Status and Trends of HVDC

Dr. Mohamed Rashwan
Chairman of CIGRE Study Committee B4
HVDC and Power Electronics
ELECTRICITY SUPPLY SYSTEMS OF THE FUTURE
The purpose of modern power systems is to supply electric energy satisfying the following conflicting requirements:

- High reliability and security of supply
- Most economic solution
- Best environmental protection
Key Challenges

- Integration of multi-infeed HVDC networks in the AC network
- Effects of PE penetration at all voltage levels
- Need for appropriate models for HVDC and PE systems for network performance studies.
- Fault recovery of HVDC networks
- Standards and Grid Codes for HVDC grids to enable gradual system development ensuring compatibility among different converter manufacturers.
<table>
<thead>
<tr>
<th>No</th>
<th>WG</th>
<th>Description</th>
<th>Convenor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WG B4.64</td>
<td>Impact of AC System Characteristics on the Performance of HVDC schemes</td>
<td>Jef Beerten</td>
</tr>
<tr>
<td>2</td>
<td>WG B4.66</td>
<td>Implications for harmonics and filtering of the installation of HVDC converter stations in proximate locations</td>
<td>Fernando Cattan</td>
</tr>
<tr>
<td>3</td>
<td>WG B4.67</td>
<td>Harmonic aspects of VSC HVDC, and appropriate harmonic limits</td>
<td>Nigel Shore</td>
</tr>
<tr>
<td>4</td>
<td>WG B4.68</td>
<td>Revision of Technical Brochure 92 – DC Harmonics and Filtering</td>
<td>Nigel Shore</td>
</tr>
<tr>
<td>5</td>
<td>JWG C4/B4.38</td>
<td>Network Modelling for Harmonic Studies</td>
<td>Marta Val Escudero</td>
</tr>
<tr>
<td>6</td>
<td>WG B4.69</td>
<td>Minimizing loss of transmitted power by VSC during</td>
<td>Dennis Woodford</td>
</tr>
<tr>
<td>7</td>
<td>WG B4.70</td>
<td>Guide for Electromagnetic Transient Studies involving VSC converters</td>
<td>Dennetiere Sébastien</td>
</tr>
<tr>
<td>8</td>
<td>WG B4.71</td>
<td>Application guide for the insulation coordination of Voltage Source Converter HVDC (VSC HVDC) stations</td>
<td>Mojtaba Mohaddes</td>
</tr>
<tr>
<td>9</td>
<td>WG B4.72</td>
<td>DC grid benchmark models for system studies</td>
<td>Ting An</td>
</tr>
<tr>
<td>10</td>
<td>JWG B4/B1/C4.73</td>
<td>Surge and extended overvoltage testing of HVDC Cable Systems</td>
<td>Markus Saltzer</td>
</tr>
<tr>
<td>11</td>
<td>WG B4.74</td>
<td>Guide to Develop Real Time Simulation Models (RTSM) for HVDC Operational Studies</td>
<td>Qi Guo</td>
</tr>
<tr>
<td>12</td>
<td>WG B4.75</td>
<td>Feasibility Study for assessment of lab losses measurement of VSC valves</td>
<td>Christian Rathke</td>
</tr>
<tr>
<td>13</td>
<td>WG B4.76</td>
<td>DC/DC converters in HVDC Grids and for connections to HVDC systems</td>
<td>Dragan Jovcic</td>
</tr>
<tr>
<td>No</td>
<td>WG</td>
<td>Description</td>
<td>Convenor</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>-----------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>14</td>
<td>TF B4.77</td>
<td>AC fault response options for VSC HVDC converters</td>
<td>John Gleadow</td>
</tr>
<tr>
<td>15</td>
<td>WG B4.78</td>
<td>Cyber Assett Management for HVDC/FACTS Systems</td>
<td>Kerry Walker</td>
</tr>
</tbody>
</table>
Cigre Task Force B4.77

Part of the perceived need of the TSO is not only to have a large reactive fault current but also, to be able to deliver this rapidly in response to an AC system fault. This is referred to as FFCI (Fast Fault Current Injection). The perception is that present day VSC controllers, which act to control the current seen by the power electronic converters, are not sufficiently fast enough to meet the future AC grid needs. A second perceived problem with FFCI requirement is that it can create temporary overvoltages following ac fault clearing in low short circuit level grid conditions.

Changing the fault response of a HVDC converter, considering FFCI, specifying fault currents greater than the converters active power rating, or even adopting a VSM type control concept will have an impact on both the converter hardware design, its rating, its losses and the effective utilisation of the capital investment by the owner.
HVDC OVERVIEW

Role of HVDC

- Long distance transmission
- Asynchronous system inter-connections
- Enhanced power system operation
- Integration of renewable generation

Two Parallel Technology Paths

- Mature and Growing Thyristor based LCC HVDC
- Developing and Growing IGBT VSC HVDC
HVDC Present

Lund Symposium paper 125

Courtesy of ABB
HVDC

Courtesy of Siemens

Courtesy of State Grid
HVDC

Location: Biswanath Chariali, Alipurduar, Agra
Power Rating: 6000MW
DC voltage: ±800kV
AC voltage: 400kV
Length: 1728km

Ground electrodes

Courtesy of ABB and Power Grid of India
<table>
<thead>
<tr>
<th>Technology</th>
<th>Line Commutated Converter (LCC)</th>
<th>Voltage Sourced Converters (VSC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semiconductor</td>
<td>Thyristor (Turn on only)</td>
<td>IGBT (Turn on/off)</td>
</tr>
<tr>
<td>Ratings</td>
<td>High DC Voltage and Power</td>
<td>Lower DC Voltage &amp; Power</td>
</tr>
<tr>
<td>Power Control</td>
<td>Active Power</td>
<td>Active &amp; Reactive Power</td>
</tr>
<tr>
<td>AC Filters</td>
<td>Required</td>
<td>Not Required (MMC)</td>
</tr>
<tr>
<td>Minimum SCR</td>
<td>&gt;2</td>
<td>0</td>
</tr>
<tr>
<td>Black Start Capability</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Overload</td>
<td>High inherent overload capabilities</td>
<td>Normally not unless specified</td>
</tr>
<tr>
<td>Footprint</td>
<td>Larger site (More space required for harmonic filters)</td>
<td>Compact, 50-60% of LCC</td>
</tr>
<tr>
<td>Configurations</td>
<td>Monopole, Bipole</td>
<td>Symmetric Monopole,, Bipole, Multi-terminal</td>
</tr>
<tr>
<td>Application</td>
<td>Point-to-Point, Back-to-Back Multi-terminal</td>
<td>Point-to-Point, Back-to-Back Multi-terminal, HVDC Grid</td>
</tr>
</tbody>
</table>
VSC Application

HVDC Transmission

- Similar to conventional HVDC, one station controls DC current and one station controls DC voltage
- Power reversal is through change of DC current direction, DC voltage polarity remains unchanged
- Reactive power is controlled independently at each terminal
- Can use XPLE cables (available up to 525kV)
VSC–HVDC Transmission

Symmetrical Monopole Configuration

- Regular AC transformer
- Dc to ground fault does not cause high short circuit current
- Uses two high voltage cables, each rated for Ud/2
- Can be realized with half bridge converters without extra equipment
- No power transfer capability with a monopole outage
VSC – HVDC Transmission

Bipolar Configuration

- Can have ground or metallic return
- Converter transformer (dc stress on secondary windings)
- Dc to ground fault cause high short circuit current affecting ac systems (worse than LCC)
- Uses two high voltage conductors and possibly one low voltage conductor
- Can be realized with half bridge or full bridge converters, in case of HB requires extra equipment for dc and ac fault
- 50% (or more) power transfer capability with a monopole outage
Symmetrical Monopole

Ground Reference

In symmetrical monopole configuration dc circuit is floating and therefore can drift.

using voltage divider resistors to prevent DC Voltage shifting
Symmetrical Monopole

Ground Reference

- Required only at one station (except for STATCOM operation with DC cable disconnected) to avoid zero sequence current (mainly 3rd harmonic) circulation between stations.
- Under normal conditions current in L1 is negligible (L1 >>)
- The voltage across R2 is equal to $\Delta U$
- Stresses during dc line to ground fault should be considered in selection of R2.

DC voltage balancing using star point reactor.

$\Delta U / 2 + \Delta U$

$-U_d / 2 + \Delta U$
Fault Performance

Pole to ground fault in symmetrical monopole with HB (no dc breaker)

- Will cause sudden discharge of cable
- Will cause overvoltage on the healthy conductor
- Will be detected and cause blocking of all sub-modules; a trip signal is issued at the same time
- After blocking the pole–pole dc is determined by diodes only (limited to peak phase–phase voltage)
- Normally cleared by opening ac breakers at both ends, can restart after discharging the cable
Fault Performance

Pole-to-pole fault in symmetrical monopole with HB

- Will discharge both converter capacitors and cables
- Will be fed from all AC systems through diodes
- Will appear like a high impedance fault to all AC systems
- All IGBT’s are blocked
- Will cause protective thyristors to be triggered at all sub-modules; trip signal will be issued to all ac breakers

- A pole to ground fault in bipolar or asymmetrical monopole will have the same behavior
Fault clearing using a full bridge
Cigre Symposium 2015 Lund Sweden paper 113
In a typical offshore wind integration project, the location is typically between 150-200 km from the point of common coupling (PCC), including both offshore and on shore cables to the converter terminal, thereby making HVDC the most appropriate technology to use for power transmission to mainland grids, recognizing the limitations in AC submarine transmission at such distances. In addition, VSC HVDC technology offers several unique advantages suitable for such environmentally harsh and difficult conditions, with yet greater energy yield potentials.
HVDC

Reference Cigre paper B4-132-2015 Session
Off–Shore VSC requirements

As compared to a completely onshore VSC HVDC link, the VSC HVDC link which connects an offshore WPP to the onshore AC system may have special requirements. For example:

- A braking chopper in the onshore converter station
- Multiple/parallel transformers in both converter stations. Each transformer is typically rated to transmit more than 50% of the WPP power (sometimes up to 100% in case of another transformer outage), and requires a more sophisticated mechanical design to withstand particularly the harsh offshore environmental conditions. It must be noted that selection of the transformer also requires cost-benefit analysis
- Other main considerations include outage time and reliability. For example, accessibility of the offshore VSC HVDC platform and maintenance
Renewable energy Integration

The first multi-terminal VSC-HVDC project
Wind Energy of Nan’ao island is transported to mainland power grid by AC and DC lines in parallel
Commissioned in 2013

±160 kV, 200/100/50/50MW Overhead Line (20.6km in total), Underground Cable (9.5 km), Submarine Cable 10.7 km

Curtesy to SERPI of CSG
HVDC Future

HVDC Diode rectifier unit complete with transformer smoothing reactor cooling

Connection of HVDC diode rectifier units

The cooling and insulation is utilizing synthetic based ester liquids- The last time oil immersed valves were used was almost 50 years ago in Cahora Bassa HVDC system between SA and Mozambique. One end is still oil immersed outdoor valves
Cigre Lund Symposium
HVDC Future

+/- 800 kV VSC project  China Southern Power Grid Cigre SC B4 meeting 2016
DC Grids
Aspects of DC Grids

- Control strategy
- Protection
- Reliability
- Grid code
- Breakers
- DC–DC converters
HVDC and FACTS performance

- Protocol for reporting of performance of HVDC systems Cigre TB 590
- Protocol for reporting operational performance of FACTS TB 717
HVDC PERFORMANCE

Cigre HVDC Performance Report Started in 1968
Protocol for Reporting the Operational Performance of HVDC (Latest revision TB 590)
55 HVDC Systems have reported
Factors affecting HVDC Performance
  Equipment Rating/performance
  System faults
  Redundancy
  Spares
  Operator skills
AC-E: all ac main circuit equipment including ac filters and other reactive power equipment, ac control & protection, converter transformer and synchronous compensator, auxiliary equipment & auxiliary power and other ac switchyard equipment.

Valve: all parts of the valves including electrical, cooling, capacitors and phase reactor as well as all auxiliaries and components integral with the valve and forming part of the operative array.

C&P: dc control and protection equipment used for control of the overall HVDC system and for the control, monitoring and protection of each HVDC substation.

DC-E: all equipment at the HVDC substations except for that in the three categories AC-E, Valves and C&P. This category includes the DC smoothing reactors, DC switching equipment, DC measurement equipment, ground electrodes and electrode lines, and other DC Switchyard and Valve Hall Equipment.

Other: Human error or unknown causes
Thank you Cigre SC B4