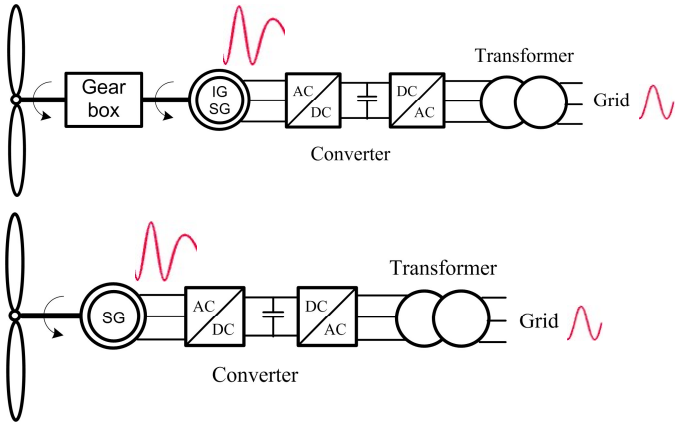
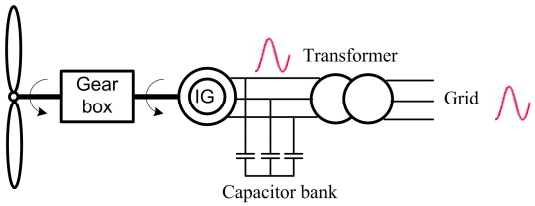
The electrical dynamics of generator and control system concepts

Full Variable Speed Wind Turbines

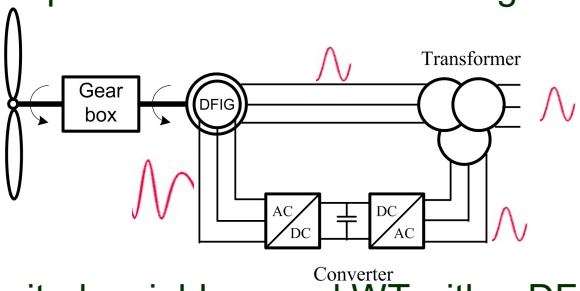


Full variable speed WT with an induction generator or a synchronous generator with and without gearbox.

Fixed and Limited Variable Speed Wind Turbines



Fixed speed WT with an induction generator



Limited variable speed WT with a DFIG

Advantages of Fixed and Variable Speed Systems

Fixed-Speed System	Variable-Speed System
Simple and inexpensive electrical system	Higher rotor efficiency, hence, higher energy capture per year
Fewer parts, hence higher reliability	Low transient torque
Lower probability of excitation of mechanical resonance of the structure	Fewer gear steps, hence inexpensive gear box
No frequency conversion, hence, no current harmonics present in the electrical system	Mechanical damping system not needed, the electrical system could provide damping if required
Lower capital cost	No synchronization problems
	Stiff electrical controls can reduce system voltage sags

Control options for wind turbines

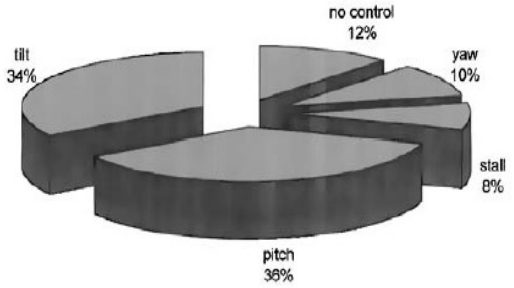
- Speed control
  - fixed speed
  - variable speed limited range
  - variable speed wide range
- Reactive power control
- Blade angle & active power control
  - fixed blade
  - pitchable blade
- Yaw control

highly dependent on generator type

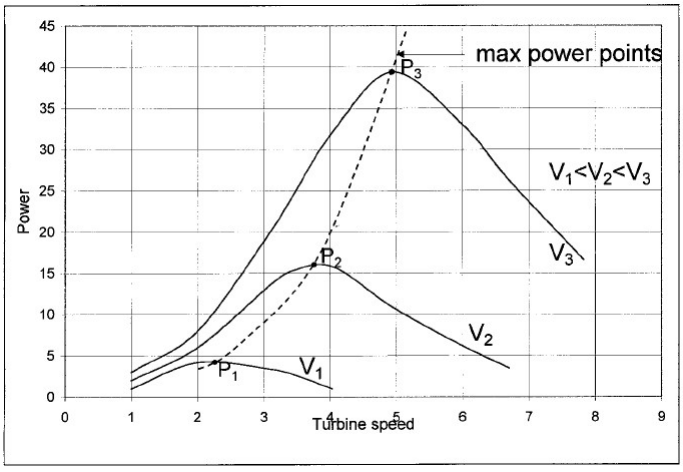
WT's Speed control

- no speed control whatsoever. In this method, the turbine, the electrical generator, and the entire system is designed to withstand the extreme speed under gusty wind.
- yaw and tilt control, in which the rotor axis is shifted out of the wind direction when the wind speed exceeds the design limit.
- pitch control, which changes the pitch of the blade with the changing wind speed to regulate the rotor speed.
- stall control. In this method of speed control, when the wind speed exceeds the safe limit on the system, the blades are shifted into a position such that they stall. The turbine has to be restarted after the gust has gone.

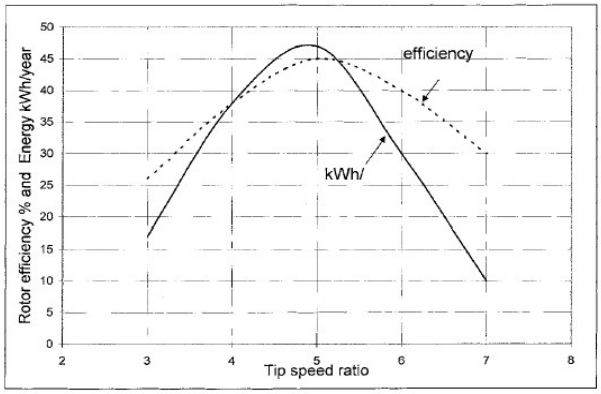
Speed control



Power-Speed curve

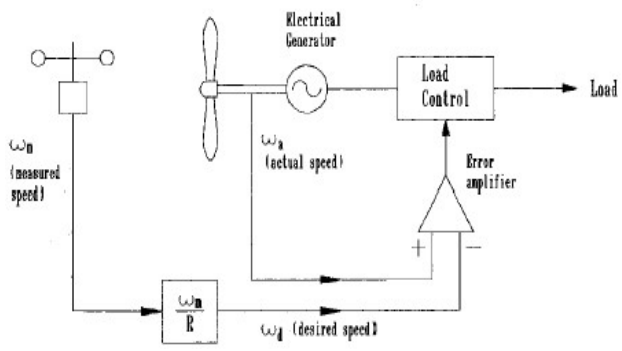


Variable speed operation

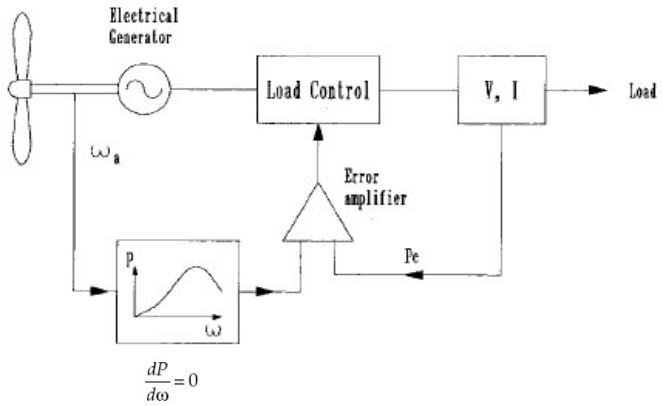


$$TSR = \frac{\textit{Linear speed of the blade outer most tip}}{\textit{Free upstream wind velocity}} = \frac{\omega \cdot R}{V}$$

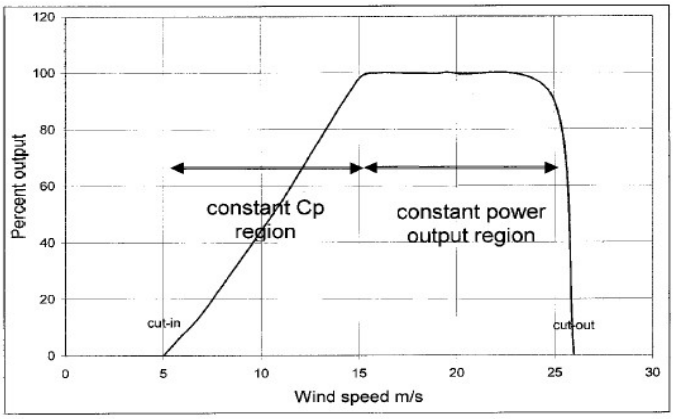
Rotor tip speed control to maximize output power



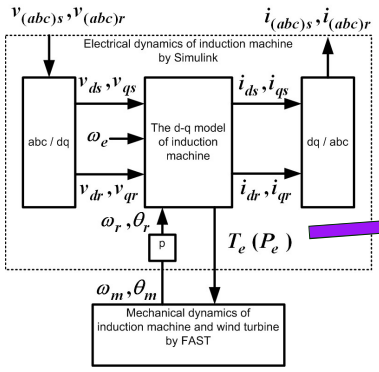
Maximum power operation using power control scheme.



Speed control regions



Modeling of Induction Machine



$$\frac{d}{dt}\varphi_{qs} = v_{qs} - \omega_e\varphi_{ds} + \frac{R_s}{\sigma L_s}\left(\frac{L_M}{L_r}\varphi_{qr} - \varphi_{qs}\right) \quad (1)$$

$$\frac{d}{dt}\varphi_{ds} = v_{ds} + \omega_e\varphi_{qs} + \frac{R_s}{\sigma L_s}\left(\frac{L_M}{L_r}\varphi_{dr} - \varphi_{ds}\right) \quad (2)$$

$$\frac{d}{dt}\varphi_{qr} = v_{qr} - (\omega_e - \omega_r)\varphi_{dr} + \frac{R_r}{\sigma L_r}\left(\frac{L_M}{L_s}\varphi_{qs} - \varphi_{qr}\right) \quad (3)$$

$$\frac{d}{dt}\varphi_{dr} = v_{dr} + (\omega_e - \omega_r)\varphi_{qr} + \frac{R_r}{\sigma L_r}\left(\frac{L_M}{L_s}\varphi_{ds} - \varphi_{dr}\right) \quad (4)$$

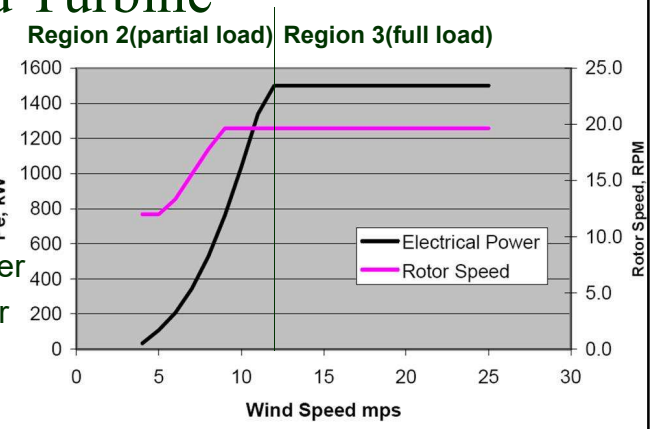
$$i_{qs} = \frac{1}{\sigma L_s}\varphi_{qs} - \frac{L_M}{\sigma L_r L_s}\varphi_{qr}, i_{ds} = \frac{1}{\sigma L_s}\varphi_{ds} - \frac{L_M}{\sigma L_r L_s}\varphi_{dr}$$

$$i_{qr} = \frac{1}{\sigma L_s}\varphi_{qr} - \frac{L_M}{\sigma L_r L_s}\varphi_{qs}, i_{dr} = \frac{1}{\sigma L_s}\varphi_{dr} - \frac{L_M}{\sigma L_r L_s}\varphi_{ds}$$

$$T_e = \frac{1.5pL_M}{\sigma L_s L_r}(\varphi_{qs}\varphi_{dr} - \varphi_{ds}\varphi_{qr})$$

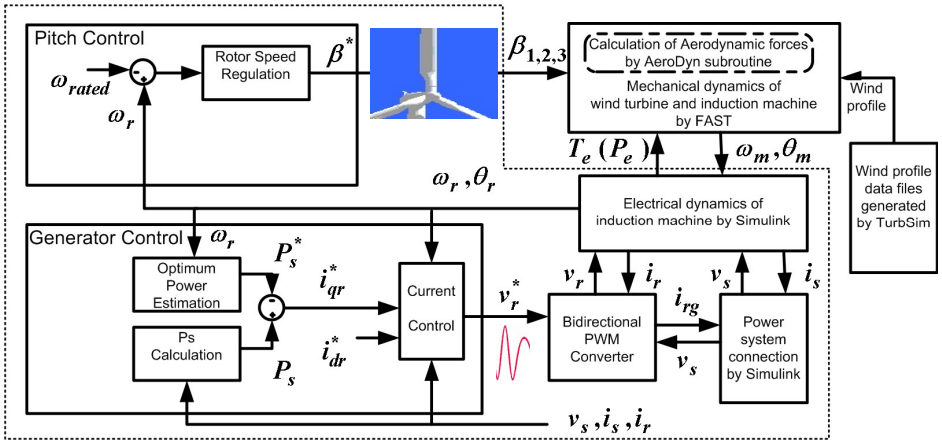
The Control Concept of a Variable Speed Wind Turbine

- Pitch controller
- DFIG Controller
  - Current controller
  - Power controller

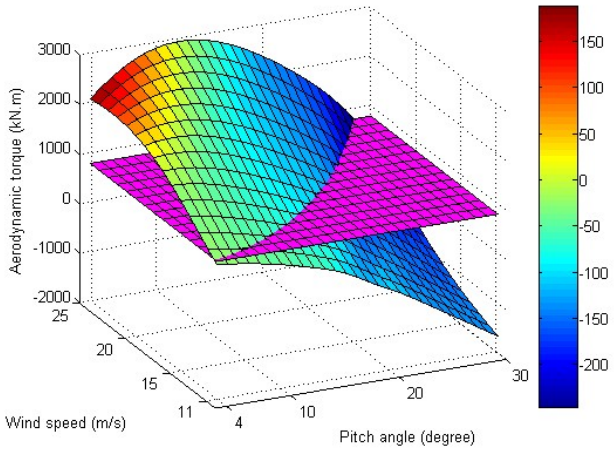


The power curve and desired rotor speed for the wind turbine

The Overall Control Structure

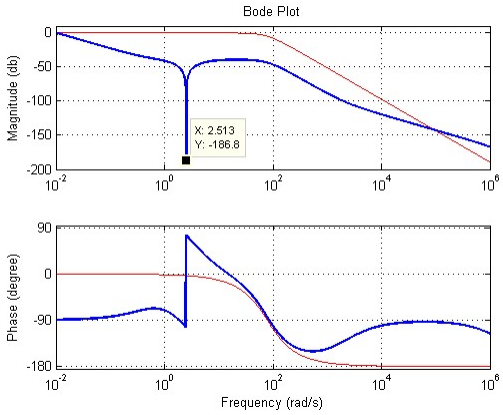


The Aerodynamic Torque Versus Wind Speed and Pitch Angle



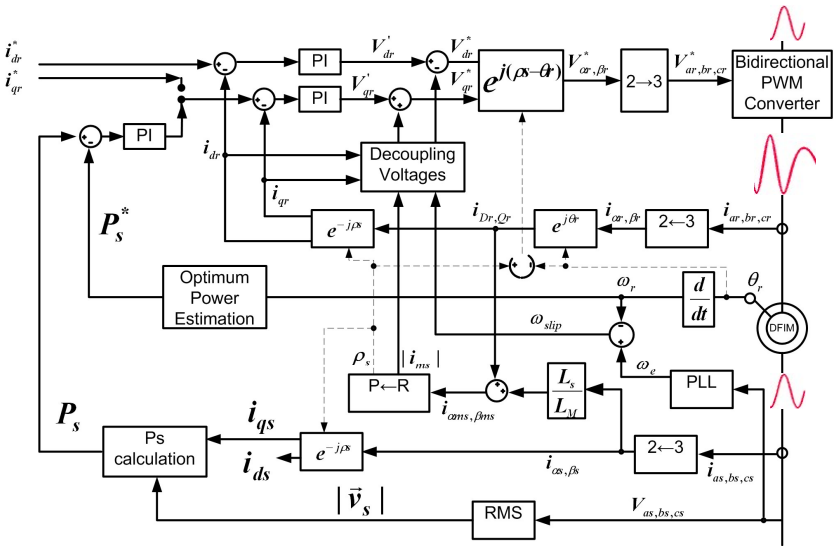
The variation of rotor aerodynamic torque versus wind speed for various blade pitch angles at rotation speed of 20 rpm.

The Bode Diagram for Pitch Control System (with Filter) and Pitch Actuator



The frequency response of the actuator and pitch control system.

The Control Scheme for the Doubly-Fed Induction Generator (DFIG)



The Relation Between Optimum Stator Power and Rotation Speed