

HVDC as Enabling Technology for Electricity Markets

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RBJ Engineering Corporation

HVDC Overview

Role of HVDC

- Long distance transmission and asynchronous system inter-connections
- Enhanced power system operation with interconnections and integration of renewable generation

Two Parallel Technology Paths

- Mature and Growing Thyristor based LCC HVDC
- Developing and Growing IGBT and IEGT based VSC HVDC

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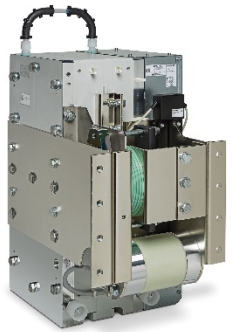

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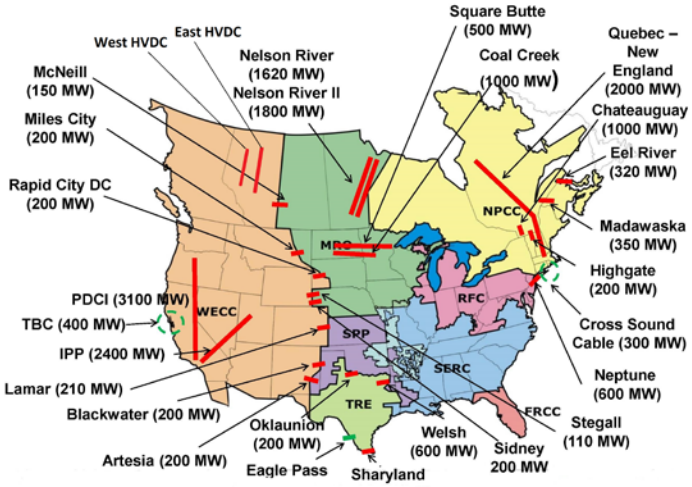
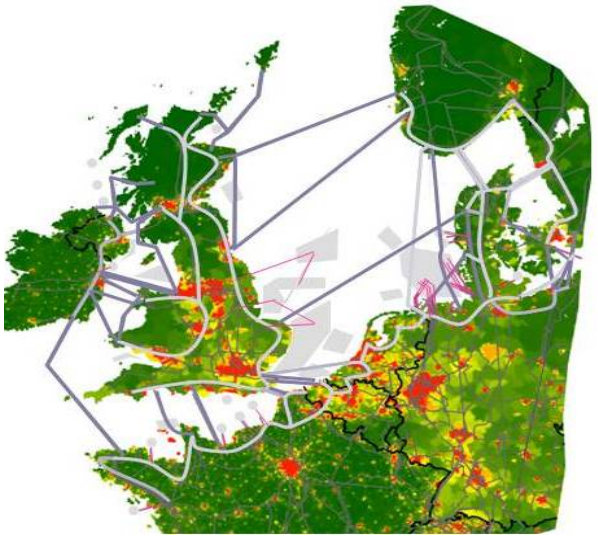
HVDC Technologies

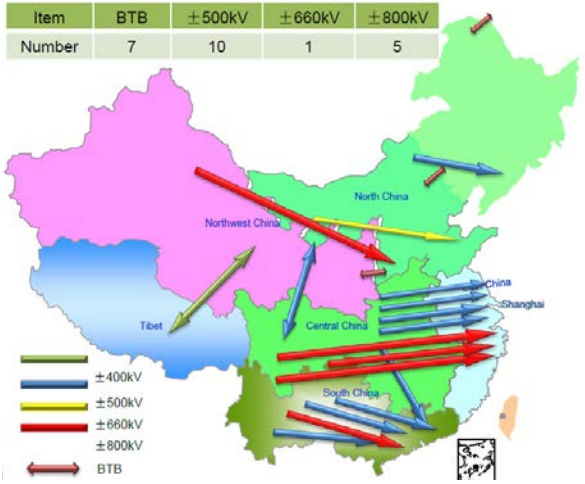
Technology	Line Commutated Converter (LCC)	Voltage Sourced Converters (VSC)
Semiconductor	Thyristor (Turn on only)	IGBT (Turn on/off)
Ratings	High DC Voltage and Power	Lower DC Voltage &Power
Power Control	Active Power	Active & Reactive Power
AC Filters	Required	Not Required (MMC)
Minimum SCR	>2	0
Black Start Capability	No	Yes
Overload	High inherent overload capabilities	Normally not unless specified
Footprint	Larger site (More space required for harmonic filters)	Compact, 50-60% of LCC
Configurations	Monopole, Bipole, Symmetric monopole	Symmetric Monopole, Asymmetric Monopole, Bipole, Multi-terminal
Application	Point-to-Point, Back-to-Back Multi-terminal	Point-to-Point, Back-to-Back Multi-terminal, HVDC Grid

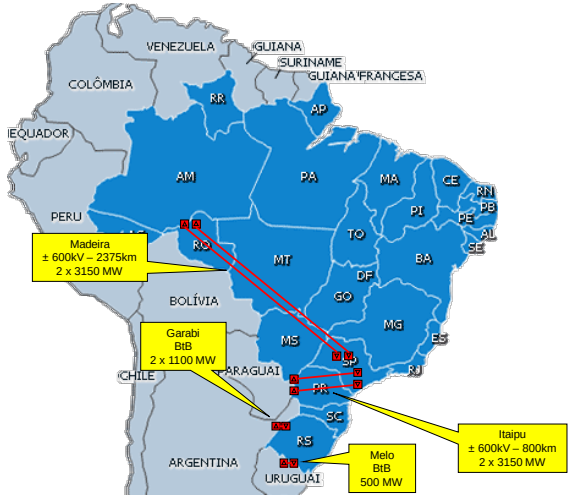
HVDC Projects

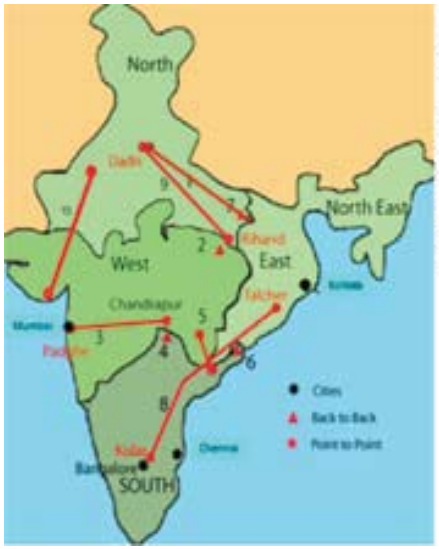




Item	BTB	±500kV	±660kV	±800kV
Number	7	10	1	5







1 – Rihand-Dadri (1500MW)
2 - Vindyachal (500MW)
3 - Chandrapur-Padghe (1500 MW) (MSEB)
4 - Chandrapur-Ramagundam (1000MW)
5 – Barsoor-Lower Sileru (100MW)
6 – Gajuwaka 1 & 2(500MW each)
7 - Sasaram (500MW)
8 - Talcher-Kolar (2500MW)
9 – Balia – Bhiwadi (2500 MW)
10- Mundra-Mahendragarh (2500 MW) (Adani Power)

HVDC Enable Integration of Electric Power Market

Global environmental concerns require more efficient and cleaner power generation and transmission

Growing Exploitation of Renewable energy resources

Large-scale energy trading & a growing share of fluctuating renewable energy

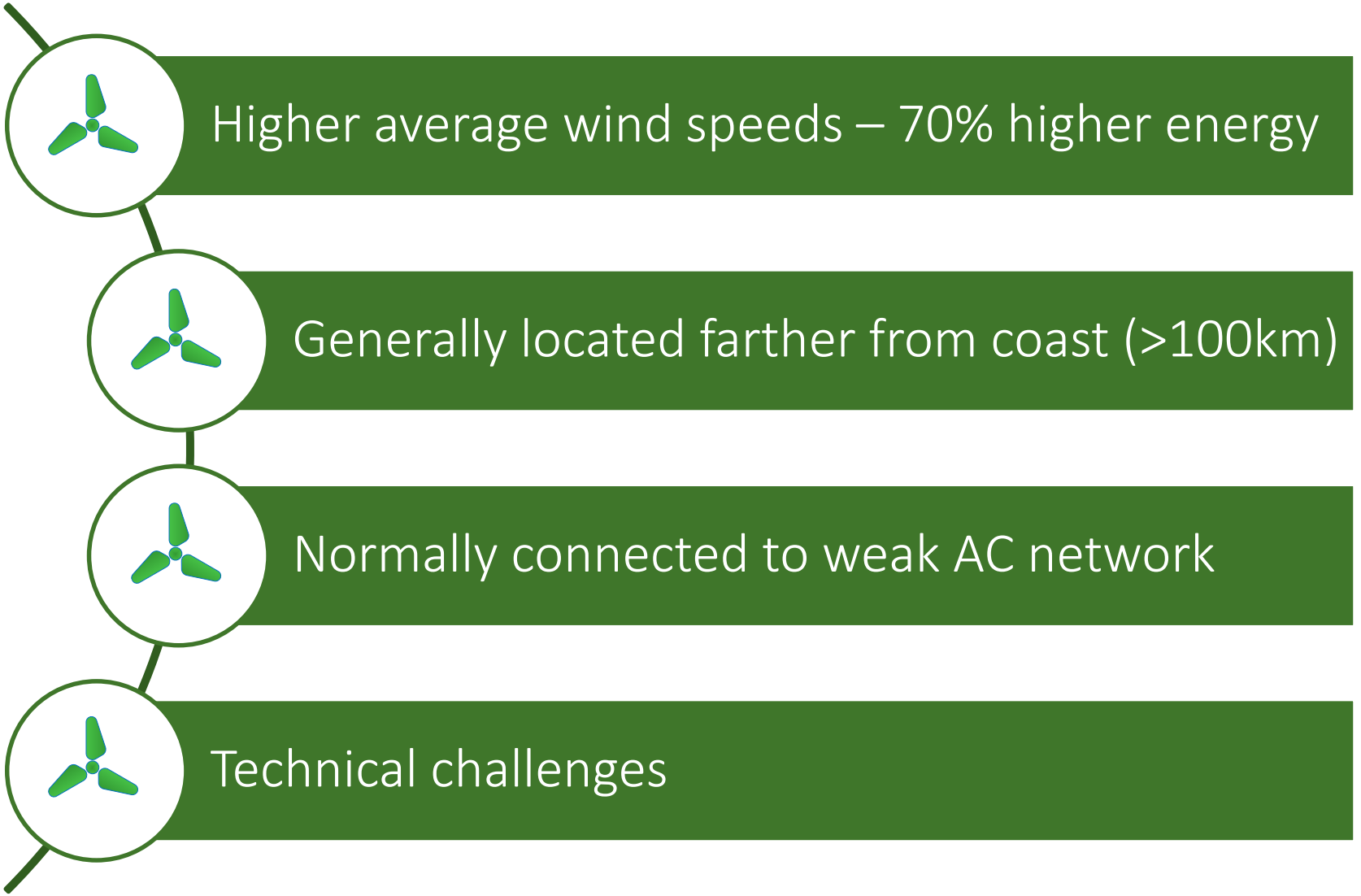
Renewable resources are frequently located far away from load centers and existing transmission system

HVDC Technology is suited to integrate Renewable Energy Resources into Power Systems

HVDC – Suitable to Integrate Renewable Energy

- Lower line/cable investment cost
- Lower losses
- Asynchronous interconnections
- Better Controllability
- Limited short circuit current contribution
- Environment benefits such as power balancing, reduced right-of-way for same amount of power transfer

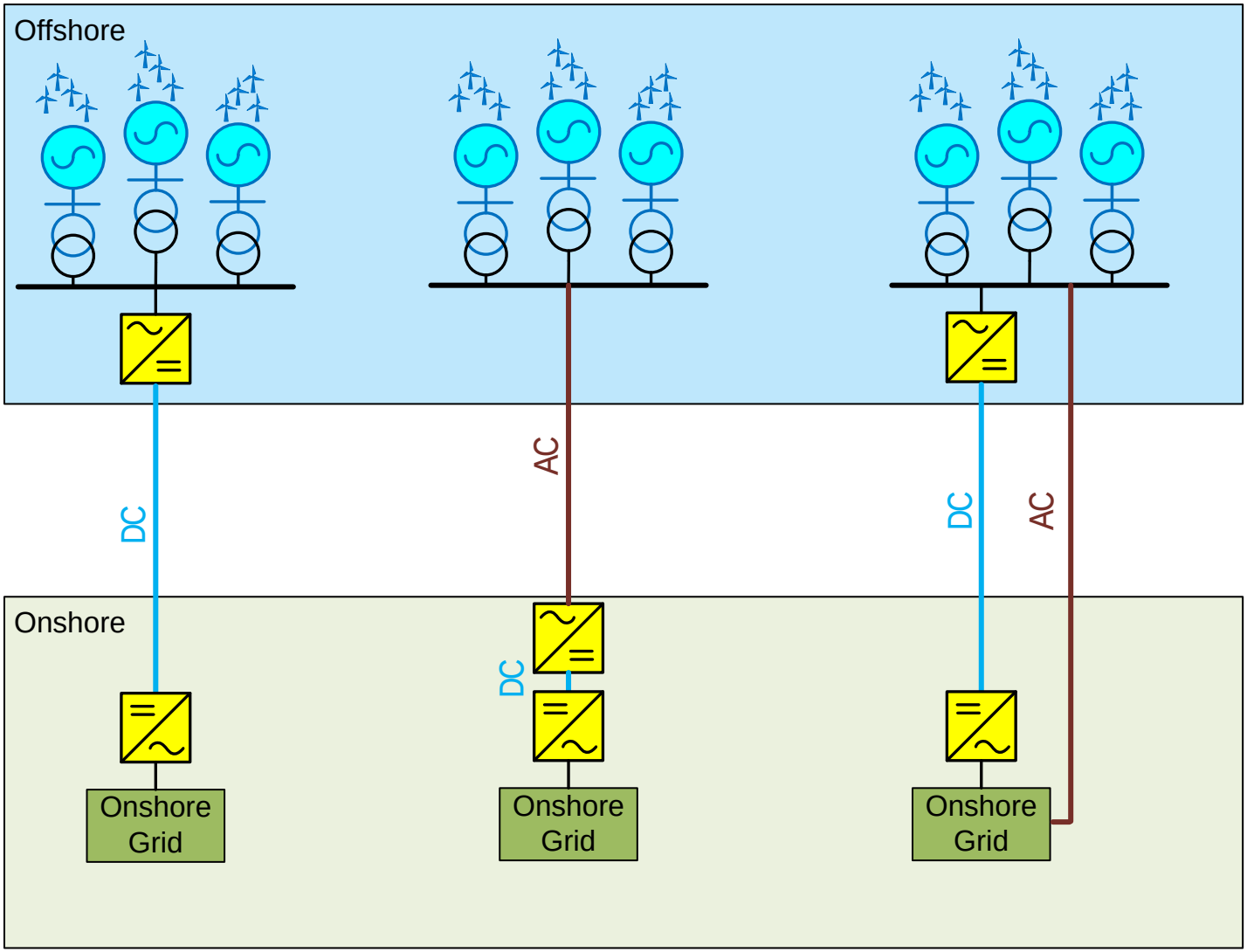
Growing Offshore Wind Power



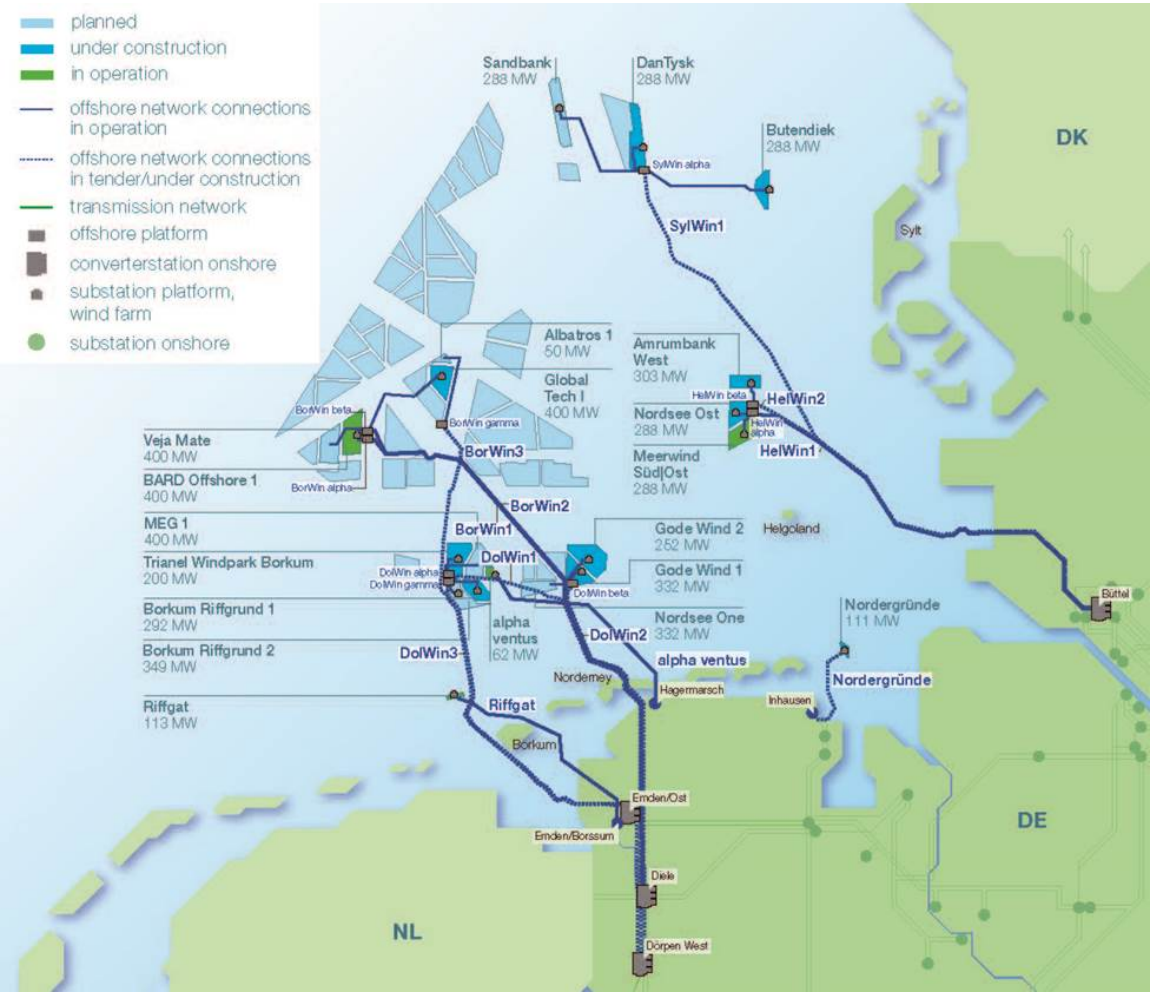
VSC-HVDC for Offshore Windfarm Connection

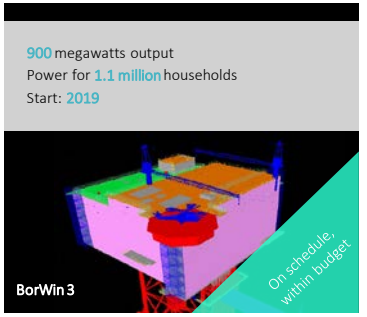
- Ability to transfer power in both directions
- Easy Integration with Wind Turbine Generators in islanded grids with very low short circuit strength
- Normally, no need for harmonic filters and additional reactive power resources
- Improved performance during onshore disturbance
- Black-start capability
- Allow building compact, partially or fully tested and assembled, converter station on shore
- Ability to utilize XLPE cables
- Expansion to future multi-terminal grids

Connection Schemes



Existing/Planned Offshore Wind Connected by VSC HVDC (North Sea)

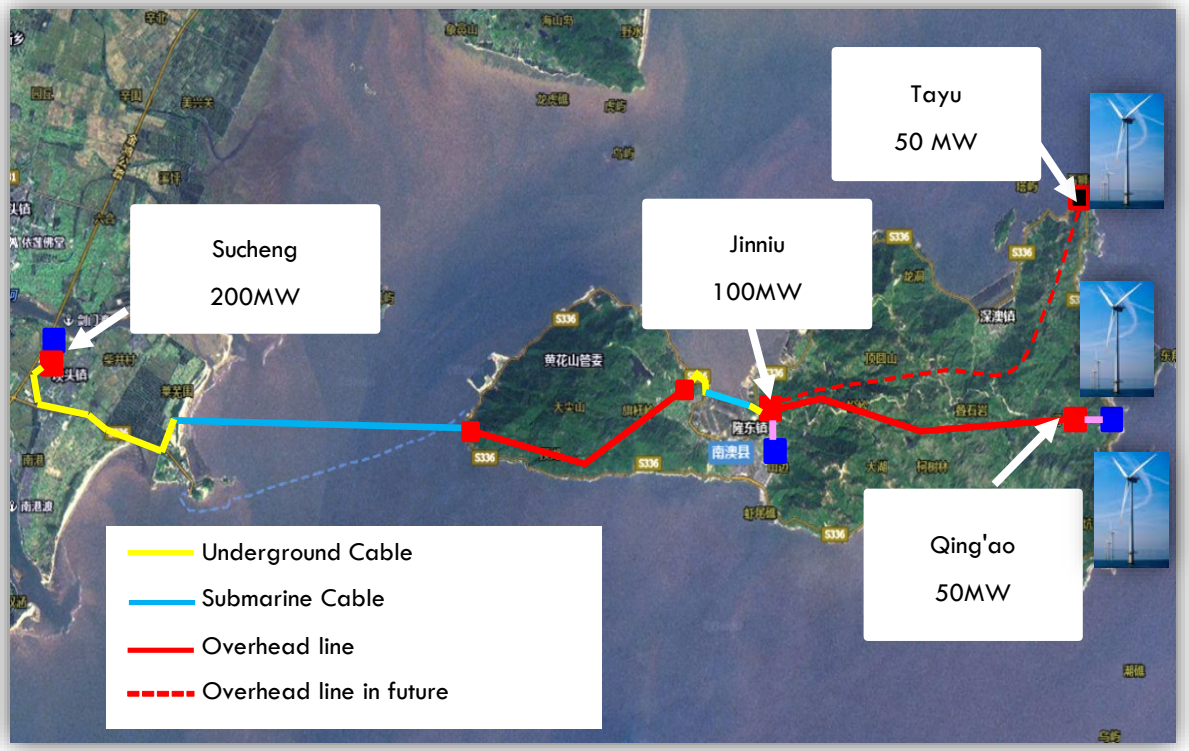




Existing/Planned Offshore Wind Connected by VSC-HVDC (North Sea)

Application	Rating (MW)	DC Voltage (kV)	AC Voltage (kV)		HVDC Cable (km)		In Service Year
			Offshore	Onshore	Submarine	Ungrounded	
BorWin1	400	±150	154	380	2x125	2x75	2009
DolWin1	800	±320	155	380	2x75	2x90	2015
Borwin2	800	±300	155	400	2x125	2x75	2015
HelWin1	576	±250	155	400	2x85	2x45.5	2015
SylWin1	864	±300	155	400	2x159	2x45.5	2015
HelWin2	690	±320	155	400	2x85	2x45.5	2015
DolWin2	900	±320	155	380	2x45	2x90	2015
DolWin3	900	±320	155	400	2x85.4	2x76.5	2018
BorWin3	900	±320	155	400	2x130	2x30	2019

VSC Project - Renewable Energy Integration
Nan'ao ±160 kV VSC-MTDC Project



Stabilizing 200MW wind power output on the island and eliminating wind curtailment

200MW

Up to May, 2016, 463 million kwh wind power in total is transported to the main land

463 million kwh

Features

- **The first multi-terminal VSC-HVDC project**
- **Wind Energy** of Nan'ao island is transported to mainland power grid **by AC and DC lines in parallel**
- Commissioned in 2013

Major Parameters

±160 kV, 200/100/50/50MW

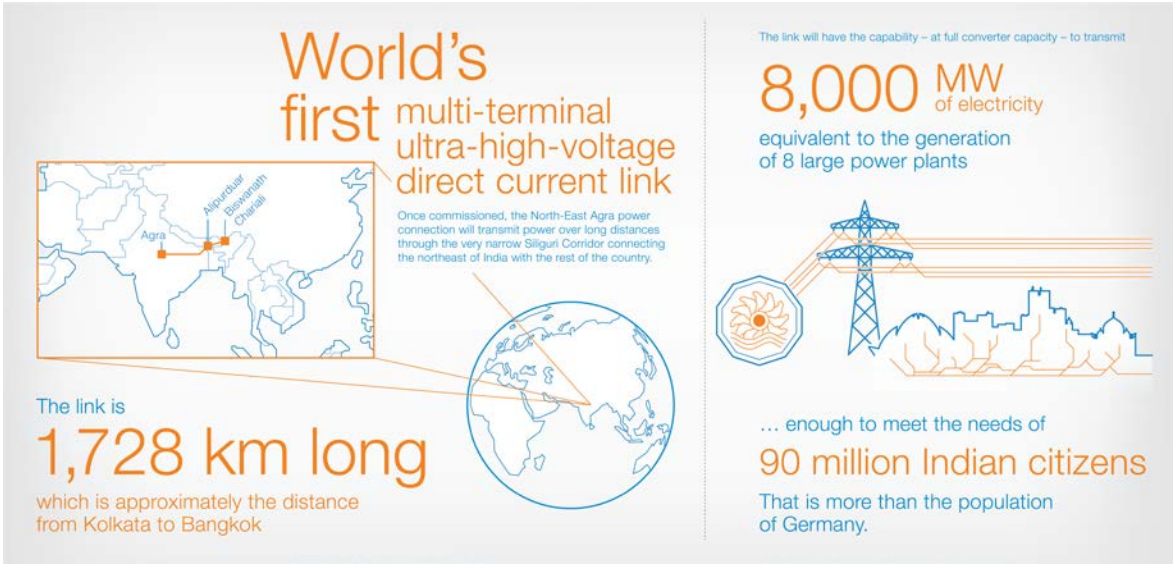
Overhead Line (20.6km in total),
Underground Cable (9.5 km),
Submarine Cable 10.7 km

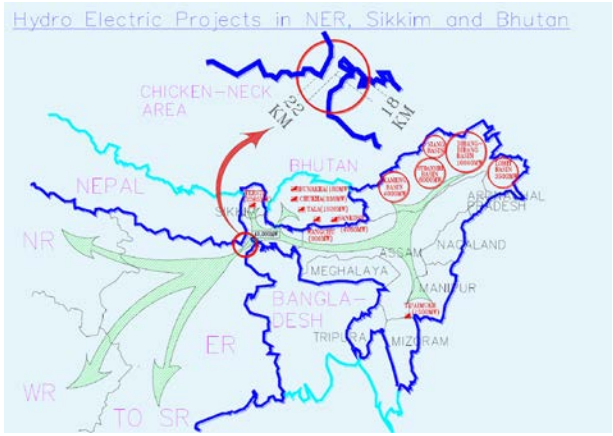
Bulk Onshore WPPs Integration using LCC-HVDC

- High reliability and availability
- Low losses
- High power ratings
- Rapid clearing of DC line fault currents
- Large onshore wind power plants are connected to the AC system
  - **to deliver wind power into the local AC systems**
  - **to supply auxiliary power for the wind power plant/ collector system in times of no wind**
- No stringent requirement for black-start capability

Multi-terminal LCC Project – North – East Agra UHVDC Link

Connecting power from the Northeast region with the rest of India

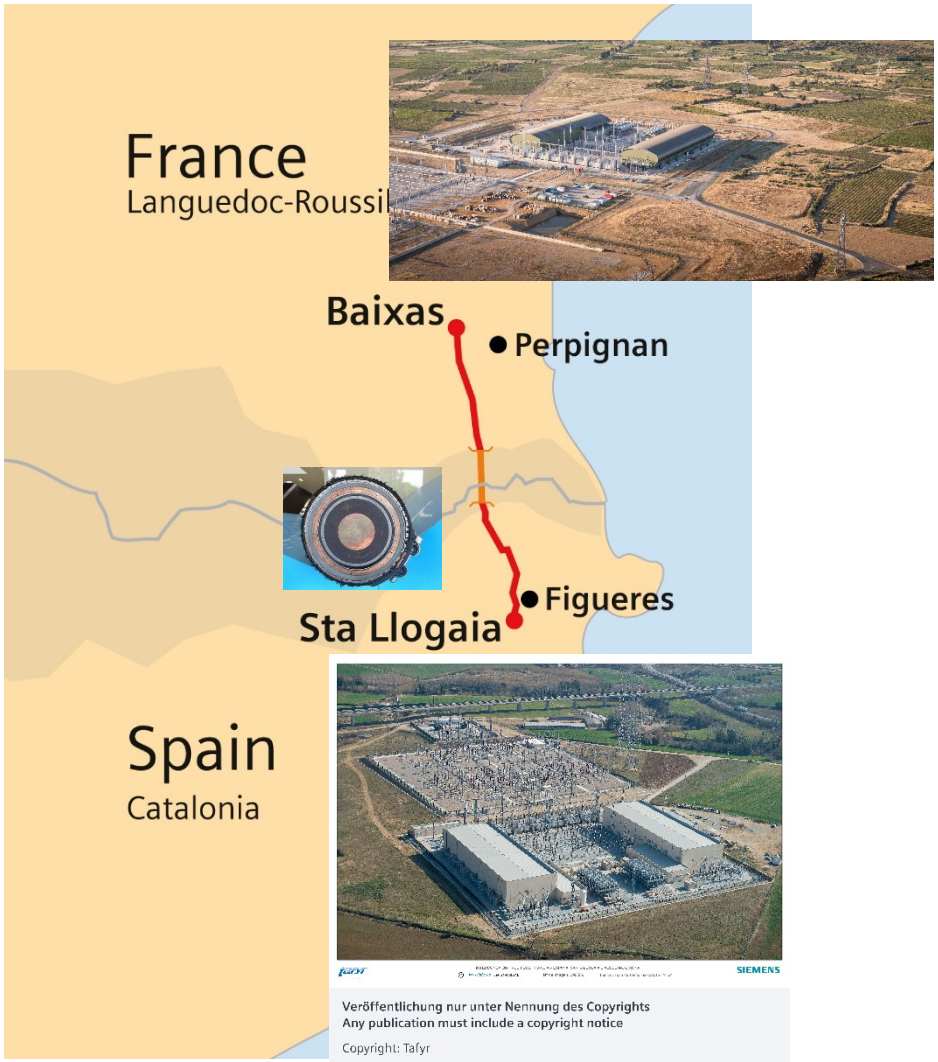




Location	Biswanath Chariali, Alipurduar, Agra
Power Rating	6000MW
DC voltage	±800kV
AC voltage	400kV
Length	1728km
	Ground electrodes

Curtesy to CBIP & ABB

VSC HVDC Project – INELFE –Milestone towards a Single EU Energy Market



Customer	INELFE (RTE and REE)
Project Name	INELFE
Location	Baixas, France – Santa Llogaia, Spain
Power Rating	2 x 1000 MW
Type of Plant	HVDC PLUS
Voltage Levels	± 320 kV DC AC 400 kV, 50 Hz
Distance	65 km underground cable
Semiconductors	IGBT

Curtesy to Siemens

LCC-VSC Project - Regional AC-Grid Support

Luxi Parallel VSC & LCC BTB HVDC Project

Features

- **Asynchronous interconnection between Yunnan and the Main grid for grid support in emergency**
- **Highest voltage level and power rating for BTB VSC-HVDC project in the world**
- **Parallel LCC & VSC BTB converters at the same station**
- **Plan to commission in 2016**

Major Parameters

- **VSC: ±350 kV 1000 MW**
- **LCC: ±160 kV 2×1000 MW**

HVDC Outlook

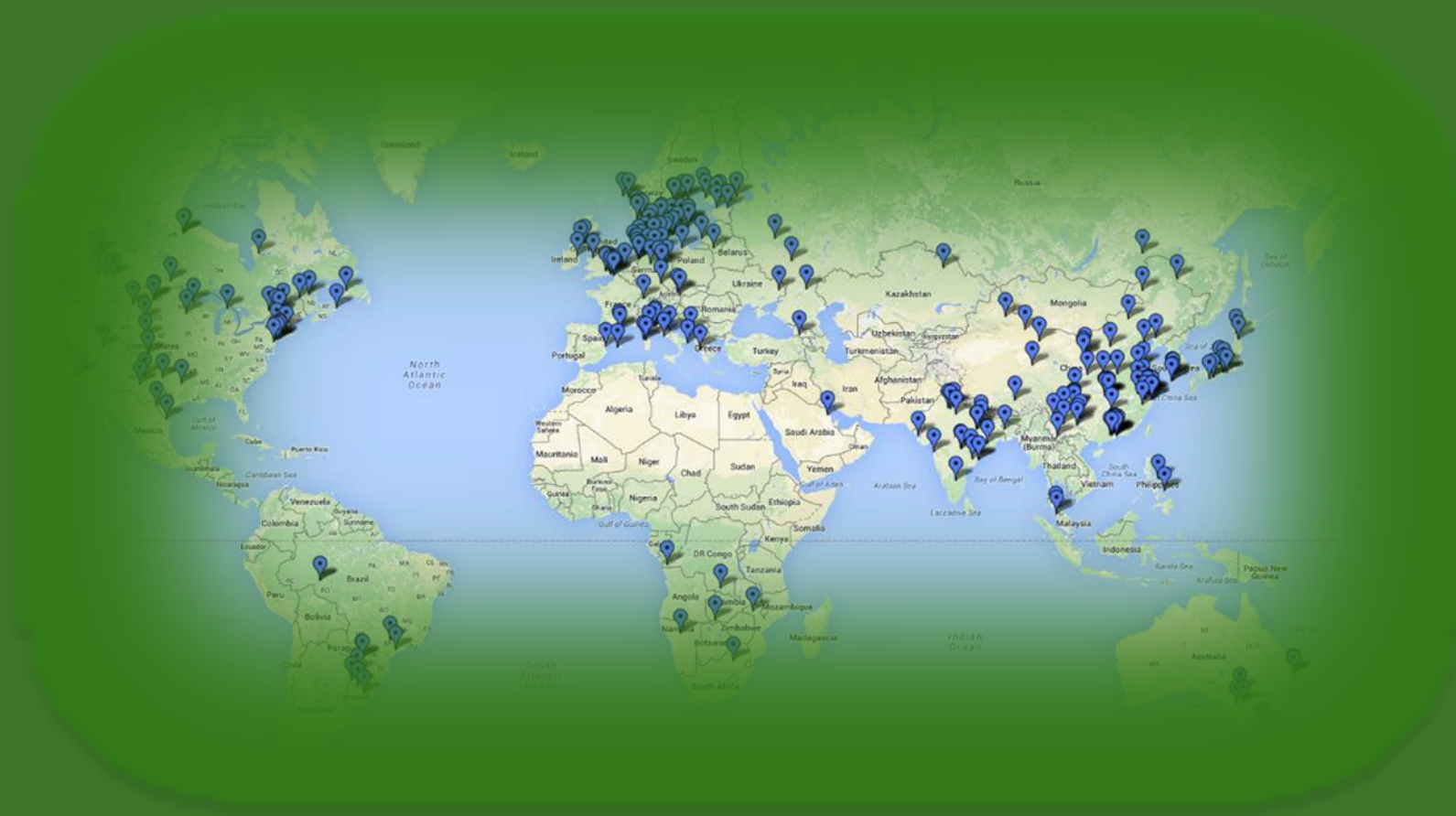
LCC continues as the workhorse for high power point to point interconnections with inherent advantages of

- *Higher power ratings for the moment*
- *Generally better short term overload capability*
- *Fast fault clearing and power restoration on overhead lines*

VSC technology is closing the gap

- *Power transfer capability is rapidly increasing*
- *Inherent advantages include reduced footprint, reduced filtering and capability to directly support ac system voltage*
- *Particularly suited for cable applications since voltage reversal is not needed for power reversal*
- *Developments in HVDC breakers, full bridge converters and cable voltage rating are allowing application at high power with overhead line applications as well as cable*

Both technologies are suitable for Integration of renewable generation



HVDC Powers Up the World!