IS 14801 (2000): Terminology for High-voltage Direct Current (HVDC) Transmission [ETD 40: HVDC Power Systems]

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IS 14801 : 2000
IEC 60633 (1998)

भारतीय मानक

उच्च वोल्टता को दिष्ट धारा (एच वी डी सी) धारा संचरण की पाक पारिभाषिक शब्दावली

Indian Standard

TERMINOLOGY FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION

ICS 29.200

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

June 2000 **Price Group 10**

NATIONAL FOREWORD

This Indian Standard which is identical with IEC 60633 (1998) 'Terminology for high-voltage direct current (HVDC) transmission' issued by the International Electrotechnical Commission was adopted by the Bureau of Indian Standards on the recommendations of HVDC Power Systems Sectional Committee (ET 40) and approval of the Electrotechnical Division Council.

This standard gives the definitions of the terms used in HVDC power systems. It is applicable to HVDC power transmission systems and HVDC Substations using electronic power converters for the conversion from a.c. to d.c. or *vice versa.*

The text of the IEC Standard has been approved as suitable for publication as Indian Standard without deviations. Only the English language text in the International Standard has been retained while adopting it in this Indian Standard.

In the adopted standard, certain terminology and conventions are not identical to those used in Indian Standards. Attention is specially drawn to the following:

> Wherever the words 'International Standard' appear, referring to this standard, they should be read as 'Indian Standard'.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards which are to be substituted in their place are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60027 : 1990 Letter symbols to be used in electrical technology	IS 3722 (Parts 1 and 2) : 1983 Letter symbols and signs used in electrical technology	Not equivalent
IEC 60050 - 551 : 1998 Electrotechnical vocabulary — Part 551 : Power Electronics	IS 1885 (Part 27) : 1993 Electrotechnical vocabulary : Part 27 Power electronics	Identical to IEC 50-551(1982)
IEC 60146 - 1 - 1 : 1991 General requirements and line commutated converters — Part 1 - 1 : Specifications of basic requirements	—	No ISS exists
IEC 60617 - 5 : 1996 Graphical symbols for diagrams — Part 5 : Semiconductors and electron tubes	—	do
IEC 60617 - 6 : 1996 Graphical symbols for diagrams — Part 6 : Production and conversion of electrical energy	IS 12032 (Part 6) : 1987 Graphical symbols for diagrams : Part 6 Production and conversion of electrical energy	Identical to IEC 617-6 (1983)

Indian Standard

TERMINOLOGY FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION

1 Scope

This International Standard defines terms for high-voltage direct current (HVDC) power transmission systems and for HVDC substations using electronic power converters for the conversion from a.c. to d.c. or vice versa.

This standard is applicable to HVDC substations with line commutated converters, most commonly based on three-phase bridge (double way) connections (see figure 2) in which unidirectional electronic valves, e.g. semiconductor valves, are used.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60027 (all parts), *Letter symbols to be used in electrical technology*

IEC 60050-551:1998, *International Electrotechnical Vocabulary – Part 551: Power electronics*

IEC 60146-1-1:1991, *General requirements and line commutated convertors – Part 1-1: Specifications of basic requirements*

IEC 60617-5:1996, *Graphical symbols for diagrams – Part 5: Semiconductors and electron tubes*

IEC 60617-6:1996, *Graphical symbols for diagrams – Part 6: Production and conversion of electrical energy*

3 Symbols and abbreviations

The list covers only the most frequently used symbols. For a more complete list of the symbols which have been adopted for static converters see IEC 60027 and other standards listed in the normative references and the bibliography.

3.1 List of letter symbols

U_d direct voltage (any defined value)

U_{d0} conventional no-load direct voltage

U_{di0} ideal no-load direct voltage

U_{dN} rated direct voltage

U_L line-to-line voltage on line side of converter transformer, r.m.s. value including harmonics

U_{LN} rated value of U_L

U_{v0} no-load phase-to-phase voltage on the valve side of transformer, r.m.s. value excluding harmonics

I_d direct current (any defined value)

I_{dN} rated direct current

I_L current on line side of converter transformer, r.m.s. value including harmonics

I_{LN} rated value of I_L

I_v current on valve side of transformer, r.m.s. value including harmonics

α (trigger) delay angle

β (trigger) advance angle

γ extinction angle

μ overlap angle

p pulse number

q commutation number

3.2 List of subscripts

0 (zero) at no load

N rated value or at rated load

d direct current or voltage

i ideal

L line side of converter transformer

v valve side of converter transformer

max maximum

min minimum

n pertaining to harmonic component of order n

3.3 List of abbreviations

The following abbreviations are always in capital letters and without dots.

HVDC high-voltage direct current

MVU multiple valve (unit) (see 6.3.2)

SCR short-circuit ratio (see 7.32)

ESCR effective short-circuit ratio (see 7.33)

MTDC multiterminal HVDC transmission system (see 8.2.2)

MRTB metallic return transfer breaker (see 9.12)

ERTB earth return transfer breaker (see 9.13)

VDCOL voltage dependent current order limit (see 12.9)

4 Graphical symbols

Figure 1 shows the specific graphical symbols which are defined only for the purposes of this standard. For a more complete list of the graphical symbols which have been adopted for static converters, see IEC 60617-5 and IEC 60617-6.

5 General terms related to converter circuits

For the purposes of this standard, the following terms and definitions apply.

NOTE – For a more complete list of the terms which have been adopted for static converters, see IEC 60050(551) and IEC 60146-1-1.

5.1
conversion
in the context of HVDC, the transfer of energy from a.c. to d.c. or vice versa, or a combination of these operations

5.2
converter connection
electrical arrangement of arms and other components necessary for the functioning of the main power circuit of a converter

5.3
bridge (converter connection)
double-way connection comprising six converter arms which are connected as illustrated in figure 2

NOTE – The term "bridge" may be used to describe either the circuit connection or the equipment implementing that circuit (see 6.2).

5.3.1
uniform bridge
bridge where all converter arms are either controllable or non-controllable

5.3.2
non-uniform bridge
bridge with both controllable and non-controllable converter arms

5.4
(converter) arm
part of an operative circuit used for conversion which is connected between an a.c. terminal and a d.c. terminal, with the ability to conduct current in only one direction, defined as the forward direction (see 7.3)

NOTE – The main function of a converter arm is conversion; it may also perform additional functions such as voltage limiting, damping, etc.

5.4.1
controllable converter arm
converter arm in which the start of forward conduction may be determined by an externally applied signal

5.4.2
non-controllable converter arm
converter arm in which the start of forward conduction is determined solely by the voltage applied to its terminals

5.5
by-pass path
low resistance path between the d.c. terminals of one or several bridges excluding the a.c. circuit

NOTE – The by-pass path may either constitute a unidirectional path, e.g. a by-pass arm (see 5.5.1), or a by-pass pair (see 5.5.2), or it may constitute a bidirectional path, e.g. a by-pass switch (see 6.20).

5.5.1
by-pass arm
unidirectionally conducting by-pass path connected only between d.c. terminals, commonly used with mercury arc valve technology (not shown in figure 2)

5.5.2
by-pass pair
two converter arms of a bridge connected to a common a.c. terminal and forming a by-pass path (see figure 2)

5.6
commutation
transfer of current between any two paths with both paths carrying current simultaneously during this process

NOTE – Commutation may occur between any two converter arms, including the connected a.c. phases, between a converter arm and a by-pass arm, or between any two paths in the circuit.

5.6.1
line commutation
method of commutation whereby the commutating voltage is supplied by the a.c. system

5.7
commutating group
group of converter arms which commutate cyclically and independently from other converter arms, i.e. the commutations are normally not simultaneous (see figure 2)

NOTE – In the case of a bridge, a commutating group is composed of the converter arms connected to a common d.c. terminal. In certain cases, e.g. when large currents and/or large commutation inductances are involved, the commutation in the two commutating groups belonging to the same bridge need not be independent.

5.8
commutation inductance
total inductance included in the commutation circuit, in series with the commutating voltage

5.9
pulse number *p*
characteristic of a converter connection expressed as the number of non-simultaneous symmetrical commutations occurring during one cycle of the a.c. line voltage

NOTE – The pulse number of a bridge converter connection defined in 5.3 is always $p = 6$.

5.10
commutation number *q*
number of commutations during one cycle of the a.c. line voltage occurring in each commutating group

NOTE – In a bridge converter connection, each commutating group has a commutation number $q = 3$.

6 Converter units and valves

6.1
converter unit
operative unit comprising one or more converter bridges, together with one or more converter transformers, converter unit control equipment, essential protective and switching devices and auxiliaries, if any, used for conversion (see figure 3)

NOTE – If a converter unit comprises two converter bridges with a phase displacement of 30°, then the converter unit forms a 12-pulse unit (see figure 7). The term "12-pulse group" is also used.

6.2
(converter) bridge
equipment used to implement the bridge converter connection and the by-pass arm, if used

NOTE – The term "bridge" may be used to describe either the circuit connection or the equipment implementing that circuit (see 5.3).

6.2.1
anode (cathode) valve commutating group
equipment used to implement the converter arms of one commutating group of a bridge with interconnected anode (cathode) terminals

6.3
valve
complete operative controllable or non-controllable valve device assembly, normally conducting in only one direction (the forward direction), which can function as a converter arm in a converter bridge

NOTE – An example of a non-controllable valve device assembly is a semiconductor diode valve. An example of a controllable valve device assembly is a thyristor valve.

6.3.1
single valve (unit)
single structure comprising only one valve

6.3.2
multiple valve (unit) (MVU)
single structure comprising more than one valve

NOTE – Examples of multiple valve units are double valves, quadrivalves and octovalves with two, four and eight series-connected valves respectively.

6.4
main valve
valve in a converter arm

6.5
by-pass valve
valve in a by-pass arm

6.6
thyristor module
part of a valve comprised of a mechanical assembly of thyristors with their immediate auxiliaries, and reactors, if used

NOTE 1 – Thyristor modules may be elements in the construction of a valve, and/or be interchangeable for maintenance purposes.

NOTE 2 – The deprecated term "valve module" has been used with an equivalent meaning.

6.7
reactor module
part of a valve, being a mechanical assembly of one or more reactors, used in some valve designs

NOTE – Reactor modules may be elements in the construction of a valve.

6.8
valve section
electrical assembly, comprising a number of thyristors and other components, which exhibits prorated electrical properties of a complete valve

NOTE – This term is mainly used to define a test object for valve testing purposes.

6.9
(valve) thyristor level
part of a valve comprised of a thyristor, or thyristors connected in parallel, together with their immediate auxiliaries, and reactor, if any

6.10
valve support
that part of the valve which mechanically supports and electrically insulates from earth the active part of the valve which houses the valve sections

6.11
valve structure
physical structure holding the thyristor levels of a valve which is insulated to the appropriate voltage above earth potential

6.12
valve interface (electronics) (unit)
electronic unit which provides an interface between the control equipment, at earth potential, and the valve electronics or valve devices

NOTE 1 – Valve interface electronics units, if used, are typically located at earth potential close to the valve(s).

NOTE 2 – The term "valve base electronics" (VBE) has also been used for this unit.

6.13
valve electronics
electronic circuits at valve potential(s) which perform control functions

6.14
valve arrester
arrester connected across a valve (see figure 3)

6.15
converter unit arrester
arrester connected across the d.c. terminals of a converter unit (see figure 3)

6.16
converter unit d.c. bus arrester
arrester connected from the high-voltage d.c. bus of the converter unit to substation earth (see figures 3 and 7)

6.17
midpoint d.c. bus arrester
arrester connected between the midpoint of the two 6-pulse bridges of a 12-pulse converter unit and substation earth (see figure 7)

NOTE – In some HVDC substation designs, two twelve-pulse converter units are connected in series. In this case, the midpoint d.c. bus arrester at the upper twelve-pulse converter unit is not connected to substation earth but to the high-voltage d.c. bus of the lower twelve-pulse converter unit.

6.18
valve (anode) (cathode) reactor
reactor connected in series with the valve, commonly used with mercury arc technology

6.19
converter transformer
transformer through which energy is transmitted from an a.c. system to one or more converter bridges or vice versa (see figure 3)

6.19.1
line side windings
converter transformer windings which are connected to the a.c. system

6.19.2
valve side windings
converter transformer windings which are connected to the a.c. terminals of one or more converter bridges

6.20
by-pass switch
mechanical power switching device connected across the d.c. terminals of one or more converter bridges to shunt the bridge(s) during the turn-off procedure of the bridge(s) and to commutate current to the by-pass arm or a by-pass pair during the turn-on procedure of the bridge(s) (see figure 3)

NOTE – A by-pass switch may also be used for prolonged shunting of the bridge(s).

7 Converter operating conditions

7.1
rectifier operation; rectification
mode of operation of a converter or an HVDC substation when energy is transferred from the a.c. side to the d.c. side

7.2
inverter operation; inversion
mode of operation of a converter or an HVDC substation when energy is transferred from the d.c. side to the a.c. side

7.3
forward direction; conducting direction
direction of current through a valve, when current flows from the anode terminal to the cathode terminal

7.4
reverse direction; non-conducting direction
direction of current through a valve, when current flows from the cathode terminal to the anode terminal

7.5
forward current
current which flows through a valve in the forward direction

7.6
reverse current
current which flows through a valve in the reverse direction

7.7
forward voltage
voltage applied between the anode and cathode terminals of a valve or an arm when the anode is positive with respect to the cathode

7.8
reverse voltage
voltage applied between the anode and cathode terminals of a valve or an arm when the anode is negative with respect to the cathode

7.9
conducting state; on-state
condition of a valve when the valve exhibits a low resistance (the valve voltage for this condition is shown in figure 6)

7.10
valve voltage drop
voltage which, during the conducting state, appears across the valve terminals

7.11
non-conducting state; blocking state
condition of a valve when the valve exhibits a high resistance (see figure 6)

7.11.1
forward blocking state; off-state
non-conducting state of a controllable valve when forward voltage is applied between its main terminals (see figure 6)

7.11.2
reverse blocking state
non-conducting state of a valve when reverse voltage is applied between its main terminals (see figure 6)

7.12
firing
establishment of current in the forward direction in a valve

NOTE – The control action to establish current in an individual thyristor is referred to as triggering or gating.

7.13
(valve) control pulse
pulse which, during its entire duration, allows the firing of the valve

7.14
(valve) firing pulse
pulse which initiates the firing of the valve, normally derived from the valve control pulse

7.15
converter blocking
operation preventing further conversion by a converter by inhibiting valve control pulses

NOTE – This action may also include firing of a valve, or valves, selected to form a by-pass path.

7.16
converter deblocking
operation permitting the start of conversion by a converter by removing blocking action

7.17
valve blocking
operation preventing further firing of a controllable valve by inhibiting the valve control pulses

7.18
valve deblocking
operation permitting firing of a controllable valve by removing the valve blocking action

7.19
phase control
process of controlling the instant within the cycle at which forward current conduction in a controllable valve begins

7.20
(trigger) delay angle α
time, expressed in electrical angular measure, from the zero crossing of the idealized sinusoidal commutating voltage to the starting instant of forward current conduction (see figure 4)

7.21
(trigger) advance angle β
time, expressed in electrical angular measure, from the starting instant of forward current conduction to the next zero crossing of the idealized sinusoidal commutating voltage

The advance angle β is related to the delay angle α by $\beta = \pi - \alpha$ (see figure 4).

7.22
overlap angle μ
duration of commutation between two converter arms, expressed in electrical angular measure (see figures 4 and 5)

7.23
extinction angle γ
time, expressed in electrical angular measure, from the end of current conduction to the next zero crossing of the idealized sinusoidal commutating voltage. γ depends on the advance angle β and the overlap angle μ and is determined by the relation $\gamma = \beta - \mu$ (see figures 4 and 5)

7.24
hold-off interval
time from the instant when the forward current of a controllable valve has decreased to zero to the instant when the same valve is subjected to forward voltage (see figure 5)

NOTE – Hold-off interval, when expressed in electrical angular measure, is commonly referred to as the extinction angle. However, the difference between the concepts of extinction angle and hold-off interval should be noted, as shown in figure 5.

7.24.1
critical hold-off interval
minimum hold-off interval for which the inverter operation can be maintained

7.25
conduction interval
that part of a cycle during which a valve is in the conducting state (see figure 6)

7.26
blocking interval; idle interval
that part of a cycle during which a valve is in the non-conducting state (see figure 6)

7.27
forward blocking interval
that part of the blocking interval during which a controllable valve is in the forward blocking state (see figure 6)

7.28
reverse blocking interval
that part of the blocking interval during which a valve is in the reverse blocking state (see figure 6)

7.29
false firing
firing of a valve at an incorrect instant

7.30
firing failure
failure to achieve firing of a valve during the entire forward voltage interval

7.31
commutation failure
failure to commutate the forward current from the conducting converter arm to the succeeding converter arm

7.32
short-circuit ratio (SCR)
ratio of the a.c. network short-circuit level (in MVA) at 1 p.u. voltage at the point of connection to the HVDC substation a.c. bus, to the rated d.c. power of the HVDC substation (in MW)

NOTE – The present definition of SCR differs from the definition given in IEC 60146-1-1.

7.33
effective short-circuit ratio (ESCR)
ratio of the a.c. network short-circuit level (in MVA) at 1 p.u. voltage at the point of connection to the HVDC substation a.c. bus, reduced by the reactive power of the shunt capacitor banks and a.c. filters connected to this point (in Mvar), to the rated d.c. power of the HVDC substation (in MW)

8 HVDC systems and substations

8.1
HVDC system
electrical power system which transfers energy in the form of high-voltage direct current between two or more a.c. buses

8.2
HVDC transmission system
HVDC system which transfers energy between two or more geographic locations

8.2.1
two-terminal HVDC transmission system
HVDC transmission system consisting of two HVDC transmission substations and the connecting HVDC transmission line(s) (see figure 8)

8.2.2
multiterminal HVDC transmission system (MTDC)
HVDC transmission system consisting of more than two separated HVDC substations and the interconnecting HVDC transmission lines (see figures 9 and 10)

8.2.3
HVDC back-to-back system
HVDC system which transfers energy between a.c. buses at the same location

8.3
unidirectional HVDC system
HVDC system for the transfer of energy in only one direction

8.4
reversible HVDC system
HVDC system for the transfer of energy in either direction

NOTE – A multiterminal HVDC system is reversible if one or more substations are reversible.

8.5
(HVDC) (system) pole
part of an HVDC system consisting of all the equipment in the HVDC substations and the interconnecting transmission lines, if any, which during normal operation exhibit a common direct voltage polarity with respect to earth (see figure 8)

8.6
(HVDC) (system) bipole
part of an HVDC system consisting of two HVDC system poles, which during normal operation, exhibit opposite direct voltage polarities with respect to earth

8.7
bipolar (HVDC) system
HVDC system with two poles of opposite polarity with respect to earth (see figure 8)

NOTE – The overhead lines, if any, of the two poles may be carried on common or separate towers.

8.7.1
bipolar earth return (HVDC) system
bipolar system in which the return current path between neutrals of the HVDC system is through the earth

8.7.2
bipolar metallic return (HVDC) system
bipolar system in which the return current path between neutrals of the HVDC system is through a metallic circuit

8.8
monopolar (HVDC) system
HVDC system with only one pole

8.8.1
monopolar earth return (HVDC) system
monopolar system in which the return current path between neutrals of the HVDC substations is through the earth

8.8.2
monopolar metallic return (HVDC) system
monopolar system in which the return current path between neutrals of the HVDC substations is through a metallic circuit

8.9
HVDC substation
part of an HVDC system which consists of one or more converter units installed in a single location together with buildings, reactors, filters, reactive power supply, control, monitoring, protective, measuring and auxiliary equipment (see figure 7)

NOTE – An HVDC substation forming part of an HVDC transmission system may be referred to as an HVDC transmission substation.

8.9.1
(HVDC) tapping substation
HVDC substation, mainly used for inversion, with a rating which is a small fraction of that of the rectifier(s) in the system

8.10
(HVDC) substation bipole
that part of a bipolar HVDC system contained within a substation

8.11
(HVDC) substation pole
that part of an HVDC system pole which is contained within a substation (see figure 8)

8.12
HVDC transmission line
part of an HVDC transmission system consisting of a system of overhead lines and/or cables. The HVDC transmission lines are terminated in HVDC substations (see figure 8).

8.13
HVDC transmission line pole
part of an HVDC transmission line which belongs to the same HVDC system pole

8.14
earth electrode
array of conducting elements placed in the earth, or the sea, which provides a low resistance path between a point in the d.c. circuit and the earth and is capable of carrying continuous current for some extended period (see figure 7)

NOTE 1 – An earth electrode may be located at a point some distance from the HVDC substation.

NOTE 2 – Where the electrode is placed in the sea it may be termed a sea electrode.

8.15
earth electrode line
insulated line between the HVDC substation d.c. neutral bus and the earth electrode (see figure 7)

9 HVDC substation equipment

9.1
a.c. filter
filter designed to reduce the harmonic voltage at the a.c. bus and the flow of harmonic current into the associated a.c. system (see figure 7)

9.2
d.c. (smoothing) reactor
reactor connected in series with a converter unit or converter units on the d.c. side for the primary purpose of smoothing the direct current and reducing current transients (see figure 7)

9.3
d.c. reactor arrester
arrester connected between the terminals of a d.c. reactor (see figure 7)

9.4
d.c. filter
filter which, in conjunction with the d.c. reactor(s) and with the d.c. surge capacitor(s), if any, serves the primary function of reducing (current or voltage) ripple on the HVDC transmission line and/or earth electrode line (see figure 7)

9.5
d.c. damping circuit
combination of circuit elements which serve to reduce voltage transients and/or change resonance conditions on the d.c. line (see figure 7)

9.6
d.c. surge capacitor
capacitor array connected between the d.c. line and the substation earth (directly or indirectly) to serve the primary function of reducing the amplitude and steepness of lightning surges applied to the substation equipment (see figure 7)

9.7
d.c. bus arrester
arrester connected between the d.c. bus (at a point between the d.c. reactor and the d.c. line disconnector) and the substation earth (see figure 7)

9.8
d.c. line arrester
arrester connected between an HVDC line (at an HVDC substation) and substation earth (see figure 7)

9.9
HVDC substation earth
array of conducting elements which provides a low impedance path from the earthed parts of the equipment in the HVDC substation to earth and which is capable of carrying high surge currents of momentary duration (see figure 7)

9.10
(d.c.) neutral bus capacitor
capacitor array connected between the d.c. neutral bus and the substation earth (see figure 7)

9.11
(d.c.) neutral bus arrester
arrester connected between the d.c. neutral bus and the substation earth (see figure 7)

9.12
metallic return transfer breaker (MRTB)
switching device used to transfer d.c. current from an earth return path to a metallic return path (see figure 7)

9.13
earth return transfer breaker (ERTB)
switching device used to transfer d.c. current from a metallic return path to an earth return path (see figure 7)

NOTE – In some applications, this function is performed by a by-pass switch (see figure 3).

10 Modes of control

10.1
control mode
manner in which a converter unit, pole, or HVDC substation is controlled in order to maintain one or more electrical quantities at desired values. These desired values may change with time or as a function of measured quantities and defined priorities.

10.2
voltage control mode
control of the a.c. or d.c. side voltages in an HVDC system

10.3
current control mode
control of the d.c. current in an HVDC system

10.4
power control mode
control of power flow in an HVDC system

10.5
reactive power control mode
control of the reactive power exchanged between a converter unit, or HVDC substation and the connected a.c. network

10.6
frequency control mode
control of the frequency of one or more connected a.c. networks by varying the transmitted power

10.7
damping control mode
supplementary control mode providing the damping of electromechanical oscillations such as network instability or sub-synchronous oscillations (SSO) in one or more connected a.c. networks

11 Control systems

11.1
(HVDC) control system
function of, or the equipment used for, controlling, monitoring or protection of main plant equipment, such as circuit breakers, valves, converter transformers and their tap changers, forming part of an HVDC system

NOTE – An example illustrating a typical HVDC control system hierarchy is shown in figure 12.

11.2
HVDC system control
control system which governs the operation of an entire HVDC system consisting of more than one HVDC substation and performs those functions of controlling, monitoring and protection which require information from more than one substation (see figure 12)

11.2.1
multiterminal control
HVDC system control for more than two HVDC substations

11.3
(HVDC) master control
general concept for control coordination of an HVDC system

NOTE – The HVDC master control may be implemented at the bipole and/or pole level.

11.4
(HVDC system) bipole control
control system of a bipole (see figure 12)

11.5
(HVDC system) pole control
control system of a pole (see figure 12)

NOTE – When the HVDC system has no bipole(s) but one or more poles, the pole control interfaces with the HVDC system control.

11.6
(HVDC) substation control
control system used for the controlling, monitoring and protection within an HVDC substation

NOTE – HVDC substation control may be implemented at the bipole and/or pole level and may be referred to as local control.

11.6.1
(HVDC) substation bipole control
control system of a substation bipole (see figure 12)

11.6.2
(HVDC) substation pole control
control system of a substation pole (see figure 12)

11.7
converter unit control
control system used for the controlling, monitoring and protection of a single converter unit (see figure 12)

11.7.1
converter unit sequence control
part of the converter unit control which co-ordinates the operation of the converter unit firing control, transformer tap changer control, monitoring and protection, and which controls the sequence of action during any change in the operating conditions of the associated converter unit

11.7.2
converter unit firing control
part of the converter unit control for timing the intended firing of the valves

11.7.3
converter unit tap changer control
part of the converter unit control for controlling the converter transformer tap changers

11.7.4
converter unit monitoring
part of the converter unit control which monitors electrical, mechanical and thermal quantities

11.7.5
converter unit protection
part of the converter unit control which initiates action to protect components of the associated converter unit against damage due to abnormal electrical, mechanical or thermal conditions

11.8
valve control
control system for the firing, monitoring, and protection of a valve

11.8.1
valve (control) firing
part of the valve control which initiates valve firing

11.8.2
valve (control) monitoring
part of the valve control which monitors valve status

11.8.3
valve (control) protection
part of the valve control which protects the valve by initiating, or disabling valve firing

12 Control functions

12.1
equal delay angle control; individual phase control
method of controlling separately the valve control pulses for each valve by timing from the zero crossings of the commutation voltages

12.2
equidistant firing control
method of controlling the valve control pulses whereby, in steady state, the delay between a control pulse and the previous control pulse is equal for all valves, irrespective of unbalance or distortion in the commutating voltages

12.3
α control
control of the delay angle between a minimum and maximum, determined by the design, to implement a control mode

12.4
minimum α control
control of the delay angle to prevent it from decreasing below a set minimum value

12.5
γ control
control of the extinction angle between a minimum and maximum, determined by the design, to implement a control mode at an inverter

12.6
minimum γ control
control of the extinction angle to prevent it from decreasing below a set minimum value

12.7
control order
reference value of a desired controlled quantity, in a control mode

12.7.1
(d.c.) current (control) order
reference value of the current to the d.c. current regulator (see figure 11)

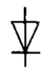
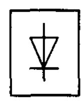
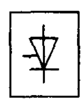
12.7.2
(d.c.) voltage (control) order
reference value of the voltage to a voltage regulator (see figure 11)

12.8
current margin
in an HVDC pole with two ends, the difference between the current order at the rectifier and the inverter (see figure 11)

NOTE – The rectifier has always a higher current order than the inverter in a two-terminal HVDC transmission system.

12.9
voltage dependent current order limit (VDCOL)
limitation of the current order as a function of the d.c. voltage

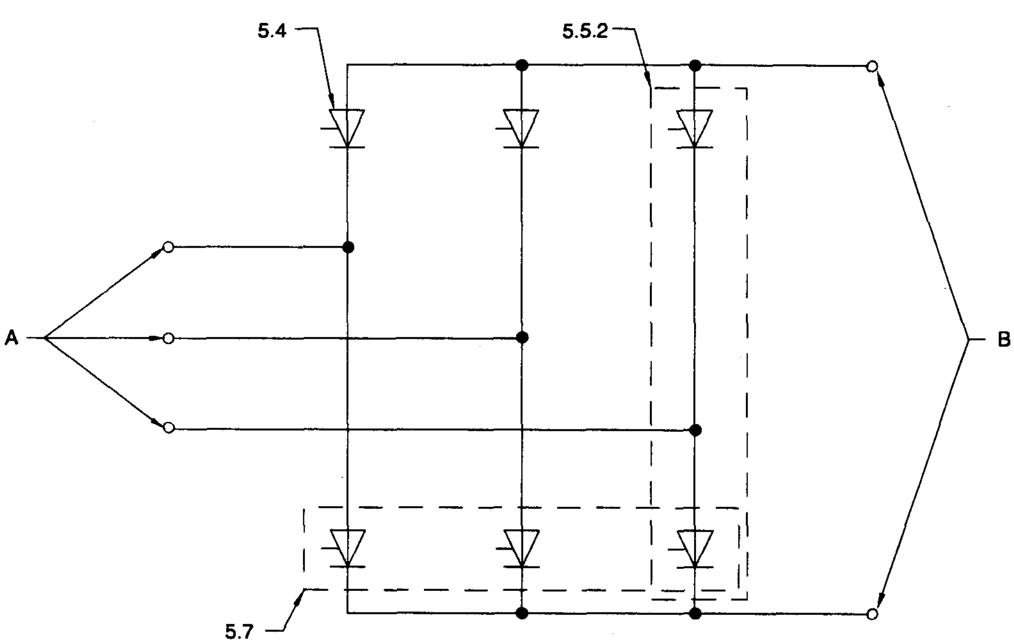
12.10
pole (current) balancing
control action to balance the currents in the two poles of a bipole system, in order to limit the amplitude of the differential current that flows between the neutrals of the HVDC system

No.	Symbol	Description
1		Non-controllable valve or arm
2		Controllable valve or arm
3		Non-controllable bridge
4		Controllable bridge

NOTE 1 – Symbols 2 and 4 are used to represent the general meaning of valve, arm, or bridge, irrespective of controllability.

NOTE 2 – The above symbols are irrespective of the type of device of which a valve, arm, or bridge is composed.

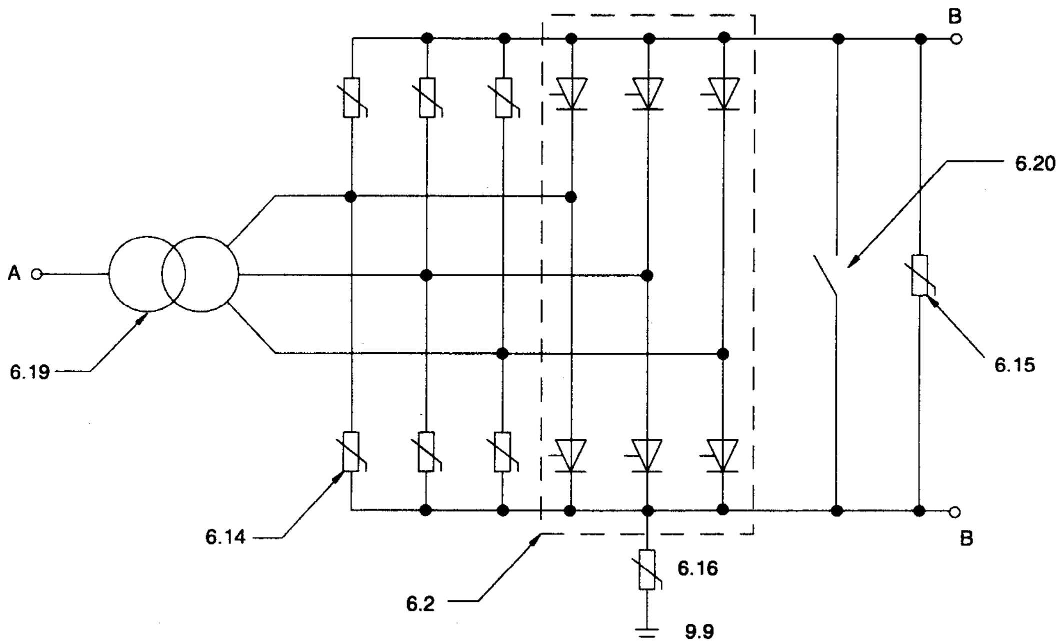
Figure 1 – Graphical symbols



Key

A AC terminals
B DC terminals
5.4 Converter arm
5.5.2 By-pass pair
5.7 Commutating group

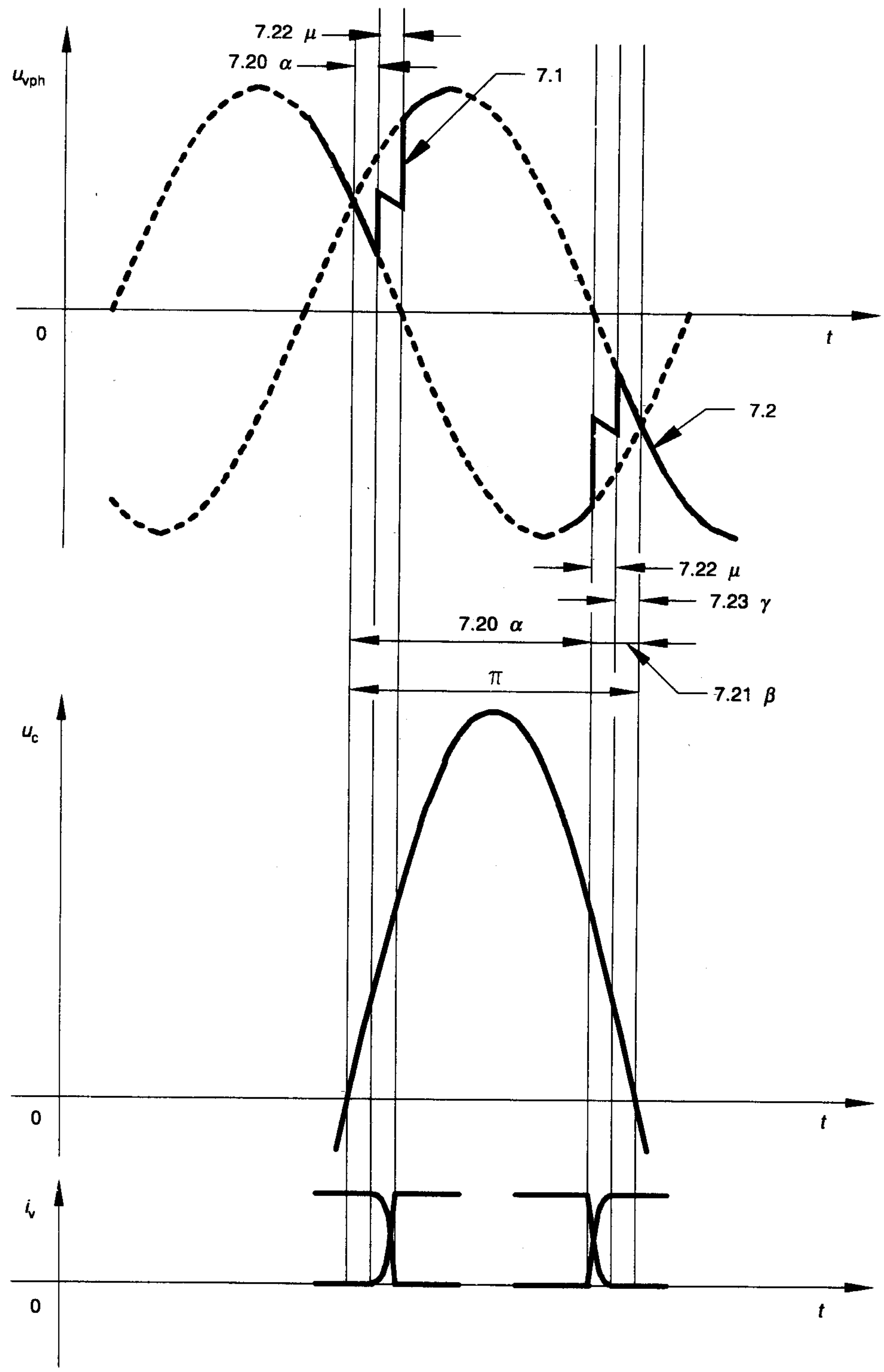
Figure 2 – Bridge converter connection



Key

A	AC terminals	6.16	Converter unit d.c. bus arrester
B	DC terminals	6.19	Converter transformer
6.2	Bridge	6.20	By-pass switch
6.14	Valve arrester	9.9	Substation earth
6.15	Converter unit arrester		

Figure 3 – Example of a converter unit



Key

u_{vph}	Phase voltage	7.2	Inverter operation
u_c	Commutating voltage	7.20	Delay angle α
i_v	Valve currents	7.21	Advance angle β
t	Time	7.22	Overlap angle μ
7.1	Rectifier operation	7.23	Extinction angle γ

Figure 4 – Commutation process at rectifier and inverter modes of operation

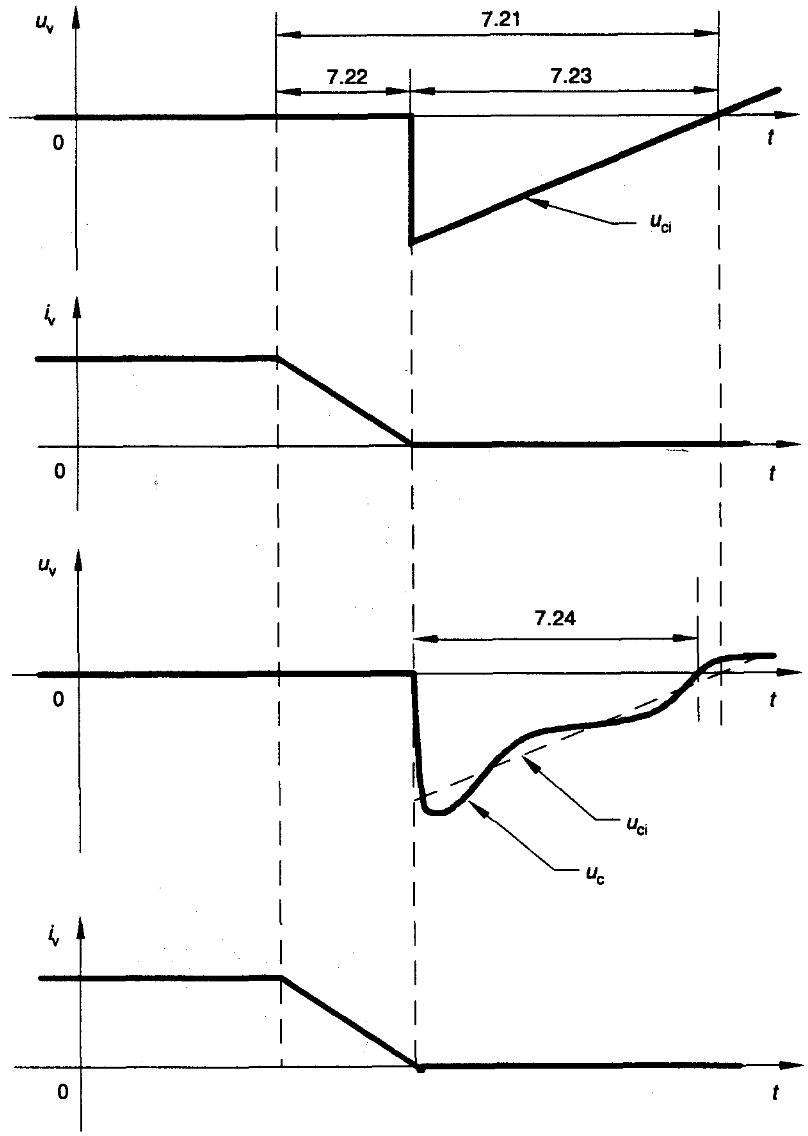


Figure 5a - Valve idealised

Figure 5b - Real valve

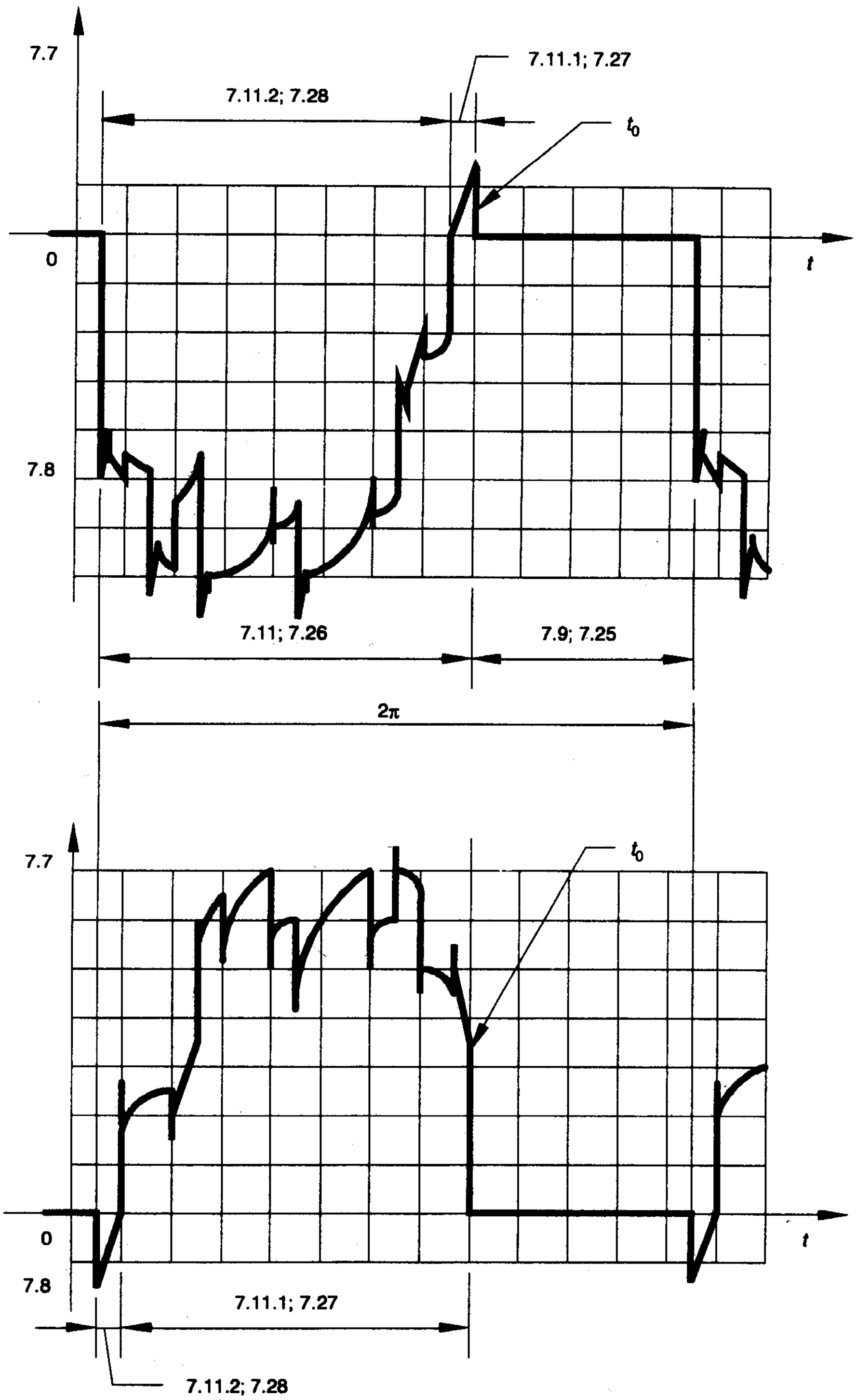
Key

u_v	Voltage across outgoing valve	7.21	Advance angle β
i_v	Current in outgoing valve	7.22	Overlap angle μ
u_{ci}	Idealized commutating voltage	7.23	Extinction angle γ
u_c	Actual commutating voltage	7.24	Hold-off interval
t	Time		

Figure 5 – Illustrations of commutation in inverter operation

Figure 6a - Rectifier operation

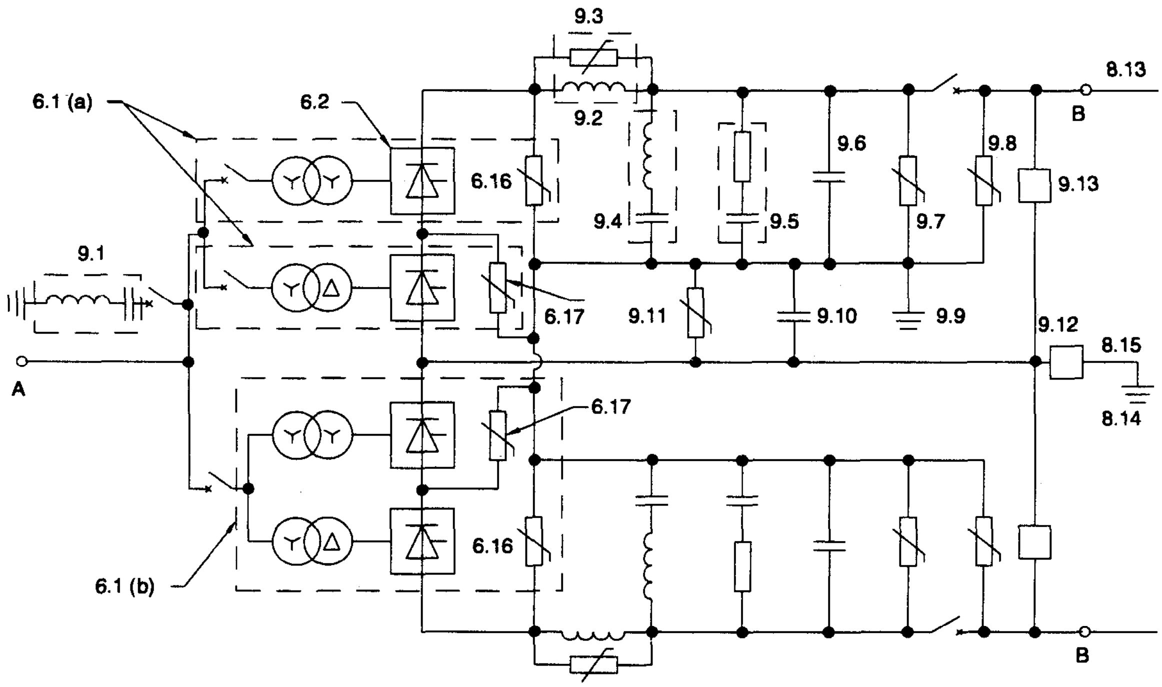
Figure 6b - Inverter operation



Key

t	Time	7.11	Non-conducting state
t_0	Firing instant	7.11.1	Forward blocking state
7.7	Forward voltage	7.11.2	Reverse blocking state
7.8	Reverse voltage	7.25	Conduction interval
7.9	Conducting state	7.26	Blocking interval
		7.27	Forward blocking interval
		7.28	Reverse blocking interval

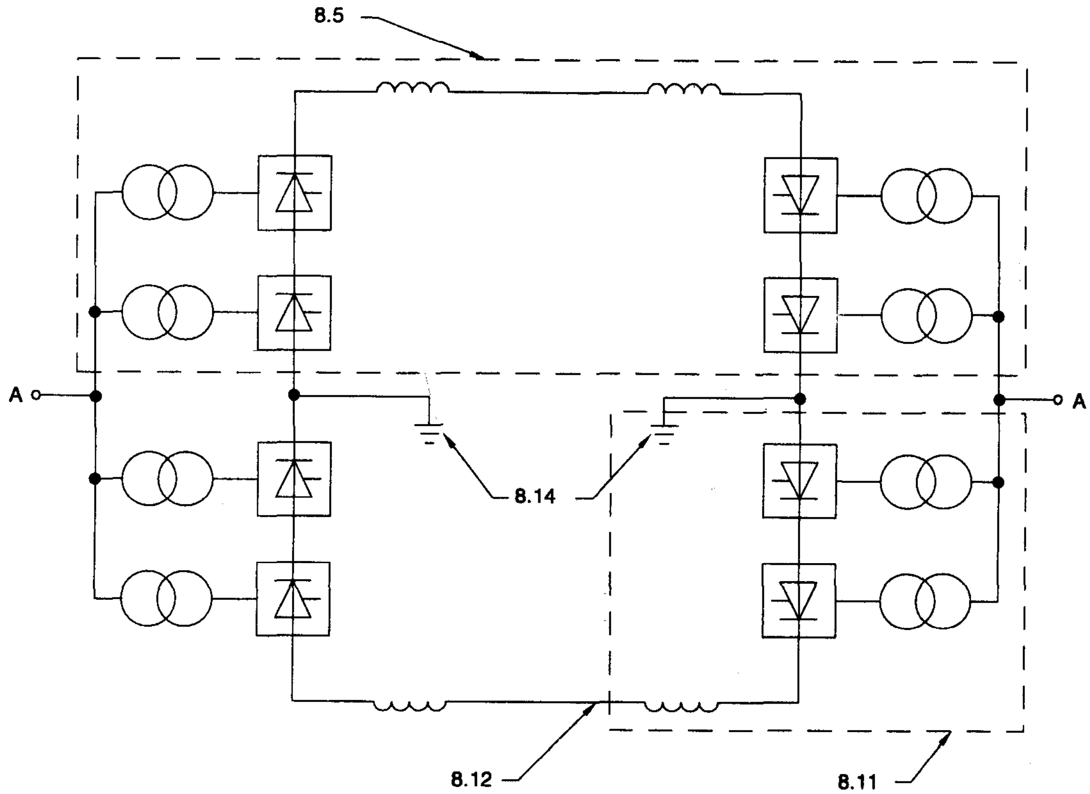
Figure 6 – Typical valve voltage waveforms



Key

A	AC system	9.3	DC reactor arrester
B	DC terminal	9.4	DC filter
6.1 (a)	Converter unit (p = 6)	9.5	DC damping circuit
6.1 (b)	Converter unit (p = 12)	9.6	DC surge capacitor
6.2	Converter bridge	9.7	DC bus arrester
6.16	Converter unit d.c. bus arrester	9.8	DC line arrester
6.17	Midpoint d.c. bus arrester	9.9	Substation earth
8.13	HVDC transmission line pole	9.10	DC neutral bus surge capacitor
8.14	Earth electrode	9.11	DC neutral bus arrester
8.15	Earth electrode line	9.12	Metallic return transfer breaker (MRTB)
9.1	AC filter	9.13	Earth return transfer breaker (ERTB)
9.2	DC (smoothing) reactor		

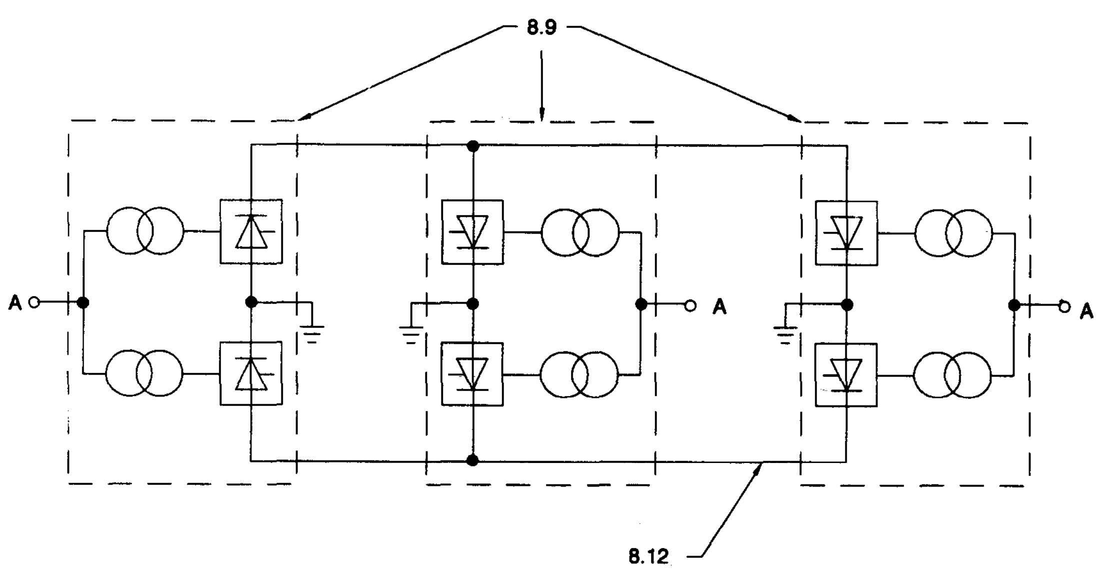
Figure 7 – Example of an HVDC substation



Key

A AC system
8.5 HVDC system pole
8.11 Substation pole
8.12 HVDC transmission line
8.14 Earth electrodes

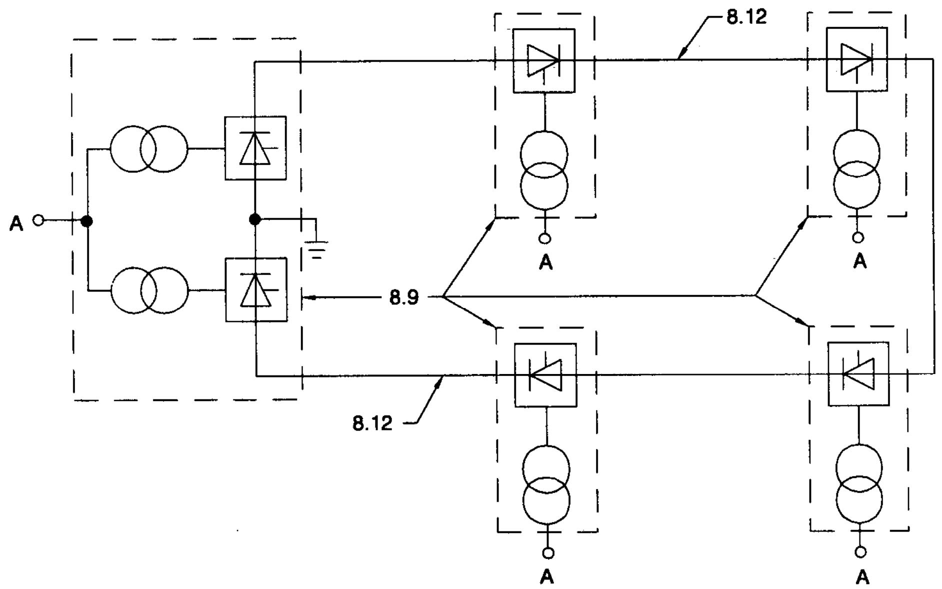
Figure 8 – Example of bipolar two-terminal HVDC transmission system



Key

A AC system
8.9 HVDC substations
8.12 HVDC transmission line

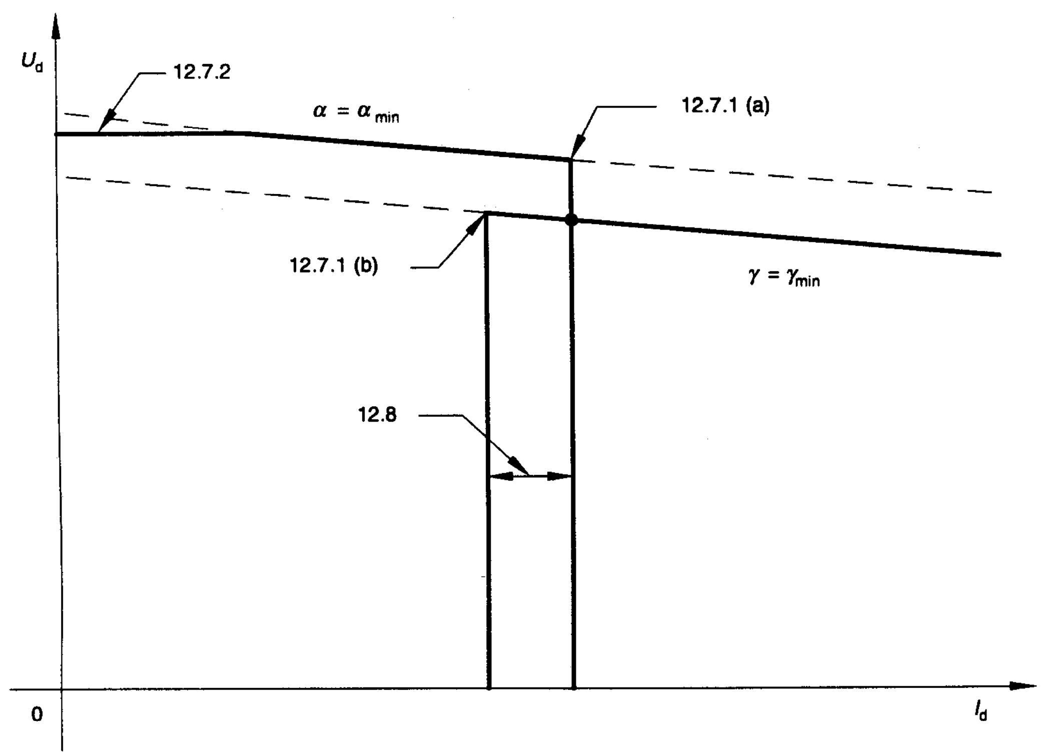
Figure 9 – Example of a multiterminal bipolar HVDC transmission system with parallel connected HVDC substations



Key

A	AC system
8.9	HVDC substations
8.12	HVDC transmission line

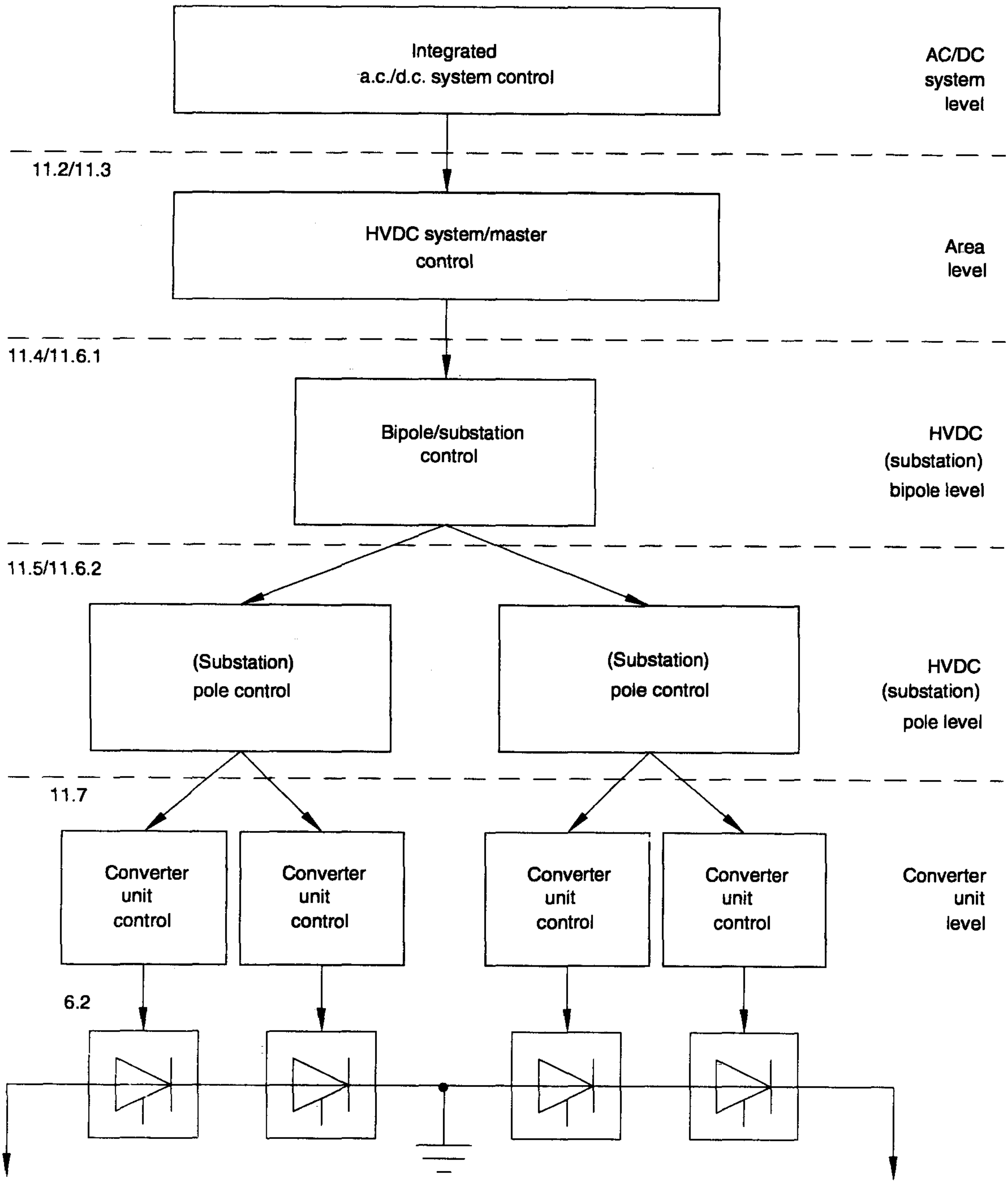
Figure 10 – Example of a multiterminal HVDC transmission system with series connected HVDC substations



Key

U_d	Direct voltage	12.7.2	Voltage order (rectifier)
I_d	Direct current	12.8	Current margin
12.7.1 (a)	Current order (rectifier)		
12.7.1 (b)	Current order (inverter)		

Figure 11 – A simplified steady-state voltage-current characteristic of a two-terminal HVDC system



Key

6.2	(Converter) bridge
11.2	HVDC system control
11.3	(HVDC) master control
11.4	(HVDC system) bipole control
11.5	(HVDC system) pole control
11.6.1	(HVDC) substation bipole control
11.6.2	(HVDC) substation pole control
11.7	Converter unit control

Figure 12 – Hierarchical structure of an HVDC control system

BIBLIOGRAPHY

IEC 60050(421):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 421: Power transformers and reactors*

IEC 60050(436):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 436: Power capacitors*

IEC 60050(521):1984, *International Electrotechnical Vocabulary (IEV) – Chapter 521: Semiconductor devices and integrated circuits*

IEC 60050(601):1985, *International Electrotechnical Vocabulary (IEV) – Chapter 601: Generation, transmission and distribution of electricity – General*

IEC 60050(604):1987, *International Electrotechnical Vocabulary (IEV) – Chapter 604: Generation, transmission and distribution of electricity – Operation*

IEC 60050(605):1983, *International Electrotechnical Vocabulary (IEV) – Chapter 605: Generation, transmission and distribution of electricity – Substations*

IEC 60076 (all parts), *Power transformers*

IEC 60099 (all parts), *Surge arresters*

IEC 60146-1-2:1991, *General requirements and line commutated convertors – Part 1-2: Application guide*

IEC 60146-1-3:1991, *General requirements and line commutated convertors – Part 1-3: Transformers and reactors*

IEC 60617-4:1996, *Graphical Symbols for diagrams – Part 4: Passive components*

IEC 60617-7:1996, *Graphical Symbols for diagrams – Part 7: Switchgear, controlgear and protective devices*

IEC 60747-6:1983, *Semiconductor devices – Discrete devices – Part 6: Thyristors*
Amendment 1 (1991)
Amendment 2 (1994)

IEC 60919-1:1988, *Performance of high-voltage d.c. (HVDC) systems – Part 1: Steady-state conditions*

IEC 60919-2:1990, *Performance of high-voltage d.c. (HVDC) systems – Part 2: Faults and switching*

IEC 60919-3; —, *Performance of high-voltage d.c. (HVDC) systems – Part 3: Dynamic conditions* [1)]

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Printed at New India Printing Press, Khurja, India