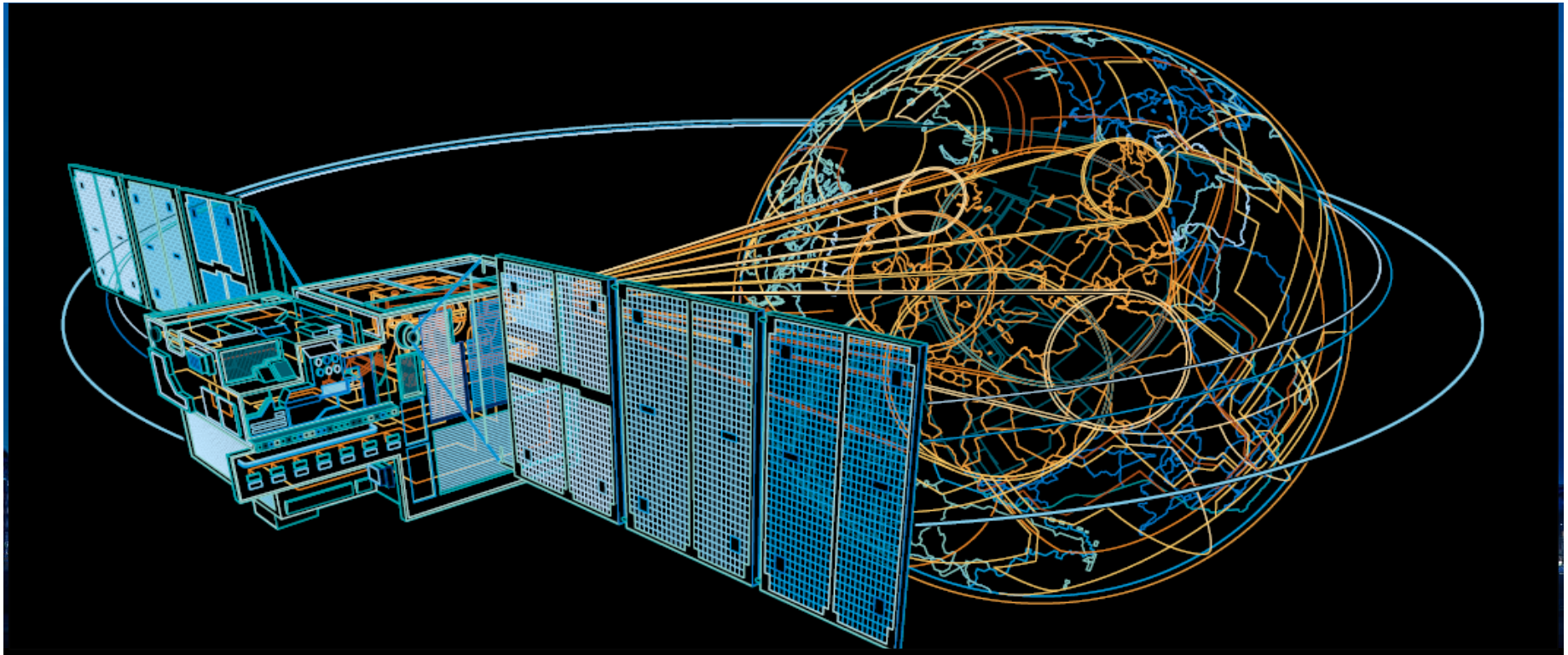


**Magnus Callavik, Vice president Grid Systems, Technology**

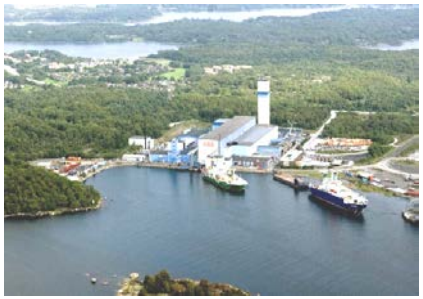
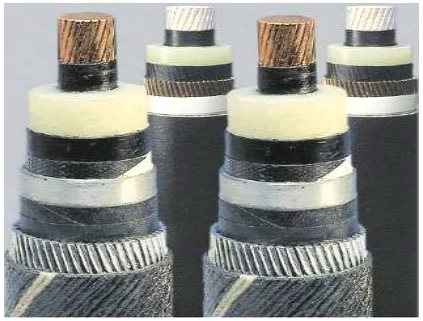
# Offshore grid technology challenges: a European Research and Innovation Agenda?

Technology Challenges and Regional Approaches for integrating Renewables and Energy Security, Brussels, 2015-May-28

Power and productivity
for a better world™

# Key components of HVDC transmission systems

## ABB's unique position in converters, semiconductors & cables

| Converters | High power semiconductors | HV Cables |
|---|---|---|
| | |  |
| | |  |
| **Conversion of AC to DC and vice versa** | **Silicon-based devices for power switching** | **Underground and marine transmission of power** |

© ABB



Three manufacturing perspectives in HVDC technologies. HV testing. Clean room, cables

# ABB – power and productivity for a better world

~150,000 employees

~$40 billion in revenues (2012)

5 divisions

~$50 billion market capitalization

Present in +100 countries

$1.5 billion Invested in R&D (2012)

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© ABB Group

# HVDC for long distance transmission, submarine connections, connecting unsynchronized grids,…

## LCC-HVDC. Since 1954

- Ca. 150 LCC-HVDC projects globally
- Up to 800 kV, 8000 MW

**Hami – Zhengzhou 2210 km**
**2014 8000 MW / 800 kV**

## VSC-HVDC. Since 1999

- Ca. 20 projects commissioned in globally
- Up to 525 kV,1400 MW
  (Inelfe 2 x 1000 MW)

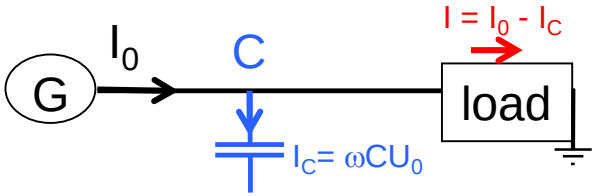
**EWIC. Ireland – UK 260 km**
**2013 500 MW / 200 kV**

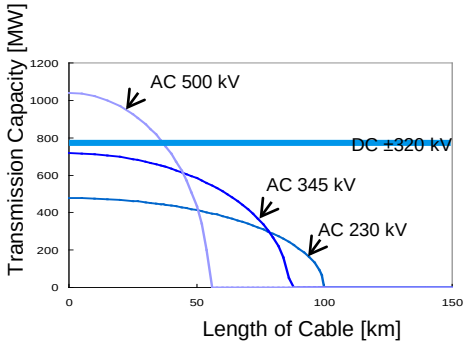
- Line commutated converter (LCC) HVDC is 45 years ahead on the technology curve of voltage-sourced converter (VSC) HVDC

# Why HVDC?
## It is ideal for long distance transmission

### Capacitance of high power cables

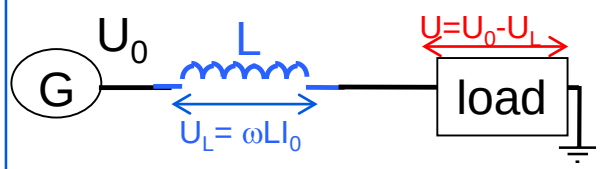
Cable > 50 km: most of AC current is needed to charge and discharge the “C“ (capacitance) of the cable

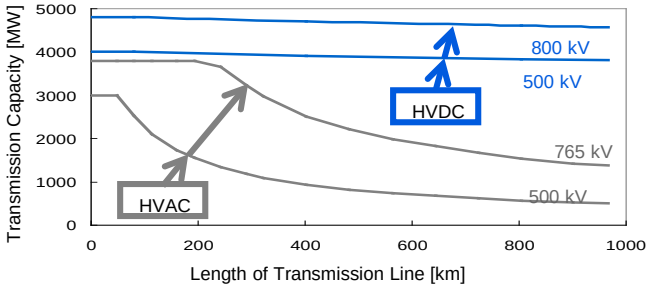



### Inductance of power lines

Overhead lines > 200 km: most of AC voltage is needed to overcome the “L” (inductance) of the line





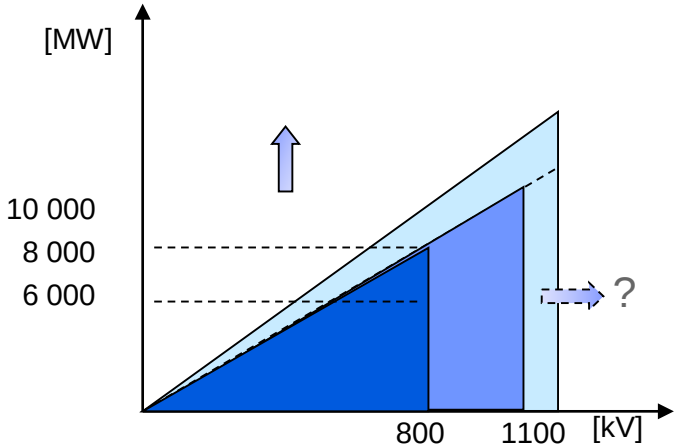

C & L can be compensated by reactors/capacitors or FACTS **or by use of DC, which means $\omega = 2\pi f = 0$**

# HVDC. More power by higher voltage and current

## Extreme LCC powers available. VSC moving up

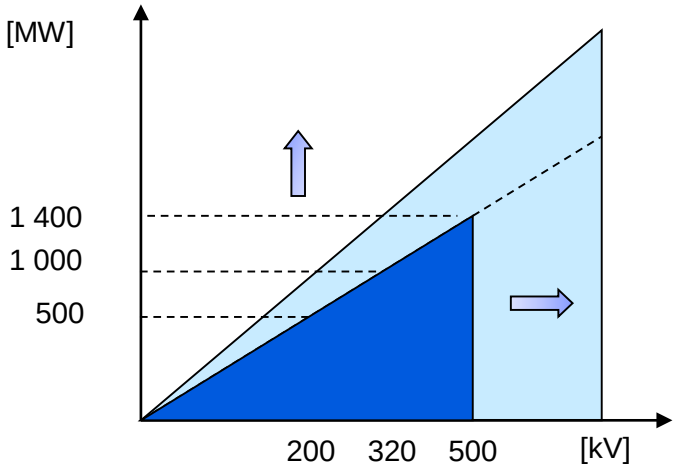
### LCC UHVDC (Classic). 8-13 GW / bipole

- Voltage increase beyond 1100 kV uncertain
- Current increases 4.5-5.0-….kA. Peak power?
- Reactive power consumption can be challenging




### VSC HVDC (HVDC Light)

- First 500 kV bipoles with cables
- Voltage increase for converters straightforward Current increase would be beneficial
- Cables at 2.6 kA, 525 kV




**Loss minimization is always important. At higher currents also for cooling design**

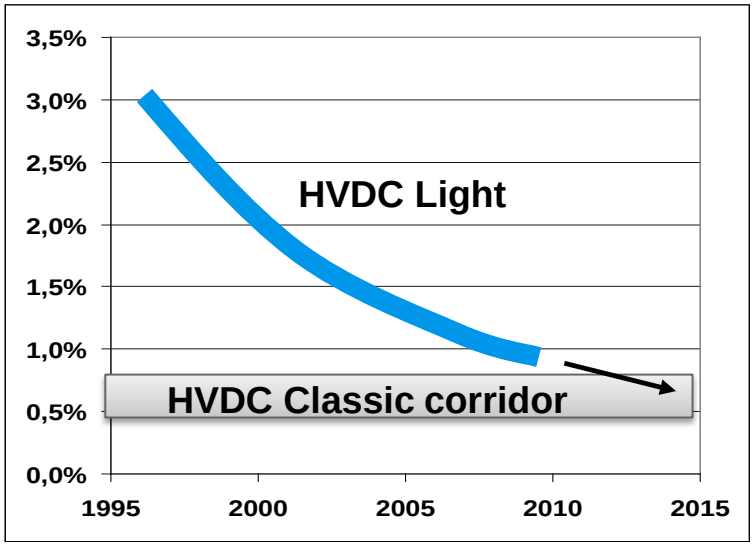
1. Dark blue in construction or operation. Light blue released
2. Examples Hami-Zhengzhou 8 000 MW (LCC, 2014). EWIC NordLink 1400 MW (VSC, award 2015)

© ABB

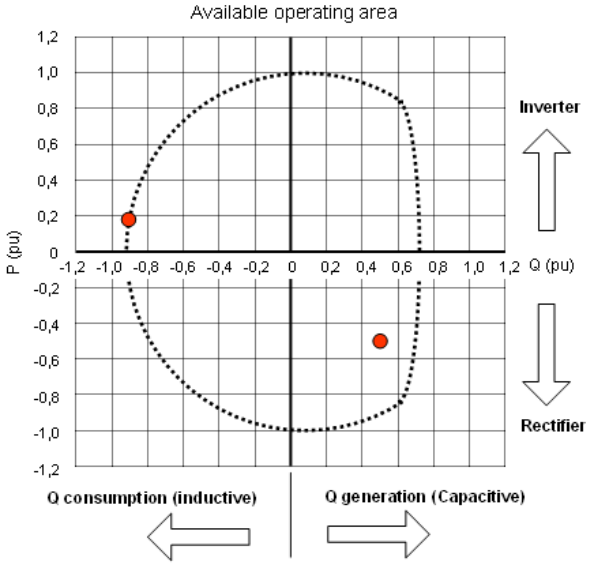
# VSC-HVDC success factors

## Losses in parity with LCC-HVDC and voltage support

### Loss reduction




### P-Q Operating area (STATCOM)




**Combined with 28-fold increase in power over 15 years**

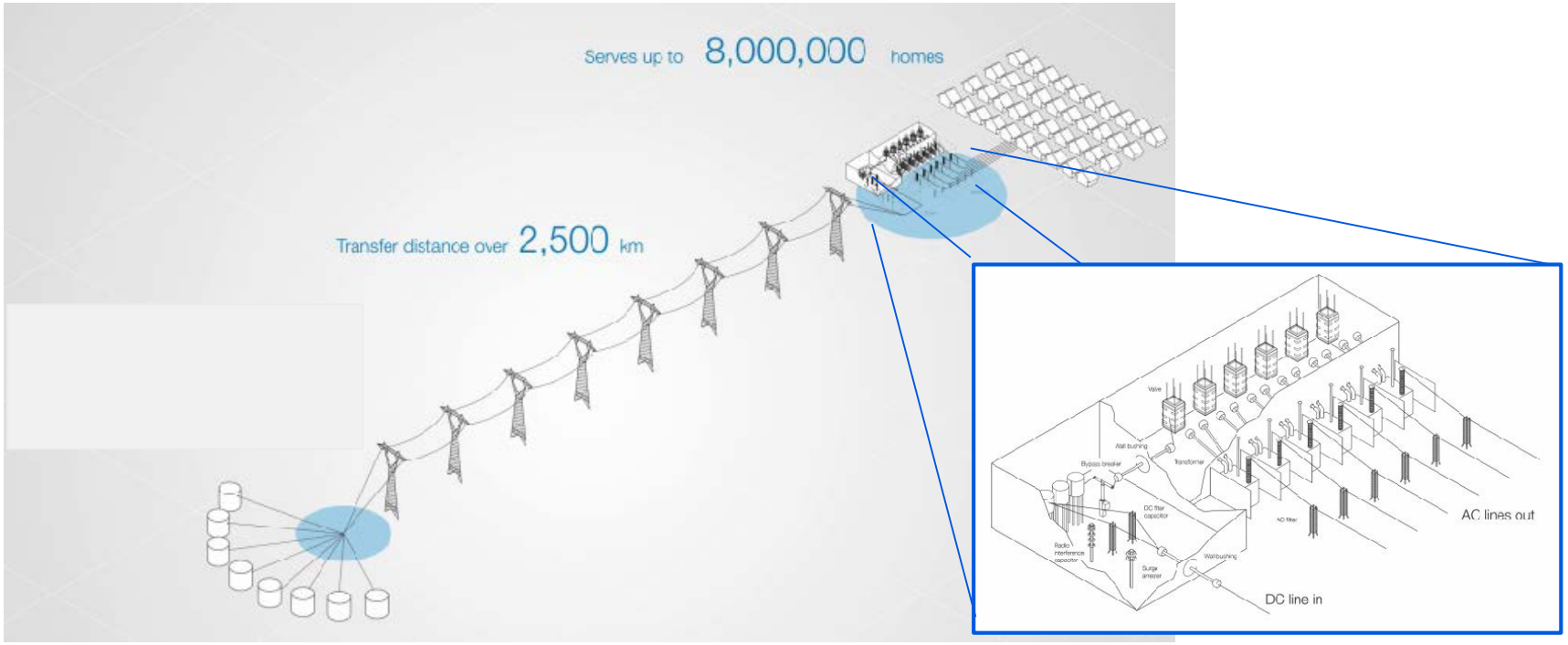
© ABB



1999 Gotland Light 50 MW commissioned. 2015 NordLink award 1400 MW

# Ultra-high voltage Direct Current (UHVDC0 conce0

## At 1100 kV, 5 kA it enable transmission of 11 000 MW, 3000 km



**1100 kV wall bushing. Components grow in size**

# Skagerrak 4.
# World record HVDC Light 500 kV, 700 MW

HVDC Light Gen 4 Quadruple valve

Bipole Classic and Light

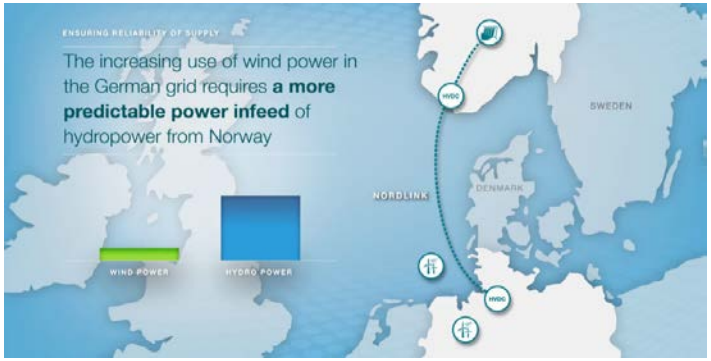
Connecting hydro (NO) and wind (DK)

© ABB

# NordLink connecting TenneT and Statnett grids
## 623 km MI cable system and VSC-HVDC converters

### Interconnecting Germany-Norway

- German wind and solar can be balanced with Norwegian hydro
- VSC to support grid connection points in Tonstad and Wilster




### 1400 MW Bipole

- 2 x 700 MW VSC-HVDC
- ± 515 kV IGBT-based converter valves
- ± 525 kV mass impregnated (MI) marine and underground cable system

**Renewable power supply to 3.6 million German households by 2020**

**Fig. 1.** http://spectrum.ieee.org/video/energy/renewables/nordlink-a-landmark-project-enabling-a-more-interconnected-europe
**Fig. 2. Skagerrak 700 MW VSC-HVDC valve**

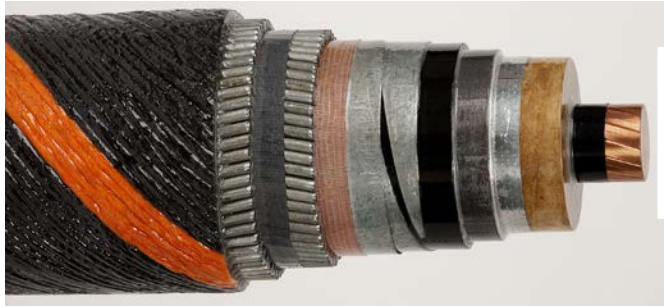
© ABB

# HVDC Cable Systems
## Mass impregnated cable systems since 100 years

### Testing of MI cables, CIGRE electra 189

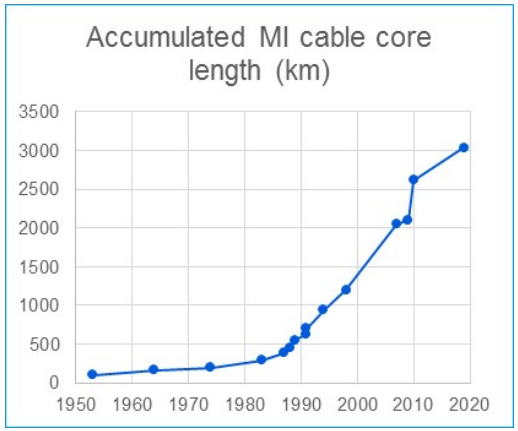
- Worlds longest marine cable NorNed 580 km in 2002
- Sea, land, cupper, aluminum,…

NorNed MI cable sample



### 100 kV MI HVDC 1954

- Long distance marine cables (600 km)
- Shorter onshore projects. ABB awarded close to 3000 km

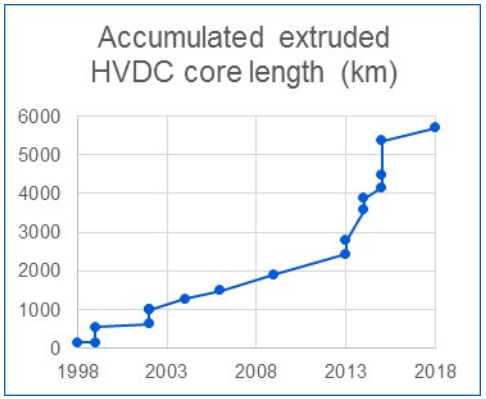



**Robust, well-proven.**
**Less suitable for long length underground (heavy drums, complex joints)**

# HVDC Cable Systems
## Existing and New extruded cable ("XLPE")

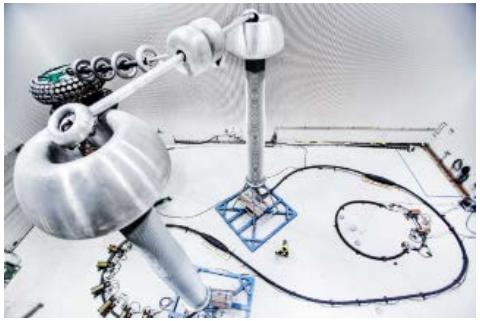
### Rapid development of extruded cables

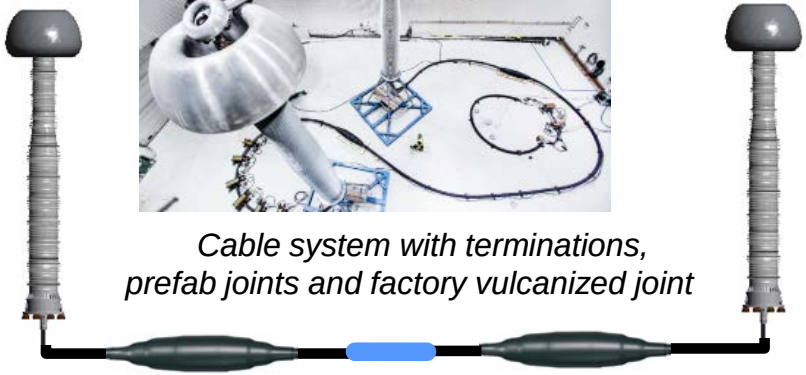
- 2014: 525 kV rated voltage
- Installed 80 kV in 1999. 320 kV 2015
- Sea, land, cupper, aluminum,…
- ABB awarded close to 6000 km



### It is a cable ***system,*** CIGRE TB 496

- Cables and accessories
- 2600 A





*Cable system with terminations, prefab joints and factory vulcanized joint*

**Both MI and Extruded DC at 525 kV.**
**There are benefit to raise the voltage even further for certain applications**

# Power Semiconductors - The heart of the matter

## More current, more voltage, lower losses, controllability

### Phase Controlled **Thyristors**

- High power and low on-state losses Used in line commutated converters (LCC, Classic) HVDC. Loss <0.7%

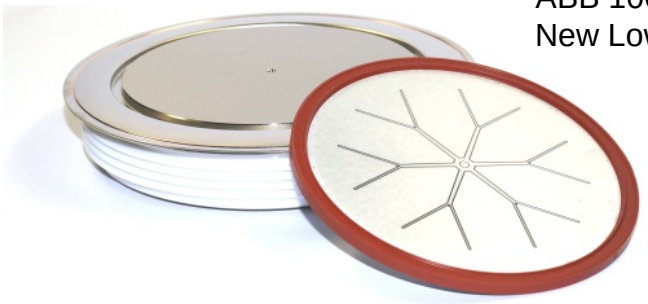


ABB 100 mm 8.5kV
New Low Loss PCT
for UHVDC

Snow-flake gate pattern

### IGBT – Insulated-gate Bipolar **Transistor**

- Controllable, increasing current, voltage handling capacity. Used in voltage source converters. (VSC, Light) Losses <1.0%

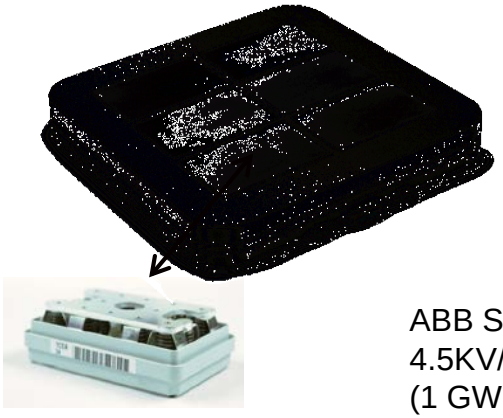


ABB Stakpak and submodule
4.5KV/2000A for HVDC Light
(1 GW) transmission

**A continuous development to break new power barriers**
**Thyristors are 20 years ahead**

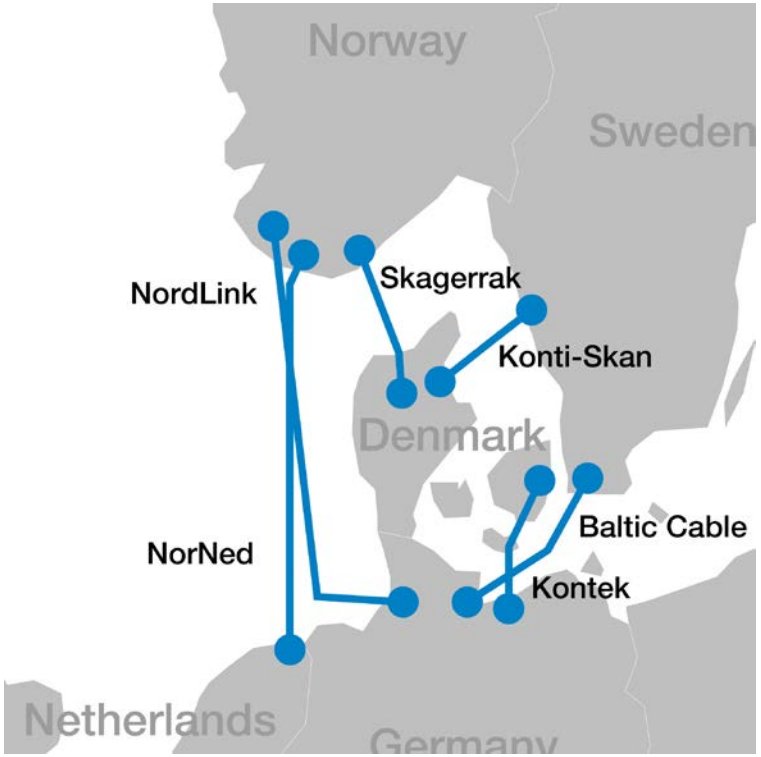


UHVDC – ultra-high voltage direct current. 800 – 1100 kV

# Across borders – HVDC *for* market integration

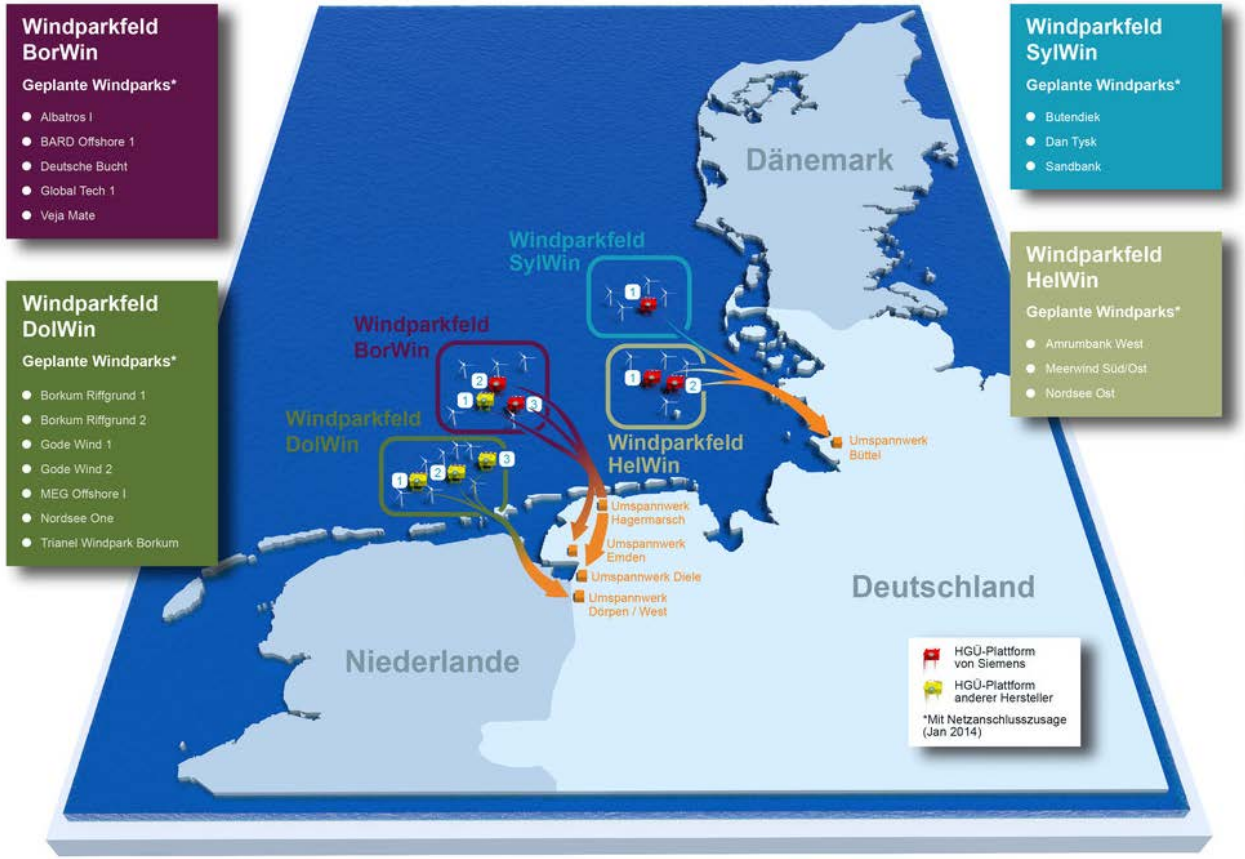
- Radii of 1000-2000-3000 km
  equals 500 – 800 – 1100 kV UHVDC

- Market integration between Continental and Nordic grids



# HVDC connection for German Offshore Wind farms

- So far nine HVDC offshore wind connections in construction or commissioned
- ABB 3
- Alstom 1
- Siemens 5

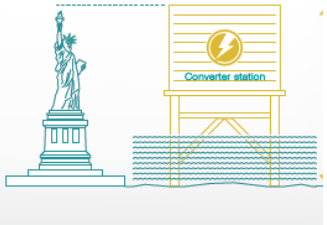


# Offshore wind connection platforms
## Dolwin 1

### Dolwin alfa platform

- ±320 kV 800 MW, 75 km off German coast. Lift weight 9 300 ton (topside).

Taller than the statue of liberty 95 m high from seabed




### Dörpen Grid Connection point

- ±320 kV 800 MW, 90 km from German coastline

**Supplying electricity to 900 000 household**

© ABB

# Dolwin 2

## Dolwin Beta platform. 900 MW

- Installation of electrical equipment in Haugesund, Norway

- Construction in Dubai

- Transport to Norway

**Worlds largest offshore connection platform**

# Offshore HVDC in the North Sea

## Connecting offshore wind and power-from-shore

### Offshore wind connections since 2009

- 9 VSC-HVDC offshore wind connections commissioned or in construction
- ABB: Borwin 1, Dolwin 1 and 2 (below)

### Power-from-shore since 2005

- ABB: Troll 1-2, 3-4, Valhall, recently Johan Sverdrup Oil&Gas
- 50-100 MW VSC-HVDC power from shore

### Outlook 2016-2020

- Largest offshore wind HVDC platforms today >20 000 ton. Too big.
- Our vision: half weight whit maintained VSC performance
- Affordable offshore size reductions
- Flexible design and installation

**Bring the best well-proven onshore technology offshore**

Pictures: Dolwin 2, 900 MW, in Haugesund Norway for electrical installation. Johan Sverdrup offshore platforms, 100 MW VSC-HVDC

© ABB

# HVDC Grids – technology is not a stumbling block

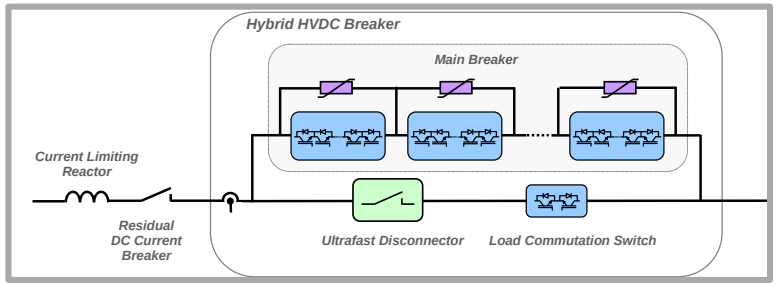
## Connection of the dots is natural next step, e.g internet, telecom, trains, and not the least AC grids

### HVDC Grids

- HIL real time simulation of multiterminal grids with several protection zones
- VSC-HVDC based. Ultra-fast breaker are needed. Protection works
- Developments in VSC-HVDC ratings and density in the grid leads the way

### How will it start?

- So far unclear market signals. A few single zone multi-terminal ready in construction
- Regulative barriers to be harmonized
- Upfront investment scenario to connect multiple users and suppliers



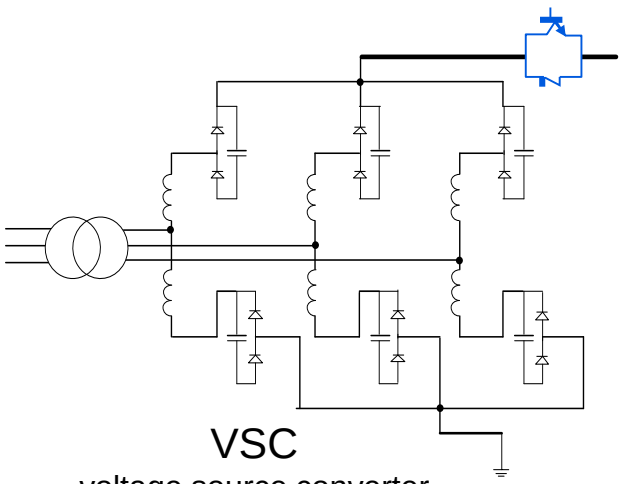

**Functional descriptions of first multi-terminals under development in CENELEC**
**Multiple CIGRE working groups and TB:s addressing HVDC Grids**



HIL – Hardware in the loop, e.g. controllers and simulators together

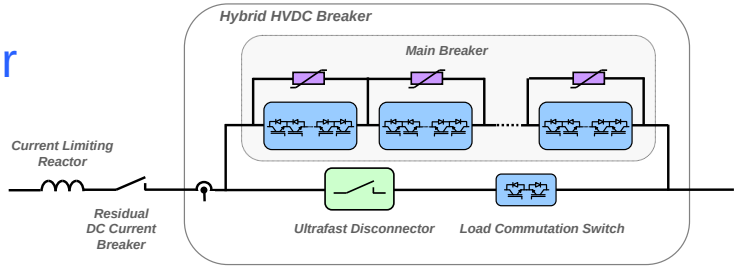
# Hybrid HVDC Breaker
## The ultrafast low-loss solution

Fault clearance < 5 ms.  Losses <0.01%. Scalable concept. First 320 kV, next level 500 kV



VSC
voltage source converter

HVDC Breaker




Hybrid concept: Mechanics and power electronics

Artist impression

**Flexible multiple protection zone HVDC can be designed and planned for**

# Future Gas Insulated Switchgear (DC-GIS)

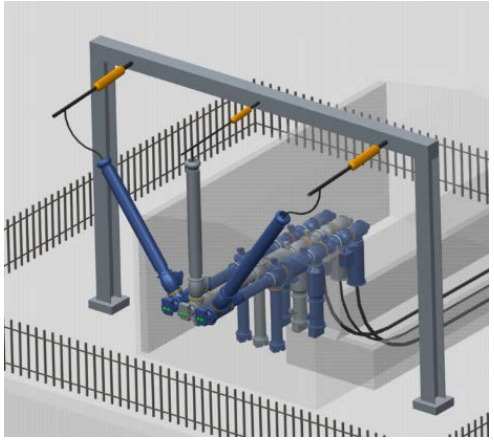
## e.g. bus-ducts, bushings, terminations, sensors, arrestors,…

### DC GIS to shrink HVDC converters stations

- DC GIS in a few installations in Sweden and Japan (150 and 250 kV)
- Next level 320 kV and beyond

### Reduce footprint of cable – overhead line transition stations

- In transmission highways with mixed cable and overhead line sections



**Available near term depending on market requirements**
**Compare AC GIS from 170 kV to 1 100 kV in 50 years**

# Wrap-up
## Opportunities

- **Continuous increase in HVDC performance higher current and voltage, lower losses**
  - Power-dense semiconductors
  - New converter valve design
  - Extruded and MI cables at 525 kV
    2.6 GW possible in one bipole transmission
    4-5 GW in a parallel bipole (4 redundant circuits)
- **Cost learning in transmission**
  - Optimization of offshore designs
  - MW-$ value
  - Life cycle cost and upgrades

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