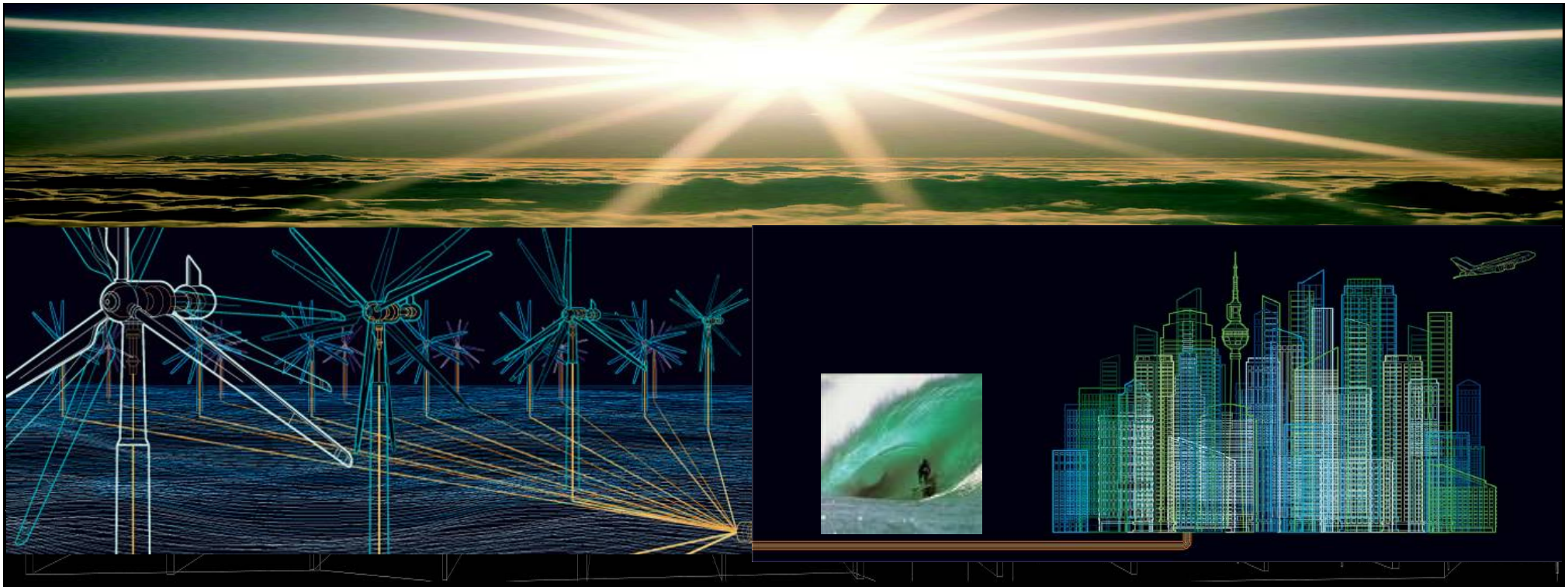


Michael Bahrman P.E., ABB Grid Systems, August 31, 2010, Asia Pacific Clean Energy Summit 2010, Honolulu

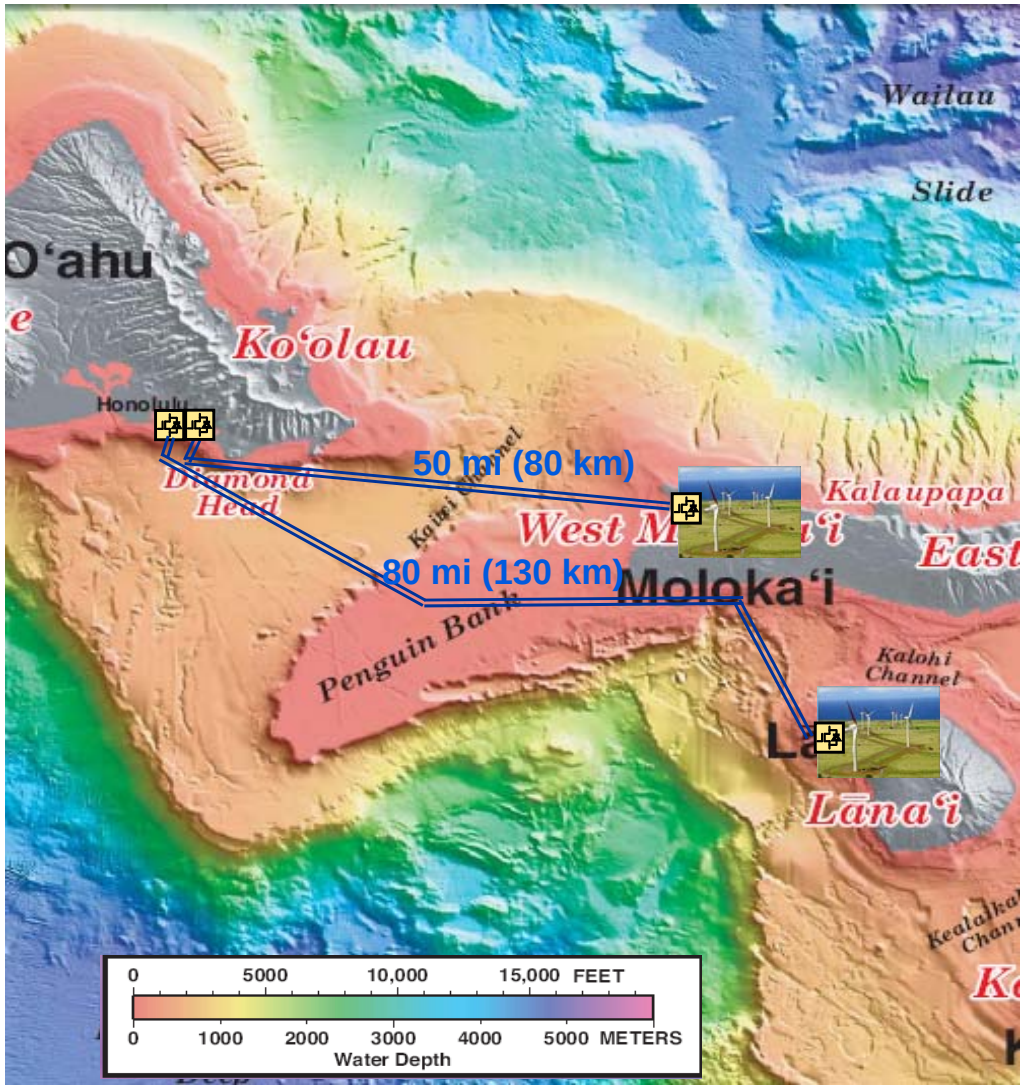
Integration of Variable Renewable Energy for Hawaii

Transmission of Isolated Resources

Transmission of Isolated Renewable Energy for Hawaii
Topics:

- Challenges
- Solution
- Enabling technologies
  - HVDC with voltage source converters
  - Extruded submarine cables
- System operation
- Project execution
- Experience
- Summary

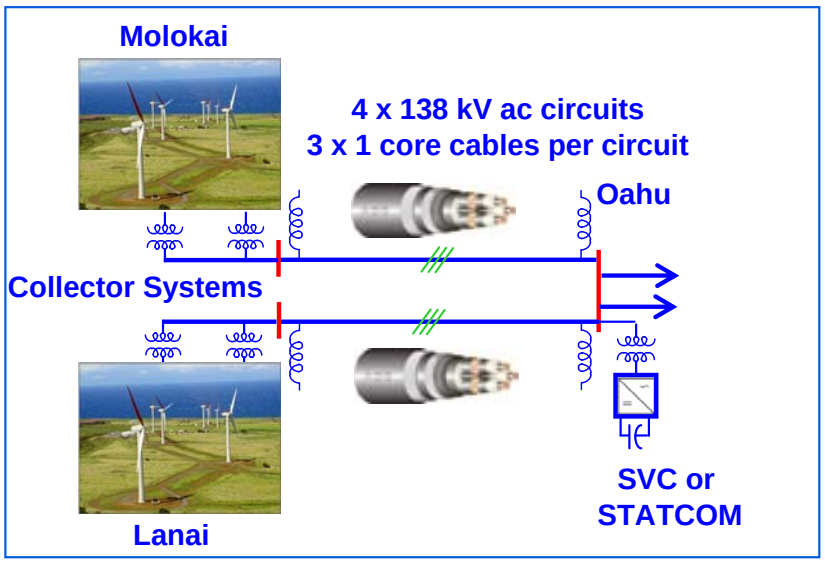
Challenges



Illustrative routes and terminations

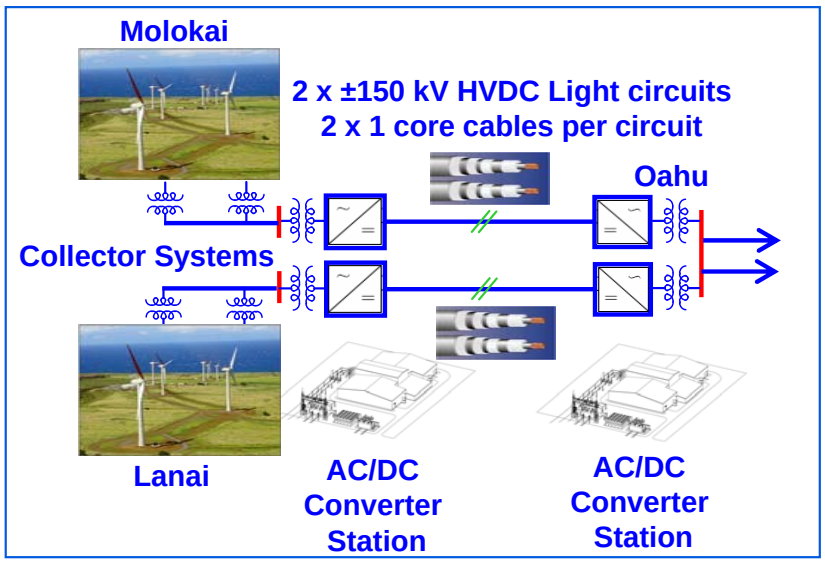
- Deliver 200 - 400 MW of wind power from Moloka'i and Lana'i to O'ahu
- Cable route distance in the order of 50 - 80 mi (80 – 130 km), laying restrictions
- Maximum ocean depths along routes in the order of 2100 ft (650 m)
- Isolated grids on Moloka'i and Lana'i
- High percentage of wind power penetration on O'ahu (~ 1200 MW load)
- Meet the voltage, stability and ride through requirements of the grid code
- Congested landing sites on O'ahu

Potential Submarine Cable Solutions
2 x 200 MW steady state capacity, d > 50 mi (80 km)



AC with reactive power compensation

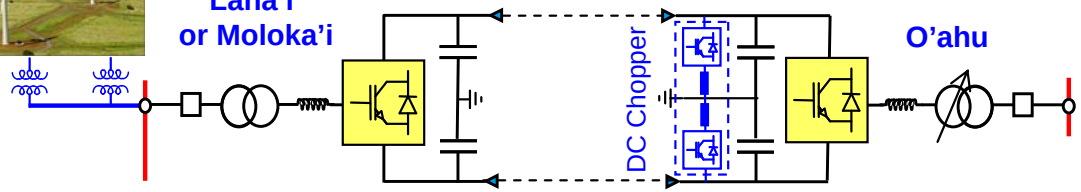
- Capacity decreases with distance due to charging
- Three heavier cables per circuit, more circuits for power level and distance
- No segmented conductors for sea cables, limiting
- Heavier cables can restrict laying in deep waters
- Requires static & dynamic reactive compensation
- Issues with ride-through, recovery, stability, start-up
- **Not practical for Oahu wind integration!**



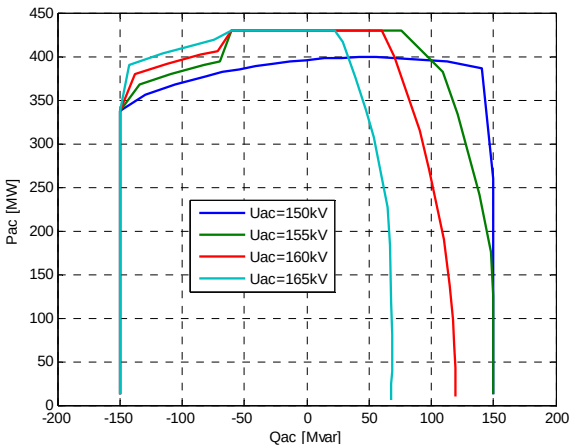
HVDC with voltage source converters (VSC)

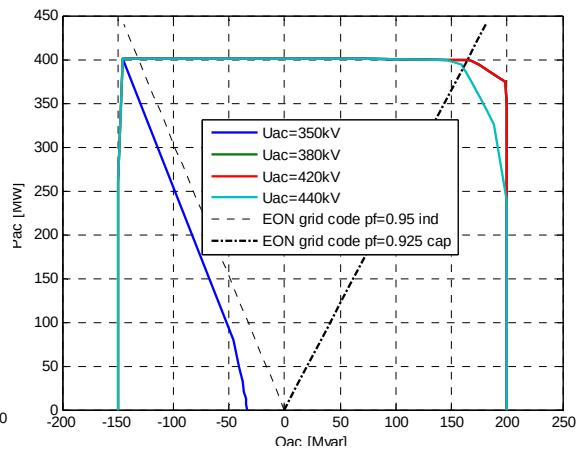
- No charging current or power decrease with distance, can transfer the entire 400 MW on one circuit
- Two cables per circuit, lighter, less expensive
- No need for reactive power compensation
- Meets ride-through requirements
- Easier start-up, black start, improved stability
- **Clear choice for Hawaii inter-island!**

O’ahu Wind Integration and Transmission
Wind plant operation is similar to offshore application



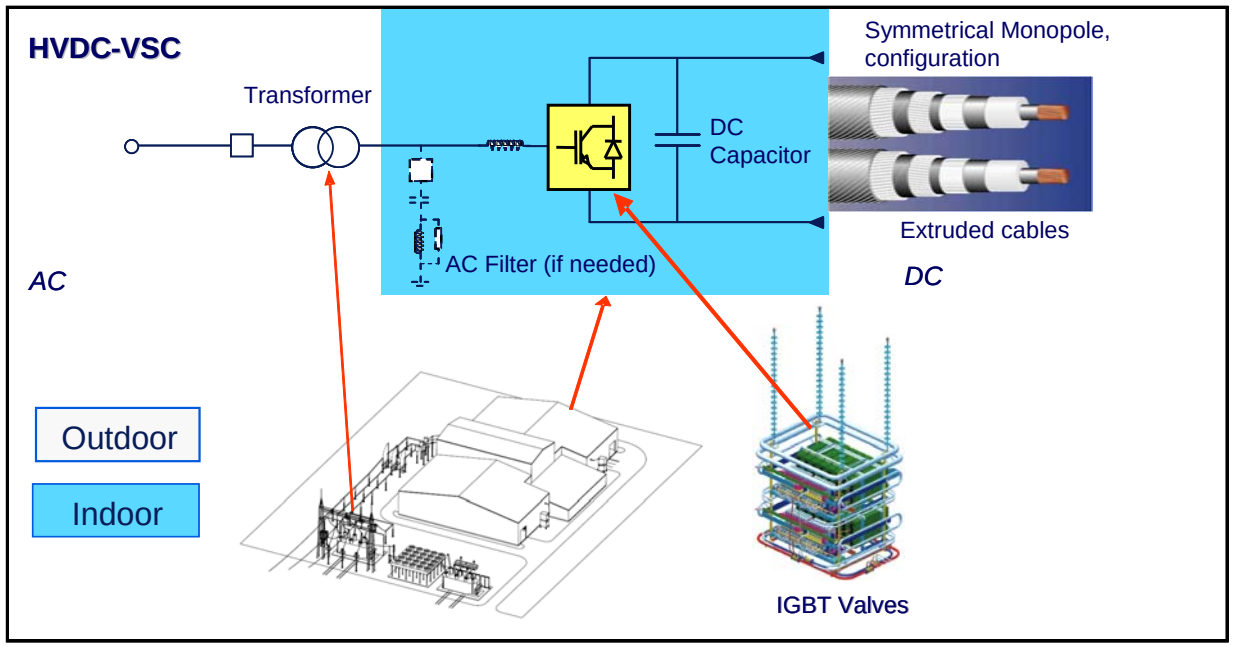
- Isolated wind plants on Moloka’i or Lana’i behave as an offshore application
- VSC converter at wind plant controls frequency and ac voltage
- VSC converter on O’ahu controls dc voltage and reactive power
- System can back-feed wind plant to provide excitation, auxiliary and start-up power at zero wind speed
- DC chopper absorbs power during faults on grid, avoiding generation overspeed
- Acts as buffer so less ride-through requirements imposed on wind plant
- DC link follows output of wind park via frequency control or by dispatch order

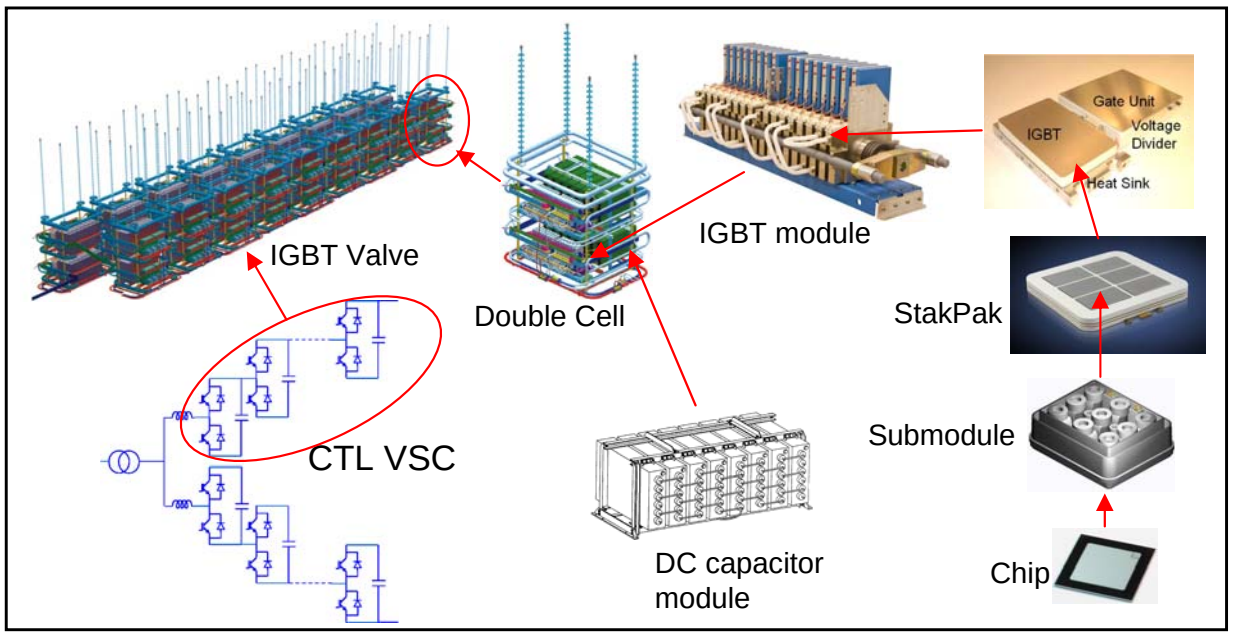




Typical Power, Reactive Power Characteristics

Technology: HVDC with Voltage Source Converters

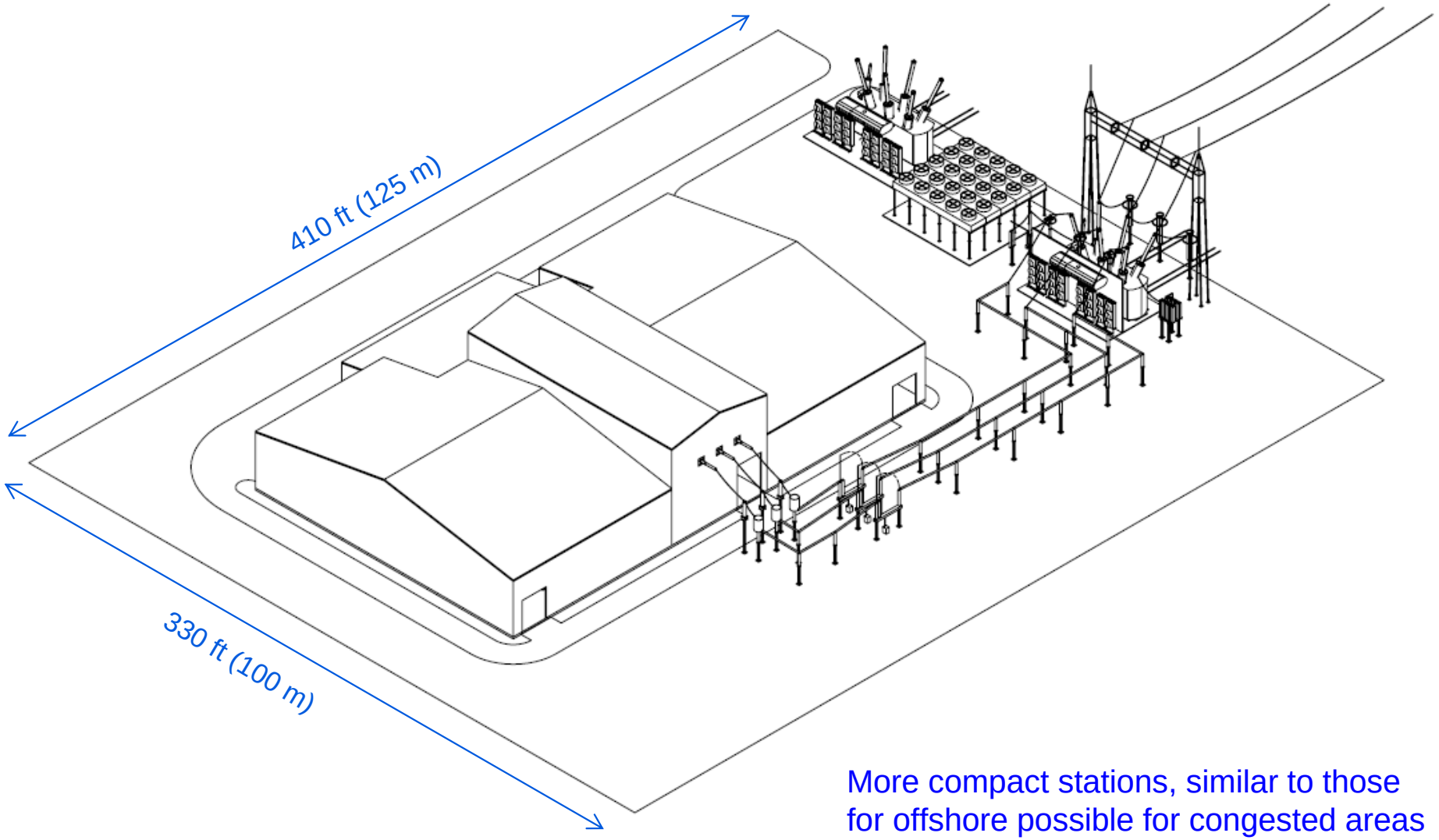




HVDC Light – 4th generation

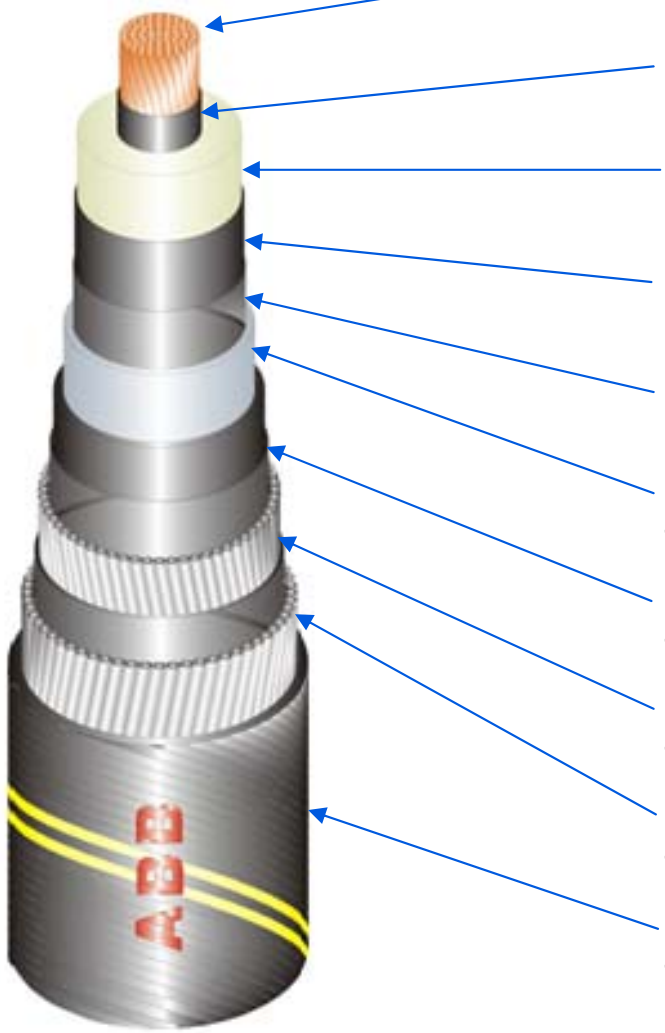
- Voltage source converter (VSC)
- Self-commutated IGBT valves
- No reactive power demand
- No harmonic filters unless required by stringent criteria
- Dynamic voltage support
- Radial wind generator outlet regardless of type of WTG
- Ride-through, black-start
- Cascade two-level converters
- DC capacitor modules
- IGBT valve modules
- StakPaks with safe short circuit failure mode
- Chips in submodules

HVDC Light Converter Station
400 MW, ±150 kV dc, 3.1 acre (1.25 hectare)



More compact stations, similar to those for offshore possible for congested areas

Submarine Cable



Conductor
Type/material — copper, profiled strands

Conductor screen
Material — semi-conductive PE

Insulation
Material — HVDC Light

Insulation screen
Material — semi-conductive PE

Longitudinal water barrier
Material — swelling tape

Metallic sheath
Type/material — extruded / lead alloy

Inner jacket
Type/material — high-density PE

Inner tensile armoring
Type/material — wire/steel

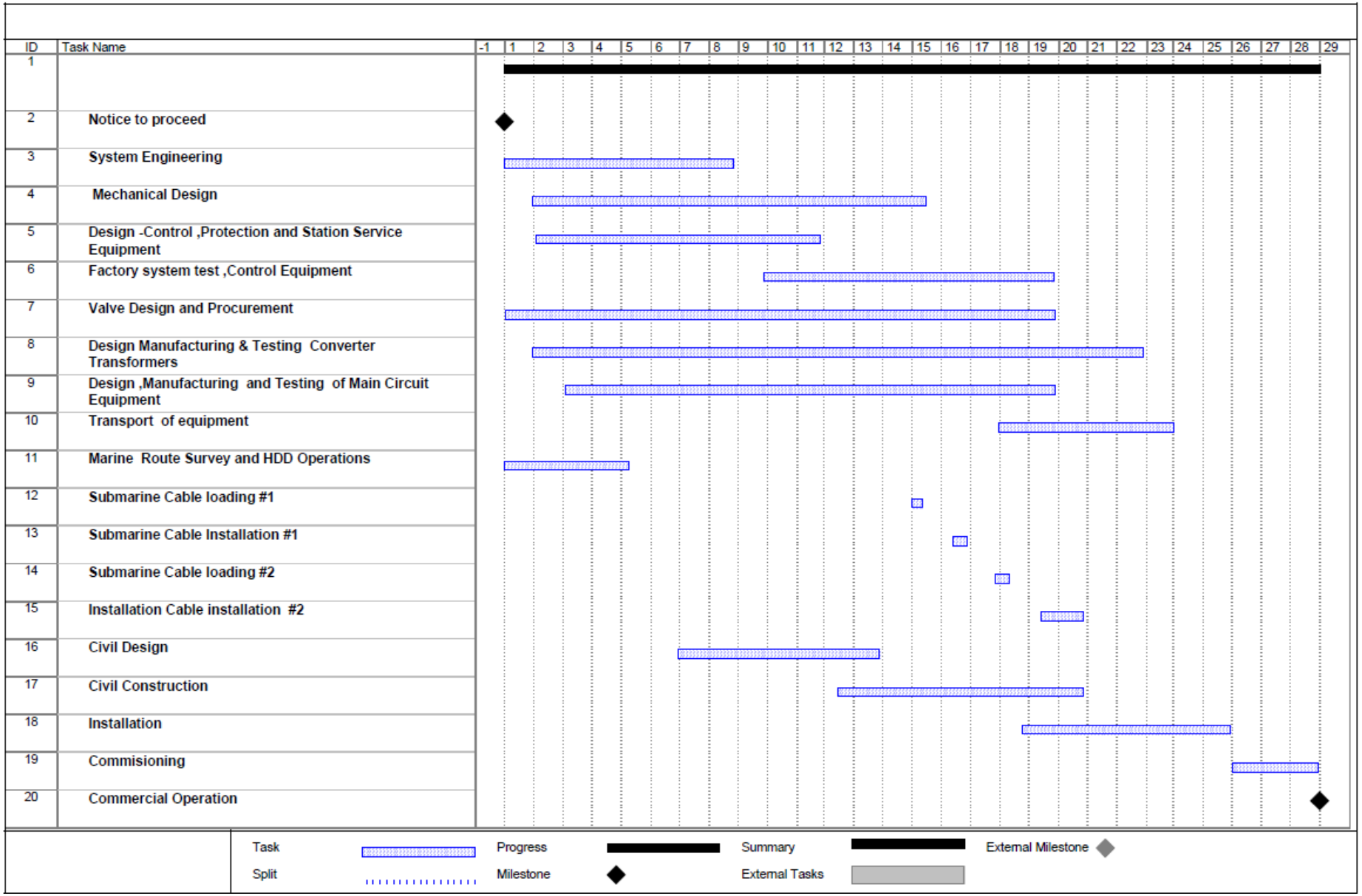
Outer tensile armoring
Type/material — wire/steel

Outer cover
Type — polypropylene yarn, 2 layers

Operation
Attributes of HVDC Light for integrating renewables

- Wind following with voltage and frequency control
- Dispatchable
- Dynamic reactive power capability for voltage control to support the ac grids at both terminals regardless of wind speed
- No reactive compensation needed for lines, cables or converters
- Ease of start-up, supply exciting and aux power to wind plant
- Rides through grid disturbances, decouples wind plant from main grid decreasing exposure and allows more flexibility in selection of type of wind turbine generators
- Minimal fault current contribution to grid, controllable
- Wind plant disturbances, e.g. energization transients and flicker isolated from main grid

Typical Project Schedule Overview
Early Finish



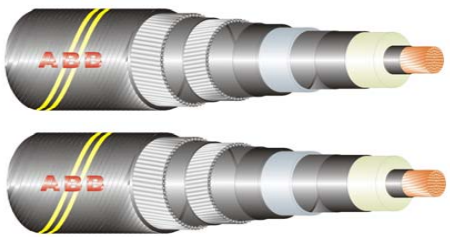
Submarine Cables
Installation Steps



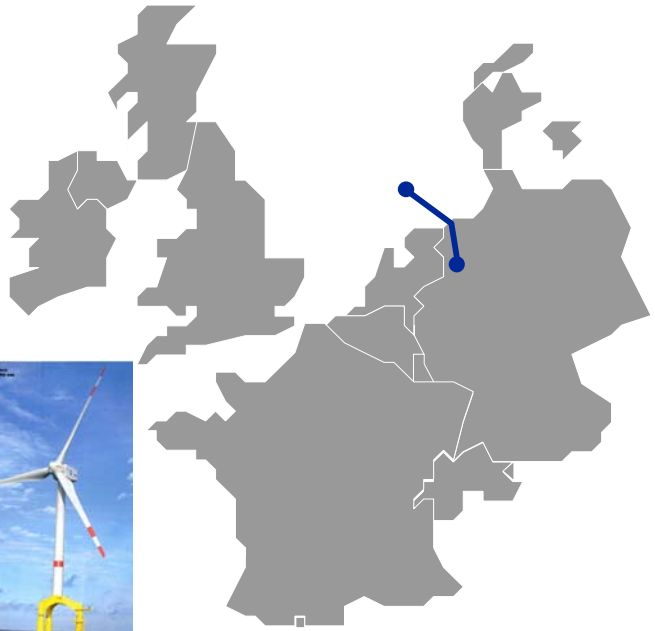




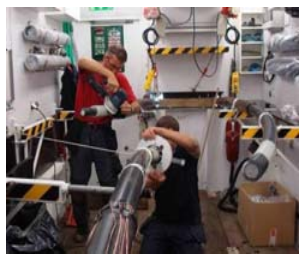

- Cable loading and transport
- First end pull to land, typically through horizontal directional drill (HDD)
- Laying and plowing (if applicable)
- Crossings (other cables or pipelines)
- Second end float to land
- Cable termination or transition splice to underground cable
- Lay down of protection if applicable
- Cable testing



BorWin1 HVDC Offshore Wind Power Connector
400 MW, ±150 kV dc



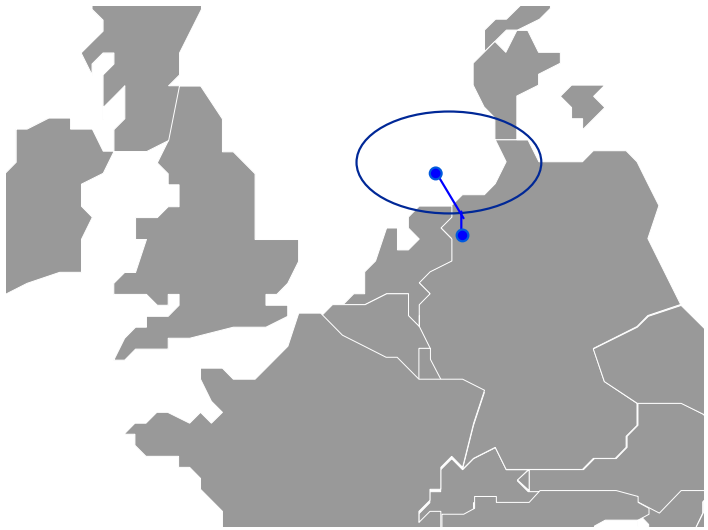
- First HVDC Offshore Wind Power Outlet
- 200 km cable connection (125 km sea, 75 km land)
- Turnkey supply including buildings and platform
- Contract – September 2007
- Completion – November 2009

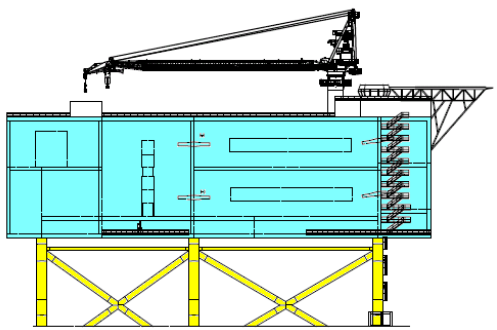


DolWin1 Offshore Wind Power Connector
800 MW, ±320 kV dc

Customer:
transpower

Year of commissioning:
2013

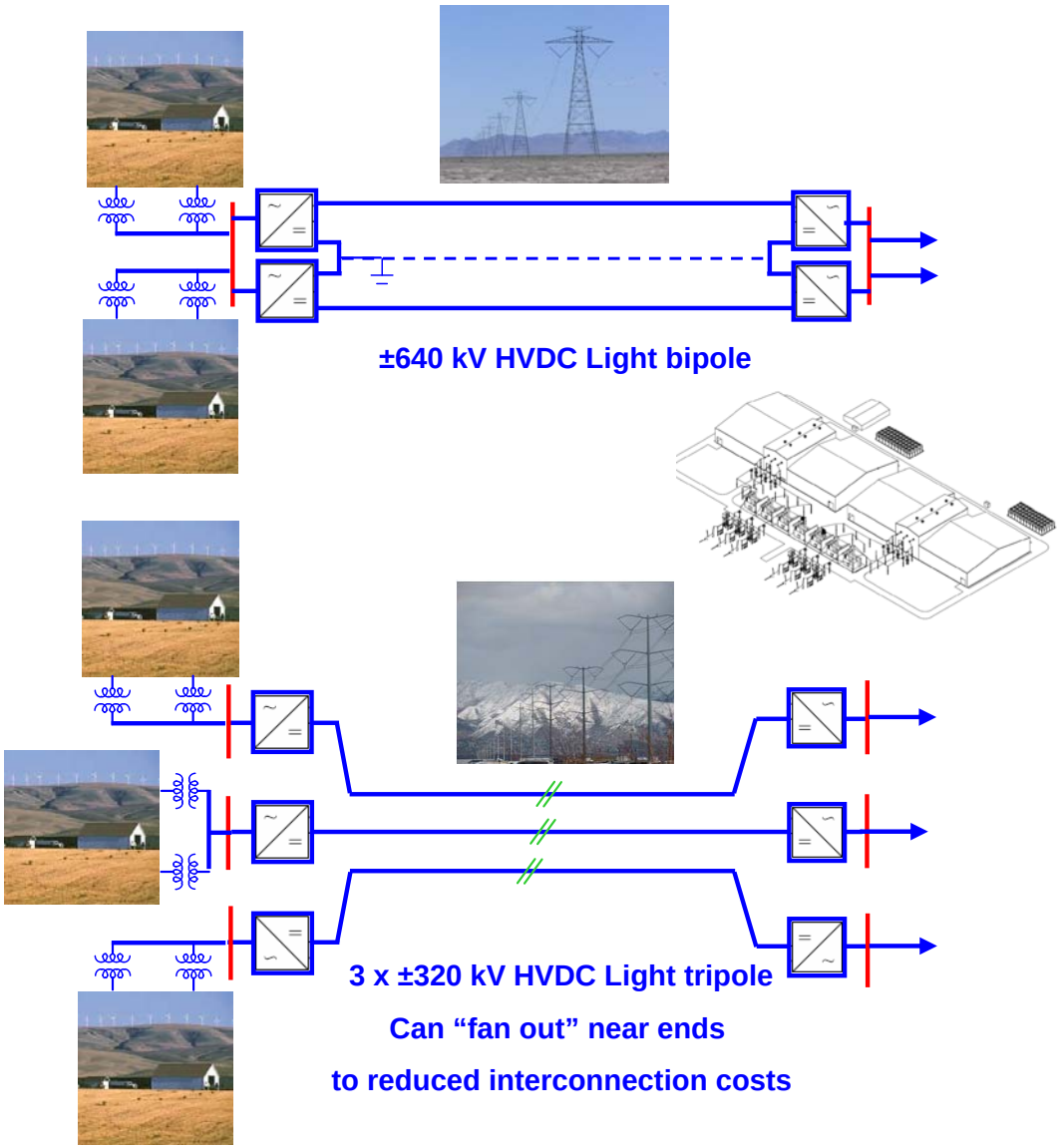




- 165 km long subsea and underground power connection to offshore wind farm
- Robust grid connection
- Turnkey 800 MW HVDC Light system
- First ± 320 kV extruded cable delivery
- Invisible, environmentally friendly power transmission
- Low losses and high reliability
- Reduce CO_2 emissions by 3 million tons per year replacing fossil-fuel generation
- Supports wind power development in Germany

14th HVDC Light project, 4th with wind, 4th offshore, proven black start

HVDC Light Solution Also Adaptable for Overhead 2000 - 3000 MW Capacity



- HVDC Light also applicable for transmission from isolated or weakly interconnected renewable resources
- Controllable, no parallel flow issues, more firm
- No reactive power demand for outlet transmission
- Dynamic reactive power support for wind plants, collector system and receiving grid
- Fault ride through

Summary

- HVDC submarine cable for distances > 50 km or for power levels > 300 MW
- HVDC Light (VSC technology) is the enabling technology for generator outlet transmission from large scale wind plants isolated or weakly interconnected to the grid
  - Ride-through
  - Black start
  - Wind following
  - Voltage support
  - Maximize wind plant output
  - Technology is proven and mature
- Can be combined with energy storage to smooth out rapid decreases in wind power and with advanced wind plant controls

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