Techno-economic feasibility of HVDC systems up to 800 kV

Gunnar Asplund

ABB

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Transmission alternatives

Estimated cost of lines, stations and losses to transmit 12 GW a distance of 2000 km

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>Lines</th>
<th>Estimated Cost (MUSD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 AC</td>
<td>6</td>
<td>7000</td>
</tr>
<tr>
<td>600 DC</td>
<td>3</td>
<td>6500</td>
</tr>
<tr>
<td>800 DC</td>
<td>2</td>
<td>6000</td>
</tr>
<tr>
<td>1000 AC</td>
<td>4</td>
<td>5500</td>
</tr>
</tbody>
</table>

Percent line losses:

- 800 kV AC 6 lines
- 600 kV DC 3 lines
- 800 kV DC 2 lines
- 1000 kV AC 4 lines
Transmission alternatives

Estimated cost of lines, stations and losses to transmit 12 GW a distance of 3000 km

- 800 kV AC 6 lines
- 600 kV DC 3 lines
- 800 kV DC 2 lines
- 1000 kV AC 4 lines
UHVDC - challenges

- 800 kV DC
  - Station equipment
  - DC Line insulation

- 6000 MW
  - Current (4000 A) through dc equipment and line
  - AC system at loss of transmission capability
UHVDC - one pole

Exposed to 800 kV dc
## Converter station equipment - need for R&D

<table>
<thead>
<tr>
<th>Major R&amp;D needed</th>
<th>Some R&amp;D needed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Converter transformers incl. Bushings</strong></td>
<td><strong>Valve cooling</strong></td>
</tr>
<tr>
<td><strong>Wall bushing</strong></td>
<td><strong>AC Breakers</strong></td>
</tr>
<tr>
<td><strong>Thyristors</strong></td>
<td><strong>AC Disconnectors</strong></td>
</tr>
<tr>
<td><strong>Converter valves</strong></td>
<td><strong>AC measuring devices</strong></td>
</tr>
<tr>
<td><strong>By- pass breaker</strong></td>
<td><strong>AC filter components</strong></td>
</tr>
<tr>
<td><strong>By- pass switch</strong></td>
<td><strong>DC filter reactors</strong></td>
</tr>
<tr>
<td><strong>Arresters</strong></td>
<td><strong>PLC filter reactors</strong></td>
</tr>
<tr>
<td><strong>DC Capacitors</strong></td>
<td><strong>DC filter resistors</strong></td>
</tr>
<tr>
<td><strong>PLC Capacitors</strong></td>
<td><strong>Steel structures</strong></td>
</tr>
<tr>
<td><strong>Control system</strong></td>
<td><strong>Building</strong></td>
</tr>
<tr>
<td><strong>DC Disconnectors</strong></td>
<td><strong>Fire system</strong></td>
</tr>
<tr>
<td><strong>Voltage measuring devices</strong></td>
<td><strong>Electrode</strong></td>
</tr>
<tr>
<td><strong>Smoothing reactor</strong></td>
<td>No R&amp;D foreseen</td>
</tr>
</tbody>
</table>
UHVDC alternative circuit configurations

4500 MW

6000 MW
Converter configurations

- 1 x 12 pulse group /pole
  - Maximum rated power 4500 MW
  - Transformer transportation (dimension & weight)
  - Same lay-out as for 500 kV DC projects

- 2 x 12 pulse groups /pole
  - Maximum rated power 6200 MW at 800 kV
  - Transformer transportation (dimension & weight)
  - Enhanced flexibility & availability
UHVDC, 1 x 12-pulse converter/pole

- "Standard" configuration
- 1 x 12 pulse group/pole
- Max power 4500 MW at 800 kV DC
- Transformer data (4500 MW)
  - No 12 units
  - Single phase 2 winding 450 MVA
  - Weight 430 tons
  - LxWxH 12 x 4 x 5m
UHVDC, 2 x 12-pulse converters/pole

- 2 x 12 pulse groups/pole
- Max power 6200 MW at 800 kV DC
- Transformer data (6200 MW)
  - No 24 units+spares
  - Single phase 2 winding 310 MVA
  - Weight 310 tons
  - LxWxH 10 x 4 x 5 meter
- Installed at Itaipu, in operation for 20 years
Reliability of converters

Large power blocks ask for extremely high reliability!

100 % separation of poles, 3000MW each
Far going separation of groups, 1500 MW each:

- Geographical
- Mechanical
- Electrical

Example:
- AC-yard
- Auxiliary power
- Control
- Cabling
- AC-filters
- Cooling, water supply
## Reliability & Availability, converter stations

<table>
<thead>
<tr>
<th></th>
<th>Design Target 1 x 12-p group</th>
<th>Design target 2 x 12-p group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bipole trip</td>
<td>0,05 / year</td>
<td>~0,05 / year</td>
</tr>
<tr>
<td>Pole trip</td>
<td>2 / year</td>
<td>~0,5 / year</td>
</tr>
<tr>
<td>12-pulse group trip</td>
<td>-</td>
<td>2 / year</td>
</tr>
<tr>
<td>Availability (forced)</td>
<td>99,75 %</td>
<td>~99,90 %</td>
</tr>
</tbody>
</table>
Overload capability/12 pulse group

Overload capability is an efficient way to limit the effect of a disturbance

At normal conditions and redundant cooling available