High Voltage Direct Current (HVDC) Power Transmission
Alternatives for power transmission
Alternating current (AC)

- Advantages
  - Voltage transformation
  - Current interruption
  - Easy conversion into mechanical energy and vice versa
  - Frequency as system-wide control signal
  - Meshed networks

- Limitations
  - Long distance transmission
  - Difficult to use cables, already at ≈ 100 km high reactive power consumption

Up to now the solution of choice for Europe.
Alternatives for power transmission
High voltage direct current (HVDC)

![Image of HVDC projects in Asia and Europe]

- **Advantages**
  - Low losses (direct current)
  - Small footprint
  - No limitations in length
  - Cables can be used over long distances as there is no reactive power consumption

- **Disadvantages**
  - Base costs for converter stations ⇒ economically interesting only at longer distances (offshore: from ≈ 80 km, onshore beyond some 100 km)
  - Point-to-point connection (multi-terminal possible with VSC HVDC)

Proven solution for long distance transmission and sub-sea cables.
HVDC technologies

- HVDC Classic (CSC) 300 – 6'400 MW (2'000 MW)
  - Current source converters
  - Line-commutated thyristor valves
  - Typical layout: valve building and outdoor installation of filters and switchyards
  - Overhead lines or mass-impregnated cables
  - Minimum short circuit capacity > 2x converter rating
  - Bulk power long distance transmission, coupling of asynchronous power systems

- HVDC Light® (VSC) 50 – 1’100 MW (2’400 MW)
  - Voltage source converters
  - Self-commutated IGBT valves
  - Typical layout: complete installation (except transformers) indoor
  - Extruded cables or overhead lines
  - No minimum short circuit capacity, black start
  - Multiple areas of application

CSC: current source converter
VSC: voltage source converter
# Comparison of HVDC technologies

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<th>HVDC CSC (Classic)</th>
<th>HVDC VSC (Light)</th>
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<td><strong>Converter technology</strong></td>
<td>Thyristor valve, grid commutation</td>
<td>Transistor valve (IGBT), self commutation</td>
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<td><strong>Relative size</strong></td>
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| **Cable technology**    | - Oil paper  
- Field joints (5 days)  
- Sea cable installation special ship (3 available)                                                                                                                                                    | - Extruded  
- Prefabricated land joints (1 day)  
- Sea cable installation from barge (> 200 available)                                                                                                                                                           |
| **Typical delivery time** | 36 months                                                                                                                                                                                                         | 24 months                                                                                                                                                                                                         |
| **Static reactive support** | yes                                                                                                                                                                                                               | yes                                                                                                                                                                                                                 |
| **Dynamic reactive support** | no                                                                                                                                                                                                                 | yes                                                                                                                                                                                                                 |
| **Independent control of active and reactive power** | no                                                                                                                                                                                                                  | yes                                                                                                                                                                                                                 |
| **Scheduled maintenance** | typically < 1 %                                                                                                                                                                                                     | typically < 0,5 %                                                                                                                                                                                                    |
| **Losses typical system** | 2,5 – 4,5 %                                                                                                                                                                                                          | 4 – 6 %                                                                                                                                                                                                             |
| **Multiterminal operation** | Complex, limited to 3 terminals                                                                                                                                                                                     | Simple, no limitations                                                                                                                                                                                                |
Development of HVDC technologies

- HVDC Light\textsuperscript{®} systems in operation since 1997
- Rapid development since mid of the 90ies due to requirements of emerging markets (HVDC Classic) and in Europe/USA (HVDC Light\textsuperscript{®})
High voltage direct current transmission
Areas of application

- HVDC Classic (CSC)
  - Point to point transmission of bulk power over very long distances
  - Sea cables (> 100 km)
  - Connection of strong, asynchronous grids with high power

- HVDC Light® (VSC)
  - Point to point transmission of small up to medium power over long distances
  - Connection of several (few) feed-in points, e.g. to support an existing AC grid
  - Suitable to be connected to weak grids or to supply passive loads (e.g. offshore platforms)

CSC: current source converter
VSC: voltage source converter

Applicability always depending on specific situation, difficult/impossible to come to general conclusions!
Examples of projects
Gotland – HVDC Light®

- Capacity: 50 MW
- Length: 70 km
- In operation since 1999
- Requirements
  - additional wind power, 90 MW
  - minimized environmental impact
- Advantages
  - voltage control for wind turbines
  - increased transmission capacity of parallel AC line
  - loss reduction on whole island due to improved voltage control

1953: first HVDC world-wide
1999: first HVDC Light®
Murraylink – HVDC Light®
The longest land cable in the world

- Capacity: 220 MW
- Length: 160 km
- In operation since 2002
- Connecting the grids of Victoria and Southern Australia
- Experiences
  - more than 400 cable joints (150 kV)
  - in operation since more than four years
  - no failures
  - availability above 98.5 %
    (including planned maintenance!)
Cross Sound – HVDC Light®
The first large VSC project

- Capacity: 330 MW
- Length 40 km
- In operation since 2003

Requirements
- Improvement of security of supply in Connecticut/Long Island
- Interconnection of two electricity markets

Advantages
- No grid enforcements required
- Improved security of supply because of continuous voltage and reactive power control
- Low space requirements
Cross Sound – HVDC Light®
Stabilizing the system instead of being sensitive

Cross Sound Cable – Dynamic Response to Network Faults
March 17, 2005 – Cross arm fault on 353 Line (345 kV)
NorNed HVDC cable, Norway–The Netherlands
The longest cable in the world

- Requirement
  - Connection of two power markets
  - Optimal use of differences in production and consumption

- ABB response
  - Turnkey 700 MW system with new ± 450 kV converter system
  - Longest cable in the world: 580 km

- Customer benefit
  - Very low losses (system losses: 3.7 %)
  - Avoiding about 1.7 mio t CO₂ emissions per year
  - Support of wind power development in The Netherlands

Customer: TenneT (NL) and Statnett (N)
In operation: 2008
Xiangjiaba–Shanghai ± 800 kV UHVDC, China
The biggest transmission system in the world

- **Requirement**
  - Utilization of renewable energy (hydro power) 2’000 km apart from load centers

- **ABB solution**
  - Most powerful and longest transmission system in the world
  - ± 800 kV UHVDC, 6’400 MW

- **Customer benefit**
  - High efficiency - 93 %
  - Compact footprint - 40 % less space requirement compared to conventional solution
  - Reliability: outage probability < 0.5 %

Customer: SGCC
In operation: 2010-2011
BorWin 1 – HVDC Light®, Germany
The world’s first HVDC offshore wind farm connection

- Capacity: 400 MW (phase 1)
- Length: 128 km sea cable, 75 km land cable
- Ready for operation: October 2009
- Requirements
  - Turnkey project execution
  - Integration into transmission grid according to grid code
  - Short delivery time
- Advantages
  - Modular extension concept
  - About two years delivery time
The future? A scenario for Europe
Power and productivity for a better world™