ISSN: 2688-8645

# The Development and Application of Light High-Voltage Direct Current Transmission Technology

Guo Chen, Yejun He and Yong Li

School of Mechatronic Engineering, Zhongshan Polytechnic, Zhongshan Guangdong, 528400, China

## Abstract

**A kind of new power transmission technology--HVDC light, is introduced in this paper, which is based on the conventional HVDC technology with VSC and IGBT as its main components. The basic principle, technology characteristics and modeling methods of HVDC light are summarized, followed by a comparison of HVDC light with conventional HVDC. Some applications of HVDC light abroad and the current development in China is briefly introduced. The main research areas at the present time are pointed out and the application prospects for HVDC light are predicted.**

## Keywords

**HVDC Light; Technology Characteristics; HVDC.**

## 1. Introduction

Since the world's first high-voltage direct current (HVDC) transmission line was put into commercial operation in 1954, HVDC, as a mature technology, has been widely applied in long-distance high-power transmission, submarine cable power supply, and asynchronous connection between two alternating current systems. However, due to technical and economic reasons, HVDC is difficult to be applied in short-distance low-capacity transmission scenarios. With the rapid development of power semiconductor technology, especially insulated gate bipolar transistors (IGBT), the HVDC light has been promoted. Small-power HVDC light systems have a promising application prospect [1-2].

HVDC light, in addition to having the advantages of conventional HVDC, can directly supply power to small isolated long-distance loads, more economically supply power to the city center, conveniently connect dispersed power sources, have flexible operation control methods, and reduce voltage drop and voltage flicker on transmission lines, thereby further improving power quality. Based on a brief introduction of the principle of HVDC light, this paper analyzes the technical characteristics of HVDC light, compares the differences between HVDC light and traditional HVDC, introduces some engineering applications abroad and the research status in China, points out the main research fields at present, and looks forward to its development prospects [3-5].

## 2. Technology of HVDC Light

The HVDC Light technology is a new type of direct current transmission technology specifically designed for low-power transmission, developed based on voltage source (VSC) converters and insulated gate bipolar transistors (IGBTs) [6]. HVDC Light consists of only two components: two converter stations and a pair of grounding cables. The converter stations employ VSC converter technology, which is different from traditional direct current transmission. The VSC converter is an passive inverter, so it has no requirements for the receiving system and can be used to supply power to small-capacity systems or passive systems without rotating motors. As shown in Fig. 1, the bridge arms of the VSC converter are composed of high-power turn-off type power electronic devices (such as IGBTs, IGCTs) and reverse parallel diodes.

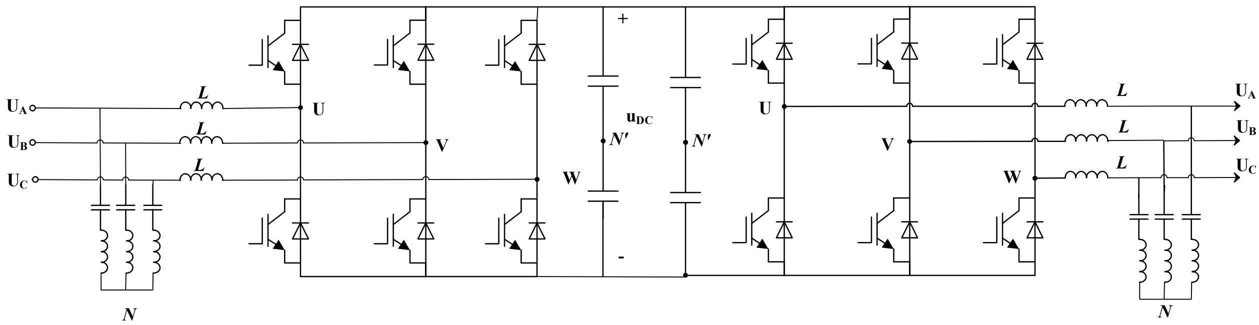


**Fig 1.** Schematic diagram of the HVDC light system structure

Since high-power controllable switching power electronic devices can be turned on or off arbitrarily, the output voltage of the VSC converter can be automatically adjusted according to the requirements of the AC system by utilizing PWM technology. Fig. 2 shows a single-phase schematic diagram of the VSC.

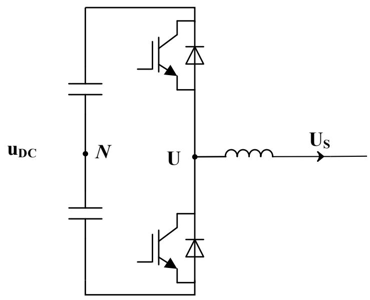


**Fig 2.** Schematic diagram of the single-phase VSC

The output voltage of single-phase SVC can be expressed as

$$U_c = \frac{1}{2} U_d M \sin(\omega t + \delta) \tag{1}$$

where $M$ is the ratio of the peak value of the modulated wave to the peak value of the carrier wave, $\omega$ is the fundamental frequency, and $\delta$ is the phase offset of the output voltage of the converter.

Assuming that the converter reactor has no loss and ignores harmonic components, the active power and reactive power transmitted between the converter and the AC power grid are expressed as

$$P = \frac{U_s U_c}{X_1} \sin\delta \tag{2}$$

$$Q = \frac{U_s (U_s - U_c \cos\delta)}{X_1} \tag{3}$$

where $X_1$ is the reactance of the converter reactor; $U_s$ is the voltage component of the AC bus connected to the power grid.

According to (2) and (3), it can be seen that the transmission of $P$ mainly depends on the angle $\delta$, while the transmission of $Q$ mainly depends on $U_c$. And $U_c$ is controlled by the voltage pulse width (PWM) output by the VSC converter. By controlling the angle $\delta$, the direction of the DC current and the magnitude of the transmitted $P$ can be accurately controlled. By controlling $U_c$, the VSC converter station can emit or absorb $Q$ and its magnitude, thus flexibly adjusting the transmission capacity of the transmission line automatically according to the power grid situation.

## 3. Characteristics of Light HVDC

The technical characteristics of light HVDC are as follows [7] :

1) The VSC adopts fully controlled switching devices, and the current can be turned off automatically. The circuit can work in passive inverter mode, without the need for external commutation voltage, thus overcoming the fundamental defect that the input end of traditional HVDC must be an active network, making it possible to use light HVDC to power isolated loads over a long distance.

2) The harmonic generated by VSC converter is greatly reduced, and the demand for reactive power is also greatly reduced. Just install a set of high pass filters on the AC bus to meet the harmonic requirements, and the capacity of reactive compensation device is also greatly reduced, so the converter transformer may not be installed.

3) VSC not only does not need the AC side to provide reactive power, but also can play the role of STATCOM, that is, to dynamically compensate the reactive power of AC bus and stabilize the voltage of AC bus. This means that if VSC capacity allows, the light HVDC system can provide both active power emergency support and reactive power emergency support to the fault area in case of fault, thus improving the voltage and power angle stability of the system.

4) When the power flow reverses, the direction of DC current reverses, while the polarity of DC voltage remains unchanged, which is just the opposite of the traditional HVDC. This feature is conducive to the formation of parallel multi terminal DC systems that can control power flow conveniently and have high reliability.

5) Since the AC side current of VSC can be controlled, the short circuit capacity of the system will not be increased. This means that the protection setting of AC system does not need to be changed after adding new light HVDC lines.

6) No commutation failure will occur. Even if power is supplied to a small capacity system or a passive load, the VSC converter will not suffer from commutation failure, thus avoiding short-term power interruption lasting for several cycles in the receiving end system, and improving the power quality of the receiving end system.

7) Multiple VSCs can be connected to a fixed polarity DC bus, which is easy to form a multi terminal DC system with the same topology as the AC system, and the operation control mode is flexible.

## 4. Mathematical Modeling of Light HVDC

When connected to the active AC network, VSC is a nonlinear and non decoupled controlled object with two inputs (PWM phase and modulation), two outputs (reactive power and DC voltage or DC current from VSC). The matching of two control variables and two controlled variables and the design of the controller need to be based on the mathematical model.

At present, the research focus of mathematical model of light HVDC system is mainly on the two terminal HVDC transmission system with two-level converter structure and three-level converter structure. Since the structure of the light HVDC side system is similar to that of the three-phase voltage source PWM rectifier, the mathematical modeling methods of the two can usually be used for reference.

The mathematical modeling methods of PWM rectifier mainly include the following three methods. 1) Establish the time domain model of three-phase PWM rectifier, and decompose the time domain model into high-frequency and low-frequency models, according to which the corresponding time domain solution can be obtained. 2) The dq0 coordinate transformation of the local circuit is used to convert the time-varying AC flow into the dq0 coordinate system that rotates synchronously with the fundamental frequency of the power grid. After the transformation, each time variable will become the DC value in the dq0 coordinate system, which is conducive to the design of the control system. By establishing the low-frequency equivalent model circuit of three-phase PWM rectifier based on transformer, the steady-state and dynamic characteristics of VSC system can be analyzed. Using the modeling method of three-phase PWM rectifier for reference, the state average mathematical model of light HVDC system is established in two-phase stationary coordinate system and synchronous rotating dq0 coordinate system. 3) In order to overcome the shortcomings of the above models in the dynamic characteristics research, the switch function modeling method began to be used in the light HVDC modeling. The switch function modeling method is a new modeling method. It lists the basic circuit equations of the power conversion device according to its physical characteristics and the topology of the main circuit, and introduces the switch function. By solving these circuit constraint equations, it is a method to describe the nature and process of the device. The method of switching function modeling improves the limitation that the internal dynamic process of the converter is not considered in the previous steady-state modeling. The switching function is used to simulate the valve on-off process, without any restrictions on the switching function, and can be applied to various modulation modes and control strategies. Therefore, the switching function modeling method has been applied and developed in the modeling and analysis of various FACTS devices. In practice, the voltage imbalance often occurs in the operation of light HVDC. When the AC system voltage is asymmetric, the negative sequence component generated will deteriorate the performance of the controller, and lead to over-voltage and over-current of VSC converter, even endangering the safety of the converter. The early literature established the mathematical model of light HVDC system under steady state conditions, which is an ideal mathematical model based on the premise that the system voltage is balanced and the commutation reactance is symmetrical and equal. In recent years, the mathematical modeling of VSC under the condition of voltage imbalance in AC system has become a research hotspot in the world.

## 5. Development and Application of Light HVDC

Compared with traditional HVDC transmission and AC transmission, light HVDC transmission has many advantages, but its application fields need further exploration. At present, it is mainly used for grid connection to isolated loads such as isolated islands and drilling platforms, distributed power generation such as wind power and solar power, and connection of two independent power grids to achieve inter network interconnection.

In foreign countries, light HVDC technology has been put into commercial application. Since the first light HVDC transmission project in the world, Hellsjon Test Project in Sweden, was successfully put into operation in 1997, nine light HVDC transmission lines have been completed and put into operation worldwide. A large amount of data shows that the light HVDC line is also very competitive in small capacity and long-distance transmission, which is also helpful to improve the power quality of the grid, reduce the short circuit current and harmonic pollution of the system. Two of the nine projects are used to transport commercial operation lines of wind power generation. In the Gotland project, it uses underground DC cables instead of overhead lines, overcoming the difficulty of installing overhead lines on Gotland Island; In addition, the use of light HVDC technology not only greatly improves the stability of the internal

AC system of the wind farm, but also improves the power quality and voltage stability of the southern grid of Gotland Island.

In China, the development of HVDC transmission projects is also very rapid. Since the Ge Nan HVDC transmission project, the first domestic ultra-high voltage DC transmission project, was completed and put into operation in 1989, nearly 20 ultra-high voltage and ultra-high voltage DC transmission projects have been completed, under construction and planned. Among them, the Sichuan Shanghai ± 800kV UHV DC transmission demonstration project is an innovative project with the highest voltage level, the largest transmission capacity and the longest transmission distance in the world, leading the development of DC transmission technology.

## 6. Summary

The progress of power semiconductor and its control technology, especially the continuous development of IGBT, has led to the emergence of light HVDC technology. The successful experience of various light HVDC projects that have been put into operation or are about to be put into operation shows that the technology is constantly improving and maturing. As a new transmission technology, light HVDC has shown great advantages in application with its own characteristics, including modular structure, standardized design, short construction period, compact structure, less impact on the environment, controllable power flow and voltage, etc. Combined with the new control algorithm, the light HVDC technology can achieve better performance in reducing voltage drop and voltage flicker of transmission lines and further improving power quality; Compared with the existing AC transmission lines, it can greatly reduce the line loss. With the rapid development of high-tech industries, the comprehensive development of renewable energy and the growing development and improvement of the power market, the requirements for high quality power quality and the flexibility and reliability of grid operation are further improved, and the light HVDC technology will be more and more widely valued, researched and applied in China.

## Acknowledgments

This work was supported by the Guangdong Provincial University Characteristic Innovation Project (Grant No. 2023KTSCX368) and the School Level Scientific Research Project of Zhongshan Polytechnic (Grant No. KYB2405).

## References

[1] Grunbaum R, Halvarsson B, Wilk-Wilczynski A. FACTS and HVDC Light for Power System Interconnection [C]. Power Delivery Conference. Madrid (Spain): 1999.

[2] Lars Weimers. HVDC Light -- A New Technology for a Better Environment[J]. IEEE Power Engineering Review, 1998, 18 (8).

[3] Aik L H, Andersoon G. Impact of dynamic system modeling on the power stability of HVDC system[J]. IEEE Transaction on power system, 1999, 14 (4): 1427-1437.

[4] Khare V, Nema S, Baredar P. Solar–wind hybrid renewable energy system: a review. Renew Sustain Energy Rev. 2016; 58:23-33.

[5] Axelsson U., Holm A., Liljegren C., Eriksson K., et al. The Gotland HVDC Light Project-experiences from trial and commercial operation [C]. CIRED, Nice, Franee, 1999.

[6] Hyttinen M., Lamell J. O., Nestli T. F. New applieation of voltage source converter (VSC) HVDC to be installed on the gas platform Troll A [C]. CIGRE Session, Pairs, Franee, 2004: B4-210.

[7] Weixing L., Boon O. Premium quality Power Park based on multi-terminal HVDC [J]. IEEE Transactions on Power Delivery, 2005, 20(2): 978-983.