HVDC Technology for Large Scale Wind Connections
MNRE Consultation on Offshore Wind Power
13 Aug 2013, New Delhi

Agenda

- Introduction to HVDC
- HVDC Technologies & HVDC Light® (VSC )Technology
- HVDC Light® for Large Scale Wind Connections
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HVDC Basics
What is an HVDC transmission system?

Customer’s Grid

HVDC converter station
> 300 MW, Classic

Submarine cables

Overhead lines
Two conductors

HVDC converter station
> 300 MW, Classic

Land or submarine, cables

HVDC converter station
< 1200 MW, Light

Bidirectional Controlled Power flow
### HVDC Basics

#### Why HVDC? – comparison with HVAC

<table>
<thead>
<tr>
<th>HVAC</th>
<th>HVDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power flow uncontrolled</td>
<td>Power 100% controlled</td>
</tr>
<tr>
<td>EMF</td>
<td>No EMF!</td>
</tr>
<tr>
<td>Limited distance OHL and Cable lengths</td>
<td>No limit for distance, allows remote connection</td>
</tr>
<tr>
<td>Faults are transferred</td>
<td>Not with HVDC – it provides a Firewall!</td>
</tr>
<tr>
<td>Must be synchronized systems!</td>
<td>HVDC connects non-synchronized systems!</td>
</tr>
</tbody>
</table>

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#### HVDC Basics

**Why HVDC?**

- RoW needed for same power being transmitted
- Traditional overhead line with HVAC
- Overhead line improved with FACTS
- HVDC Classic Overhead Line
- Underground HVDC Cable

*Substantially lower 1) Right of Way; 2) Losses*
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HVDC Technologies

**HVDC Classic 300 – 6,400 MW**
- Thyristor controlled
- Switched reactive power control
- Typical design: valve building plus switchyard
- Overhead lines or mass impregnated cables

**HVDC Light® 50 – 1,200 MW**
- Transistor (IGBT) controlled
- Continuous reactive power control
- Easily expandable to more terminals
- Dynamic voltage regulation
- Black start capability
- Typical design: All equipment (excluding transformers) in compact building
- Extruded cables
HVDC Technologies
HVDC Classic

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

HVDC Technologies
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
HVDC Technologies
Key Attributes

What makes HVDC special?
Lower investment and lower losses for bulk power transmission
Asynchronous interconnections
Improved transmission in parallel AC circuits
Instant and precise power flow control
3 times more power in a ROW than AC

What makes HVDC Light® special?
Underground cables
Easy permits
Costs close to overhead lines
Connection to passive loads
Enhancement of connected AC networks
Independent control of active and reactive power flow
Short delivery times

Development of HVDC applications

HVDC Classic
Very long sub sea transmissions
Very long overhead line transmissions
Very high power transmissions

HVDC Light
Offshore power supply
Wind power integration
Underground transmission
DC grids
Agenda

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HVDC Light® - A merger of two technologies
LCC + SVC = VSC
**HVDC Light®**

**P-Q Diagram**

- Available operating area
- Inverter
- Rectifier
- Conclusion: A VSC can behave like a motor or a generator

**HVDC Light®**

**IGBT presspack and valve module**

- Gate unit and voltage divider unit
- External resistors
- Water pipes
- Heat sink

4.5 kV

| DC currents | ~ 627 A | ~ 1233 A | ~ 1881 A |

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Slide 16

08MR0045
HVDC Light® land and sea cables
50 – 1,200 MW

Conductor of aluminium or copper
Triple extruded insulation system
  conductor screen
  HVDC polymer insulation
  insulation screen
Copper wire screen and/or lead sheath
Steel wire armor or aluminium laminate
Outer jacket of PE or polyethylene yarn

HVDC VSC Technology
Key Building Blocks

Semiconductor & Converter Technology
Control & Protection
Cable Systems

In-house co-ordinated development
Agenda

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Introduction
Wind Demand Forecast

Offshore share ~15 % of total

HVDC Light® for Evacuation of Offshore Power

Needs

Issues with Wind Power Connection to Grid/ Loads

- Wind Farms are usually located in remote areas far from loads/grid connections points.
- Right of Way (RoW) is often a problem with pursuant permitting issue.
- Wind farms are often located at outer fringes of Grids which are inherently weak and more susceptible to disturbances.
- Wind Power fluctuates over time.
- Wind Power injection may create reactive power issues at connecting point.
- For Offshore Wind Farms, distance to shore may not permit an AC solution.
- To gain from economies of scale, size of wind farms is increasing

Features and Benefits

HVDC VSC Features

- No theoretical limit to transmission distance
- “Zero” RoW with underground cables
- Small footprint, compact design
- Continuously controlled reactive power compensation
- Full power flow control
- Decouples the wind park from the grid
  - Reduces mechanical stresses on turbines due to electrical transients and oscillations
  - Wind park can operate asynchronous to grid
- Augments Grid capacity
- Lower transmission losses (compared with AC)
HVDC Light® References

<table>
<thead>
<tr>
<th>Project</th>
<th>In service</th>
<th>Power/Voltage</th>
<th>Length</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helgoland</td>
<td>1997</td>
<td>3 MW / ±10 kV</td>
<td>10 km</td>
<td>Pilot system</td>
</tr>
<tr>
<td>Gotland</td>
<td>1999</td>
<td>50 MW / ±80 kV</td>
<td>70 km</td>
<td>Wind, undergrounding</td>
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<tr>
<td>Direct Link</td>
<td>2000</td>
<td>3x60 MW / ±60 kV</td>
<td>65 km</td>
<td>Undergrounding</td>
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<tr>
<td>TransMont</td>
<td>2000</td>
<td>7.2 MW / ±8 kV</td>
<td>4.4 km</td>
<td>Wind</td>
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<tr>
<td>Eagle Pass</td>
<td>2000</td>
<td>30 MW / ±15 kV</td>
<td>40 km</td>
<td>Grid reliability</td>
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<tr>
<td>Cross Sound</td>
<td>2002</td>
<td>300 MW / ±150 kV</td>
<td>100 km</td>
<td>Undergrounding</td>
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<tr>
<td>Murny Link</td>
<td>2002</td>
<td>200 MW / ±150 kV</td>
<td>67 km</td>
<td>Power from shore</td>
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<tr>
<td>Trelleken</td>
<td>2005</td>
<td>2x41 MW / ±60 kV</td>
<td>105 km</td>
<td>Grid reliability</td>
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<tr>
<td>Estrie</td>
<td>2006</td>
<td>560 MW / ±150 kV</td>
<td>292 km</td>
<td>Power from shore</td>
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<tr>
<td>Valthal</td>
<td>2008</td>
<td>76 MW / ±150 kV</td>
<td>203 km</td>
<td>Offshore Wind, 75 km a-ground</td>
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<tr>
<td>Brotventer</td>
<td>2010</td>
<td>400 MW / ±150 kV</td>
<td>203 km</td>
<td>Power from shore</td>
</tr>
<tr>
<td>Capital Link</td>
<td>2010</td>
<td>300 MW / ±150 kV</td>
<td>197 km</td>
<td>Grid reliability</td>
</tr>
<tr>
<td>Jail</td>
<td>2012</td>
<td>500 MW / ±200 kV</td>
<td>256 km</td>
<td>Grid reliability</td>
</tr>
<tr>
<td>Stadhamm</td>
<td>2013</td>
<td>600 MW / ±200 kV</td>
<td>160 km</td>
<td>Offshore Wind, 75 km a-ground</td>
</tr>
<tr>
<td>Macanais</td>
<td>2014</td>
<td>715 MW / ±500 kV</td>
<td>242 km</td>
<td>Grid reliability</td>
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<tr>
<td>Albatros</td>
<td>2012</td>
<td>200 MW / ±20 kV</td>
<td>14 km</td>
<td>Grid reliability</td>
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<tr>
<td>DolWin2</td>
<td>2014</td>
<td>706 MW / ±300 kV</td>
<td>45 km</td>
<td>Offshore Wind, 45 km a-ground</td>
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<tr>
<td>DolWin4</td>
<td>2015</td>
<td>906 MW / ±200 kV</td>
<td>135 km</td>
<td>Power from shore</td>
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<tr>
<td>Troll 3&amp;4</td>
<td>2015</td>
<td>2x50 MW / ±50 kV</td>
<td>80 km</td>
<td>Power from shore</td>
</tr>
</tbody>
</table>

Introduction
DolWin2 – System Specifications

Customer
- TenneT Offshore GmbH, Germany

Scope
- Turnkey delivery of HVDC Light offshore wind connection system including onshore building and offshore platform
  - Power rating: 924 MW
  - DC voltage: ±320 kV
  - Platform: Aibel, self-installing type, mother class, depth 27m
- DC cable system
  - 2 x 45 km 320 kV DC sea cable, 2 x 90 km 320 kV DC land cable
  - Cable laying on- and offshore
- AC cable system
  - 2 x 14 km 155 kV AC sea cable (to Gode Wind II)
  - Cable laying offshore

Time schedule
- Contract effective date: July 2011
- In service: March 2015
Introduction
DolWin2 Geographical Overview

45 km subsea Cu cable
90 km underground Al cable

Introduction
DolWin2 - Single Line Diagram

380 kV AC grid onshore
155 kV AC grid offshore

ABB
Platform Design & Installation

- All equipment is indoor
- All equipment is designed for long periods of maintenance-free operation, including redundancy at most levels.
- Avoid equipment that can be functionally substituted. E.g. transformer tap changer (use land station tap changer instead)
- Equipment is easily accessible for maintenance when needed
- All equipment is installed on platform before shipping – reduces startup time on site.
- Platform has a gravity based structure so no cranes needed for installation
- Offshore installation limited to connection of external AC & DC cables

Operation & Maintenance

- Off shore maintenance is difficult, expensive & time consuming.
- Design is largely maintenance free
- Layouts facilitate easy access and removal/ replacement of main equipment
- High level of redundancy is built in that eliminates downtime or considerably reduces MTTR.
- High level of automation with redundant system and automatic switch over
- Remote operation and continuous operation from shore
- Extensive safety systems and safety routines to ensure adherence to strict safety regulations
Dolwin1 Installation
"Topside" on way to site in North Sea

Dolwin1 Installation
To be put in place on foundation
Conclusions

HVDC for Large Scale Wind Farms is here to Stay

- Large scale offshore wind farms have special needs that conventional HVAC evacuation cannot address
- HVDC Light addresses these requirements and also provides additional benefits
- HVDC VSC technology for integrating large scale Wind Power to the Grid is accepted and established.
- Designed for reliability, safety, performance and O&M needs
- Turnkey design delivery and startup capability of the entire evacuation needs is a key to successful outcome

We look forward to the 1st Offshore Wind Farm in India!
A lot more information available on the web portal: www.abb.com/hvdc

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