IEC

IEC TR 62672

Edition 1.0 2018-09

TECHNICAL REPORT

Reliability and availability evaluation of HVDC systems

IEC TR 62672:2018-09(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue
The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org
The world's leading online dictionary of electronic and electrical terms containing 21 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC TR 62672

Edition 1.0 2018-09

TECHNICAL REPORT

Reliability and availability evaluation of HVDC systems

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.240.01 ISBN 978-2-8322-6065-4

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

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

RELIABILITY AND AVAILABILITY EVALUATION OF HVDC SYSTEMS

FOREWORD

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 62672, 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.

This first edition cancels and replaces the first edition of IEC 62672-1 published in 2013. This edition constitutes a technical revision.

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

a) HVDC stations with voltage sourced converters have been included;
b) this document has been aligned with latest Cigré TB 590:2014, which has superseded the previous Cigré TB 346:2008.

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

Enquiry draft	Report on voting
115/177/DTR	115/185/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.

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

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.

RELIABILITY AND AVAILABILITY EVALUATION OF HVDC SYSTEMS

1 Scope

This document applies to all line-commutated and voltage-sourced high-voltage direct current (HVDC) transmission systems used for power exchange in utility systems.

In order to assess the operational performance of HVDC transmission systems, reliability and availability are evaluated. The intention of the performance evaluation is to identify further design improvements. For this purpose the HVDC users/owners are encouraged to compile reports on an annual basis based on the recommendations given in this document. The purpose of this document is to define a standardized reporting protocol so that data collected from different HVDC transmission systems can be compared on an equitable basis. Such reports can be sent to Cigré SC B4, "HVDC and Power Electronics" (http://b4.cigre.org) which collects such data and publishes it in a survey of HVDC systems throughout the world on a bi-annual basis.

This document covers point-to-point transmission systems, back-to-back interconnections and multi-terminal transmission systems. For point-to-point systems and back-to-back interconnections, i.e. two-terminal systems, statistics are reported based on the total transmission capability from the sending end to the receiving end measured at a given point. If, however, the two terminals are operated by different users/owners, or are composed of equipment of a different vintage or of equipment from different suppliers, statistics can be reported on an individual station basis if so desired by those responsible for reporting. In such a case, the outage is only reported under the originating converter station, taking care not to report the same event twice. For multi-terminal systems, i.e. systems with more than two terminals, statistics are reported separately for each converter station based on its own individual capability.

Multi-terminal systems, incorporating parallel converters but having only two converter stations on the DC line, can be considered as either point-to-point systems or as multi-terminal systems for purpose of reporting. Therefore, statistics for this special type of multi-terminal system can be reported based on either total transmission capability or on individual station capability. If the converters at one station use different technology, converter station statistics can be reported separately for each different type of capacity if desired. Multiple bipoles are also reported individually. Special mention is given in the text and in the tabulations to any common events resulting in bipolar outages.

NOTE Usually the agreement between the purchaser and the turnkey suppliers of the HVDC converter station includes specific requirements regarding contractual evaluation. Such specific requirements will prevail over this document.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, abbreviated terms and symbols

For the purposes of this document, the following terms, definitions, abbreviated terms and symbols 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 Outage terms

3.1.1
outage
state in which the HVDC system is unavailable for operation at its rated continuous capacity due to an event directly related to the converter station equipment or DC transmission line

Note 1 to entry: Failure of equipment not needed for power transmission is not to be considered as an outage for purposes of this evaluation. AC system related outages are to be recorded but not included in HVDC system reliability calculations.

Note 2 to entry: For purposes of this evaluation, outages taken for major reconfiguration or upgrading, such as the addition of converters, are not to be reported.

3.1.2
scheduled outage
outage, which is either planned or which can be deferred until a suitable time

Note 1 to entry: Scheduled outages can be planned well in advance, primarily for preventive maintenance purposes such as an annual maintenance program. During such planned maintenance outage, it is usual to work on several different equipment or systems concurrently. It is not necessary to allocate such outage time to individual equipment categories. Only the elapsed time should be reported in Table 5 as “PM”.

Note 2 to entry: Classified under the scheduled outage category are also outages for work which could be postponed until a suitable time (usually night or weekend) but cannot be postponed until the next planned outage. Equipment category code in Table 5 should be used to identify the affected equipment. This includes discretionary outages based on operating policies, user/owner’s preference and maintenance of redundant equipment.

Note 3 to entry: If the scheduled outage is extended due to additional work which would otherwise have necessitated a forced outage, the excess period is to be counted as a forced outage.

3.1.3
forced outage
state in which equipment is unavailable for normal operation but is not in the scheduled outage state

3.1.3.1
trip
sudden interruption in transmission by automatic protective action or manual emergency shutdown

3.1.3.2
other forced outage
other unexpected HVDC equipment problems that force immediate reduction in capacity of HVDC converter stations or system but do not cause or require a trip

Note 1 to entry: Also in this category are outages caused by start-up or de-block delays caused by HVDC equipment.

Note 2 to entry: In some cases the opportunity exists during forced outages to perform some of the repairs or maintenance that would otherwise be performed during the next scheduled outage. See 6.3.3, rule (f).

3.2 Capacity terms

3.2.1
rated capacity
P_m
maximum capacity (MW), excluding the added capacity available through means of redundant equipment, for which continuous operation under designed conditions is possible

Note 1 to entry: For two-terminal systems reporting jointly, the rated capacity refers to a particular point in the system, usually at one or the other converter station. For multi-terminal systems or two-terminal systems reporting separately, the rated capacity refers to the rating of the individual converter station.

Note 2 to entry: When the maximum continuous capacity varies according to seasonal conditions, the highest value can be used as the capacity when reports are prepared according to this document for simplicity's sake. However this excludes over-load capability such as is available during low ambient temperature.

3.2.2
outage capacity
P_o
capacity reduction (MW) which the outage would have caused if the system was operating at its rated capacity (P_m) at the time of the outage

Note 1 to entry: The outage capacity is calculated based on the same point in the system as that used for defining P_m.

3.2.3
outage derating factor
ODF
ratio of outage capacity to rated capacity, expressed as

$$ODF = P_o / P_m$$

3.3 Outage duration terms

3.3.1
actual outage duration
AOD
time elapsed in decimal hours between the start and the end of an outage

Note 1 to entry: It is expressed for example as follows: 6 h:30 min = 6,50 h.

Note 2 to entry: The start of an outage is typically the first switching action related to the outage. The end of an outage is typically the last switching action related to the return of the equipment to operational readiness.

Note 3 to entry: In some contractual evaluations between purchaser and supplier, AOD can be subjected to correction to adjust for long waiting times, administrative delays, non-availability of tools and tackles, non-availability of spare parts or other needed resources including trained man power, delay in permits etc.

3.3.2
equivalent outage duration
EOD
actual outage duration (AOD) in decimal hours, multiplied by the outage derating factor (ODF), so as to take account of partial loss of capacity, and expressed as

$$EOD = AOD \times ODF$$

Note 1 to entry: Each equivalent outage duration (EOD) may be classified according to the type of outage involved: equivalent forced outage duration (EFOD) and equivalent scheduled outage duration (ESOD).

3.4 Time categories

3.4.1
period hours, pl.
PH
number of calendar hours in the reporting period

Note 1 to entry: In a full calendar year the period hours are 8 760, or 8 784 in leap years.

Note 2 to entry: If the equipment is commissioned part way through a year, the period hours will be proportionately less.

3.4.2
actual outage hours, pl.
AOH
sum of actual outage durations within the reporting period, expressed as

$$AOH = \Sigma\ AOD$$

Note 1 to entry: The actual outage hour (AOH) may be classified according to the type of outage involved: actual forced outage hours (AFOH) and, actual scheduled outage hours (ASOH). AFOH and ASOH are expressed, respectively, as

$$\text{AFOH} = \Sigma\ \text{AFOD}$$

$$\text{ASOH} = \Sigma\ \text{ASOD}$$

3.4.3
equivalent outage hours, pl.
EOH
sum of equivalent outage durations within the reporting period, expressed as

$$\text{EOH} = \Sigma\ \text{EOD}$$

Note 1 to entry: The equivalent outage hours (EOH) may be classified according to the type of outage involved: equivalent forced outage hours (EFOH) and equivalent scheduled outage hours (ESOH). EFOH and ESOH are expressed, respectively, as

$$\text{EFOH} = \Sigma\ \text{EFOD}$$

$$\text{ESOH} = \Sigma\ \text{ESOD}$$

3.5 Availability and utilization terms

3.5.1
energy unavailability
EU
measure of the energy which could not have been transmitted due to outages

Note 1 to entry: The energy unavailability is calculated based on the same point in the system as that used for defining P_m.

Note 2 to entry: The energy unavailability (EU) may be classified according to the type of outage involved: forced energy unavailability (FEU) and scheduled energy unavailability (SEU). EU, FEU and SEU are expressed, respectively, as

$$\text{EU} = (\text{EOH} / \text{PH}) \times 100\ (\%)$$

$$\text{FEU} = (\text{EFOH} / \text{PH}) \times 100\ (\%)$$

$$\text{SEU} = (\text{ESOH} / \text{PH}) \times 100\ (\%)$$

Note 3 to entry: SEU covers both scheduled energy unavailability due to planned outage (SEUP) as well as scheduled energy unavailability due to deferred outage (SEUD).

3.5.2
energy availability
EA
measure of the energy which could have been transmitted except for limitations of capacity due to outages

Note 1 to entry: The energy availability is calculated based on the same point in the system as that used for defining P_m. EA is expressed as

$$\text{EA} = 100 - \text{EU}\ (\%)$$

3.5.3
energy utilization
U
factor giving a measure of the energy actually transmitted over the system

Note 1 to entry: The energy utilization is calculated based on the same point in the system as that used for defining P_m. It is expressed as follows:

$$U = \frac{E_{total}}{P_m \cdot PH} \times 100 \ \%$$

where

E_{total} is the total energy transmitted (MWh) during the reporting period;

P_m is the rated capacity (MW);

PH is the period hours (h).

Note 2 to entry: The total energy transmitted is the sum of energy exported and energy imported (expressed in MWh), both calculated based on the same point in the system as that used for defining P_m.

3.6 Commutation failure performance terms

NOTE This is not applicable to VSC HVDC systems.

3.6.1
recordable AC system fault
AC system fault, which causes one or more of the inverter AC bus phase voltages at the terminals of the harmonic filter to drop immediately following the fault initiation below 90 % of the voltage prior to the fault

Note 1 to entry: AC system faults at, or near, the rectifier are not relevant in this context and are not required to be included in this reporting. An exception to this rule is a special case where the network topology dictates that an AC fault near the rectifier also produces a simultaneous recordable fault at the inverter or where specific converter configuration (e.g. no smoothing reactor) is susceptible to a commutation failure in a rectifier operation.

3.6.2
commutation failure start
CFS(A)
initiation or onset of commutation failure(s) in any valve group immediately following the occurrence of an AC system fault, regardless of whether or not the AC fault is “recordable” as defined in 3.6.1

Note 1 to entry: Commutation failures as a result of control problems or switching events are not to be included.

3.6.3
commutation failure start
CFS(B)
initiation or onset of commutation failure(s) in any valve group as a result of control problems, switching events or other causes, but excluding those initiated by AC system faults under 3.6.2

3.7 Abbreviated terms and symbols

AC	alternating current
AFOD	actual forced outage duration
AFOH	actual forced outage hours
AOD	actual outage duration
AOH	actual outage hours
ASOD	actual scheduled outage duration
ASOH	actual scheduled outage hours
CFS	commutation failure start
CT	current transformer
DC	direct current
DMR	dedicated metallic (conductor) return
EA	energy availability
EFOD	equivalent forced outage duration

EFOH	equivalent forced outage hours
EOD	equivalent outage duration
EOH	equivalent outage hours
ESOD	equivalent scheduled outage duration
ESOH	equivalent schedules outage hours
EU	energy unavailability
FEU	forced energy unavailability
HVDC	high voltage direct current
IGBT	insulated gate bipolar transistor
LCC	line-commutated converter (also current-commutated converter)
MMC	modular multi-level (VSC) converter
OH	overhead (line)
PH	period hours
PLC	power line carrier
P_m	rated capacity
P_o	outage capacity
ODF	outage derating factor
RAM	reliability, availability, maintainability
RI	radio interference
SEU	scheduled energy unavailability
SEUD	scheduled energy unavailability deferred
SEUP	scheduled energy unavailability planned
STATCOM	static synchronous compensator
SVC	static var compensator
U	(energy) utilization
VBE	valve based electronics
VSC	voltage-sourced converter

4 Classification of HVDC transmission system equipment

4.1 General

For the purpose of reporting the cause of capacity reduction or converter outages, converter station equipment is classified into major categories. Failure of equipment resulting in an outage or loss of converter capacity is to be charged to the category to which the failed equipment belongs. The outage may be forced as a direct consequence of the failure or mis-operation, or the outage may be scheduled due to maintenance requirements. Only scheduled outages classified as deferred are categorized according to the equipment type.

The major categories are listed in the following subclauses and are as follows:

a) AC and auxiliary equipment (AC-E): 4.2

b) Valves (V): 4.3

c) DC control and protection equipment (C-P): 4.4

d) Primary DC equipment (DC-E): 4.5

e) Other (O): 4.6

f) DC transmission line (TL): 4.7

g) External (EXT): 4.8

The above major categories are further divided into subcategories.

4.2 AC and auxiliary equipment (AC-E)

4.2.1 General

This major category covers all AC main circuit equipment at the converter station. This includes everything from the incoming AC connection to the AC connection of the converter valve. This category also covers low voltage auxiliary power, valve cooling equipment (including pumps, fans, electrical auxiliaries, etc., but excluding parts at high potential integral within the valve, see 4.3.3) and AC control and protection.

NOTE This category does not apply to capacity outages resulting from events in the AC network external to the converter station.

The "AC and auxiliary equipment" category is divided into six subcategories described in 4.2.2 to 4.2.7.

4.2.2 AC filter and other reactive power equipment (AC-E.F)

Loss of converter station capacity due to failure of AC filters (passive and/or active) or other reactive power compensation equipment is to be assigned to this subcategory. The types of components included in this subcategory are capacitors, reactors, resistors, CTs and arresters comprised within the AC filtering or reactive power compensation equipment of the converter station.

NOTE Associated disconnectors/breakers, etc., with filters/reactive compensated equipment are excluded from this subcategory, as they are included in 4.2.7.

AC PLC/RI filters, SVCs, series capacitors (including those between converter transformers and valves), STATCOM, etc., when included in a converter station are also to be reported under this subcategory.

4.2.3 AC control and protection (AC-E.CP)

Loss of converter station capacity due to failure of AC protections, AC controls, or AC current and voltage measuring devices is to be assigned to this subcategory. AC protections or control could be for the main circuit equipment, for the auxiliary power equipment or for the valve cooling equipment.

NOTE CTs with AC filters or CTs on transformer bushings are not reported in this subcategory.

4.2.4 Converter/interface transformer (AC-E.TX)

Loss of converter station capacity due to failure of a converter transformer or interface transformer is to be assigned to this subcategory. Any equipment integral with the converter/interface transformer such as tap changers, bushings, bushing CTs or transformer cooling equipment is included in this subcategory.

4.2.5 Synchronous compensator (AC-E.SC)

Loss of converter station capacity due to failure of a synchronous compensator is to be charged to this subcategory. Anything integral or directly related to the synchronous machine such as its cooling system or exciter is included in this subcategory.