagram of DC current-blocking devices, refer to Annex D.

7.2 Ability to withstand effects of short-circuit current

7.2.1 Ability to withstand thermal effects of short-circuit current

DC current-blocking devices shall have the capability to withstand thermal effects of short-circuit current in accordance with short-circuit capacity of the grid at the installation location, which can be obtained through short-circuit current analysis of the power grid. The thermal equivalent short-circuit current of no less than 8 kA for a duration of 2 s is recommended as the lowest limit. In addition, the maximum temperature rise shall not exceed the specified heat tolerance of the insulation.

7.2.2 Ability to withstand dynamic effects of short-circuit current

DC current-blocking devices shall have the capability to withstand dynamic effects of short-circuit current in accordance with short-circuit capacity of the grid at the installation location. A peak value of asymmetrical current of no less than 20 kA for a duration of 0,2 s is recommended as the lowest limit. The asymmetrical factor to assess the peak current under short circuit condition shall be calculated according to IEC 60076-5.

7.3 Temperature rise

The maximum temperature rise due to withstand thermal effects of short-circuit current shall not exceed the specified heat tolerance of the insulation.

7.4 Insulation level

The insulation level requirements of the device shall correspond to the insulation of the neutral of the power transformer to which the device is to be installed.

8 Tests

8.1 Test classification

Table 1 gives the test items to be performed.

Table 1 – Test items

Test class	Test items	DC current-limiting device	DC current-blocking device
Routine tests	Visual inspection	✓	✓
	DC resistance measurement	✓	
	Capacitance measurement		✓
	Insulation resistance measurement	✓	✓
	Withstand voltage test	✓	✓
	Gap discharge test	✓	✓ (if applicable)
	Function check		✓
Type tests	Temperature rise test	✓	
	Thermal stability test	✓	✓
	Dynamic stability test	✓	✓
	Lightning impulse test	✓	
	Ingress protection test	✓	✓

8.2 Routine tests

8.2.1 General

Each product shall be routinely inspected before leaving the factory, the test results shall be qualified, and product certification shall be provided.

8.2.2 Visual inspection

The appearance of the devices shall be checked visually or with necessary operation, to ensure that the overall dimensions and mounting dimensions meet the design requirements. The components and sub-assemblies are installed correctly without any defects. Air clearance and creep distance of the insulations meet design requirements. Cabinets and plates of the devices shall be clean and circuit terminals clearly marked.

8.2.3 DC resistance measurement

DC resistance of DC current-limiting devices should be measured with the current-voltage method, DC resistance value obtained shall meet the technical requirements of design.

8.2.4 Capacitance measurement

The measurement of the capacitance of DC current-blocking devices shall be carried out according to IEC 61071, with either the voltage-current method or the bridge method. The difference between the measured value and the rated value shall not exceed +10 % and −5 % of the rated capacitance.

8.2.5 Insulation resistance measurement

The insulation resistance between live components and the earth shall be measured with a 1 000 V megaohmmeter. The insulation resistance shall be greater than 1 000 MΩ.

8.2.6 Withstand voltage test

Apply a power frequency withstand voltage between the live components and the earth according to the test voltage listed in Table 2. Gap protection and other protections shall be removed before the test.

Table 2 – Rated insulation level (kV)

Highest voltage for equipment U_m kV	**Applied voltage or line terminal AC withstand** (AV)(LTAC) kV	**Full wave lightning impulse** (LI) kV
7,2	20	60
12	28	75
36	70	170
72,5	140	325
If the nominal voltage is not in the range of this table, the power frequency voltage and impulse withstand voltage can be obtained by linear interpolation.		

The test shall be performed according to the specifications of IEC 60076-3. There shall be no discharge and flashover in the test process.

If the resistor of a DC current-limiting device is of a multiple-cell structure, the power frequency withstand voltage test between the adjacent cells shall be carried out, and the test voltage is:

$$V \times 2{,}5 + 2\ \text{kV}$$

where

V is the rated voltage of each resistance unit, in kV.

For the capacitor of the DC current-blocking devices, power frequency withstand voltage is 3 kV.

8.2.7 Gap discharge test

Testing of power frequency discharge voltage of the gap shall be carried out according to IEC 60060-1.

8.2.8 Function check of DC current- blocking devices

The requirements of the function check are the following:

- Manually operate the mechanical bypass switch. The switch on and off operation should be normal and the state indication correct.
- Switching from direct-grounding mode to DC-blocking mode: in direct-grounding mode, the device shall not change operation mode automatically when applying to the device a DC current that is 0,9 times the set value of the DC current threshold. The device shall change to the DC-blocking mode automatically when the DC current exceeds the set value of the DC current threshold and lasting for the set value of the time duration. The switching time shall be less than 1 s.
- Switching from DC-blocking mode to direct-grounding mode: in DC-blocking mode, the device shall not change operation mode automatically when applying to the capacitor a DC voltage that is 1,1 times the set value of the DC voltage threshold. The device shall change to the direct-grounding mode automatically when the DC voltage falls below the set value of the DC voltage threshold and lasting for the set value of time duration. The switching time shall be less than 200 μs.
- Switching from DC-blocking mode to direct-grounding mode: in DC-blocking mode, the device shall not change operation mode automatically when applying to the device an AC current that is 0,9 times the set value of the AC current threshold. The device shall change to the direct-grounding mode automatically when the AC current exceeds the set value of the AC current threshold. The switching time shall be less than 200 μs.

8.3 Type tests

8.3.1 General

The type tests of 8.3.2 to 8.3.6 shall be performed.

8.3.2 Temperature rise test of DC current-limiting device

Apply a long-term operating current (if it is not clear, a 50 A AC current should be taken as the test current) to the device, the temperature rise of the resistive elements shall meet the temperature rise requirements in Clause 6.

8.3.3 Thermal stability test

Protection gap and other protection shall be removed before the test. The test shall be carried out according to the requirements of IEC 62271-1 and IEC 60076-5. The test current is specified in Clause 6 and Clause 7. After the test, the device shall have no visible damage and still function normally. The device shall be able to pass the power frequency withstand test again with no obvious deterioration of the insulation materials.

8.3.4 Dynamic stability test

Tests shall be carried out according to IEC 62271-1 and IEC 60076-5. The test current is specified in Clause 6 and Clause 7. For DC current-blocking devices, the initial mode should be in DC blocking state and the device shall switch to direct grounding mode automatically. After the test, the device shall have no visible damage and shall still function normally. The device shall be able to pass the power frequency withstand test again with no obvious deterioration of the insulation materials.

8.3.5 Lightning impulse test

Apply the standard full lightning wave (1,2/50 µs) with positive and negative polarity between the live components and the earth for 15 times each. The test shall be carried out according to the requirements of IEC 60060-1. Gap protection and other protection shall be removed before the test.

8.3.6 Ingress protection test

Tests shall be carried out according to the requirements of IEC 60529.

9 Packing, transportation and storage requirements

It is essential that the packing, transport and storage be performed in accordance with instructions given by the manufacturer. Consequently, the manufacturer should provide instructions for the transport and storage of the devices. The instructions for the transport and storage should be given at a convenient time before delivery, and the instructions for the installation, operation and maintenance should be given by the time of delivery at the latest.

When the device is not fully assembled for transport, all transport units should be clearly marked. Drawings showing assembly of these parts should be provided with the device.

10 Nameplate specification

Each device shall be fitted with a nameplate in a visible position. The content marked on the nameplate shall be permanently legible.

The nameplate shall include the following content:

- name of the device;
- IEC standard number;
- manufacturer's names;
- manufacturer's serial number;
- insulation level (not mandatory for DC current-blocking device);
- rated power frequency current;
- measured impedance;
- measured DC resistance value for DC current-limiting device;

- measured capacitance value for DC current-blocking device;
- heat resistant grade of insulating materials (not mandatory for DC current-blocking device);
- rated thermal short-circuit current and duration;
- rated dynamic short-circuit current and duration;
- date of manufacturing;
- overall dimensions;
- total weight.

11 Technical documentation requirements

Manufacturers shall provide the purchaser with the following technical documentation:

- general assembly drawings, including dimensions and position of the centre of gravity, total weight, windward area, transportation size and weight, dimensions and materials of terminals and other accessories;
- drawings for lifting, nameplates and terminal diagram;
- factory certification, test reports or certification of major components or materials;
- type test reports;
- routine test reports;
- user manual.

Annex A
(informative)

Generation mechanism of DC bias current of power transformers caused by HVDC system

DC current flowing through power transformer windings can be caused by an HVDC system in monopole grounding return operation. When the HVDC system is in monopole grounding return mode, the ground acts as another transmission line to conduct the operating current of the DC transmission system. The current flowing through the grounding electrode of the HVDC system can reach the level of 4 000 A to 5 000 A. Figure A.1 shows the path through which the DC current flows in monopole ground return mode.

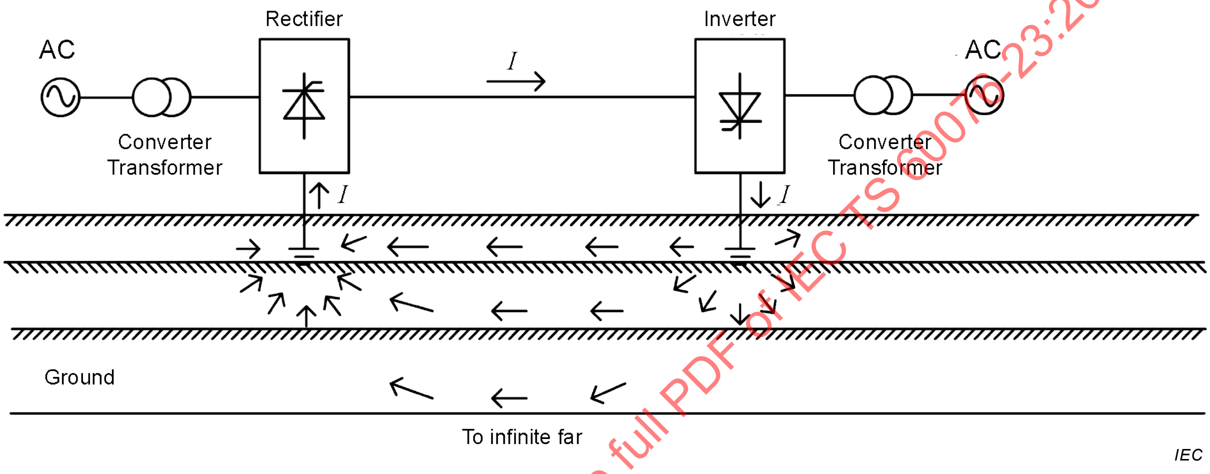


Figure A.1 – Schematic diagram of DC flowing path in the monopole ground return mode

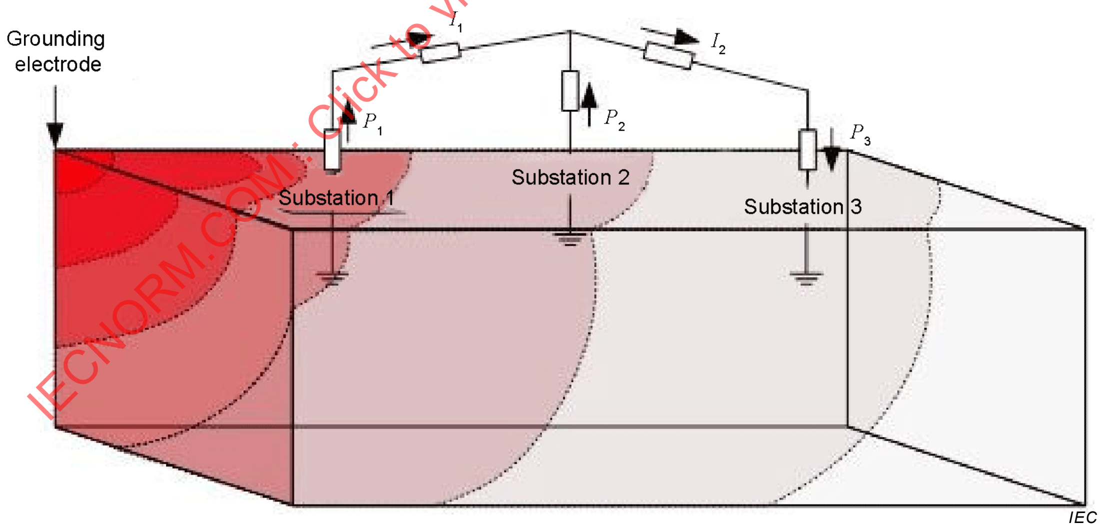


Figure A.2 – Resistance network and ground electric field distribution

Figure A.2 shows the basic principle when power substations are influenced by HVDC systems in monopole ground return operation. A huge DC current injected into the ground changes the ground potential in a large area around the electrodes. As a result, the substations of the nearby AC power grid may be operated on different DC ground potentials. The neutral grounded power transformers in these substations and transmission lines form circuits for DC current, causing DC current to flow through the AC power network. The DC current flowing through transformer windings may cause DC bias in transformers.

Annex B
(informative)

Examples of harmful effects of DC bias current

The DC bias phenomenon is an abnormal operation state of power transformers. When DC current flows through transformer windings, a DC magnetic potential and a magnetic flux is set up in the transformer core. The excitation characteristic curve and the output current waveform of the transformer are shown in Figure B.1. In graph (a) of Figure B.1, the dashed line is the magnetic flux curve influenced by the DC component, and the solid line is the magnetic flux curve without the influence of the DC component. Graph (b) in Figure B.1 is the typical excitation curve of the transformer. In graph (c) of Figure B.1, the solid line is the magnetization current curve without the influence of the DC component, and the dashed line is the distorted excitation current curve influenced by the DC component. Since the flux peak of transformers is generally designed near the saturation point of the iron excitation curve, the work point of the core excitation would enter saturation zone of the excitation curve for half a period, even if the DC bias current only generates a little DC flux component in the transformer core. The half-wave saturation phenomenon causes the excitation current peak in transformer to increase rapidly in the corresponding half period and the current waveform in the transformer is distorted seriously.

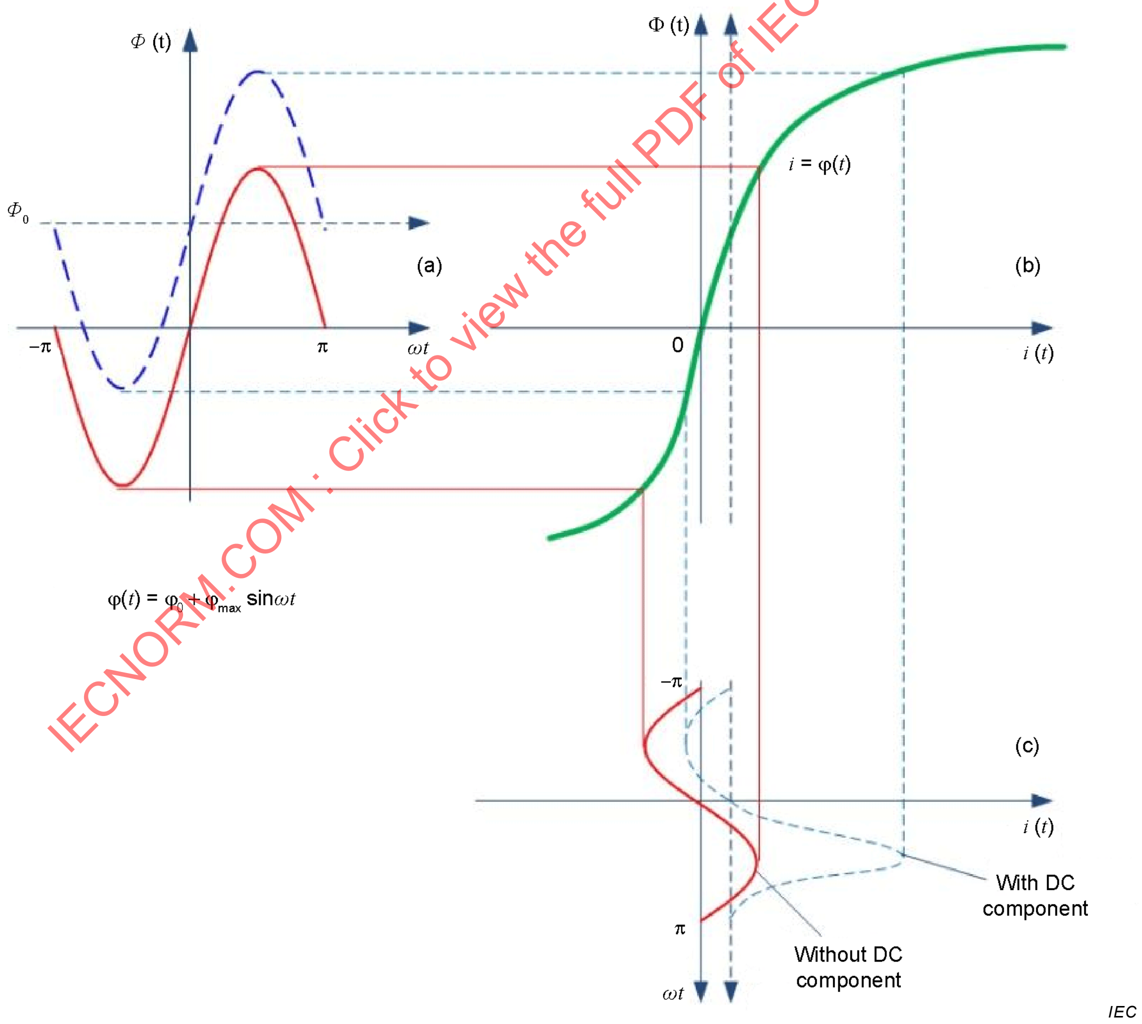


Figure B.1 –Mechanism of DC bias

The influences of DC bias current on power transformers and transmission systems are as follows:

- power loss and temperature rise of power transformers;
- vibration of power transformers;
- noise of power transformers;
- harmonics in power grid;
- increase of the power transformers' reactive loss;
- faults of relay protection system.

Two cases showing influences of DC bias current are shown as below.

- Case 1

In May 2010, a heavy load test in monopole ground return mode was performed for a ±800 kV DC transmission system in Shanghai. At the same time, field tests were conducted to measure the neutral-point current, vibration and noise of power transformers in 500 kV substation A and 220 kV substation B near the ground electrode of the HVDC system. The test results are shown in Table B.1.

Table B.1 – Test results of DC bias influence on DC system

Transformer number	DC transmission current A	DC current in the neural point of transformer A	Average value of noise (normal bipolar mode) dB	Average value of noise (monopole ground return mode) dB	Maximum of vibration acceleration (monopole ground return mode) m/s^2
No.1 transformer in substation A	4 000	20,4	63,2	91,1	11,69
No.3 transformer in substation A		20,6	65,1	90,8	10,42
No.1 transformer in substation B		15,2	63,6	89,4	2,32

In June 2010, the vibration of one 500 kV transformer was measured when the ±800 kV DC transmission system was in monopole ground return operation again. The results are shown in Table B.2.

Table B.2 – Vibration data of transformer (mm/s)

Measuring spot	Working condition							
	Background			Monopole operation				
Time				13:12	13:16	13:19	13:22	13:30
Spot No.1	1,8	1,06	0,92	2,19	6,27	7,51	7,62	7,72
Spot No.2	3,75	2,59	2,42	4,49	9,58	11,3	11,4	11,5
Spot No.3	1,39	1,04	1,04	1,56	2,92	3,34	3,39	3,39

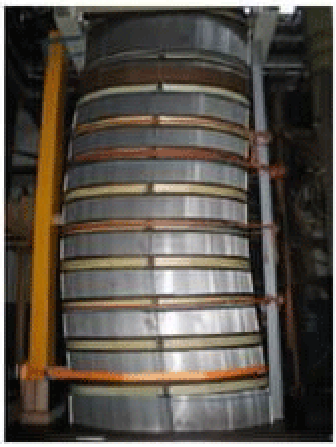
Test results show that the change of the operation mode of the DC system has direct influence on the noise and vibration of transformers near the grounding electrode pole.

- Case 2

In February 2004, when a ±500 kV DC transmission system in Guangdong province (China) was in monopole ground return operation, the vibration and noise of a 500 kV transformer which is 10 km from the ground electrode increased obviously.

In March 2004, when two ±500 kV DC transmission systems were in monopole ground return operation, the maximum DC current detected at the neutral points of the 500 kV transformer was 43 A. After the period of monopole operation of HVDC systems, an internal check of the power transformer was performed. It was found that the insulation block of the iron clamp had dropped, the insulation block below the windings was displaced, the windings were loosened and the iron beam was severely bent. Damage is shown in Figure B.2.

a) The foot block of bolts below iron droped



b) The iron beam bended heavily

Figure B.2 – Damage to transformer

Annex C
(informative)

DC current-limiting device

Figure C.1 shows the electrical schematic diagram of a DC current-limiting device.

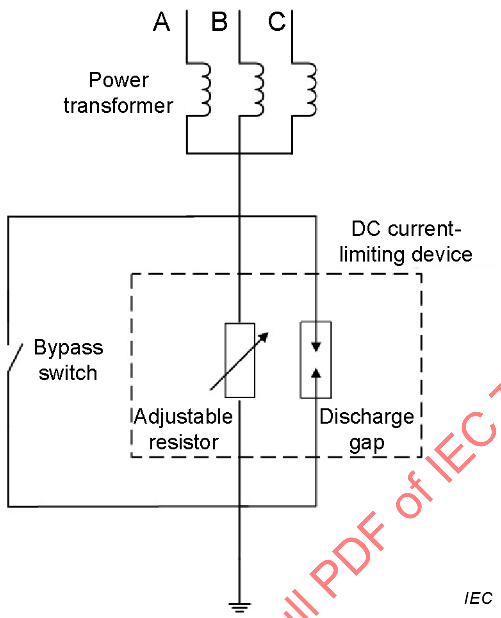


Figure C.1 – Electrical schematic diagram of DC current-limiting device

Annex D
(informative)

DC current-blocking device

Figure D.1 shows the electrical schematic diagram of a DC current-blocking device.

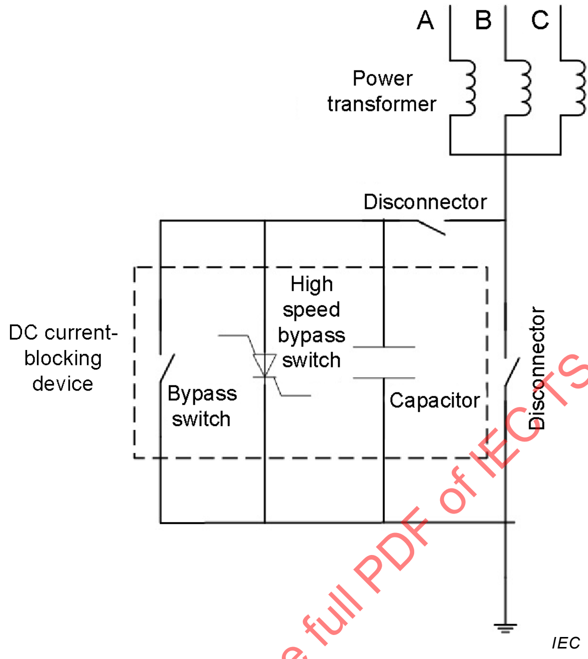


Figure D.1 – Electrical schematic diagram of DC current-blocking device

Annex E
(informative)

Information needed to calculate the DC bias current of transformers

E.1 General

The following information should be collected for the purpose of calculation of DC bias current of power transformers.

E.2 Information of grounding electrode of HVDC system

The information needed for calculation includes the following:

- design data: structure of ground electrode, buried depth of ground electrode, soil layer construction of the electrode area, soil resistivity of the electrode area.
- geographical location of the ground electrode.

E.3 Parameters of equipment in substations and converter stations

For all power substations having transformers with neutral point grounded within 50 km from the grounding electrode, the following data should be collected:

- data of transformation equipment: DC resistance of transformers, grounding resistance of substations.
- data of power grid: power network diagram.

E.4 Parameters of power transmission lines

The DC resistance of transmission lines in the area of calculation should be collected.