Wind generation

and their grid connection

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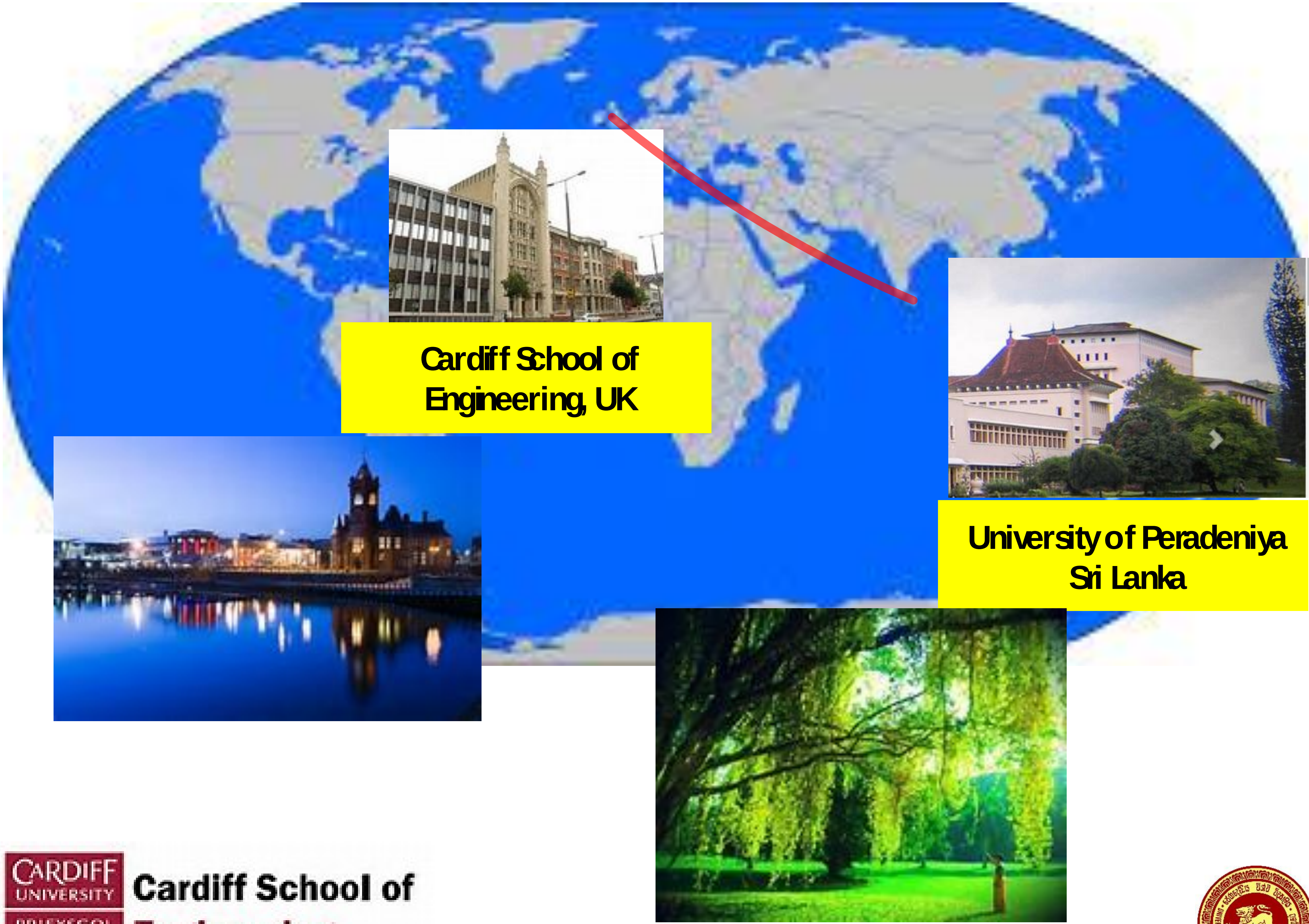
FIET, SMIEEE, CEng



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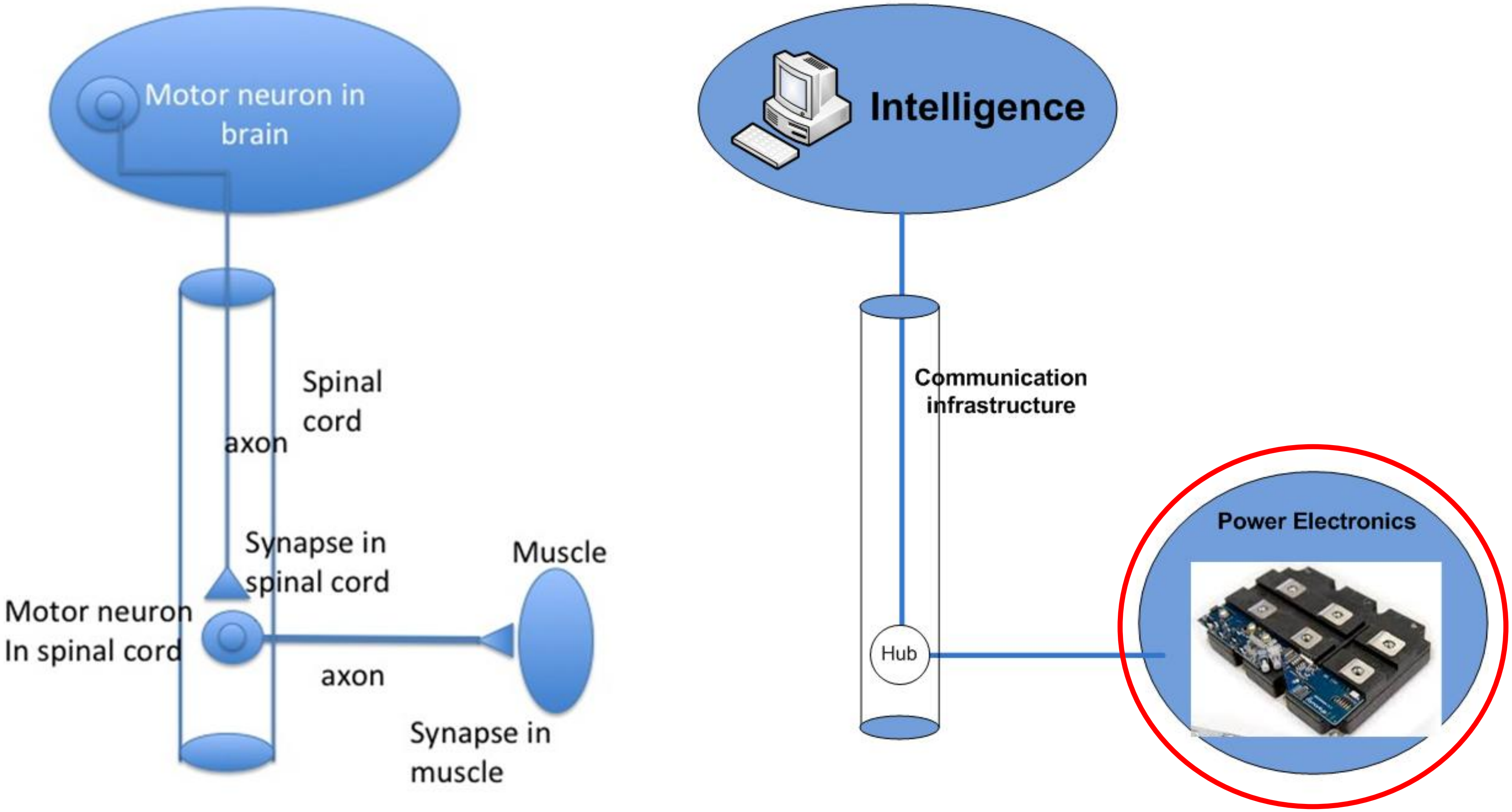
Changes expected in with smart grid?

Mainly driven by decarbonisation and modernization

- Centralised generation → Distributed generation
- Conventional → Renewables
- Manual operations → Automation
- Call centres → Automatic actions
- Passive distribution networks → Active DN
- Customers → Procumers
- AC networks → DC networks
- …….

Role of PE in Smart Grid

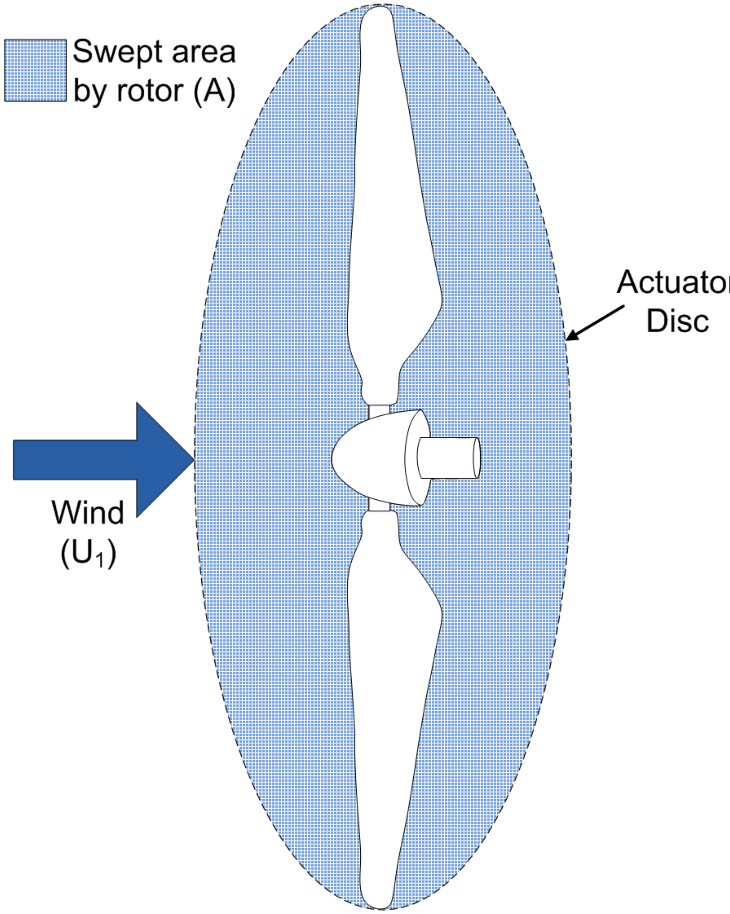


Content

- Wind turbine basics
- Wind turbine generators
- Wind integration

Power available in a wind stream

- The kinetic energy in a flow of air $= \frac{1}{2}U_1^2$ per unit mass
- Mass flow rate= $\rho A U_1$ (kg/s)
  - ρ is the air density in kg/m^3
- Power available in the wind stream $= \frac{1}{2}\rho A U_1^3$



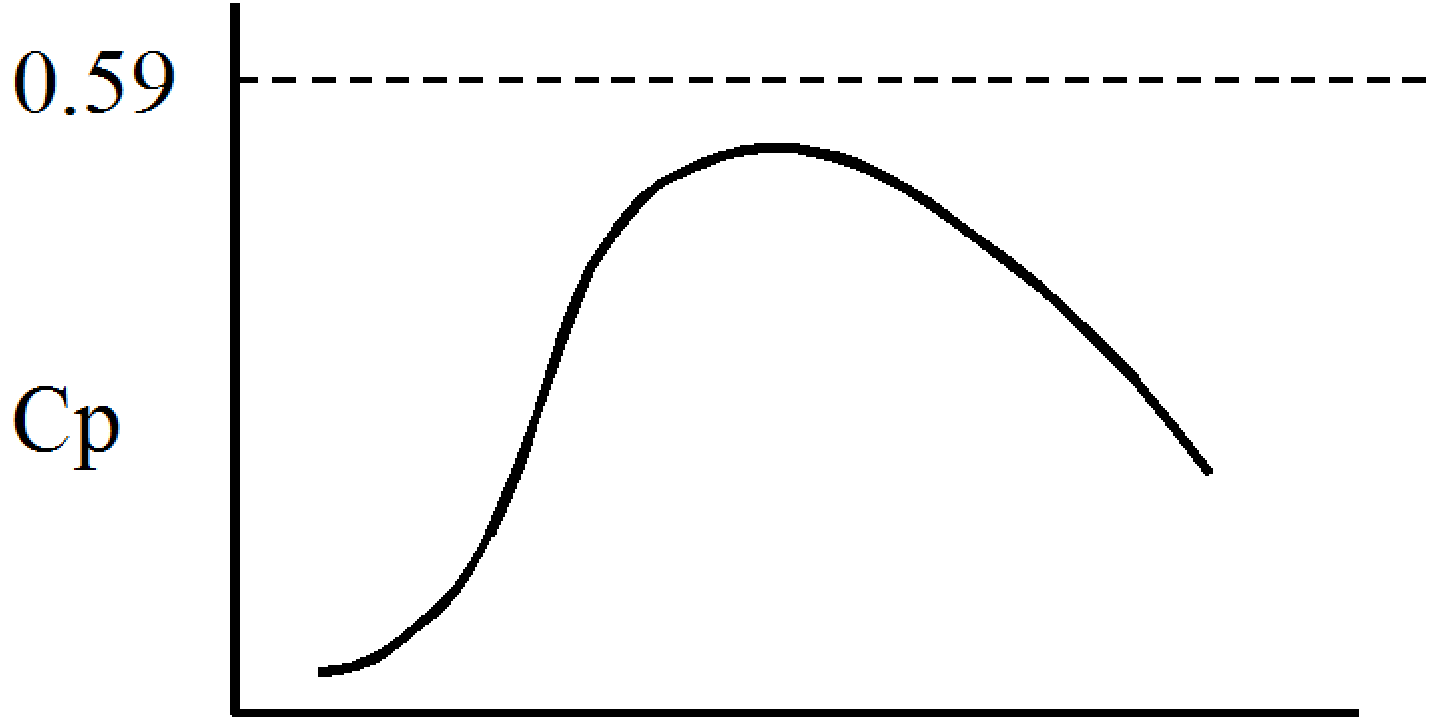
Energy- extracted by the wind turbine

- Power extracted by the aerodynamic rotor

  = C_p x Power available
- C_p is the coefficient of performance
- *C_p (max) is 59% - The Betz limit*
- *C_p depends on the tip speed ratio*

$$\lambda = \frac{\omega R}{V} = \frac{\text{Velocity at rotor tip}}{\text{Wind velocity}}$$

Cp vs Tip speed ratio for fine pitch angle



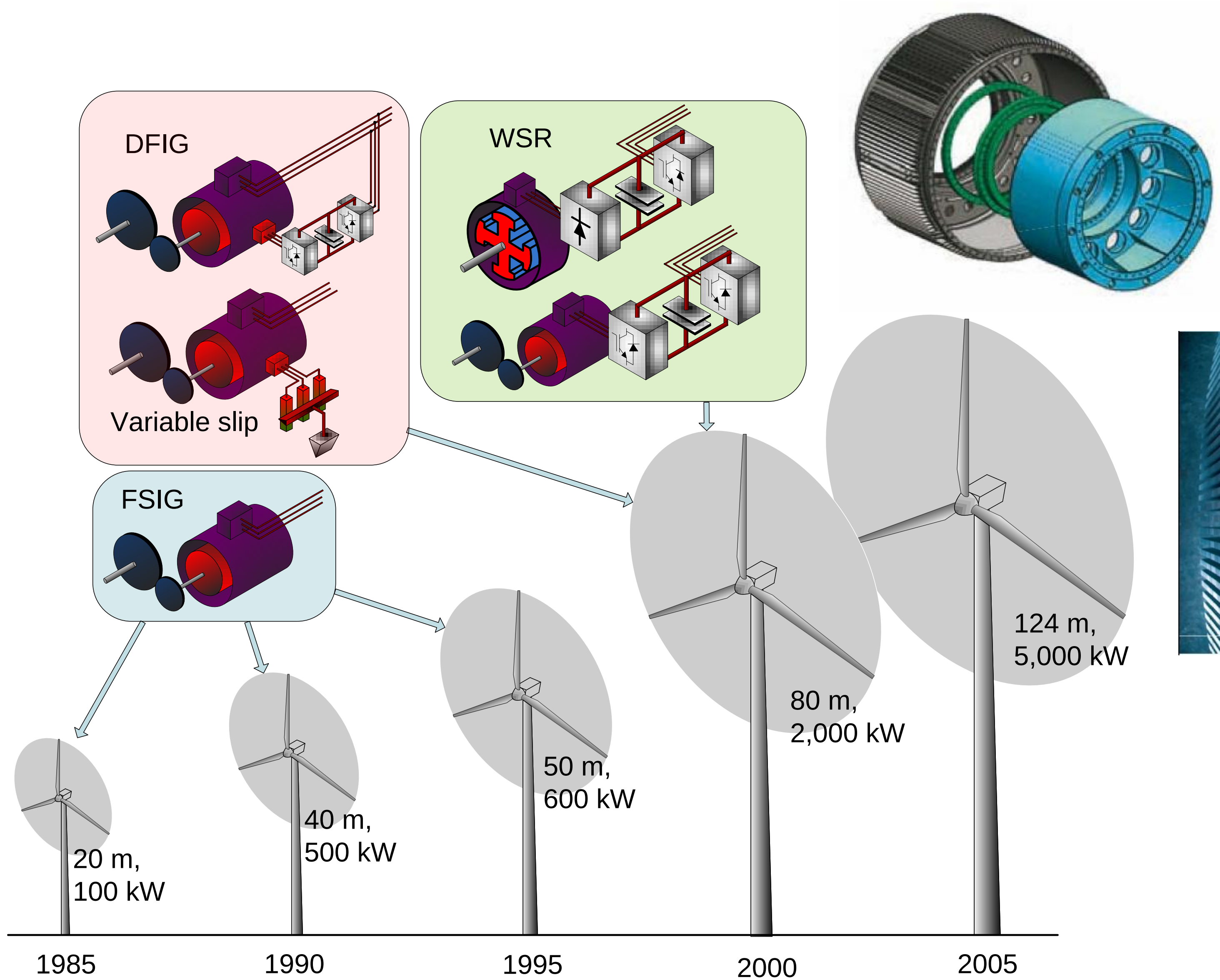
$$\lambda = {}^{\omega R}\!/_{U}$$

Power extraction

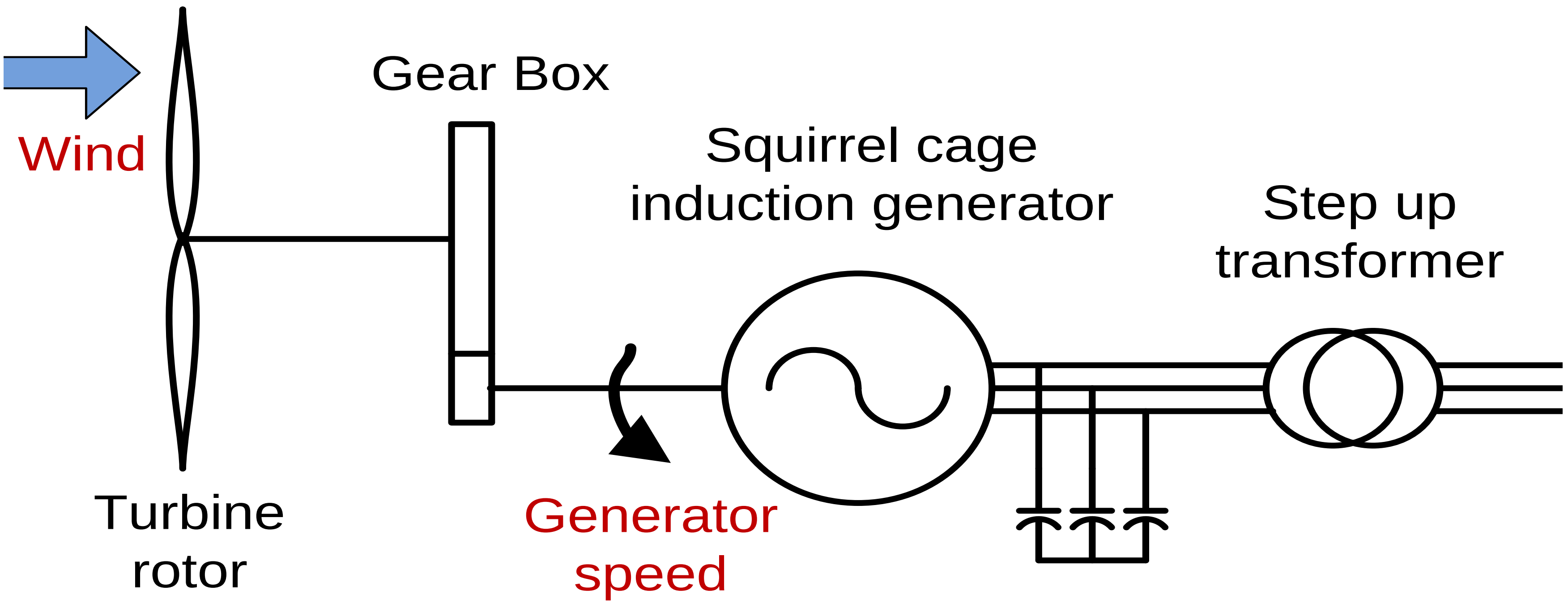
$$P = \frac{1}{2} C_p(\lambda, \beta) \times \rho A U^3$$

- *P* depends on
  a) Wind speed
  b) Rotor diameter
  c) λ which is proportional to ω/U (for a given diameter)
  d) β the pitch angle

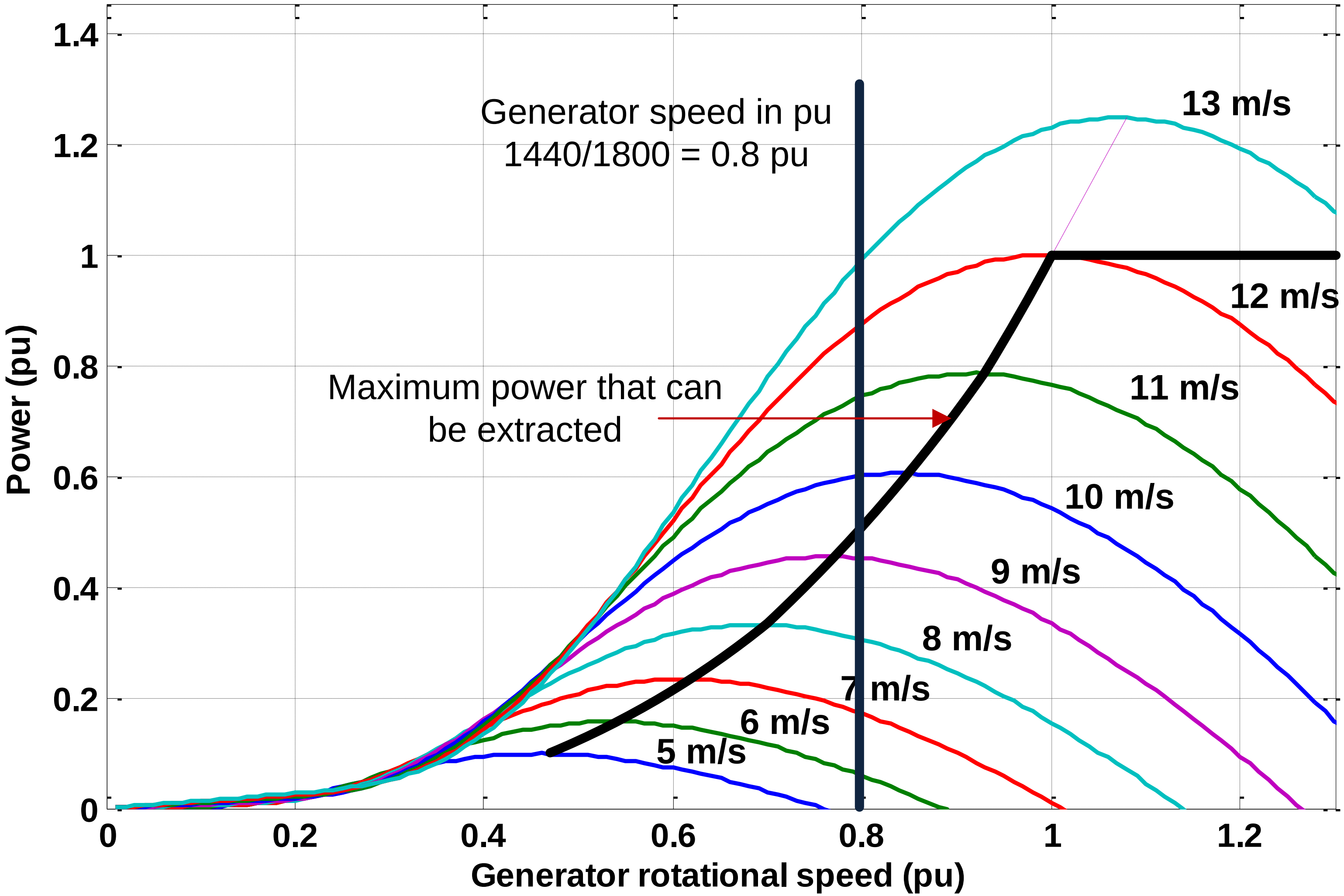
Evolution of Wind Turbines



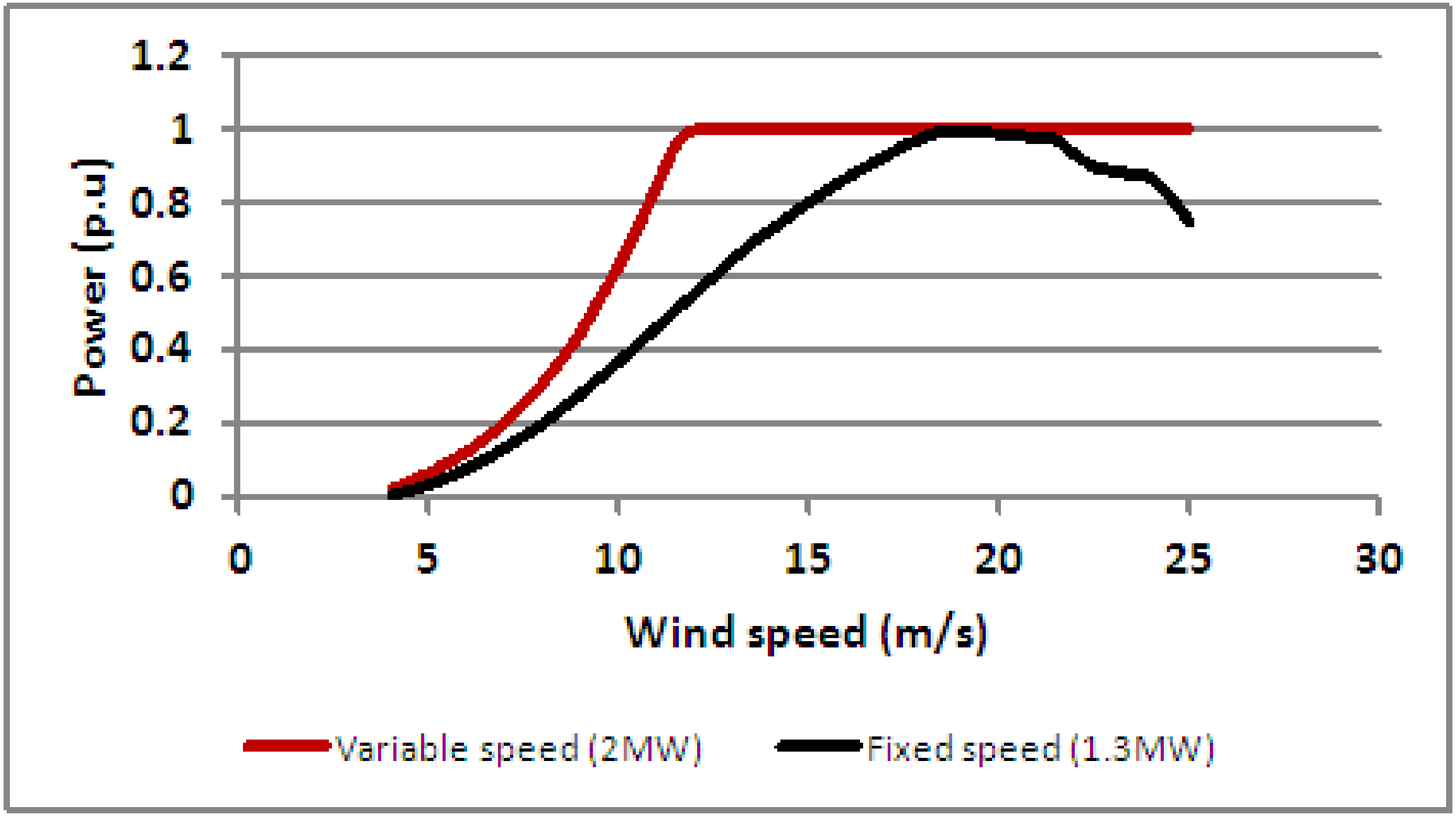
Fixed speed wind turbine



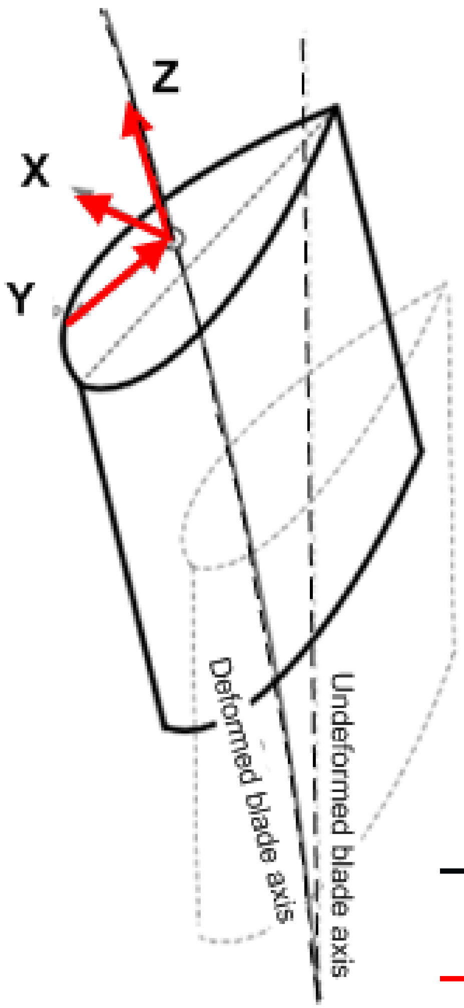
Variable speed operation



Power output

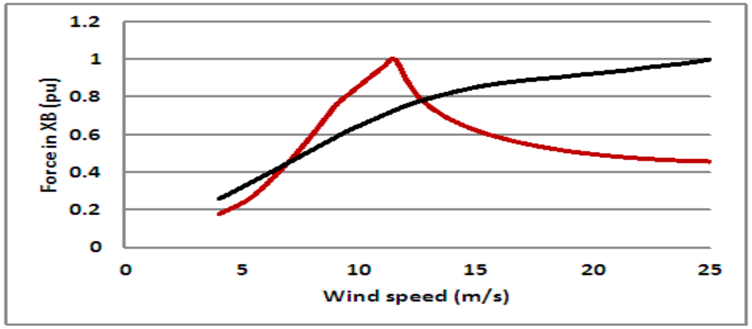


Forces on wind turbines

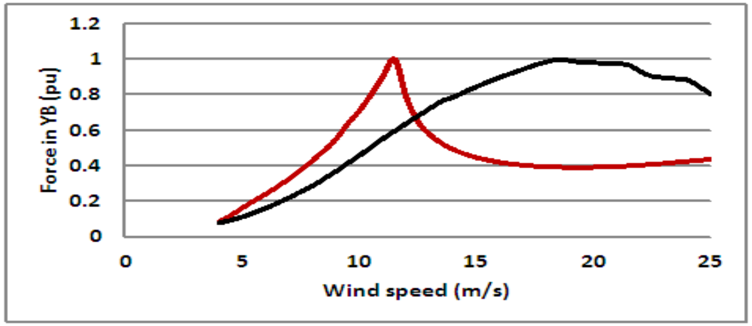


Fixed speed

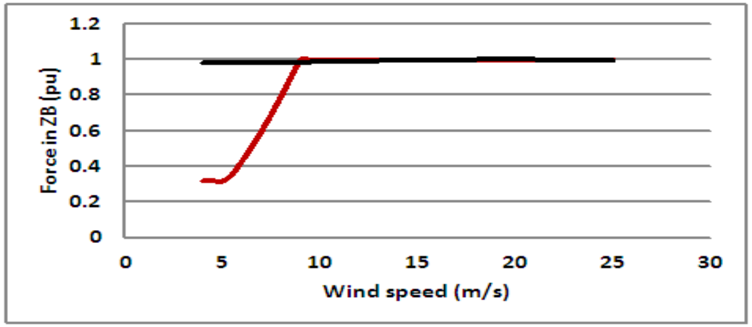
Variable speed



Blade x direction



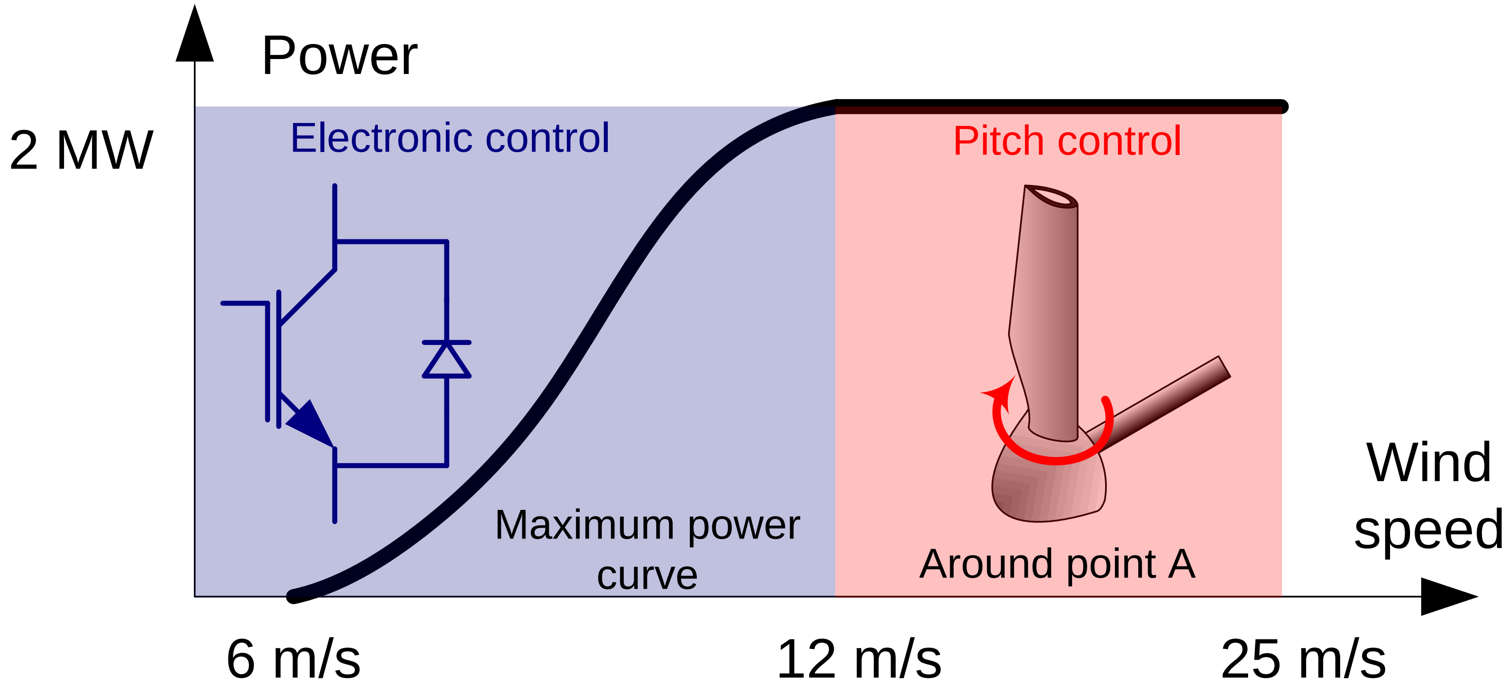
Blade y direction



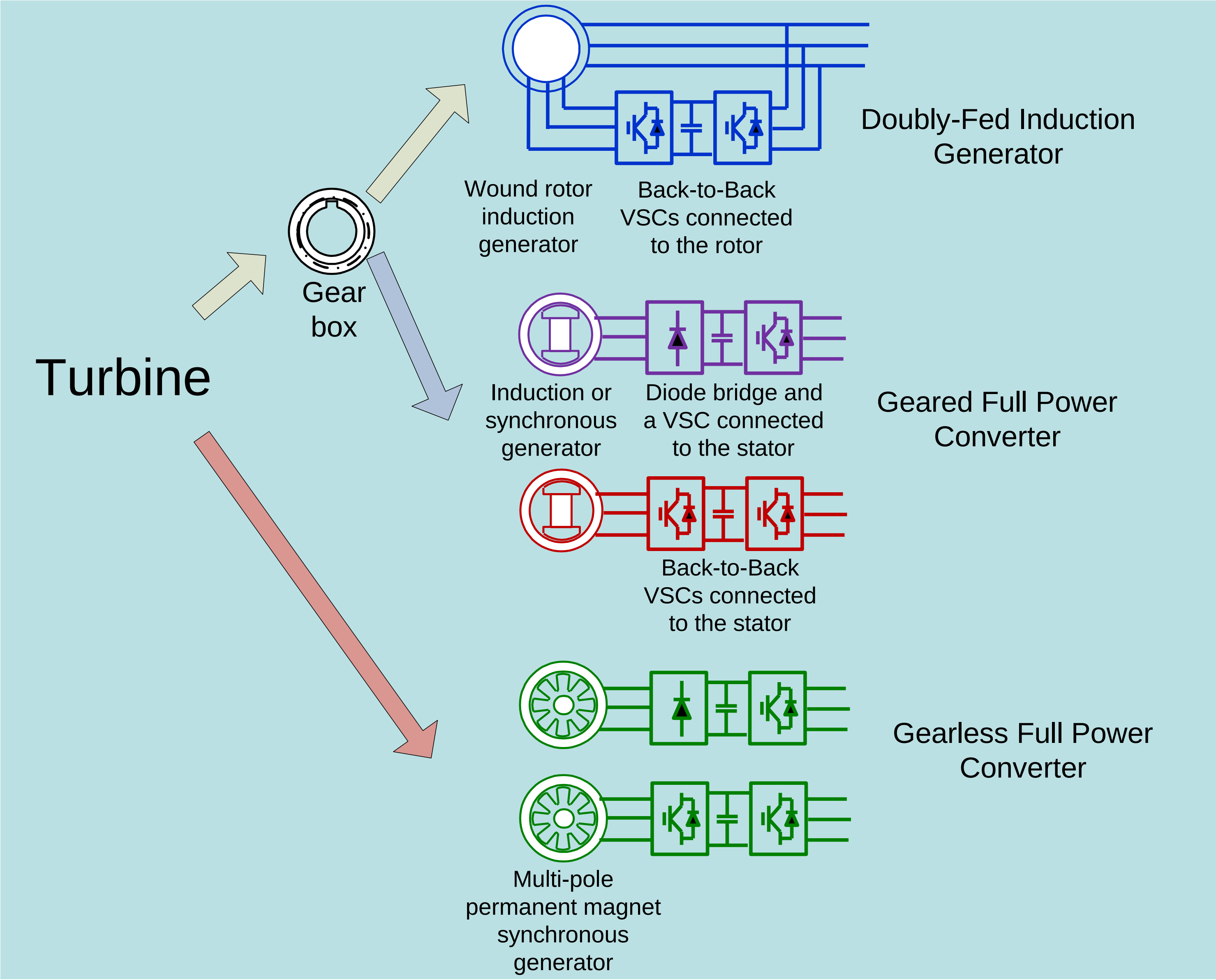
Blade z direction

Variable speed wind generators

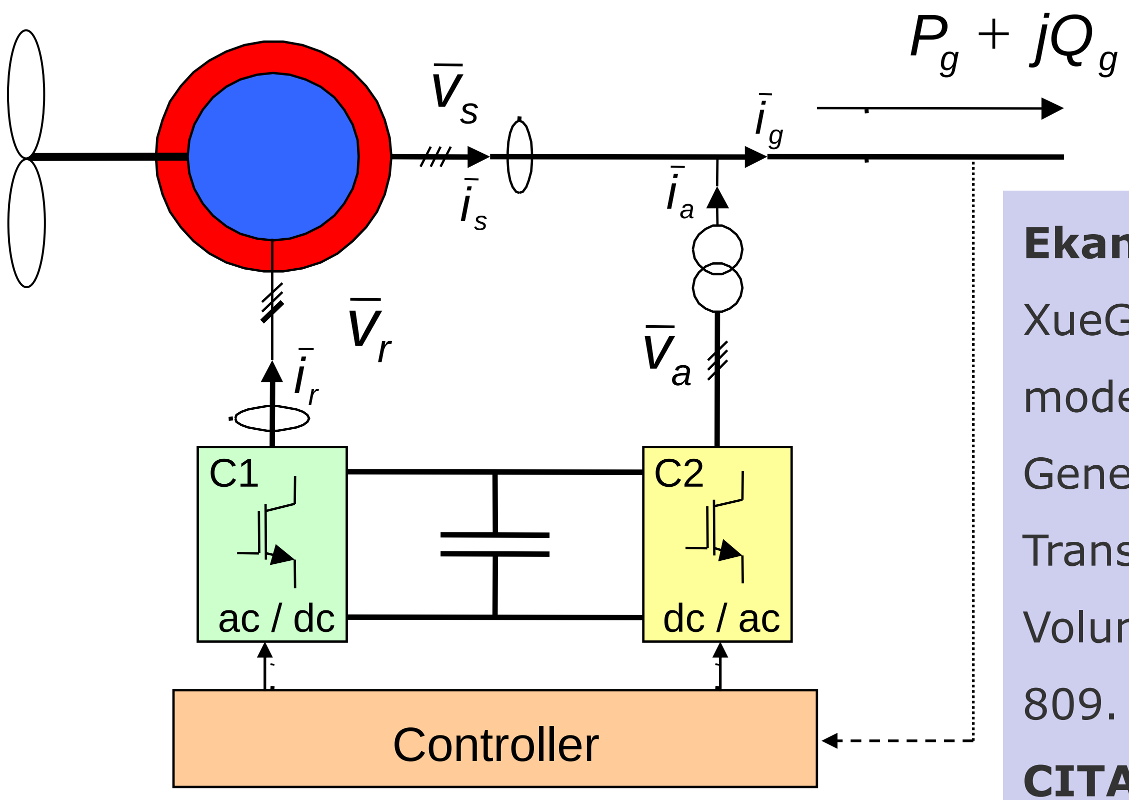
- Wind speed 7 to 12 m/s → Electronic control
- Wind speed above 12 m/s → Pitch control
- Input aerodynamic power is reduced by increasing the pitch angle at high wind speed



Variable speed wind turbines



Doubly fed induction generator (DFIG)

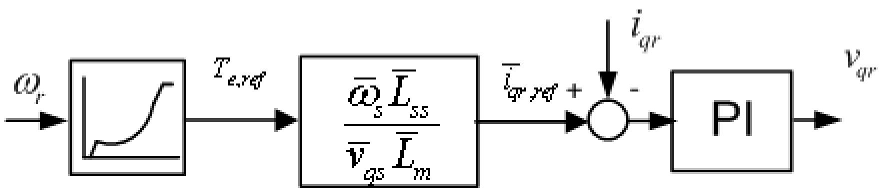


Ekanayake, J.B, Holdsworth, L, XueGuang Wu, Jenkins, N, "Dynamic modeling of Doubly Fed Induction Generator wind turbines", IEEE Transactions on Power Systems, Volume 18, No 2, May 2003, p 803 - 809.

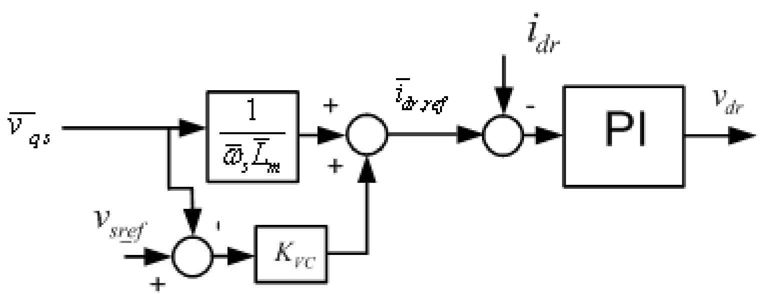
CITATIONS – More than 500

Control of DFIG wind turbines

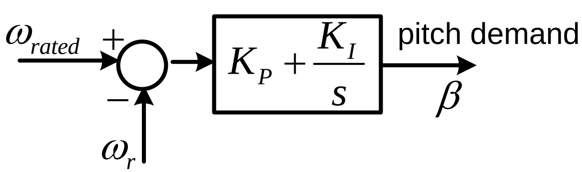
- **Torque control in q-axis**



- **Voltage control in d-axis**



- **Pitch controller**

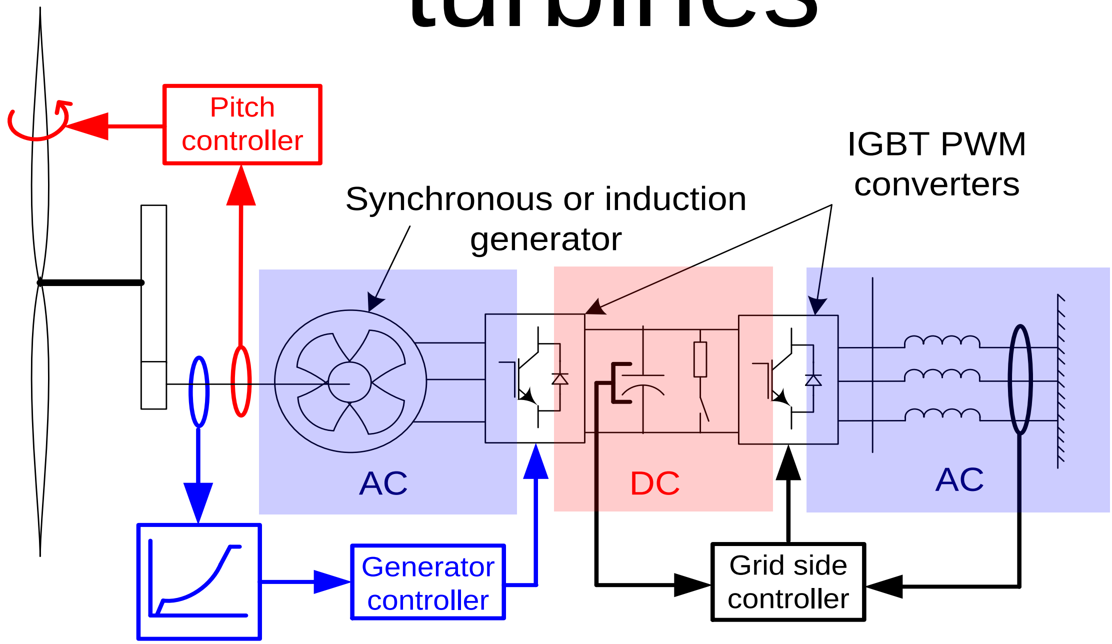


Maintaining the turbine operation point on the maximum power curve is by means of controlling the generator torque

Generator terminal voltage is controlled by manipulating the reactive power supply from the generator

Orientation of the turbine blades are Physically moved to control the aerodynamic torque.

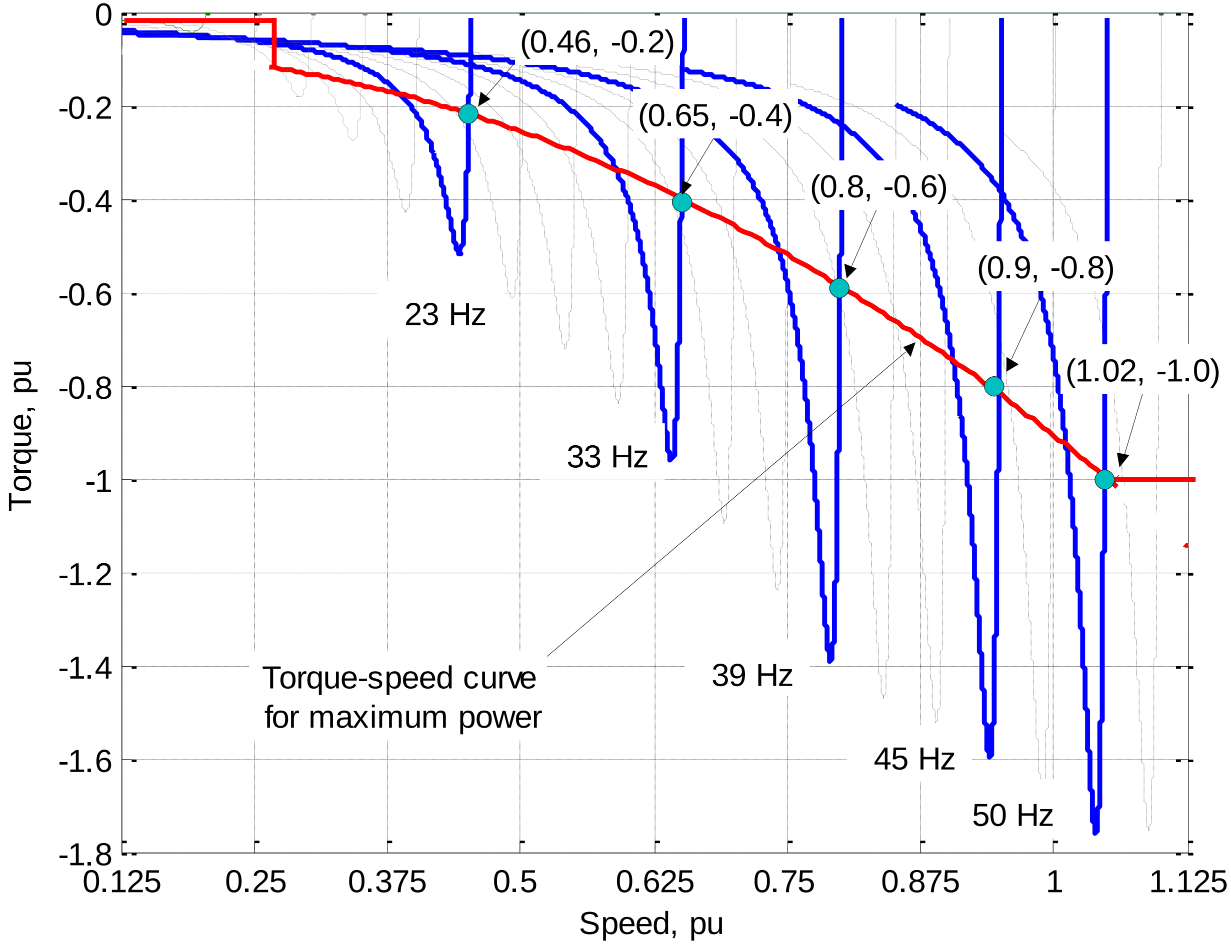
Fully rated converter (FRC) wind turbines



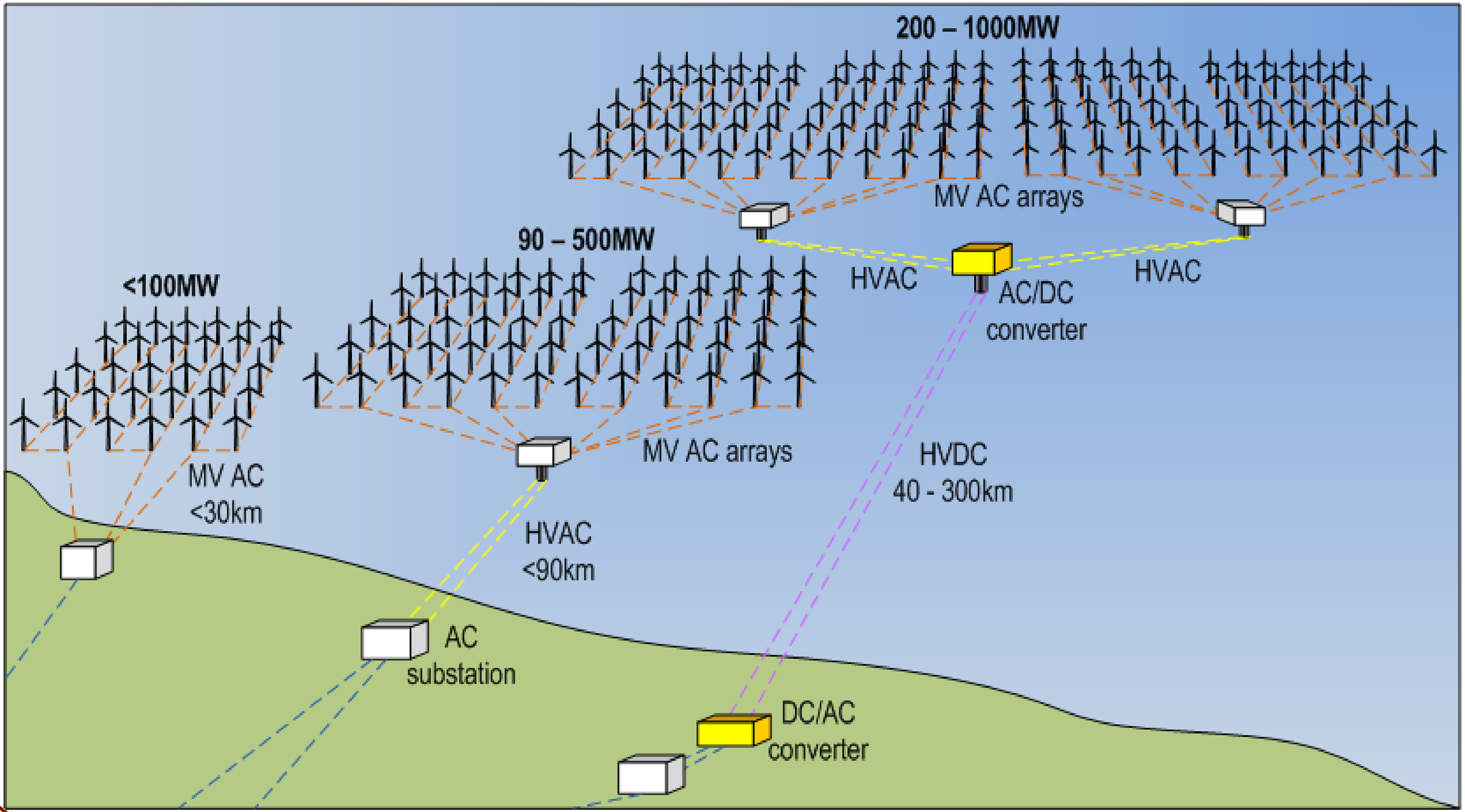
- DC-link totally decouple the generator from the grid
  - Grid frequency is decoupled, wind turbine can operate at any rotor speed
  - Grid voltage is decoupled, change in grid voltage does not affect the generator dynamics

- Gearbox can be avoided if a multi-pole synchronous generator is used, e.g. Enercon turbines with 64 poles

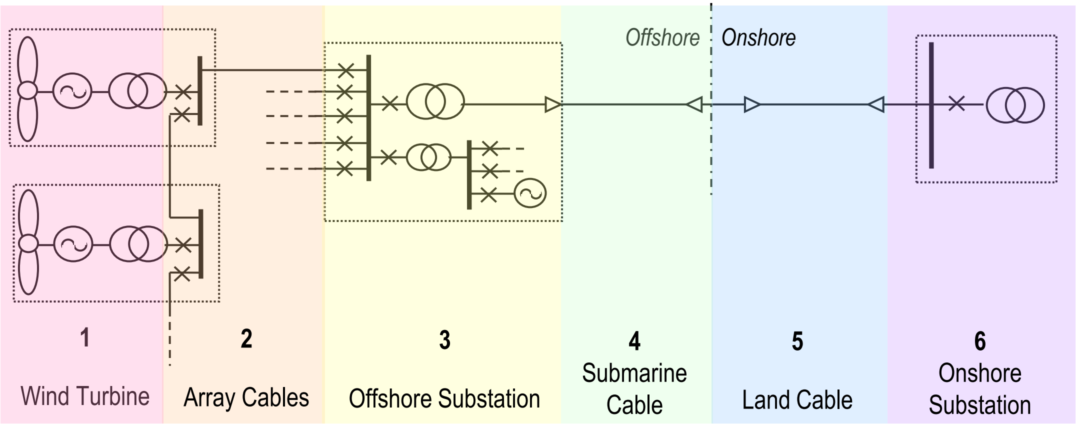
Control of FRC wind turbines



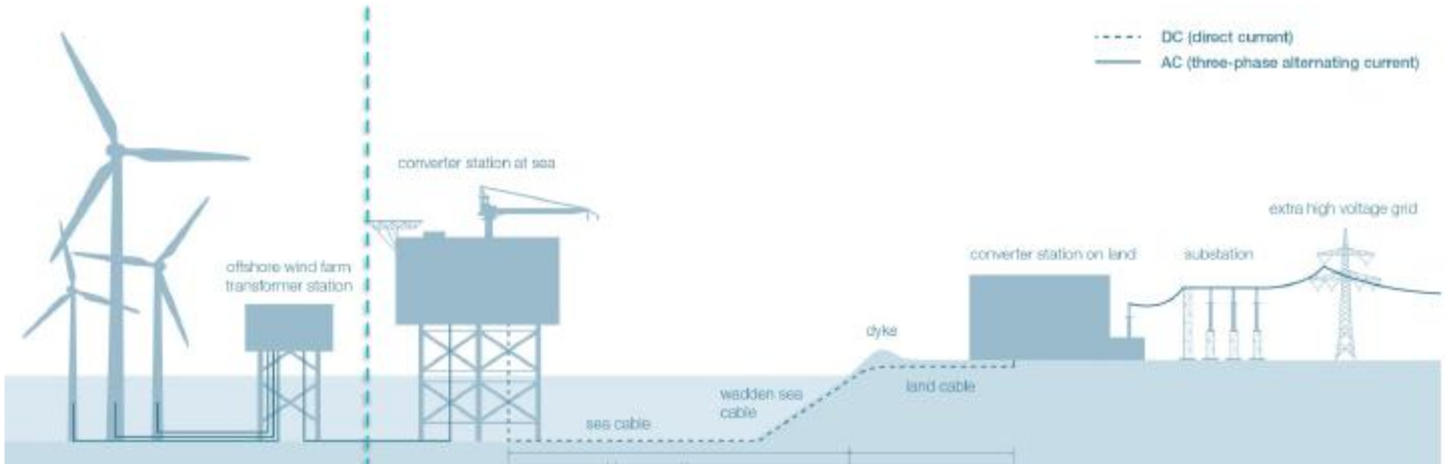
Wind farms connections: offshore

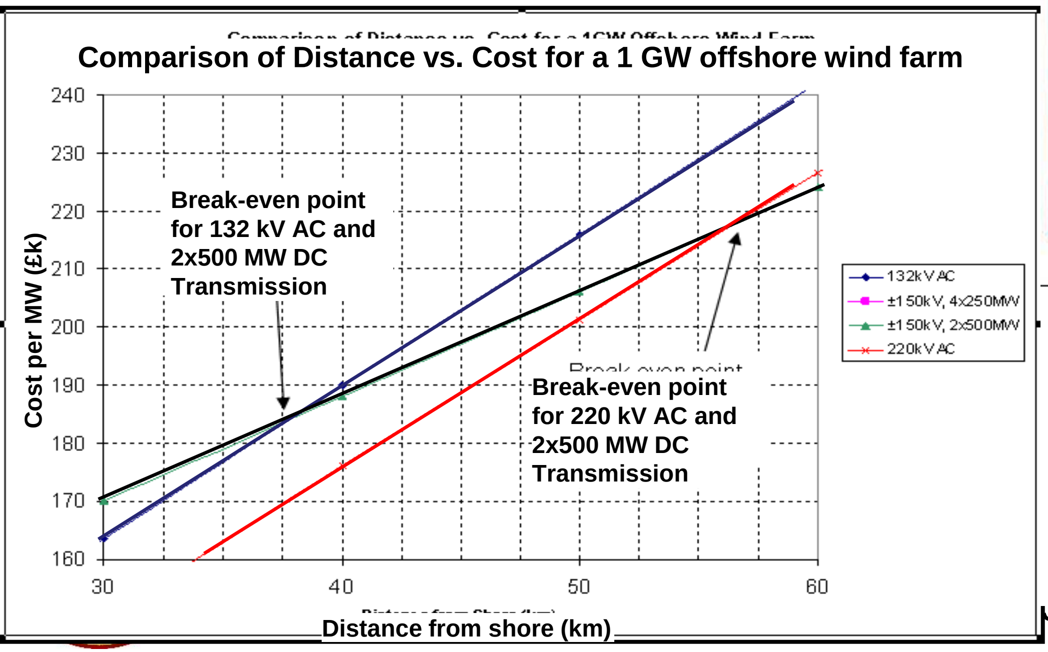


Offshore wind farm – ac connection



Reasons for choosing HVDC transmission offshore



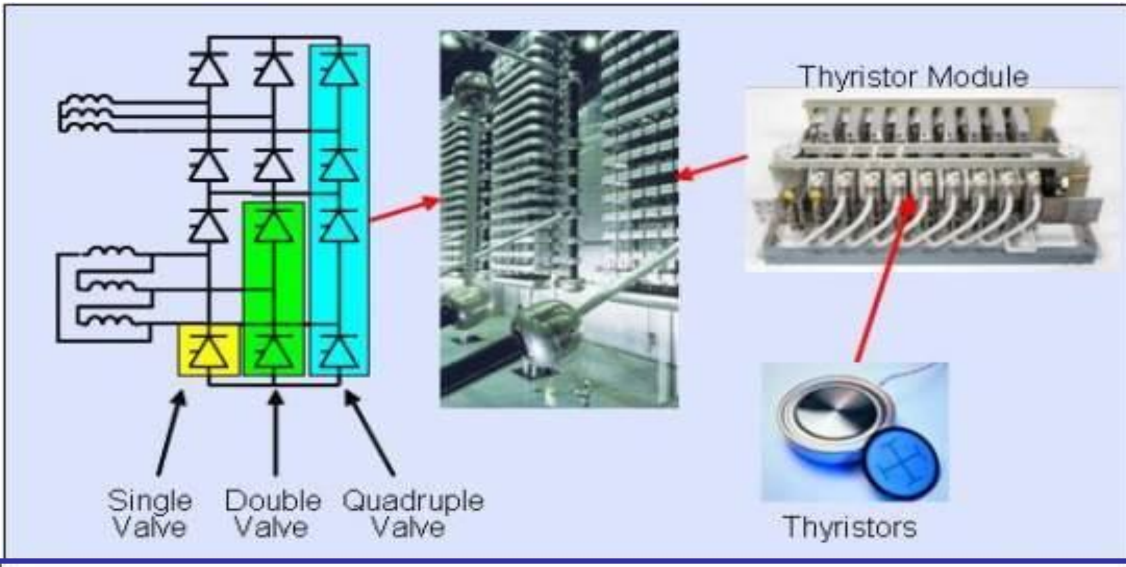


(a)

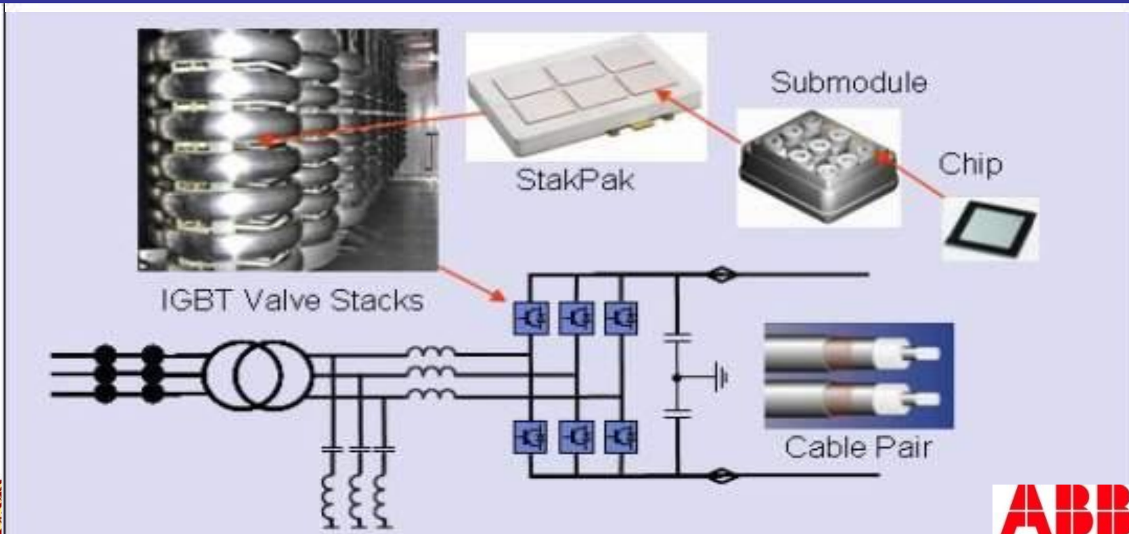
2x 1core ±300kV bipolar HVDC

Ref: Econnect, *East Coast Transmission Network Technical Feasibility Study*. 2008, Crown Estate.

HVDC technologies



- Current Sourced Converter (CSC)
- Thyristor based

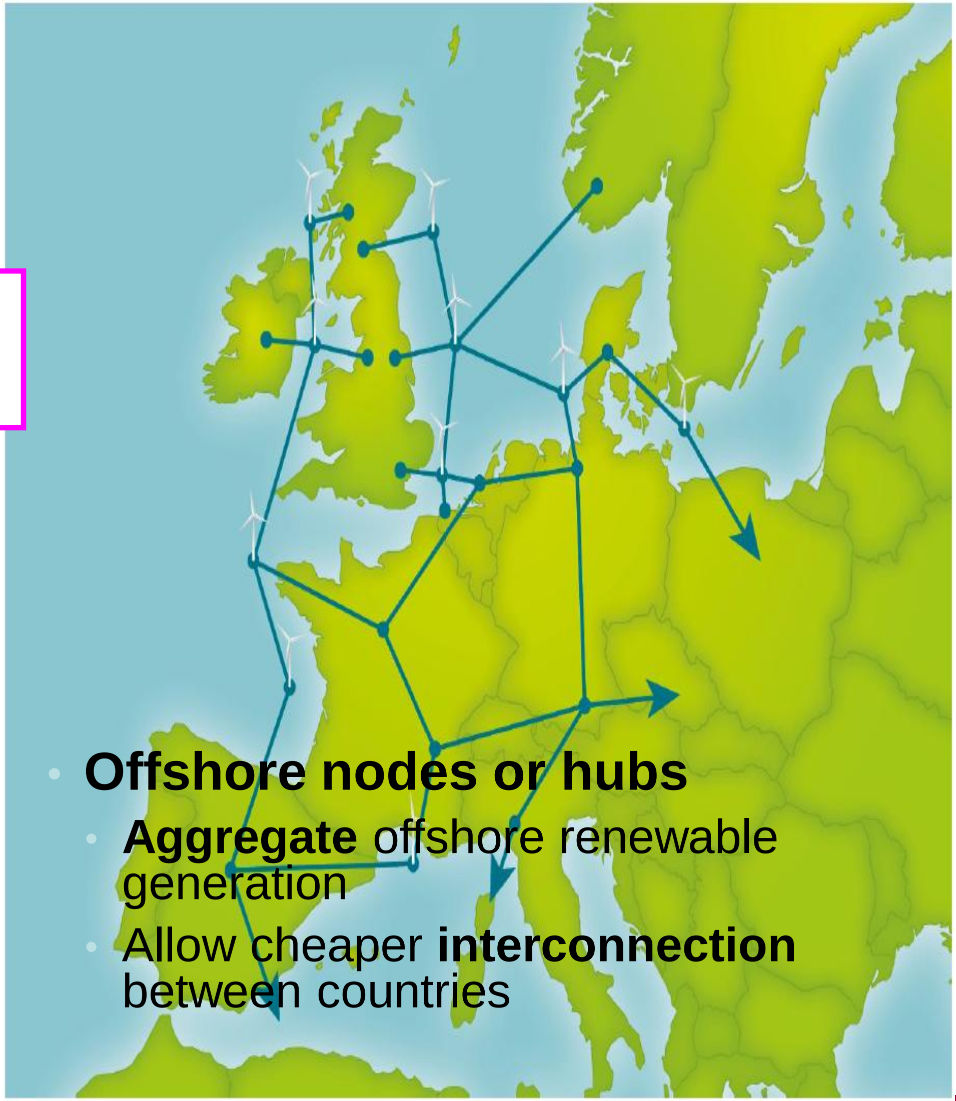


- Voltage Sourced Converters
- IGBT based

European Supergrid

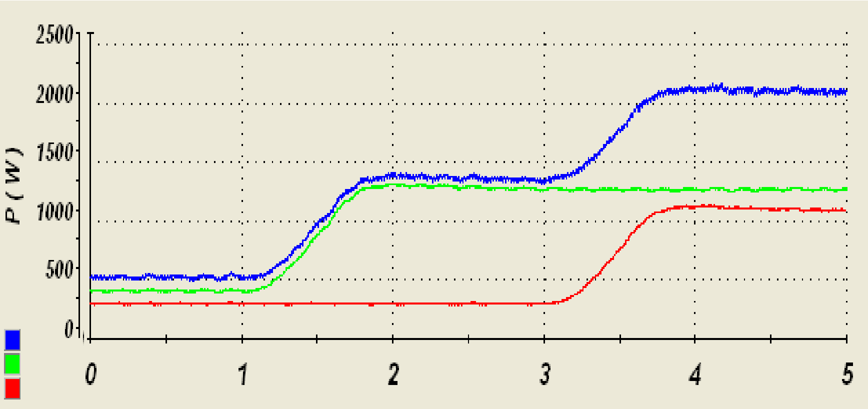
50GW of wind power in the North ?

30GW of solar power in the South ?

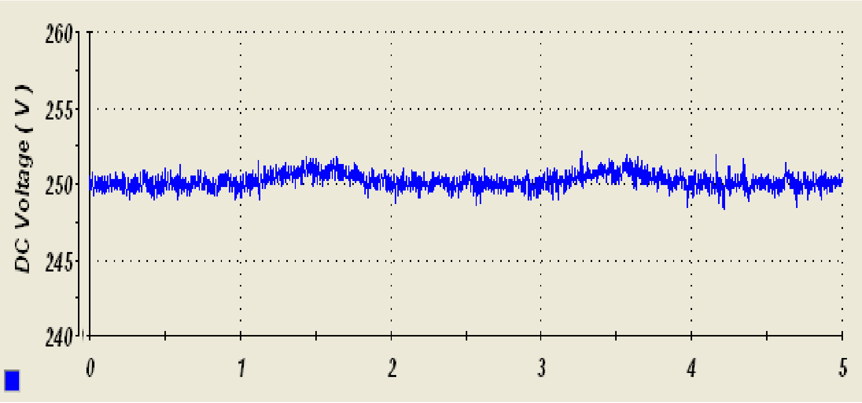


- **Offshore nodes or hubs**
  - **Aggregate** offshore renewable generation
  - Allow cheaper **interconnection** between countries

Multi-terminal HVDC

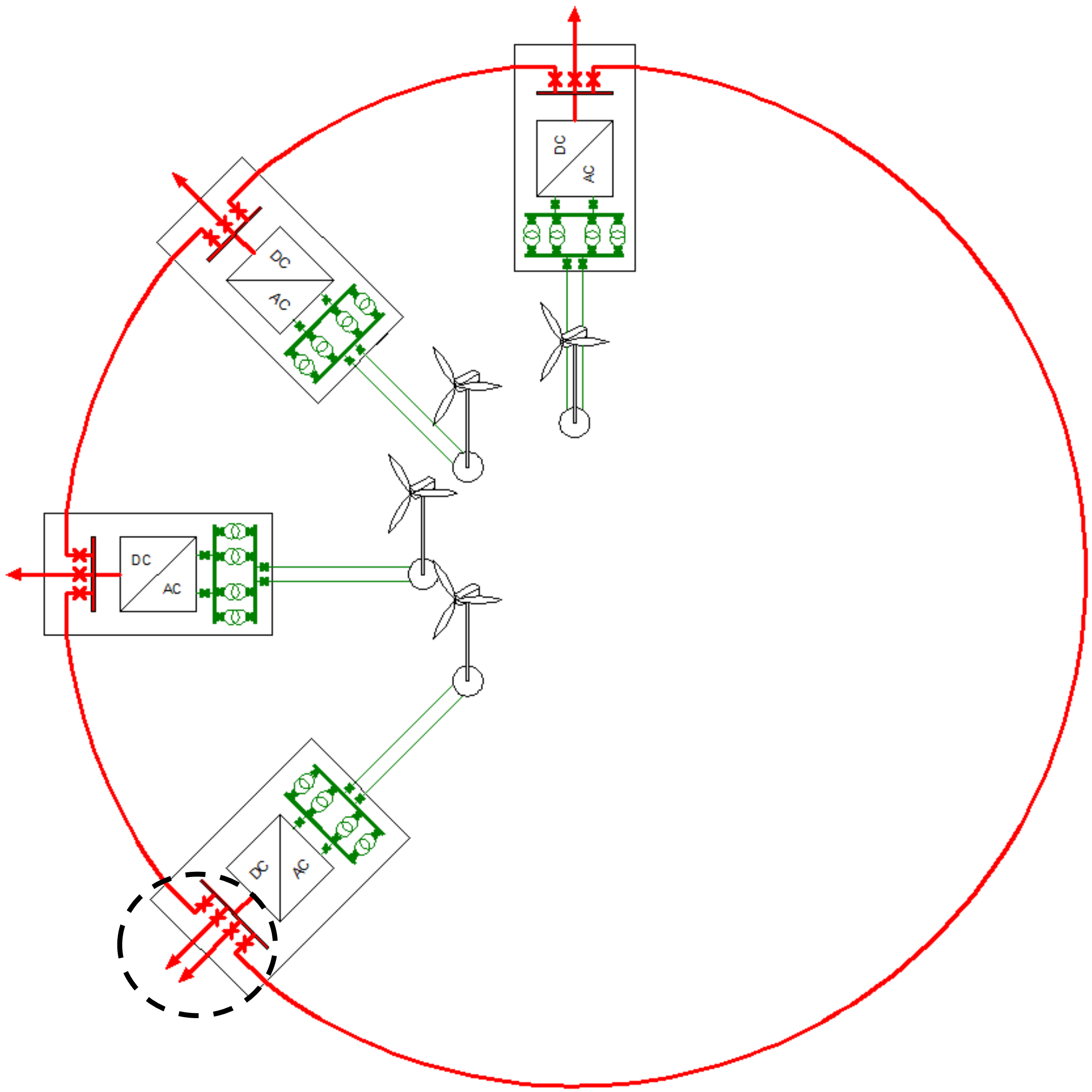


Real Power

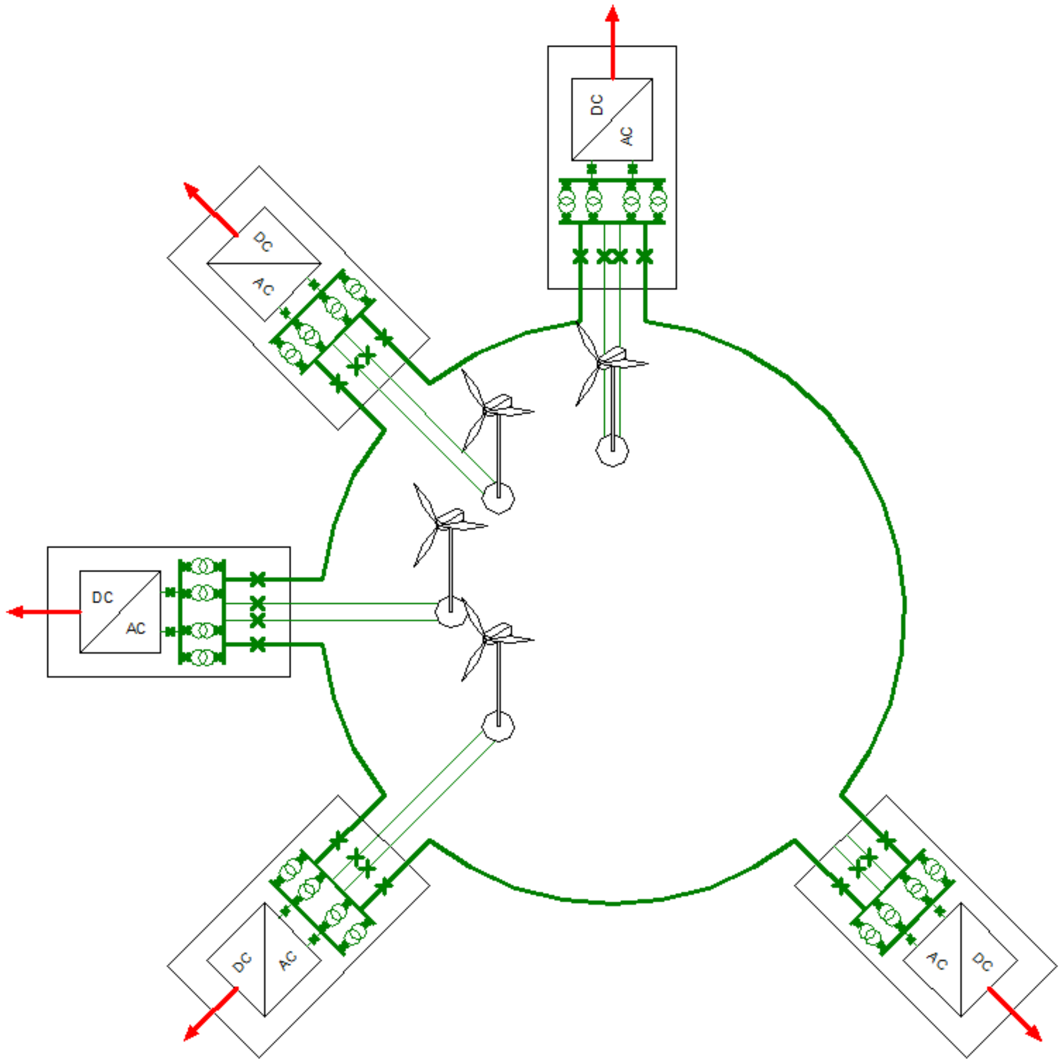


DC voltage

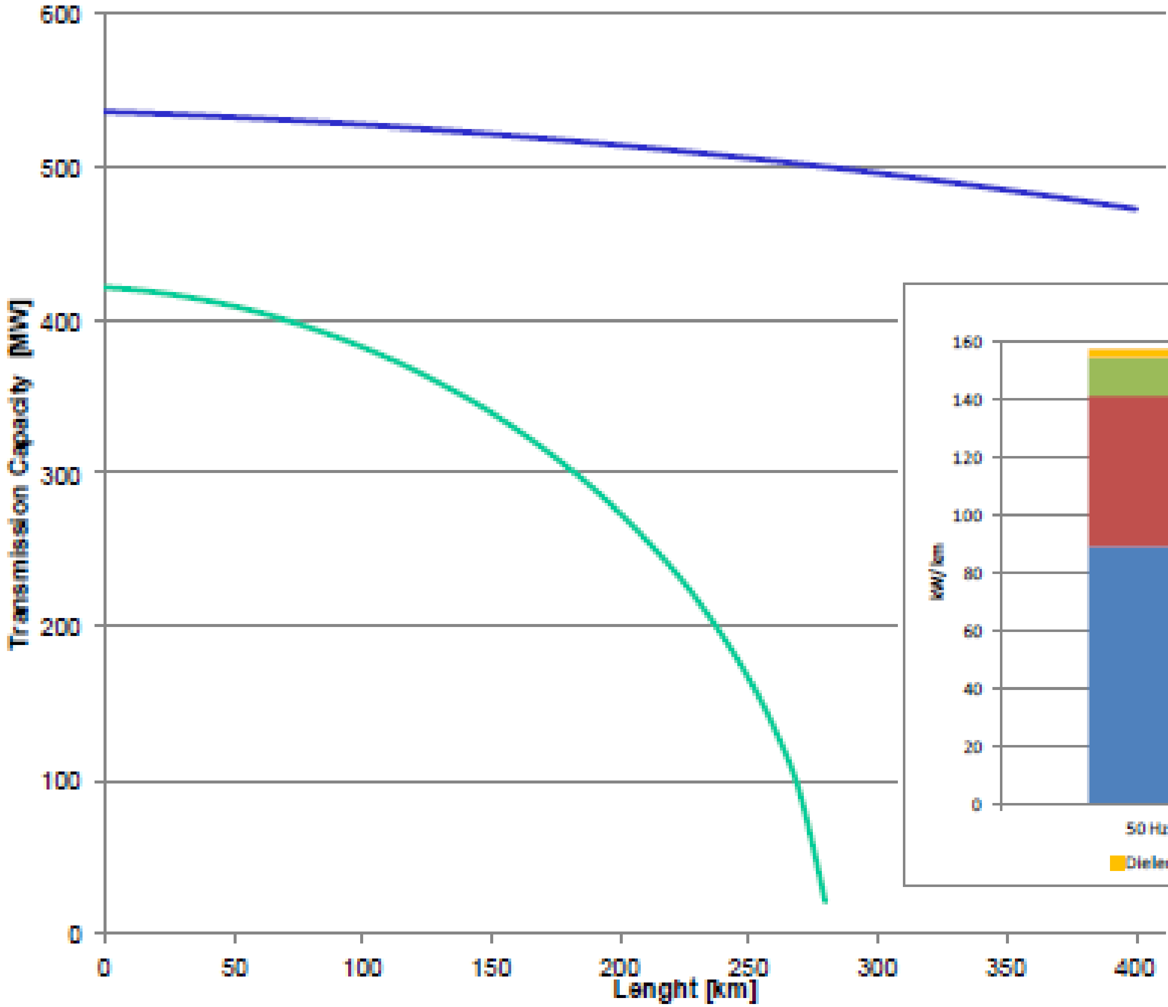
Development of a MT-HVDC Hub

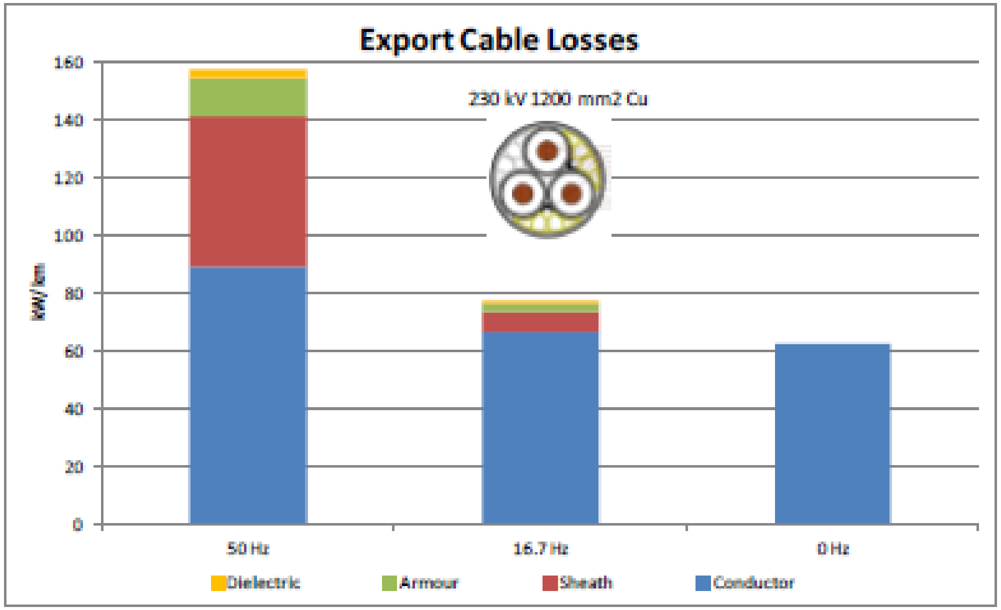


Development of an AC-Hub



LFAC – Low Frequency AC





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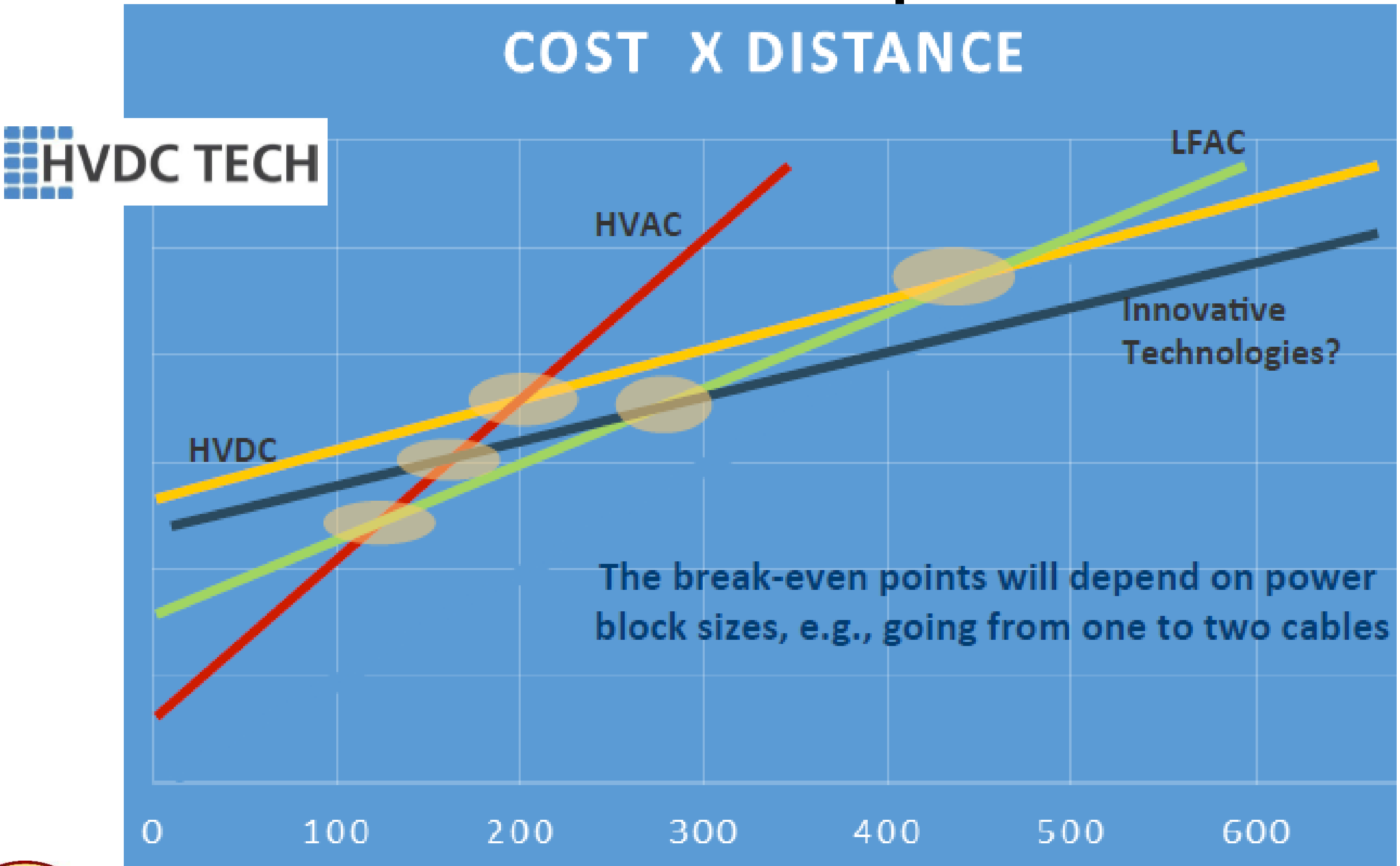
Break even point



Summary

- Power electronics will play a key role in the Smart Grid mainly as an interface between the renewable energy sources and the grid

- Multi-terminal HVDC connections are emerging which has potential to connect cross countries and renewables