HVDC Technologies & ABB Experience

DOE Workshop – Applications for High-Voltage Direct Current Transmission Technologies
In cable > 50 km (>30 miles), most of AC current is needed to charge and discharge the “C“ (capacitance) of the cable.

In overhead lines > 200 km (>120 miles), most of AC voltage is needed to overcome the “L“ (inductance) of the line.

⇒ C& L can be compensated by reactors/capacitors or FACTS
⇒ or by use of DC, which means $\omega = 2\pi f = 0$
Benefits of HVDC vs. HVAC

- Higher transmission capacity
- Possibility to use underground and subsea cables
- Lower losses on long distances

Different technologies:
Same power transmitted

Overhead line with AC
Overhead AC line with FACTS
HVDC overhead line
Underground line with VSC
HVDC or AC cable

Energy Losses

HVAC: 2 x 400 kV
HVDC: 1 x ±400 kV

AC/DC conversion losses

Transmission Line [km]

VSC HVDC*
1 x ±400 kV
1200 A
1620 mm² conductors

HVAC
2 x 400 kV
2 x 1200 mm² conductors

*Voltage Source Converter: High Voltage Direct Current
HVDC technology development
More power and lower losses

HVDC Classic

Capacity up 6 times since 2000;
Voltage up from +/- 100kV to +/- 800kV since 1970

Xiangjiaba - Shanghai
± 800 kV UHVDC. World’s most powerful link commissioned

HVDC Light

Capacity up 10 times; losses down from 3% to 1% per converter station since 2000

BorWin:
400 MW, 200km subsea and underground
World’s most remote offshore wind park
ABB’s track record of HVDC innovation
Many firsts – some examples

World’s longest / highest power capacity - first 800 kV commercial link - China

Integrating the world’s most remote offshore wind farm - Germany

World’s longest underwater power link - Norway-Netherlands

World’s first offshore platform connected to shore power - Norway

World’s longest underground cable link - Australia

World’s first HVDC Light on an overhead line - Namibia
### ABB’s unique position in HVDC
In-house converters, semiconductors, cables

#### Key components for HVDC transmission systems

<table>
<thead>
<tr>
<th>Converters</th>
<th>High power semiconductors</th>
<th>HV Cables</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Converters" /></td>
<td><img src="image2.png" alt="High power semiconductors" /></td>
<td><img src="image3.png" alt="HV Cables" /></td>
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- **Conversion of AC to DC and vice versa**
- **Silicon based devices for power switching**
- **Transmit large amounts of power- u/ground & subsea**

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ABB - Leading Supplier of High Voltage DC Cables

Market Segments

A key enabler for emerging trends

- **Borwin, Germany** - integrating the world’s most remote offshore wind farm
- **Troll A, world’s first offshore platform connected to shore supply**
- **Murraylink, Australia** - world’s longest underground cable
- **BritNed, high-voltage direct-current (HVDC) submarine power cables between UK and NL**

<table>
<thead>
<tr>
<th>Offshore Wind farms</th>
<th>Offshore Oil and Gas</th>
<th>Undergrounding</th>
<th>Interconnector</th>
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<tbody>
<tr>
<td>Export cables connecting wind farms to land based grid</td>
<td>Export cables from land electrifying offshore platforms</td>
<td>Land cables replacing traditional overhead lines, mainly in and around city centers</td>
<td>Land and sea cables between countries or regions</td>
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Solid Dielectric Cables for HVDC transmission

- **1999**: Gotland
  - 160 kV (±80 kV)
  - 50 MW
  - 43 miles

- **2000**: Direct Link
  - 160 kV (±80 kV)
  - 3×60 MW
  - 3×40 miles

- **2002**: Murray Link
  - 300 kV (±150 kV), 220 MW
  - 112 miles

- **2006**: EstLink
  - 300 kV (±150 kV), 350 MW
  - 20 miles (+46 miles subsea)

- **2009**: BorWin
  - 300 kV (±150 kV), 400 MW
  - 47 miles (+80 miles subsea)

- **2012**: EWIP
  - 400 kV (±200 kV), 500 MW
  - 46 miles (+116 miles subsea)

- **2007-2009**: Type and PQ test
  - 640 kV (±320 kV), up to 1100 MW

- **2013**: DolWin1
  - 640 kV (±320 kV), 800 MW
  - 60 miles (+47 miles subsea)

- **2015**: NordBalt
  - 600 kV (±300 kV), 700 MW
  - 31 miles (+248 miles subsea)

- **2015**: DolWin 2
  - 640 kV (±320 kV), 900 MW
  - 56 miles (+28 miles subsea)
ABB has more than half of the 145 HVDC projects
The track record of a global leader

58 HVDC Classic Projects since 1958
14 HVDC upgrades since 1990
19 HVDC Light Projects since 1997
DC grid vision first conceived in 1999
Now a shared vision

Future developments
- Multi-taps / DC grids / Mixed AC/DC grids

Why DC grids vs DC single links
- Optimize investment & system performance
- Need for renewable integration
- Technology advance

How
- From point to point connections to small multi-terminal HVDC and taps to pan-continental HVDC grids

Technology gaps to close
- DC breaker
- Control and protection
- Power flow control
- Cables with higher power ratings

Other gaps to close
- Political consensus/Regulatory framework
- Funding and operation models

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HVDC breakers
State of the art technology

R&D – 2 parallel approaches
Option 1 (2011): Semiconductor Breaker High losses
Option 2 (2012): Hybrid Breaker: Mechanical + Semiconductor Lower Losses

Main challenges:
- Energy
- Speed (Short circuit current)
- Losses

Existing products

LV CB      Traction CB     DC Grid Breakers

1kV
3kV
500 kV
300 kV
1kV
Modular design of Main DC Breaker for improved reliability and enhanced functionality
Fast DC current measurement for control and protection
Disconnecting residual DC current breaker isolate arrester banks after fault clearance
ABB’s hybrid HVDC breaker
How it works?

A. Normal operation. Power flow in the path with less resistance (=lower losses)

B. Breaker started by power electronic breaker closing pushing the current flow into the lower path

C. Mechanical breaker opens to block the upper path

D. Main electronic breaker block in the lower path
Hybrid HVDC Breaker Breaking timeline

- **Load commutation switch opens**
- **UFD opens**
- **Main breaker opens**
- **Fault clearance**

- **I\text{main breaker}**
- **I\text{arrester}**
- **U\text{DC}**

- **I\text{UFD}**

Timeline:
- **1-2 ms**
- **2 ms**
- **xx ms**

**Fault**

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