Brazil-China-India meeting on HVDC and Hybrid Systems, planning and Engineering Issues

Rio de Janeiro, Brazil
July 16th-18th, 2006

HVDC Systems Planning Considerations

Rajendra Iyer
Project Manager- HVDC Projects
Dilemma for the Emerging Economies

Rapid economic growth → Continued Infrastructure development → Power Demand

- **Growth Circle**

  Economy → Infrastructure → Power

- **Murphy’s law (Law of Nature)** → Cheap power generation source always farthest away from the loads.

  - BULK POWER TRANSFERS OVER LONGER DISTANCES
New challenges for transmission systems

- Important aspects from perspective of Developing countries
  - Reliable Bulk power transmissions over larger distances
  - Value for Money
  - Minimal Environmental Impact
  - Assistance in economic development of new areas
  - Power cuts and Black outs - Intolerable to economic growth
  - Increasing the efficiency of existing Power grid
  - Power quality
Planning considerations for Bulk Power Transmission

- Reliability
- Maintainability
- ROW
- Interconnections
- Technology
- Environmental Impact
- Power trade
- Utilisation
- Transmission Distance
- Transmission Planning
- Economics
Potential 800 kV HVDC projects in the world

Total 320 GW
= 50 projects * 6 GW
Brazil: Potential Amazonas River Projects

AMAZON RIVER (Left bank)
21,000 MW

NORTH ATLANTIC
1,800 MW

LOW XINGU
26,000 MW

LOW TOCANTINS/LOW ARAGUAIA
20,000 MW

MADEIRA
18,000 MW

LOW TAPAJÓS/LOW MADEIRA
21,000 MW

HIGH TAPAJÓS/HIGH XINGU
13,000 MW

1900 km
2400 km
1300 km
2100 km
2200 km
1600 km
2200 km
Brahmaputra River Hydro Power Development

- Agra
- Mysore
- Indore
- Subansiri

ROW 20x20 km

Economical development of the east

Investment considerations $$$$$$$$$$$$$$$$$$$$$$$$

© ABB Group - 7 -
22-Oct-07
South Africa: West Cor Line

Proposed DC voltage level in both bipoles: 800 kV

Approx. 3000 km

Inga station, Cuanza station, Auas station, Omega Station, Gaborone station, Pegasus station, Cong station, Angola, Botswana, Namibia, South Africa.

Inga, the world's largest hydro power resource:
- > 5000 MW run-of-river
- > 40,000 MW with dam
Jinsha River I (Xiluodu, Xiangjiaba), Jingping & Xiaowan Dams, for 800kV UHVDC

- **Xiangjiaba – Shanghai**
  - 800kV, 6400 MW, 1950km
  - 2011

- **Xiluodu – Zhejiang**
  - 800kV, 6400 MW, 1870km
  - 2015

- **Jingping – East China**
  - 800kV, 6400 MW, 2100km
  - 2012

- **Xiluodu – Hubei (C.China)**
  - 800kV, 6400 MW, 1070km
  - 2014

- **Xiluodu Dam**

- **Xingjiaba Dam**

- **Jingping Dam**

- **Xiaowan Dam**

- **Yunnan – Guangdong**
  - 800kV, 5000 MW, 1500km
  - 2009

- **Updated 2006-4-14, CNABB-PTSG**

[Map of China showing the locations of the dams and transmission lines]
Planned Future HVDC Projects by 2020 in China

(The year means project in operation)

- Irkutsk (Russia) - Beijing
  800kV, 6400 MW, 2015

- Xianjiaba – Shanghai
  800kV, 6400 MW, 2011

- Xiluodu - Hanzhou
  800kV, 6400 MW, 2015

- Xiluodu - Hunan
  800kV, 6400 MW, 2014

- Jinsha River II – East China
  800kV, 6400 MW, 2016

- Jingping – East China
  800kV, 6400 MW, 2012

- Jinsha River II – East China
  800kV, 6400 MW, 2019

- Jinsha River II - Fujian
  800kV, 6400 MW, 2018

- Nuozhadu-Guangdong
  800kV, 5000-6000 MW, 2015

- Humeng – Shandong
  800kV, 6400 MW, 2015

- Xiluodu - Hunan
  800kV, 6400 MW, 2014

- Nuozhadu-Guangdong
  800kV, 5000-6000 MW, 2015

- Gezhouba-Shanghai Expansion
  3000 MW, 2011

- Lingbao BtB Expansion
  750 MW, 2009

- BtB China-Russia (HeiHe)
  750 MW, 2008

- BtB Northeast-North (Gaoling)
  1500 MW, 2008

- BtB North - Central
  1000 MW, 2012

- Gezhouba-Shanghai Expansion
  3000 MW, 2011

- Lingbao BtB Expansion
  750 MW, 2009

- Yunnan - Guangdong
  800kV, 5000 MW, 2009

- BtB North - Central
  1000 MW, 2012

- BtB North - Central
  1200 MW, 2011

- BtB North - Central
  1000 MW, 2012

- Gezhouba-Shanghai Expansion
  3000 MW, 2011

- Lingbao BtB Expansion
  750 MW, 2009

- Goupitan - Guangdong
  3000 MW, 2016

- Humeng - Liaoning
  800kV, 6400 MW, 2018

- Hulunbeir (Inner Mongolia) - Shenyang
  3000 MW, 2010

- NWPG

- NEPG

- CCPG

- ECPG

- SCPG

- NCPG

Updated 2006-4-14, CNABB-PTSG
What makes UHVDC an obvious choice

- Typically over such larger distances, there aren’t any existing direct corridors for transmission.

- An AC interconnection would be technically extremely challenging and economically unviable.
Economics
Transmission of 6000 MW over 2000 km. Total evaluated costs in MUSD

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Losses</th>
<th>Line cost</th>
<th>Station cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>765 kV AC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 kV DC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>800 kV DC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of lines:

Right of way (meter):

- 765 kV AC: ~240
- 500 kV DC: ~110
- 800 kV DC: ~90
Transmission Economics

Estimated cost of stations, lines, compensation and losses

- Power 6000 MW
- Line length 2000 km
- 765 kV AC 4 lines
- 500 kV DC 2 lines
- 500 kV AC 10 lines
- 800 kV DC 1 lines

MUSD vs. Percent line losses
Why do we need HVDC links in a grid?

- **Control** rather than **Be Controlled**
  - Gives much more flexibility to the grid operators.
  - Through the controlling facility that HVDC offers, an increase in power via the AC lines can be permitted without jeopardising the stability of the network.

- **Support to Existing AC corridors**
  - Reactive power support / Voltage Support.
  - Frequency Stabilisation.
  - Control Features- Run Up / Run Down Power.
  - Interaction via SSC (system stability control).
Transmission line corridor

HVDC cables
Suggested Configurations
UHVDC plans - India

- Agra
- Mysore
- Indore
- Subansiri

500 km
2100 km
2700 km

6000-8000 MW  +/- 800 kV
Built in steps

© ABB Group - 18 -
22-Oct-07
Parallel converters. Single 12 pulse bridge for each pole. 800 kV over the bridge. Phase 1.
Parallel converters. Single 12 pulse bridge for each pole. 800 kV over the bridge. Phase 2.
Series Connected converters – Chinese Plans

- Two 400kV, 12 pulse groups/pole
- Transformer data
  - № 24 units
  - 1Ø2W ~ 248 MVA
- Smoothing inductance split in pole and neutral
- Scheme: two converters per pole:
  - Installed at Itaipú,
  - In operation for 20 years
Transmission Alternatives
Transmission alternatives – Hybrid with UHVDC and HVDC Light®

L1

L2

800 kV DC

~2500 - 3000 km
Transmission alternatives - EHVAC

Compensation

~2500 - 3000 km
Stability Issues

The ac-system should not be loaded more than it can safely withstand the loss of any line or generator.
Stability Issues

- "Bulk Power through Pure DC link" is more robust and provides considerable isolation and hence system stability due to the inherent independence from system phase angles.

- Also in Hybrid solutions, the DC link will stabilise the parallel AC transmission.

![Graph showing power comparison with and without modulation of DC link.](image)
Itaipu - A valuable Hybrid experience

Technology step taken 2 decades ago

Customer needs
- Long distant energy link between the hydro power generation in Foz do Iguaçu to the power consumption in the Sao Paulo area

ABB’s response
- Turnkey 6300 MW HVDC in two bipoles
- Highest +/- 600 kV DC voltage in the world

Customer benefits
- Itaipu project is serving as an important link for electricity
- Compact lines with low losses
- Security of supply through controllable power flow and redundancies
### Itaipu - Overhead line reliability

<table>
<thead>
<tr>
<th>Year</th>
<th>HVDC 600 kV</th>
<th>HVAC 765 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1993</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1994</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1995</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1996</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1997</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>1998</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1999</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2000</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HVAC 765 kV: 1.2 permanent fault/100 km/year

HVDC 600 kV: 0.2 permanent fault/100 km/year
## ITAIPU HVDC SYSTEM: Availability

### Converter Bipole Availability Performance

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(average)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bipole 1 %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forced Unavailability</td>
<td>1,9</td>
<td>0,25</td>
<td>0,18</td>
<td>0,35</td>
<td>0,05</td>
<td>0,23</td>
<td>0,86</td>
<td>0,03</td>
<td>0,22</td>
<td>0,05</td>
</tr>
<tr>
<td>Scheduled Unavailability</td>
<td>8,5</td>
<td>8,80</td>
<td>2,59</td>
<td>6,39</td>
<td>2,03</td>
<td>1,90</td>
<td>2,10</td>
<td>1,23</td>
<td>2,55</td>
<td>2,24</td>
</tr>
<tr>
<td>CIGRE Availability</td>
<td>89,6</td>
<td>90,9</td>
<td>97,2</td>
<td>93,2</td>
<td>97,9</td>
<td>97,9</td>
<td>97,0</td>
<td>98,7</td>
<td>97,2</td>
<td>97,7</td>
</tr>
<tr>
<td><strong>Bipole 2 %</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forced Unavailability</td>
<td>11,3</td>
<td>0,67</td>
<td>0,19</td>
<td>0,23</td>
<td>0,49</td>
<td>0,09</td>
<td>0,13</td>
<td>0,61</td>
<td>0,71</td>
<td>0,05</td>
</tr>
<tr>
<td>Scheduled Unavailability</td>
<td>10,2</td>
<td>6,40</td>
<td>2,50</td>
<td>5,92</td>
<td>2,12</td>
<td>1,23</td>
<td>1,54</td>
<td>1,23</td>
<td>1,28</td>
<td>2,64</td>
</tr>
<tr>
<td>CIGRE Availability</td>
<td>76,5</td>
<td>92,9</td>
<td>99,3</td>
<td>93,9</td>
<td>97,4</td>
<td>98,7</td>
<td>98,3</td>
<td>98,2</td>
<td>98,0</td>
<td>97,3</td>
</tr>
<tr>
<td>Contract Availability</td>
<td>98,9</td>
<td>99,4</td>
<td>99,4</td>
<td>99,3</td>
<td>99,6</td>
<td>99,6</td>
<td>99,1</td>
<td>99,0</td>
<td>99,7</td>
<td>99,7</td>
</tr>
</tbody>
</table>
Necessity to have a technically viable and economical means to transmit Bulk Power over large distances was the driving force for R and D of 800 kV UHVDC technology.

It’s now clear that UHVDC technology is far superior for Point to Point Bulk Power transfers over long distances.

UHVDC technology is READY FOR COMMERCIAL USE!
Avoid National waste

- There are various ways to avoid PASS THROUGH traffic!!

Or

City Bypass

Or

Fly-Overs