Detailed Modelling of MMC-HVDC Links

Antony Beddard
VSC-HVDC

- Demand for VSC-HVDC systems is growing worldwide.
- Modular Multi-level Converters (MMC) is the VSC topology of choice.
- Focus is on the DC components
MMC

- Types of MMC
  - Half-bridge
  - Full-bridge
  - Alternate arm converter

- Selecting MMC Parameters
  - Number of voltage levels
  - SM capacitance
  - Arm reactance
MMC Modelling Techniques

- Type 1 – Full physics based model
- Type 2 – Full detailed model
- Type 3 – Traditional detailed model (TDM)
- Type 3.5 – Accelerated model (AM)
- Type 4 – Detailed equivalent model (DEM)
- Type 5/6 – Average value model (AVM)
- Type 7 – Phasor domain model
- Type 8 – Power flow model
Comparison of TDM(3), AM(3.5) and DEM(4)

DC line-to-line Fault

<table>
<thead>
<tr>
<th>Signal</th>
<th>DEM error (%)</th>
<th>AM error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_d$</td>
<td>0.41</td>
<td>2.29</td>
</tr>
<tr>
<td>$V_a$</td>
<td>0.22</td>
<td>1.12</td>
</tr>
<tr>
<td>$I_{ua}$</td>
<td>0.51</td>
<td>1.83</td>
</tr>
<tr>
<td>$V_c$</td>
<td>0.07</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Simulation duration (s)

Number of MMC levels

DeepWind’2015
Trondheim
4-6th February 2015
HVDC Cable Modelling

Types of HVDC Cable Model:-

- Lumped Parameter Model
- Bergeron Model
- Frequency Dependent Mode Model (FDMM)
- Frequency Dependent Phase Model (FDPM)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Material</th>
<th>Radial Thickness (mm)</th>
<th>Resistivity (Ω/m)</th>
<th>Relative Permittivity</th>
<th>Relative Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductor</td>
<td>Stranded Copper</td>
<td>24.9</td>
<td>2.2x10^-8*</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Conductor screen</td>
<td>Semi-conductive polymer</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Insulation</td>
<td>XLPE</td>
<td>18</td>
<td>-</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>Insulator screen</td>
<td>Semi-conductive polymer</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sheath</td>
<td>Lead</td>
<td>3</td>
<td>2.2x10^-7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Inner Jacket</td>
<td>Polyethylene</td>
<td>5</td>
<td>-</td>
<td>2.3</td>
<td>1</td>
</tr>
<tr>
<td>Armour</td>
<td>Steel</td>
<td>5</td>
<td>1.8x10^-7</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Outer cover</td>
<td>Polypropylene</td>
<td>4</td>
<td>-</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Sea-return</td>
<td>Sea water/air</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Copper resistivity is typically given as 1.68x10^-8 Ω/m. It has been increased for the cable model in PSCAD due to the stranded nature of the cable which cannot be taken into account directly in PSCAD.
Comparison of Cable Models

- The choice of cable model can have a significant impact on the simulation results.
- Computational efficiency is approximately the same for the travelling wave models.
- The CEPIM was found to be the least computationally efficient model.
- FDPM is therefore the default model of choice for typical VSC-HVDC studies in this work.
Dynamic Braking System

- Typically employed for HVDC windfarm connections
- Normally located onshore
- Common models:
  - Voltage dependent current source
  - Power electronic switch with resistor
  - Control – Two level switching, PWM etc.
HVDC Circuit Breaker

• Required for large HVDC grids
• Hybrid DC breakers are currently the preferred topology
• Modelling options – Cigre WG B4-57 technical brochure
Control

- MMC Control

  - Modulation - Nearest level control (NLC), selective harmonic elimination etc.
  - Capacitor balancing controller (CBC)
  - Circulating current suppressing controller (CCSC),
  - Outer controllers similar to traditional VSCs. i.e. not specific to valve topology
MTDC Control Strategies

<table>
<thead>
<tr>
<th>Control Method</th>
<th>MMC1 control mode</th>
<th>MMC4 control mode</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralised DC slack bus</td>
<td>DC voltage &amp; AC voltage magnitude</td>
<td>Active power &amp; reactive power</td>
<td>P* = 500MW</td>
</tr>
<tr>
<td>Voltage margin control</td>
<td>DC voltage &amp; AC voltage magnitude</td>
<td>Voltage margin &amp; reactive power</td>
<td>Vd-High = 620kV,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vd-Low = 580kV</td>
</tr>
<tr>
<td>Droop control</td>
<td>Standard droop &amp; AC voltage magnitude</td>
<td>Standard droop &amp; reactive power</td>
<td>Droop gain = - 0.1</td>
</tr>
</tbody>
</table>

Diagram showing control methods and parameters for different windfarms and MMC control modes.
Example Simulation Results – MMC disconnection

Centralised DC slack bus

Margin Control

Droop control
Example Simulation Results – MMC1 AC fault

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5
Current (kA)

Time (s)
Droop
Margin
Slack
Thank you!
References

- Slide 1 – Picture courtesy of: Danish Energy Authority (left) CleanTechnica (right)
- Slide 6 - Picture courtesy of ABB