VSC-BASED HVDC POWER TRANSMISSION SYSTEMS: AN OVERVIEW

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Abstract- The ever increasing progress of high-voltage high power fully controlled semiconductor technology continues to have a significant impact on the development of advanced power electronic apparatus used to support optimized operations and efficient management of electrical grids, which, in many cases, are fully or partially deregulated networks. Developments advance both the HVDC power transmission and the flexible ac transmission system technologies. In this paper, an overview of the recent advances in the area of voltage-source converter (VSC) HVDC technology is provided. Selected key multilevel converter topologies are presented. Control and modeling methods are discussed. A list of VSC-based HVDC installations worldwide is included. It is confirmed that the continuous development of power electronics presents cost effective opportunities for the utilities to exploit, and HVDC remains a key technology. In particular, VSC-HVDC can address not only conventional network issues such as bulk power transmission, asynchronous network interconnections, back-to-back ac system linking, and voltage/stability support to mention a few, but also niche markets such as the integration of large-scale renewable energy sources with the grid and most recently large onshore/offshore wind farms.

I. INTRODUCTION

HVDC POWER transmission systems and technologies associated with the flexible ac transmission system (FACTS) continue to advance as they make their way to commercial applications. Both HVDC and FACTS systems underwent research and development for many years, and they were based initially on thyristor technology and more recently on fully controlled semiconductors and voltage-source converter (VSC) topologies. The ever increasing penetration of the power electronics technologies into the power systems is mainly due to the continuous progress of the high-voltage high power fully controlled semiconductors. The fully controlled semiconductor devices available today for high-voltage high-power converters can be based on either thyristor or transistor technology (see Table I). These devices can be used for a VSC with pulse width modulation (PWM) operating at frequencies higher than the line frequency.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Type</th>
<th>Full Name</th>
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<tbody>
<tr>
<td>IGBT</td>
<td>Transistor</td>
<td>Insulated Gate Bipolar Transistor</td>
</tr>
<tr>
<td>IEGT</td>
<td>Transistor</td>
<td>Injection Enhanced Gate Transistor</td>
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<tr>
<td>GTO</td>
<td>Thyristor</td>
<td>Gate Turn-off Thyristor</td>
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<td>IGCT</td>
<td>Thyristor</td>
<td>Integrated Gate Commutated Thyristor</td>
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<td>GCT</td>
<td>Thyristor</td>
<td>Gate Commutated Turn-off Thyristor</td>
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These devices are all self-commutated via a gate pulse. Typically, it is desirable that a VSC application generates PWM waveforms of higher frequency when compared to the thyristor-based systems. However, the operating frequency of these devices is also determined by the switching losses and the design of the heat sink, both of which are related to the power through the component. Switching losses, which are directly linked to high-frequency PWM operation, are one of the most serious and challenging issues that need to be dealt with in VSC-based high-power applications. Other significant disadvantages that occur by operating a VSC at high frequency are the electromagnetic compatibility/electromagnetic interference (EMC/EMI), transformer insulation stresses, and high frequency oscillations, which require additional filters. HVDC and FACTS systems
are important technologies, supporting in their own way the modern power systems, which, in many cases, are fully or partially deregulated in several countries. In the near future, even higher integration of electrical grids and market-driven developments are expected, as for instance, countries in the Middle East, China, India, and South America require infrastructure to power their growth and interconnection of “island” grids. Today, there are approximately 100 HVDC installations worldwide (in operation or planned for the very near future) transmitting more than 80 GW of power employing two distinct technologies as follows.

1) Line-commutated current-source converters (CSCs) that use thyristors (Fig. 1, CSC-HVdc): This technology is well established for high power, typically around 1000 MW, with the largest project being the Itapúa system in Brazil at 6300 MW power level. The longest power transmission in the world will transmit 6400 MW power from the Xiangjiaba hydropower plant to Shanghai. The 2071 km line will use 800 kV HVDC and 1000 kV ultrahigh-voltage ac transmission technology.

2) Forced-commutated VSCs that use gate turn-off thyristors (GTOs) or in most industrial cases insulated gate bipolar transistors (IGBTs) (Fig. 2, VSC-HVDC): It is well-established technology for medium power levels, thus far, with recent projects ranging around 300–400 MW power level (see Table II). The CSC-HVDC systems represent mature technology today (i.e., also referred to as “classic” HVDC), and recently, there have been a number of significant advances. It is beyond the scope of this paper to discuss developments associated with the CSC-HVDC that are well documented in reference. On the other hand, VSC-HVDC systems represent recent developments in the area of dc power transmission technology. The experience with VSC-HVDC at commercial level scatters over the last 12 years. The breakthrough was made when the world’s first VSC-based PWM-controlled HVDC system using IGBTs was installed in March 1997 (Hellsjö on project, Sweden, 3 MW, 10 km distance, ±10 kV). Since then, more VSC-HVDC systems have been installed worldwide (see Table II). The CSCs have the natural ability to withstand short circuits as the dc inductors can assist the limiting of the currents during faulty operating conditions. The VSCs are more vulnerable to line faults, and therefore, cables are more attractive for VSC-HVDC applications. It is worth mentioning relevant developments that led to the success of VSC-HVDC such as the advanced extruded dc cable technologies. Faults on the dc side of VSC-HVDC systems can also be addressed through the use of dc circuit breakers (CBs). In the event of the loss of a VSC in a multi terminal HVDC, the excess of power can be restricted by the advanced dc voltage controller. The objective of this paper is to provide an overview of the HVDC technologies associated with VSC-based systems including converter topologies. Modeling and control are another area of importance, and recent contributions presented in the technical literature are analyzed briefly. Finally, emerging applications of VSC-HVDC systems and multi terminal dc configurations that can be used to interconnect large-scale wind energy sources with the grid are discussed. The paper is organized as follows. Section II provides a summary of the CSC-HVDC system configurations, which also apply, with some modifications, to the VSC-HVDC ones as well.

2. CSC-HVDC SYSTEM CONFIGURATIONS

Depending upon the function and location of the converter stations, various configurations of HVDC systems can be identified. The ones presented in this section...
involve CSC-HVDC configurations but similar types of configurations exist for VSC-HVDC with or without transformers depending upon the project in question.

A. Back-to-Back CSC-HVDC System
In this case, the two converter stations are located at the same site and there is no transmission of power with a dc link over a long distance. A block diagram of a back-to-back CSC-HVDC system with 12-pulse converters is shown in Fig. 3. The two ac systems interconnected may have the same or different frequency (asynchronous interconnection).

B. Monopolar CSC-HVDC System
In this configuration, two converters are used that are separated by a single pole line, and a positive or a negative dc voltage is used. Many of the cable transmissions with submarine connections use a monopole system. The ground is used to return current. Fig. 2 shows a block diagram of a monopole CSC-HVDC system with 12-pulse converters.

C. Bipolar CSC-HVDC System
This is the most commonly used configuration of a CSC-HVDC system in applications where overhead lines are used to transmit power. In fact, the bipolar system is two mono polar systems. The advantage of such system is that one pole can continue to transmit power in case the other one is out of service for whatever reason. In other words, each system can operate on its own as an independent system with the earth return. Since one is positive and one is negative, in case that both poles have equal currents, the ground current is zero theoretically, or, in practice, within a difference of 1%. The 12-pulse-based bipolar CSC-HVDC system is depicted in Fig. 3.

D. Multi terminal CSC-HVDC System
In this configuration, there are more than two sets of converters. A multi terminal CSC-HVDC system with 12-pulse converters per pole is shown in Fig. In this case, converters 1 and 3 can operate as rectifiers while converter 2 operates as an inverter. Working in the other order, converter 2 can operate as a rectifier and converters 1 and 3 as inverters. By mechanically switching

3. PROPOSED SYSTEM

Bipolar CSC-HVDC system with one 12-pulse converter per pole. Increase the dc bus voltage level of the HVDC system. It should be noted that an anti parallel diode is also needed in order to ensure the four-quadrant operation of the converter. The dc bus capacitor provides the required storage of the energy so that the power flow can be controlled and offers filtering for the dc harmonics. The VSC-HVDC system can also be built with other VSC topologies. Key topologies are presented in Section IV. The converter is typically controlled through sinusoidal PWM (SPWM), and the harmonics are directly associated with the
Switching frequency of each converter leg. Fig. presents the basic waveforms associated with SPWM and the line-to-neutral voltage waveform of the two-level converter (see Fig.). Each phase leg of the converter is connected through a reactor to the ac system. Filters are also included on the ac side to further reduce the harmonic content flowing into the ac system. Generalized two ac voltage sources connected via a reactor is shown in Figs. shows the relative location of the phases of the two ac sinusoidal quantities and their relationship through the voltage drop across the line reactor (see Fig.). One voltage is generated by the VSC and the other one is the voltage of the ac system. At the fundamental frequency, the active and reactive powers are defined by the following relationships, assuming that the reactor between the converter and the ac system is ideal.

Fig. 3.4: Interconnection of two ac voltage sources through a lossless reactor.

Fig. 3.5: Phasor diagram of two ac voltage sources interconnected through a lossless reactor.

Fig. 3.6: Active-reactive locus diagram of VSC-based power transmission system.

4. CONCLUSION

In this paper, recent advances of the VSC-based HVDC technology are presented. The development of high-voltage high-power semiconductors have successfully assisted utilities to exploit the benefits of the four-quadrant static converter interlinking two ac systems through HVDC with a number of key
benefits, namely independent control of active and reactive power through the PWM control of the converter, fast dynamic response, and possibility to connect ac island with no synchronous generation in the grid. It is confirmed that developments associated with VSC-based HVDC technology have delivered systems at voltage levels up to 350 kV and power levels up to 400 MW. VSC-HVDC undoubtedly will continue to provide solutions in many areas of the power systems where installations necessitate proven solutions.

5. REFERENCES


