Operation and Control of an HVDC Circuit Breaker with Current Flow Control Capability

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Outline

1. Motivations
2. Proposed device
3. Simulation results
4. Conclusion
1. Motivations
Multi-terminal DC systems

- Multi-terminal HVDC systems
  - Improve system’s flexibility
  - Improve system’s reliability
  - Integrate different types of renewable energy

Zhangbei ± 500 kV HVDC system for Beijing Olympic Games 2022

DC fault and Current flow control

- Challenges of MTDC grids: dc fault
  - No zero crossings (dc current)
  - High rising rate of current (di/dt)
  - Low capability of overcurrent (IGBTs)

- Challenges of MTDC grids: Current flow control
  - Dominated by the resistance of the transmission lines
  - Overloading of transmission lines
  - Limit capacity of power transmission

Examples of dc fault for VSC

Four-terminal system
Challenges

Challenges for DCCB and CFC

- Cost
- Reliability

‘Zhangbei’ ± 500 kV HVDC system for Beijing Olympic Games 2022

500 kV HCB developed for Zhangbei project

Targets

- Integrate several CBs and CFC into one device
- Reduce semiconductors and costs
- Maintain same function

(a) Separate HCBs and CFC.
(b) Integrated device.

2. Proposed device
Proposed device

➢ Topologies

▪ Two CBs and one CFC integrated

![Proposed device diagram]

System configuration with the CB/CFC
Proposed device

- DC fault isolating
  - Four steps

Fault isolation process. (a) Pre-fault. (b) Current commutation. (c) Fault current interruption. (d) Post fault.
Proposed device

Current flow control

Topography of CB/CFC

Simplified equivalent circuit as a CFC
Proposed device

- **Bypass mode**

  \[ I_1 = I_{12} + I_{13} \]

- **Current nulling mode**

  \[ I_{12} = I_1, \quad I_{13} = 0 \]

- **Current sharing mode**

  \[ I_{12} = I_1 D \]

  \[ I_{12} = I_1 / D \]
Proposed device

- Control and modulations

(a) Level-shift modulation

(b) Dual-loop control loop

Carrier (500Hz)
3. Simulation results
Proposed device

- System parameters

### TABLE I

<table>
<thead>
<tr>
<th>MTDC System Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Rated dc voltage</td>
</tr>
<tr>
<td>Rated power MMC1, 2, 3</td>
</tr>
<tr>
<td>Transformer rated capacity</td>
</tr>
<tr>
<td>Transformer ratio</td>
</tr>
<tr>
<td>Transformer leakage inductance</td>
</tr>
<tr>
<td>Arm inductance</td>
</tr>
<tr>
<td>SM Capacitor</td>
</tr>
<tr>
<td>Number of SMs in each arm</td>
</tr>
<tr>
<td>DC current limiting inductor</td>
</tr>
<tr>
<td>Pi-section (per 40 km)</td>
</tr>
<tr>
<td>Capability of transmission line</td>
</tr>
<tr>
<td>Length of Line 12, Line 13, Line 23</td>
</tr>
</tbody>
</table>
Proposed device

- Simulation results of dc fault isolation

Protection of dc faults at transmission lines. (a) Fault current. (b) Currents of MB and MOV. (c) Voltage of MB. (d) Energy absorbed by the CB/CFC.

Protection of dc faults at transmission lines. (a) Fault current. (b) Currents of MB and MOV. (c) Voltage of MB. (d) Energy absorbed by the CB/CFC.
Proposed device

➢ Simulation results of current flow control

Current reversal mode for CFC operation. (a) Active power of converters. (b) DC currents of converters. (c) Currents of transmission lines. (d) Modulation and carrier signals.
Proposed device

➢ Comparisons

Integrated schemes of CFC with HCB. (a) Scheme I: Sharing LCSs. (b) Scheme II: Sharing LCSs and MBs. (c) Scheme III: CB/CFC.

<p>| TABLE IV  |
| NUMBER OF HIGH VOLTAGE COMPONENTS |</p>
<table>
<thead>
<tr>
<th>Scheme</th>
<th>No. of IGBTs</th>
<th>No. of UFD Units</th>
<th>No. of MOV Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>4(n+6\times4)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>II</td>
<td>3(n+6\times4)</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>III</td>
<td>(n+7\times4)</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: \(n\) is determined by the residual voltage of MOVs and the cut-off current of the HCBs and \(n\) is in the level of hundreds for a 500 kV HCB [29].

<p>| TABLE V  |
| COST CALCULATION OF THE MB BRANCH FOR A 500 kV SYSTEM |</p>
<table>
<thead>
<tr>
<th>Scheme</th>
<th>No. of MB units</th>
<th>No. of IGBTs</th>
<th>Costs (Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>4</td>
<td>800 \times 4 = 3200</td>
<td>$28.8</td>
</tr>
<tr>
<td>II</td>
<td>3</td>
<td>800 \times 3 = 2400</td>
<td>$21.6</td>
</tr>
<tr>
<td>III</td>
<td>1</td>
<td>800 \times 1 = 800</td>
<td>$7.2</td>
</tr>
</tbody>
</table>

Note: 400 IGBTs are in series to withstand a transient voltage of 900 kV and 400 IGBTs are in parallel to withstand the fault current. Therefore, 800 IGBTs are considered per MB unit.
4. Conclusion
Conclusion

1. DC protection and current flow control were analysed for MTDC applications
2. The proposed device was described.
3. Simulation results were given to verify the function of the proposed device.

Publications on this topic:


