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CONSOLIDATED VERSION

TECHNICAL REPORT

colour inside

Guideline for the system design of HVDC converter stations with line-commutated converters

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GUIDELINE FOR THE SYSTEM DESIGN OF HVDC CONVERTER STATIONS WITH LINE-COMMUTATED CONVERTERS

FOREWORD

This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC TR 63127 edition 1.1 contains the first edition (2019-06) [documents 115/195/DTR and 115/203/RVDTR] and its amendment 1 (2024-04) [documents 115/361/DTR and 115/364/RVDTR].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

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

IEC TR 63127, 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 document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document and its amendment 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- withdrawn, or
- revised.

IMPORTANT – The *'colour inside'* logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

HVDC is an established technology that has been in commercial use for more than 60 years. With the changes in demands due to evolving environmental needs, installation of HVDC systems has increased dramatically in the last 30 years and ~~almost~~ more than half of HVDC projects were commissioned after the year 2000. HVDC has become a common tool in the design of future global transmission systems.

HVDC systems transmit more electrical power over longer distances than a similar alternating current (AC) transmission system, which means fewer transmission lines are needed, saving both money and land and simplifying permissions. In addition to significantly lowering electrical losses over long distances, HVDC transmission is also very stable and easily controlled, and can stabilize and interconnect AC power networks that are otherwise incompatible. Typically line-commutated converter (LCC) HVDC systems provide unique or superior capabilities in the following aspects:

- long distance bulk power transmission;
- asynchronous interconnections;
- long distance cable;
- controllability;
- lower losses;
- environmental concerns;
- limitation of short-circuit currents.

Simply due to these technical merits, the market demand for HVDC transmission technology is spreading widely over the world. There are many HVDC power transmission systems with a DC voltage from 50 kV up to ~~660~~ 1 100 kV in different countries. ~~In addition, there are several ±800 kV HVDC power transmission systems which have been built or operated or which are under construction in China, India and Brazil. In 2016, one ±1 100 kV HVDC power transmission system project was started in China.~~

The fast development of the HVDC power transmission and distribution industry has been accompanied by IEC standardization work. More than 40 IEC documents, from DC equipment to DC systems, have been published. Among these, the IEC TR 60919 series, IEC 60633, IEC 60071-5, the IEC TR 62001 series and the IEC 60700 series provide essential information for the design and operation of HVDC power transmission systems.

However, this document provides only a basic guide and refers to typical numbers and examples. Other points and values may also be valid in particular cases and should also be considered accordingly.

GUIDELINE FOR THE SYSTEM DESIGN OF HVDC CONVERTER STATIONS WITH LINE-COMMUTATED CONVERTERS

1 Scope

System design is the basis of construction and operation of HVDC systems. It defines the overall philosophy for the HVDC transmission system and enables the ratings and specifications for the equipment integrated in the project.

This document focuses on the system design of converter stations. It is applicable to point-to-point and back-to-back HVDC systems based on line-commutated converter (LCC) technology.

This document provides guidance and supporting information on the procedure for system design and the technical issues involved in the system design of HVDC transmission projects for both purchaser and potential suppliers. It can be used as the basis for drafting a procurement specification and as a guide during project implementation.

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 60633, *High-voltage direct current (HVDC) transmission – Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60633 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

4 Symbols

4.1 Letter symbols for variables

U_d DC voltage between the pole and the neutral bus at the line side of the smoothing reactor

U_{dL} DC voltage of pole line to ground at the measuring point

I_d DC current

U_{dmeas} measured DC voltage

P_{ref} power setting at the line side of the smoothing reactor in the rectifier station

X_t commutation reactance, including converter transformer reactance and other reactance in the commutation circuit that will affect the commutation process

P_u on-load losses of converter transformer and smoothing reactor when a six-pulse converter is operating at rated capacity

R_{th} equivalent resistance of the voltage drop of the thyristor valve (current dependent resistance of the thyristors)

U_{dio} ideal no-load DC voltage of six-pulse converter

U_k relative converter transformer inductive voltage drop (short-circuit reactance)

U_{plc} relative voltage drop of AC PLC filter reactors

d_x relative inductive DC voltage drop of converter

d_r relative resistance DC voltage drop of converter

U_T forward voltage drop of converter valve under conducting state

d_{xtotR} total relative inductive DC voltage drop of converter – contains both commutation circuit reactance and the system impedance converted onto valve side

P_{dc} active power of converters

Q_{conv} reactive power consumption of individual converter

Q_f reactive power supplied by filters

S_{SC} short-circuit capacity of AC bus

R_d total resistance of DC transmission line at each pole

R_e resistance of electrode

R_g resistance of electrode line

S_n rated capacity of a three-phase converter transformer connected to a six-pulse valve group

S_{n3w} rated capacity of a single-phase three-winding converter transformer connected to a 12-pulse valve group

S_{n2w} rated capacity of a single-phase two-winding converter transformer connected to a 12-pulse valve group

U_v valve side line voltage of converter transformer

I_v valve side line current of converter transformer

U_l line voltage of line side of converter transformer

n_{nom} rated ratio of converter transformer at normal tap position

η needed OLTC range of converter transformer

$\Delta\eta$ step size of converter transformer OLTC

L_d total inductance from DC side

L_{dr} smoothing reactor inductance

L_{tr} converter transformer inductance per phase

μ overlap angle

α	delay angle
γ	extinction angle
Q_{total}	total reactive power supplied by AC filters and shunt capacitors at normal voltage
Q_{sb}	reactive power supplied by the largest AC filter or shunt capacitor sub-bank at normal voltage
Q_{ac}	reactive power supplied by AC system (negative value means the capability to supply reactive power by AC system)
Q_{dc}	reactive power consumption of converters
K_{v}	voltage correction factor, normally 0,95 to 1,05
Q_{r}	total reactive power absorbed by the shunt reactors of converter station at normal AC voltage
Q_{fmin}	capacity of the minimum filter combination which shall be switched in to meet the harmonic performance requirement at normal AC voltage
ΔU_{AC}	dynamic voltage change because of sub-bank switching
Q_{filter}	reactive power capacity of the filter or shunt capacitor sub-bank to be switched
$\sum Q_{\text{filter}}$	reactive power capacity of the filter or shunt capacitor sub-banks in operation after switching
ΔQ_{dc}	change of reactive power consumption of converters due to sub-bank switching, which sometimes can be ignored

4.2 Subscripts

N	normal value of the variables
R	value of rectifier side
I	value of inverter side
max	maximum value of the variable
min	minimum value of the variable

5 Overview of HVDC system design

5.1 General

In implementing HVDC projects, the purchaser or the supplier will do preliminary system design work to prepare the various required documents needed by the project. Specific studies and simulations are conducted during the system design to find the optimal project schemes and to demonstrate performance. As a minimum, the following main system features should be determined:

- HVDC system ratings;
- HVDC system operation configurations and control modes;
- reactive power compensation and control;
- harmonic filtering;
- AC/DC interaction and control;
- insulation coordination;
- environmental impacts, such as audible noise, electromagnetic fields, etc.

The system design may be conducted in several phases by different parties, such as purchaser or supplier, during planning, bidding, detailed design stages, for example, as shown in Figure 1. Different tools and models may be introduced in the system design because of different targets or designs at each stage. One should be very careful to adopt the tools and models in a coordinated manner.

A functional specification for the project is usually prepared by the purchaser before the detailed design. It may consist of project objectives and conditions, grid codes, targeted system performance requirements and operation regulations, etc. This functional specification should be treated as both providing inputs and the guide for the system design of an HVDC project. Because the final technology solution is undefined before the detail design stage, it is always necessary to reserve adequate space in the functional specification for further optimization. The owner will issue the specification as a document for bidding if this is a turn-key project. After evaluation of bidding for the specific technology solution, especially for HVDC control, the owner may choose the appropriate solution. Thus, the system features listed above will be studied in more detail based on the chosen technology solution and some additional studies and surveys usually need to be performed to finalize the system design. Finally, all the equipment ratings and specifications will be prepared.

The flowchart of an HVDC system design is summarized in Figure 1.

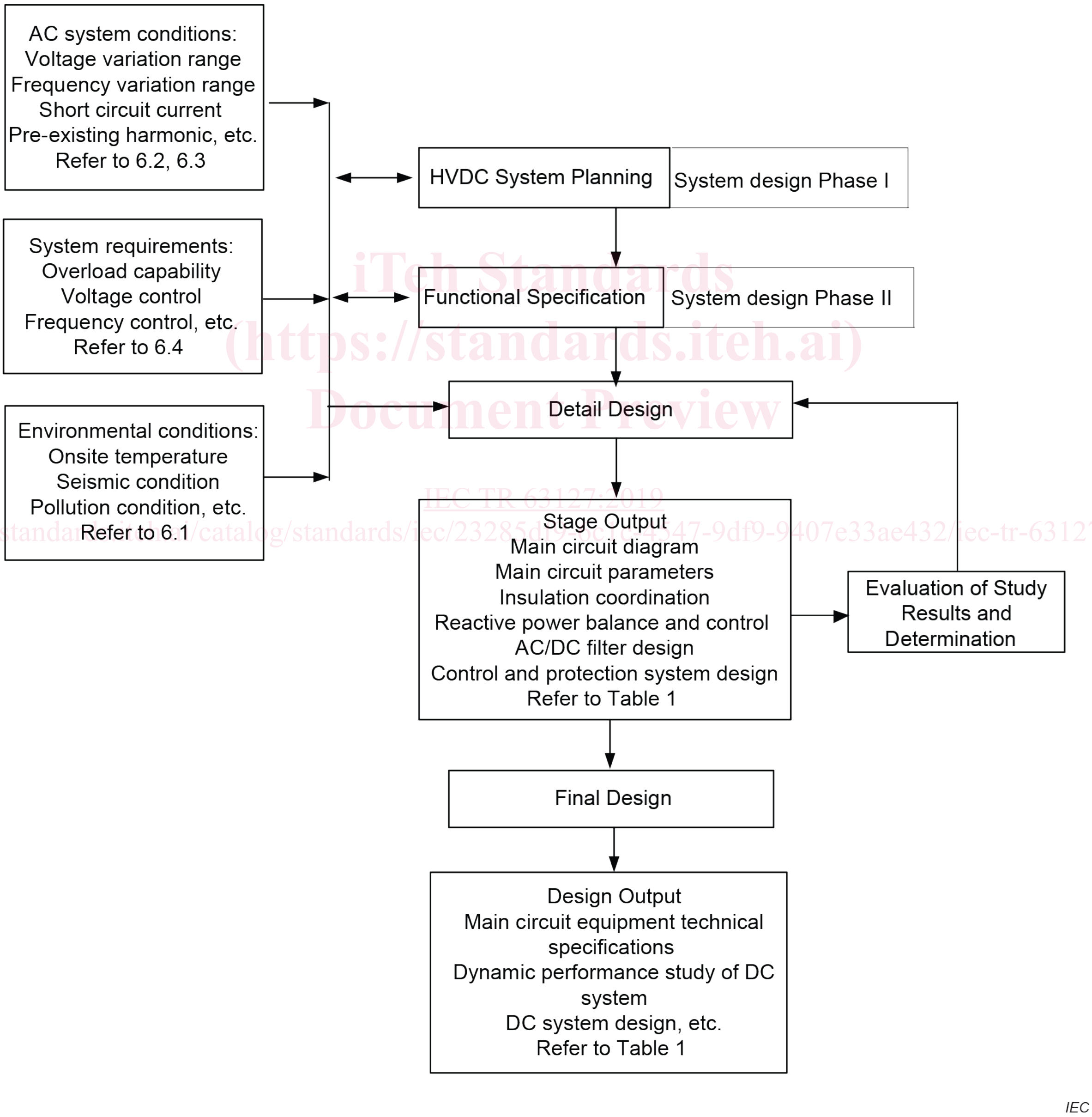

Figure 1 – System design in an HVDC project