HVDC Converter Operations and Performance, Classic and VSC
Dhaka, September 18, 2011
Agenda

- HVDC technologies
  - HVDC Classic
  - HVDC Light (VSC)
- Future
Key Renewable Energy Alternatives
Located at remote locations and off-shore

- Increase the use of renewable energy:
  - Reduce our CO2 emissions
  - Reduce our dependence on fossil energy
- Hugh drivers for new transmission!
Market drivers for HVDC transmission
Environmentally friendly grid expansion

- Integration of renewable energy
  - Remote hydro
  - Offshore wind
  - Solar power

- Grid reinforcement
  - For increased trading
  - Share spinning reserves
  - To support intermittent renewable energy
What is an HVDC transmission system?

1. **HVDC converter station**:
   - **> 300 MW, Classic**

2. **Submarine cables**

3. **Overhead lines**
   - Two conductors

4. **Power / energy direction**

- **Customer's Grid**
- **HVDC converter station**
  - **> 300 MW, Classic**
- **Land or submarine, cables**
- **Overhead lines**
  - Two conductors
- **Power / energy direction**

- **Customer’s Grid**
What is an HVDC Back-to-back system?

HVDC Back-to-back Converter Station
> 300 MW, Classic

HVDC Light Converter Station in
a Back-to-back mode < 1200 MW

Power / Energy direction
Technical benefits of HVDC

- Control of power flow
- Increased system stability
- No increase of short circuit currents
- Asynchronous connections
- Reactive power control
- Robustness and resistance to disturbances
- Low losses
- Reduced construction time
- Better use of right-of-way *(see figures)*
- Low cost line construction
Investment cost versus distance for HVAC and HVDC

- Investment Costs
- Distance
- Critical Distance
- AC Terminal costs
- Total AC cost
- DC terminal Costs
- Total DC Cost
- DC Line/Cable Cost
- AC Line/Cable Cost with Series Compensation

Variables:
- Cost of Land
- Cost of Materials
- Cost of Labour
- Time to Market
- Permissions
- etc.
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
- Standard transformers
- No minimum short circuit capacity, black start
With HVDC Classic, for power levels up to more than 6.400 MW using thyristor technology

or

With HVDC Light, for power levels up to 1.200 MW using IGBT technology
Development of HVDC converter capacity

Transmission capacity
HVDC Classic (MW)

Transmission capacity
HVDC VSC (MW)
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
HVDC Technologies

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
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

600 MW
200 x 120 x 22 m
6 acres
73 feet high

550 MW
120 x 50 x 11 m
1.5 acre
36 feet high
Comparison HVDC-Classic and HVDC-Light®

HVDC Light has fewer components and most equipment indoors
Comparison of Reactive Power Characteristics

HVDC Classic:
~ reactive compensation by switched filters and shunt capacitor banks

HVDC Light:
No reactive compensation necessary, STATCOM with dynamic range ~ 0.5Pd/+0.5Pd MVar below 90% p.f.
HVDC Configurations

- Point to Point Transmissions
- Back to Back
- Multi-terminal Systems
HVDC Transmission Modes

### Monopole, ground return
- 12-pulse groups
- Capacity up to appr. 1500 MW

### Monopole, metallic return
- 12-pulse groups
- Capacity up to appr. 3000 MW (6-7000 MW)

### Monopole, midpoint
- Grounded
- 6-pulse groups
- Capacity up to appr. 1500 MW

### Bipole
- 12-pulse groups
- Capacity up to appr. 1000 MW

Connection between Converter Stations can be Overhead Lines or Cables.
HVDC Light Generation 4
Operation configurations and modes

Symmetric monopole

Asymmetric monopole, metallic return

Asymmetric monopole, ground return

Bipole

Bipole, metallic return

Multiterminal Symmetric monopole
HVDC Control

AC and DC transmission principles

\[ P = \frac{E_1 E_2}{X} \sin \delta \]

\[ P = \frac{U_{d1} (U_{d1} - U_{d2})}{R} \]
Control of HVDC Links

The KEY to mitigation of disturbances in Transmission systems

Different ways to control a two-terminal HVDC Link:

1. Constant power
2. Constant current
3. Constant frequency (either in the receiving or sending AC network)

A combination can also be used or change from one mode to another

The DC Link can also be used to stabilize an AC network
HVDC Light
Merge of two technologies
LCC + SVC = VSC
PQ-diagram

Available operating area

Inverter

Rectifier

Conclusion: A VSC can behave like a motor or a generator

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Converter bridge technology - Today's design
Generation 4 - Cascaded Two-Level Converters (CTLC)

- Significantly reduced switching losses (~150 Hz)
- Excellent output voltage quality
- Scalable to high voltages
HVDC Light Generation 4
No filters required....
HVDC Light® – Simplified Single Line Diagram

- Converter Valves
- DC Capacitors (Voltage Sources)
- Cables
- Phase Reactors
- AC Transformers, breakers/disconnectors
Key building elements for HVDC Light

- Converter Technology
- Control & Protection Technology
- Cable Technology
- All in coordinated in-house ABB development
HVDC Light
Extended range

Base – symmetrical

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<td>+/- 150 kV</td>
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<td>+/- 320 kV</td>
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Power in MW (BtB)

Bipolar

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HVDC Light
Technical development

- Hällsjön: 3 MW, ± 10 kV
- Gotland: 50 MW, ± 80 kV
- Cross Sound: 330 MW, ± 150 kV
- Estlink: 400 MW, ± 350 kV
- BorWin1: 300 MW, ± 350 kV
- Caprivi: 300 MW, ± 350 kV
- East-West Interconnector: 500 MW, ± 320 kV
- Dolwin 1: 800 MW, ± 320 kV
- Skagerrak 4: 700 MW, 500 kV

- 1997
- 1999
- 2001
- 2003
- 2005
- 2007
- 2009

- 500 MW
- ± 10 kV
- ± 80 kV
- ± 150 kV
- ± 350 kV
- ± 320 kV
- ± 500 kV

MW vs. kV
HVDC Light Generation 4
Station layout 2 x 1000 MW ± 320 kV

150 m

220 m
Lower losses in HVDC Light stations

- Reduce losses
- Compactness
- Maintain functionality
- Maintain availability and reliability

150 x 100 m
±320 kV, 1000 MW
HVDC Light land and sea cables
50 – 1,200 MW

- Conductor of aluminum or copper
- Triple extruded insulation system
  - conductor screen
  - HVDC polymer insulation
  - insulation screen
- Copper wire screen and/or lead sheath
- Steel wire armor or aluminum laminate
- Outer jacket of PE or polyethylene yarn
HVDC Light applications
HVDC Light
City center infeed

System with converters and cables
- Easier permit procedure
- Low project risk
- Short installation and implementation time
- Low operation and maintenance cost

Grid improvement
- Voltage and reactive power control
- Loss reduction in connected AC network
- Increased transfer capability in AC lines
- Connection in weak network points
- Passive load operation (Black Start)

Environmentally adapted
- Short permitting time
- Small footprint and low profile of converters
- Oil free cable
- Reduced magnetic fields
- “Invisible” transmission
HVDC Light
Powering islands

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HVDC Light
Connecting wind farms

System with converters and cables
- Easier permit procedure in coastal areas
- Low project risk
- Short installation and implementation time
- Low operation and maintenance cost

Grid improvement
- Voltage and reactive power control
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HVDC Light
Offshore platforms

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- “Invisible” transmission
HVDC Light
Improved grid reliability

System with converters and cables
- Embedded link incl. SVC functionality
- Easier permit procedure - low project risk
- Short installation and implementation time
- Low operation and maintenance cost

Grid improvement
- Voltage and reactive power control
- Loss reduction in connected AC network
- Increased transfer capability in AC lines
- Connection in weak network points
- Passive load operation (Black Start)

Environmentally adapted
- Short permitting time
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Agenda

- HVDC technologies
  - HVDC Classic
  - HVDC Light
- Future
Next development steps

**HVDC Classic and HVDC Light**
- Higher reliability
- Lower footprint
- Environmentally adapted

**HVDC Classic**
- > 1000 kV

**HVDC Light**
- Higher ratings
- Lower losses
- More compact, particularly offshore
- Multi terminal configurations
- Control features

**DC Grids**
Regional DC grids - multi-terminal

- A DC regional grid is a system that constitutes of one protection zone for DC short circuits

- Characteristics
  - Fast restart of faultless part of system
  - DC breakers are not needed
  - Normally radial or star network configuration
  - Limited power rating compared to connecting AC-grid

Can be built today with existing, proven technology
The DC grid vision is a shared by many

- wind-energy-the-facts.org
- mainstreamrp.com
- wikipedia/desertec
- Desertec-australia.org
- claverton-energy.com
Future overlay DC grid of Europe
HVDC Light is required
Thank you for your attention!

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