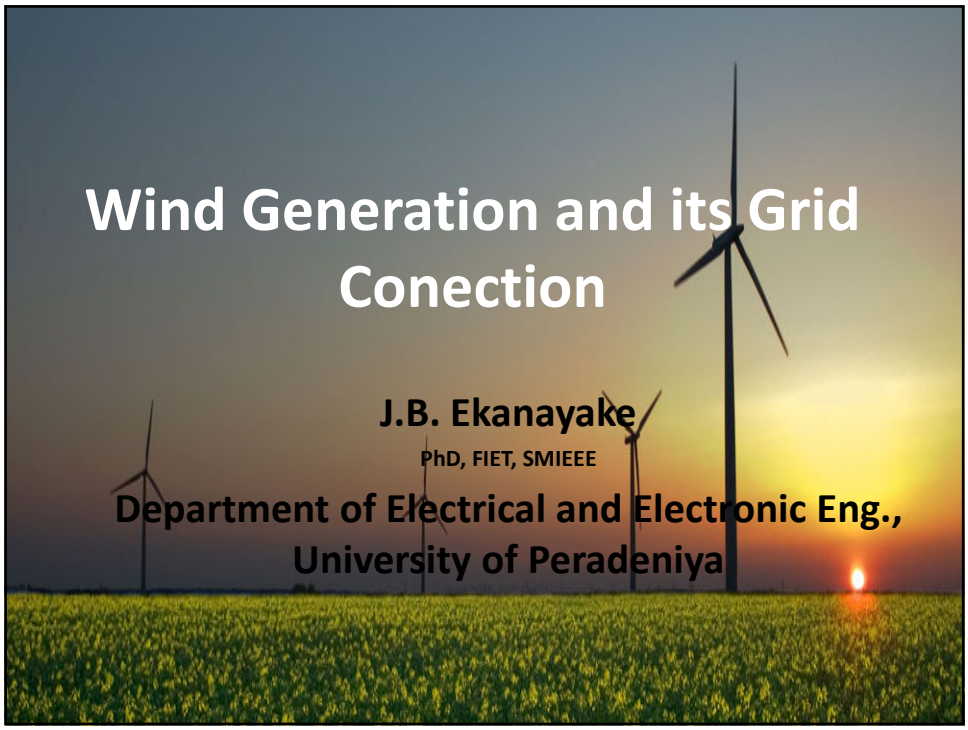

Wind Generation and its Grid Conection

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PhD, FIET, SMIEEE

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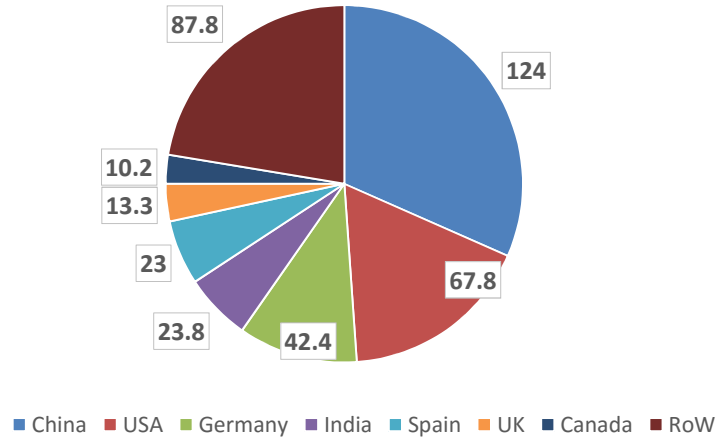
Content

- Wind turbine basics
- Wind generators
- Why variable speed?
- Grid Code requirements
- Concluding remarks

Introduction

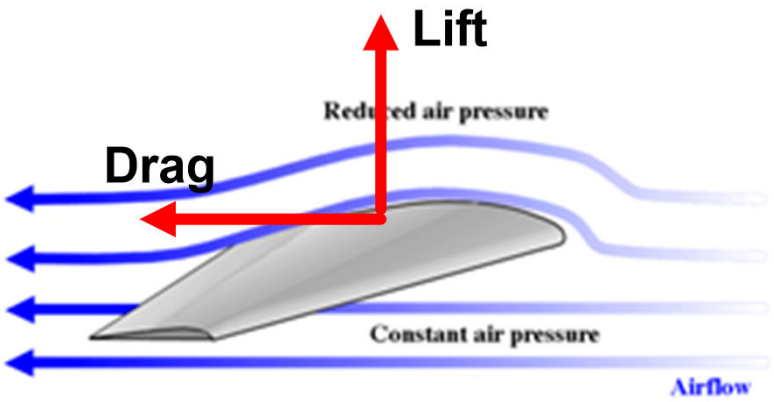
Worldwide wind capacity as at mid of 2015 = 393 GW



http://www.wwindea.org/hyr2015/

WIND TURBINE BASICS

How wind turbine works?



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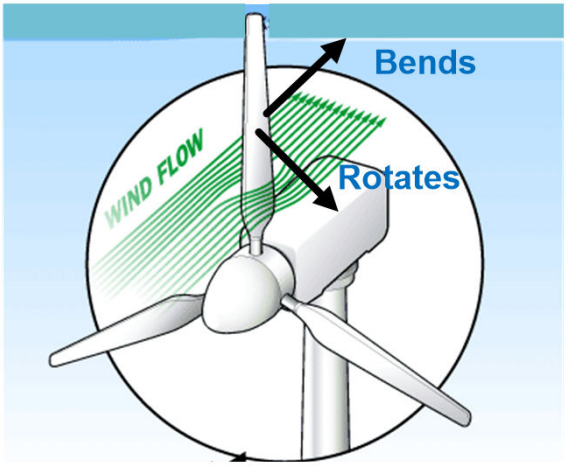
How wind turbine works?



- Air incident on the airfoil produces plenty of lift which aid the rotation of the blade.
- The drag tries to bend the blade towards the tower.

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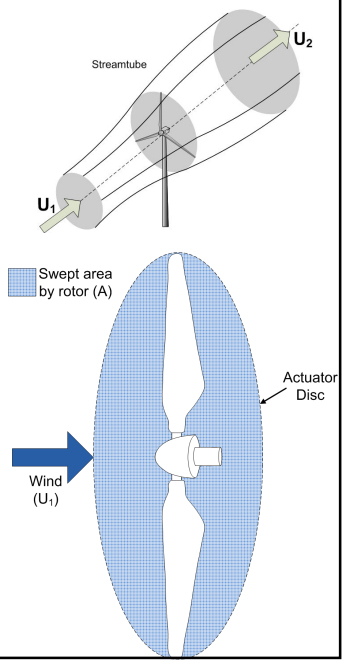
Power available in a wind stream

- 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 $= \frac{1}{2}\rho A U_1^3$

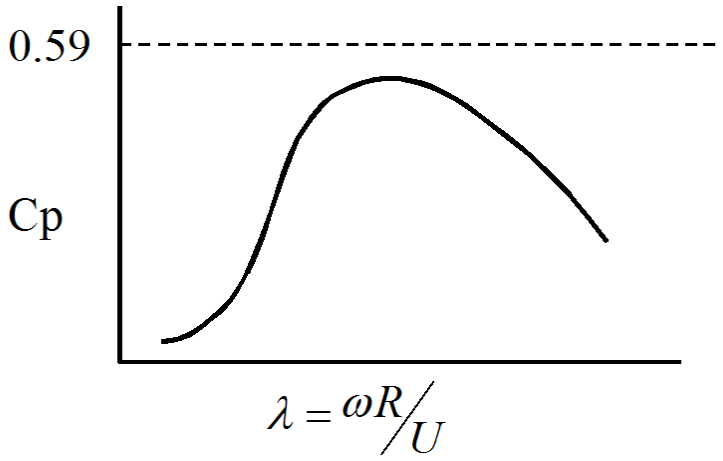


Energy- extracted by the wind turbine

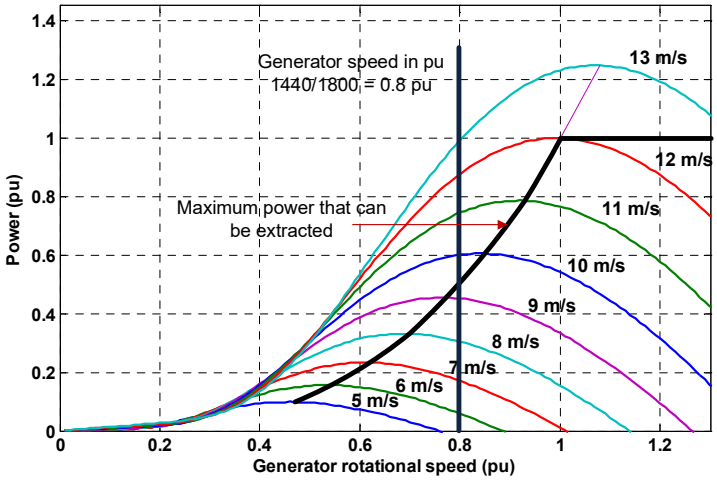
- Power extracted by the aerodynamic rotor = C_p x Power available
- C_p is the coefficient of performance
- *The Betz limit: Maximum value of the coefficient of performance C_p is 59%.*
- *C_p depends on the tip speed ratio*

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

Cp vs Tip speed ratio

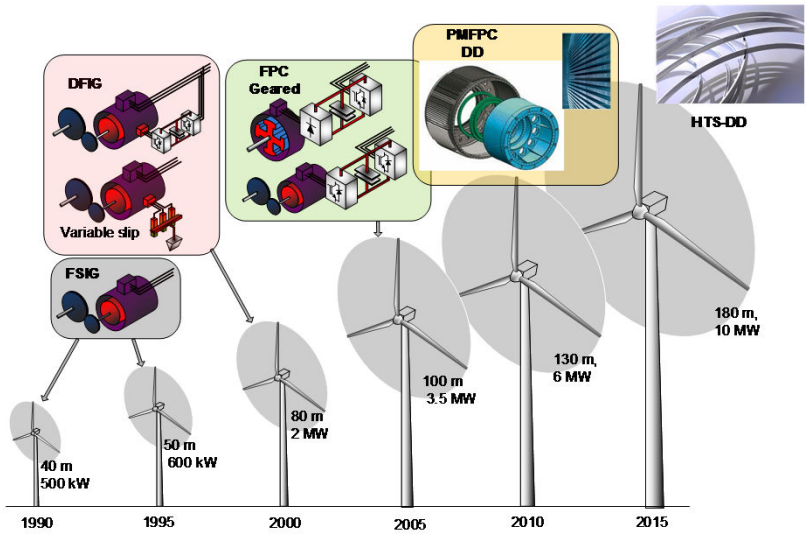


Variable speed operation



- To extract maximum power ω_r should vary with the wind speed

Evolution of Wind Turbine Technologies

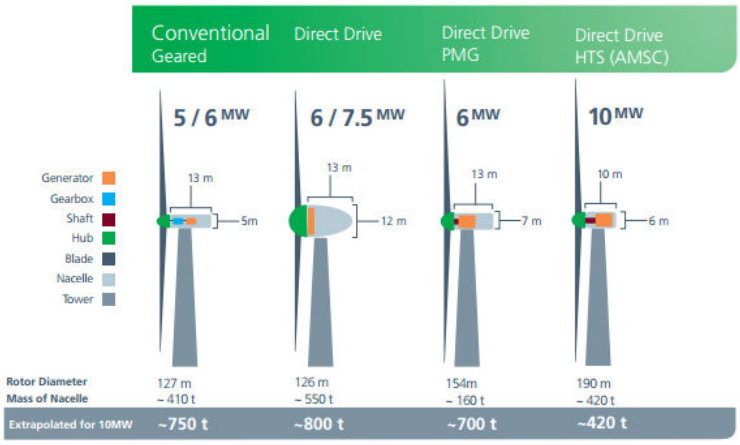


Available wind turbines

Turbine	Capacity	Generator	Rotor diameter	Geared
Vestas V164	8 MW	FPC	164 m	Yes
Enercon E126	7.5 MW	FPC	127 m	No
Repower 6M	6 MW	DFIG	126 m	Yes
Siemens SWT-6.0 150	6 MW	FPC - PMG	154 m	No
Alstom Haliade 150	6 MW	FPC - PMG	150 m	No
Areva M5000	5 MW	FPC - PMG	135 m	Yes
Gamesa G128	5 MW	FPC - PMG	128 m	Yes

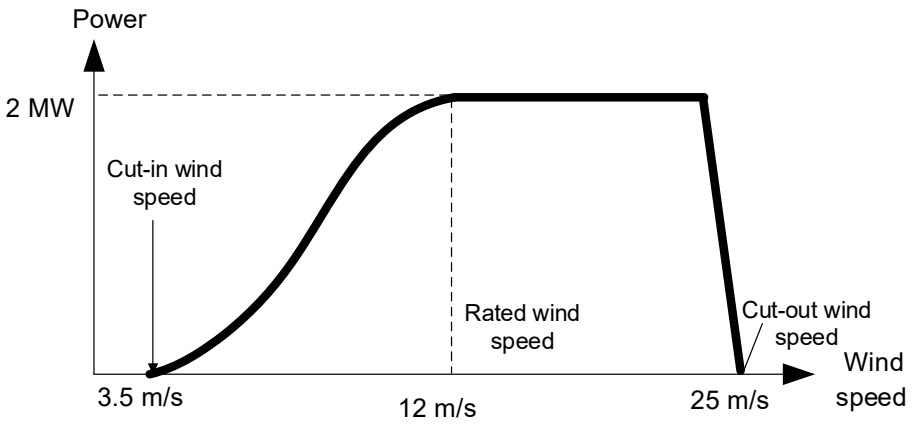
http://en.wind-turbine-models.com/

HTS - DD



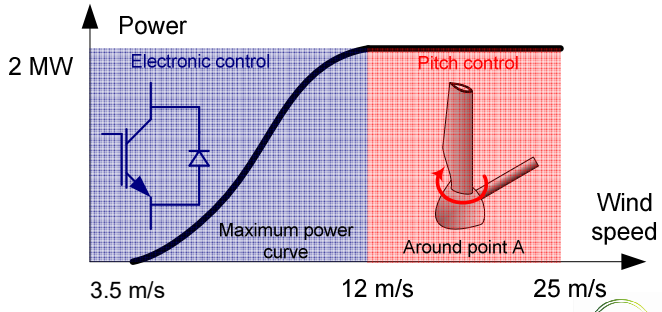
http://www.amsc.com/documents/hts-generator-solutions-brochure/

Power curve of modern wind turbines



Control of modern wind generators

- Wind speed 7 to 15 m/s → Electronic control
- Wind speed above 15 m/s → Pitch control
- Input aerodynamic power is reduced by increasing the pitch angle at high wind speed



WIND GENERATORS

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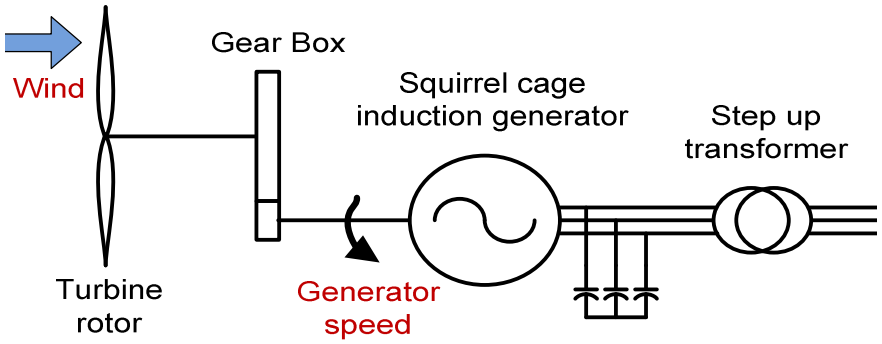
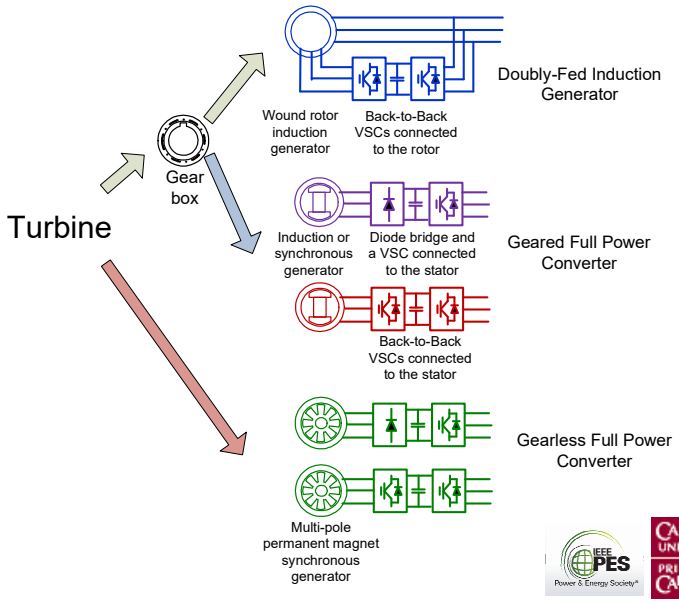
Fixed speed wind turbine



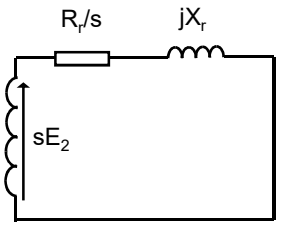
Variable speed wind turbines

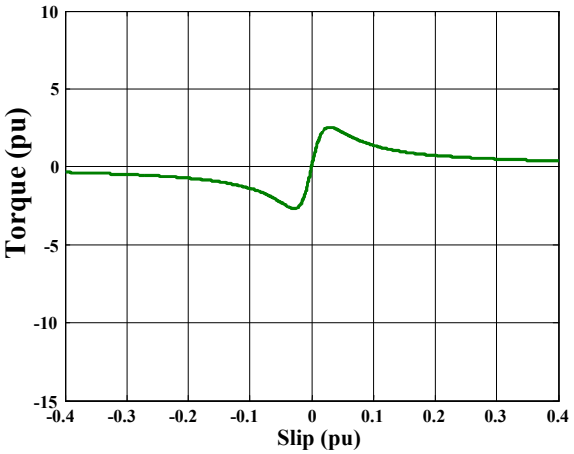


Doubly-fed arrangement

- Variable speed operation is possible by absorbing or injecting slip power using an external means.
- The sub-synchronous or super-synchronous speeds can be obtained by feeding in or taking out electric power to/from the rotor.
- This is normally done by injecting a voltage into the rotor circuit through slip rings.

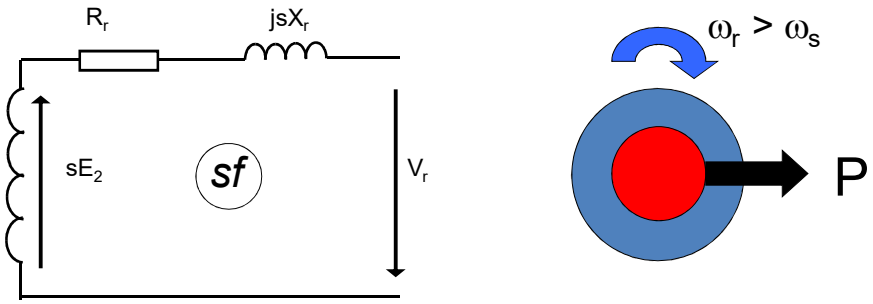
Zero rotor injection





Operates as a fixed speed machine

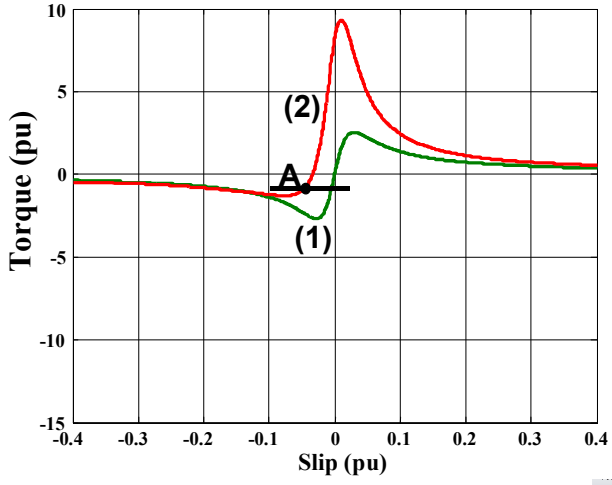
Negative injected voltage



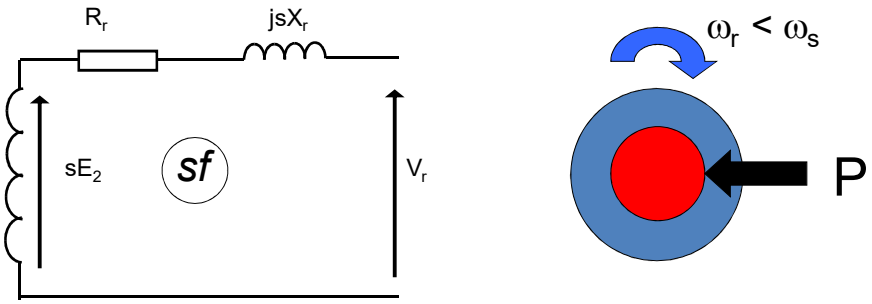
- Will deliver power from the rotor through the converters to the network.

Negative injected voltage

The DFIG wind turbine running at super-synchronous speed



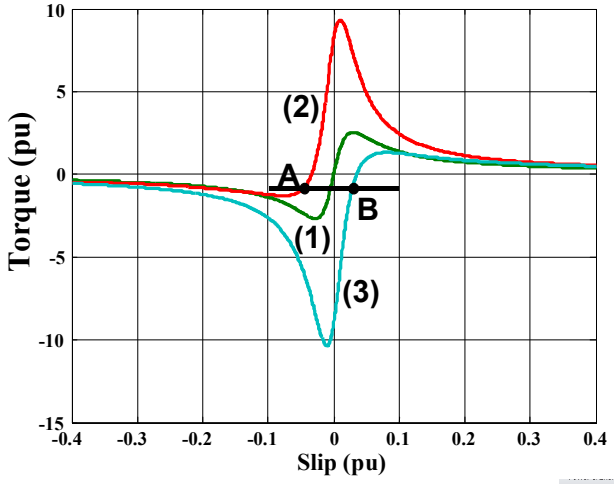
Positive injected voltage



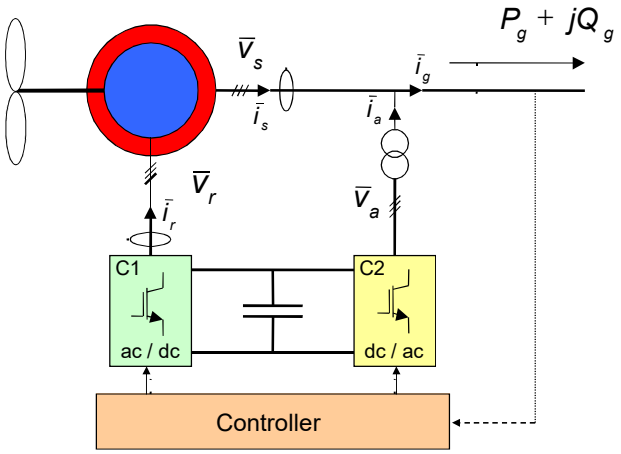
The DFIG rotor absorbs power.

Slip – torque curve

The DFIG wind turbine running at sub-synchronous speed



Doubly fed induction generator (DFIG)



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DFIG

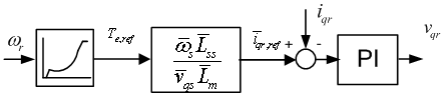
- Converter C1 inverts dc voltage into slip frequency ac
- It can inject both positive and negative voltages by properly controlling the switching signals
- Converter C2 maintains a constant voltage on the DC capacitor

Control of converter C1

- By injecting proper voltage through converter C1
  - Speed can be controlled for optimum power extraction.
  - No – load power factor of the generator can be controlled.
  - Terminal voltage of the generator can be controlled.

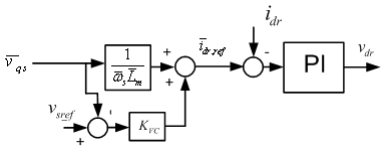
Control of DFIG wind turbines

❑ **Torque control in q-axis**



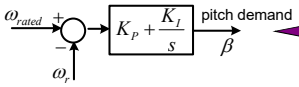
Maintaining the turbine operation point on the maximum power curve is by means of controlling the generator torque

❑ **Voltage control in d-axis**



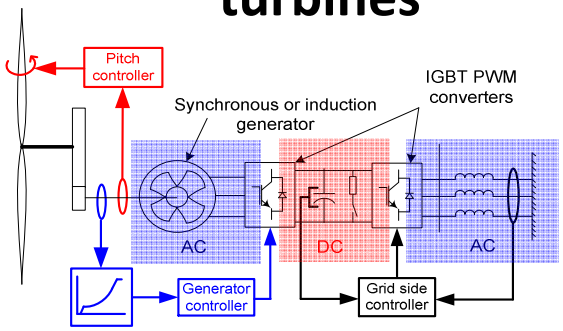
Generator terminal voltage is controlled by manipulating the reactive power supply from the generator

❑ **Pitch controller**



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

Fully rated converter (FRC) wind turbines



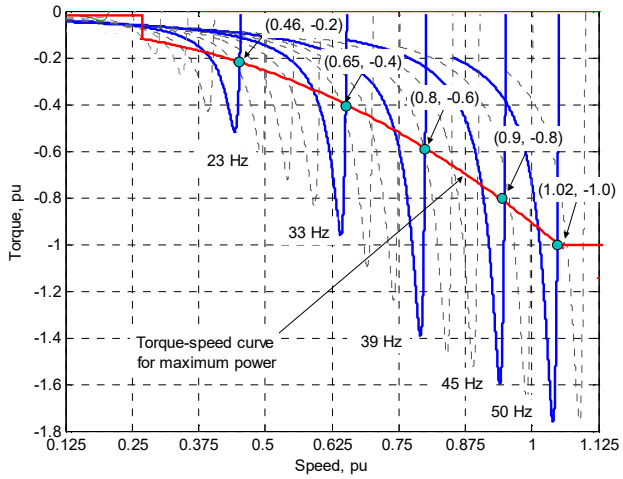
- DC-link totally decouple the generator from the grid
  - Grid frequency is decoupled, wind turbine can operate at any rotor speed
  - Grid voltage is decoupled, change in grid voltage does not affect the generator dynamics
- Gearbox can be avoided if a multi-pole synchronous generator is used, e.g. Enercon turbines with 64 poles

Control of FRC wind turbines

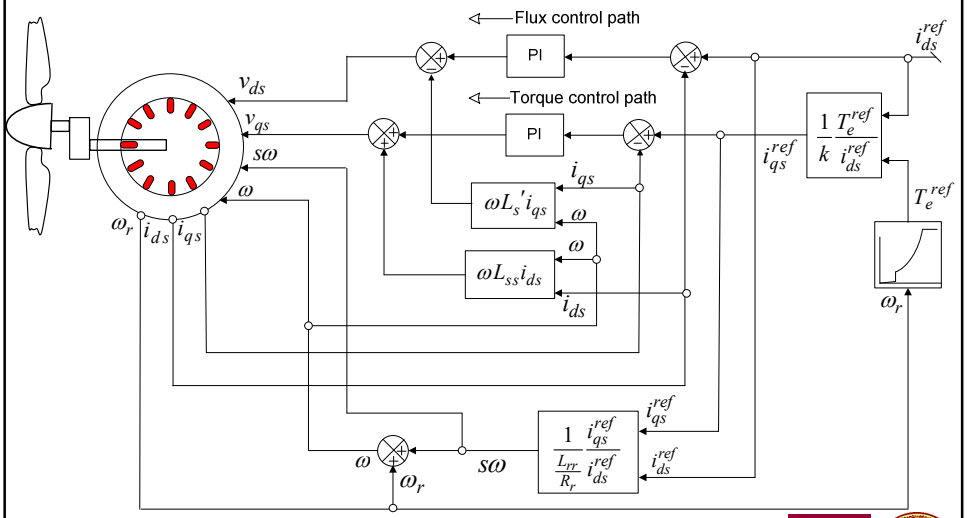
Machine side converter control

- In order to ensure maximum power extraction and wide speed range operation, the controller of machine side converter varies the operating frequency.
- This shifts the torque-speed curve and thus moves the operating point to match the maximum power extraction curve.

Control of FRC wind turbines

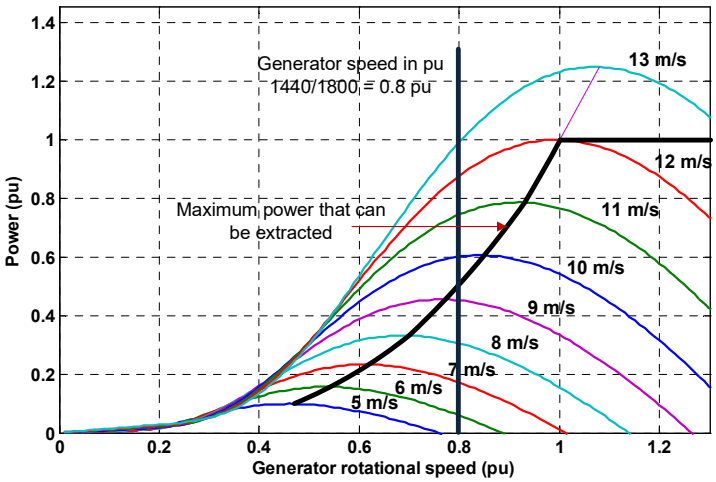


Control of FRC wind turbines



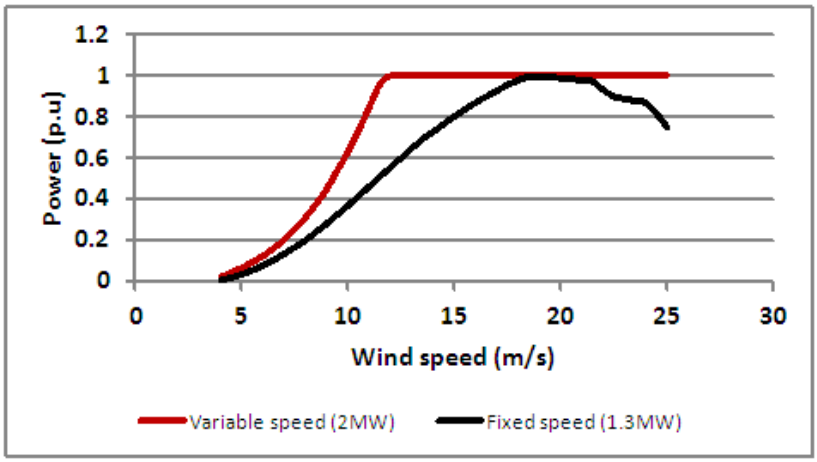
WHY VARIABLE SPEED?

Variable speed operation

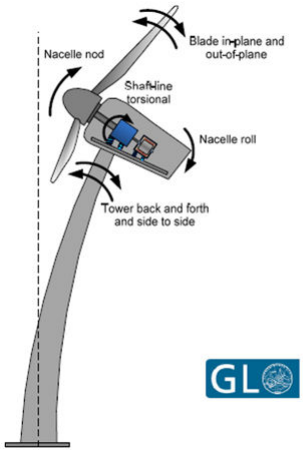


- To extract maximum power ω_r should vary with the wind speed

Power output



Forces on wind turbines



Loads on Blades

- Blade Flapwise bending
  Aerodynamic forces in flapwise direction
- Blade Edgewise bending
  Gravity forces
  Aerodynamic forces in edgewise direction

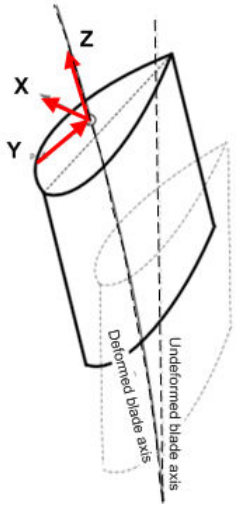
Loads on Rotor Hub

- In-plane bending moments of the blades
- Out-of-plane bending moments of the blades
- Drive train interaction – torque fluctuations due to control action

Loads on Tower

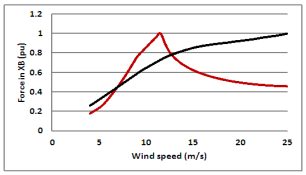
- Axial bending moment

Forces on wind turbines

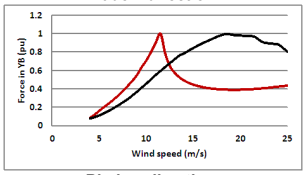


Fixed speed

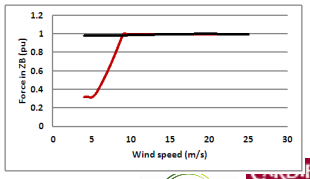
Variable speed



Blade x direction



Blade y direction



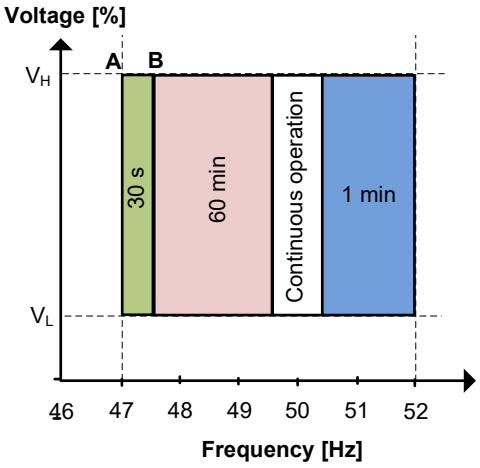
Blade z direction

GRID CODE REQUIREMENTS

Grid Codes

- Grid Codes specify the mandatory minimum technical requirements that a power plant should fulfil and additional support that may be called on to maintain the second-by-second power balance and maintain the required level of quality and security of the system.
- Grid Codes for wind farm connections demand requirements at the point of connection of the wind farm not at the individual wind turbine generator terminals.

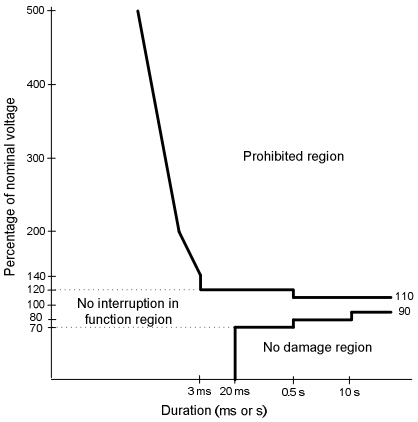
General Requirements



As most of the controllers employed in modern wind turbines are digital, the maximum allowable voltage limit for ICT should be considered.

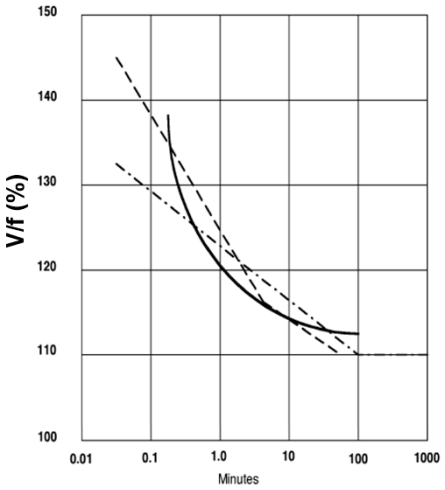
As all the wind turbines and PV parks are connected to the collector network through a transformer, a typical transformer V/f characteristic should be considered.

General Requirements



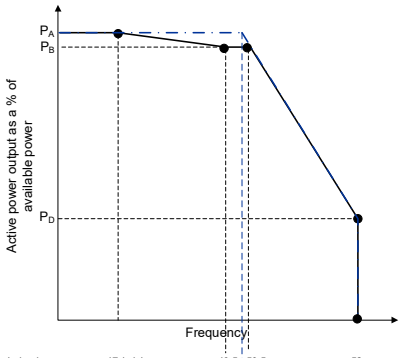
ITI (CBEMA) Curve

V/f characteristics of transformers



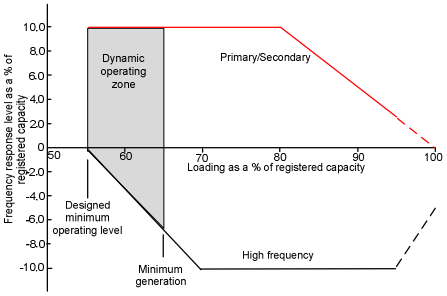
Active power control

Ireland, India, Denmark and Germany

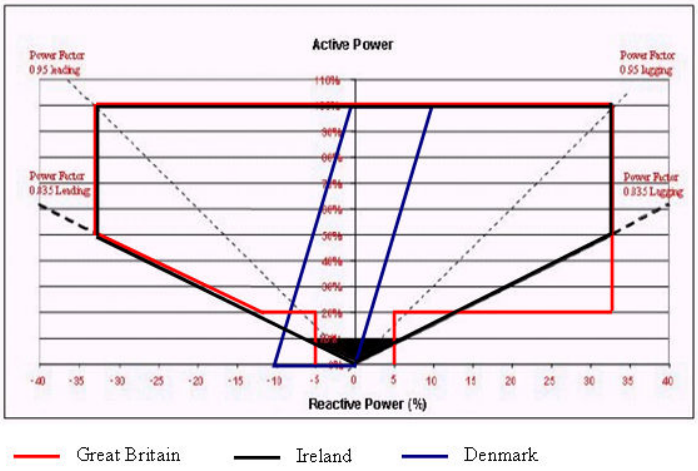


Ireland	47 (min)	49.5	50.5	52
Denmark	47 (min)	49.9	50.1	53
India		50.3		
Germany		50.2		

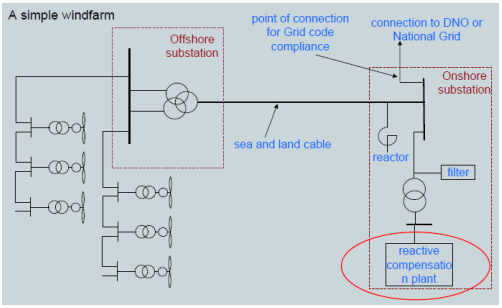
UK

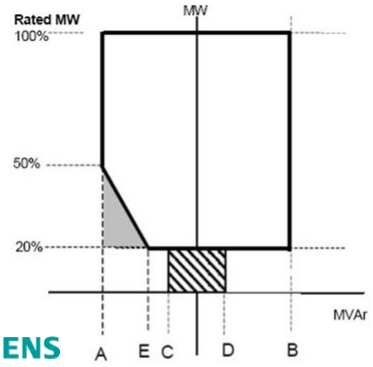


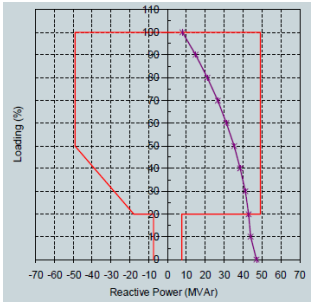
Reactive Power and Voltage Control



Reactive power requirements



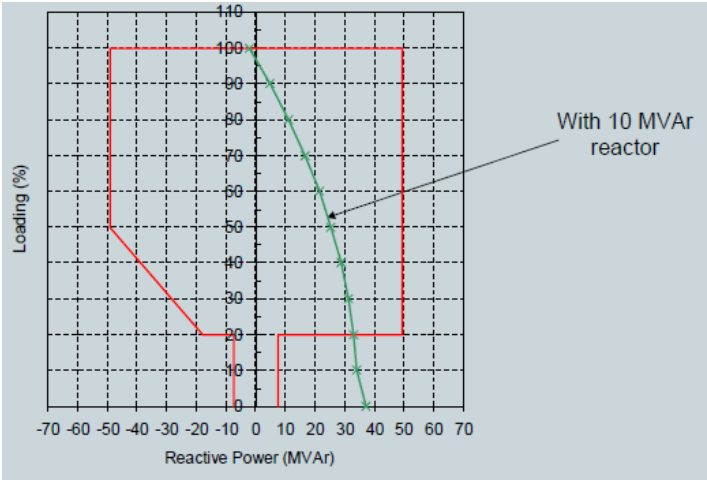




SIEMENS

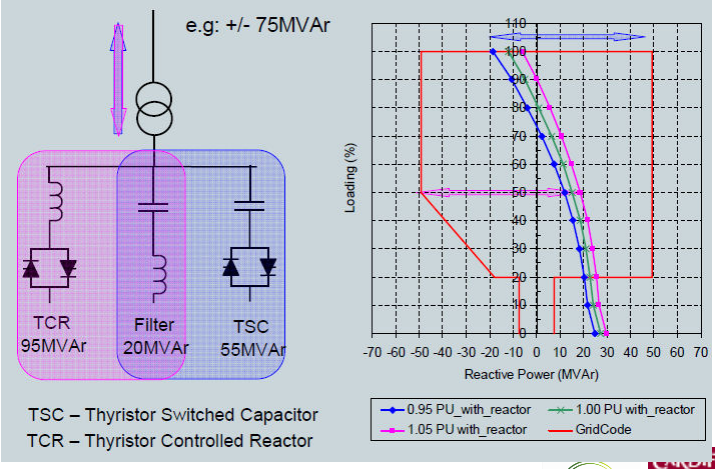
Point A is equivalent (in MVAr) to: 0.95 leading Power Factor at Rated MW output
Point B is equivalent (in MVAr) to: 0.95 lagging Power Factor at Rated MW output
Point C is equivalent (in MVAr) to: -5% of Rated MW output
Point D is equivalent (in MVAr) to: +5% of Rated MW output
Point E is equivalent (in MVAr) to: -12% of Rated MW output

Reactive power requirements



Reactive power requirements

- If reactive power requirement is not satisfied then a source of reactive power is required.



SIEMENS

Fault Ride-Through (FRT)

- With the penetration of wind generation increasing, Grid Codes now generally demand Fault Ride-Through capability for wind turbines connected to transmission networks.
- What is FRT?

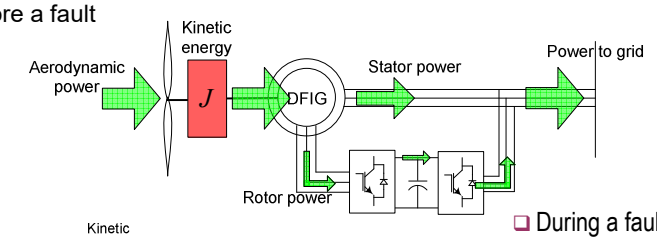
Pre
- Wind turbines operate normally and generate electricity

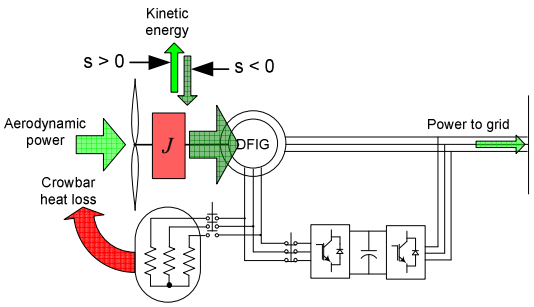
Fault
- Fault occurs and power generated from wind turbines can not be supplied.
- Generator speeds-up or DC cap voltage rise

Post
- Fault is cleared by a circuit breaker
- Generators should come back to normalcy

Grid disturbances and DFIG

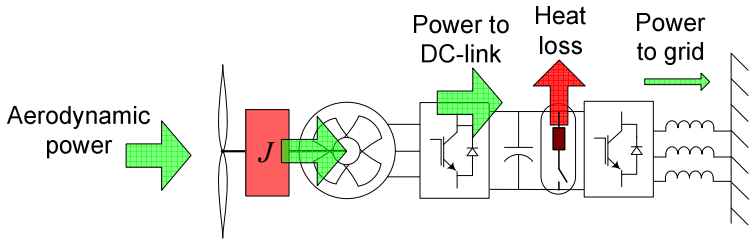
Before a fault



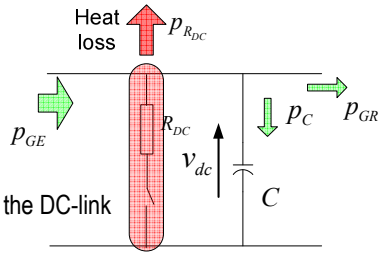


- During a fault, terminal voltage of the generator goes to very low value. In order to maintain the power flows, the controller increases the rotor currents.
- Crowbar is employed to protect the converter when the rotor current increases beyond its maximum limit.

Grid disturbances and Full range

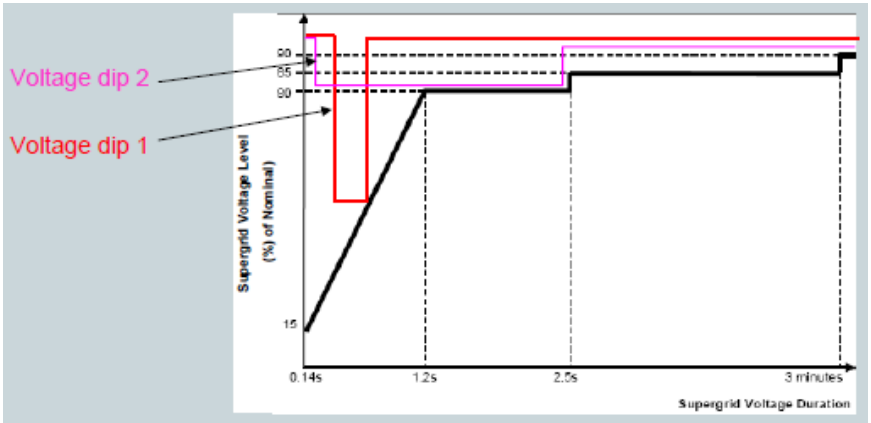


- During a fault, power to the grid is limited
- DC-link voltage rises rapidly
- Input power has to be reduced or excessive power has to be dissipated



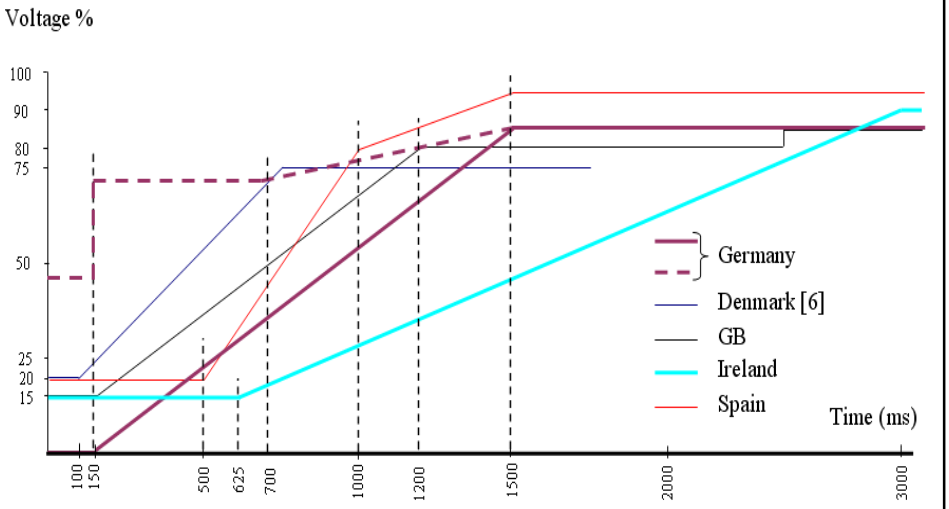
Chopper resistor at the DC-link

LVRT capability



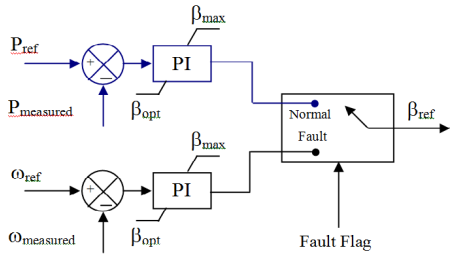
The wind farm and any constituent wind turbine generating unit must remain transiently stable and connected to the system without tripping for balanced voltage dips and associated durations anywhere on or above the heavy black line

LVRT capability requirements

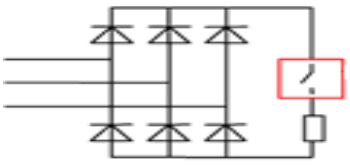


FRT capability of wind turbines

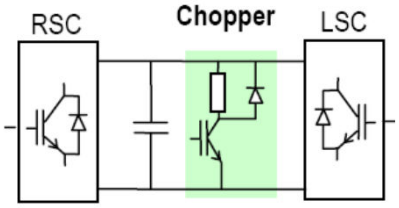
Fast pitching



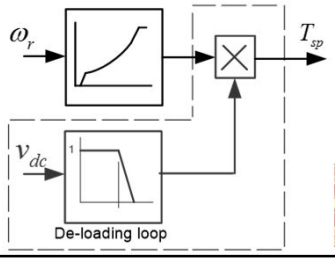
Active crowbar



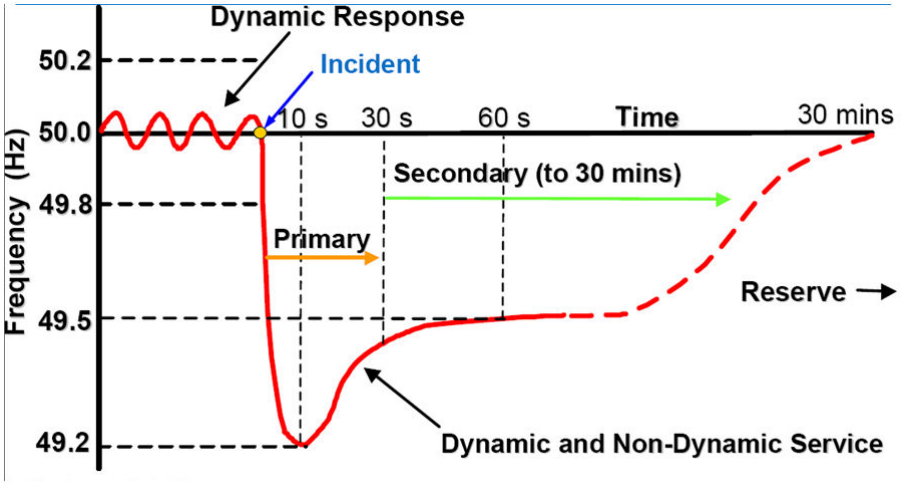
Braking resistor



De-loading

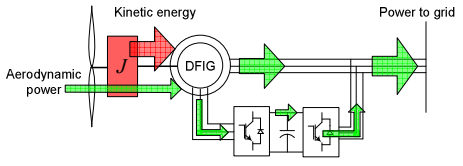


Primary response

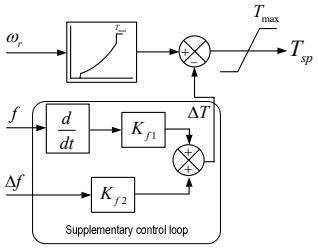


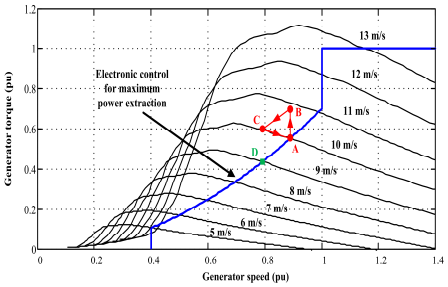
Frequency support from DFIG wind turbine

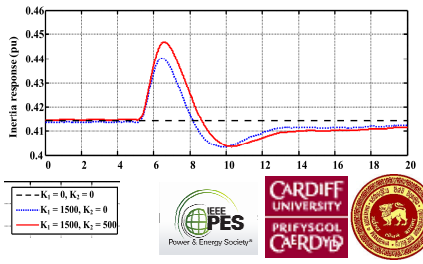
- Stored kinetic energy of the rotor is high and can be used to support the power system.



Inertia support







Concluding remarks

- Penetration of wind generation is increasing
- Large wind turbines and new technologies are emerging
- Utilities now expect wind farms to perform exactly like a large synchronous generator
  - This demands extra plants to be connected at the point of connection
  - In turn the CAPEX will increase

Thank you



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