VSC-HVDC System for Performance Enhancement

Mr. Niraj Dhananjay Gondhalekar [1]

Ms. Deepa Kotur [2]

Ms. Anwesha Sengupta [3]

M. Tech Power Electronics and Drives[1,2,3]
VIT, Chennai Campus, Chennai[1,2,3]

Dr. (Mrs.) Sonali R Dasgupta [4]
Associate Professor[4]
VIT, Chennai Campus, Chennai[4]

ABSTRACT

Voltage Source Converter (VSC) based HVDC is the most recent HVDC technology with extruded DC cables in small and medium power transmission. VSC-HVDC converters include Insulated Gate Bipolar Transistors (IGBT'S) and operated with high frequency Pulse Width Modulation (PWM) in order to get high speed control of both active and reactive power. This paper gives the details of existing VSC-HVDC project in the world. This paper also highlights the different characteristic of VSC-HVDC system and its need for now a day problem of transmission & interconnection.

Keywords: AC-DC power conversion, HVDC converters, Insulated gate bipolar transistors.

I. INTRODUCTION

The VSC option provides several unique options in order to support the AC power grid in addition to the energy transfer [1]. The conventional HVDC transmission is based on line commutated, current-source converters demanding a synchronous voltage source at both sides of the converters [2]. The conversion process demands reactive power through filters, shunt banks, which usually are part of the converter station. Any kind of excessive or shortage within reactive power must be accommodated through the ac system. VSC-HVDC avoids these kinds of requirements as well as offers additional advantages due to the possibility of independently controlling both active and reactive power [3].

VSC-HVDC is the effective as well as environmentally-friendly [4] technique in order to design a power transmission system for the purpose of a submarine cable, an underground cable or back-to-back transmission.

VSC-HVDC cables have extruded polymer insulation [8]. Their strength and flexibility make the VSC-HVDC cables well suited for several installation conditions both underground as a land cable or as a submarine as shown in figure 1.2. In the VSC-HVDC transmission schemes, the switching of the IGBT valves follows a pulse width modulation (PWM) pattern with a frequency in the kHz range as per the figure 1.1.

This switching control allows simultaneous adjustment of the amplitude and phase angle of the converter [9].

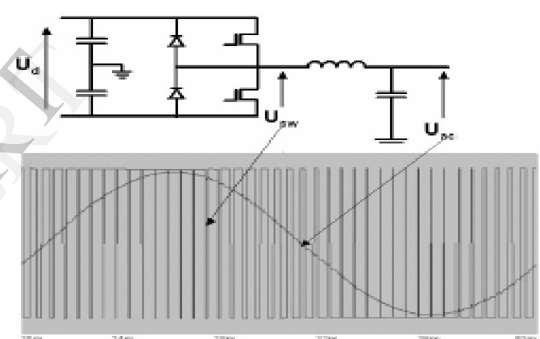

Figure 1.1 Single line Diagram of VSC-HVDC Converters [9].

Figure 1.2 VSC-HVDC Cable [8]

Figure 1.3 VSC-HVDC Converter Station [9]

In this paper section II highlights the basic concept of VSC-HVDC operation. In section III the comparison is made between HVDC current control method and voltage control method. Section IV gives the details of existing VSC-HVDC project in the world. Section V summaries the feature of VSC-HVDC system, and in section VI the conclusion is made.

II HVDC transmission using forced commutated voltage – source converters (VSC-HVDC System)

A new version involved with HVDC system was developed in the course of the 1990s based upon Forced Commutated Voltage Source Converters (VSC).

The Forced Commutated Voltage Source Converter (VSC) is based on turn-off devices as switching elements like IGBTs instead of thyristors. The utilization of high power VSCs for HVDC is intended possible with the advancement of such type of high power turn-off device and also the possibility to connect them in series [9].

2.1 Two and three level-converter bridge

The particular two-level bridge, displayed in Figure 2.1, is considered the most basic circuit layout, which is often utilized in order to develop a three - phase, Forced Commutated VSC bridge. The particular bridge is comprised of six valves and each valve consists of a turn-off semi-conductor along with an anti parallel diode. To operate the two level bridge in high power applications series connection of semi-conductors could be essential and then suddenly each one valve are going to be built up associated with a number of series connected turn-off devices along with anti parallel diodes. The actual number of devices required is dependent upon the actual rated power of the bridge as well as the power handling capacity of the switching devices used.

The three-level bridge is certainly an interesting replacement for the two level bridge found in high power applications in the perception of the fact that phase potentials is usually modulated between three levels instead of two. The harmonic content in the bridge voltage in the three-level bridge is actually decreased for an even switching.

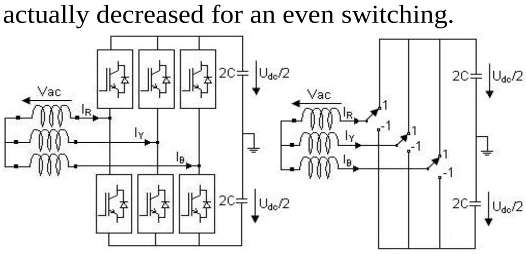

Figure 2.1 Two level VSC topology with switch representation.

2.2 Consideration regarding losses in Voltage Source Converter

One of the major drawbacks associated with today's Voltage Source Converters designed for bulk power transmission is the moderately high power losses [10]. The losses of the VSC-based HVDC converters are usually higher in comparison with the conventional HVDC solution using Line Commutated Converters. The 2-level VSC is attractive because of its simplicity, although, the switching frequency must be then chosen comparatively high in order to maintain the current ripple reasonably low, unfavorable lead to high switching losses. One method of lowering the losses is to apply more complex converter topologies at the expense of simplicity [11]. The 3-level converter may be the option with regard to this purpose. It is usually predicted that a substantial loss improvement might be achieved in the foreseeable future by utilizing new semiconductor materials such as SiC. Table 2.2 illustrates a comparison regarding typical converter station losses for different form of converters operating at 1 pu power, assuming the present manufacturing technology of IGBTs and also for thyristor valves.

Table 2.2 Typical Losses for Different Types of HVDC Converters

2 Level VSC	>3%
3 Level VSC	Range [1% to 2%]
Classical converter	~0.5%

III A comparison is between the conventional HVDC and VSC-HVDC System.

Even though appearing quite similar at a first glance conventional HVDC and VSC-HVDC possess a generic difference providing VSC-HVDC distinctive properties.

Basically conventional HVDC can be describe as a DC current based transmission. The rectifier end takes current from one phase, and transfers it in the DC line, and then the inverter forces it in to the proper phase at the receiving end. That is displayed in Figure 3.1 The DC link relies upon on the receiving end voltage in order to determine towards which phase it should direct the current, we say that this requires short circuit capacity. The return path will be controlled similarly closing the current direction. Both the inversion as well as rectification demands reactive power which can be provided locally through filtration systems along with reactive compensation.

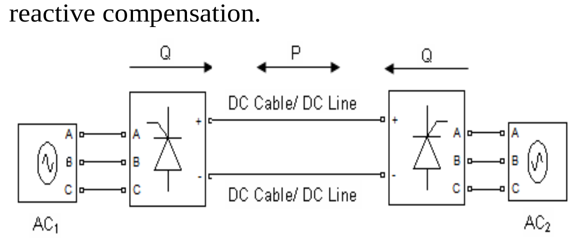

Figure 3.1 Simple model of Conventional HVDC

VSC-HVDC performs through the DC voltage and it is therefore a DC Voltage based transmission. Through switching between the two extremisms associated with DC voltage can get average any voltage in between. By applying unique switching patterns we can easily create a sinusoidal voltage.

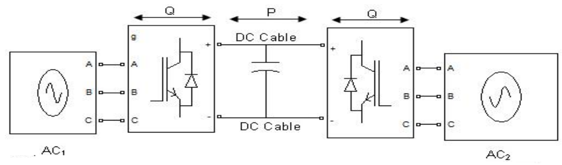

Figure 3.2 Simple model of VSC – HVDC

With the rapid innovation on power semiconductors, thyristors with phase commutation are replaced by IGBT with pulse width modulation [1], [2].

IV VSC-HVDC Based project in world

1) Cross Sound Cable

Cross Sound Cable is a VSC underwater cable link between Connecticut and Long Island, New York. The system is made up of high-tech extruded (oil-free) cables buried under the seabed, with a converter station at New Haven, it is a 330 MW, 40-kilometer VSC transmission system. The Cross-Sound link improves the reliability of power supply in the Connecticut and New England power grids, while providing urgently needed electricity to Long Island.


Figure 4.1 Overview of the Shoreham station [16]

Main Data:	
Commissioning year:	2002
Power rating:	330 MW
No of circuits:	1
AC Voltage:	345KV(New Heaven) 138 KV(Shoreham)
DC Voltage:	±150 KV
Length of DC submarine cable:	2 x 40 km
Main reason for choosing VSC:	Controlled connection for power exchange. Submarine cables.

2) Murray Link

This is a second VSC project in Australia. The Murray link 220 MW interconnector between the River land in South Australia and Sunraysia in Victoria is a 180 kilometer underground high-voltage power link. Murray link is believed to be the world's longest under-ground transmission system. Murray link benefits both South Australia and Victoria by enabling electricity trading in Australia's deregulating power market.

Main Data:	
Commissioning year:	2002
Power rating:	220MW
No of circuits:	1
AC Voltage:	132KV(Berri) / 220 KV(Berry)
DC Voltage:	±150 KV
Length of DC submarine cable:	2 x 180 km
Main reason for choosing VSC:	Controlled connection for trading.

3) Estlink

The Estlink VSC link is one of the EU priority projects for the Trans-European Network. Estlink is owned by a special purpose company: Nordic Energy Link AS. [17]. The link crosses the Gulf of Finland and connect to substations near Tallinn and Helsinki. The whole link is underground or underwater by high-tech extruded (oil-free) VSC cables; there are no overhead lines. Estlink is the latest part of the Baltic ring. It allows for power exchange between the Baltic countries (Estonia, Latvia and Lithuania) and the Nordic grid [16].


Figure 4.2 Harku station [16]

Main Data:	
Commissioning year:	2006
Power rating:	350 MW
No of circuits:	1
AC Voltage:	132KV(Estonia) 220KV(Finland)
DC Voltage:	±150 KV
Length of DC underground cable:	2 x 31 km
Length of DC submarine cable:	2 x 74 km
Main reason for choosing VSC:	Length of land cable, sea crossing and Non Synchronous AC System.

4) Eagle Pass

The VSC installation in Eagle Pass mitigates voltage instability, and at the same time allows power exchange between the U.S. and Mexico [3]. A 36 MVA back-to-back VSC was installed at Eagle Pass, Texas by Central Power and Light Company (CPL), a subsidiary of American Electric Power Company (AEP). The project was executed jointly by EPRI, AEP, and ABB. Eagle Pass load is served by two 138 kV transmission lines and due to load growth the area is prone to voltage instability following transmission contingencies during peak load periods, reducing the reliability of power delivery on the U.S. side of the border.

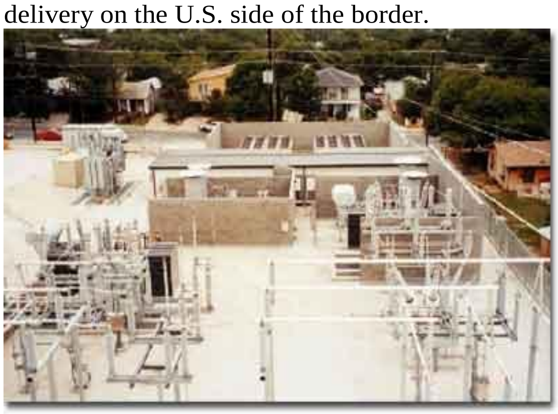

Figure 4.3 over view of Eagle Pass VSC - HVDC station [16]

5) Direct Link

Direct Link, Australia, a 65-kilometer long, 60-megawatt VSC underground transmission system, consisting of three parallel 60 mega-volt ampere links connecting the regional power markets of New South Wales and Queensland [3]. The flow of power is precisely defined, controlled and delivered to the highest-value regional market. Direct link is a 180 MVA VSC project, consisting of three parallel 60 MVA transmission links that connect the regional electricity markets of New South Wales and Queensland. Direct link is a non-regulated project, operating as a generator by delivering energy to the highest value regional market [17]. The Direct link project features three innovations which minimize its environmental, aesthetic and commercial Impact: the cable is buried underground for the entire 65 km, it is an entrepreneurial project; it was paid for by its developers; and the flow of energy over VSC facilities can be precisely defined and controlled.

Main Data:	
Commissioning year:	2000
Power rating:	180 MW
No of circuits:	1
DC Voltage:	±80 KV
Length of cable:	6 x 65 km
Type of link:	Back to Back VSC station
Main reason for choosing VSC:	Synchronous AC System, Controlled connection for power exchange.

6) Gotland

An important reason for selecting VSC was that great difficulties were experienced in getting the necessary permits to build an additional overhead transmission line.

Main Data:	
Commissioning year:	2000
Power rating:	36 MW
No of circuits:	1
AC Voltage:	132KV Both sides
DC Voltage:	±15.9 KV
Type of link:	Back to Back VSC station
Main reason for choosing VSC:	Controlled Asynchronous connection for trading, voltage control.

The push for renewable forms of energy has brought wind power plants to southern Gotland, a Swedish island in the Baltic Sea [3]. Southern Gotland already had a wind power capacity of 40 MW installed, and more capacity additions were in progress [18], [13]. The transmission link between the southern part of Gotland and the city of Visby is rated 50 MW and was put into operation in June 1999. Two 70 km long extruded 80 kV VSC underground cables, ploughed into ground close to each other, connect the terminal stations. All equipment was mounted in enclosed modules in the factory and were fully factory tested, so that civil works, installation and commissioning was kept to a minimum.

Figure 4.4 VSC converter station, exterior view [16]

Main Data:	
Commissioning year:	2005
Power rating:	84 MW
No of circuits:	2
AC Voltage:	132 KV(Kollsnes) 56 KV (Troll)
DC Voltage:	±60 KV
Length of DC Submarine cables:	4 x 70 km
Main reason for choosing VSC:	Environment, long submarine cable distance, compactness of converter on platform

7) Tjaereborg

Reactive power and voltage problems can be overcome by connecting the wind power to the grid by VSC. Tjaereborg is a demonstration project by Energinet for installing and testing an 8 MVA VSC transmission for the connection of a 6 MW onshore wind farm at Tjæreborg in the western part of Denmark [3]. The 4.3 km cable link operates at 9 kV. The project was commissioned in August 2000 Fluctuating wind power production will replace the steady power production from conventional power plants, as well as their voltage control and contribution to the reactive power balance in the grid [12].

Figure 4.5 H Tjaereborg VSC Light converter station [16]

8) Troll A, Norway

The first offshore VSC project transmits power to Statoil's Troll A gas production platform in the North Sea. In 2002 ABB was awarded the first project in the world for offshore transmission with HVDC from Statoil, Norwa. This project is called Troll A Pre compression Electrical Drive System [12]. The tests on the Drive System were successfully completed in February 2005.

The rectifier at Kollsnes (onshore station) is connected through a standard power transformer to an existing 132 kV network with a breaker. From rectifier approximately 70 km VSC cable connects the rectifier with the Inverter placed on the Troll A platform [16].

Figure 4.6 The Troll platform module [16]

Main Data:	
Commissioning year:	1999
Power rating:	50 MW
No of circuits:	1
AC Voltage:	80 KV Both sides
DC Voltage:	±80 KV
Length of DC Submarine cables:	2 x 70 km
Main reason for choosing VSC:	Wind power (voltage support).Easy to get permission for underground cables.

V Features of VSC-HVDC System

a) Independent Power transfer and power quality control: The VSC-HVDC system allows fully independent control of both the active and the reactive power flow within the operating range of the VSC-HVDC system [4]. The active power can be continuously Controlled from full power export to full power import. Normally each station controls its reactive power flow independently of the other station [2], [14].

b) Absolute and predictable power transfer and voltage control: The active power flow can be determined either by means of an active power order or by means of frequency control [13], [15]. In an AC network the voltage at a certain point can be increased/ reduced through generation / consumption of reactive power. This means that VSC-HVDC can control the AC voltage independently in each station [7].

c) Low power operation: Unlike conventional HVDC converters, the VSC-HVDC converter can operate at very low power, and even at zero power. The active and reactive power is controlled independently, and at zero active power the full range of reactive power can be utilized [17].

d) Power reversal: The VSC-HVDC transmission system can transmit active power in any of the two directions with the same control setup and with the same main circuit configuration. This means that an active power transfer can be quickly reversed without any change of control mode, and without any filter switching or converter blocking. The power reversal is obtained by changing the direction of the DC current and not by changing the DC voltage as for conventional HVDC [9].

e) Reduced power losses in connected AC systems: By controlling the grid voltage level, VSC-HVDC can reduce losses in the connected grid. Both transmission line ohmic losses and generator magnetization losses can be reduced. Significant loss reductions can be obtained in each of the connected networks [9].

f) Increased transfer capacity in the existing system:

- Voltage increase: The fast and accurate voltage control capability of the VSC- HVDC converter makes it possible to operate the grid closer to the upper limit. Transient over voltages would be counteracted by the fast reactive power response. The higher voltage level would allow more power to be transferred through the AC lines without exceeding the current limits [7], [12].

- Stability margins - Limiting factors for power transfer in the transmission grid also include voltage stability. VSC-HVDC can support the grid with the necessary reactive power. The grid operator can allow a higher transmission in the grid if the amount of reactive power support that the VSC-HVDC converter can provide [11].

g) Powerful damping control using P and Q simultaneously: As well as voltage stability, rotor angle stability is a limiting factor for power transfer in a transmission grid. VSC-HVDC is a powerful tool for damping angle (electro-mechanical) oscillation. Many control methods that influence the transmission capacity can have difficulties in these complex situations. Modulating shaft power to generators, switching on and off load demand or using a VSC-HVDC connected to an asynchronous grid are methods that can then be considered [4].

These methods have the advantage that they actually take away or inject energy to damp the oscillations. VSC-HVDC is able to do this in a number of ways:

- by modulating active power flow and keeping the voltage as stable as possible
- by keeping active power constant and modulating reactive power to achieve damping (SVC – type damping)

h) Fast restoration after blackouts: VSC-HVDC can aid grid restoration in a very favorable way. Voltage support and frequency support are much needed during such conditions [11].

i) Islanded operation: The VSC-HVDC converter station normally follows the AC voltage of the connected grid. The voltage magnitude and frequency are determined by the control systems of the generating stations. In case of a voltage collapse, a "black-out", the VSC-HVDC converter can instantaneously switch over to its own internal voltage and frequency reference and disconnect itself from the grid. The converter can then operate as an idling "static" generator, ready to be connected to a "black" network to provide the first electricity to important loads [12].

j) Flexibility in design: The VSC-HVDC station consists of four parts:

- The DC yard, with DC filtering and switches
- The converter, with the IGBT valves and the converter reactors
- The AC filter yard
- The grid interface, with power transformer and switches

The different parts are interconnected with HV cables, which makes it easy to separate the parts physically, so as to fit them into available sites [2].

K) Under grounding: Except for back-to-back, VSC-HVDC always employs HV cables for the DC power transmission. The cables are buried all the way into the DC part of each converter building. When the landscape has been restored after the cable laying, the transmission route quickly becomes invisible [10].

l) No magnetic fields: The two VSC-HVDC cables can normally be laid close together. As they carry the same current in opposite directions, the magnetic fields from the cables cancel each other out. The residual magnetic field is extremely low, comparable to the level of the Earth's magnetic field. Magnetic fields from DC cables are static fields, which do not cause any induction effects, as opposed to the fields from AC cables and lines [6]. The electromagnetic field around an VSC-HVDC converter installation is quite low since all apparatus is located in a building designed to be a very efficient shield. The shielding is needed to minimize emissions in the radio frequency range, i.e. radio interference.

m) Low environmental impact: The fact that no electric or magnetic clearance from the cables is needed, and that the converter stations are enclosed in a building, makes the impact of the transmission system on the environment very low. The building can be designed to resemble other buildings in the neighborhood, and the cables are not even visible [9].

n) Indoor design: To avoid high steel support structures, to facilitate maintenance and to improve personal safety, the AC filters, converter reactors and DC filters are mounted directly on low foundations/supports and are kept within a simple warehouse-style building with lockable gates and doors. The building will keep high frequency emissions and acoustic noise low and protect the equipment from adverse weather [16].

o) Short time schedule: The converter valves and associated control and cooling systems are factory built in transportable enclosures. This ensures fast installation and on-site testing of the core systems. The building is made up of standardized parts, which are shipped to the jobsite and quickly assembled. A typical delivery time from order to hand-over for operation is 20 months or less, depending of course on local conditions for converter sites and cable route.

VI Conclusions: VSC-HVDC is a power system designed to transmit power through underground and underwater. It offers numerous environmental benefits, such as no overhead lines, neutral electromagnetic fields, oil-free cables and compact converter stations. These benefits make new transmission projects in densely populated areas acceptable for the public. For the power system engineer the VSC HVDC technology offers a number of additional benefits such as:

- Independent active/reactive power control
- Black start capability
- Power stability benefits

An example from real life has shown that the VSC-HVDC system worked as planned during a blackout situation and was a key factor for fast system restoration.

V. REFERENCE

[1] Imal, E., Bagriyanik, M., Ali-Zada, P., Rajdabl, K., Al-Zada, R.; "A FACTS technique for converting existing AC transmission into HVDC (and back)" Power Engineering, LESCOPE '01 2001, pp.59 – 62.

[2] Bahrman, M.P.; "OVERVIEW OF HVDC TRANSMISSION" Power Systems Conference and Exposition, PSCE '06, Oct. 29 2006-Nov. 1 2006, pp.18 – 23.

[3] Li Guangkai, Li Gengyin, Liang Haifeng, Yin Ming; "Research on hybrid HVDC", Vol. 2, 21-24 Nov. 2004, pp.1607 – 1612.

[4] Valiquette, R.A.; "HVDC life extension for Nelson River HVDC system" Power Engineering Society Winter Meeting, IEEE Vol. 2, 27-31 Jan. 2002, pp.1059 – 1062.

[5] Takeda H., Ayakawa H., Tsumenaga M., Sanpei M.; "New protection method for HVDC lines including cables", Power Delivery, IEEE Transactions, Vol.10, Issue 4, Oct. 1995, pp. 2035 – 2039.

[6] Andersen, B., Barker, C.; "A new era in HVDC?" IEE Review, Volume 46, Issue 2, March 2000, pp.33 – 39.

[7] Eriksson, K.; "Operational experience of HVDC Light/sup TM/" AC-DC Power Transmission, Seventh International Conference,28-30 Nov. 2001, pp.205 – 210.

[8] Jeroense, M.; "HVDC, the next generation of transmission highlights with focus on extruded cable systems" Electrical Insulating Materials, 2008. (ISEIM 2008). International Symposium, 2008, pp.10 – 15.

[9] Li Guangkai, Li Gengyin, Liang Haifeng, Yin Ming; "Research on hybrid HVDC", Power System Technology, 2004. PowerCon 2004. 2004 International Conference, Volume 2, 21-24 Nov. 2004, pp. 1607 – 1612.

[10] Daelemans G., Srivastava K., Reza M., Cole S., Belmans R.; "Minimization of steady-state losses in meshed networks using VSC HVDC" Power & Energy Society General Meeting, 2009. PES '09, IEEE, 2009, pp.1– 5.

[11] Hu Zhaoqing, M Chengxiong, Lu Jiming; "Improvement of transient stability in AC system by HVDC Light", Transmission and Distribution Conference and Exhibition: Asia Pacific, IEEE/PES, 2005, pp.1 – 5.

[12] Liu Y.H., Zhang R.H., Arrillaga, J., Watson, N.R.; "An Overview of Self Commutating Converters and Their Application in Transmission and Distribution", Transmission and Distribution Conference and Exhibition: Asia and Pacific, 2005 IEEE/PES, pp. 1 – 7.

[13] Konishi H., Takahashi C., Kishibe H., Sato H.; "A consideration of stable operating power limits in VSC-HVDC systems" AC-DC Power Transmission, 2001. Seventh International Conference 28-30 Nov. 2001, pp. 102 – 106.

[14] Jingmei Fang, Gengyin Li, Ming Zhou, Xuefeng Liang; "Research on the Voltage Source Converter in VSC-HVDC" Power System Technology (POWERCON), 2010 International Conference, 2010 , pp. 1 – 8.

[15] N.R. Watson, J. Arrillaga, "Incorporation of VSC Transmission in Power-Flow Simulation", 8th International Power Engineering Conference (IPEC 2007), 3-6 Dec. 2007.

[16] Guanjun Ding, Guangfu Tang, Zhiyuan He, Ming Ding; "New technologies of voltage source converter (VSC) for HVDC transmission system based on VSC", Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, IEEE, 2008 , pp.1 – 8.

[17] B. D. Railing, J. J. Miller, G. Moreau, J. Wasborg, Y. Jiang-H¨afner, and D. Stanley; "The DirectLink VSC-based HVDC project and its commissioning," CIGR ´E conference, Paris, France, August 2002.

[18] Axelsson, U.; Holm, A.; Liljegren, C.; Aberg, M.; Eriksson, K.; Tollerz, O.;"The Gotland HVDC Light project-experiences

from trial and commercial operation" Electricity Distribution, Part 1: Contributions. CIRED. 16th International Conference and Exhibition (IEE Conf. Publl No. 482), vol.1, June 2001, pp. 18-21.

[19] N.R. Watson, J. Arrillaga, "Incorporation of VSC Transmission in Power-Flow Simulation", 8th International Power Engineering Conference (IPEC 2007), 3-6 Dec. 2007.