IEC 60700-3

Edition 1.0 2022-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Thyristor valves for high voltage direct current (HVDC) power transmission –
Part 3: Essential ratings (limiting values) and characteristics**

**Valves à thyristors pour le transport d'énergie en courant continu à haute tension (CCHT) –
Partie 3: Valeurs assignées (valeurs limites) et caractéristiques essentielles**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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IEC 60700-3 has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronic systems and equipment. It is an International Standard.

The text of this International Standard is based on the following documents:

Draft	Report on voting
22F/667/CDV	22F/686/RVC

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 60700 series, published under the general title *Thyristor valves for high voltage direct current (HVDC) power transmission*, can be found on the IEC website.

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- withdrawn,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

THYRISTOR VALVES FOR HIGH VOLTAGE DIRECT CURRENT (HVDC) POWER TRANSMISSION –

Part 3: Essential ratings (limiting values) and characteristics

1 Scope

This part of IEC 60700 specifies the service conditions, the definitions of essential ratings and characteristics of thyristor valves utilized in line commutated converters with three-phase bridge connections to realize the conversion from AC to DC and vice versa for high voltage direct current (HVDC) power transmission applications. It is applicable for air insulated, liquid cooled and indoor thyristor valves.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC 60071-1*, Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60700-1:2015, *Thyristor valves for high voltage direct current (HVDC) power transmission – Part 1: Electrical testing*
IEC 60700-1:2015/AMD1:2021[1]

IEC 60700-2:2016, *Thyristor valves for high voltage direct current (HVDC) power transmission – Part 2: Terminology*

IEC 61803:2020, *Determination of power losses in high-voltage direct current (HVDC) converter stations with line-commutated converters*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

[1] There exists a consolidated edition 1.1 (2021) that comprises IEC 60700-1:2015 and its Amendment 1:2021.

3.2 Symbols and abbreviated terms

3.2.1 General

Clause 3.2 covers only the most frequently used symbols and abbreviated terms related to this document. The documents listed in Clause 2 contain additional symbols and abbreviated terms.

3.2.2 Subscripts

0 (zero)	at no load
i	ideal
N	nominal or rated value
d	direct current or voltage
ac	alternating current or voltage
r	resistive or overvoltage
x	inductive
u	undervoltage
j	thyristor junction
v	valve or valve side of converter transformer
m	multiple valve (unit)
vs	valve support
s	switching impulse or stray
l	lightning impulse
st	steep front impulse
PF	protective firing
RP	recovery protection
T	temporary
S	short term
SC	short circuit
max	maximum
min	minimum
RMS	root mean square
av	average
ar	arrester
DRM	off-state repetitive maximum value
DSM	off-state non-repetitive maximum value
RRM	reverse repetitive maximum value
RSM	reverse non-repetitive maximum value

3.2.3 Letter symbols

α	(trigger/firing) delay angle
γ	extinction angle
μ	(commutation) overlap angle
X_t	commutation circuit reactance, including leakage reactance of converter transformer and other reactance in the commutation circuit which influence commutation process

P_{cu} on-load losses of converter transformer and DC smoothing reactor when a six-pulse bridge is operating at rated load

R_{th} equivalent resistance of the voltage drop of the thyristor valve

f_N rated AC system frequency

t_p valve conduction interval

t_G valve hold-off interval

k_{df} uneven voltage distribution factor, defined as the maximum deviation of the peak voltages of thyristor levels in a valve under the specified type of impulses, representing the degree of uneven voltage distribution due to tolerances of the voltage divider components, stray capacitances and differences in recovery charge of thyristors

3.2.4 Abbreviated terms

MVU multiple valve (unit)

SIPL switching impulse protective level

LIPL lightning impulse protective level

STIPL steep front impulse protective level

4 Service conditions

4.1 General

Thyristor valves shall be able to operate continuously and reliably under the specified service conditions throughout their entire service life except for maintenance periods. Such conditions, as the main input parameters for valve design, are essential to define the ratings and characteristics of the thyristor valves, and should be specified by the purchaser or by the system designer or the supplier as recommended in Annex A. The conditions mainly include the environmental conditions of valve halls under which thyristor valves will be required to operate, system conditions directly related to the design and operation of thyristor valves, main technical parameters of six-pulse bridges required by the system design, and any other conditions provided by the purchaser. Some of these conditions cannot be applicable depending upon the HVDC system design.

4.2 Environmental conditions

4.2.1 Site altitude

The altitude of the HVDC substation above sea-level shall be provided for insulation design of thyristor valves.

For external insulation (as defined in 3.1.3 of IEC 60700-1:2015), the insulation level of thyristor valves under standardized reference atmospheric conditions shall be determined in accordance with 4.2 of IEC 60700-1:2015.

For internal insulation (as defined in 3.1.3 of IEC 60700-1:2015), 8.2 of IEC 60700-1:2015 shall be referred to.

4.2.2 Air temperature and humidity range in valve halls

The maximum temperature and minimum relative humidity inside valve halls shall be considered in the atmospheric correction in accordance with 4.2 of IEC 60700-1:2015. In addition, the air temperature and the relative humidity in the valve hall shall be considered to prevent condensation on any surface of components within the valve hall.

4.2.3 Cleanness in valve halls

The cleanness in valve halls (e.g. equivalent salt deposit density on the surface of insulators and insulating materials) shall be provided for determination of creepage distances of thyristor valves. Dust and pollution in valve halls shall be kept as low as possible to avoid un-economical increase of creepage distances of thyristor valves.

4.2.4 Seismic conditions

Thyristor valves shall have the ability to withstand seismic stresses and to maintain their function without failure during and after an earthquake of any specified intensity possibly occurring at the location of the HVDC substation. Maximum expected horizontal and vertical acceleration along with the frequency range of oscillations shall be provided.

4.3 System conditions

4.3.1 General information of the system

The information shall include at least the following:

a) the purpose of the project,

b) rated power,

c) direction of power flow,

d) converter configuration, including a simple one-line diagram,

e) converter operating modes such as monopolar, bipolar, parallel or multi-terminal, and

f) interface information.

NOTE 1 For long distance HVDC transmission systems, the most commonly used converter unit configuration is one 12-pulse group per pole or two 12-pulse groups in series connection or parallel connection per pole. Each valve group is composed of two series-connected six-pulse bridges that are supplied from three single-phase three-winding transformers or six single-phase two-winding transformers. For more details on converter unit configuration, refer to IEC TR 60919-1.

NOTE 2 The interfaces between the thyristor valves and other components of the system need to be coordinated, including the location and dimensions of points of attachment on the floor of the valve hall or to the roof, dimensions of cable ducts for fibre optic cable, the location and dimensions of the connecting flange for cooling water pipes, and the interfaces to valve-hall buswork.

4.3.2 AC system voltage

The steady state and temporary state AC system voltage ranges shall be specified, including the maximum and minimum steady state voltages under rated operating condition, as well as the maximum and minimum temporary state voltages along with their durations during AC system faults and during the recovery period immediately following fault clearing. The temporary state AC system voltage range will directly affect the voltage ratings of thyristor valves.

4.3.3 AC system frequency

The rated frequency, steady state frequency variation range, temporary state frequency variation range, as well as temporary state extreme frequency variation range shall be specified.

4.3.4 DC system voltage

The rated DC voltage, and the maximum and minimum DC voltages in continuous operation considering control and measurement errors and manufacturing tolerance shall be specified.

If thyristor valves are required to operate continuously with reduced DC voltages, the DC system voltages, along with the operating parameters of the thyristor valves, i.e. valve side winding voltages and firing delay angles under these operating conditions, shall also be provided.

4.3.5 DC system current and overload requirements

The rated DC current and minimum DC currents in continuous operation, as well as the required short term overload and temporary overload DC currents along with their durations shall be specified.

4.3.6 Short circuit current requirements for thyristor valves

For converter units, short circuits can be caused by breakdown of external or internal insulation, i.e. flashover or puncture of insulators, or by inadvertent operation of switches, or from other causes. Usually the most severe fault is a short circuit of the thyristor valve operating in rectifier mode with minimum delay angle and maximum AC system voltage. The maximum peak values of one-loop and multiple-loop short circuit currents, along with their durations and the maximum peak values of re-applied forward voltages and reverse recovery voltages that the thyristor valves are required to withstand, shall be specified.

4.3.7 Insulation coordination design related to thyristor valves

The required overvoltage withstand capability of thyristor valves, as well as the protective levels (residual voltages and coordination currents for specified types of overvoltage) of valve arresters, shall be specified, based on the insulation coordination design of the system.

A typical arrangement for the arresters directly related to the thyristor valves of a station consisting of two series-connected 12-pulse converters per pole is shown in Figure 1. Some of the arresters may be eliminated depending upon the specific design.

For thyristor valve design and test, the required withstand voltages for switching and lightning impulses of the valves between the locations, as shown in Figure 1, shall be specified, including:

a) withstand voltages across a valve,
b) withstand voltages between the upper 12-pulse bridge DC bus and earth,
c) withstand voltages between the upper 12-pulse bridge mid-point DC bus and earth,
d) withstand voltages between the two 12-pulse bridges mid-point DC bus and earth,
e) withstand voltages between the lower 12-pulse bridges mid-point DC bus and earth, and
f) withstand voltages between the neutral bus and earth.

For more details about the insulation coordination design refer to IEC 60071-5.

NOTE Valve arrester design is one unseparated part of thyristor valve design for an optimized converter. Defining the withstand voltages across a valve without considering the interaction between valve and valve arrester always leads to an uneconomic valve.

4.4 Technical parameters for six-pulse bridge design

4.4.1 General

The parameters described in 4.4 are related to converters comprised of six thyristor valves. The values of these parameters shall be considered in the design of thyristor valves.

4.4.2 Voltage parameters

4.4.2.1 Rated DC voltage per converter (U_{dN})

This refers to the mean value of DC voltage between the high voltage and low voltage terminals of a converter (six-pulse bridge) under rated operating condition. It is defined at nominal valve side winding voltage and nominal converter firing delay angle while operating at rated DC current.

4.4.2.2 Nominal ideal no-load DC voltage per converter (U_{di0N})

This refers to the ideal no-load DC voltage of a converter at nominal valve side winding voltage, idealized firing delay and overlap angles equalling zero.

4.4.2.3 Maximum ideal no-load DC voltage per converter (U_{di0max})

This refers to the maximum value of ideal no-load DC voltage of a converter at nominal valve side winding voltage, idealized firing delay and overlap angles equalling zero, taking into account the control and measurement errors and manufacturing tolerance of the system.

4.4.2.4 Minimum ideal no-load DC voltage per converter (U_{di0min})

This refers to the minimum value of ideal no-load DC voltage of a converter at nominal valve side winding voltage, idealized firing and overlap angles equalling zero, taking into account the control and measurement errors and manufacturing tolerance of the system.

4.4.2.5 Temporary overvoltage factor (k_r)

This refers to the factor defined as the ratio of maximum temporary state AC system voltage during AC system faults, such as load rejection, to nominal AC system voltage.

4.4.2.6 Temporary undervoltage factor (k_u)

This refers to the factor defined as the ratio of minimum temporary state AC system voltage during AC system faults, such as single-phase or three-phase short circuits to ground, to nominal AC system voltage.

4.4.3 Current parameters

4.4.3.1 Rated DC current (I_{dN})

This refers to the nominal value of direct current that the system should be able to transmit continuously for all ambient conditions specified and without time limitations.

4.4.3.2 Maximum continuous operating DC current (I_{dmax})

This refers to the maximum value of direct current that the system should be able to transmit continuously without time limitations. The current value may vary under different ambient conditions and different cooling conditions.

4.4.3.3 Minimum continuous operating DC current (I_{dmin})

This refers to the minimum value of direct current that the system should be able to transmit continuously without time limitations. It is defined to avoid the intermittent direct current for steady state operation. A value of 5 % to 10 % of rated DC current is commonly used.

4.4.3.4 Short term overload DC current (I_{dS})

This refers to the maximum value of direct current that the system should be able to transmit under specified short term overload conditions, typically in the time span from minutes up to hours. The current value may vary under different ambient conditions, different durations and different cooling conditions.

4.4.3.5 Temporary overload DC current (I_{dT})

This refers to the maximum value of direct current that the system should be able to transmit under specified temporary overload conditions, typically in the range of seconds.

4.4.4 Valve arrester parameters

4.4.4.1 Crest value of continuous operating voltage (CCOV)

This refers to the highest continuously occurring crest value of the voltage across the arrester excluding commutation overshoots and commutation notches. The continuous operating voltage waveform for the valve and valve arrester is shown in Figure 2. The CCOV is proportional to the maximum ideal no-load DC voltage per converter (U_{di0max}), and is given by Formula (1):

$$\text{CCOV} = \frac{\pi}{3} \cdot U_{di0max} \tag{1}$$

4.4.4.2 Peak value of continuous operating voltage (PCOV)

This refers to the highest continuously occurring peak value of the voltage across the arrester including commutation overshoots and commutation notches.

See Figure 2.

4.4.4.3 Switching impulse protective level of valve arrester ($SIPL_v$)

This refers to the residual arrester voltage for maximum switching current impulse possibly occurring in service.

4.4.4.4 Lightning impulse protective level of valve arrester ($LIPL_v$)

This refers to the residual arrester voltage for maximum lightning current impulse possibly occurring in service.

4.4.4.5 Steep front impulse protective level of valve arrester ($STIPL_v$)

This refers to the residual arrester voltage for maximum steep front current impulse possibly occurring in service.

4.4.4.6 Maximum surge arrester commutation current （I_{ar}）

This refers to the maximum peak value of the surge arrester coordination current that can be flowing in the forward direction at the time the valve turns on. Due to the commutation of the arrester current, the thyristors and their associated electrical circuits shall withstand the maximum turn-on current stress under the specified high voltage conditions.

4.4.5 Other system parameters

4.4.5.1 Rated relative inductive DC voltage drop (d_{xN})

This refers to the maximum and minimum values of the relative inductive DC voltage drop of a converter under rated operating condition, which can be calculated with Formula (2).

$$d_{xN} = \frac{3}{\pi} \cdot \frac{X_t \cdot I_{dN}}{U_{di0N}} \tag{2}$$