Topics

- HVDC Fundamentals
  - Conventional Converters
  - Capacitor Commutated Converters
  - Voltage Source Converters
  - Reactive Power Requirements
  - System Configurations
  - Tapping
  - Control basics
  - High Power Transmission
Evolution . . .
Core HVDC Technologies

- **HVDC Classic**
  - Current source converters
  - Line-commutated thyristor valves
  - Requires 50% reactive compensation (35% HF)
  - Converter transformers
  - Minimum short circuit capacity > 2x converter rating

- **HVDC Light**
  - Voltage source converters
  - Self-commutated IGBT valves
  - Requires no reactive power compensation (15% HF)
  - Standard transformers
  - No minimum short circuit capacity, black start
The HVDC Classic Converter Station

Converter station

Transmission line or cable

Converter
Smoothing reactor
DC filter
Telecommunication

AC bus
Shunt capacitors or other reactive equipment
AC filters
Control system
The CCC* Station

*Capacitively-commutated converter

Conversion

AC bus

Contune AC filters

Converter

Commutation capacitors

Smoothing reactor

DC filter

Control system

Telegram

Telecommunication

Transmission Line, Cable or Back-Back
Modular Back-to-Back CCC Asynchronous Tie
Improved Stability and Higher Power Transfer

HVDC Classic

HVDC CCC
The HVDC Light Converter Station

Converter station

Indoor

Voltage Source Converter - VSC

Phase Reactor

AC filters

DC Capacitor

Control system

AC bus

Dry DC Capacitor

Transmission Cable

IGBT Valves

ABB
Comparison of Reactive Power Characteristics

- Conventional HVDC – HVDC Classic
  (~ SVC with TCR+FC, -0.5Pd / +0 MVAr)

- VSC Based HVDC – HVDC Light
  (~ STATCOM, -0.5Pd/+0.5Pd MVar)
HVDC Converter Arrangements

## HVDC Classic
- Thyristor valves
- Thyristor modules
- Thyristors
- Line commutated

## HVDC Light
- IGBT valves
- IGBT valve stacks
- StakPaks
- Submodules
- Self commutated
Tapping OVHD HVDC with Large VSC Converters

**HVDC Tap**
- Reverse power by polarity reversal
- Electronic clearing of dc line faults
- Fast isolation of faulty converters
- Reactive power constraints
- Momentary interruption due to CF at tap
- Limitations on tap rating, location and recovery rate due to stability

**HVDC Light Tap**
- Polarity reversal if main link is bidirectional
- Cannot extinguish dc line fault current contribution without special provision, e.g., diode coupling for inverter
- No interruption to main power transfer due to CF at tap
- Less limitations on tap rating and location
- Cascade VSC connection for lower tap rating
- No reactive power constraints
- Improved voltage stability
HVDC Classic Control
Control of VSC Based HVDC Transmission

Principle control of HVDC-Light
## Comparison - AC, HVDC, HVDC CCC and HVDC Light

<table>
<thead>
<tr>
<th>Attributes</th>
<th>AC Cable</th>
<th>HVDC - Conventional</th>
<th>HVDC – Capacitor Commutated</th>
<th>HVDC Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power flow control</td>
<td>None unless PST or series reactor</td>
<td>Continuous ±0.1Pr to ±Pr</td>
<td>Continuous ±0.1Pr to ±Pr</td>
<td>Continuous 0 to ±Pr</td>
</tr>
<tr>
<td>Reactive power demand</td>
<td>3 I^2 X - 3 V^2 B</td>
<td>Reactive power demand = 50% power transfer</td>
<td>Reactive power demand reduced by series cap</td>
<td>No reactive power demand</td>
</tr>
<tr>
<td>Reactive power compensation &amp; control</td>
<td>Shunt reactors</td>
<td>Switched shunt banks 35% in filters + 15% in capacitors</td>
<td>Filters + series compensation of 3 I^2 Xcc</td>
<td>STATCOM + 15% in fixed filters</td>
</tr>
<tr>
<td>AC voltage control</td>
<td>Static</td>
<td>Slow - switched filters, capacitors &amp; reactors + LTC</td>
<td>Slow - switched filters, capacitors &amp; reactors + LTC</td>
<td>Dynamic – virtual generator</td>
</tr>
<tr>
<td>Voltage stability</td>
<td>Dependent on P, Q and Z</td>
<td>Degraded, special control</td>
<td>Improved, CF lower probability</td>
<td>Superior, no CF</td>
</tr>
<tr>
<td>AC system limitation</td>
<td>Cable derated with distance by charging current</td>
<td>Min SCC&gt;2x converter rating</td>
<td>Min SCC&gt;1.3x converter rating</td>
<td>None – black start, passive load, induction generators OK</td>
</tr>
</tbody>
</table>
Running Underground

500 kV EHV
1500 MW

± 500 kV HVDC
3000 MW

± 320 kV HVDC Light
1000 MW
Comparison of overall line design

800 kV

±600 kV

1000 kV

±800 kV
## Itaipu 765 kV AC Line Performance

<table>
<thead>
<tr>
<th>Year</th>
<th>Trans</th>
<th>Perm</th>
<th>Length</th>
<th>Trans</th>
<th>Perm</th>
<th>Length</th>
<th>Trans</th>
<th>Perm</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>0</td>
<td>4</td>
<td>891</td>
<td>1</td>
<td>11</td>
<td>891</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>1996</td>
<td>1</td>
<td>13</td>
<td>891</td>
<td>0</td>
<td>7</td>
<td>891</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>1997</td>
<td>0</td>
<td>6</td>
<td>891</td>
<td>2</td>
<td>13</td>
<td>891</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>1998</td>
<td>0</td>
<td>10</td>
<td>891</td>
<td>2</td>
<td>16</td>
<td>891</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>1999</td>
<td>1</td>
<td>27</td>
<td>891</td>
<td>1</td>
<td>10</td>
<td>891</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>3</td>
<td>15</td>
<td>891</td>
<td>3</td>
<td>14</td>
<td>891</td>
<td>2</td>
<td>9</td>
<td>602</td>
</tr>
<tr>
<td>2001</td>
<td>2</td>
<td>4</td>
<td>891</td>
<td>4</td>
<td>8</td>
<td>891</td>
<td>2</td>
<td>5</td>
<td>915</td>
</tr>
<tr>
<td>2002</td>
<td>4</td>
<td>12</td>
<td>891</td>
<td>1</td>
<td>7</td>
<td>891</td>
<td>4</td>
<td>16</td>
<td>915</td>
</tr>
<tr>
<td>8 year</td>
<td>11</td>
<td>91</td>
<td>7128</td>
<td>14</td>
<td>86</td>
<td>7128</td>
<td>8</td>
<td>30</td>
<td>2432</td>
</tr>
</tbody>
</table>

Trans = 0,198 faults / 100km / year  
Perm = 1,240 faults / 100km / year

Trans = Successful reclose, one attempt  
Perm = Permanent, excluding tower failures

Isokeraunic Level 90 (Foz) to 50 (SP)

Tower Failures due to wind:  
1994: 3 both circuits*  
1997: 2 both circuits*  
1998: 2 both circuits*  
*total of 3 events

Note: “,” = “.”
Itaipu 600 kV HVDC Line Performance

<table>
<thead>
<tr>
<th></th>
<th>Bipole 1</th>
<th></th>
<th>Bipole 2</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P1 -</td>
<td>P2 +</td>
<td>P3 -</td>
<td></td>
<td>P4 +</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>8</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1994</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1995</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1996</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1997</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1998</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1999</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>8 year</td>
<td>24</td>
<td>4</td>
<td>9</td>
<td>33</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Ave.</td>
<td>3</td>
<td>0,5</td>
<td>1,13</td>
<td>4,13</td>
<td>0,38</td>
<td>1</td>
</tr>
</tbody>
</table>

Trans = 0.659 pole faults / 100km / year
RedV = 0.078 pole faults / 100km / year
Perm = 0.202 pole faults / 100km / year

*Line Tower Failures total two events

Isokeraunic Level 90 (Foz) to 50 (SP)

Trans = Successful restart at full voltage
RedV = Successful restart at reduced voltage (450 kV)
Perm = Permanent, excluding tower failures

Note: “,” = “.”