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PRE-STANDARD

DC transmission using voltage sourced converters

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This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document:

Draft PAS	Report on voting
22F/129/NP	22F/148/RVN

Following publication of this PAS, which is a pre-standard publication, the technical committee or subcommittee concerned will investigate the possibility of transforming it into an International Standard.

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DC TRANSMISSION USING VOLTAGE SOURCED CONVERTERS

INTRODUCTION

HVDC transmission was first put into commercial service in 1954 and has since been used extensively for the interconnection of asynchronous a.c. networks and for the transmission of power over long distances. The switching elements used for the conversion between a.c. and d.c. were able to switch on as commanded, but depended on a naturally occurring current zero for the turn-off process. Thus the technology relies on the presence of an a.c. voltage in the network for the commutation process, and is known as line commutated converter (LCC) HVDC technology. In this PAS, it will be referred to as LCC HVDC. This technology is still used extensively for HVDC transmission. LCC HVDC schemes installed by the end of 2004 have a total rating in excess of 60 GW, with more being added each year.

The use of voltage sourced converters for d.c. power transmission (VSC transmission) was introduced with the commissioning in 1997 of the 3MW, ± 10kVd.c. technology demonstrator at Hellsjön, Sweden. VSC transmission enables reliable and controllable power transfer between networks. In principle, the operation of its converters (rectifier and inverter) at the two ends of the VSC transmission does not rely on the strength of the connected a.c. systems. Furthermore, it provides independent control of the reactive power at the two ends and independently of the active power transfer over the d.c. transmission.

The object of this PAS is to describe the VSC transmission technology, with a particular view to the issues to be considered when it is applied at voltages above 100 kVdc, and power in excess of 100 MW. It provides information about the equipment included in a VSC transmission scheme, as well as the characteristics and performance that can be expected.

The information presented here is aimed at several groups of people:

- transmission network owners/operators planning to build a VSC transmission scheme;
- those involved in the specification of a VSC transmission scheme, for example transmission or distribution network owners/operators;
- investors considering inter-connectors and other merchant transmission links;
- anyone wanting to know more about the VSC transmission technology.

Some readers may have technical interests and some may have non-technical interests. Therefore, this PAS has been structured in such a way that different needs can be met by reading selected sections.

For readers without particular interest in the detailed technical issues, the chapters of greatest interest are:

Chapter 2 VSC Transmission Applications
Chapter 10 Environmental Impact
Chapter 13 Life Cycle Cost
Chapter 14 Comparison of Line Commutated Converter and VSC

For readers wanting a deeper insight into the VSC transmission technology, but without knowledge of LCC HVDC technology, it may be advantageous to read Appendix C before reading the rest of the PAS.

OVERVIEW OF VSC TRANSMISSION TECHNOLOGY

Since its introduction in the early 1950s, LCC HVDC technology has undergone continuous development, particularly in the areas of converter switches and controls. Today LCC HVDC schemes provide reliable, efficient and cost-effective solutions for many applications. The use of modern techniques have made it possible to obtain stable operation for LCC HVDC schemes connected to much weaker a.c. networks than previously.

Other fields of power electronics, such as industrial drives, have contributed to the development of new semiconductor devices, because the quantity of devices produced each year for these applications can be many times the number required for HVDC schemes. Motor drives have, over the years, moved on from using line-commutated converters to the use of voltage sourced converters (VSC) with pulse width modulation (PWM) control, which results in compact and more controllable drives. Usually such drives operate at relatively low a.c. and d.c. voltage and do not use series-connected semiconductors.

The 3-MW Hellsjön VSC transmission installation put into service in Sweden in 1997 was an extension of modern motor drive technology. To reach a transmission voltage of 10 kVdc, however, series-connected semiconductors were required. The trial installation proved the feasibility of the technology and demonstrated its superior technical capability when compared to LCC HVDC. Subsequently, more schemes have been installed, with the largest in service at the end of 2004 having a rating of 330 MW and ±150 kVdc. CIGRÉ has given this new type of d.c. transmission the name VSC transmission.

VSC transmission has a number of technical features that are superior to those of LCC HVDC schemes and make it especially attractive for the following applications:

- feeding into passive networks;
- transmission to/from weak a.c. systems;
- enhancement of an a.c. system;
- land cable systems;
- supply of offshore loads;
- connection to wind far.m.s (on-shore or off-shore) or wave power generation;
- in-feeds to city centres;
- multi-terminal systems.

Continuing developments in semiconductors and VSC transmission technology are likely to make VSC transmission attractive in an increasing number of applications as research and development efforts continue to bring down the capital cost and power losses of the converters.

OVERVIEW OF THIS PAS

This PAS consists of 16 chapters and three appendices.

Chapter 1 provides a list of definitions of symbols and terms introduced in the PAS. Where possible, the terminology for high-voltage direct current (HVDC) transmission, as defined in IEC 60633, has been used. The definitions included in Chapter 1 have been limited to those which are new, as far as HVDC transmission is concerned.

Chapter 2 describes a VSC transmission scheme as a black box and outlines the main characteristics of a VSC transmission scheme, in particular the principles of active and reactive power control, and its operational characteristics. The chapter also outlines potential applications and the present status of VSC transmission technology.

Chapter 3 presents the operational characteristics of a VSC transmission scheme in greater detail, starting from the operation of a 2-level converter. The basic characteristics of 3-level and multi-level converters are described, as well as the use of pulse width modulation (PWM).

Chapter 4 describes different converter topologies which may be used for VSC transmission. Simplified circuit diagrams are given for each of these topologies, along with their waveshapes.

Chapter 5 gives an overview of the switches, called VSC valves, which are used to convert between a.c. and d.c. The chapter includes a description of the various semiconductors that could be used for a VSC valve, and outlines the design considerations for a high-voltage VSC valve.

Chapter 6 presents a typical power circuit diagram for a VSC substation and outlines the characteristics of the other major power equipment that may be used.

Chapter 7 discusses the different modes of control that can be used for a VSC transmission scheme, as well as the information needs and performance required. A possible hierarchy of controls is described, followed by a discussion of the controls for a number of different applications.

Chapter 8 discusses the fault performance and protection requirements for a VSC transmission scheme. It outlines the mechanisms leading to different faults and their consequences. Faults (and transients) within the converter on the a.c. and the d.c. side are discussed.

Chapter 9 describes the harmonics generated by a VSC substation and various methods that can be adopted to minimise the need for filtering, including the use of multi-level or multi-pulse converters and PWM switching. The consequences of harmonics in power networks are outlined, and the design of a.c. and d.c. harmonic filters is presented.

Chapter 10 covers the environmental impact of a VSC substation. The topics include audible noise, electric and magnetic fields (EMF), and radio-frequency interference (RFI).

Chapter 11 discusses the studies that may be performed as part of the planning and implementation of a VSC transmission scheme. The studies include those needed as background to the investment decision, those required for the tender exercise, and those for the simulation of critical system tests.

Chapter 12 gives a brief overview of the testing and commissioning associated with a VSC transmission scheme. The process to be followed is very similar to that used for HVDC or FACTS.

Chapter 13 outlines the life-cycle cost of a VSC transmission scheme, including capital cost, power losses, maintenance, disposal costs, refurbishment and cost of unavailability.

Chapter 14 provides a brief comparison of LCC HVDC and VSC transmission.

Chapter 15 looks ahead to the next generation of semiconductors and outlines developments that could further improve the characteristics of the VSC transmission technology and lead to an increase in the number of installed VSC schemes.
Chapter 16 is a brief conclusion.

Appendix A gives a list of VSC transmission schemes in operation at the end of 2004.

Appendix B provides a guideline for a functional specification of a VSC transmission scheme.

Appendix C presents a brief overview of LCC HVDC transmission and is primarily intended for readers who have little or no knowledge of this technology. A list of all LCC HVDC schemes in service at the end of 2004 is included.

DC TRANSMISSION USING VOLTAGE SOURCED CONVERTERS

1. SCOPE

The object of this PAS is to describe the VSC transmission technology, with a particular view to the issues to be considered when it is applied at voltages above 100 kVdc, and power in excess of 100 MW. It provides information about the equipment included in a VSC transmission scheme, as well as the characteristics and performance that can be expected.

1.1 Introduction

This PAS uses the terminology established by IEC 60633 [1-1]. However, due to the differences in converter technology and operating characteristics of voltage sourced converters (VSC) compared to line-commutated converters (LCC), it was felt to be appropriate to define some new terms used in this PAS. Those terms that are either identical to, or obvious extensions, of the IEC 60633 terminology have not been defined.

To support the explanations, Figure 1.1 presents the basic diagram of a VSC substation.

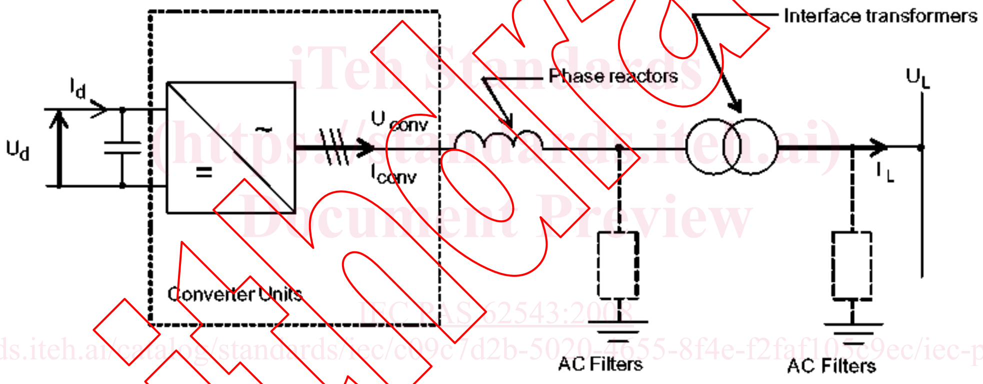

Figure 1.1- Basic diagram of a VSC substation

For the purpose of this PAS, the symbol for a VSC valve is shown in Figure 1.2.

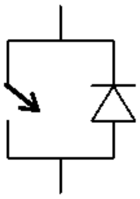

Figure 1.2 - Symbol of a VSC valve as used in this PAS

1.2 List of Letter Symbols

U_{conv}	Line-to-line a.c. voltage of the converter unit(s), r.m.s value, including harmonics
I_{conv}	Alternating current of the converter unit(s), r.m.s value, including harmonics

1.3 GENERAL TERMS AND DEFINITIONS RELATED TO CONVERTER CIRCUITS AND POLE TOPOLOGIES FOR VSC CIRCUITS

1.3.1 VSC Transmission

A high-voltage d.c. transmission system in which the conversion between a.c. and dc and vice versa is performed by means of voltage sourced converters.

1.3.2 VSC Phase Unit

The equipment used to connect the two d.c. busbars to one a.c. terminal.

> **Note**: In the simplest implementation, the VSC phase unit consists of two VSC valves. It may also include control and protection equipment and other components.

1.3.3 VSC Unit

System consisting of three VSC phase units, together with VSC unit control equipment, essential protective and switching devices and auxiliaries, if any, used for conversion.

1.3.4 VSC Substation

Part of a VSC transmission scheme, consisting of one or more VSC unit(s) installed in a single location together with buildings, VSC d.c. capacitors, reactors, transformers, filters, control, monitoring, protective, measuring and auxiliary equipment, as applicable.

1.3.5 Two-Level Converter

A converter in which the voltage at the a.c. terminals of the VSC unit is switched between two discrete d.c. voltage levels.

1.3.6 Three-Level Converter

A converter in which the voltage at the a.c. terminals of the VSC unit is switched between three discrete d.c. voltage levels.

1.3.7 Multi-Level Converter

A converter in which the voltage at the a.c. terminals of the VSC unit is switched between more than three discrete d.c. voltage levels.

1.3.8 VSC Pulse Number p

Characteristic of a VSC unit connection expressed as the number of non-simultaneous symmetrical commutations occurring during one cycle of the a.c. line voltage, assuming the valves in each VSC unit are controlled to achieve full wave rectification/inversion.