Michael Bahrman P.E., Grid Systems, UWIG Technical Workshop, Maui, October 2011

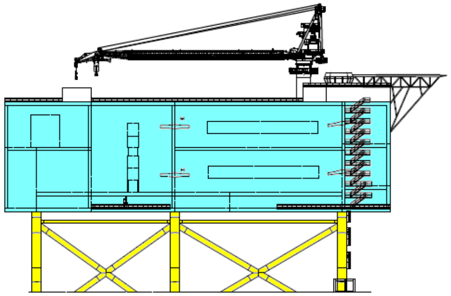
Offshore Wind Connections
HVDC for Offshore Grids

Power and productivity
for a better world™

HVDC for Offshore Grids
Topics

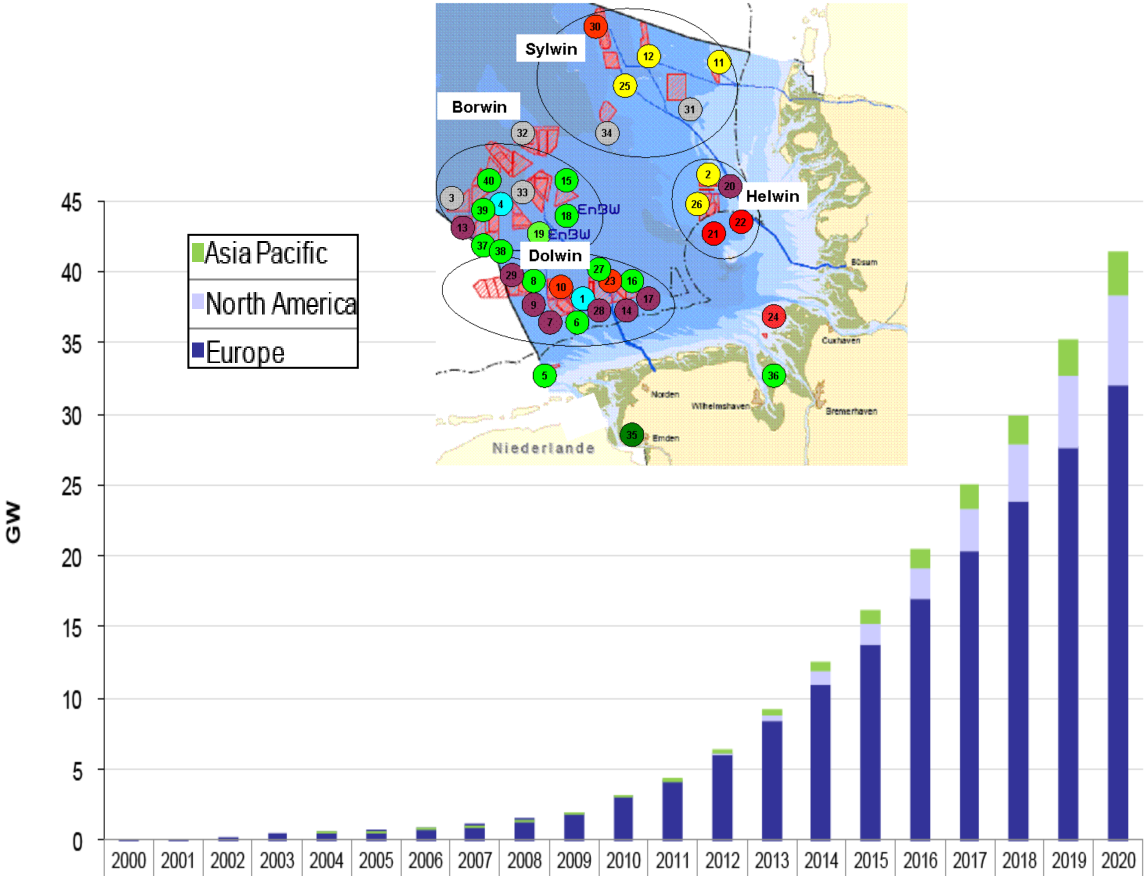
- Offshore wind market
- Offshore wind connection
- Technology
- Project examples
- Offshore grids

Why offshore?



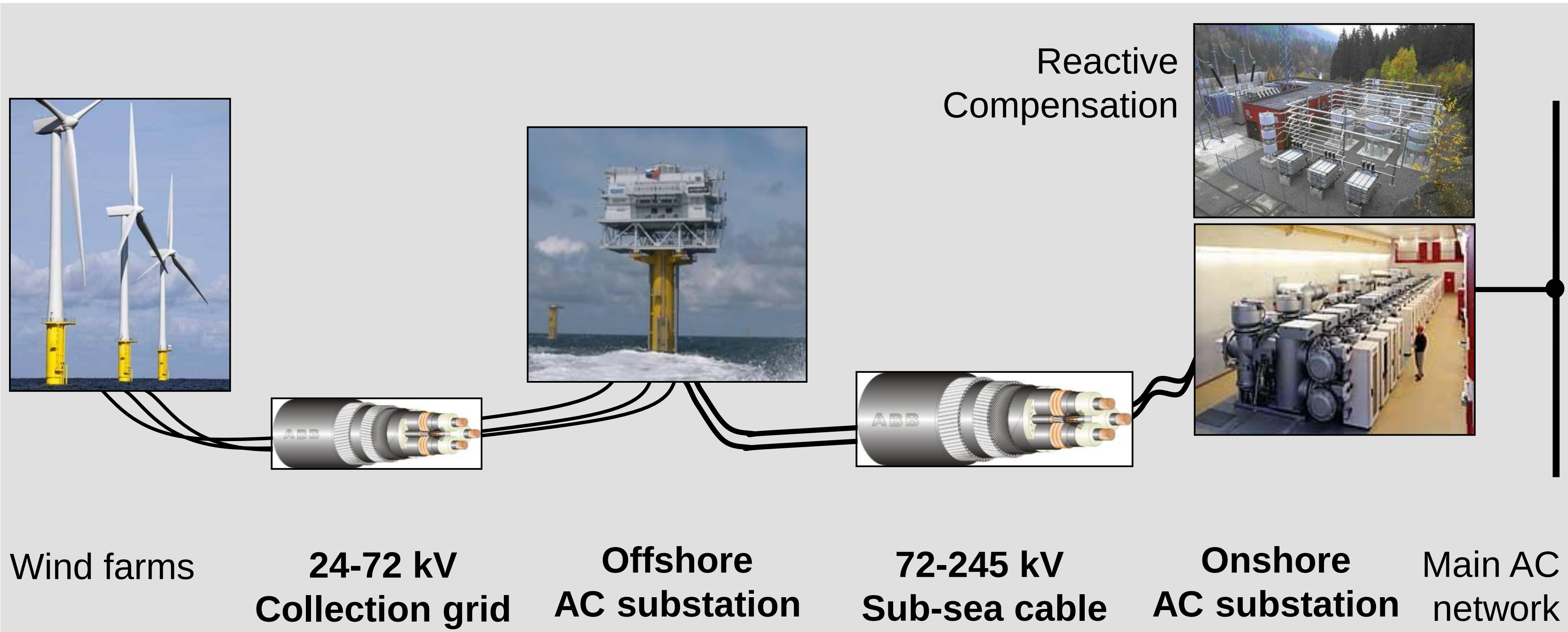
- More wind, better wind
- Large areas available
- Closer to population centers
- Less environmental impacts
- Coastal land use - circuit can extend underground to power delivery point
- Offshore grids for greater flexibility, reliability, efficiency and reduced cost compared to radial connectors

Offshore Wind Connectors (OWC)
World market – wind power plants



- Europe very dominant
- Exceptional growth in Europe, from 1GW to 33 GW (EER forecast - 51 GW planned)
- Estimated investment in connections 0.8 BUSD / GW
- Wind farms increasing in size, most of them above 300 MW
- Larger farms will require large cable deliveries, both ac array and ac or dc export cables
- Longer distances & increased size favors HVDC connectors (up to 1000 MW / ckt planned)

Offshore wind power connectors
AC for lower power levels / shorter distances



72 - 150 kV: 50 – 300 MW, **distance dependent**
150-245 kV: 200 – 500 MW, **distance dependent**

Traditional AC-substations located off-shore
Key issue is to fulfill grid code compliance

(Longest AC sub-sea cable is the Isle of Man connector – 104 km, 90kV / 40 MW)

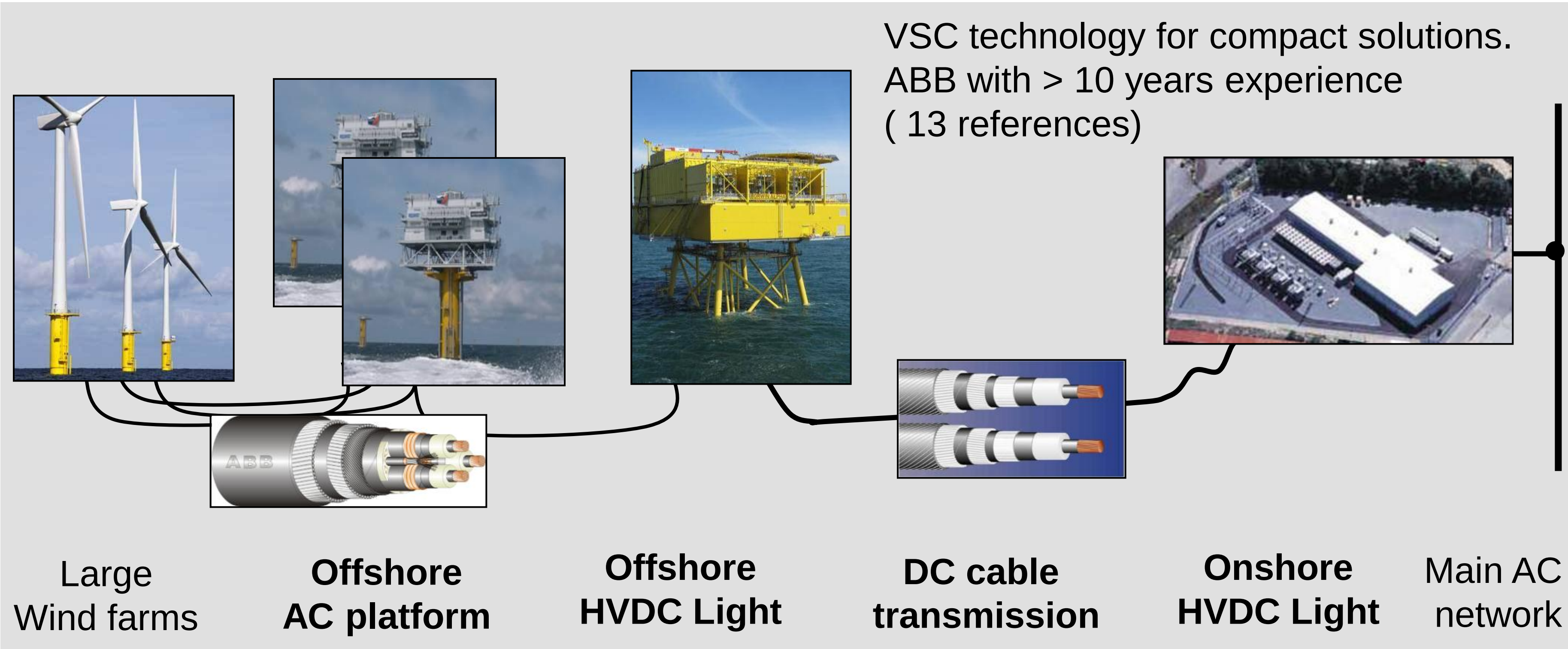
Offshore applications with VSC HVDC
Isolated operation – power to / from shore

- Generator outlet transmission from high power, remote offshore wind plants, > 40 km, > 300 MW
- AC voltage and frequency regulation of wind plant
- Back feed excitation and auxiliary power to wind plant during low wind or calm conditions (black start)
- Grid code compliant

- Feed power from shore to remote offshore oil & gas production platforms
- More economic
- Increased efficiency
- Lower emissions
- Reduced weight and space on platform

ABB

Offshore wind power connectors
VSC-based HVDC for higher power / longer distances



100 – 300 MW: ± 80 kV HVDC Light (VSC)
300 – 500 MW: ± 150 kV HVDC Light (VSC)
500 – 1000 MW:± 320 kV HVDC Light (VSC)

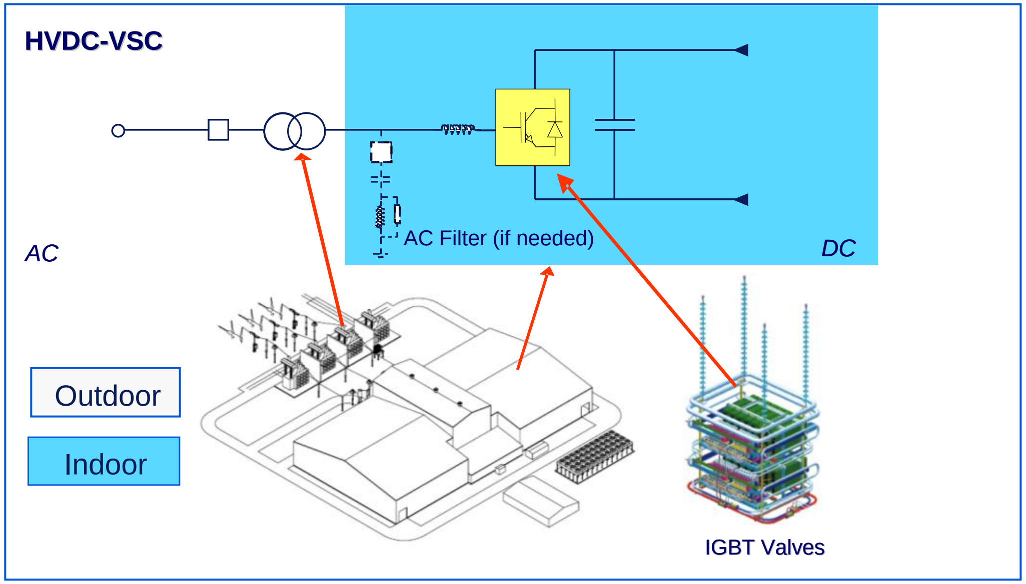
Grid code compliant – VSC HVDC can act as ‘buffer’ between wind plant and ac grid

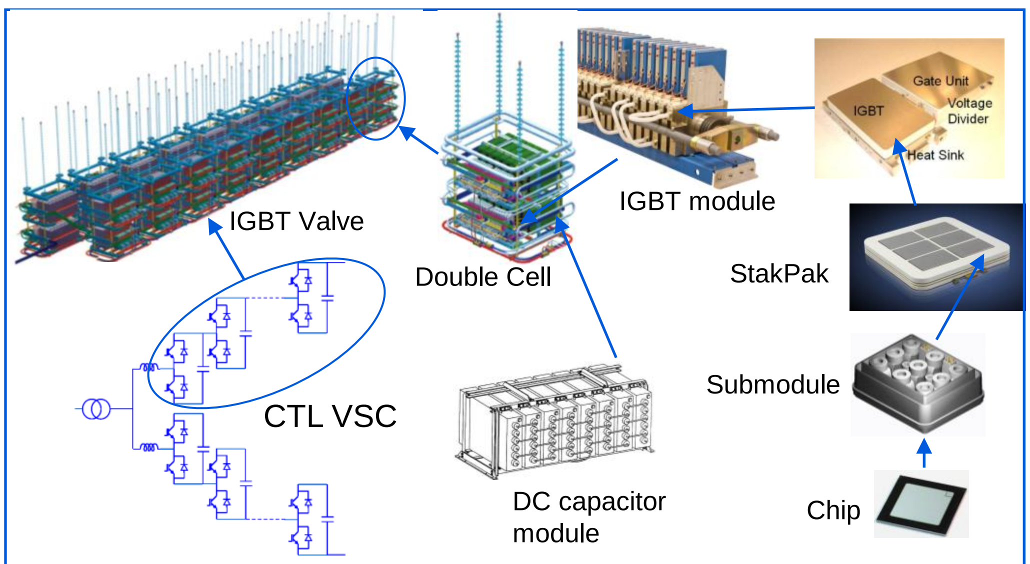
ABB

Platform design, fabrication and installation issues

- Harsh environment
- Remote location
- HSE
- Primary access and egress systems
- Emergency response
- Material handling
- Remote monitoring
- Accommodation
  - Permanent
  - Emergency shelters
- Limited number of qualified yards, yard loading, competition with oil & gas sector
- Transport and installation

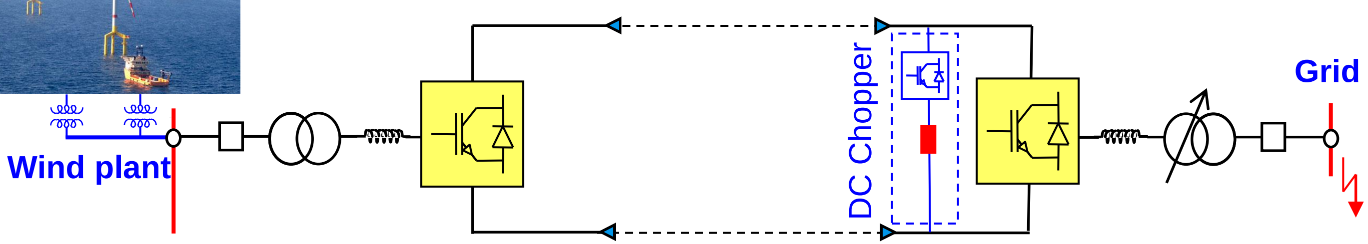
Voltage-sourced converter (VSC) HVDC technology





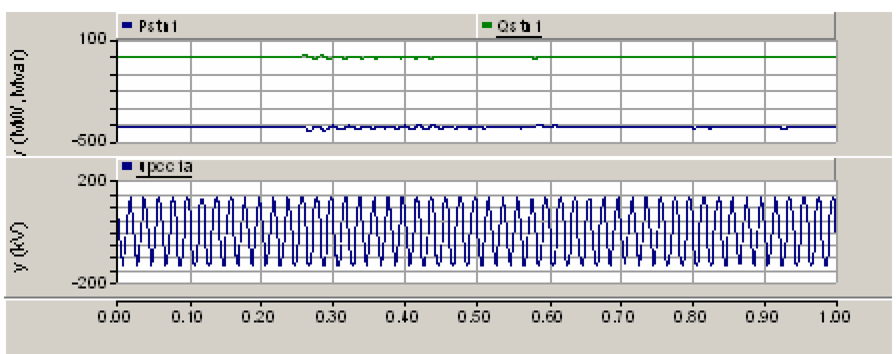
- No reactive power demand (~0-10% HF as required)
- Virtual generator at receiving end: independent P, Q control
- Black start, grid code compliance
- No minimum power limit
- Standard transformers
- Self-commutated with IGBT valves
- Cascaded two-level converter (CTL) topology - multilevel
- Press-pack, safe short-circuit failure mode, SCFM
- Symmetrical or asymmetrical connection, land segment can be cable or OVHD

Offshore or isolated wind applications
Fault ride through for wind park applications

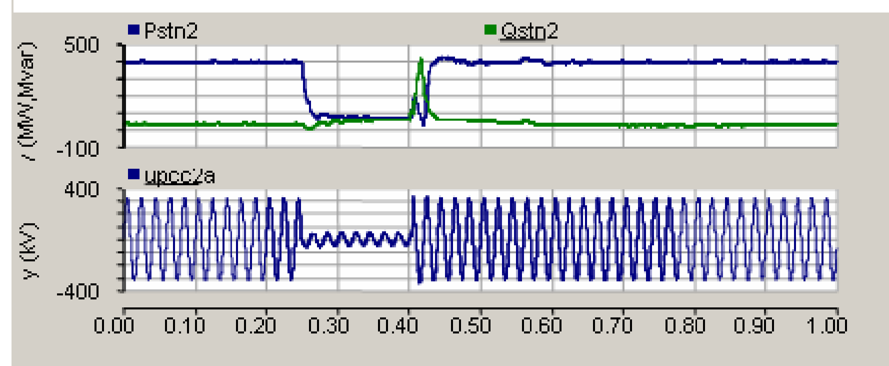


DC with chopper isolates the wind plant from faults on mainland grid

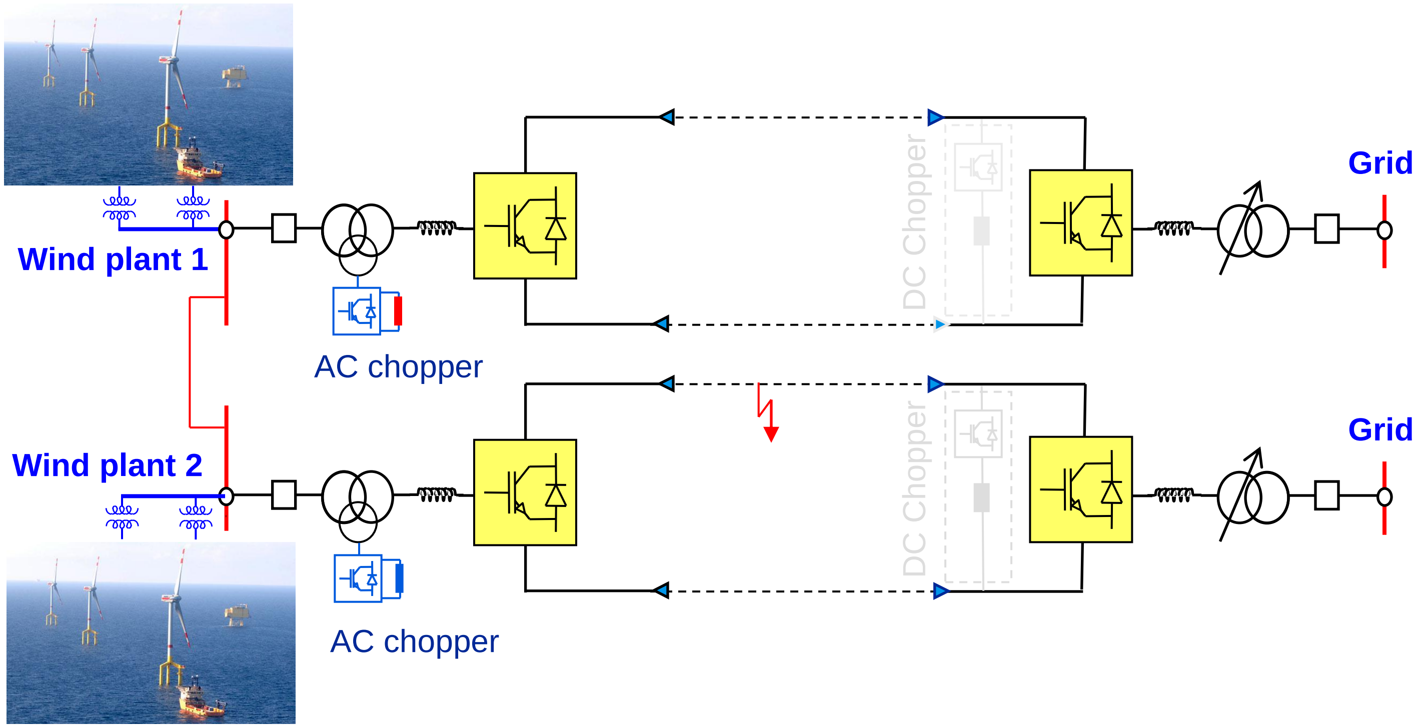
Wind plant



AC network



Offshore or isolated wind applications
Loss of generator outlet with parallel wind plants



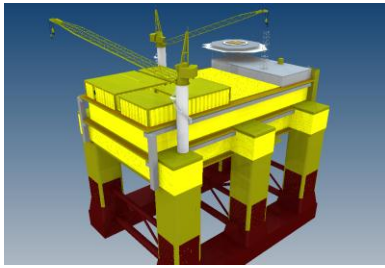
Curtailment of surplus wind power is slow resulting in over-speed of low-inertia WTG. AC chopper mitigates wind plant over-frequency for loss of outlet circuit at high wind production.

Borwin 1, Dolwin 1-2
HVDC Light 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

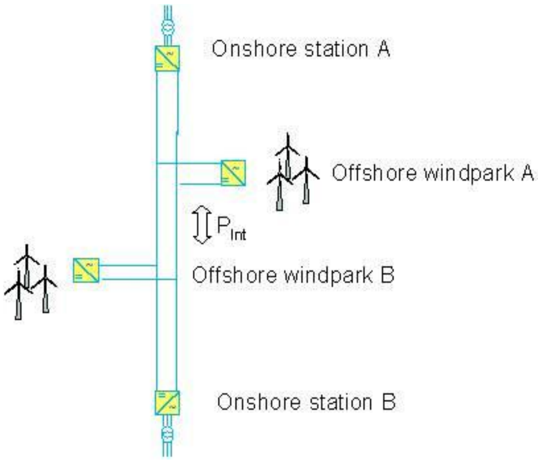
Main reasons for choosing HVDC Light:

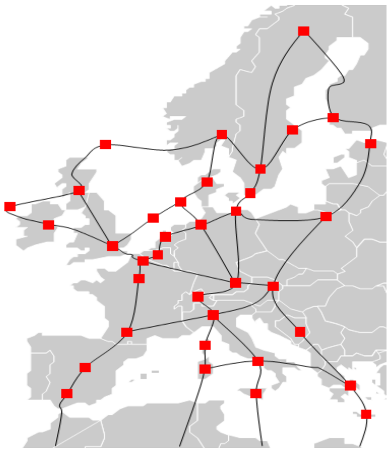
Total length of land and sea cables.



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

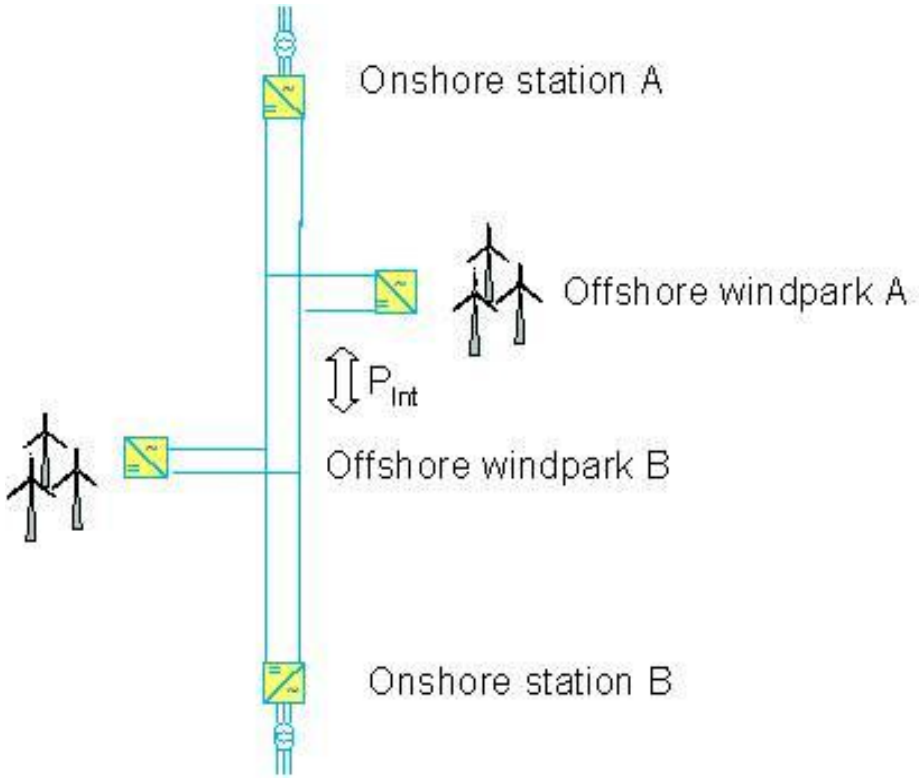
Can HVDC grids be built today?
Regional and interregional HVDC Grids





- 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?

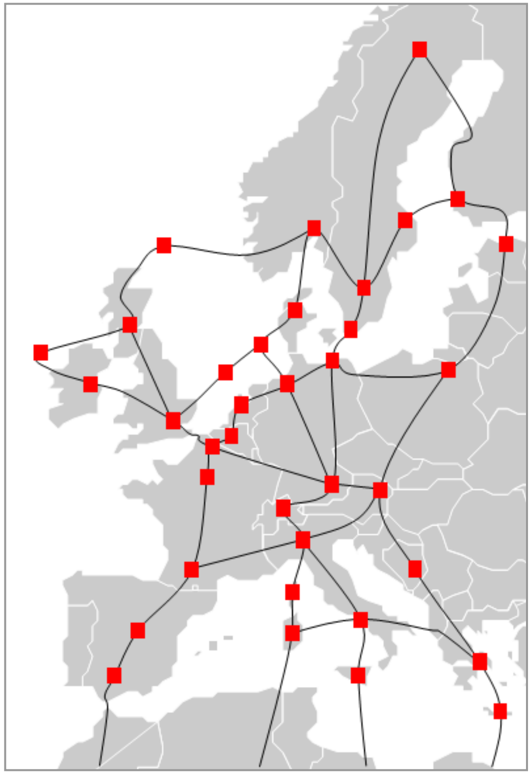


- *Regional DC Grid with optimized voltage level.*

- 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 unfaulted part of the system
  - HVDC breakers are not needed
  - Normally radial or star network configurations
  - *Limited power rating due to system impact*

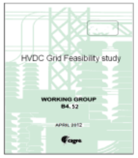
Can be built today with proven technology

What is an interregional HVDC Grid?



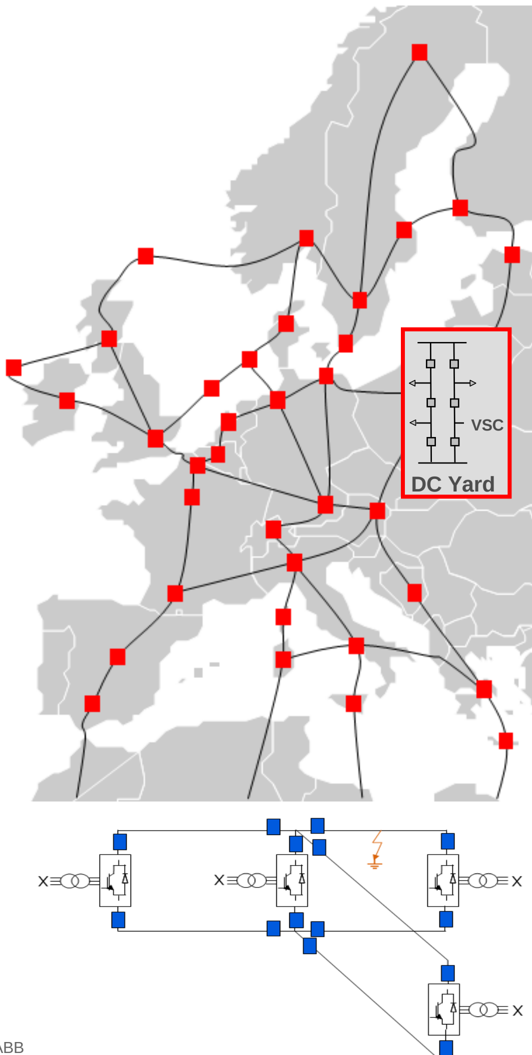
- An interregional HVDC grid is defined as a system that needs several protection zones for DC earth faults.
- *Development focus:*
  - HVDC breakers and fast protections
  - Grid Power flow control/Primary control: automatic control
  - Master control: start/stop, re-dispatching
- Long-term development, e.g.
  - High voltage DC/DC converters for connecting different regional systems
  - *On-going Cigré WG B4.52 ”HVDC Grid Feasibility study”*

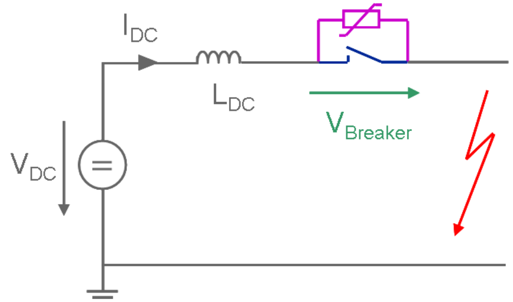
- *Regulatory issues* such as how to manage such new grids need to be solved.

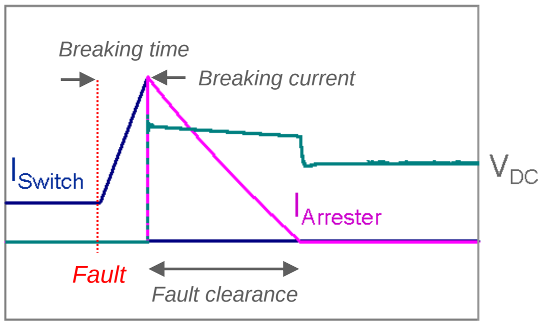


ABB

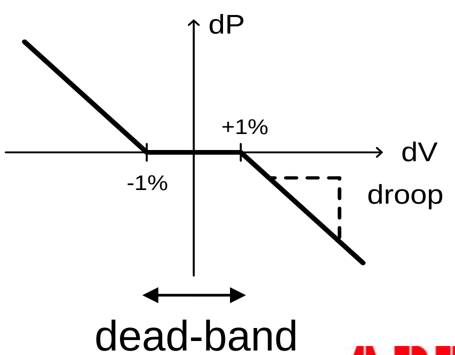
DC Grid Requirements
DC breaker for fast isolation, rebalancing control



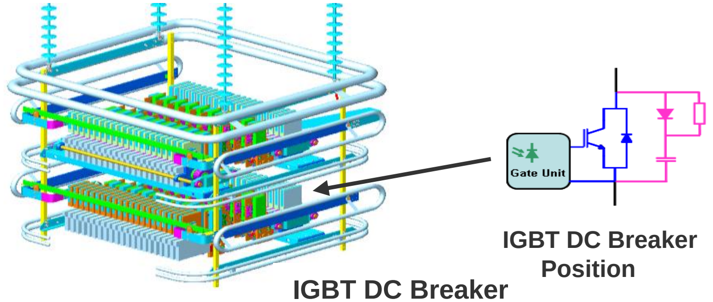


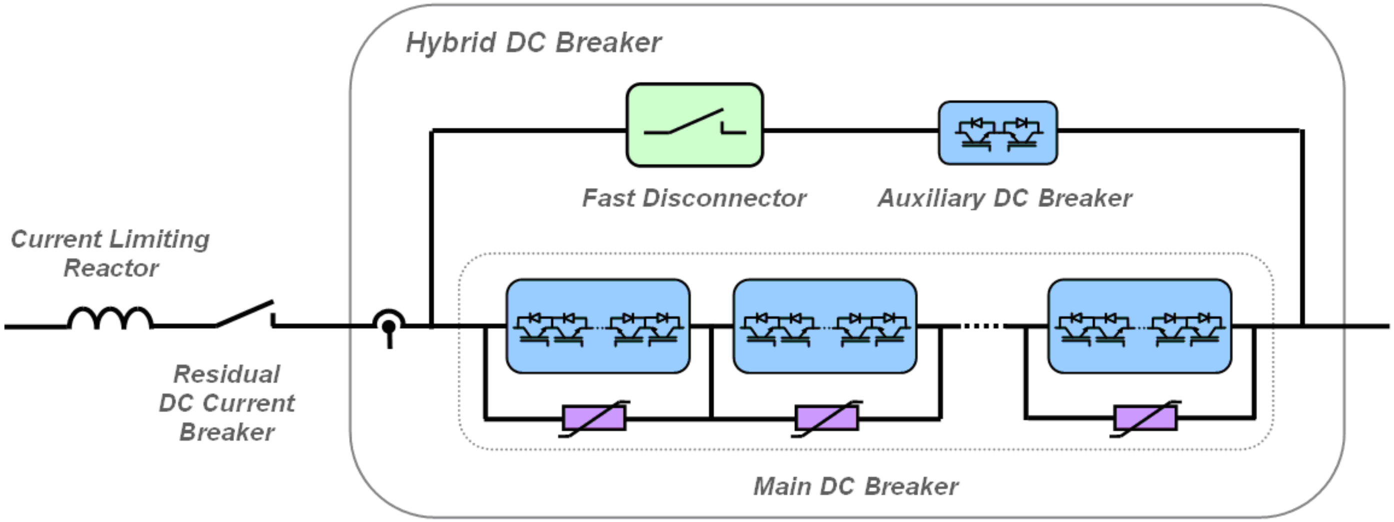


- Low surge impedance of cable based DC grids results in fast and deep fault penetration
- Fast isolation of faulted parts keeps DC voltage at reasonable levels to maintain operation of converter stations
- Fast DC Breakers with breaking times in ms range are required to avoid voltage collapse in DC grid
- Limit the consequences, droop control



Hybrid IGBT DC Breaker
Main Features



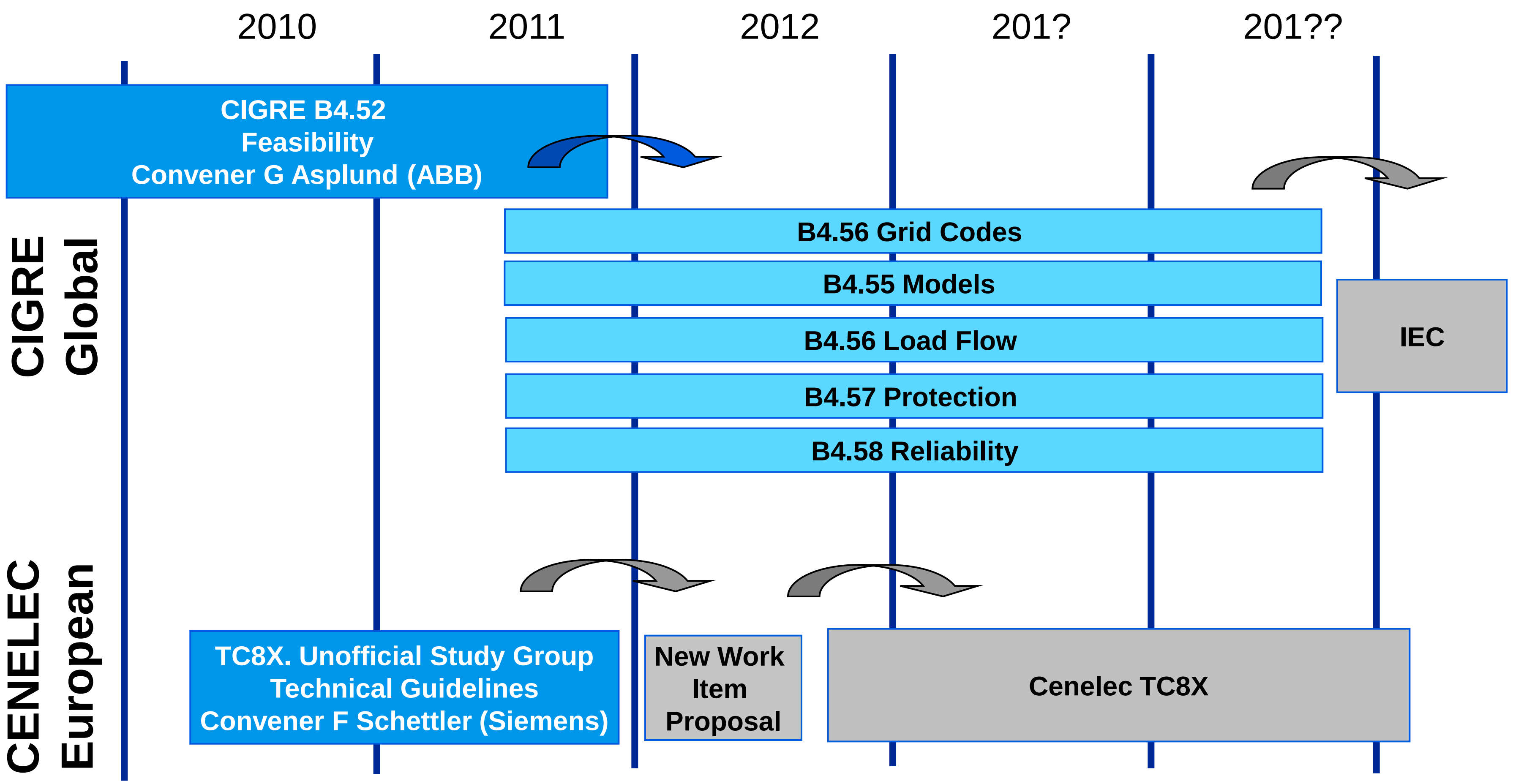


- Very low transfer losses in bypass, < 0.01% of transmitted power
- Fast protection without time delay if opening time of Fast Disconnector is within delay of selective protection (< 2ms)
- Immediate backup protection in DC switchyard
- Self protection due to internal current limitation
- In-service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

Ref. “Proactive Hybrid HVDC Breakers – A key innovation for reliable HVDC grids”, CIGRE, Bologna 2011, 264

HVDC grid standardization

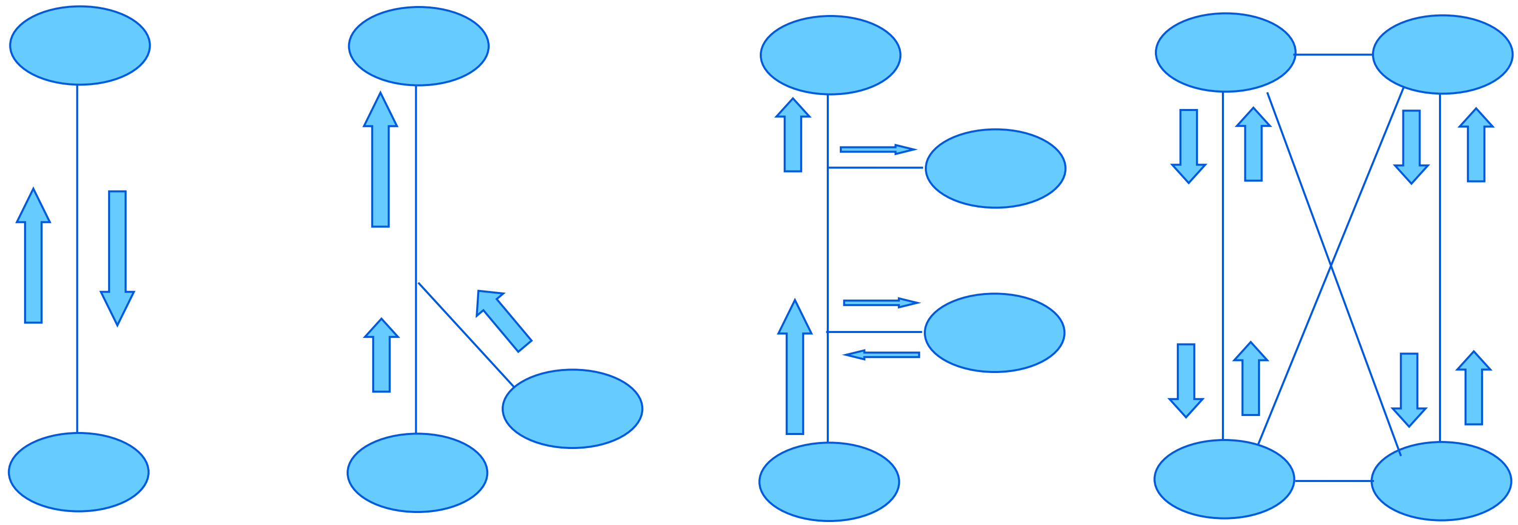
Multiterminal HVDC can be built today also without standards



No ANSI or Chinese standardization on DC grids open

Blue ongoing/starting. Grey in planning

HVDC evolution towards a DC grid
Introduction of dc protective zones requires breakers



Point-to-Point	Power in-feed	Tapping 10-20%	DC grid
Connection of asynchronous AC Networks	Connection of remote renewables	Tapping-off from long-distance DC-transmissions	Strong combined AC & DC grid. Redundancy

LCC Classic	YES 6 GW, 800 kV	YES 1 zone	YES with VSC taps	Very Unlikely
VSC Light	YES 1-2 GW, 320 kV	YES many zones	YES	Vision 2015+

Mahalo!