Björn Jacobson, ABB Power Systems – HVDC, Oct. 4, 2011

Developments in Multiterminal HVDC

Drivers, Building Blocks (Cables, Offshore), EU and US Examples, Grid-Enabled HVDC, LCC-MTDC

IEEE EPEC 2011 – Winnipeg, Manitoba

Why multi-terminal?

- Saving cost and conversion losses
- Providing enhanced reliability and functionality
- Combining purposes

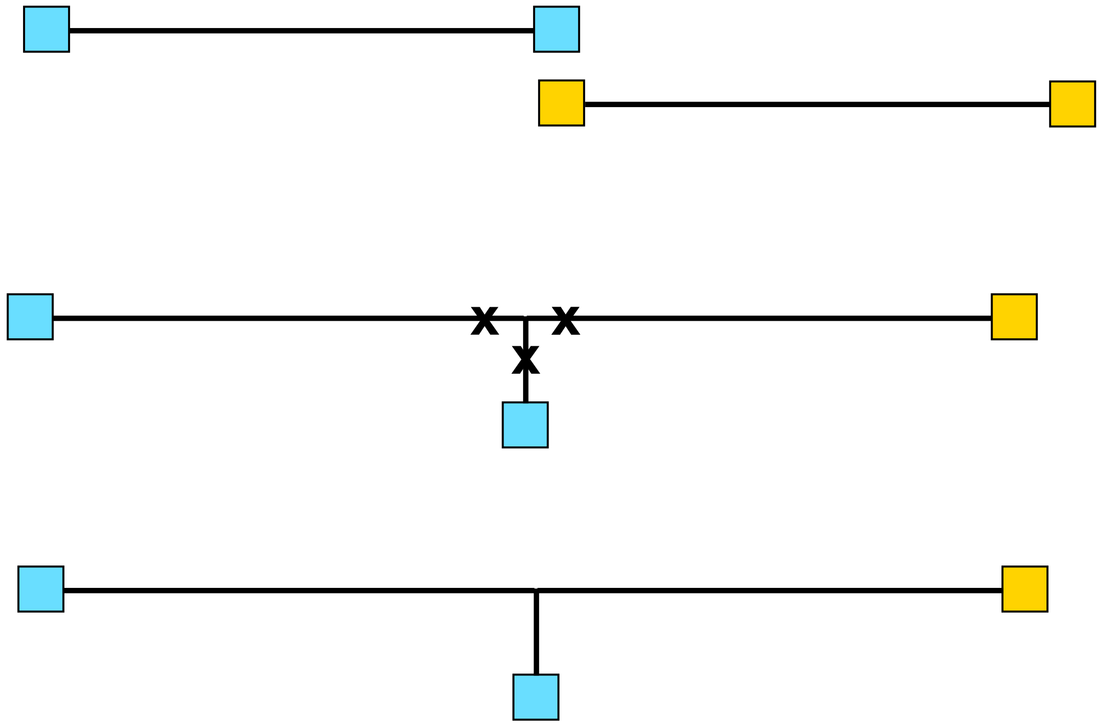
AC/DC Converter station

Cable or Overhead line

x Breaker

Why multi-terminal?

Adding to an existing point-to-point



4 converters

3 converters
”3” breakers

3 converters

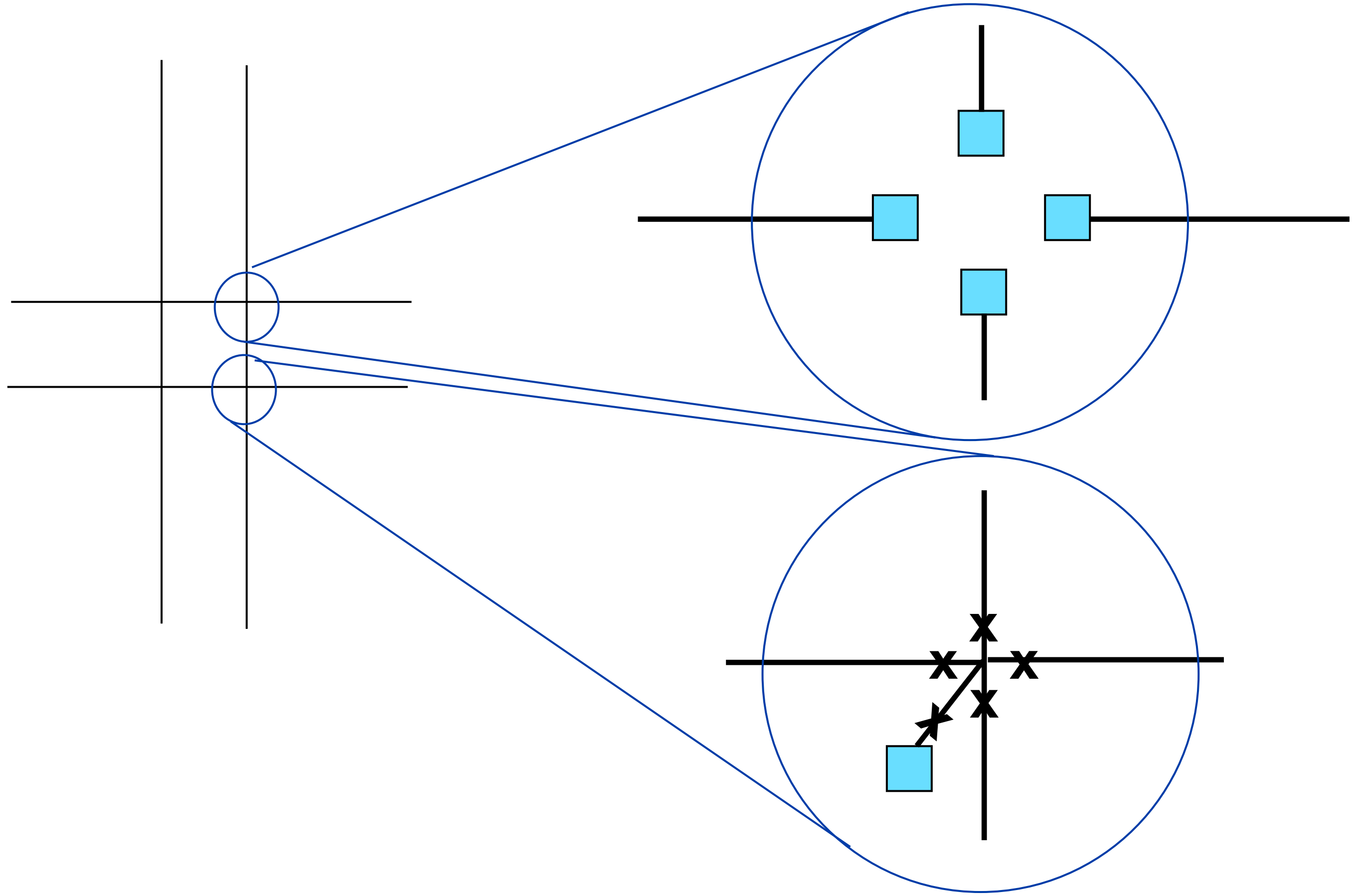
AC/DC Converter station, existing and additional

Cable or Overhead line

X **Breaker**

Why multi-terminal?

A node in a DC network



4 converters

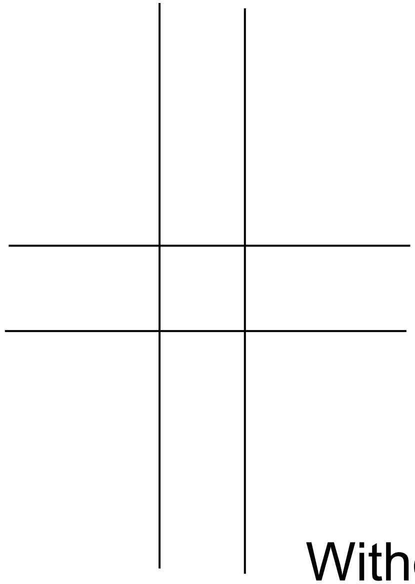
1 converter
"5" breakers

AC/DC Converter station, existing and additional

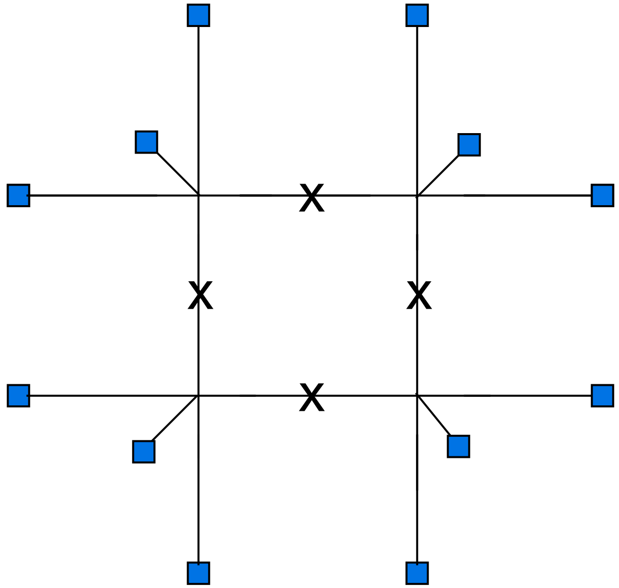
Cable or Overhead line

Breaker

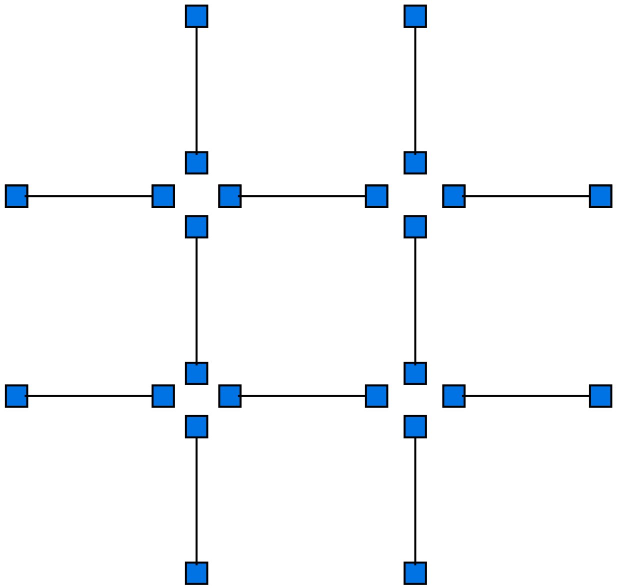
Why multiterminal?



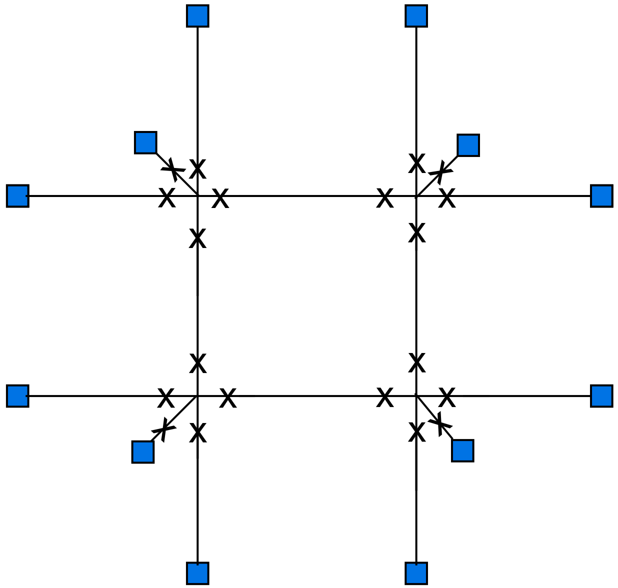
Sectioning into sub-systems



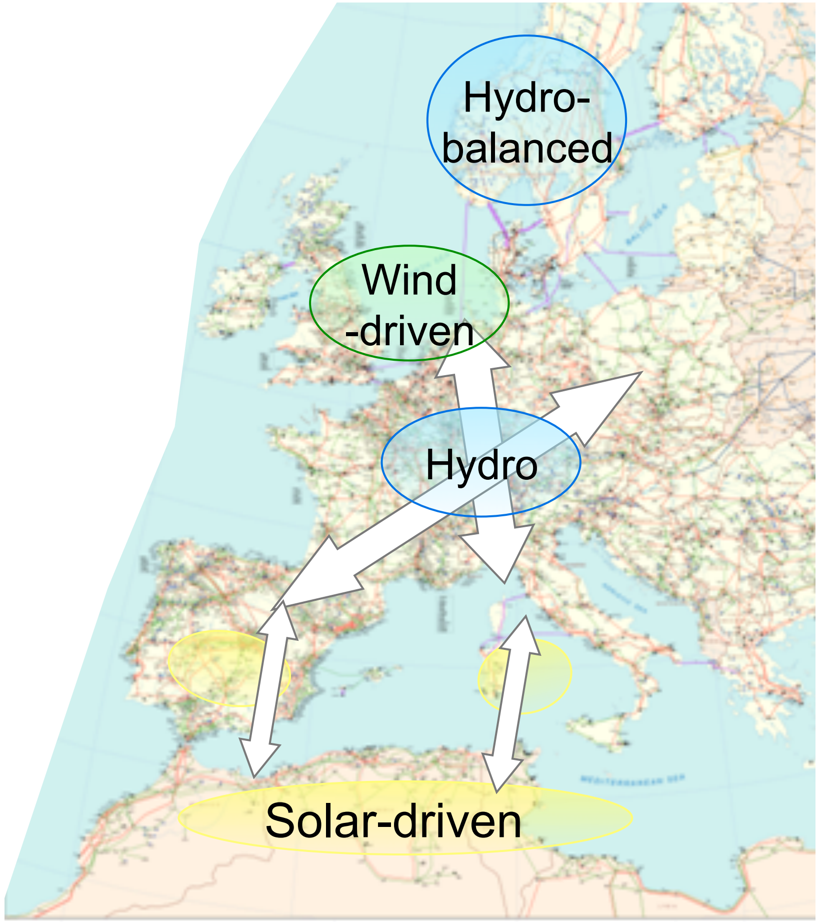
Without multi-terminal approach



Protecting each object



Pan-continental Grid in Planning Now
We know where to go, but how?



Generation changes

- Massive renewables North & South Europe, e.g. €30B (CAD 42B) North Sea wind, €6B (CAD 8B) Mediterranean solar grids
- New sites for conventional power

Transmission changes

- East-West and North-South power flows meet in central Europe
- Balancing by hydro

Loads change

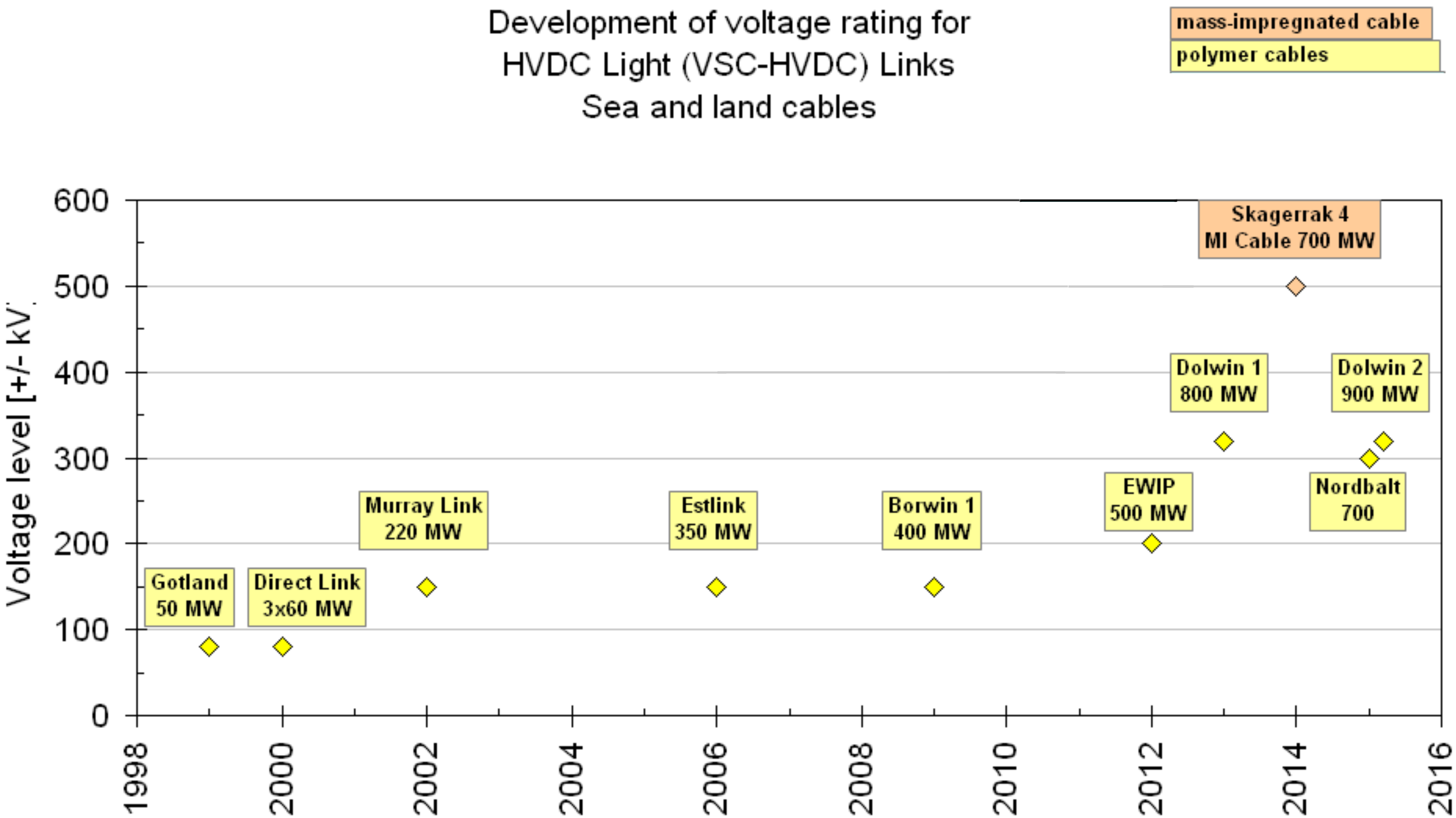
- Urbanization, feeding large cities

Similar transmission scenario emerges in North America

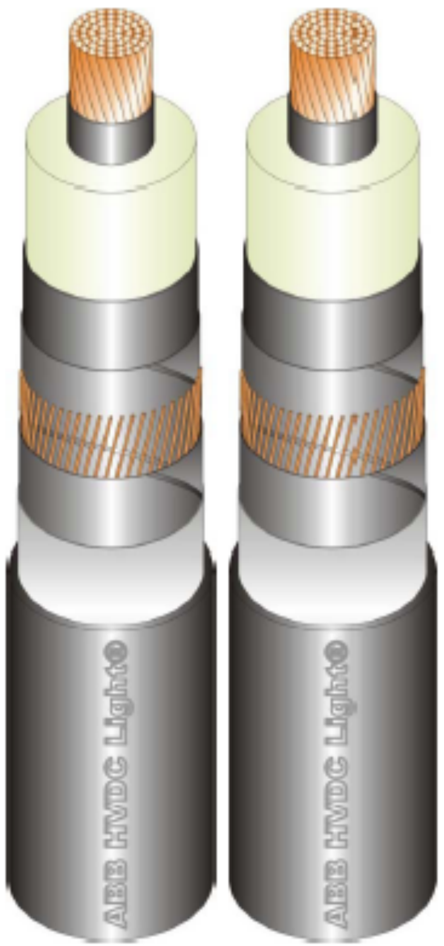
- New transmission capacity will be needed
  - retire older fossil fuel based power plants
  - expand (remote) renewable generation resources
  - maintain reliability
- Public opposition to overhead transmission line and legal and permitting barriers can cause severe delays
- Common factors against overhead transmission lines:
  - Aesthetics, Land use constraints, EMF
- HVDC cable transmission system used in existing infrastructures can release these permission barriers
  - AC cables have significant length limitations due to capacitive charging that requires shunt compensation
  - DC cable systems are proven technology

Polymer cables are proven technology for HVDC since 1999

In use for AC since 1970:s. HVDC voltage and power increase by factors of 4 and 20 times, respectively, over ten years



Solid Dielectric Cables for HVDC transmission



1999
Gotland
160 kV (±80 kV)
50 MW
43 miles

2000
Direct Link
160 kV (±80 kV)
3×60 MW
3×40 miles

2002
Murray Link
300 kV (±150 kV), 220 MW
112 miles

2006
EstLink
300 kV (±150 kV), 350 MW
20 miles (+46 miles subsea)

2009
BorWin
300 kV (±150 kV), 400 MW
47 miles (+80 miles subsea)

2012
EWIP
400 kV (±200 kV), 500 MW
46 miles (+116 miles subsea)

2007-2009
Type and PQ test
2500 mm^2 Cu or Al
640 kV (±320 kV), up to 1100 MW

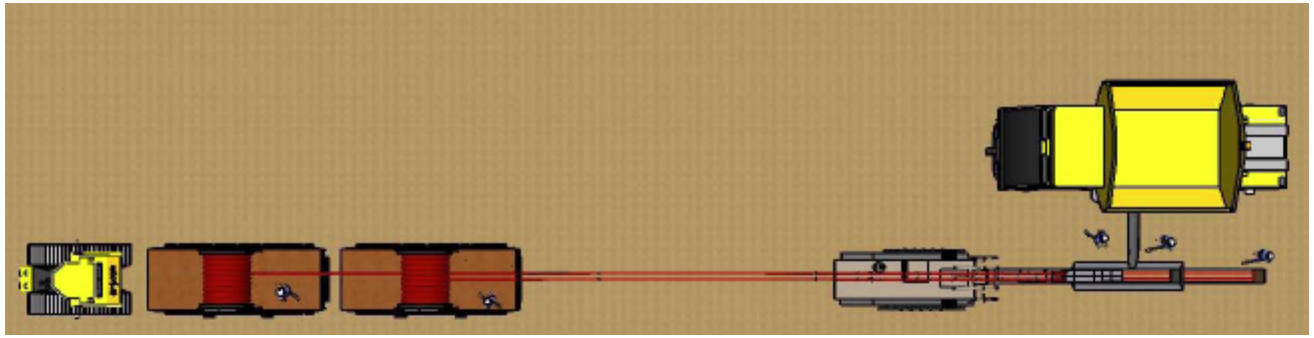
2013
DolWin1
640 kV (±320 kV), 800 MW
60 miles (+47 miles subsea)

2015
NordBalt
600 kV (±300 kV), 700 MW
31 miles (+248 miles subsea)

2015
DolWin 2
640 kV (±320 kV), 900 MW
56 miles (+28 miles subsea)

Land Cable Project Laying

Example of Cable Trenching
Proven Efficient and Fast Process



Existing infrastructure corridors (such as overhead transmission lines, railway, highways) can be used to "host" cable transmission systems

500 kVAC US transmission corridor
Multi GW DC transmission can be trenched in parallel

New ABB land cable factory in Huntersville, NC
Fits supply-chain requirements

Mid-Atlantic Power Pathway Project

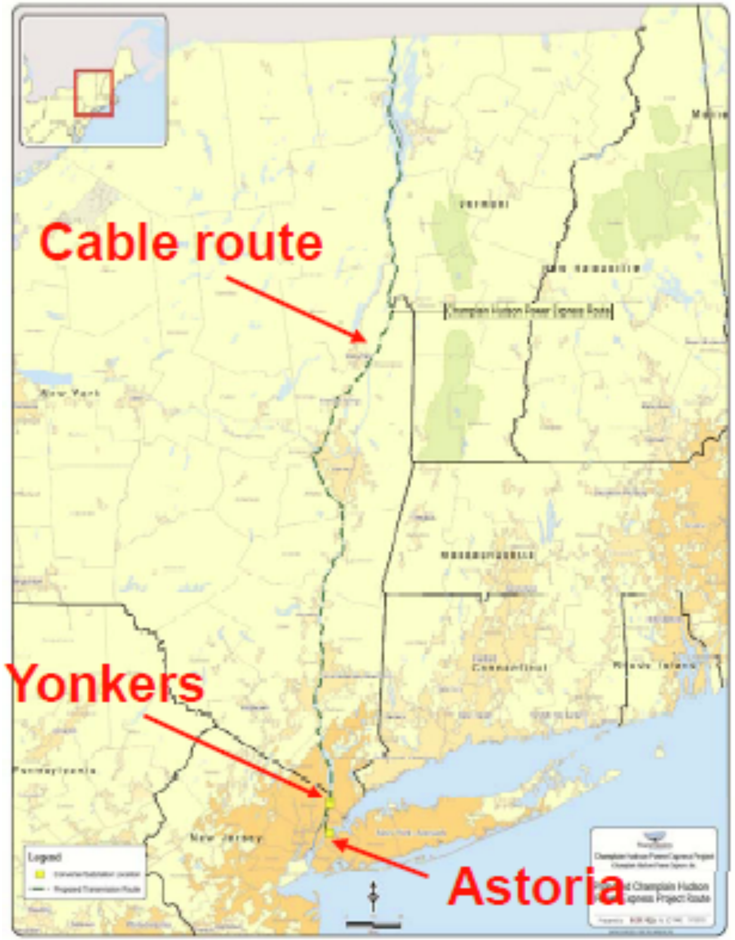
- **Application**
- New transmission path from Pepco to DPL.
- **Solution**
- Two parallel 43 miles long, 640kV (±320kV) submarine (39 miles) and underground (4 miles) HVDC cable circuits plus approximately 40 miles of HVDC overhead circuit.
- Compact on-shore HVDC voltage source converters.

pjm

EMAAC Alternative Summary

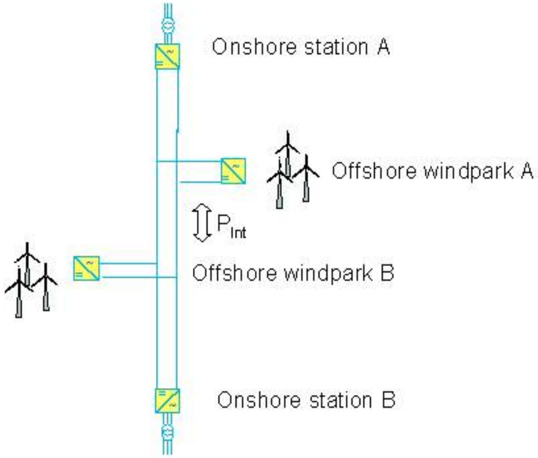
- The MAPP alternative will remain the recommendation to the PJM Board as the preferred alternative for Eastern Mid-Atlantic reliability criteria violations
  - Effectiveness
  - Cost
  - Construction Schedule

Champlain Hudson Power Express Project
Using cables and existing infrastructure



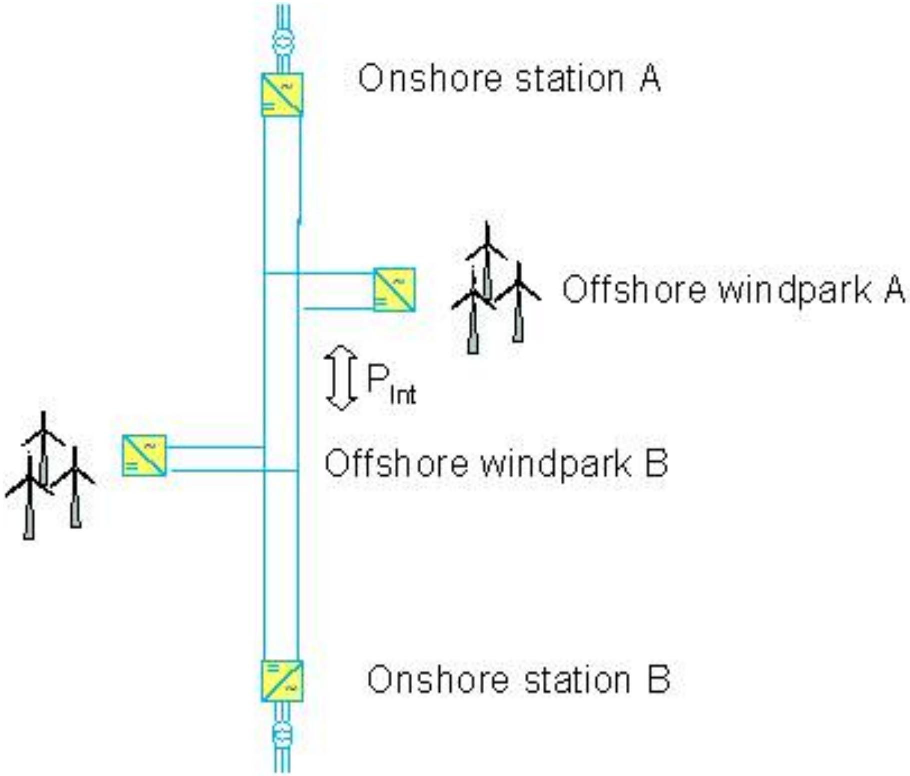
- 1000MW, 600kV (±300kV)
- 320 miles all HVDC cable route (210 miles in water and 110 miles underground)
- The HVDC cable circuit will be laid in the Hudson River from Yonkers to a landing site south of Albany, New York.
- From the landing site south of Albany, the HVDC cable circuit will be installed underground within existing railroad rights of-way to the southern shore of Lake Champlain
- The HVDC cable circuit will then be laid in Lake Champlain to the Canadian border.

Can HVDC Grids be built today?
Regional and interregional HVDC Grids



- At least two different types of HVDC transmission schemes involving more than two converter stations can be identified:
  - *Regional HVDC grids, which are possible to build already today.*
  - Interregional HVDC grids, where new developments are required.

What is a Regional HVDC grid?



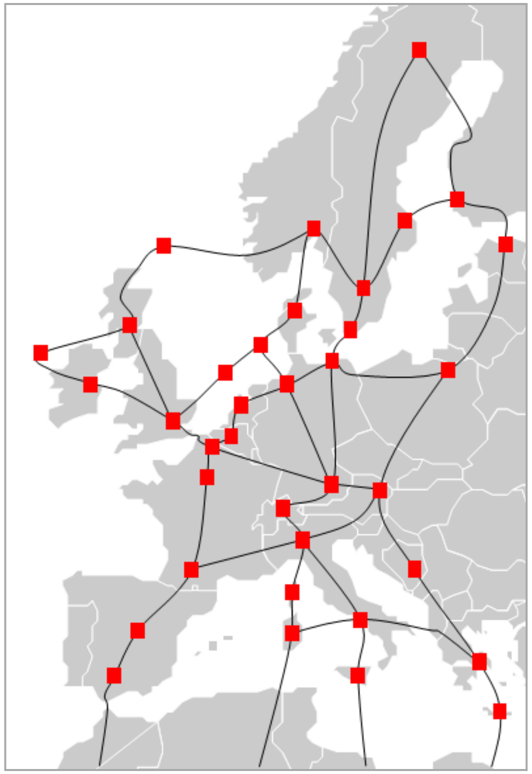
- *Regional DC Grid with optimised voltage level.*

- A typical regional HVDC Grid is defined as a system that constitutes of one protection zone for DC earth faults.
  - *To temporarily and rarely lose the whole HVDC system has a limited impact on the overall power system.*
  - Fast restart of the faultless part of the system
  - HVDC breakers are not needed
  - Normally radial or star network configurations
  - *Limited power rating*
  - *To enable multi-vendor approach, standardized high level control interface needed*

Are built today with proven technology

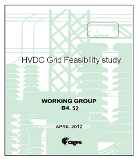
ABB

What is an interregional HVDC Grid?



- An interregional HVDC grid is defined as a system that needs several protection zones for DC earth faults.
- *Developments focus:*
  - HVDC breakers and fast protections
  - Grid Power flow control/Primary control: automatic control
  - Master control: start/stop, re-dispatching
- Long-term development, e.g.
  - High voltage DC/DC converters for connecting different regional systems

- *Regulatory issues* such as how to manage such new grids need to be solved.



On-going Cigré WG B4.52 ”HVDC Grid Feasibility study”

Borwin 1, Dolwin 1-2 Summary

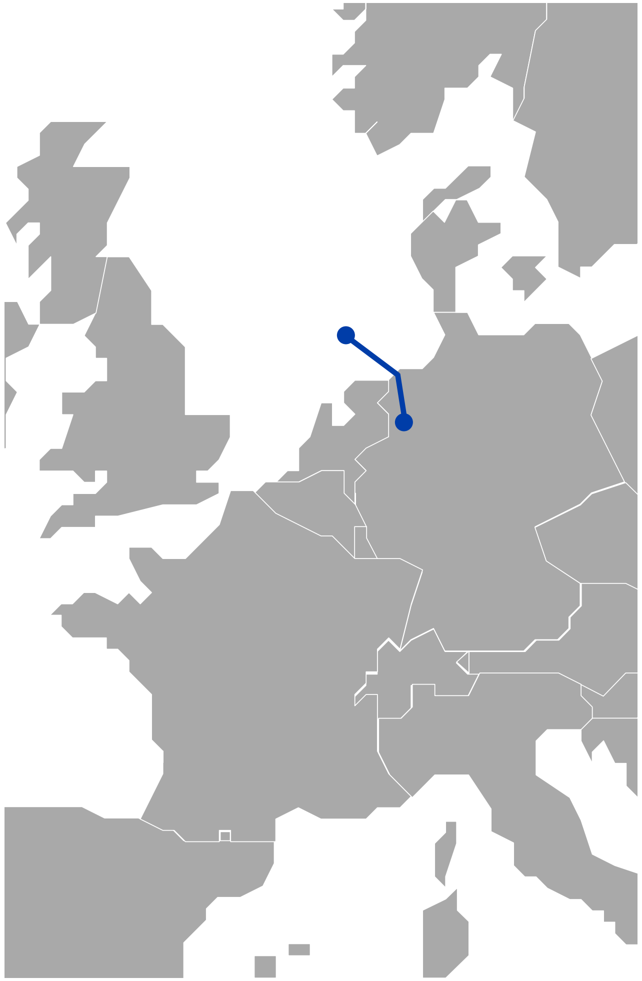
Main data	Borwin 1	Dolwin 1	Dolwin 2
Commissioning year:	2012 *	2013	2015
Power rating:	400 MW	800 MW	900 MW
No of circuits:	1	1	1
AC Voltage:	170 kV (Platform)	155 kV (Platform)	155 kV (Platform)
	380 kV (Diele)	380 kV (Dörpen W)	380 kV (Dörpen W)
DC Voltage:	±150 kV	±320 kV	±320 kV
DC underground cable:	2 x 75 km	2 x 75 km	2 x 45 km
DC submarine cable:	2 x 125 km	2 x 90 km	2 x 90 km

Main reasons for choosing HVDC Light:

Length of land and sea cables.

*) when all Bard 1 wind generation is in operation. Transmission since 2010

BorWin1
The first HVDC project to connect offshore wind



Customer

- Tennet, Germany

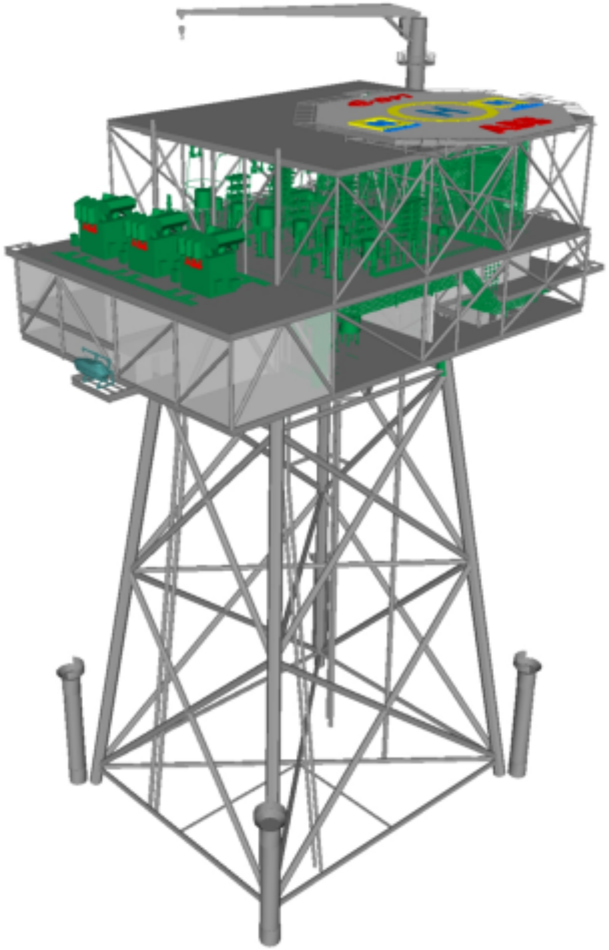
Customer's need

- Connection of 400 MW from offshore wind farm to the German transmission grid
- 125 km distance to coast
- 75 km from coast to connection point
- Robust grid connection

Customer's benefits

- Environmentally friendly power transport
- Reduce CO_2 emissions by nearly 1.5 million tons per year by replacing fossil-fuel generation
- Supports wind power development

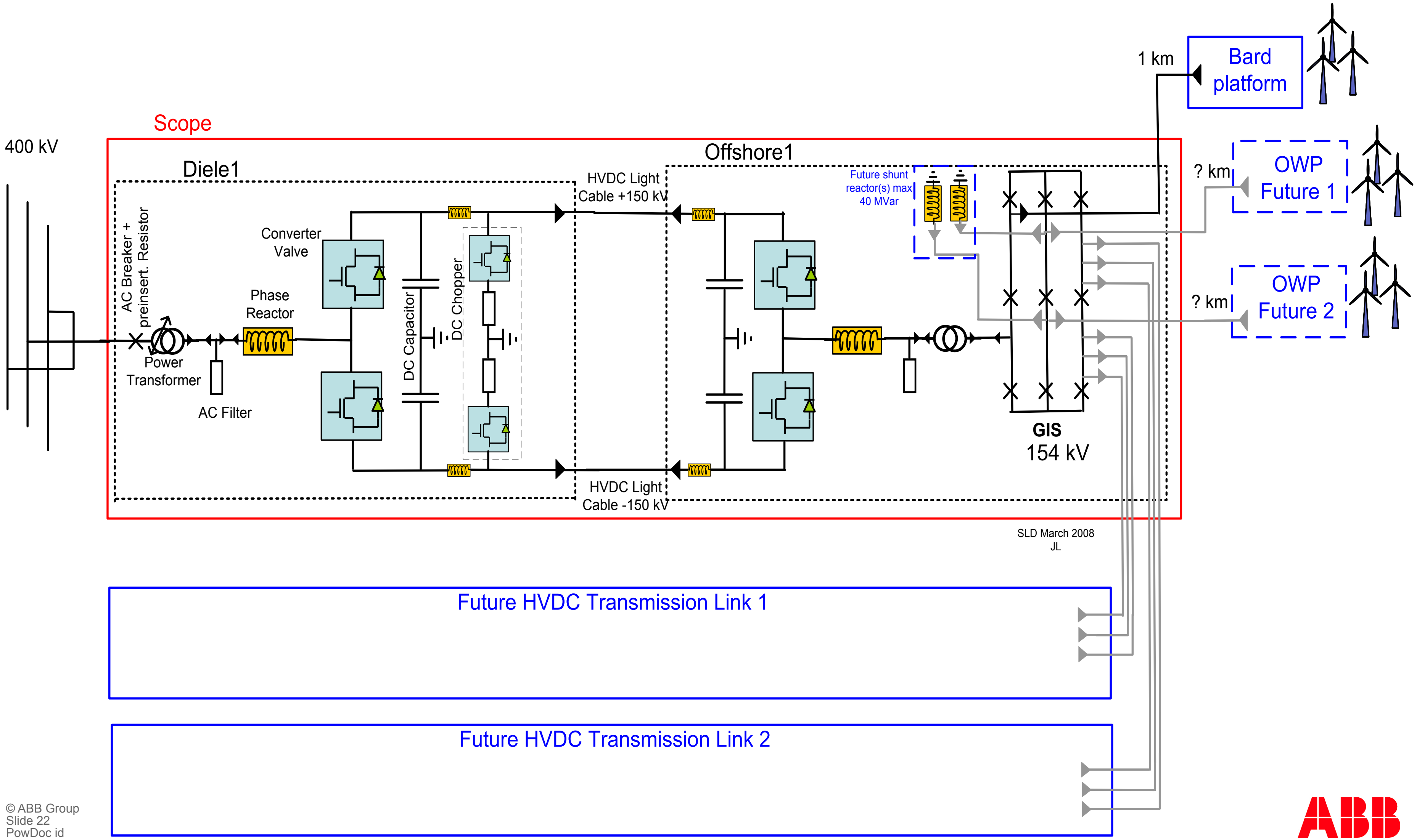
BorWin1
The first HVDC project to connect offshore wind



ABB's response

- 400 MW HVDC Light® system at ±150 kV
- 125 km sea cable route
- 75 km land cable route
- Turnkey delivery including platform
- Full grid code compliance

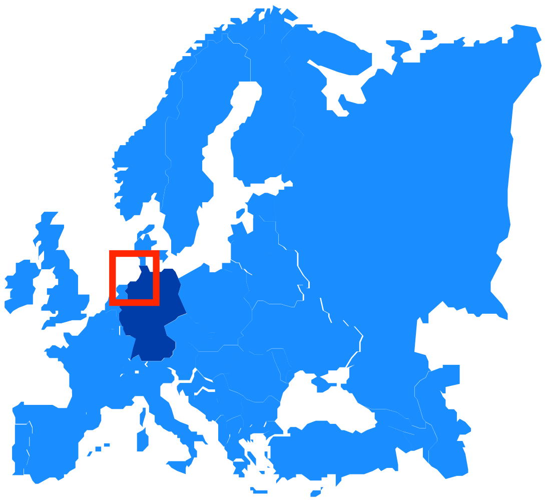
BorWin1
Single Line Diagram



DolWin2
Germany

Customer: TenneT

Year of commissioning: 2015



Customer’s need

- 135 km long subsea and underground power connection
- Robust grid connection

ABB’s response

- Turnkey 900 MW HVDC Light system
- ± 320 kV extruded cable delivery

Customer’s benefits

- Environmentally sound power transport
- Low losses and high reliability
- Reduce CO_2-emissions by 3 million tons per year by replacing fossil-fuel generation
- Grid connection 90 km inland

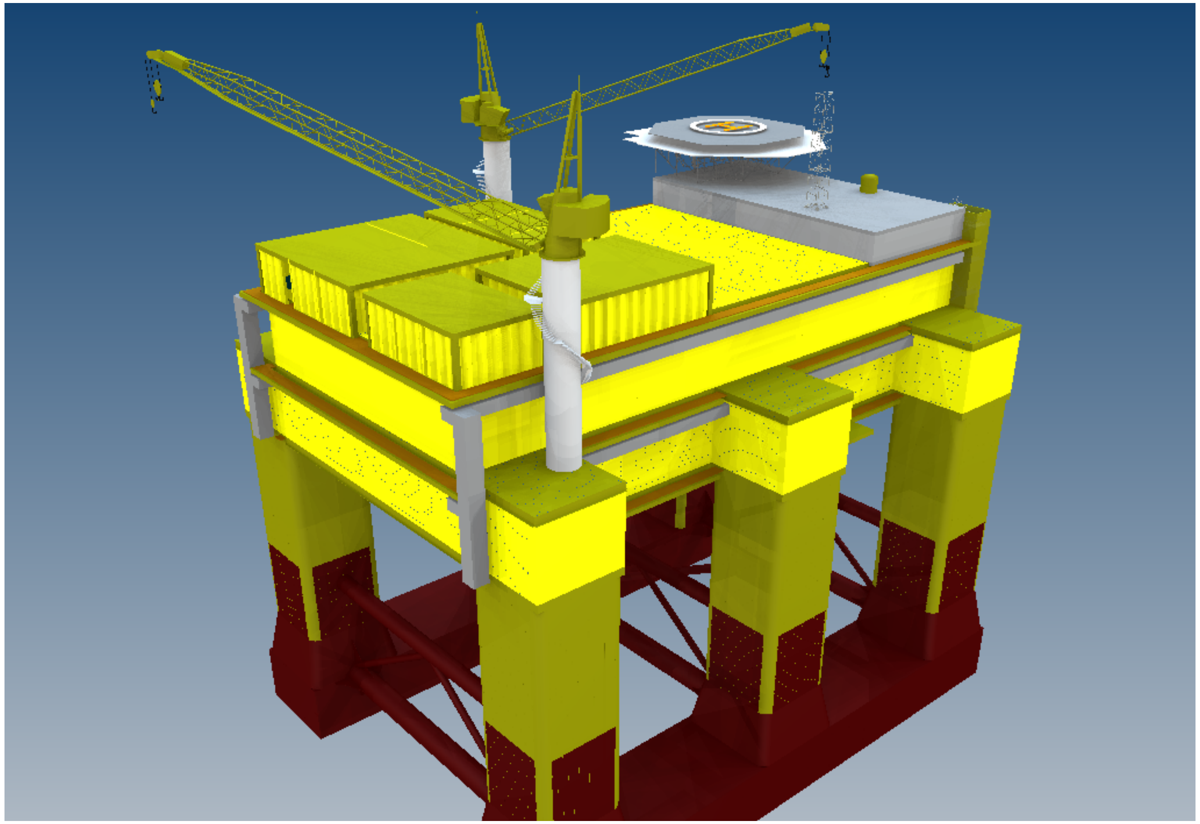
DolWin2
Germany

1. DolWin beta DC platform
2. Dörpen-West substation

- Customer: TenneT
- Country: Germany
- Scope of works: design, supply and installation of
  - HVDC Light ±320 kV 900 MW system
    - Two converter stations - one offshore and one onshore
    - Offshore platform
    - 135 km ±320 kV extruded cables
      - 45 km sea cable
      - 90 km land cable
- Order value: 1 BUSD
- In service: 2015

HVDC Light grid connection concept by ABB

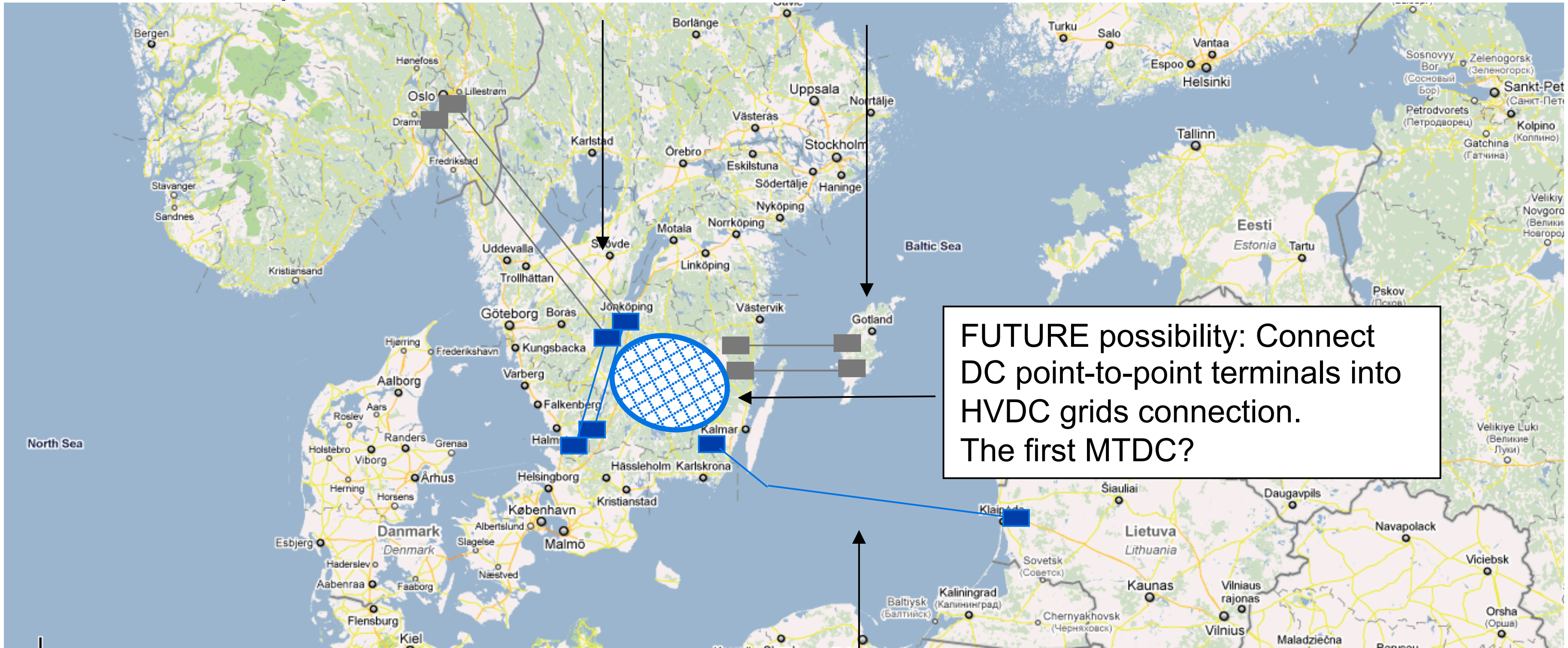
New platform concept developed together with a Norwegian off-shore firm for Dolwin 2



View from Scandinavian TSO (Svenska Kraftnät)
Prepare for multiterminal operation: Grid enabled P-t-P

Southwest link VSC Tendering: 1000-1200 MW
2 x 3-terminal in parallel

Gotland VSC in planning: 2 x 500 MW
Support 1000 MW wind



FUTURE possibility: Connect DC point-to-point terminals into HVDC grids connection.
The first MTDC?

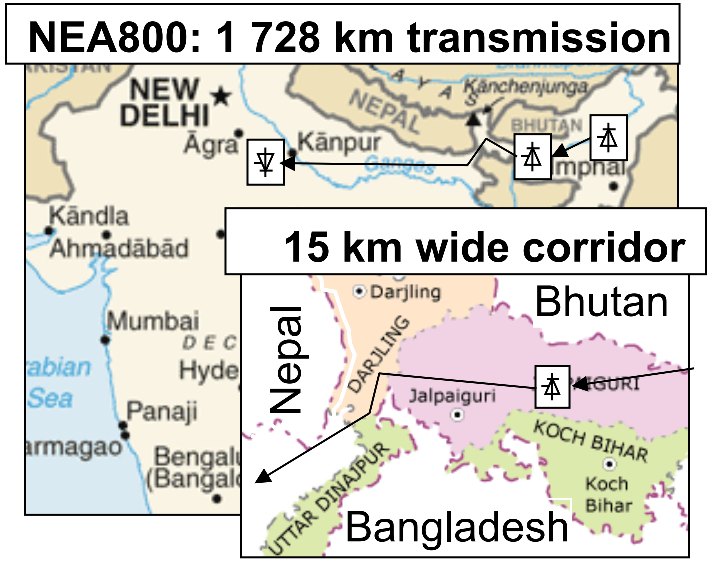
Nordbalt VSC Order received: 700 MW
Security of supply, market integration
Commission end 2015

Planning / discussion

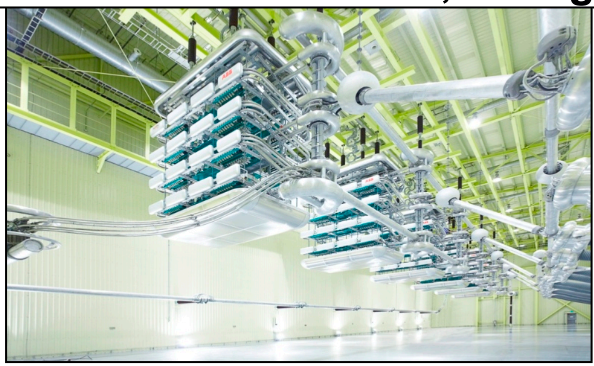
Awarded / tendering

2014: North East - Agra: Multiterminal Classic UHVDC*

8 000 MW World Record Power Transmission



800 kV Converter Valve, Shanghai



HVDC connection of multiple remote hydro power regions in NE India

- Low losses, reliability, flexibility

North East - Agra (NEA 800)

- Hydro resources NE locally
  13 m of rainfall per year
- 15 km narrow "Chicken Neck" Transmission Corridor, between Buthan, Nepal & Bangladesh
- Electricity to 90 M people

ABB:s second Multiterminal HVDC

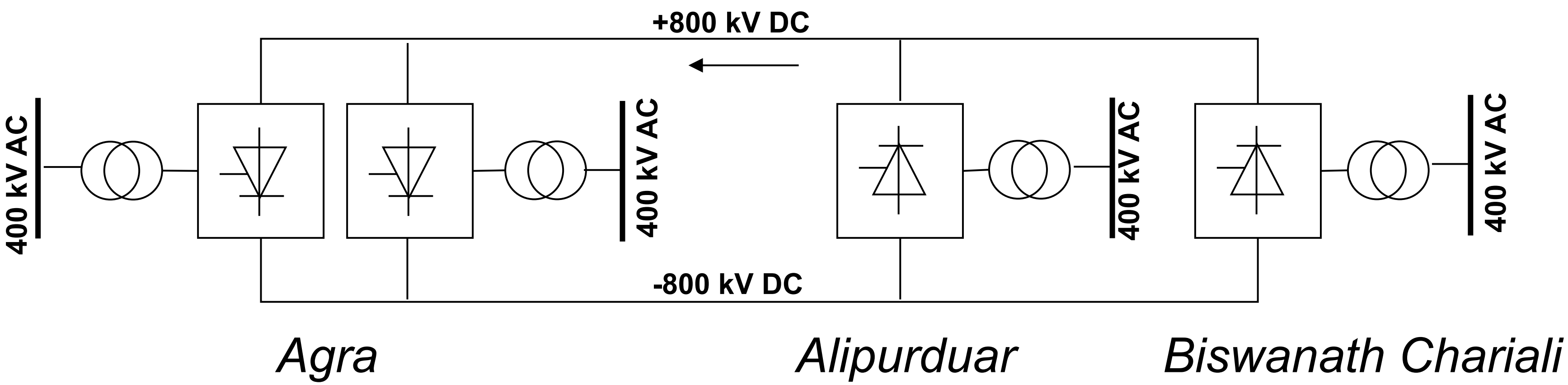
1. New England – Hydro Quebec 1992
   Three terminal, 2000 MW

ABB:s second 800 kV HVDC

1. Xiangjiaba – Shanghai 2010
   2000 km, 6400 MW UHVDC

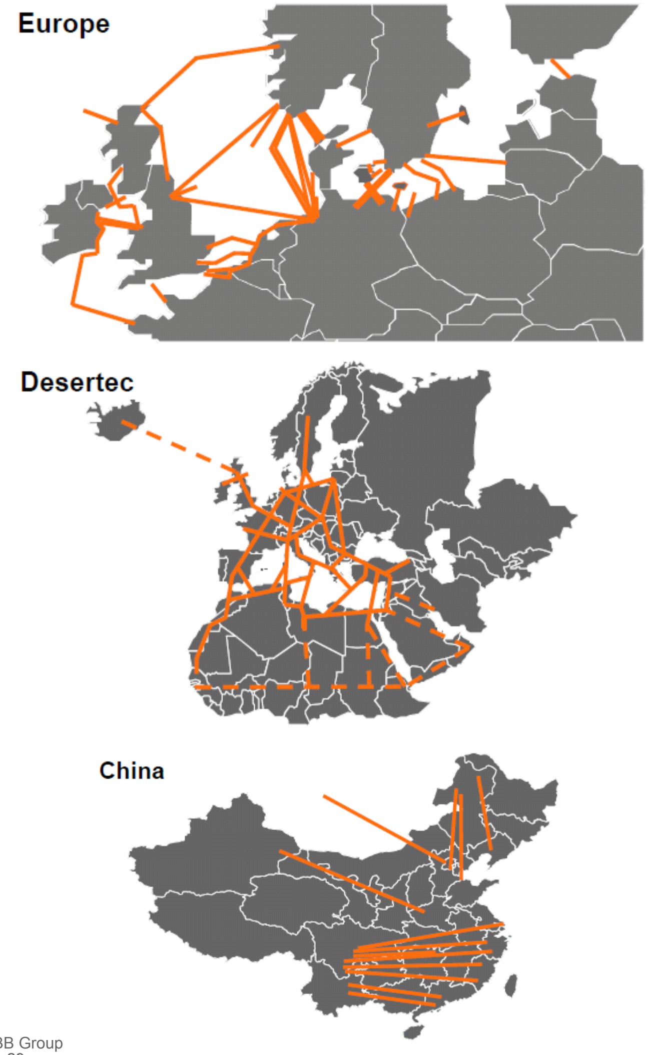
* Classic UHVDC = Line-commutated converters ultra-high voltage direct current

NEA800 Four station Multiterminal HVDC Simplified Single Line Diagram



Customer	India Power Grid Corp.
Value	$1 190 M
Distance	1 728 km
Power	8 000 MW
Terminals	Four (2x2 bipoles)
Voltage	±800 kV
In operation	2014 - 2015
Delivery time	39 - 42 months

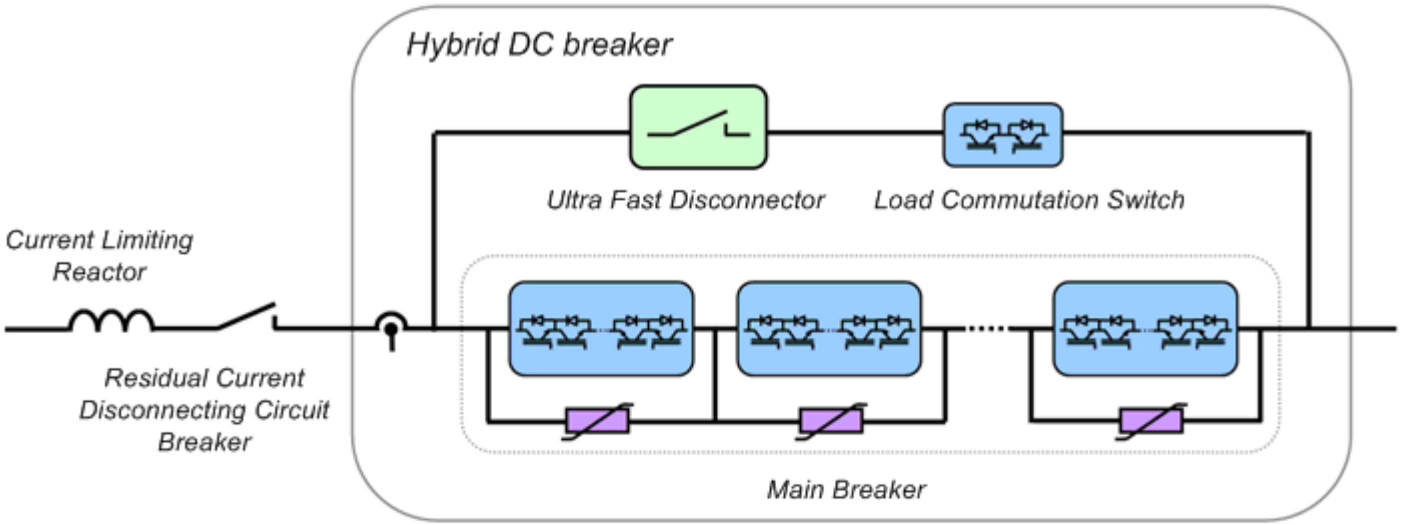
Multiterminal HVDC emerges as the first steps towards HVDC Grids



- Significant loss reduction
- Increased power capacity per line/cable vs. AC
- Stabilized AC & DC grid operation
- Less visual impact and lower electromagnetic fields
- Easier acceptance of new DC projects if lines can be tapped
- DC = only solution for subsea connections > 60 km
- Connection of asynchronous AC Networks

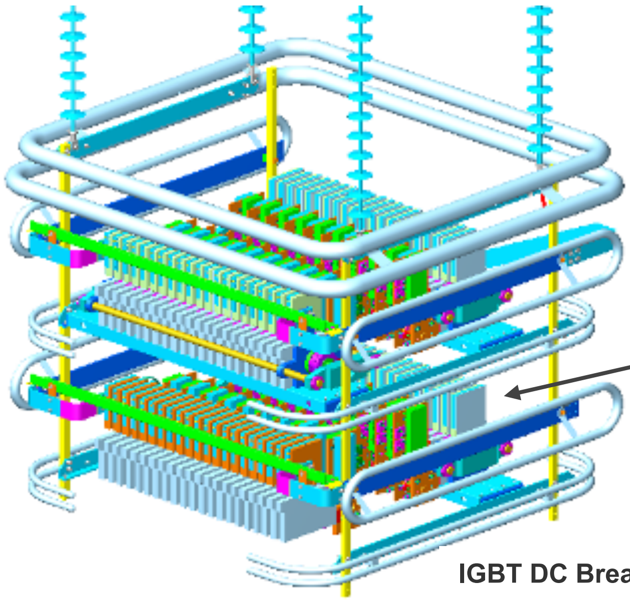
Technology required for visions like Desertec & North Sea Offshore Grid, but can be built today for smaller grid e.g. for efficient power balancing

Hybrid DC Breaker
Basic Design

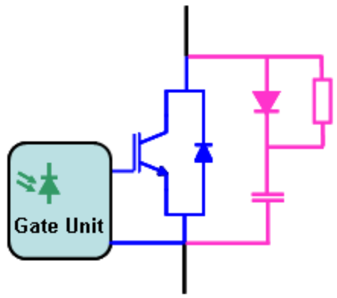


- Modular design of Main DC Breaker for improved reliability and enhanced functionality
- Fast DC current measurement for control and protection
- Disconnecting residual DC current breaker isolate arrester banks after fault clearance

IGBT DC Breaker
IGBT DC Breaker Cell



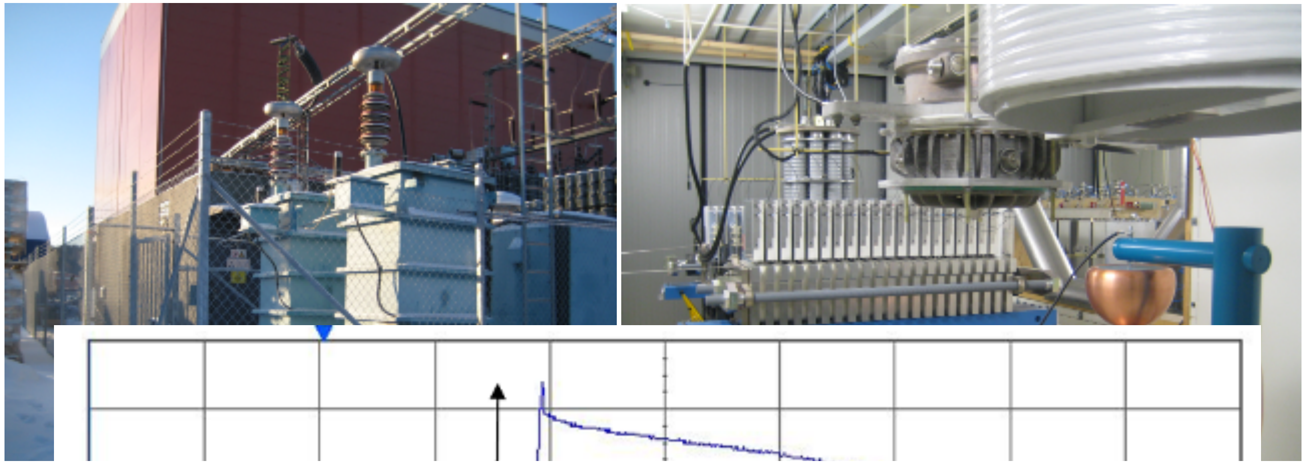
IGBT DC Breaker Cell

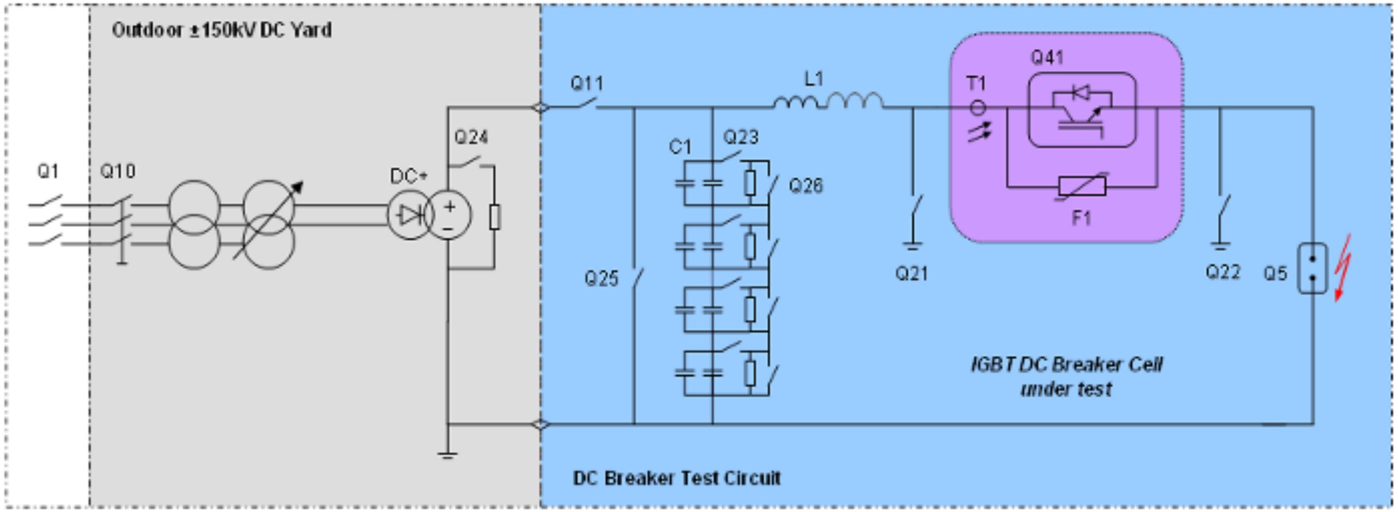


IGBT DC Breaker Position

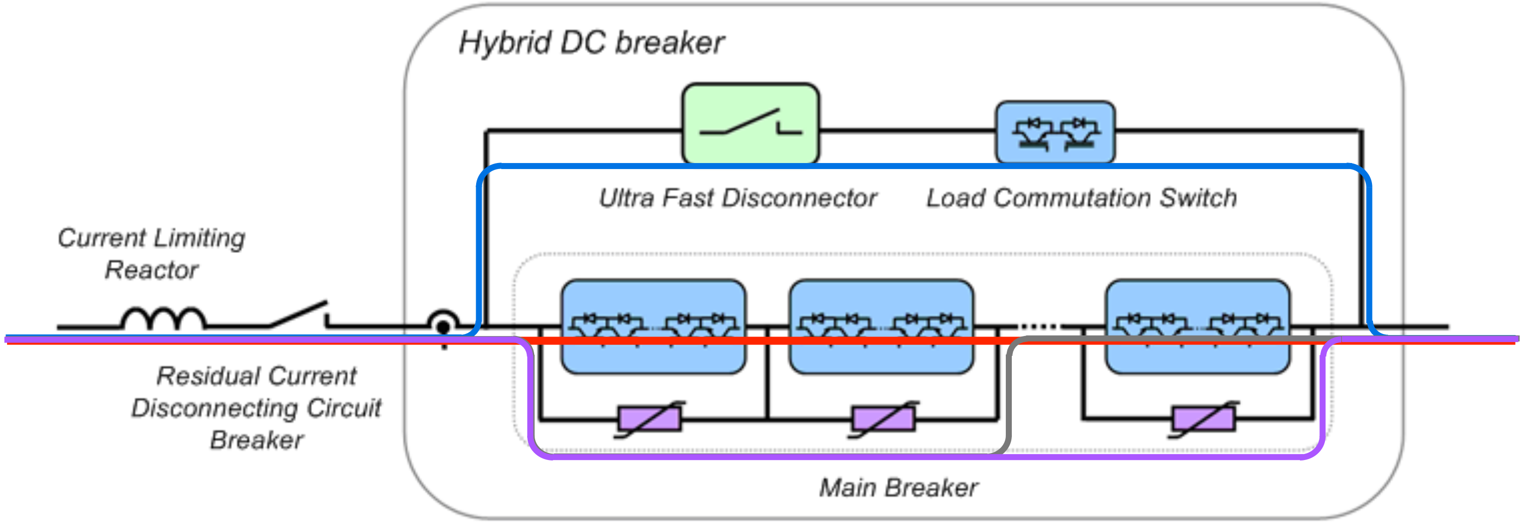
- 80kV IGBT DC Breaker cell consists of four IGBT stacks, two stacks required to break fault current in either current direction
  - Compact design using reliable 4.5kV Press-pack IGBTs
  - Resistor-Capacitor-Diode snubbers ensure equal voltage distribution
  - Optically powered gate units for independent DC Breaker operation

IGBT DC Breaker
IGBT DC Breaker Test Circuit



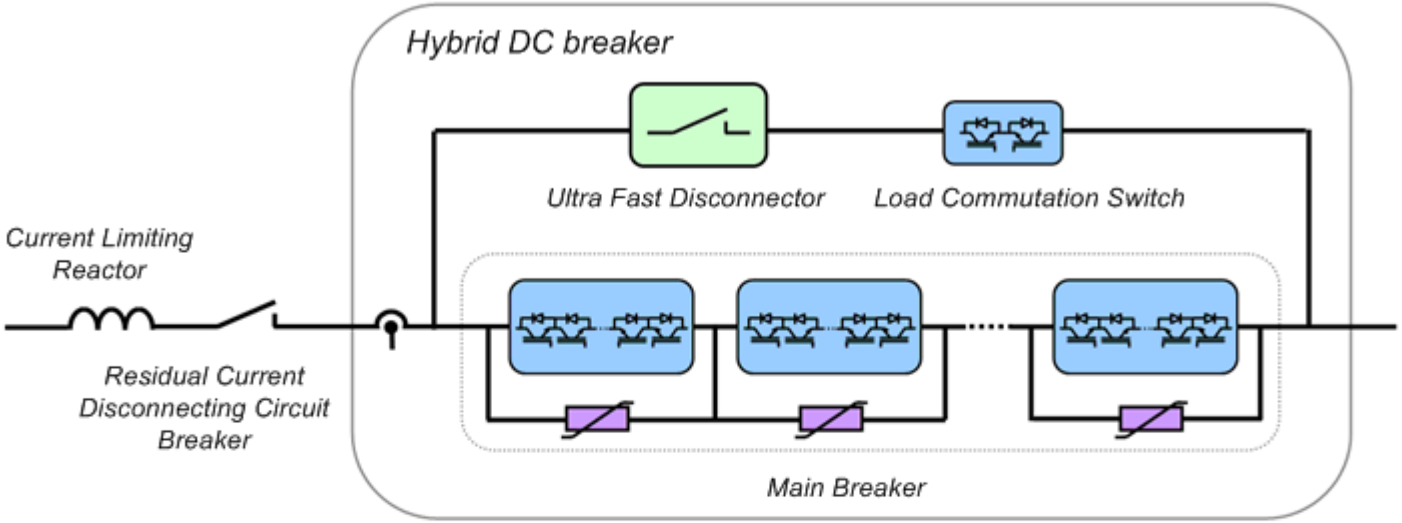


Hybrid DC Breaker
Basic Functionality



- Normal operation: Current flows in low-loss bypass
- Proactive control: Load commutation switch transfer current into Main DC Breaker switch, the Ultra Fast Disconnector opens with very low voltage stress
- *Current limitation: Main DC Breaker switch commutates fault current into parts of the sectionalized arrester bank*
- Fault clearance: Main DC Breaker switch commutates fault current into arrester bank

Hybrid DC Breaker
Main Features



- Very low transfer losses in bypass, < 0.01% of transmitted power
- Fast protection without time delay if opening time of Ultra Fast Disconnector is within delay of selective protection (< 2ms)
- Immediate backup protection in DC switchyard
- Self protection due to internal current limitation
- In-service functional tests allow for maintenance on demand

IGBT DC Breaker
Conclusions

- With breaking times of less than 2ms and a current breaking capability of 16kA, the proposed Hybrid DC Breaker is well suited for DC grids
  - The modular concept is easily adapted to different voltage and current ratings
  - Protective current limitation and in-service functionality tests enhance system reliability
  - Transfer losses are less than 0.01% related to the transmitted power

- DC Breakers are no longer a showstopper for large DC grids

Summary
Key equipment status

- Status today – we can offer complete Multi-Terminal systems
  - Converter – monopolar or bipolar
  - Cable system
  - IGBT breaker
  - Conventional mechanical DC Breaker
  - Future Hybrid DC Breaker will enhance functionality
- **Regional DC Grids can be built without DC Breakers**
- **Several HVDC projects in Europe are built “Multi-terminal enabled”**

Power and productivity
for a better world™

ABB