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TECHNICAL REPORT

Guidelines for operation and maintenance of line commutated converter (LCC) HVDC converter station

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GUIDELINES FOR OPERATION AND MAINTENANCE OF LINE COMMUTATED CONVERTER (LCC) HVDC CONVERTER STATION

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IEC TR 63065, which is a technical report, has been prepared by IEC technical committee 115: High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV.

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

Enquiry draft	Report on voting
115/153/DTR	115/163/RVDTR

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

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GUIDELINES FOR OPERATION AND MAINTENANCE OF LINE COMMUTATED CONVERTER (LCC) HVDC CONVERTER STATION

1 Scope

This Technical Report provides general guidance on basic principles and general proposals for the safe and economic operation and maintenance of an LCC converter station.

These guidelines are based on the operation and maintenance practices that have been used successfully during the last decades at HVDC converter stations all over the world, and can be referred to by new HVDC users to optimize operation and maintenance policy and assist in performing the operation and maintenance work.

This document focuses only on the operation and maintenance of the equipment inside an LCC converter station, including back-to-back HVDC systems. The operation and maintenance of HVDC overhead transmission lines, HVDC cables and voltage sourced converter (VSC) are not covered by this document.

NOTE Usually the agreement between the purchaser and the suppliers of the HVDC converter station includes specific requirements regarding contractual requirements of particular systems. Such specific requirements will supersede the general/typical description mentioned in this document and all functions mentioned in this document are not necessarily applicable for all systems.

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2 Normative references

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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 60633, *Terminology for high-voltage direct current (HVDC) transmission*

IEC 60919 (all parts), *Performance of high-voltage direct current (HVDC) systems with line-commutated converters*

IEC 61975, *System tests for High-voltage direct current (HVDC) installations*

IEC TS 62672-1, *Reliability and availability evaluation of HVDC systems – Part 1: HVDC systems with line commutated converters*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60633 and the following 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

3.1.1
manned station
MS
HVDC converter station that is operated locally by several operators, 24 h a day

Note 1 to entry: In some systems the manned station controls and observes not only its own converter station but also the opposite unmanned station.

3.1.2
unmanned station
US
HVDC converter station that is operated remotely with no operator on site

3.1.3
time based maintenance
TBM
maintenance carried out in accordance with a specified time schedule, in most cases annually

3.1.4
condition-based maintenance
CBM
necessary maintenance performed based on the equipment's condition, sometimes combined with TBM

3.1.5
reliability centred maintenance
RCM
necessary maintenance performed after analyzing the performance of the equipment

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3.1.6
operator
person operating the converter station

3.1.7
asset manager
person that manages the plant/asset for the overall planning, operation, maintenance and performance in accordance with a set of criteria as assigned by the asset owner

3.2 Abbreviated terms

BOD	break over diode
BPS	by-pass switch
CBM	condition-based maintenance
CT	current transformer
DGA	dissolved gas analysis
GIS	gas insulated switchgear
GRTS	ground return transfer switch
HMI	human-machine interface
LCC	line commuted converter
MCB	micro circuit breaker
MRTB	metallic return transfer breaker
MV	medium voltage
NBS	neutral bus switch
OEM	original equipment manufacturer

OLT	open line test
OLTC	on line tap changer
OTDR	optical time domain reflectometer
RCM	reliability-centred maintenance
RPC	reactive power control
SCADA	supervisory control and data acquisition
SER	sequence of event records
TBM	time-based maintenance
TFR	transient fault record

4 Operation

4.1 Operation policy

4.1.1 Target reliability and availability

Generally, an availability of 97 % is requested as the minimum value in the design specification of a new HVDC project. This is based on a forced unavailability of less than 1 % and a scheduled unavailability of about 2 %. With good quality control applied in the design, manufacture, installation and testing stages, as well as appropriate operating and careful maintenance during operation, this requirement can be met in most modern HVDC systems.

According to the survey conducted by CIGRE B4 AG4 ([2] to [6][1]) for the period 2003 to 2014, typical target performance indicators for an HVDC system can be:

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a) forced unavailability < 1 %;
b) availability > 97 %.

Scheduled unavailability varies from system to system depending on which operation and maintenance policy is taken. This can be seen from the performance reports of CIGRE B4 AG4. For example, some systems perform maintenance using 24 h shifts, whereas others work only 8 h a day and leave the system out of service for 16 h each day and on weekends. In other systems, maintenance is performed when the generator is not available (thermal unit out for maintenance or low water conditions, etc.). That is why the typical scheduled unavailability and overall unavailability is not given above.

The number of forced outages, including sudden interruption of power transmission both by protections and by manual emergency shutdown, is an important parameter for reliability. Usually, for a bipolar LCC HVDC scheme, the number of monopole trips is designed to be four times or fewer a year and the number of bipolar trips below once every ten years. According to the operation practice of modern HVDC systems, the number of monopole trips can be even limited to once a year. In systems with more than one converter in series per pole, the converters' trips can be limited to two trips per converter per station.

Outage hours, a parameter that indicates not only the health of the equipment but also the ability of maintenance, also affect the reliability and availability considerably. The outage hours would be longer due to severe damage of the equipment, complex fault analyzing and troubleshooting, or long waiting times for tools or spare parts. Every effort should be made to put the HVDC system back into full operation as soon as possible.

Refer to IEC TS 62672-1 for the main performance indicators.

[1] Numbers in square brackets refer to the Bibliography.

4.1.2 Operation cost

The operation cost covers the following aspects:

a) human resources (salary for the operation and maintenance staff),

b) consumables,

c) maintenance and tests,

d) auxiliary power and cooling waters,

e) spare parts,

f) improvements and upgrade, and

g) other costs.

There are a number of variables that will impact the operational cost of an HVDC station. The human resources cost for an unmanned station is much less than for a manned station. The maintenance cost for an RCM station is much less than for a TBM station. The spare parts cost for an old station is usually higher than for a new station.

Due to the above reasons, it is hard to give an average cost for running an HVDC converter station for one year. The costs can be reduced if optimal operation, maintenance and spare part policies are considered.

4.1.3 Manned or unmanned

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Traditionally, an LCC HVDC converter station is a manned station, where several operators monitor the status of the HVDC link and the equipment 24 h a day. Even for a manned station, the power flow on the HVDC system may be dispatched remotely. As development in automation increases, as well as the improvement of HVDC equipment, unmanned stations or less-manned stations (e.g. manned only during office hours) are more common. Many stations in Europe (like FennoSkan, SwePol) are unmanned. An unmanned converter station is operated remotely from an operation centre or even a dispatch centre, and manned only when something has failed.

Some important HVDC converter stations, such as Itaipu (Brazil), Nelson River (Canada) and Fulong (China),which are responsible for transmitting 70 % of the power generated by nearby hydro plants, are still manned stations. Equipment failure can be fixed faster at a manned station. This in turn contributes to the reliability and availability of the HVDC link.

Whether a station is manned or unmanned can be evaluated technically and economically. If it takes more than two hours to drive from a nearby city to the station, if the equipment failure rate of the station is still high, or if the converter station is critical to the grid, it may be better to man the station.

NOTE Some parts of the text in this document are applicable for manned stations only and are not applicable for unmanned stations, as there is no operator in the station.

4.2 Operation condition and limits

Before entering commercial operation of an HVDC converter station, the following conditions are normally required to be fulfilled:

a) the system test (IEC 61975) and the trial operation have been completed successfully;

b) the operating and maintenance staff is available and has been trained;

c) the communication between the dispatch centre and the converter station has been set up;

d) the standard operating procedure for operation and maintenance of the HVDC station has been established; and

e) spare parts are available.

Keeping and preserving the life of an HVDC converter station/link is the most important aspect to manage. Generally, HVDC systems are planned, designed and expected to have a lifetime of 30 years or more. To meet this requirement, operation limits should be clearly defined and faithfully followed by the operating and maintenance staff. They at least include:

1) the current, voltage and temperature of the main equipment are within the limits defined by HVDC suppliers;
2) the temperature, humidity and cleanliness of the valve hall, valve cooling system, relay buildings and control rooms can meet the requirements of normal operation of related equipment or devices;
3) the maximum acceptable current for electrodes and station grounds is such that it will not affect nearby industry pipes or the environment;
4) environment (oil, water, PCB, etc.) management systems and procedures are in place and the staff regularly reviews these procedures.

4.3 Operations of an HVDC system

4.3.1 General

Subclause 4.3 gives a generic guidance as to how to operate an HVDC system. Note that the suppliers' documentation for the given HVDC system shall always be consulted for the particular HVDC system.

4.3.2 Typical operation configuration

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4.3.2.1 General

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Availability, reliability, and flexibility for operation and maintenance are closely related to the operational configuration of HVDC systems. The general configuration and performance of high voltage direct current (HVDC) system are given in IEC 60919.

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4.3.2.2 Point-to-point HVDC system

A point-to-point HVDC system is mainly for bulk transmission. It usually consists of two separate poles, which can be operated individually or together in a bipolar arrangement. This kind of system can be operated in three operating configurations.

a) Bipolar ground return with bipolar power control

   This is the normal operation mode for a bipolar HVDC system. Active power order is shared between each pole and the current of both poles is balanced so that the earth current is kept to a low value, typically less than 10 A. Furthermore, if one pole is tripped, part of its power can be taken up by the healthy pole so that less power will be lost. The above benefits make this the most commonly used operation modes in a bipolar HVDC system.

   During bipolar operation, the bipole neutral bus can be connected to either the electrode or the station ground. This allows the electrode or electrode lines maintenance job to be done without interruption of normal power transmission. However, it may be noted that when the station ground is used, in the event of a trip of a pole, another pole will also be tripped as a consequence of increased station ground current. Attention should also be paid to a possible station ground potential change at pole ground fault.

   Under contaminated conditions, which are often a combination of rain or fog in an HVDC station or along the corridor of its DC lines, the affected pole can continue the power transmission by running at reduced voltage, for instance 70 % or 80 % of rated DC voltage.The current of each pole is balanced by the control system and the earth current is still limited to a low value. The HVDC system can resume the rated voltage when the weather conditions improve.

   In the case where the DC equipment of one pole develops a fault such that the power or current needs to be limited to a certain level, the defective pole can be set to pole power control or pole current control.

b) Monopole metallic return

This is an optional operation mode for a bipolar system. If one pole for a bipolar HVDC system is not available, and if long-term flow of high earth current is not allowable and the DC line of the other pole is still available, the remaining pole can be connected to both DC lines and earthed at one predefined station. The equipment belonging to the outage pole can be checked or repaired and put into operation again. Compared to monopole ground return, the power loss on the DC line will be doubled, so once the faulty pole is available again, the operating pole can be transferred back first from metallic return to ground return and then to bipolar ground return.

c) Monopole ground return

This is also an optional operation mode for a bipolar HVDC system. If one pole is not available, for example when it is under construction, maintenance, or it is tripped by protections, and if long-term flow of earth current is acceptable, the remaining pole is connected to the electrode via the MRTB and can go on operating. The equipment belonging to the faulty pole, as well as its DC line, can be checked or repaired and put into operation again.

4.3.2.3 Back-to-back HVDC system

A back-to-back HVDC system is mainly used for asynchronous connections. In this arrangement, there are no DC transmission lines or DC filters, and both converters are located at one station. The valves for both the rectifier and the inverter are typically located in one valve hall.

There is only one operating configuration for a back-to-back system. The 12-pulse converters of both the rectifier and the inverter are connected directly through busbars. Some back-to-back systems are comprised of several units so that the loss of a converter will not lead to a total loss of power transmission or network islanding.

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4.3.2.4 Two 12-pulse converters per pole

If the DC voltage or DC current of the converter reach their limits, two 12-pulse converters are connected in series or in parallel for higher voltage or higher current. This configuration is applied to Nelson River, Itaipu, and the UHVDC systems in China and India.

The operational configuration of 12-pulse converters per pole is the same as for bipolar systems except that the system can still be operated in bipole mode when one converter is out of service (forced or scheduled). In this case, the pole will operate at half the normal voltage or half the DC current capability.

4.3.2.5 Set up the operation configuration

Operators should evaluate the state of main circuit equipment including:

a) AC configuration and minimum availability of AC filter;
b) availability of HVDC equipment of each pole;
c) allowed ground return current;
d) connectivity of DC lines;
e) ensuring all major or critical alarms have already been acknowledged and reset.

The operational configuration can then be set up by connecting both poles or a single pole, in ground return or metallic return, and the DC lines of each pole or of both poles.

4.3.3 Set up the control mode

4.3.3.1 General

A combination of different DC voltage settings, power direction, power control methods, power control modes, reactive power control methods and reactive power control modes gives a large combination of options.

Bipolar power control ensures that the total power of the DC bipolar transmission remains at the ordered value and that the current is equally distributed between the two poles, thus minimizing the earth current. This is the main mode of operation, and to fully synchronize the two stations, telecommunication has to be in service.

Pole power control keeps the transmitted DC power equal to the power order given by the operator. To keep the power constant, the DC voltage variation is compensated by adjusting the DC current accordingly. The current order I_o is obtained by dividing the total power order by the DC voltage of the converter.

Pole current control keeps DC current equal to the current order given by the operator.

4.3.3.2 Basic control mode

Before starting the power transmission of an HVDC system, the operators should set up the following control modes:

a) reference DC voltage of each pole;
b) power transmission direction of each pole;
c) select control method and control mode of active power control;
d) enable joint control as long as telecommunication is available;
e) select control method and control mode of reactive power control;
f) enable or disable the supplementary control function such as frequency control, damping control.

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4.3.3.3 Additional control functions

The inherent high-speed power control capability of the HVDC transmission system may be used for different objectives such as frequency control, power modulation, and power oscillation damping.

Frequency control modifies the DC power transfer to assist the connected AC systems in recovering from severe contingencies by limiting AC system frequency deviation above and below the nominal frequency. The characteristics and dead bands of the frequency controls are determined during the design studies.

Contingencies involving loss of generation in the inverter AC system and loss of load in the rectifier AC system may require that the power on the DC system be rapidly increased to improve the performance of the AC systems. Contingencies involving a loss of generation in the rectifier AC system or a loss of load in the inverter AC system may require an automatic reduction in DC power transfer. Power modulation functions are available both in bipolar and monopolar operation.

Some HVDC systems of which both ends are connected to the same synchronized AC system apply power modulation that can dampen the power oscillations that may be caused either by a large disturbance or specific system conditions. The power flow of the HVDC system is quickly controlled to repress power oscillation.

Therefore, before starting the power transmission of an HVDC system, operators should also set up the following additional controls.

a) Enable or disable automatic frequency control and set up its parameters. Automatic frequency control should be enabled if the HVDC link is connected to a weak AC system or an islanded system.

b) Enable or disable power modulation and set up its parameters. Power modulation is commonly used for network stability control. After loss of AC lines, DC transmission power can be ramped down if needed. After tripping of DC link, the generators connected to the rectifier and the loads connected to the inverter can be turned off.

c) Enable or disable oscillation damping and set up its parameters. Oscillation damping is mainly used for the rectifier that is fed from thermal power generators and is weakly connected to a power grid. To avoid subsynchronous oscillation, the power at special frequencies is measured and modulated.

4.3.4 Operation procedure

4.3.4.1 Control position and control authority

Control orders to the HVDC system, either in digital or analogue, can be given from the dispatch centre, SCADA, or from backup or local control locations. By default orders from SCADA are accepted by the control system, unless the dispatch centre takes over the control rights or when backup control is enabled.

Only the master station can control the power transmission of an HVDC link. If the slave station needs to control the power, it needs to first take master control from the other station first.

iTeh STANDARD PREVIEW
(standards.iteh.ai)

To increase the security of the HVDC system, only authorized operators should control the equipment in corresponding areas such as the DC yard, AC yard, AC filters, and auxiliary power system.

IEC TR 63065:2017
https://standards.iteh.ai/catalog/standards/sist/7f69601a-e1c8-4d80-8b40-53156683f907/iec-tr-63065-2017

Operators shall log onto the human-machine interface (HMI) before performing any operation.

4.3.4.2 OLT

The open line test (OLT) is a test that is used by the operators to energize the pole DC side with direct voltage for the purpose of testing the insulation on the DC side, as well as the converter. The OLT can be performed either in manual or automatic mode.

The OLT is performed in one station at a time because the DC line will be energized up to the pole disconnector of the other station. When one pole is in open line test the other pole may, depending on the system design and operation permission, be operated independently.

The OLT is usually part of the commissioning of the HVDC scheme, in some cases it is also carried out after annual maintenance or a DC line fault. But it is not necessary to carry out an OLT every time before deblocking a pole. Some HVDC systems have never been subjected to an OLT in the last thirty years, even after pole maintenance.

4.3.4.3 Deblock

Once the main circuit and the control mode are chosen, i.e. an operating mode is set up, the HVDC system can be deblocked for power transmission. Before deblock, the status of the main circuit equipment, control and protections and auxiliary systems should be confirmed to ensure that the HVDC system is ready for operation. If any of the systems indicates a severe alarm, maintenance staff should investigate its cause and should take steps to restore the system to normal condition.

The inverter is always deblocked first to build up DC voltage, and then the rectifier is deblocked to build up the DC current. The control of the two stations is synchronised via telecommunication. In the event of a telecommunication failure, operators of the two stations shall cooperate by telephone to manually deblock the HVDC link.