Voltage source converter based HVDC

by Dale Rudney, HVT Power Systems and Luo Wei, NR Electric Co

VSC based HVDC (also called HVDC Lite) is an important technology that is suited to strengthen the weak transmission and distribution systems in Africa. There has been much development in the power electronics field to the point where NR Electric Co. is busy designing a five terminal VSC HVDC system for the city of Shanghai.

VSC HVDC power transmission uses IGBT-based voltage source converters with advanced control strategies. It not only achieves efficient power transmission, but also provides dynamic reactive power support for the linked AC system(s). VSC HVDC technology is state-of-the-art application of power electronic, and also a key technology for smart grid systems.

A point-to-point VSC transmission scheme is shown in Fig. 1, which consists of two VSCs interconnected on the DC side via a DC transmission line and connected to two different AC grids on the AC side. A passive or active AC network can be connected on the AC side of the VSC. If the VSC is connected to a passive network on its AC side, the power flow can be from the DC input side towards the passive load on the AC side. However, if the AC side is connected to an active AC network, the power flow can be in both directions by controlling the AC voltage output of the VSC.

Because VSC HVDC uses modular IGBT technology, it has high response times, good controllability, flexible operation modes, and can reduce the system short-circuit current and supply to passive grids. The VSC HVDC is also an effective way to solve a large-area power blackout and long-distance power transmission to isolated grid. With VSC HVDC transmission, there are several possibilities for the DC circuit and converter units.

VSC HVDC transmission technology is the best technology for grid connection of wind farm, photovoltaic and other renewable energy generation. It not only provides a robust connection to the grid, but also effectively improves the low-voltage ride-through capability, to meet the grid code requirements on transient performance. NR Electric company is a technology leader in control and protection of conventional HVDC as well as power electronic solutions, and has proven itself as an innovator in the VSC HVDC field with its R&D engineers busy working on a five terminal VSC HVDC solution. The NR VSC HVDC technology features:

- Active and reactive power controlled independently
- Application for passive loads, isolated loads and isolated generation nodes
- Suitable for long-distance small power transmission
- Emergency assistance to provide reactive power support
- Smaller filtering capacity requirement
- Provide black-start capability
- Multi-terminal network interconnection capacity
- Modular design with relatively small foot print

The benefits of the HVDC transmission system are low switching frequency, lower running losses, easily extendable, stable operation, reliable, easy-to-use, high performance and long life cycle. This system is suitable for application in:

- Wind, solar and other renewable energy grid-connection

<table>
<thead>
<tr>
<th>Classic HVDC</th>
<th>VSC HVDC</th>
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<tbody>
<tr>
<td>Thyristor</td>
<td>IGBT</td>
</tr>
<tr>
<td>Need AC system to support commutation</td>
<td>Self commutation</td>
</tr>
<tr>
<td>Risk of commutation failure during transients</td>
<td>No commutation failure</td>
</tr>
<tr>
<td>Difficult for multi-terminal system</td>
<td>Easy for multi-terminal system</td>
</tr>
<tr>
<td>Difficult to connect to weak system</td>
<td>Easy to use in weak system</td>
</tr>
<tr>
<td>Large amount of reactive power required</td>
<td>Reactive power can be self regulated</td>
</tr>
<tr>
<td>Larger foot print</td>
<td>Smaller foot print</td>
</tr>
<tr>
<td>Lower losses (0,08%)</td>
<td>Higher losses (1,7%)</td>
</tr>
<tr>
<td>Suitable for bulk power transfer in large interconnected systems</td>
<td>Suitable for small power transfer to/from isolated load or generation points</td>
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Table 1: Comparison between classic and VSC HVDC.

Fig. 1: VSC HVDC transmission scheme.

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passive network, constant P–Vac control, V_r–U_d control, P–Q control, Q–UDC control and frequency control. The control configuration of VSC substation is shown in Fig. 3.

VSC systems should be designed, where practical, to permit operation of the rest of the system to continue in the presence of AC disturbance, DC disturbance and internal faults within one converter station. A typical protection diagram for a VSC substation is shown on Fig. 4.

The typical protective functions in a VSC system include
- Over-current protection of AC circuit breakers (1)
- Abnormal AC voltage protection (2)
- Earth fault protection (3)
- AC filter protections (4)
- Differential protection (5)
- Over-current protection of the converter (6)
- Abnormal DC voltage protection (7)
- Over-current protection of the VSC DC capacitors (8)
- DC discharge unit (9)
- Valve protection, e.g., in the valve gate electronics (10)

Additional protections are also applied, like the loss of cooling protection; DC line/cable earth fault protection/supervision; frequency protection; impedance relay protection; fire protection; mechanical protection.

The NR design of HVDC protection system aims at sensitivity and high reliability. It supports many configuration schemes, including:
- Duplicated configuration: i.e. configured by two complete sets of protection equipment. Each protection adopts the logic of "fault detection + protection calculation".
- Two-out-of-three configuration: i.e. configured by three complete sets of protection equipment which work simultaneously and use two-out-of-three vote logic. It's possible to trip out if and only if two of the three protections allow.
- Redundant configuration: i.e. configured by two complete sets of protection equipment. During operation, one set is active, while the other is hot standby. In case of fault, system changeover is required firstly before protection action.

VSC DC control and protection system is a distributed system, and consists of the flexible DC control and protection units, the distributed I/O units for the field device, optical-fibre field bus connecting the master unit to I/O devices. It is shown in Fig. 5.

The control and protection system is comprised of state of the art computers, micro-controllers and digital signal processors. Each VSC has two independent CP systems for redundancy to ensure high reliability. Multiple transient fault recording (TFR) functions are integrated into the CP. This allows recording of any signals.
in the CP at selectable time spans and resolutions limited only by data storage capacity.

This feature provides complete information about the dynamic performance of the converter.

This system is the control platform and data processing centre of the entire flexible DC control and protection system. And is responsible for the station GPS, the remote-dispatch centre’s communication interface and other related functions.

The operating control system covers: workstation of operating personnel, engineers workstation, owners workstation, the system server, file server, SCADA, LAN, station clock system, with remote dispatch centre / control centre interface and so on, as shown in Fig. 6.

The HMI in Fig. 7, is via local and remote OWS (operator work stations). The OWS allows the operator on-line access to operational status and settings of control and protection systems and to integrated diagnostic information such as the event list, alarm list, fault list, and disturbance recordings of the control and protection system. Serial connections to SCADA systems are made via standards and common hardware. The site HMI photo is shown in Fig. 8.

The VSC HVDC control and protection system should have high reliability for the system, hardware and software, using:

- Embedded systems
- No operating system in real-time applications
- Overall enclosed design without fan

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The NR control and protection system should also be easy to maintain, operate, monitor and upgrade featuring:

- Modular application software
- Graphical programming and debugging tool
- Less field bus fibre
- All software remote maintenance from a workstation
- I/O boards plug and play
- Cross-platform operator control system
- Friendly man-machine interface
- Rich and accurate alarm event
- Internal fault recorder function
- Spare parts guarantee, free chip upgrade

The NR control and protection system has other features, including:

- High flexibility
- Support the electronic transducer interface
- IEC 61850 standard
- Supports a variety of centralised control centre scheme
- Support flexible protective redundancy configuration
- Support communication interface to stability control system
- Backup control system

VSC HVDC application in Southern Africa

Southern Africa, and Africa in general, has weak and overstressed electrical networks with long distances between small load (e.g. remote towns, mines and processing plants, etc.) and generation nodes (small hydro, upcoming wind farms, solar farms, etc.). VSC HVDC is a good choice from an economic and technical point of view for the unique challenges faced in transmitting and distributing power in Southern Africa.

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