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Technical Guidelines for Radial HVDC Networks

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Technical Guidelines for Radial HVDC Networks

Directives techniques pour les réseaux HVDC radiaux

Technischer Leitfaden für radiale HGÜ-Netze

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

This document (CLC/TR 50609:2014) has been prepared by CLC/TC 8X "System aspects of electrical energy supply".

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association.

This document was already sent out within CLC/TC 8X for comments and the comments received were discussed within CLC/TC 8X/WG 06 and were incorporated in the current document as far as appropriate.

0 Introduction

0.1 The European HVDC Grid Study Group

Existing power systems in Europe have been developing for more than 100 years to transmit the power, generated mainly by fossil and nuclear power plants to the loads. Climate change, limited fossil resources and concerns over the security of nuclear power are drivers for an increased utilization of renewable sources, such as wind and solar, to realize a sustainable energy supply. According to the geological conditions, the location of large scale renewable energy sources is different to the location of existing conventional power plants and imposes new challenges for the electric power transmission networks, such as extended transmission capacity requirements over long distances, load flow control and system stability. The excellent bulk power long distance transmission capabilities, low transmission losses and precise power flow control make High Voltage Direct Current (HVDC) the key transmission technology for mastering these challenges, in particular for connection of offshore wind power plants to the onshore transmission systems.

While the power system reinforcement is already underway by a number of new point-to-point HVDC interconnections, the advantages offered by multiterminal HVDC systems and HVDC grids become more and more attractive. Examples are grid access projects connecting various wind power plants or combining wind plants with point-to-point transmission, e.g. in the North and Baltic Seas. Multiterminal projects are already in execution and there is planning for pan-European HVDC grids. In this document, multiterminal HVDC systems and HVDC grids are referred to as HVDC Grid Systems.

To become reality, HVDC Grid Systems need, in addition to the necessary political framework for cross country system design, construction and operation, competitive supply chains of equipment capable of operating together as an integrated system. This marks a significant change in the HVDC technology market. While today - with very few exceptions – a HVDC transmission system has been provided by a single manufacturer, future HVDC Grid Systems will be built step by step composed of converters and HVDC substations supplied by different manufacturers. Interoperability will thus become a fundamental requirement for future HVDC technology.

Common understanding of basic operating and design principles of HVDC Grid Systems is seen as a first step towards multi vendor systems, as it will help the development for the next round of European multiterminal projects. Furthermore, it will prepare the ground for more detailed standardization work.

Based on an initiative by the DKE German Commission for Electrical, Electronic and Information Technologies, the European HVDC Grid Study Group has been founded in September 2010 to develop “Technical Guidelines for first HVDC Grids”. The Study Group has the following objectives:

- to describe basic principles of HVDC grids with the focus on near term applications;
- to develop functional specifications of the main equipment and HVDC grid controllers;
- to develop “New Work Item Proposals” to be offered to CENELEC for starting standardization work.

CIGRÉ SC B4, CENELEC TC8x and ENTSO-E and “Friends of the Supergrid” are involved at an informative level with the results of the work.

Members affiliated with the following companies and organizations have been actively contributing to the results of the Study Group achieved so far: 50 Hz Transmission, ABB, ALSTOM, Amprion, DKE, TransnetBW, Energinet.dk, ETH Zurich, National Grid, Nexans, Prysmian, SEK, Siemens, TenneT and TU Darmstadt.

As a starting point the Study Group has been investigating typical applications and performance requirements of HVDC Grid Systems. This information helps elaborating the basic principles of HVDC networks, which are described in the following clauses:

- Clause 3, Typical Applications of HVDC Grids;
- Clause 4, Principles of DC Load Flow;
- Clause 5, Short-Circuit Currents and Earthing;
- Clause 6, Principles of HVDC Grid Protection.

From the technical principles described, functional specifications for the main equipment of HVDC networks are derived and summarized in Clause 7.

0.2 Technology

0.2.1 Converters

HVDC transmission started more than 60 years ago. Today, the installed HVDC transmission capacity exceeds 200 GW worldwide. The vast majority of the existing HVDC links are based on so-called Line-Commutated-Converters (LCC). LCC today are built from Thyristors. The power exchange of such converters is determined by controlling the point-on-wave of valve turn-on, while the turn-off occurs due to the natural zero crossing of valve current forced by the AC network voltage. That is why LCC rely on relatively strong AC systems to provide conversion from AC to DC and vice versa.

With so-called Voltage Sourced Converters (VSC), a different type of converters has been introduced to HVDC transmission slightly more than a decade ago. VSCs today utilize Insulated Gate Bipolar Transistors (IGBT) as the main switching elements. IGBTs have controlled turn-on as well as turn-off capability making the VSCs capable of operating under weak AC system conditions or supplying power systems where there is no other voltage source, also referred to as passive networks.

The evolution of VSC transmission was started with so-called Two-Level converters at the end of the 1990s and has commenced to Three Level Converters and further to Modular Multilevel Converters (MMC) which have made their break-through in the mid to late 2000s. All MMC type converters apply the same principle of connecting a number of identical converter building blocks in series. However, at the present time there are basically two types of such building blocks: referred to as Half-Bridge (HB) and Full-Bridge (FB) modules.

Other converter equipment which have been proposed for HVDC Grid applications, such as DC/DC converters, load flow controllers, etc. are not discussed in this document.

0.2.2 DC Circuit

Similar to AC networks, HVDC transmission systems can be distinguished by their network topologies as radial and/or meshed networks and with respect to earthing in effectively grounded and isolated systems. Both aspects influence the design criteria and the behaviour of the HVDC system.

– Radial and Meshed Topologies:

In radial systems, there is not more than one connection between two arbitrary nodes of the network. The DC voltages of the converter stations connected to each end of a line solely determine the power flow through that line, for example in Figure 1-1, station C is radially connected with station D.

In meshed systems, at least two converter stations have more than one connecting path. Without any additional measures the current through a line will then be determined by the DC voltages of the converter stations as well as the resistances of the parallel connections. In Figure 1-1, the DC circuit connecting stations A, B and C forms a meshed system while C and D is a radial connection. A HVDC Grid System having a meshed topology can be operated as a radial system if parallel connections are opened by disconnectors or breakers.

Figure 1-1 — Example of an HVDC Grid System having a meshed and radial structure

– Earthing:

DC circuits can be effectively grounded if one DC pole is connected to earth through a low ohmic branch. Such systems are also referred to as asymmetrical Monopoles or just “Monopoles”. Two Monopoles of opposite DC voltage polarity are often combined into so-called bipolar systems or just “Bipoles”.

Isolated DC circuits do not have a low ohmic connection to ground on the DC side. These configurations are also referred to as “Symmetrical Monopoles”.

0.2.3 Technological Focus of the European HVDC Grid Study Group

Various technologies are available for building HVDC Grid Systems. Some of them have already been used in commercial projects; others are in the demonstration phase or are in an early stage of discussion. This applies to the converter technology as well as the topologies of connecting them into a HVDC Grid System.

Serving the near term applications, the Study Group decided to focus its scope of work on radial HVDC network structures as well as pure VSC based solutions. Both grounded and ungrounded DC circuits are considered.

The integration of HVDC Grid Systems is seen as an important part of developing future electric power systems. The Study Group bases its work on typical requirements applied to state of the art HVDC converter stations today and investigates aspects that are specifically related to the design and operation of converter stations and DC circuits. The requirements from the AC systems as known today are included. Secondary effects associated with changing the AC systems, e.g. the replacement of rotating machines by power electronic devices, are not within the scope of the Study Group.

The Study Group report summarizes the selected results of work and gives recommendations for the next steps towards preparing the ground for standardization of HVDC multiterminal systems and HVDC Grid Systems.

The interface requirements and functional specifications given in this document are intended to support the specification and purchase of multi vendor multiterminal HVDC Grid Systems.

1 Scope

This Technical Report applies to HVDC Systems having more than two converter stations connected to a common DC network, also referred to as HVDC Grid Systems. Serving the near term applications, this report describes radial HVDC network structures as well as pure VSC based solutions. Both grounded and ungrounded DC circuits are considered.

Based on typical requirements applied to state of the art HVDC converter stations today this report addresses aspects that are specifically related to the design and operation of converter stations and DC circuits in HVDC Grid Systems. The requirements from the AC systems as known today are included. Secondary effects associated with changing the AC systems, e.g. the replacement of rotating machines by power electronic devices, are not within the scope of the present report.

The report summarizes applications and concepts of HVDC Grid Systems with the purpose of preparing the ground for standardization of such systems.

The interface requirements and functional specifications given in this document are intended to support the specification and purchase of multi-vendor multiterminal HVDC Grid Systems.

2 Terminology and abbreviations

2.1 General

In the work undertaken here it has been identified that a common list of terminology and abbreviations used specifically to describe HVDC Grids should be established.

The International Electrotechnical Commission (IEC) standard EN 60633 [1] describes General Terminology for HVDC Transmission and is the reference for common terms and abbreviations. Furthermore EN 62501 [2] describes electrical testing of VSC. A new proposed work item in IEC is to develop terminology for VSC HVDC systems. In addition CIGRÉ has published a brochure 269 on basic operational principles of VSC-HVDC [3]. Specific terms required for components and methods for multiterminal HVDC Transmission, e.g. HVDC breakers and control modes, are described here.

The Study Group has established information exchange established with the ongoing CIGRÉ B4.52 feasibility study on DC Grids. Also in the CIGRÉ work, new terms used to describe phenomena and components in DC grids are used. The terminology used in this report corresponds to the terminology used in the CIGRÉ working group.

2.2 Terminology and abbreviations for HVDC Grid Systems used in this report

AC	Alternating Current
DC	Direct Current
ENTSO-E	European Network of Transmission System Operators for Electricity
FB	Full Bridge
GW	Giga Watts

HB	Half Bridge
HSS	High Speed Switch
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IGBT	Insulated Gate Bipolar Transistor
LCC	Line Commutated Converter
MMC	Modular Multilevel Converter
OHL	Overhead transmission line
PCC AC	Point of common coupling (ac side)
PCC DC	Point of common coupling (dc side)
TRV	Transient Recovery Voltage
TSO	Transmission System Operator
VCD•	Voltage-current droop
VPD•	Voltage-power droop
VPDDB•	Voltage-power droop together with dead band
VSC	Voltage Sourced Converter

2.3 Proposed Terminology by the Study Group

– Converter Station Controller — A controller determining the voltages and currents at DC and AC terminals of its converter station.

4.2.2, Converter Station Controller

– Dynamic Braking Device — A controllable branch absorbing energy from the DC circuit.

7.2.2.2, Energy absorption capability (Dynamic Braking Device)

– HVDC Grid Controller — A high level controller linked to each individual Converter Station Controller

4.2.3, HVDC Grid Controller