AC vs DC

Dr. Ram Adapa, EPRI
radapa@epri.com

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Topics addressed in this course:

• What is AC and what is DC?
• What are basic differences between AC and DC?
• What are the traditional applications of DC?
• Why recent Interests in DC?
• What are the new developments?
• What are the new and possible applications?
• What is the future for DC in the Power Grid?
Long Distance Transmission – AC versus DC

• AC versus DC debate goes back to beginnings of Electricity
  – DC was first (Thomas Edison)
  – AC came later (Tesla / Westinghouse)

• AC became popular due to transformers and other AC equipment

• Long Distance Transmission
  – AC versus DC - based on economics and technical requirements
HVDC Scheme Types

- **Back-to-Back**
  - frequency changing
  - asynchronous connection

- **Point-to-Point Overhead Line**
  - bulk transmission
  - overland

- **Point-to-Point Submarine Cable**
  - bulk transmission
  - underwater or underground
**AC versus DC: Break Even Distances**

Note: Assume right-of-way costs same for AC or DC

- The cost of a DC link depends on:
  - the cost of the substations
  - the cost of the line or cable

- HVDC is more economical than AC when the transmission distance:
  - is >300 miles for Overhead lines
  - is >30 miles for underground cables
Typical Tower Structures

Typical tower structures and rights-of-way for alternative transmission systems of 2,000 MW capacity.

Source: Arrillaga (1998)
When comparing costs for AC and DC, the following need to be considered:

- DC Converter / AC substation costs
- Line costs
- Corridor costs
- Operation & Maintenance costs
- Costs associated with losses (e.g. DC losses are lower than AC)

**Bottom line – Complete life cycle cost should be considered over an estimated life span (30 to 40 years) of the equipment.**
Examples of HVDC Projects Around the World

- Nelson River 2
- CU-project
- Vancouver Island Pole 1
- Pacific Intertie Upgrading
- Pacific Intertie Expansion
- Intermountain Blackwater
- Highgate
- Chateauguay Quebec-New England
- Hällsjön
- Hagfors
- Skagerrak 1&2
- Skagerrak 3
- Konti-Skan 1
- Konti-Skan 2
- Baltic Cable Tjæreborg
- Mowstahlwerke
- English Channel
- Dünrohr
- Sardinia-Italy
- Italy-Greece Cross Sound Cable
- Eagle Pass
- Itaipu
- Inga-Shaba
- Cahora Bassa
- Brazil-Argentina Interconnection I
- Brazil-Argentina Interconnection II
- Chandrapur-Padghe
- Rihand-Delhi
- Vindhyachal
- Murraylink
- Directlink
- Three Gorges - Changzhou
- Sakuma
- Gezhouba-Shanghai
- Leyte-Luzon
- Broken Hill
- New Zealand 1
- New Zealand 2
- Gotland 1
- Gotland 2
- Gotland 3
- Gotland
- Kontek
- SwePol
- Fenno-Skan
- Gotland 1
- Gotland 2
- Gotland 3
- Gotland
- Kontek
- SwePol
- Three Gorges - Changzhou
- Sakuma
- Gezhouba-Shanghai
- Leyte-Luzon
- Broken Hill
- New Zealand 1
- New Zealand 2
- Gotland 1
- Gotland 2
- Gotland 3
- Gotland
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- SwePol
- Three Gorges - Changzhou
- Sakuma
- Gezhouba-Shanghai
- Leyte-Luzon
- Broken Hill
- New Zealand 1
- New Zealand 2

HVDC Classic Converters
- CCC Converters

HVDC Light (VSC) Converters

Source: ABB
North American HVDC Stations

HVDC in North America
Representative HVDC Submarine Cable Links with Extruded Dielectric

<table>
<thead>
<tr>
<th>Name of Link</th>
<th>Date</th>
<th>Voltage (kV)</th>
<th>Power (MW)</th>
<th>Length (cable-km)</th>
<th>Max. Water Depth (m)</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>Cross Sound (CT-NY)</td>
<td>2002</td>
<td>150</td>
<td>330</td>
<td>2 x 42</td>
<td>40</td>
<td>XLPE</td>
</tr>
<tr>
<td>Estonia-Finland (Estlink 1)</td>
<td>2006</td>
<td>150</td>
<td>350</td>
<td>2 x 74</td>
<td>100</td>
<td>XLPE</td>
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<tr>
<td>Germany (BorWin1)</td>
<td>2009</td>
<td>150</td>
<td>400</td>
<td>2 x 125</td>
<td>100</td>
<td>XLPE</td>
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<tr>
<td>TransBay (San Fran Bay)</td>
<td>2010</td>
<td>200</td>
<td>400</td>
<td>2 x 88</td>
<td>30</td>
<td>XLPE</td>
</tr>
<tr>
<td>Ireland-Wales (Eirgrid)</td>
<td>2012</td>
<td>200</td>
<td>500</td>
<td>2 x 186</td>
<td>120</td>
<td>XLPE</td>
</tr>
<tr>
<td>Honshu-Hokkaido 2</td>
<td>2012</td>
<td>250</td>
<td>350</td>
<td>2 x 42</td>
<td>260</td>
<td>XLPE</td>
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<tr>
<td>Germany (DolWin 1)</td>
<td>2013</td>
<td>320</td>
<td>800</td>
<td>2 x 75</td>
<td>100</td>
<td>XLPE</td>
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<tr>
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<td>800</td>
<td>2 x 125</td>
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<tr>
<td>Germany (HelWin1)</td>
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<td>250</td>
<td>576</td>
<td>2 x 85</td>
<td>100</td>
<td>XLPE</td>
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<tr>
<td>Germany (DolWin 2)</td>
<td>2015</td>
<td>320</td>
<td>900</td>
<td>2 x 135</td>
<td>100</td>
<td>XLPE</td>
</tr>
<tr>
<td>Sweden - Lithuania</td>
<td>2015</td>
<td>300</td>
<td>700</td>
<td>2 x 453</td>
<td>?</td>
<td>XLPE</td>
</tr>
</tbody>
</table>
EPRI HVDC Cable Interest Group
Contact - Ram Adapa, radapa@epri.com

- HVDC Cable applications for Wind Integration & Power Grid Interconnection
- EPRI provides unbiased information and research results
  - Operational experience of existing DC cables
  - Mechanical & electrical issues
  - State of the art knowledge and economic choices
  - DC cable type selection
  - Voltage Source Converter based DC applications
  - Challenges and Opportunity presented by cable technologies
- Interest Group to be formed in 2012 to address HVDC cable issues
- Participation fee $20k per year
- Funders include: AEP, Hydro One, KEPCO, ESKOM, ATC, National Grid, & Scottish Power
DC Grids – The Future of DC Transmission

– DC Grids for Offshore Wind
– Considered more in Europe than in other countries
– Need to resolve many issues
  • Power & Voltage control
  • DC circuit breakers
  • Standard DC voltages
  • Communication needs

– CIGRE WGs

Two Topologies

(a) DC Node
(b) AC Node

DC Line
DC Grid Configurations: Offshore Development – Point to Point System

Source: ALSTOM
DC Grid Configurations: Offshore Grid System

Source: ALSTOM
Atlantic Wind Connection
Current State of HVDC versus HVAC

• Many Existing HVDC systems are old (30 - 50 years old)
  – Life extension is taking place
• Highest DC Voltage is UHVDC at +/- 800 kV in China & India
  – South Africa & Brazil are also considering
  – For long distances over 3000 km
  – For Bulk Power Transfer (3000 to 6000 MW)
• UHVDC of +/- 1000 to 1100 kV is planned in Asia for up to 8000 MW - China & India
• VSC HVDC is increasing (+/- 320 kV up to 1000 MW)

• Max AC Voltage in North America is 765 kV (EHVAC)
• UHVAC (1000 kV to 1200 kV) is considered in China (highest in the world)
Future Trends in HVDC

• For transfers of above 6,000 MW over 4,000 km, the optimum voltage rises to 1,000–1,200 kV.
  – Technological developments in LCC converter stations seem to be ready to handle these voltages.

• HVDC and HVAC overlays for regional interconnections

• Segmenting AC grids with DC back-to-backs for improved reliability

• Growth of VSC DC applications – more dc cable projects

• DC Grids for renewable integration
Together…Shaping the Future of Electricity