HVDC-VSC: transmission technology of the future

A new hybrid HVDC circuit technology using voltage source converters is only half the size of conventional designs, but still keeps losses low – a big advantage for urban areas, offshore wind farms and other tight spaces.

Modern high voltage direct current (HVDC) systems can transmit up to three times more megawatts across the same pylons and wires as AC systems and represent the technology of choice for bulk transmission over long distances. Moreover, given the increasing difficulties in obtaining permission for new power lines in both urban and rural areas, HVDC is often the only solution for increasing capacity over shorter distances, too. There are also other advantages associated with HVDC. The development of high power insulated gate bipolar transistors (IGBT) makes smaller HVDC systems economical. These may be installed in existing AC grids to stabilise power flow without the additional short-circuit current that would be produced by adding an AC transmission line. When an HVDC link is embedded in an AC network, it dramatically improves power flow controllability. Add HVDC converter substations, and dynamic reserve power sharing becomes possible across two AC networks with different frequencies – which means cutting standby power consumption in half. HVDC is also a firewall against faults and outages since an HVDC interconnection stops the propagation of faults that otherwise would cascade through a network. HVDC is also the choice for some short distances, notably underwater cables, where above a certain distance, the reactive power produced by an AC submarine cable would take up the entire current-carrying capacity of the conductor, so no usable power would be transmitted.

However, as Dr Norman MacLeod, HVDC & FACTS Technical Marketing Director at Alstom Grid, explains: “Classical...”
HVDC has operational drawbacks that can limit its application. It requires a relatively strong AC system on both sides of the HVDC link; it creates harmonic distortion on the AC systems; it has limited control of the reactive power interchange with the AC system; and it needs a lot of space.”

VSC overcomes the drawbacks

HVDC MaxSine®, the voltage source converter (VSC) HVDC technology being developed by Alstom Grid, solves many of these problems by combining the advantages of the two kinds of existing circuit topologies. In the first, low-pulse-number converters are used, employing large numbers of IGBTs in series, with pulse width modulation (PWM). The second category uses a multi-level approach to achieve very high pulse numbers for independently controlling a large number of bridges in each phase.

In Alstom Grid’s circuit, the basic concept is to use the multi-level converter cells to provide a voltage wave-shaping function, directed to the appropriate AC or DC network using the semiconductor switches. The new design is derived from a VSC technology that Alstom Grid developed in the 1990s for static synchronous compensator (STATCOM) applications, based on the “chain link” concept. This used a distributed DC capacitor and a full H-bridge switching circuit as the basic link in the chain. This circuit provides three possible output voltage levels (+ve, 0 and –ve), so a converter based on this arrangement can reverse its polarity. This is the basis of the first generation HVDC MaxSine® as installed at the HVDC Demonstrator station in Stafford, UK. For the new hybrid VSC technology (second generation), the semiconductor switches are arranged to form the converter, and the multi-level cells are used to synthesise a desired voltage waveform to satisfy the requirements of either the AC or DC network. A fully offset rectified sinusoidal waveform is produced in both cases, but a parallel arrangement could produce a more constant voltage at the DC network if required. The multilevel converter behaves...
like an active DC capacitor with voltage wave-shaping functionality. To direct this synthesised waveform to the AC side of the circuit, the H-bridge switches are switched at the frequency of the AC supply, but also at near zero voltage. “That’s an important benefit,” argues MacLeod, “because it enables ‘soft-switching’ of the series IGBT valves at low frequency. This offers minimal switching losses and simple dynamic voltage sharing along the series string of semiconductors forming the H-bridge switches.” Because conversion from AC to DC requires only one polarity, it is also possible to use a half-bridge circuit for HVDC applications. This is ideal for point-to-point cable schemes, while a full bridge is better for overhead lines or mixed line/cable schemes.

Ideal for offshore wind
As a self-commutated device, the VSC converter can operate into very weak systems, or even passive AC systems with no sources of generation. This makes it ideal for connecting island loads or “black starting” AC systems. Because the VSC

A NEW VSC TOPOLOGY

Conventional voltage source converters (VSC) suffer from losses and are susceptible to faults, especially on the DC side. A new hybrid topology from Alstom Grid combines concepts from traditional current-source converters and multi-level converters. It provides the advantages of half-bridge multi-level converters (low distortion and low losses) and of full H-bridge converters (mainly DC-side fault blocking). In this topology, two stacks of H-bridge cells alternate between switching in and out of the circuit to construct the converter phase voltage using director switches composed of a number of IGBTs in series. The resulting converter generates AC current with low harmonic content and with low loss. Furthermore, the converter is still very responsive to faults. Analysis suggests that this new topology is highly promising for a wide range of VSC applications. Simulations demonstrate good performance, including the capability of the converter to provide reactive power during severe abnormal conditions, even during a pole-to-pole DC-side fault. “This last feature may bring additional functionalities to HVDC MaxSine®. For instance, this new topology emerges as a good candidate for multi-terminal DC grids where the converter not only isolates a DC fault but also can offer support to the AC grid during the fault period. This may play a vital role in the evolution of future DC grids,” says Fainan Hassan, senior research technologist at Alstom Grid’s Research & Technology Centre.
The VSC converter generates a controlled output voltage, it can inherently and independently control real and reactive power flow into the AC system. In other words, it has a built-in STATCOM functionality. These advantages make VSC technology the most efficient option for offshore wind farms, allowing them to inject “clean” power into the network. The functionality of VSC technology also means it is suitable for building multi-terminal HVDC schemes, as reversing power flow does not involve a change of DC polarity, like classic HVDC, but only a change of DC voltage level at each converter.

In a typical HVDC application operating at 200 to 400 kV DC, there would be several hundred sub-modules in series, and the voltage waveform would be sufficiently sinusoidal to avoid the need for any additional harmonic filtering on the AC side. This means that the site area for a VSC HVDC station can be half the size of a comparable classic line commutated converter (LCC) HVDC station, a considerable advantage where space is at a premium, for instance in existing substations, in metropolitan areas and in offshore installations for wind farms.

As the DC capacitor is switched at low frequency, the switching losses in the IGBTs are significantly reduced in comparison with a PWM control scheme, where the switching frequency can be 1,000 Hz or higher.

Controlling reactive power

The VSC converter can deliver both real and reactive power to the AC system by controlling the magnitude and phase angle of the converter voltage waveform in relation to the AC supply voltage waveform. This function is available at both the rectifier and inverter terminals of the HVDC transmission scheme. Thus the VSC scheme can operate as a power transmission system, or as two independent STATCOMs if no power is required or available, for example, due to a cable outage.

The ability to control reactive power is critically important on a weak AC system like an offshore wind farm to avoid adverse interactions between the HVDC link and the system. A conventional LCC HVDC would require a source of rotational EMF (diesel generator) and a dynamic reactive power source (synchronous compensator). Both the full-bridge and the half-bridge power electronics can be built into a single sub-module containing:
- IGBTs (two for the half bridge or four for the full bridge), mounted on water-cooled heat sinks;
- protective thyristor (for half bridge only);
- DC capacitor (oil-free design);
- gate drive units for the IGBTs;
- fast-acting mechanical by-pass switch, which short circuits the level in the event of an IGBT failure to open the circuit;
- laminated busbars for low inductance connections;
- bleed (discharge) resistors for safe handling of the DC capacitor.

When space is at a premium

The complete sub-module is a compact assembly as shown on page 14. Eight sub-modules are mounted in a rack to form a complete power module, stacked vertically or horizontally depending on site limitations. On an offshore platform, floor area may be the key factor, while the height of

The new VSC design helps address environmental issues.
Colin Davidson, Power Electronics, R&D Director

How do you see the future of power electronics?

Very bright! When embedded in a transmission network, power electronics improve control and provide ancillary services, such as reactive power compensation needed to operate fluctuating energy resources allowing easier integration of these to the AC network. The use of power electronics in AC grids (HVDC & FACTS) allows better utilisation of existing transmission infrastructure such that more power arrives at its final destination, and electro-intensive customers do not impose any limitations on the operation of the grid.

What are the advantages of DC over AC?

With DC transmission, power flow is fully controllable, fast and accurate in steady-state conditions as well as in dynamic and transient regimes. An HVDC link can adapt to any voltage or frequency and can be used to assist the AC networks at each end of the link to operate in any scheduled mode or to survive disturbances. HVDC can act as a “firewall” to prevent a disturbance in one AC system from propagating into a neighbouring system. It’s particularly interesting for the integration of large hydropower generation, since sites are often remote, and HVDC can transmit energy economically and efficiently over long distances.

Is VSC the technology of the future?

Definitely. It easily connects unpredictable or fluctuating energy resources, such as are frequently associated with renewable sources of energy, to the AC grid. It also serves as a feeder to radial systems such as islands or large cities. And only VSC can handle the Smart Grid’s multiple interconnections, making it the perfect technology for both microgrids and continent-wide DC “supergrids.”