High-Voltage Direct Current transmission

Enabling single EU energy market
## Electricity interconnection targets

Recommendations for development of additional interconnections

<table>
<thead>
<tr>
<th>Motivation</th>
<th>Indicator</th>
<th>Indicative threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimising price differentials</td>
<td>Price difference between countries, regions or bidding zones</td>
<td>&gt;€2/MWh</td>
</tr>
<tr>
<td>Ensuring that electricity demand can be met</td>
<td>Ratio between nominal transmission capacity of interconnectors and peak load</td>
<td>&lt;30%</td>
</tr>
<tr>
<td>Enabling export potential of excess renewable production</td>
<td>Ratio between nominal transmission capacity of interconnectors to renewable installed generation capacity</td>
<td>&lt;30%</td>
</tr>
</tbody>
</table>

Further recommendations:

- Interconnectors helping reach any of the 30% thresholds should be included in the TYNDP and future lists of PCI.
- Countries above the 30% but below 60% thresholds should investigate regularly possible options of further interconnectors.

Source: Report of the Commission Expert Group on electricity interconnection targets, November 2017
# Electricity interconnection targets

## Projects of Common Interest (PCI)

### Background

According to the European Commission, a PCI should:

- Significantly affect the energy markets of at least two EU countries
- Increase energy market competition
- Enhance the EU's security of supply by allowing countries to receive energy from more sources
- Contribute to the EU's energy and climate goals, for example, by integrating renewable energy into the grid

### Benefits

- Accelerated planning and permit-granting procedures, including a three-and-a-half-year time limit for granting permits
- One national permitting authority
- Lower administrative costs for project promoters and authorities
- Streamlined environmental assessment
- More transparency and public participation
- More visibility for investors
- Possibility of financial support -5.35 b€ total from 2014 to 2020 under the Connecting Europe Facility (CEF)
Electricity interconnection targets
Third list of Projects of Common Interest (2017)

90 PCIs related to transmission network expansion
- 50% interconnectors (between countries)
- 50% internal projects

Share of HVDC projects among them:
- 1/3 among all projects (internal and interconnectors)
- >55% for interconnectors (between countries)


HVDC transmission is a key enabler of the emerging single energy market
entso-e Ten Year Network Development Plan
Key boundaries identified in the system needs analysis of the TYNDP 2016

Transmission network expansion projects in TYNDP

New overhead lines, underground/subsea cables
143 projects in permitting, under construction or commissioned
– >20% HVDC projects (32 in total)
– 24 subsea HVDC cables
– 7 underground HVDC cables
– 1 HVDC OHL
136 projects under consideration or planned, but not permitted
– >25% HVDC projects (37 in total)
– 30 subsea HVDC cables
– 3 underground HVDC cables
– 3 HVDC OHL

Source: entso-e Ten Year Network Development Plan 2018
What is an HVDC transmission system?

- HVDC converter station: 
  - > 300 MW, Classic
  - < 3,600 MW, Light

- Submarine cables
- Overhead lines
- Two conductors
- Land or submarine cables

Power / energy direction
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 – 10,000 MW**
- Thyristor controlled
- Switched reactive power control
- Typical design: valve building plus switchyard
- Overhead lines or mass impregnated cables

**HVDC Light 50 – 3,600 MW**
- Transistor (IGBT) controlled
- Continuous reactive power control
- Easily expandable to more terminals
- Dynamic voltage regulation
- Black start capability
- Typical design: more equipment in compact building
- Extruded cables
Installed base
Over 120 projects and over 60 years experience

**America**
- CU Upgrade: 2019
- Maritime Link: 2017
- Madawaska Upgrade: 2016
- Celilo Upgrade: 2016
- Railroad DC Tile: 2014
- Oklawah: 2014
- Mackinac: 2014
- IPP Upgrade: 2010
- Blackwater: 2009
- Outaouais: 2009
- Rapic City: 2007
- Nelson River 2: 2002
- Square Butte: 1977
- Eel River: 1972
- Pacific Intertie Expansion: 1998
- Chateauguay: 1984
- Cu-project: 1979
- Steppe Butte: 1978
- Vancouver Island Pole 1: 1968

**Europe**
- North-sea Link: 2021
- Nordlink: 2021
- IFA2: 2020
- Kriegers Flak Cgs: 2019
- Johan Svedrup: 2019
- Gotland Upgrade: 2018
- Calthness – Moray: 2018
- Kontek Upgrade: 2016
- Troll 1 & 2, 3 & 4: 2015
- Birorin 1: 2015
- Dolwin 1, 2: 2015
- Åland: 2015
- Nordbalt: 2015
- Litpol Link: 2015
- Skagerrak 4: 2014
- East West: 2019
- Interconnector: 2013
- Sapei: 2011
- Valhall: 2008
- Norned: 2006
- Estlink: 2001
- Italy – Greece: 2000
- Tjæreborg: 1985

**South America**
- Rio Madeira Back-to-back: 2013
- Rio Madeira: 2013
- Brazil – Argentina Interconnection I & II: 1999
- Itaipu: 1984

**Africa**
- Inga – Kolwezi Upgrade: 2016
- Cahora Bassa, Songo: 2015
- Caprivi Link: 2010
- Apollo Upgrade: 2008
- Inga – Kolwezi: 1982
- Cahora Bassa: 1977

**Asia**
- Changji-Guzuan: 2019
- Raigarh-Pugalur: 2019
- North East Agra: 2016
- Jingpin - Sunan: 2012
- Müllnebe – Liaoning: 2010
- Lingboa II Extension: 2010
- Xiangjiaba – Shanghai: 2010
- Three Gorges – Shanghai: 2006
- Vizag Li: 2005
- Three Gorges – Guangdong: 2004
- Three Gorges – Changzhou: 2002
- Chapad: 1999
- Rihand-Delhi: 1990
- Gezhouba – Shanghai: 1989
- Vindyachai: 1989
- Sakuma: 1965

**Australia and Oceania**
- Broken Hill: 2013
- Murraylink: 2013
- Directlink: 1999
- Leyte-Luzon: 1999
- New Zealand 1 & 2: 1984
VSC HVDC Light
ABB supplied 70% of all VSC links in the world

*VSC: Voltage sourced converter
**HVDC technologies**

Transmission capacity

- **Voltage (kV)**
  - HVDC Light with extruded cable
  - HVDC Classic with overhead lines
  - HVDC Classic with mass impregnated cable

- **Power (MW)**
  - HVDC Light with overhead lines
  - HVDC Classic with overhead lines
  - HVDC Classic with mass impregnated cable

- **U_{dc} (kV)**
  - HVDC Light with extruded cable
  - HVDC Classic with overhead lines
  - HVDC Classic with mass impregnated cable

- **Commissioning**

- **Power (GW)**
  - 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Evolution of HVDC Light
20 years of HVDC Light development

How is it done?

- Increased voltage rating
- Cutting-edge, bi-mode insulated gate transistor (BIGT)
- Optimized switching
- Modular multi-level converter (MMC) technology
- Very low no-load losses
HVDC Light
Plant Design (symmetric monopole)
# HVDC Light

Value proposition with new offering

<table>
<thead>
<tr>
<th>Values</th>
<th>Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>high availability</td>
<td>increased service intervals</td>
<td>increased utilization</td>
</tr>
<tr>
<td>low losses</td>
<td>improved converter valves</td>
<td>reduced OPEX</td>
</tr>
<tr>
<td>small footprint</td>
<td>optimized mechanical design</td>
<td>reduced environmental impact</td>
</tr>
<tr>
<td>highly modularized</td>
<td>simplified project adaption</td>
<td>proven technical solutions</td>
</tr>
<tr>
<td>higher ratings</td>
<td>higher voltage and current ratings</td>
<td>technology suitable in more applications</td>
</tr>
<tr>
<td>reduced delivery time</td>
<td>base design and standardized delivery model</td>
<td>lower project and capital cost</td>
</tr>
</tbody>
</table>

HVDC Light able to cover all market demands
Introduction to HVDC Light

System configuration

**Symmetric monopole**

- Positive: Low cost
- Positive: Low transmission losses
- Negative: Loss of 100% power at trip

**Asymmetric monopole**

- Positive: Only one high voltage cable
- Positive: Bipole enabled
- Negative: Less compact

**Bipole**

- Positive: High Availability for half power
- Negative: Temporary ground current (can be avoided at the expense of a metallic return conductor)
# Introduction to HVDC Light

## System configuration

### Rigid Bipole

**Positive**
- Half power at converter outage
- Lower stress on cable compared to sym. monopole

**Negative**
- Loss of 100% power at line trip
- Less compact, higher cost than sym. monopole

### Back-to-Back

**Positive**
- Low Cost
- Low losses
- Simpler permitting
- Compact station

**Negative**
- Limited suitable locations

### Multi-terminal

**Positive**
- Converters at different locations on one line

**Negative**
- Complex control system
Power transmission with HVDC Light

Independant active and reactive power control

Voltage source converter

Output voltage at AC valve terminals can be freely adjusted in both magnitude and phase angle
- Active power control via phase angle
- Reactive power control via magnitude
- Control in dq coordinates

Power and current control common for all valve topologies

\[
P = \frac{U_v \cdot U_c \cdot \sin(\varphi - \theta)}{X}
\]
\[
Q = \frac{U_c \cdot (U_v \cdot \cos(\varphi - \theta) - U_c)}{X}
\]
**Power transmission with HVDC Light**

Independant active and reactive power control

---

**Example: step change of active power**

- Step decrease of transmitted power by 10%
- No change in reactive power exchange with the AC network
- Transient change in DC voltage, quickly regulated to reference value by remote station
- New load flow results in decreased direct current flow -100% to +100% power without changing the DC polarity
Operational flexibility

Enhanced system resiliency – black start with HVDC Light
Operational flexibility

Field experience from reference projects

**Caprivi Link Interconnector**

“The field experience in Caprivi link project shows that HVDC Light can not only operate in extremely weak AC system with SCR below one and down to zero, but also enhance the stability of the weak AC system significantly.”

“Stability enhancement and blackout prevention by VSC based HVDC”, Cigré Symposium, Bologna

**Fenno-Skan**

Stationary load flow optimization between Sweden and Finland

POD control for small-signal stability

In operation for over 20 years

**Pacific Intertie**

The ability to damp depends on the converter station location and the feedback control signals used

Most favorable with parallel connection of AC ties with an HVDC link

The Pacific HVDC Intertie – Significant improvement of the damping of the Western interconnected power system

“The successful operation of dc modulation was a key factor in permitting an increase in the rating of the Pacific AC Intertie from 2100 MW to 2500 MW”

*Reference: IEEE TRA-PAS-97, No. 4, July/Aug. 1978*