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TECHNICAL REPORT

Reliability and availability evaluation of HVDC systems

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Reliability and availability evaluation of HVDC systems

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RELIABILITY AND AVAILABILITY EVALUATION OF HVDC SYSTEMS

FOREWORD

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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b) this document has been aligned with latest Cigré TB 590:2014, which has superseded the previous Cigré TB 346:2008.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- withdrawn,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
$\boldsymbol{P_o}$
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

$$\text{ODF} = P_o / P_m$$

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

$$\text{EOD} = \text{AOD} \times \text{ODF}$$

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

$$\text{AOH} = \Sigma\ \text{AOD}$$

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.

4.2.6 Auxiliary equipment and auxiliary power (AC-E.AX)

Loss of converter station capacity due to failure or mis-operation of any auxiliary equipment is to be assigned to this subcategory. Such equipment includes auxiliary transformers, pumps, battery chargers, heat exchangers, cooling system process instrumentation, low voltage switchgear, motor control centres, fire protection and civil works.

4.2.7 Other AC switchyard equipment (AC-E.SW)

Loss of converter station capacity due to failure of circuit breakers, pre-insertion resistors, disconnect switches or earthing switches in the AC switchyard (including for AC filtering and reactive power compensation) is to be assigned to this subcategory. Also included is other AC switchyard equipment such as AC surge arresters, bus-work or insulators.

4.3 Valves (V)

4.3.1 General

This major category covers all parts of the thyristor/IGBT valve itself. The valve is the complete operative array forming an arm, or part of an arm of the converter bridge. It includes all auxiliaries and components integral with the valve and forming part of the operative array.

The "valves" category is divided into four subcategories described in 4.3.2 to 4.3.5, where 4.3.4 and 4.3.5 are only applicable to VSC HVDC systems.

4.3.2 Valve electrical (V.E)

Loss of converter station capacity due to any failure of the valve except for failure related to the part of the valve cooling system integral with the valve is to be assigned to this subcategory.

NOTE The VBE (valve base electronics) equipment is also included in this subcategory.

4.3.3 Valve cooling (V.VC)

Loss of converter station capacity due to any failure of the valve, related to the valve cooling system at high potential integral with the valve, is to be assigned to this subcategory.

4.3.4 Valve capacitor (V.C)

Loss of converter station capacity due to any failure of the valve capacitor (e.g. power module or cell capacitor) is to be assigned to this subcategory.

4.3.5 Phase reactor (V.PR)

Loss of converter station capacity due to any failure of the phase reactor is to be assigned to this subcategory.

4.4 DC control and protection equipment (C-P)

4.4.1 General

This major category covers the equipment used for control of the overall HVDC system and for the control, monitoring and protection of each HVDC substation excluding control and protection of a conventional type which is included in 4.2.3. This also excludes the AC measuring transducers which are included in 4.2.3 as well as DC measuring transducers which are included in 4.5.5.

NOTE The equipment provided for the coding of control and indication information to be sent over a telecommunication circuit and the circuit itself is included. Devices such as disconnectors, circuit-breakers and transformer tap changers which can actually perform the control or protection action are excluded from this subcategory.

The "DC control and protection equipment" category is divided into three subcategories described in 4.4.2 to 4.4.4.

4.4.2 Local control and protection (C-P.L)

Loss of converter station capacity due to any failure of the control, protection or monitoring equipment of the local HVDC station is to be assigned to this subcategory. Examples would include failures of the converter firing control, current and voltage regulators, converter and DC yard protections, valve control and protection, and local station control sequences.

4.4.3 Master control and protection (C-P.M)

Loss of converter station capacity due to any failure of the master control equipment is to be assigned to this subcategory. The master control equipment usually includes bipolar control, inter-station coordination of current and voltage orders, inter-station sequences, auxiliary controls such as damping controls or higher level controls such as run-back/run-up, power control or frequency control.

4.4.4 Telecommunication equipment (C-P.T)

Loss of converter station capacity due to any failure of the equipment provided for the coding of control and indication information to be sent over a telecommunication circuit as well as the telecommunication circuit itself, for example, optical communication, microwave or PLC, is to be assigned to this subcategory.

NOTE The earth wire itself, when optical fibre is integrated with such wire, is included in 4.7.

4.5 Primary DC equipment (DC-E)

4.5.1 General

This major category covers all equipment at the HVDC substations except for that in the three categories "AC and auxiliary equipment" which includes converter/interface transformers, "valves" and "DC control and protection equipment".

The "primary DC equipment" category is divided into seven subcategories presented in 4.5.2 to 4.5.8.

4.5.2 DC filters (DC-E.F)

Loss of converter station capacity due to failure of shunt/series DC filters (active and/or passive) or DC-side PLC/RI filters is to be assigned to this subcategory. Types of components included in this subcategory are capacitors, reactors, resistors, CTs and arresters, etc., which comprise the DC filtering of the converter station.

4.5.3 DC smoothing reactors (DC-E.SR)

Loss of converter station capacity due to failure of the DC smoothing reactors is to be assigned to this subcategory.

4.5.4 DC switching equipment (DC-E.SW)

Loss of converter station capacity due to failure of any DC circuit breakers, DC commutating switches, DC disconnect switches, isolating switches, by-pass switches or earthing switches is to be assigned to this subcategory.

Components forming active/passive circuits for any commutating switch/breaker are also to be included under this subcategory.

4.5.5 DC measuring equipment (DC-E.ME)

Loss of converter station capacity due to failure of the direct current and voltage measuring devices is to be assigned to this subcategory.

4.5.6 DC earth electrode (DC-E.GE)

Loss of converter station capacity due to problems with or failure of the earth electrode and its local termination or connecting equipment is to be assigned to this subcategory.

This covers all types of electrode arrangements for example land, shore, sea type.

NOTE Earth electrodes are also called ground electrodes.

4.5.7 DC earth electrode line (DC-E.EL)

Loss of converter station capacity due to failure of the earth electrode line or cable is to be assigned to this subcategory.

4.5.8 Other DC switchyard and valve hall equipment (DC-E.O)

Loss of converter station capacity due to failure of other DC switchyard and valve hall equipment is to be assigned to this subcategory. This subcategory includes valve arresters and other DC-side surge arresters, bus-work insulators and wall bushings.

NOTE Arresters within filters are excluded from this subcategory, as those are included in 4.5.2.

4.6 Other (O)

Loss of converter station capacity or extension of outage duration due to human error, administrative delays or unknown causes is to be assigned to this category. If, after an outage due to an event in another category, the outage duration is extended due to human error in maintenance, or to operation or administrative delays, the consequential extension in outage time is to be assigned to this category.

4.7 DC transmission line (TL)

4.7.1 General

Loss of transmission capacity due to faults on the DC transmission line, which can be overhead, underground or submarine cables, is to be assigned to this category. Only permanent DC line faults are classified as forced outages, whereas successful automatic restarts after a DC line fault are excluded.

When a dedicated metallic (conductor) return (DMR) is used instead of electrode lines and electrode arrangement, such DMR is to be considered under this category.

It should be ensured that same outage in not reported twice when reporting is made on a station basis.

NOTE Outage due to false operation of the line protection is not included in this category.

The "DC transmission line" category is divided into two subcategories described in 4.7.2 and 4.7.3.

4.7.2 DC overhead transmission line (TL-OH)

Loss of transmission capacity due to any faults on the DC overhead transmission line is to be assigned to this subcategory.

4.7.3 DC underground/submarine cable (TL-C)

Loss of transmission capacity due to faults on the underground or submarine cable or cable terminal is to be assigned to this subcategory. This category covers auxiliaries associated with oil-filled cables.

NOTE Outages due to cable bushings as well all equipment in cable terminal/OH line-cable transition stations are included under this category.

4.8 External (EXT)

Loss of transmission capacity due to faults or events in the AC network external to the converter station is to be assigned to this category. Examples include AC network instability, AC over-voltage in excess of the converter protective rating, short-circuit level lower than the minimum design level, loss of AC outlet line(s) or loss of generation, etc.

Loss of transmission capacity due to events (including natural disasters) or operating conditions beyond specified design considerations is also to be assigned to this category. Examples include higher ambient temperature or higher pollution than the maximum specified design levels, etc.

5 Classification and severity of fault events and restoration codes

5.1 Classification of fault events

Fault events are classified according to the converter equipment classification given in Clause 4 and summarized in Table 1:

Table 1 – Classification of fault events

Fault classification	Outage category and subcategory codes
AC and auxiliary equipment	AC-E
AC filter and other reactive power equipment	AC-E.F
AC control and protection	AC-E.CP
Converter/interface transformer	AC-E.TX
Synchronous compensator	AC-E.SC
Auxiliary equipment and auxiliary power	AC-E.AX
Other AC switchyard equipment	AC-E.SW
Valves	V
Valve electrical	V.E
Valve cooling (integral to valve)	V.VC
Valve capacitor	V.C
Phase reactor	V.PR
DC control and protection equipment	C-P
Local control and protection	C-P.L
Master control and protection	C-P.M
Telecommunication equipment	C-P.T
Primary DC equipment	DC-E
DC filters	DC-E.F
DC smoothing reactor	DC-E.SR
DC switching equipment	DC-E.SW
DC measuring equipment	DC-E.ME
DC earth electrode	DC-E.GE
DC earth electrode line	DC-E.EL
Other DC switchyard and valve hall equipment	DC-E.O
Other	O
DC transmission line	TL
DC overhead transmission line	TL-OH
DC underground/submarine cable	TL-C
External	EXT

5.2 Severity codes

Each forced outage is classified according to an outage severity code as follows:

BP bipolar total outage

P monopolar total outage

C converter total outage

RP other capacity reduction

For reporting purposes, bipolar outage is one in which both poles are lost as a direct or immediate consequence of a single event. Since such bipole outages are of special significance, it is advised to include a narrative discussion of every bipole outage in the discussion section of the report. The discussion should indicate whether both poles tripped simultaneously, and if not, the sequence of events involved.

Overlapping pole outages due to different events or with a prior outage of the other pole should be reported as separate pole outages, not as a bipole outage. A converter or valve group is the smallest switchable operating unit of capacity in the converter station. Overlapping converter outages in the same pole due to different events or with prior outages of another converter should be reported as two separate converter outages rather than as a pole outage.

For converter stations not having series or parallel connected converters, the converter category does not apply. For converter stations having only a single DC circuit or monopole, the bipole category does not apply. If an outage affects multiple bipoles, each bipole should be reported separately but the event should be described in the annual report.

Failures or outages of redundant equipment which do not result in a loss of converter capacity are not reported.

5.3 Restoration codes

Each outage is classified according to a restoration code as follows:

R equipment causing outage is repaired or adjusted

S failed equipment is replaced by spare

M no equipment failure, manual restart

6 Instructions for compilation of report

6.1 General

It is recommended that a report on the operational performance of each HVDC power transmission system or back-to-back interconnection in commercial service be prepared for each year. These reports are to be made in accordance with this document to ensure uniformity and comparability of the data. From time to time older systems, for which further data is judged to be of only marginal value, can be specifically excluded from the reporting. For an established system, the reporting period is to be from January to December. For a system in its initial calendar year of commercial operation, the report is to cover the period from the start of commercial operation to December of that year.

6.2 General instructions

The blank tables given in this document, completed in accordance with these instructions, will form the basis of each annual report. It is recognized that these blank tables may not suit exactly each and every HVDC station/system, but since the comparison of performance of different HVDC systems is a central purpose of the evaluation and reporting, it is recommended that the standard blank tables be used throughout.

It is recommended that the tables include an explanation of the major contributions of the unavailability.

The presentation of information or clarification of the data in the tables is to be considered under the following topics:

a) Utilization: State the reason for exceptionally high or low figures, for example, low generator availability.

b) Availability: Elaborate on major or abnormal factors influencing availability, for example, special maintenance requirements, expansion or upgrade of equipment.

c) Reliability: Give reasons behind exceptionally high outage rates, for example, repetitive outages due to an intermittent control problem difficult to find and not initially corrected.

d) Severity of outage: Comment on the relative frequency of valve group, pole or bipole outages. Elaborate on major outages especially bipolar outages.

NOTE An example of tables that have been filled out is shown in Annex B for information.

6.3 Instructions for Table 2 and Table 3

6.3.1 Section 1

For reporting as a combined system, for a back-to-back system, and for a two-terminal system, complete lines 1.1 and 1.2 with the HVDC substation names so as to indicate the direction of the energy flow and give the total energy in each direction in GWh. In the case of an HVDC back-to-back system, identify the direction of energy flow by using the names of the AC systems so connected. In the case of converters operating in a multi-terminal system or in a two-terminal system which is reporting separately, record station energy for both rectifier and inverter operation by completing one Table 3 for each station.

6.3.2 Section 2

Calculate the percentage of energy utilization (EU) in accordance with the formula given in 3.5.3 and complete the line. For two-terminal systems, the preferred method of energy utilization is calculation based on a system basis whereas for multi-terminal systems, energy utilization is calculated and reported separately for each converter station.

6.3.3 Sections 3, 4 and 5

In order to calculate the availability and unavailability for these sections, it is necessary to maintain a log of outages through the year. The system log can most conveniently be prepared by first preparing separate logs for each HVDC substation and for the transmission line. For two-terminal systems, these separate logs can then be merged into a single combined log for the system which eliminates the effects of concurrent outages. For multi-terminal systems or two-terminal systems reporting separately, no combination of station outages is to be made. Care should be taken, however, that outages due to other stations are correctly assigned without duplication, including DC line faults.

An example of a typical log is given in Annex A for information only. The completed log need not be submitted as part of the annual report.

The rules set out here are to be applied when preparing the log and subsequently calculating the availability and unavailability:

a) Record all outages in the log that cause a reduction in system capacity below the rated capacity.

b) Indicate if the outage involves a total converter (valve group), a total pole, or a total bipole or other capacity reduction by supplying the appropriate severity code as described in 5.2.

c) Classify each outage as either a scheduled or a forced outage. For each scheduled outage record if the outage is scheduled according to the definition given in 3.1.2.

d) For each forced outage or scheduled outage, determine the primary cause of the outage and select the most appropriate category from the seven major equipment and fault categories and associated subcategories given in Clause 4. All equipment in the HVDC system is included uniquely in one of these categories and subcategories.

e) For each outage determine the outage derating factor (ODF) as per 3.2.3. Calculate the equivalent outage duration (EOD) of each outage (3.3.2).

f) If during a forced outage, an opportunity is taken to carry out some repair or maintenance that would otherwise be done during the next scheduled outage, record this as a scheduled outage with its own outage reference number. Record the equivalent outage duration (EOD) as zero, however, unless this scheduled outage increases the outage derating factor above that caused by the forced outage, or extends in time beyond the end of the forced outage. Should either of these events occur, calculate the outage derating factor and equivalent outage duration attributable to the scheduled outage (see Clause A.2).

g) If during a forced outage a further forced outage occurs, record the new outage also. When determining the equivalent outage duration (EOD) of the new outage take into account only the extent to which the new outage increases the outage derating factor or extends in time the pre-existing outage (see Clause A.3).

At the end of the year when the outage log is complete, proceed as follows to calculate the numerical data required to complete sections 3, 4 and 5 of Table 2 or Table 3.

1) Step 1: Group the outages into scheduled and forced. Group the forced outages according to the major outage categories and severity codes.
2) Step 2: Total the equivalent scheduled outage durations (ESOD) to obtain the equivalent scheduled outage hours (ESOH). Calculate the energy unavailability due to scheduled outages (3.5.1) and complete line 4.1.
3) Step 3: Total the equivalent forced outage durations (EFOD) to obtain the equivalent forced outage hours (EFOH). Calculate the energy unavailability due to forced outages (3.5.1) and complete line 4.2. Break down the equivalent forced outage hours and forced energy unavailability into those due to HVDC substations and those due to the DC transmission line and complete lines 4.21 and 4.22.
4) Step 4: Add the energy unavailability percentage due to scheduled outages (line 4.1) to that for forced outages (line 4.2) and subtract from 100 to obtain the energy availability percentage and complete section 3.
5) Step 5: Record the number of forced outage events in each of the seven classification and fault categories. Likewise total the equivalent forced outage durations (EFOD) for each of the seven categories to obtain the equivalent forced outage hours (EFOH) for each category. Record values in lines 5.11 to 5.15 and lines 5.2 and 5.3.
6) Step 6: Total the number of events and equivalent outage hours for categories AC-E, V, C-P, DC-E and O (lines 5.11 to 5.15) to obtain the number of events and equivalent outage hours for line 5.1 HVDC substations.

6.3.4 Section 6

Transfer the number of commutation failure starts CFS(A) and recordable AC faults from Table 4 to complete line 6. For VSC stations/systems, write “Not applicable”.

6.3.5 Section 7

Record the number of forced outage events in each of the four severity codes. Compute the forced energy unavailabilities for each of the severity codes. The forced energy unavailabilities are calculated in accordance with 3.5.1 using the equivalent forced outage hours in Table 6 for each of the severity codes. Only the outage time due to the HVDC substations and DC line are to be used. Outages due to external causes (4.8) such as external AC systems are to be excluded. Total the number of events and the forced energy unavailabilities to complete section 7. The total FEU should equal the value on line 4.2.

Table 2 – DC system performance for back-to-back systems and for two-terminal systems reporting jointly (corresponding to Table 1 of Cigré TB 590:2014)

System ______________________

Year ______________________

1. Energy transmitted (GWh)			
1.1 From: ______________ To: ___________________________			
1.2 From: ______________ To: ___________________________			
1.3 Total			
2. Energy utilization (%)	P_m = MW U		
3. Energy availability (%)	EA		
4. Energy unavailability (%) due to:			
4.1 Scheduled outages	SEU		
4.11 Deferred	SEUD		
4.12 Planned	SEUP		
4.2 Forced outages	FEU		
4.21 HVDC substations	FEUS		
4.22 DC transmission line [a]	FEUTL		
5. Forced outages due to:		Number of events	Equiv. outage hours
5.1 HVDC substations	SS		
5.11 AC and auxiliary equipment	AC-E		
5.12 Valves	V		
5.13 HVDC control and protection equip.	C-P		
5.14 Primary DC equipment	DC-E		
5.15 Other	O		
5.2 DC transmission line [a]	TL		
5.3 External [b]	EXT		
6. Commutation failure starts CFS(A) / recordable AC faults [c]			

7. Forced outage severity	Capacity reduction		Converter		Pole		Bipole		Total	
	Number of events	Forced energy unavail.	Number of events	Forced energy unavail.	Number of events	Forced energy unavail.	Number of events	Forced energy unavail.	Number of events	Forced energy unavail.

[a] Not applicable for back-to-back systems.

[b] Not included in unavailability.

[c] Not applicable for VSC systems.

Table 3 – DC system performance for multi-terminal systems and for stations reporting separately as part of two-terminal systems (corresponding to Table 1 M/S of Cigré TB 590:2014)

System ____________________

Station ____________________

Year ____________________

1. Energy transmitted (GWh)				
1.1 As rectifier				
1.2 As inverter				
1.3 Total				
2. Energy utilization (%)	P_m =	MW		
	U			
3. Energy availability (%)	EA			
4. Energy unavailability (%) due to:				
4.1 Scheduled outages	SEU			
4.11 Deferred	SEUD			
4.12 Planned	SEUP			
4.2 Forced outages	FEU			
4.21 HVDC substations	FEUS			
4.22 DC transmission line [a]	FEUTL			
5. Forced outages due to:			Number of events	Equiv. outage hours
5.1 HVDC substations	SS			
5.11 AC and auxiliary equipment	AC-E			
5.12 Valves	V			
5.13HVDC control and protection equip.	C-P			
5.14 Primary DC equipment	DC-E			
5.15 Other	O			
5.2 DC transmission line [a]	TL			
5.3 External [b]	EXT			
6. Commutation failure starts CFS(A) / recordable AC faults [c]				

7. Forced outage severity	Capacity reduction		Converter		Pole		Bipole		Total	
	Number of events	Forced energy unavail.	Number of events	Forced energy unavail.	Number of events	Forced energy unavail.	Number of events	Forced energy unavail.	Number of events	Forced energy unavail.

[a] Ensure DC Line outages have been allotted only once.

[b] Not included in unavailability.

[c] Not applicable for VSC systems.

6.4 Instructions for Table 4 and Table 5

6.4.1 Forced outages – Table 4

Record details of all forced outages that cause a reduction in rated capacity. The log used to compile Table 2 data can additionally provide the input for Table 4. Annex A gives an example of this.

For two-terminal systems, either a common table for both stations or separate tables for each station can be provided as long as the same outage is not reported twice. For multi-terminal systems, separate tables are to be provided for each station.

1) Step 1: For each forced outage determine which of the equipment and fault category codes and subcodes apply. Record the code and subcode in the first column. Record the severity code (5.2) and percentage capacity reduction.
2) Step 2: Identify the failed equipment by a brief description, for example the code and subcode can be AC-E.AX while the description could be auxiliary power transformer. Record the forced outage type after the description (e.g. delayed deblock (DD), ramped down and blocked (RB), reduction in MW (RE), stopped ramp (SR), automatic trip (TR)).
3) Step 3: Record the actual outage duration and restoration code (5.3) to indicate the corrective measure for example was repair (R) or replacement by a spare (S).

6.4.2 Scheduled outages – Table 5

Record details of all scheduled outages that cause a reduction in rated capacity. The log used to compile Table 2 data can additionally provide the input for Table 5. If the scheduled outage can be attributed to a certain category of equipment, supply the appropriate outage code. For two-terminal systems, either a common table for both stations or separate tables for each station can be provided as long as the same outage is not reported twice. For multi-terminal systems, separate tables are to be provided for each station.

1) Step 1: Record the code and subcode in the first column. Record the severity code (5.2) and percentage capacity reduction.
2) Step 2: Identify the maintained equipment by a brief description, for example the code can be AC-E.TX, while the description could be converter transformer failed bushing. If the outage is for a planned maintenance program, use the code “PM”.
3) Step 3: Record the actual outage duration and restoration code (5.3) to indicate the corrective measure for example was repair (R) or replacement by a spare (S).

Table 4 – Forced outages of HVDC substation (corresponding to Table 2FS of Cigré TB 590:2014)

System ____________

Station ____________

Year ____________

Forced outages due to:	Outage code:	Severity code:		Restoration code:	
AC and auxiliary equipment	AC-E.X	Bipolar	BP	Repaired	R
Valves	V.X	Monopolar	P	Replaced by spare	S
DC control and protection equip.	C-P.X	Converter	C	Manually restored	M
Primary DC equipment	DC-E.X	Capacity reduction	RP		
Other	O.X				

Outage code	**Event or equipment failure description**	**Severity code**	**Restoration code**	**Actual outage duration** AOD (h)	**Reduction of capacity** (%)

NOTE See Table 1 for outage code sub-classification.

Outage type examples are:

DD – delayed deblock

RB – ramped down and blocked

RE – reduction in MW

SR – stopped ramp

TR – automatic trip

Table 5 – Scheduled outages of HVDC substation (corresponding to Table 2 SS of Cigré TB 590:2014)

System ____________

Station ____________

Year ____________

Scheduled outages due to:	Outage code:	Severity code:		Restoration code:	
AC and auxiliary equipment	AC-E.X	Bipolar	BP	Repaired	R
Valves	V.X	Monopolar	P	Replaced by spare	S
DC control and protection equip.	C-P.X	Converter	C	Manually restored	M
Primary DC equipment	DC-E.X	Capacity reduction	RP		
Other	O.X				
Planned maintenance	PM				

Outage code	**Event or equipment failure description**	**Severity code**	**Restoration code**	**Actual outage duration** AOD (h)	**Reduction of capacity** (%)

NOTE See Table 1 for outage code sub-classification.

6.5 Instructions for Table 6

If the HVDC system includes one or more HVDC overhead line sections, and line protection is arranged to initiate auto-restart perhaps at a lower pole operating voltage, for occurrences such as pollution or lightning induced flashovers, complete Table 6 as follows:

1) Step 1: Give each line protection event a unique number and record this together with the date and time using the 24-h clock. Treat repeated operations of the protection within the reset time, usually some tens of seconds, as one event.
2) Step 2: Record the actual steady operating voltage and polarity, disregarding transients, of the affected pole immediately prior to the protection operation.
3) Step 3: Complete the event entry with the number of automatically attempted restart sequences, and whether or not the final automatic restart is successful. If the restart is unsuccessful, record the actual outage time. Give in a note any available information relevant to the cause of the protection operation and subsequent restoration if successful. If the DC system is multi-terminal, indicate any automatic sectionalizing that takes place.

Table 6 – HVDC overhead line protection operations (corresponding to Table 3 of Cigré TB 590:2014)

System ____________________

Year ____________________

Event no.	Date	Time of day	Pole voltage and polarity	Number of attempted restarts	Final restart successful/ unsuccessful	Actual outage duration if unsuccessful	Notes [a]

[a] For example, record whether the restart was successful at reduced voltage, or which line section was affected or whether automatic sectionalizing occurred.

6.6 Instructions for Table 7

Table 7 is not applicable for VSC HVDC systems.

In order to complete Table 7 it is necessary to keep a log at each inverter HVDC substation to record information about AC system faults and any associated commutation failure starts.

NOTE See 3.6.2 if/when another station is applicable.

The rules set out here are to be applied in the preparation of this log:

- Determine whether the AC system fault is recordable or not at the station as defined in 3.6.1.

  When determining whether or not the voltage drops to or below 90 % of the pre-fault voltage, consider only the fundamental voltage, i.e. disregard distortion. Reductions in voltage caused only by phase-to-phase or phase-to-earth faults on the AC system are to be considered.

- Exclude the cases of temporary voltage reduction caused by other means such as normal switching of lines, transformers or reactive compensation, or faulty AC voltage regulating equipment.

For the reporting period complete the table as follows:

1) Step 1: Complete the first column of lines 1.1 and 1.2 with the HVDC substations names. In the case of an HVDC coupling system identify the two sides of the coupling by the names of the AC systems so coupled. For a multi-terminal system, record the data for each station.
2) Step 2: Count the number of recordable AC system faults during inverter operation at each HVDC substation and record the separate totals.
3) Step 3: Count the number of commutation failure starts, CFS(A), as defined in 3.6.2. A CFS can be determined by automatic recording for each converter unit or by inspection of the oscillographic records, but no more than one CFS(A) is to be attributed to each AC system fault.
4) Step 4: Count the number of commutation failure starts, CFS(B), as defined in 3.6.3.

Table 7 – AC system faults and commutation failure starts (back-to-back, two-terminal or multi-terminal LCC systems) (corresponding to Table 4 of Cigré TB 590:2014)

System ____________

Year ____________

	Number of AC recordable system faults at inverter	Number of CFS(A)	Number of CFS(B)
1.1 HVDC substation A:			
1.2 HVDC substation B:			
1.3 HVDC substation C:			
1.4 HVDC substation D:			
1.5 HVDC substation E:			
2. Complete HVDC system			

CFS(A) – Commutation failure starts initiated by AC system faults (see 3.6.2).

CFS(B) – Commutation failure starts initiated by control problems, switching events or other causes (see 3.6.3).

6.7 Instructions for Table 8

For the reporting period complete Table 8 as follows:

1) Step 1: Complete the first column by listing separately the converter units at both HVDC substations or both sides in the case of coupling systems (for example 1, 2, 3 and 4, or Pole 1 Norway, Pole 2 Norway, Pole 1 Denmark, Pole 2 Denmark).
2) Step 2: For each converter unit record whether it is a six- or twelve-pulse converter unit for LCC HVDC systems and the converter topology for VSC HVDC systems, such as symmetric monopole, asymmetric monopole, MMC, etc.
3) Step 3: Record the hours during which each converter unit is available, irrespective of whether there is transmitting power or not.
4) Step 4: Record the number of semiconductor devices that failed in each converter unit. To provide uniformity in reporting, all failure modes of a semiconductor device due to any cause are to be recorded.

If two or more semiconductor devices are used in parallel in a valve, record the short-circuiting of the parallel connected semiconductor devices as a single failure. For example, when two or more semiconductor devices are used in parallel within a valve, record the short-circuiting of the parallel semiconductor devices as a single failure even though two or more of the semiconductor devices have in fact failed.

Table 8 – Converter unit hours and semiconductor devices that failed (corresponding to Table 5 of Cigré TB 590:2014)

System ____________________

Year ____________________

Converter unit reference [a]	Six- or twelve-pulse or VSC topology	Hours available	Number of semiconductor devices that failed [b]
	Totals:		

[a] Converter unit reference refers to station, pole or converter, according to 6.7.

[b] See 6.7, step 4.

6.8 Instructions for Table 9

Table 9 summarizes the information contained in Table 4. All forced outages are summed up by outage classification and by sub-classification as well as by severity code. Completion of Table 9 is an intermediate step in preparation for filling out Table 2 or Table 3.

7 Interpretation and evaluation of reports

7.1 Calculation of outage duration

Reported outage time should be the calendar time during which the DC system or station is not available. The maintenance or forced outages often span several working days, possibly including weekends. The purpose of recording scheduled outage time is to develop a database indicating the actual maintenance time. Therefore, clarification is needed on how “non-working” time is to be considered. If the system is made available but not operated during a portion of the non-working time or can be made available if required to be operated, for example on a weekend, then such time should be excluded from the scheduled outage time. The key to computation of chargeable scheduled outage time is not whether or not work is performed, but whether or not the system is or can be available for operation.

In some cases, outage duration can be longer than would normally be required. For example, there can be a period of low demand during which there is no economic loss due to unavailability of the DC link. This can allow the annual maintenance to be conducted on a more leisurely basis. Other examples could be inclement weather causing delay in accessibility for maintenance or non-availability of required spares, needed tools and tackles or manpower at hand. Such extenuating circumstances should be noted in the discussion section of the report.

Similarly, lack of DC transmission resulting from the scheduled outage of a generating plant which supplies the DC link should not be recorded as an outage of the DC system, provided that the DC system remains available for service. If maintenance is conducted on the DC link during such times, then the maintenance time should be reported as scheduled outage time.

7.2 External events

Events external to the HVDC system which result in interruption of HVDC power transmission are not to be considered as outages of the DC system as long as the DC system operates as designed and is available for service after the event is over. For example, if the AC lines feeding the DC link open due to faults or if the AC system hosting the DC link goes unstable, the outage time is not recordable.

7.3 Protective operation

Transient faults which are successfully cleared by correct operation of protection equipment do not constitute outages and should not be recorded in Table 4. Incorrect operation of protection equipment, either operation when not intended (false trip) or failure to automatically restart, would be reported as an outage, regardless of duration. Interruptions which require manual restart should be counted as forced outages if the system is designed to recover from such events.

7.4 Performance of special controls

A number of DC systems are equipped with special supplementary controls, such as frequency control, damping control or runback, to help support the AC system. It is encouraged to include narrative comments regarding any significant positive or negative system aspects due to operation of such controls at the bottom of Table 4.

Operation of special controls when it operates to support the AC system is not to be counted as DC forced outage but is to be recorded as forced external AC outage.

Table 9 – Forced outage summary
(corresponding to Table 6 of Cigré TB 590:2014)

System: ____________________________ Station: ______________________________ Year:_________________

FORCED OUTAGE due to	Outage code	Capacity reduction			Converter			Pole			Bipole			Total	
		Number of events	Actual outage hours	Equiv. outage hours	Number of events	Actual outage hours	Equiv. outage hours	Number of events	Actual outage hours	Equiv. Outage hours	Number of events	Actual outage hours	Equiv. outage hours	Number of events	Equiv. outage hours
AC filter and other RP equipment	AC-E.F														
AC control and protection	AC-E.CP														
Converter/interface transformer	AC-E.TX														
Synchronous compensator	AC-E.SC														
Aux. equipment and auxiliary power	AC-E.AX														
Other AC switchyard equipment	AC-E.SW														
Total AC and auxiliary equipment	AC-E														
Valve electrical	V.E														
Valve cooling	V.VC														
Valve capacitor	V.C														
Phase reactor	V.PR														
Total valve	V														
Local control and protection	C-P.L														
Master control and protection	C-P.M														
Telecommunication equipment[a]	C-P.T														
Total DC C and P equipment	C-P														
DC filters [a]	DC-E.F														
DC smoothing reactor	DC-E.SR														
DC switching equipment	DC-E.SW														

FORCED OUTAGE due to	Outage code	Capacity reduction			Converter			Pole			Bipole			Total	
		Number of events	Actual outage hours	Equiv. outage hours	Number of events	Actual outage hours	Equiv. outage hours	Number of events	Actual outage hours	Equiv. Outage hours	Number of events	Actual outage hours	Equiv. outage hours	Number of events	Equiv. outage hours
DC measuring equipment	DC-E.ME														
DC earth electrode [a]	DC-E.GE														
DC earth electrode line [a]	DC-E.EL														
Other DC switchyard and VH equipment	DC-E.O														
Total primary DC equipment	DC-E														
Other	O														
Total HVDC substations	SS														
DC overhead transmission line	TL-OH														
DC underground/submarine cable	TL-C														
Total DC transmission line [a]	TL														
External [b]	EXT														

[a] Not applicable for back-to-back systems.

[b] Not included in unavailability.

Annex A
(informative)

Outage log form and examples

A.1 Example of an outage log

Table A.1 is an example of an outage log.

Table A.1 – Example of an outage log

System: ____________________ Station: ____________________ Year: ____________________

	Outage code [a] Forced:	Scheduled:
Outage due to faulty equipment		
AC and auxiliary equipment	F.AC-E	S.AC-E
Valves	F.V	S.V
DC control and protection equipment	F.C-P	S.C-P
Primary DC equipment	F.DC-E	S.DC-E
Other	F.O	S.O
DC transmission line	F.TL	S.TL
External	F.EXT	
Scheduled outage for planned maintenance		S.PM

Outage reference number	Date and time		Actual outage duration (AOD)	Outage derating factor (ODF)	Equivalent outage duration (EOD)	Outage code [a]	Severity code BP, P, C, RP	Description of event, equipment or component causing outage	Restoration code R, S, M
	Start	Finish							

[a] See 5.1 for outage code sub-classification for forced or for deferred scheduled outages.

Care is to be taken not to report the same outage twice. Therefore, only record an outage code for outages caused by the respective station. If the outage is caused by a remote station and leads to a consequential outage of the local station, the outage should be charged to the remote station. Exclude outages caused by remote stations in the preparation of Table 2 for the local station.

For single non-overlapping outages having a constant outage derating factor, complete the log as follows:

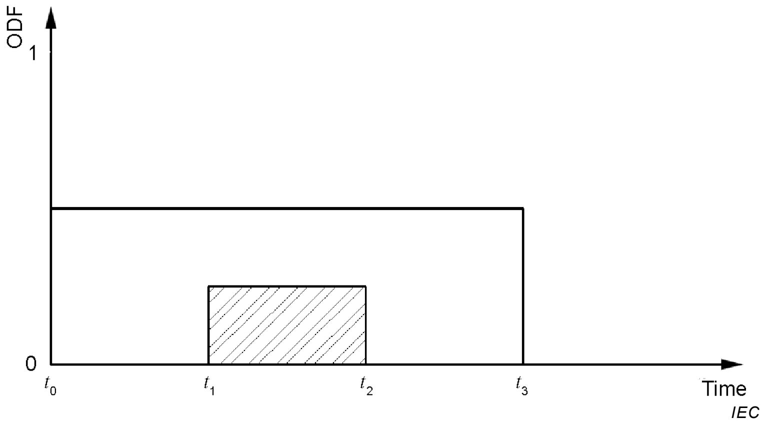
1) Step 1: Assign the outage reference number. This is a unique number given to each outage event at the start of the outage.
2) Step 2: Record the date and time at the start of the outage and subsequently the date and time at the end of the outage. Record times to the nearest minute using the 24-h clock.
3) Step 3: Determine and record the main cause of the outage using only one of the outage codes given at the head of the form. For forced outages and for deferred scheduled outages extend the outage code by appending the outage sub-classification from 5.1. For example, the primary cause of the outage can be indicated by “F.AC-E.AX” indicating a forced outage caused by AC equipment in the station auxiliaries.
4) Step 4: Calculate and record the actual outage duration (AOD) which is the time elapsed between the start and end of the outage in accordance with 3.3.1.
5) Step 5: Describe the event, equipment or component causing the outage.
6) Step 6: Determine and record the restoration code to indicate if the restoration required equipment repair (R), replacement by spare (S) or just a manual restart (M).
7) Step 7: Determine and record the outage derating factor (ODF) in accordance with 3.2.3.
8) Step 8: Calculate and record the equivalent outage duration (EOD) which is the product AOD × ODF in accordance with 3.3.2.

For single non-overlapping outages having a variable outage derating factor and for overlapping outages, additional information is to be recorded in order to calculate the correct EOD.

A.2 Examples of application of rule f) of 6.3.3 – Scheduled outage during a forced outage

A.2.1 Case 1: Scheduled outage does not increase ODF or extends outage duration

Figure A.1 shows an example where scheduled outage does not increase ODF or extends outage duration.



t_0 forced outage due to AC-E starts ODF = 0,5

t_1 scheduled outage starts ODF = 0,25

t_2 scheduled outage ends

t_3 forced outage ends

AOD = $t_3 - t_0$

ODF = 0,5

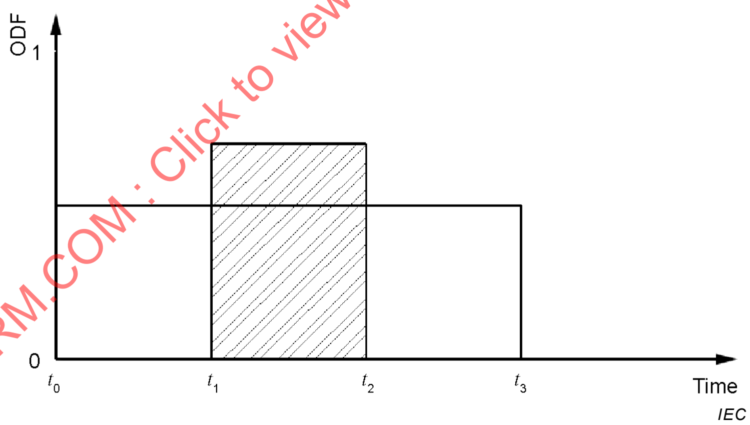
EOD due to AC-E = 0,5 ($t_3 - t_0$)

Scheduled outage does not contribute to unavailability.

Figure A.1 – Scheduled outage does not increase ODF or extends outage duration

A.2.2 Case 2: Scheduled outage increases ODF

Figure A.2 shows an example where a scheduled outage increases ODF.



t_0 forced outage due to TL starts

t_1 scheduled outage starts

t_2 scheduled outage ends

t_3 forced outage ends

AOD due to TL = $t_3 - t_0$

ODF due to TL = 0,5

EOD due to TL = 0,5 ($t_3 - t_0$)

AOD due to scheduled outage = $t_2 - t_1$

Excess ODF due to scheduled outage = 0,75 – 0,5 = 0,25

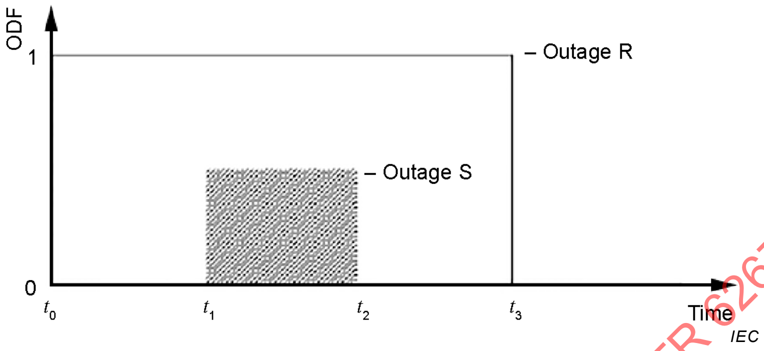
Scheduled outage contributes to unavailability.

Figure A.2 – Scheduled outage increases ODF

A.3 Examples of application of rule g) of 6.3.3 – Second outage during an outage

A.3.1 Case 1: Second outage does not increase ODF or extends outage duration

Figure A.3 shows an example where a second outage does not increase ODF or extends outage duration.



t_0 forced outage due to TL starts – outage reference R ODF = 1,0

t_1 forced outage due to DC-E starts – outage reference S ODF = 0,5

t_2 forced outage due to DC-E ends

t_3 forced outage due to TL ends

AOD due to TL = $t_3 - t_0$

ODF due to TL = 1,0

EOD due to TL = 1,0 ($t_3 - t_0$)

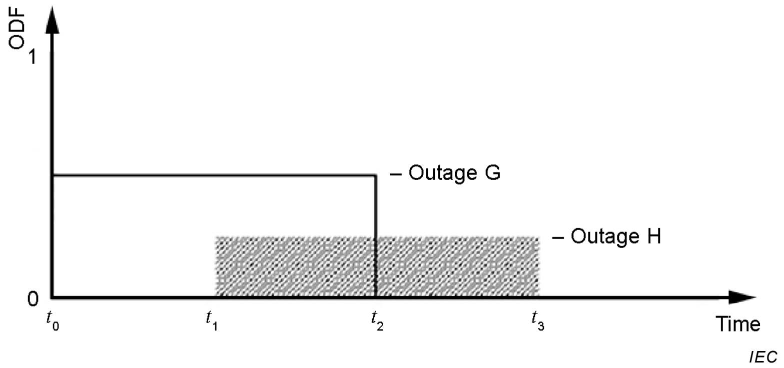
Outage reference R is counted in the total number of events attributable to TL.

Outage due to DC-E does not increase ODF and so the EOD = 0. Since EOD is zero, outage reference S is not counted in the total number of events attributable to DC-E.

Figure A.3 – Second outage does not increase ODF or extends outage duration

A.3.2 Case 2: Second outage extends duration

Figure A.4 shows an example where a second outage extends duration.



t_0	forced outage due to AC-E starts – outage reference G	ODF = 0,5
t_1	forced outage due to another event AC-E starts – outage reference H	ODF = 0,25
t_2	forced outage – reference G ends	
t_3	forced outage – reference H ends	

AOD due to AC-E reference G = $t_2 - t_0$

ODF for outage reference G = 0,5

EOD due to AC-E reference G = 0,5 ($t_2 - t_0$)

AOD due to AC-E reference H = $t_3 - t_1$, but period t_1 to t_2 already accounted for so effectively it is taken as = $t_3 - t_2$.

ODF due to outage reference H = 0,25

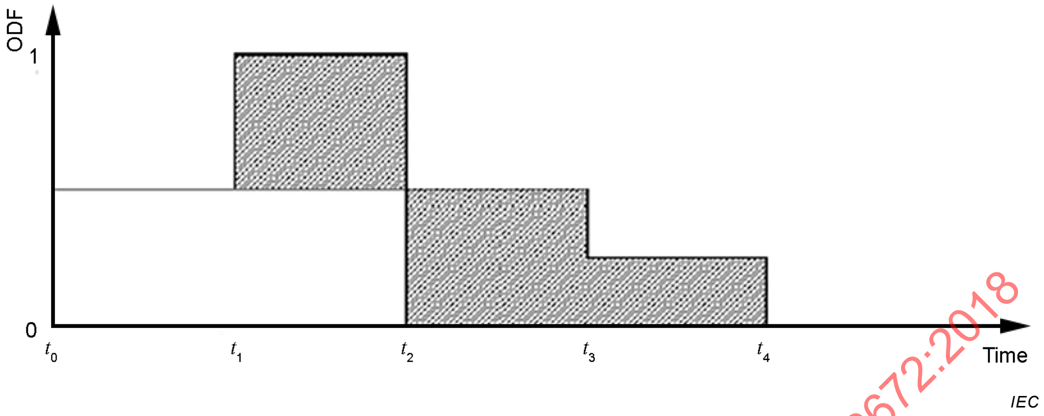
EOD due to AC-E reference H = 0,25 ($t_3 - t_2$)

Since both outages are category AC-E and both EODs are non-zero, 2 is added to the total number of AC-E events by these two outages.

Figure A.4 – Second outage extends duration

A.3.3 Case 3: Second outage with variable ODF

Figure A.5 shows an example of a second outage with variable ODF.



t_0	forced outage due to V starts	ODF = 0,5
t_1	forced outage due to AC-E starts	ODF = 0,5
t_2	forced outage due to V ends	
t_3	forced outage due to AC-E changes ODF	ODF = 0,25
t_4	forced outage due to AC-E ends	

This type of outage diagram occurs when the second outage takes out of service equipment not affected by the first outage.

EOD due to V = 0,5 ($t_2 - t_0$)

EOD due to AC-E = 0,5 ($t_3 - t_1$) + 0,25 ($t_4 - t_3$)

Figure A.5 – Second outage with variable ODF