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LVDC systems – Assessment of standard voltages and power quality requirements

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LVDC systems – Assessment of standard voltages and power quality requirements

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

LVDC SYSTEMS – ASSESSMENT OF STANDARD VOLTAGES AND POWER QUALITY REQUIREMENTS

FOREWORD

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IEC TR 63282, which is a Technical Report, has been prepared by IEC technical committee 8: System aspects of electrical energy supply.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
8/1549/DTR	8/1556/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- withdrawn,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.

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INTRODUCTION

LVDC (Low voltage direct current) distribution systems have recently been recognized by a number of stakeholders as an alternative approach to provide efficient power supply to the consumers. LVDC covers a wide range of power applications from USB-C up to megawatts for aluminium melting. LVDC is now seen not only as a solution for electricity access in developing economies but also as a solution for greener and more sustainable energy in developed economies.

In industrial applications, LVDC is utilized where processing of resources results in the production, distribution and storage of physical goods, especially in a factory or special area of a factory.

The standardization of DC voltages is a key issue, and urgent work is needed. Existing LVAC systems have different standard voltages, depending on the geography and application. LVDC distribution voltages should be optimized to provide a good context for industries that import and export equipment but also for general travellers. Appropriate international LVDC voltage ranges will provide a basis for design and testing of electrical equipment and systems and ease of transition for equipment from AC to DC supply.

LVDC voltages should meet the range of use cases where LVDC systems can make a difference. The list of standard voltages should be as short as possible and allow for cost-effective and safe operation.

The power quality phenomena for the distribution of DC power are not identical to AC phenomena while there are some common issues. Power quality considerations are well studied and standardized on AC power systems, but many power quality phenomena and EMC have not yet been fully evaluated for DC distribution systems.

Power electronic converters/inverters add further demands. Power quality phenomena in LVDC distributed systems can be related to the topology of the entire system, and the operating condition of sources and loads. At the same time, the DC output performance of a single converter and the coordination among several converters can also result in different power quality issues and grid stability.

Requirements for power quality and EMC in LVDC distribution should be established in order to provide a solid basis for the planning and operation of LVDC distribution systems. In addition, the design and configuration of the protection system is to be addressed with the objective to enhance the availability of the source, the reliability, and the lifetime of the system.

Generally, the standardization of voltage level and PQ phenomena of LVDC distribution should greatly stimulate the wide adoption of LVDC.

Besides the main contents concerning voltage level and power quality, the following topics are also presented:

Clause 4 discusses architectures and topologies for LVDC networks.

Clause 7 recommends permissible limits for voltage bands and PQ phenomena.

LVDC SYSTEMS – ASSESSMENT OF STANDARD VOLTAGES AND POWER QUALITY REQUIREMENTS

1 Scope

The purpose of this document is to collect information and report experience in order to make recommendations for the standardization of voltage levels and related aspects (power quality, EMC, measurement …) for LVDC systems (systems with voltage level lower than 1 500 V d.c.).

Rationale for the proposed voltage values are given. Variation of parameters for the voltage (power quality) and recommendation for their boundaries are defined. Nevertheless, some of the technical items are not exhaustively explained in this document and some gaps are identified for future work.

Attention is paid to the definition of DC voltage.

Systems in which a unipolar voltage is interrupted periodically for certain purposes, e.g. pulse voltage, are not considered.

Traction systems are excluded from this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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
nominal system voltage
suitable approximate value of voltage used to designate or identify a system

[SOURCE: IEC 60050-601:1985, 601-01-21]

3.2
DC supply voltage
line-to-line or line-to-midpoint voltage at the supply terminals

3.3
bipolar DC system
DC system comprising positive, midpoint and negative lines

3.4
unipolar DC system
DC system comprising of two lines

3.5
DC system nominal voltage
U_n
suitable approximate value of voltage used to designate or identify a DC system

Note 1 to entry: A bipolar DC system is preferred to use a dual notation, for example, "$\pm U_{L-M}$ "or "U_{L-M}/ U_{L-L}".

3.6
DC voltage deviation
voltage deviation due to the slow change in power system operation state

Note 1 to entry: Voltage deviation is the difference between actual voltage and nominal system voltage when the change rate of the average DC voltage is in the appropriate speed in order to limit the deviation in an acceptable range.

3.7
voltage unbalance
condition in a bipolar system in which the line to mid-point voltages are not equal

3.8
ripple
set of unwanted periodic deviations with respect to the average value of the measured or supplied quantity, occurring at frequencies which can be related to that of the mains supply, or of some other definite source, such as a chopper

Note 1 to entry: Ripple is determined under specified conditions and is a part of PARD (Periodic and/or random deviation). It may be assessed by instantaneous value or RMS value.

Note 2 to entry: Sources of ripple may include, but are not limited to, voltage regulation instability of the DC power source, commutation/rectification within the DC power source, and load variations within utilization equipment.

Note 3 to entry: Ripple is determined as well in percentage to DC component and in RMS value computed in frequency range < 150 kHz (in line with SC77A and CISPR for conducted disturbances).

[SOURCE: IEC 60050-312: 2001, 312-07-02, modified – A sentence has been added to Note 1 to entry; Notes 2 and 3 to entry have been added]

3.9
over-voltage
voltage, the value of which exceeds a specified limiting value

[SOURCE: IEC 60050-151:2001,151-15-27]

3.10
under-voltage
voltage, the value of which is lower than a specified limiting value

[SOURCE: IEC 60050-151:2001,151-15-29]

3.11
voltage swell
sudden increase of the voltage at a point in the electrical supply system followed by voltage recovery after a short period of time

Note 1 to entry: Application: for the purpose of this document, the swell start threshold is equal to the 110 % of the reference voltage (see CLC/TR 50422, Clause 3, for more information).

Note 2 to entry: For the purpose of this document, a voltage swell is a two dimensional electromagnetic disturbance, the level of which is determined by both voltage and time (duration).

3.12
voltage dip
sudden voltage reduction at a point in the electrical supply system, followed by voltage recovery after a short period of time

Note 1 to entry: The residual voltage may be expressed as a value in volts, or as a percentage or per unit value relative to the reference voltage.

[SOURCE: IEC 60050-614:2016,614-01-08, modified – Reference to sinusoidal voltage has been removed and time interval has been changed to period of time]

3.13
voltage surge
transient voltage wave propagating along a line or a circuit and characterized by a rapid increase followed by a slower decrease of the voltage

[SOURCE: IEC 60050-161:1990, 161-08-11]

3.14
voltage supply interruption
disappearance of the supply voltage for a time interval whose duration is between two specified limits

3.15
rapid voltage change
RVC
quick transition in voltage occurring between two steady-state conditions, and during which the voltage does not exceed the dip/swell thresholds

3.16
active distribution system
ADS
distribution networks that have systems in place to control a combination of distributed energy resources (i.e., distributed generation, controllable loads or energy storage)

Note 1 to entry: Protection can also be included in ADS.

3.17
passive distribution system
PDS
distribution systems in which the energy balance is controlled by the voltage source (e.g., outside grid or battery)

3.18
droop in a DC system
ratio of per-unit change in voltage to the corresponding per-unit change in power of the demand

3.19
distribution network operator
DNO
party operating a distribution network

3.20
distribution system operator
DSO
party extending the function of a DNO to incorporate active management of some power resources

3.21
positive voltage
U+
voltage between the positive line and the midpoint

Note 1 to entry: Only defined for bipolar DC systems.

3.22
negative voltage
U-
voltage between the midpoint and the negative line

Note 1 to entry: Only defined for bipolar DC systems.

3.23
balanced voltage
U_b
average of the positive and the negative voltage

Note 1 to entry: $U_b = (U_p+U_n)/2$.

Note 2 to entry: Only defined for bipolar DC systems.

3.24
unbalanced voltage
U_u
average difference of the positive and the negative voltage

Note 1 to entry: $U_u = (U_p-U_n)/2$.

Note 2 to entry: Only defined for bipolar DC systems.

3.25
midpoint
common point between two symmetrical circuit elements the opposite ends of which are electrically connected to different line conductors of the same circuit

Note 1 to entry: Only defined for bipolar DC systems.

[SOURCE: IEC 60050-195:1998, 195-02-04, modified – The note to entry has been added]

3.26
under-voltage ride through
capability of equipment to stay connected and continue functioning during loss or drop of supply voltage

3.27
DC voltage
voltage equal to its average value during a defined time interval

3.28
over-voltage ride through
capability of equipment to stay connected and continue functioning during voltage swells

4 Structure of LVDC systems

4.1 General

A LVDC system is a combination of different electronic devices, whose operation is strongly based on different control strategies. Thus, as far as the recommended voltages and power qualities of certain LVDC systems are concerned, different analysis dimensions and elements should be taken into consideration, including different architectures, operation modes, etc..

4.2 Architecture

Several use cases concerning existing technologies and projects have been introduced to support the analysis and classification of LVDC systems, including but not limited to:

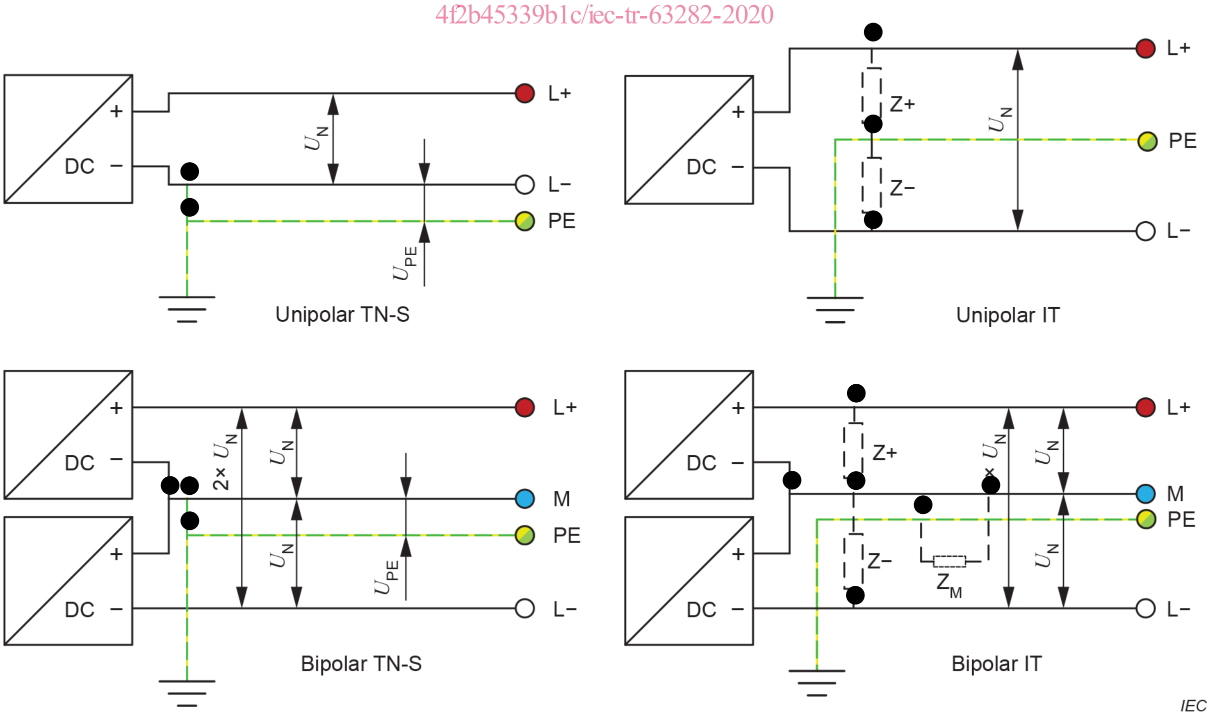
- LVDC system in buildings,
- LVDC systems between buildings.

Details and examples can be found in Annex D, Annex E and Annex F. Formal use cases are also under work in the frame of the SyC LVDC WG2.

Unipolar or bipolar DC systems can be designed with two or three output lines, respectively. Taking the earthing into account, it can be divided into TN-S system and IT system as Figure 1 shows.

In the TN-S system, the midpoint connection (M) is directly connected to the protective earth (PE) while in the IT system, the midpoint connection is not directly connected to the protective earth (PE) and there are intentional (by design) or unintentional impedances which are between conductors and earth.

A list of differences between unipolar and bipolar systems can be seen in Table 1.



NOTE All IT systems will have impedances between conductors and earth. These impedances can be parasitic and poorly defined, or can be well designed.

Figure 1 – Unipolar, balanced and bipolar DC systems

Table 1 – Difference between unipolar and bipolar systems

Item	Unipolar	Bipolar
Cable utilization*	U^*I / 2 (U * I / 3 with PE)	2 U^* I / 3 (U^* I / 2 with PE)
Available operating voltage(s)	U+ nominal	U+ nominal, U- nominal, 2 U nominal
Maximum fault voltage	U nominal	2 U nominal
Protection and Control Complexity	Low	Higher High in case of multiple sources
Connectors	2-pin (3-pin with PE)	3-pin (4-pin with PE)
Switching and breakers	Single-pole	Double-pole
RCD	2-pole	3-pole
* Cable utilisation = (Max voltage to ground) × (Max conductor current) / (number of conductors)		

NOTE Both positive earthing and negative earthing are possible. However, the positive earthed system will introduce negative leakage currents, and in the case of very high voltages, the metal structure of DC systems including earthing conductors might become more brittle. On the other hand, the negative earthed system will introduce positive leakage currents that can result in corrosion issues.

4.3 Operation modes

4.3.1 Passive DC systems

In passive DC systems, most of the integrated sources, which need control objectives as an input from outside, can be either voltage source or current source. The control strategy of passive sources is frequently based on master-slave control and the energy balance margin of the system mostly relies on the capability of the voltage source. Normally, the voltage source is designed to support the power supply of the system. The system voltage can only vary within a narrow range under normal operating conditions.

4.3.2 Active DC systems

In active DC systems, nearly all the sources and loads are connected to the DC bus by self-controllable electronic devices. The control strategies of active sources are frequently based on drooped control and the energy balance of the system is realized automatically by tracing the U-I curves configured in the devices. In this case, the voltage can fluctuate in a wider range than that in passive DC systems, which is regarded as voltage band. The normal operation voltage band can be adjusted by different configurations of control parameters in devices. A wider voltage band brings higher technical requirements to the system and equipment.

5 LVDC voltage division

5.1 General

In active DC systems, the voltages are divided into different levels for temporary and continuous operation.

Between zero and maximum, the voltages are divided into 6 different stages: U_1 … U_6 and in the centre U_n for continuous and steady state operation.

To cover steady state and transient voltage levels, a matrix with all the voltages, voltage bands, operating states and areas is made. The matrix is presented in Figure 2.