High Voltage Direct Current (HVDC) Technology

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Agenda

- What is HVDC?
- HVDC market
- Alstom Grid’s experience
- Roadmap for the future
A short history of AC and DC transmission

- VS -

**In the AC corner:**
George Westinghouse

**In the DC corner:**
Thomas Edison

**Circa 1885:** Two technologies

**1920s:** AC grids became common

**1960s:** Birth of power electronics

**Today:** HVDC is the key technology for interconnecting regions and countries.
Uses of HVDC today

1. Back-to-back interconnections
   - Connects ‘mismatched’ AC networks
   - Frequency conversion 50-60 Hz

2. Point-to-point connections
   - Connects power generation to distant load-centres
   - Develops energy highways to transfer large amounts of power over long distances
HVDC = ‘more power per tower’ in less space and with less infrastructure

Break even distance:
- Overhead lines = 700 km
- Submarine cable = 40 km
Types of HVDC technologies

- **Line Commutated Converters (LCC) – HVDC**
  - Back-to-back interconnections up to 500 kV

- **LCC – UHVDC**
  - Point-to-point long distance transmission (energy highways) up to 800 kV

- **Voltage Source Converters (VSC) – HVDC**
  - Connecting renewable energies
    - For bi-directional grids
    - For multi-terminal networks
    - For black-start applications (any renewable energy)
The difference between LCC and VSC

LCC = Line Commutated Converters

VSC = Voltage Source Converters

“The best of the best for major projects”

“Modern, compact and flexible”
Key drivers for efficient networks of the future

**Move more power, further**
- LCC up to 800 kV creates long-distance energy highways
- LCC and VSC transmission systems have less losses than AC systems

**Connect AC grids and renewable energies**
- LCC interconnects AC grids for energy trading and security of supply
- VSC connects renewable generation such as offshore wind farms

**Improve quality, stability and reliability**
- All HVDC solutions prevent cascading disturbances, even in connected AC networks
HVDC Market
Americas, China, India & Europe offer the greatest potential

€50 billion market potential up to 2020
<table>
<thead>
<tr>
<th>Geographies most impacted - by type of HVDC technology</th>
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<tr>
<td>Back-to-back HVDC interconnections</td>
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<tr>
<td>Point-to-point HVDC transmission</td>
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<td>Connecting renewable energies - VSC</td>
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- United States
- China
- European Union
- India
- Brazil
The Americas

North America Challenges
- An ageing AC network
- Need to connect on and offshore wind farms
- Need to improve power quality and network reliability

South America Challenges
- Power generation far from consumers
- Need to interconnect regions / countries for shared energy reserves

Market Potential to 2018
- LCC 500 kV = €12 billion
- LCC 800 kV = €2 billion
- VSC = €2 billion
Europe and Northern Africa

**European & North African Challenges**

- European network built on individual country grids.
- Need to enable increased power transmission.
- Need to connect on and offshore wind generation to the grid.
- Major renewable resources in Northern Africa will be connected to continental Europe.

**Market Potential to 2018**

- LCC 500 kV = €3 billion
- VSC = €6-10 billion

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combined AC and DC grid by 2020 as foreseen by “Friends of the SuperGrid”
China Challenges

- Power generation located far from the mega cities
- Need to support economic growth which is linked to its power supply
- Network requires large amounts of UHVDC to move bulk energy to cities

Market Potential to 2018
LCC 600 kV = €2 billion
LCC 800 kV = €9 billion
India Challenges

- Resource and load locations
- Long distance bulk transmission
- Alleviate chicken neck congestion from Bhutan
- National grid to efficiently share energy

Market Potential to 2018
LCC 800 kV = €2 billion

HVDC Interconnections
Existing/under construction
Proposed
Agenda

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- Roadmap for the future
Alstom Grid HVDC solutions delivered worldwide

- Back-to-back
- Point-to-point
CHINA - Nindong-Shandong: an example of Alstom Grid point-to-point HVDC experience

- Power electronics valve specifically qualified and delivered by Alstom Grid for this project.
- 1,335 km DC link to connect power to distant load centre
- 4,000 MW of power
- Voltage level at 660 kV
Long distance connections between generation and load

**BRAZIL - Rio Madeira Pole 2:**
an example of Alstom Grid point-to-point HVDC experience

- The longest DC interconnection in the world
- Alstom Grid is delivering the full DC converter solution for the 2,375 km DC link connecting power from Jirau and San Antonio dams in the Amazon Region to distant points of consumption
- 3,150 MW of power
- Voltage level at 600 kV
Interconnecting two or more independent grids

GCCIA - Back-to-back HVDC:
Sharing energy by interconnecting 6 Gulf member states

First HVDC in the Gulf (3 x 600 MW)

Alstom Grid’s scope included:
- 3 identical HVDC converter stations on one site
- HVDC Thyristor valves
- Energy Management System
- Substation automation
- Long-term maintenance contract.
Agenda

What is HVDC?

HVDC market

Alstom Grid’s experience

Roadmap for the future
Ultra High Voltage Direct Current LCC 800 kV

The key technology to deliver bulk power over long distance
+/- 800 kV, 7.6 GW (4,750 A) over 2,500 to 3,000 km

Successful intense collaborative R&D program throughout Alstom Grid

- HVDC valves and control systems
- Power converter transformers
- Current and voltage transformers
- Bushings
- By-pass switch
Ultra High Voltage Direct Current LCC 800 kV
Alstom Grid’s HVDC MaxSine - The latest VSC technology

The key technology to connect offshore wind power to the grid and create multi-terminal connections
Alstom Grid’s HVDC MaxSine - The latest VSC technology
The Grid of Today

[Diagram showing a power grid with voltage levels: 400 kV, 132 kV, 11 kV, and 400 V.]
The Grid of Tomorrow:
Combining DC grid technology with the existing AC grid

Offshore wind farm
150 kV

Bulk power import using UHVDC
600 kV

AC

DC
Conclusion: Alstom Grid and the future

• Alstom Grid is strategically positioned to play a leading role in the development of HVDC networks and connections over the coming years:
  - With long and recognized global experience
  - By investing in the right technology to meet customers’ needs

• We are one of the only three global players today capable of delivering these high and ultra high voltage solutions, in a field with a very long learning curve

• Alstom Grid supplies engineered solutions for the world’s energy challenges