2.5 VSC topologies

Conventional HVDC transmission employs line-commutated, current-source converters with thyristor valves. These converters require a relatively strong synchronous voltage source in order to commutate. The conversion process demands reactive power from filters, shunt banks, or series capacitors, which are an integral part of the converter station.

Any surplus or deficit in reactive power must be accommodated by the ac system. This difference in reactive power needs to be kept within a given band to keep the ac voltage within the desired tolerance. The weaker the system or the further away from generation, the tighter the reactive power exchange must be to stay within the desired voltage tolerance.

These VSC-based systems are force-commutated with insulated-gate bipolar transistor (IGBT) valves and solid-dielectric, extruded HVDC cables HVDC transmission and reactive power compensation with VSC technology has certain attributes which can be beneficial to overall system performance. VSC converter technology can rapidly control both active and reactive power independently of one another. Reactive power can also be controlled at each terminal independent of the dc transmission voltage level. This control capability gives total flexibility to place converters anywhere in the ac network since there is no restriction on minimum network short-circuits capacity.

1. **Physical Structure**

The main function of the VSC-HVDC is to transmit constant DC power from the rectifier to the inverter. As shown in Figure.1, it consists of dc-link capacitors C_{dc}, two converters, passive high-pass filters, phase reactors, transformers and dc cable.

2. **Converters**

The converters are VSCs employing IGBT power semiconductors, one operating as a rectifier and the other as an inverter. The two converters are connected either back-to-back or through a dc cable, depending on the application.

3. Transformers

Normally, the converters are connected to the ac system via transformers. The most important function of the transformers is to transform the voltage of the ac system to a value suitable to the converter. It can use simple connection (two-winding instead of three to eight-winding transformers used for other schemes). The leakage inductance of the transformers is usually in the range 0.1-0.2p.u.

4. Phase Reactors

The phase reactors are used for controlling both the active and the reactive power flow by regulating currents through them. The reactors also function as ac filters to reduce the high frequency harmonic contents of the ac currents which are caused by the switching operation of the VSCs. The reactors are essential for both active and reactive power flow, since these properties are determined by the power frequency voltage across the reactors. The reactors are usually about 0.15p.u. Impedance.

5. AC Filters

The ac voltage output contains harmonic components, derived from the switching of the IGBTs. These harmonics have to be taken care of preventing them from being emitted into the ac system and causing malfunctioning of ac system equipment or radio and telecommunication disturbances. High-pass filter branches are installed to take care of these high order harmonics. With VSC converters there is no need to compensate any reactive power consumed by the converter itself and the current harmonics on the ac side are related directly to the PWM frequency. The amount of low-order harmonics in the current is small.

6. Dc Capacitors

On the dc side there are two capacitor stacks of the same size. The size of these capacitors depends on the required dc voltage. The objective for the dc capacitor is primarily to provide a low inductive path for the turned-off current and

energy storage to be able to control the power flow. The capacitor also reduces the voltage ripple on the dc side.

7. Dc Cables

The cable used in VSC-HVDC applications is a new developed type, where the insulation is made of an extruded polymer that is particularly resistant to dc voltage. Polymeric cables are the preferred choice for HVDC, mainly because of their mechanical strength, flexibility, and low weight.

8. <u>IGBT Valves</u>

The insulated gate bipolar transistor (IGBT) valves used in VSC converters are comprised of series-connected IGBT positions. The IGBT is a hybrid device exhibiting the low forward drop of a bipolar transistor as a conducting device. A complete IGBT position consists of an IGBT, an anti parallel diode, a gate unit, a voltage divider, and a water-cooled heat sink. Each gate unit includes gate-driving circuits, surveillance circuits, and optical interface. The gate-driving electronics control the gate voltage and current at turn-on and turn-off, to achieve optimal turn-on and turn-off processes of the IGBT. To be able to switch voltages higher than the rated voltage of one IGBT, many positions are connected in series in each valve similar to thyristors in conventional HVDC valves.

9. <u>AC Grid</u>

Usually a grid model can be developed by using the Thevenin equivalent circuit. However, for simplicity, the grid was modeled as an ideal symmetrical three-phase voltage source.

HVDC Circuit breakers & Operating problems

Circuit breakers will be positioned on DC grids and act when a fault occurs. Breakers would have to fulfill some basic requirements. Current zero crossing should be created to interrupt the current once a fault occurs. At the same time the energy that is stored in the system's inductance should be dissipated and the breaker should withstand the voltage response of the network.

There are two types of HVDC circuit breakers: electromechanical and solid-state. Electromechanical can be grouped into three categories: (1) inverse voltage generating method, (2) divergent current oscillating method, and (3) inverse current injecting method. Only the inverse current injecting method can be used in high voltage and current ratings. In this type of breaker, current zero can be created by superimposing an inverse current (of high frequency) on the input current by dis-charging a capacitor (that was pre- charged) through an inductor. (Explained on next section) The cost of components required for an electromechanical DC circuit breaker would not be significantly higher than that of an AC circuit breaker. Electromechanical HVDC circuit breakers are available up to 500 kV, 5 kA and have a fault-clearing time of the order of 100 ms.

Solid-state circuit breakers are the second type of HVDC breakers. These breakers can interrupt current much faster (which is required in some cases) than electromechanical circuit breakers, having an interruption time of a few milliseconds. They are based on Integrated Gate Commutated Thyristors (IGCT), which compared to IGBT (bipolar thyristors) have lower on-state losses. Current flows through the IGCT and in order to interrupt, the IGCT is turned off. Once that happens, voltage quickly increases until a varistor (that is in parallel to the thyristor) starts to conduct. The varistor is designed to block voltages above the voltage level of the system. The main disadvantages of these types of circuit breakers are the high on-state losses and the capital costs.Typical ratings of solid-state circuit breakers in operation are 4 kV, 2 kA, although in ratings of up to 150 kV, 2 kA were considered.

Electromechanical HVDC circuit breakers:

- The nominal current path is where DC current passes through and the switch is closed during normal operation
- The commutation path consists of a switch and a resonant circuit with an inductor and a capacitor and is used to create the inverse current
- The energy absorption path consists of a switch and a varistor

The commutation path has a series resonance. When interruption is required, current oscillation can occur between the nominal and the commutation path at the natural frequency (1/LC). If the amplitude of the oscillating current is larger than that of the input current then zero crossing occurs and the switch can interrupt the current in the nominal path. Current (Io) will continue to flow and will charge the capacitor.

If the capacitor voltage exceeds a given value, which is chosen to be the voltage capability of the circuit breaker, the energy absorption path will act causing the current to decrease.

This is a basic circuit that would need further implementations to be efficient in high voltages. Reduction in cost and better use of the costly components (varistor, capacitor) will be required. Also, the optimum capacitance value would minimize the breaker's interruption time and improve the whole interruption performance. Furthermore, current oscillations grow when the arc resistance (dU/dt) of the switch on the nominal path is negative. Growing oscillations can lead to faster current interruption. At the same time a large C/L ratio can help maximize the breaker's interruption performance.

Solid State Circuit Breakers:

The second type of circuit breaker we will be analyzing is the solid-state circuit breaker. In the following figure we can see that a solid-state circuit breaker uses gate-commuted thyristors instead of integrated gate-commuted thyristors for semiconductor devices, this is due to the fact that in this topology our immediate concern is lowering the on-state losses.