모듈형 멀티레벨 컨버터로 구성된 고압직류 송전시스템의 제어

최성휘, 설승기
서울대학교 전기정보공학부

Control of a VSC-HVDC Transmission System based on Modular Multilevel Converters

Shenghui Cui, Seung-Ki Sul
Department of Electrical and Computer Engineering, Seoul National University

ABSTRACT

VSC-HVDC system based on Modular Multilevel Converter (MMC) is an emerging technology since compared to the conventional VSC-HVDC system an MMC presents several advantages such as modularity, low dv/dt, low harmonics, and low switching losses. In this paper, a comprehensive control strategy of an MMC-based VSC-HVDC system is proposed. In contrast to the conventional system control strategy, the DC side of the MMC operates as a controlled voltage source by the proposed method, and the dynamics of the transmission line voltage and current can be actively controlled. Validity of the proposed strategy was verified by 201-level full-scale computer simulation.

1. Introduction

Compared to the classical line commutated converter based HVDC system, the VSC-HVDC system presents several benefits such as black start capability, low harmonics, and finer reactive power controllability. Besides the two level and three level converters as a first approach, the MMC seems to be a promising solution for future applications of VSC-HVDC[1].

Investigations on MMC based back-to-back (BTB) systems and point-to-point (PTP) systems have been reported by several articles[2-4]. In the conventional control method, direct modulation has been employed and it was revealed that the terminal behavior of the MMC under direct modulation was like that of a two-level converter[4]. In this paper, a novel control strategy of the MMC based PTP HVDC system is proposed. Different from the conventional method, the DC bus voltage is fully decoupled from the energy stored in the cell capacitors and the transmission line voltage oscillation during power flow variation is actively suppressed by the proposed method.

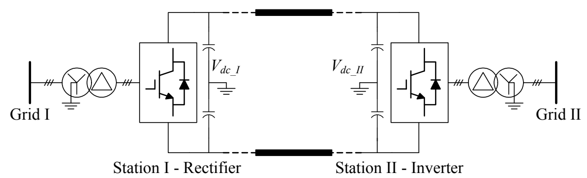

Figure 1. Conceptual structure of the transmission system by the conventional method.

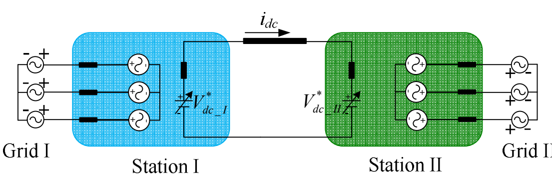

Figure 2. Conceptual structure of the transmission system by the proposed method.

2. Control of the MMC based PTP system

2.1 Conventional control strategy

In the conventional control strategy, the terminal behavior of the MMC was like that of a two level converter and the DC bus voltage was coupled with the energy stored in the cell capacitors. In Fig. 1, it is assumed that Station I operates in rectifier mode and the Station II in inverter mode. In Station I, a constant DC bus voltage controller was employed to control the transmission line voltage. In Station II a constant active power controller was employed, and the power flow of the transmission line was determined by the command of the active power controller. The DC bus voltage of the Station II was passively determined by that of the Station I, and the transmission line current was passively determined by the power flow. Since a capacitor-inductor-capacitor coupling existed in the transmission line as shown in Fig. 1, voltage oscillations occurred in the transmission line during power flow variation.

2.2 Proposed control strategy

In the first approach of this work, a new modeling of the MMC was proposed and three independent models were extracted from the MMC circuit to describe the AC grid currents, the DC bus current, and the circulating currents[5]. The energy stored in the capacitors of six different arms were balanced only by the circulating currents flowing inside the converter. By the proposed method, the AC gird side, the DC bus side, and the energy stored in the cell capacitors are fully decoupled, and the DC bus of the MMC looks like a controlled voltage source behind an inductor and the voltage of the controlled source can be update at every sampling period as shown in Fig. 2.

If the transmission system is to connect two strong AC grids, both stations can operate in rectifier mode as shown in Fig. 3. The energy stored in cell capacitors are controlled by drawing active currents from the AC grids for both converters. In this paper, it's assumed that the space vector of the grid voltage is oriented to the q-axis of the synchronous reference frame.

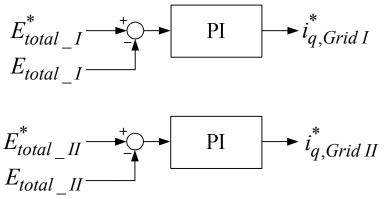

Figure 3. Proposed total capacitor energy controller

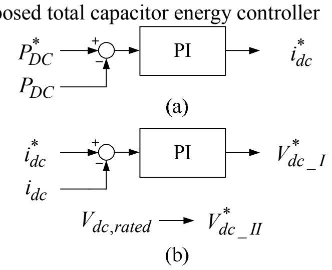

Figure 4. Proposed power flow controller. (a) Transmission line current generator. (b) Transmission line regulator.

Table 1. Parameters of the investigated transmission system.

Quantity	Values
Number of cells per arm	200
Rated DC bus voltage	400 kV
Rated cell capacitor voltage	2.0 kV
Cell capacitor	4.5 mF
Grid voltage	180.5 kV
Arm inductor inductance	15.0 mH
Arm inductor resistance	367.0 mΩ
Transmission line resistance	1.0 Ω
Transmission line inductance	1.0 mH

The proposed power flow controller which contains a transmission line current generator and a transmission line regulator was shown in Fig. 4. The power flow is controlled by regulating the transmission line current, and the transmission line current is regulated by actively controlling the DC bus voltages of two stations. The DC bus voltage of the Station II is controlled as the rated value of the transmission line voltage in an open-loop manner, and the reference of the DC bus voltage of the Station I is generated by the transmission line regulator to actively control the transmission line current.

2.3 Simulations

To verify the validity of the proposed method, computer simulations are performed. Parameters of the simulated transmission system are shown in Table 1.

The transmission line current and the DC bus voltages of two stations under the conventional control strategy are shown in Fig. 5. As indicated by Fig. 5, voltage oscillation appears in the transmission line during power flow variation which is induced by the capacitor-inductor-capacitor coupling. Damping of the oscillation voltage in the transmission line voltage is a crucial aspect of the VSC-HVDC transmission system.

The transmission line current and the DC bus voltages of two stations under the proposed control strategy are shown in Fig. 6. Since the DC bus voltage of the Station II is controlled as the rated transmission line voltage in an open-loop manner, it maintains constant value regardless of power flow variation. Since the power flow is controlled by actively regulating the transmission line current, no oscillation occurs in the transmission line, and the DC bus voltage of the Station I varies

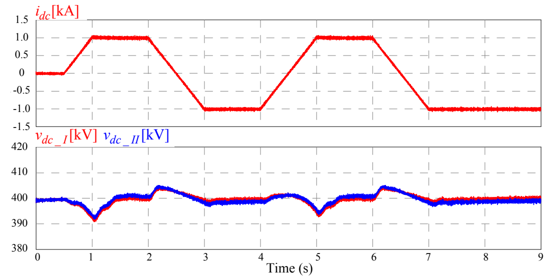

Figure 5. Transmission line current and voltages under the conventional control strategy during power flow variation.

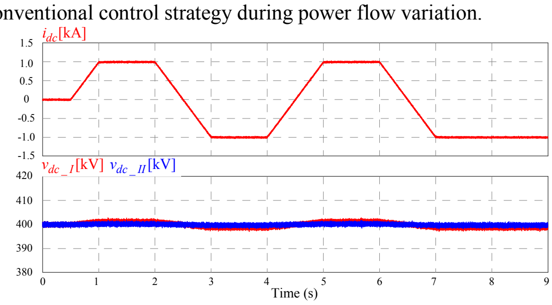

Figure 6. Transmission line current and voltages under the proposed control strategy during power flow variation.

smoothly to compensate the voltage drop across the transmission line resistance. Voltage oscillation in the transmission line can be actively damped by the proposed method without employing any additional hardware equipment.

3. Conclusion

A novel control strategy has been proposed for MMC based VSC-HVDC transmission system. By the proposed control method, the DC side of the MMC acts as an actively controlled voltage source instead of a passive capacitor in the conventional method. In contrast to the conventional control strategy, the transmission line current can be controlled actively and the voltage oscillation in the transmission line has been fully suppressed by the proposed method. The advantages of the proposed method are verified by full-scale computer simulations.

References

[1] Davies, M., et al. "HVDC plus–Basics and Principle of Operation." *Siemens Energy Sector, ET PS SL/DSoe/Re-2008-08-10-HVDC PLUS* 3 (2008).

[2] Guan, Minyuan, and Zheng Xu, "Modeling and control of a modular multilevel converter-based HVDC system under unbalanced grid conditions." *Power Electronics, IEEE Transactions on* 27. 12 (2012): 4858-4867.

[3] Saeedifard Maryam, and Reza Iravani, "Dynamic performance of a modular multilevel back-to-back HVDC system," *Power Delivery, IEEE transactions on* 25.4 (2010): 2903-2912.

[4] Liu, Sheng, *et al.* "Electromechanical transient modeling of modular multilevel converter based multi-terminal HVDC systems." *Power Systems, IEEE Transactions on* (2012).

[5] Shenghui Cui, Sungmin Kim, Jae-Jung Jung, and Seung-Ki Sul, "A comprehensive cell capacitor energy control strategy of a modular multilevel converter (MMC) without a stiff DC bus voltage source," *IEEE Applied Power Electronics Conference and Exposition*, pp. 602-602, 2014.