Renewable Electric Energy Systems EE—546

Wind Power Generation

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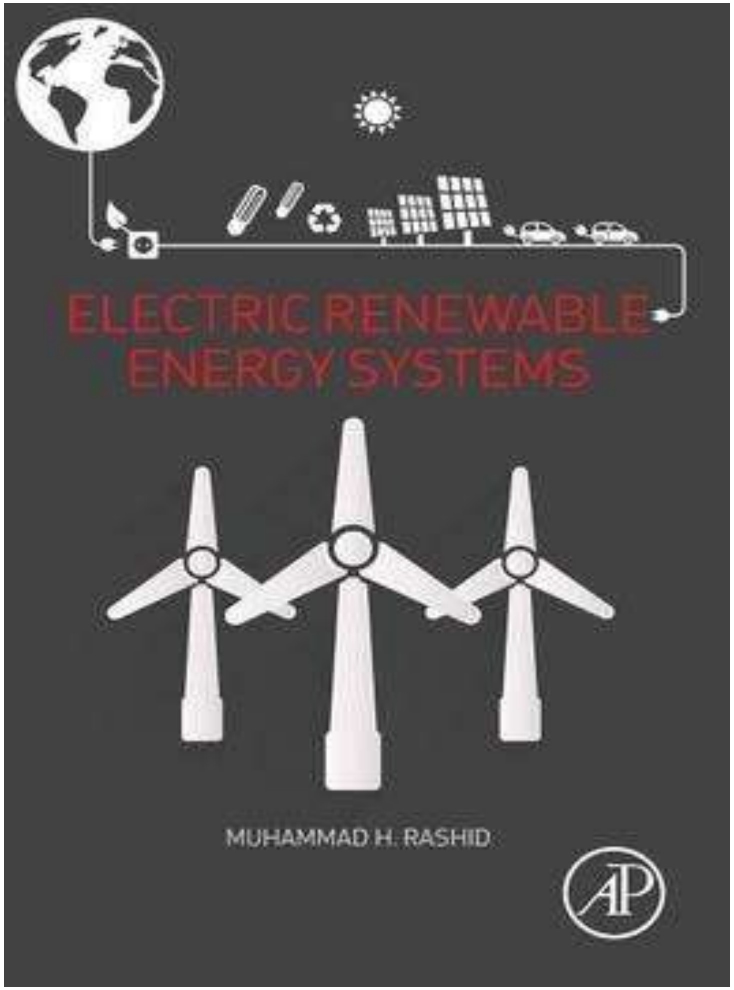
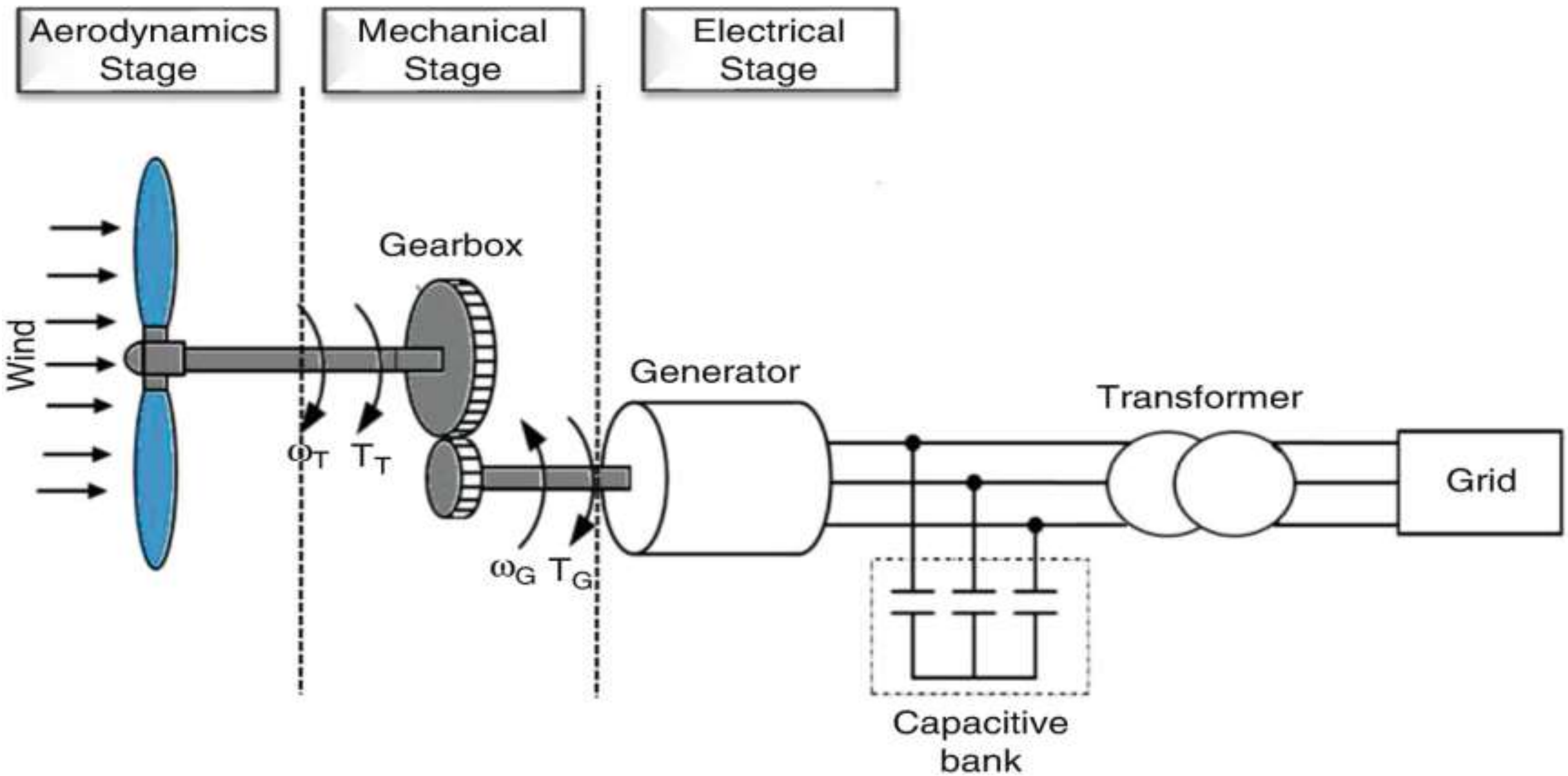
Wind Power Generation Part—1: Slides are prepared



Muhammad H. Rashid—Electric Renewable Energy Systems

Introduction

Conventional energy sources such as natural gas, oil, coal, or nuclear are finite but still hold the majority of the energy market. However, renewable energy sources like wind, fuel cells, solar, biogas/biomass, tidal, geothermal, etc. are clean and abundantly available in nature and hence are competing with conventional energy sources.



Introduction

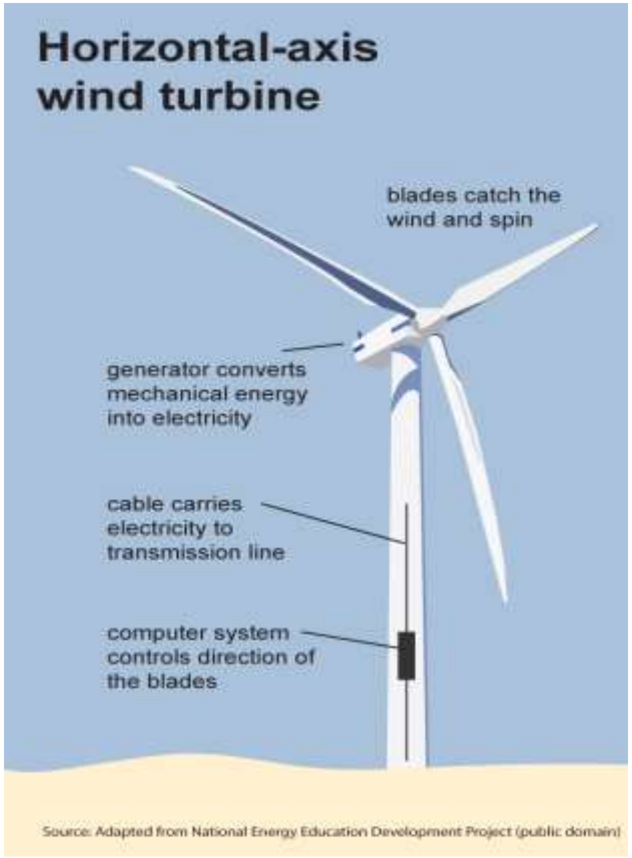
Among renewable energy sources wind energy has a huge potential of becoming a major source of renewable energy for this modern world. Wind power is a clean, emissions-free power generation technology.

As per the Global Wind Energy Council (GWEC) 2013 statistics, cumulative global capacity has reached to a total of 318 GW, which shows an increase of nearly 200 GW in the past 5 years. GWEC predicts that wind power could reach nearly 2000 GW by 2030, supply between 16.7% and 18.8% of global electricity and help save over 3 billion tons of CO_2 emissions annually.

Wind energy is the only power generation technology that can deliver the necessary cuts in CO_2 emissions from the power sector.
However, grid integration, voltage, and power fluctuation issues should adequately be addressed due to the huge penetration of wind power to the grid.

4.2 Wind turbine

The wind turbine is the most essential part of the wind energy system. It converts the kinetic energy associated with wind (known as wind energy) into mechanical energy and then to electrical energy.



GE 12MW offshore wind turbine

Wind turbine

Since then there have been major improvements in wind turbine technology and currently there are several wind farms successfully installed in different parts of world generating large amounts of power of the order of a few thousand megawatts. The following section will briefly explain different parts of the wind turbine: rotor blades, gearbox, generator, tower, yawing, brakes, cables, anemometer,
and pitch angle. These parts for the horizontal axis type turbine are shown in Figure 4.1.

Wind turbine

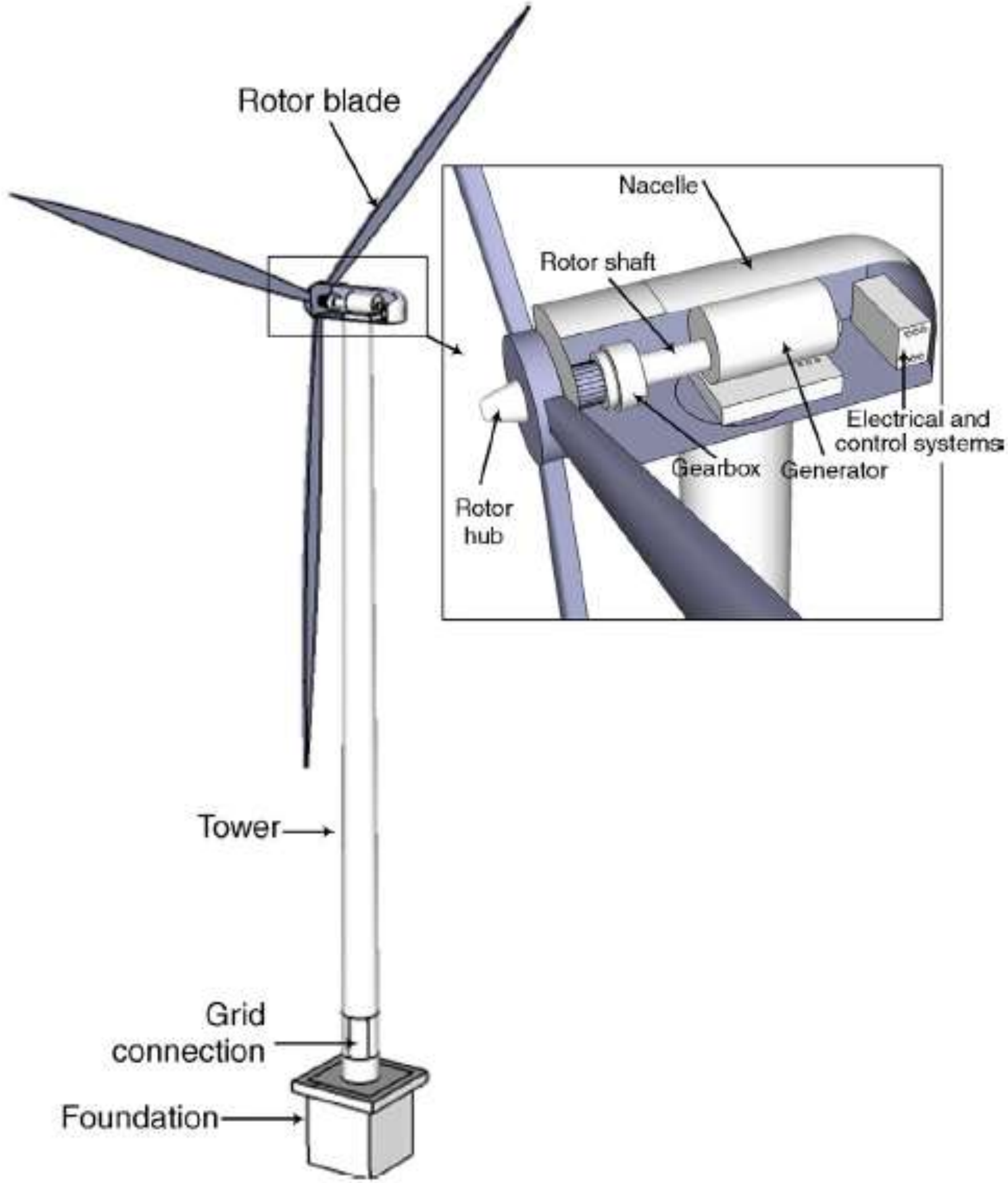


Figure 4.1 Parts of the horizontal axis wind turbine.

Wind turbine

The majority of wind turbines are the horizontal axis type with three blades. The turbine blades must have low inertial and good mechanical strength for durable and reliable operation. The blades are made up of aluminum or fiberglass reinforced polyester, carbon fiber reinforced plastics, or wood or epoxy laminates.

A schematic diagram of a rotor blade is given in Figure 4.2. The exterior shape of the blades is based on aerodynamics but the interior is determined by attention to strength.

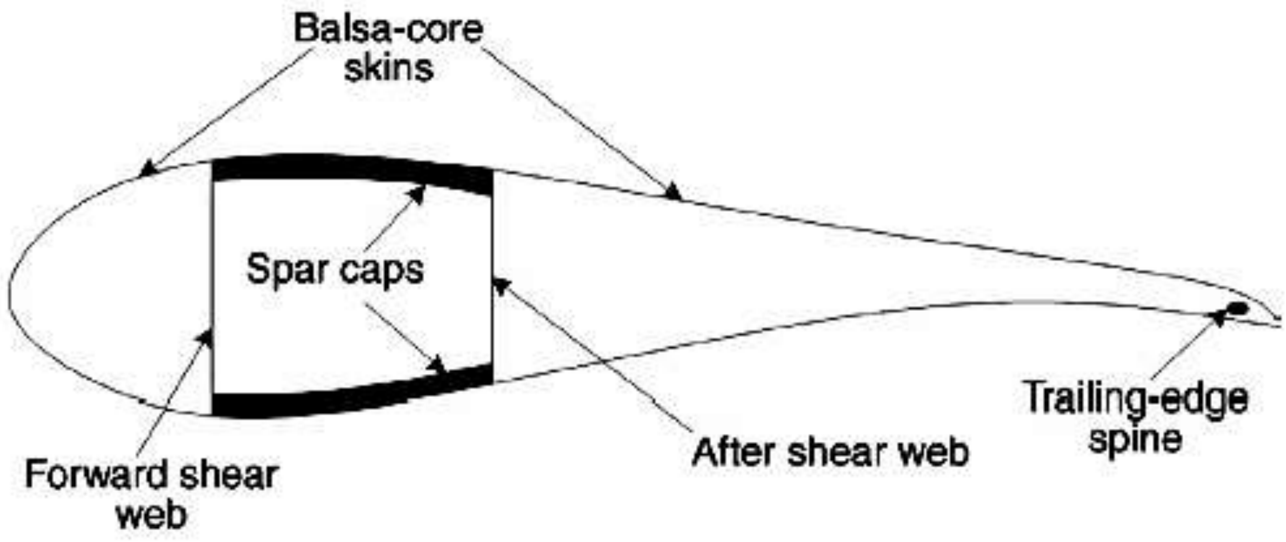
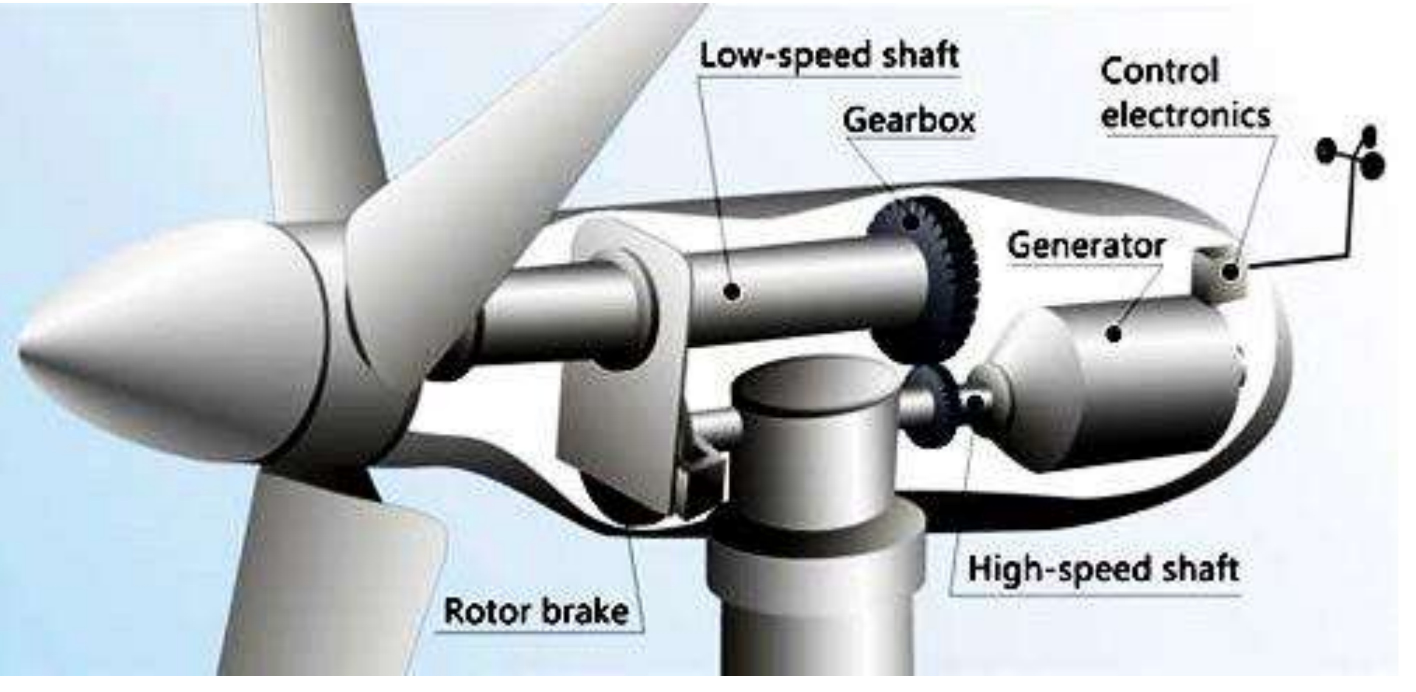


Figure 4.2 Schematic diagram of the blade.

Nacelle

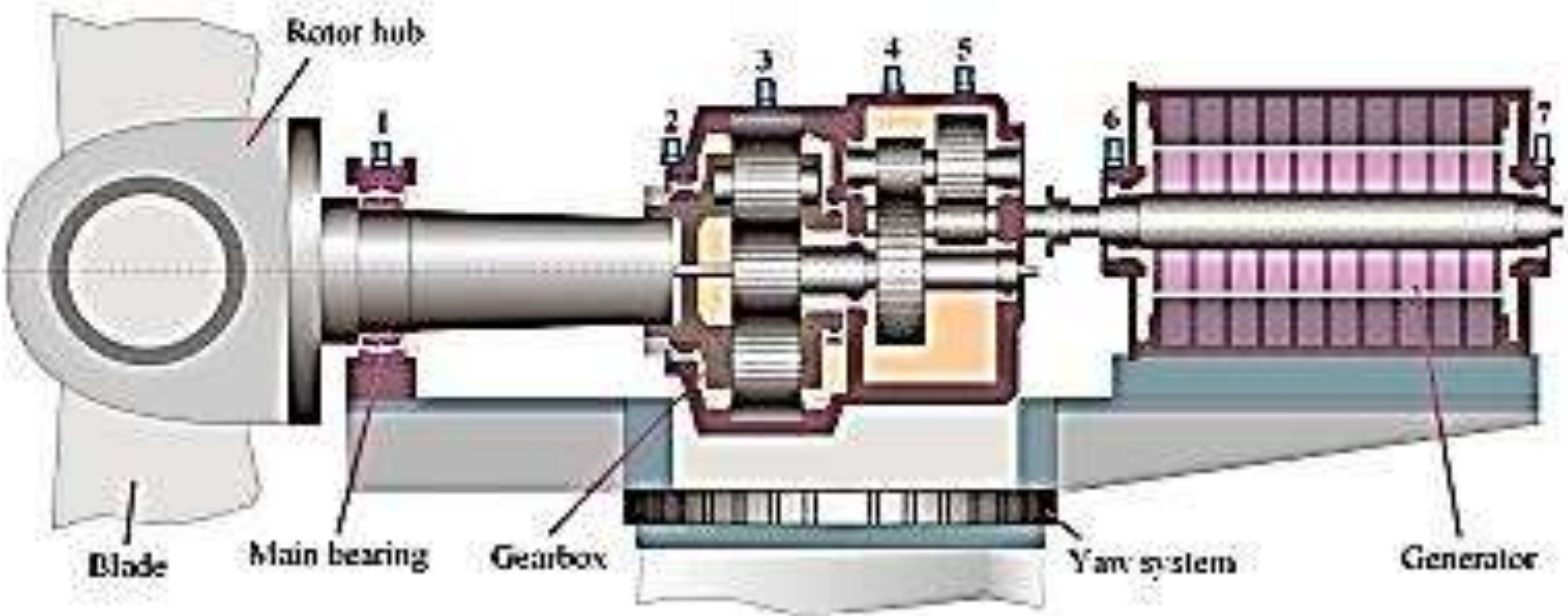
A nacelle is a box type structure that sits at the top of the tower and is attached to the rotor. The nacelle houses all of the generating components in a wind turbine, including the generator, gearbox, drive train, and brake assembly. The nacelle is made up of fiberglass and protects the wind turbine components from the environment. Modern
large farms have a helicopter-hoisting platform built on top of the nacelle, capable of
supporting service personnel.



Gearboxes

Mechanical power from the rotation of the wind turbine rotor is transferred to the generator rotor through the main shaft, the gearbox, and high-speed shaft. The wind turbine rotates at very slow speed. This requires a large number of poles to the generator.

For economic and optimal design it is necessary to have the gearbox between the wind turbine shaft and generator shaft to increase the speed. The gearbox is of a fixed speed ratio and mainly increases speed. The gear ratio is in the range 20–300.



Generators

The generators convert the mechanical energy into electrical energy. The generator has widely varying mechanical input. It is usually connected to the grid in high power systems. In low power ratings the generator may be working in isolation supplying power to the local grid. The generator generally produces variable frequency, variable voltage, three-phase alternating current (AC). This voltage is usually converted to DC, then to regulated and fixed frequency AC using an AC-to-DC/DC-to-AC converter.

Tower

Towers are used to mount the wind turbine. Wind energy yield increases with the height. But optimal design limits the height of the tower, as the cost of the tower will be very high if it is too tall. Towers are usually made of tubular steel or concrete. Tubular towers are conical in shape with their diameter decreasing toward the tip. Steel towers are expensive. An alternate solution is concrete towers.

Yaw mechanism

Horizontal axis wind turbines use forced yawing where generators and gearboxes keep the rotor blades perpendicular to the direction of the wind. The upwind machines use brakes on the yaw mechanism. The yaw mechanism is activated by automatic control, which monitors the rotor. Cable carries the current from the wind turbine down through the tower. The yaw mechanism also should be equipped to protect the cable should it become twisted.

Brakes

There are three main types of braking mechanism, namely aerodynamic brakes, electro brakes, and mechanical brakes. In the case of aerodynamic brakes, the blades are tuned such that the lift effect disappears. In electro blades, the electrical energy is dumped into a resistor bank. In mechanical type brakes, the disc or drum brakes are used to lock the blades.

Protection of Wind Turbines

Wind turbines need to be protected against overheating, over-speed, and overloading.

Vibration is one of the main sources of turbine failure.

Wind direction and wind speed are also important for the satisfactory operation of the turbine.

The sensors installed on WT are temperature of the gearbox, temperature of the generator, voltage–frequency measurement, speed measurement, etc.

Kinetic energy of wind

Kinetic energy in a packet of air of mass $\boldsymbol{m}$ flowing at speed $\boldsymbol{v}_{\mathbf{w}}$ in the $\boldsymbol{x}$ direction is:

$$E_{w} = \frac{1}{2} m v_{w}^{2} = \frac{1}{2} (\rho A x) v_{w}^{2} \quad (4.1)$$

where, $\boldsymbol{E}_{\mathbf{w}}$ is the kinetic energy in joules, $\boldsymbol{A}$ is the cross-sectional area in m^2, $\boldsymbol{\rho}$ is the air density in kg/m^3, and $\boldsymbol{x}$ is the thickness of the parcel in m.

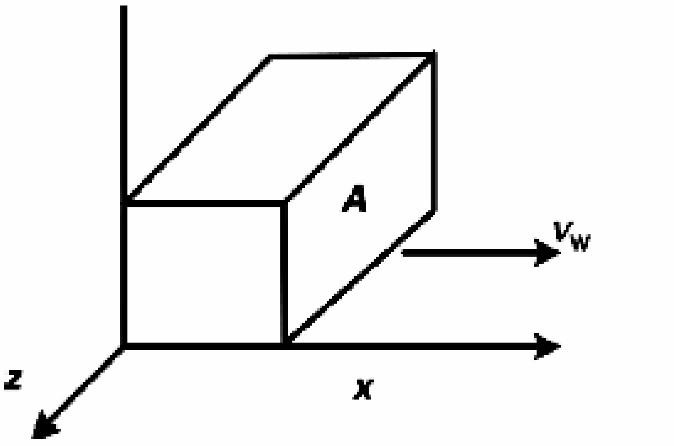


Figure 4.3 Packet of air moving in the x direction with speed v_w.

The power in the wind $\boldsymbol{P}_{\mathbf{w}}$ is the time derivative of the kinetic energy, given by:

$$P_{w} = \frac{dE_{w}}{dt} = \frac{1}{2} \rho A v_{w}^{2} \frac{dx}{dt} = \frac{1}{2} \rho A v_{w}^{3} \quad (4.2)$$

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Thus, the wind power is directly proportional to the cross-sectional area and the cube of the wind velocity.

Aerodynamic force

Ideal wind turbine output

Ideal wind turbine output can be viewed as the power being supplied at the origin to cause the energy of the parcel to increase according to Equation (4.1).

The physical presence of a wind turbine in a large moving air mass modifies the local air speed and pressure as shown in Figure 4.4.

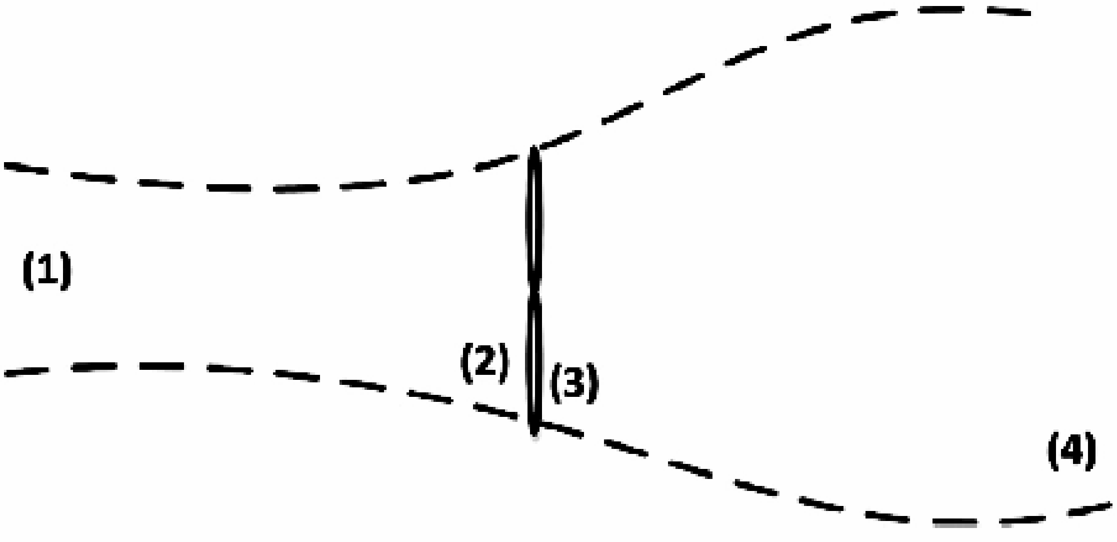

Figure 4.4 Circular tube of air flowing through ideal wind turbine.

Consider a tube of moving air with initial or undisturbed diameter d_1, speed v_{w1}, and pressure p_1, as it approaches the turbine. The speed of the air decreases as the turbine is approached, causing the tube of air to enlarge to the turbine diameter d_2. The air pressure will rise to the maximum just in front of the turbine and will drop below atmospheric pressure behind the turbine. Part of the kinetic energy in the air is converted

It can be shown [2,4,5] that under optimum conditions, when maximum power is being transferred from the tube of air to the turbine, the following relationships hold:

$$v_{w2} = v_{w3} = \frac{2}{3} v_{w1}; \qquad v_{w4} = \frac{1}{3} v_{w1} \tag{4.3a}$$

$$A_2 = A_3 = \frac{3}{2} A_1; \qquad A_4 = 3A_1 \tag{4.3b}$$

The mechanical power extracted is then the difference between the input and output power in the wind:

$$P_{m,\text{ideal}} = P_1 - P_4 = \frac{1}{2}\rho\left(A_1 v_{w1}^3 - A_4 v_{w4}^3\right) = \frac{1}{2}\rho\left(\frac{8}{9} A_1 v_{w1}^3\right) \tag{4.4}$$

This states that eight-ninths of the power in the original tube of air is extracted by an ideal turbine. This tube is smaller than the turbine, however, and this can lead to confusing results. The normal method of expressing this extracted power is in terms of the undisturbed wind speed v_{w1} and the turbine area, A_2. This method yields:

$$P_{\mathrm{m,ideal}} = \frac{1}{2}\rho\left[\frac{8}{9}\left(\frac{2}{3}A_2\right)v_1^3\right] = \frac{1}{2}\rho\left(\frac{16}{27}A_2 v_1^3\right) \tag{4.5}$$

Power output from practical turbines

The fraction of power extracted from the power in the wind by a practical wind turbine is usually given by the symbol C_p, standing for the coefficient of performance or power coefficient. Using this notation and dropping the subscripts of Equation (4.3), the actual mechanical power output can be written as:

$$P_m = C_p\left(\frac{1}{2}\rho A v_w^{\ 3}\right) = \frac{1}{2}\rho\pi R^2 v_w^{\ 3} C_p(\lambda,\beta) \tag{4.6}$$

where, R is the blade radius of wind turbine (m), v_w is the wind speed (m/s), and ρ is the air density (kg/m^3). The coefficient of performance is not constant, but varies with the wind speed, the rotational speed of the turbine, and turbine blade parameters like angle of attack and pitch angle. Generally it is said that power coefficient C_p is a function of tip speed ratio λ and blade pitch angle β (°).

Tip speed ratio

Tip speed ratio is the ratio of the circumferential velocity of the rotor at the end of the blade, that is, the maximum velocity v_m and the wind velocity v_w in front of the rotor blade. Originally it was defined as:

$$\lambda = \frac{v_m}{v_w} \tag{4.7}$$

A more popular form of tip speed ratio in the wind industry is as follows:

$$\lambda = \frac{\omega_R R}{v_w} \tag{4.8}$$

where, ω_R is the mechanical angular velocity of the turbine rotor in rad/s and v_w is the wind speed in m/s.

Coefficient of Performance and Turbine Efficiency

There will be energy loss in the mechanical components of the rotor, gear system, and generator. So the overall efficiency can be obtained as:

$$\eta = C_p \eta_m \eta_g$$

where η_m is the mechanical efficiency and η_g is the generator efficiency.

$$\eta = \frac{P_o}{(1/2)\rho A v_w^3}$$

where P_o is the electrical output power.

Coefficient of Performance and Turbine Efficiency

Typical C_p–λ curves for MOD-2 wind turbine is shown in Figure 4.5 for different values of β [6,7].

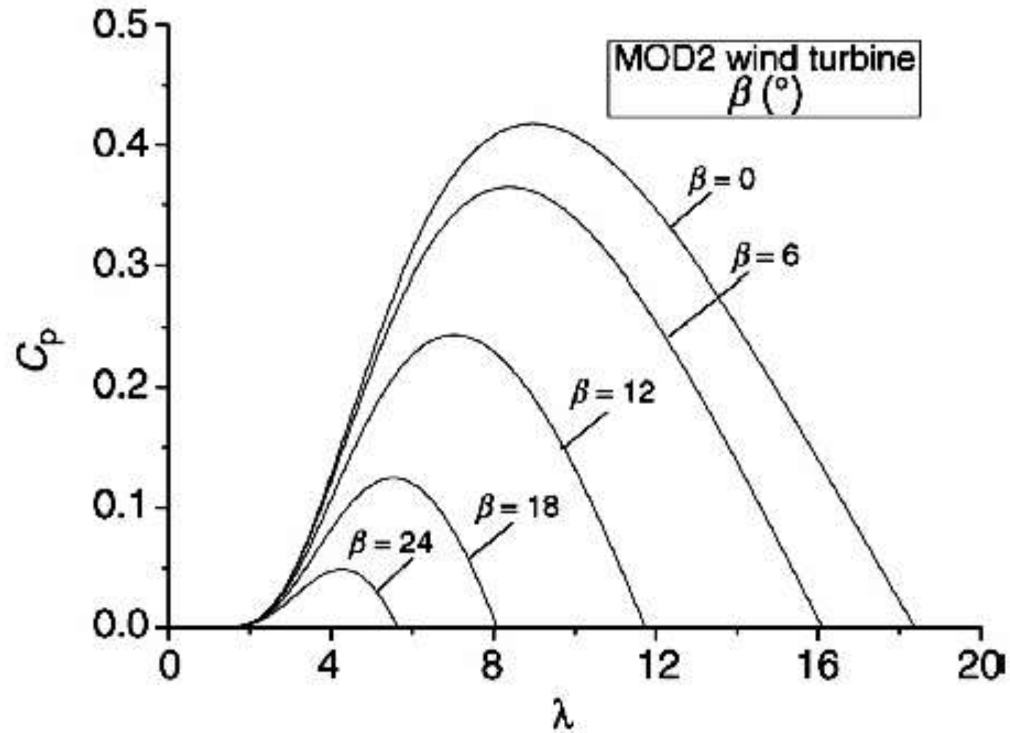

Figure 4.5 C_p–λ **curves for different pitch angles.**

Operating Range of Wind Turbine

Wind turbines are allowed to run only in a well-defined range of wind speed. A minimum wind speed is required for the blades to overcome inertia and friction. This minimum speed is called cut-in wind speed ($v_{\text{cut-in}}$). The typical value of cut-in wind speed is 3–5 m/s. At very high wind speed, say 25 m/s, in order to avoid damage to wind turbines, the wind turbines are stopped from rotating. This is called cut-out speed ($v_{\text{cut-out}}$). The operating range of a wind turbine can be best explained by a wind power curve as shown in Figure 4.6.

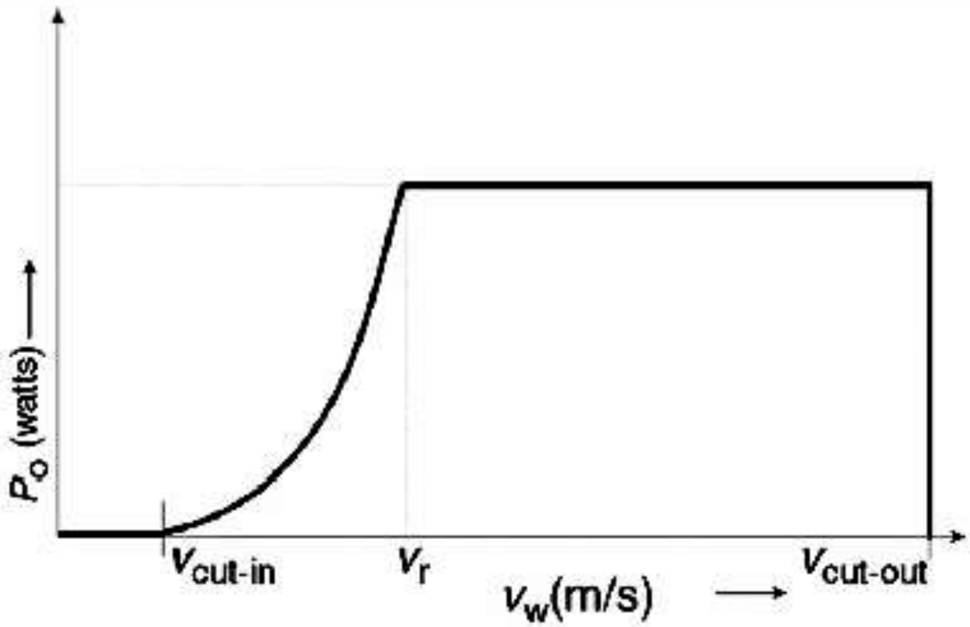

Figure 4.6 Output power versus wind speed.

Classifications of wind turbines

Horizontal axis wind turbine

Vertical axis wind turbine

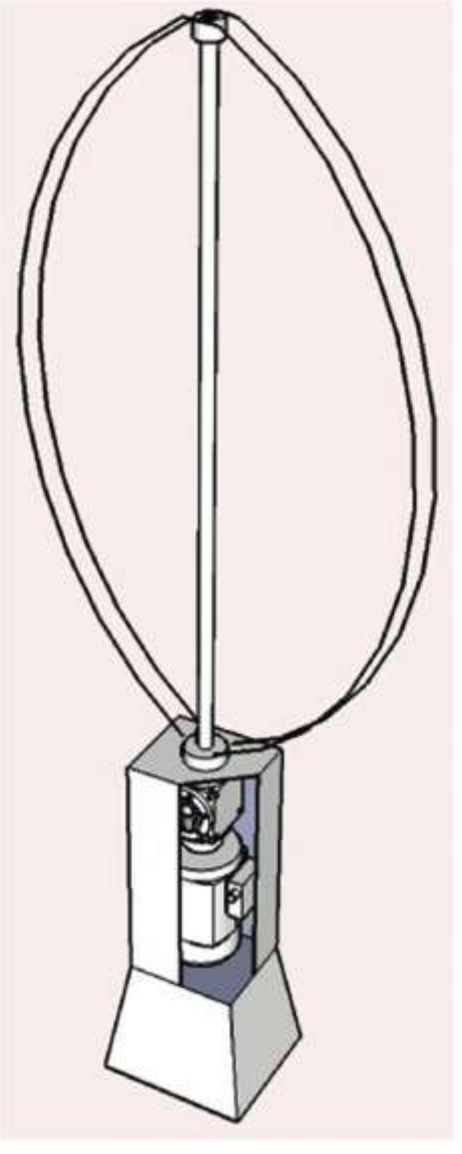

Figure 4.7 Darrius type vertical axis turbine.

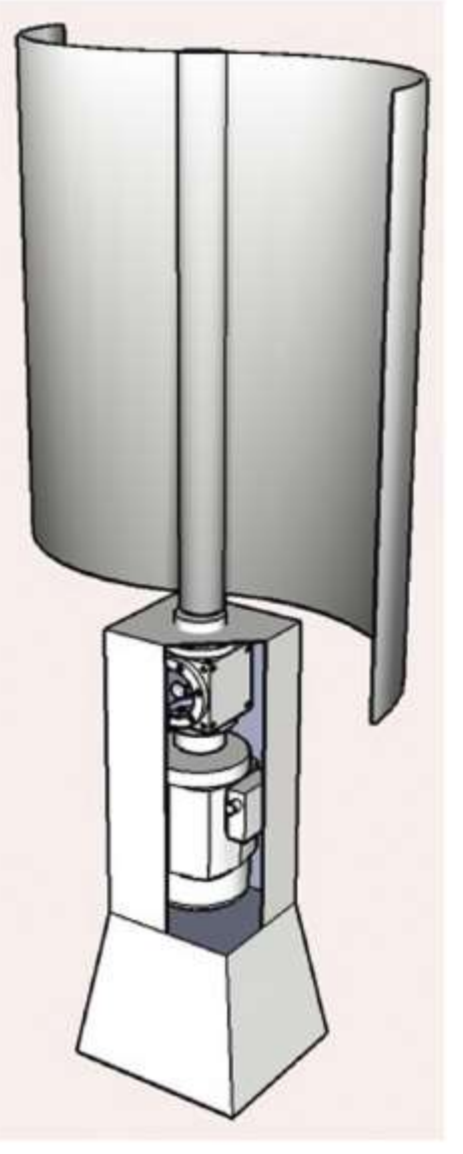

Figure 4.8 H type vertical axis turbine.

Maximum Power Point Tracking

For each instantaneous wind speed of a VSWT, there is a specific turbine rotational speed, which corresponds to the maximum active power from the wind generator. In this way, the maximum power point tracking (MPPT) for each wind speed increases the energy generation in the VSWT [8,9]. This is illustrated in Figure 4.12.

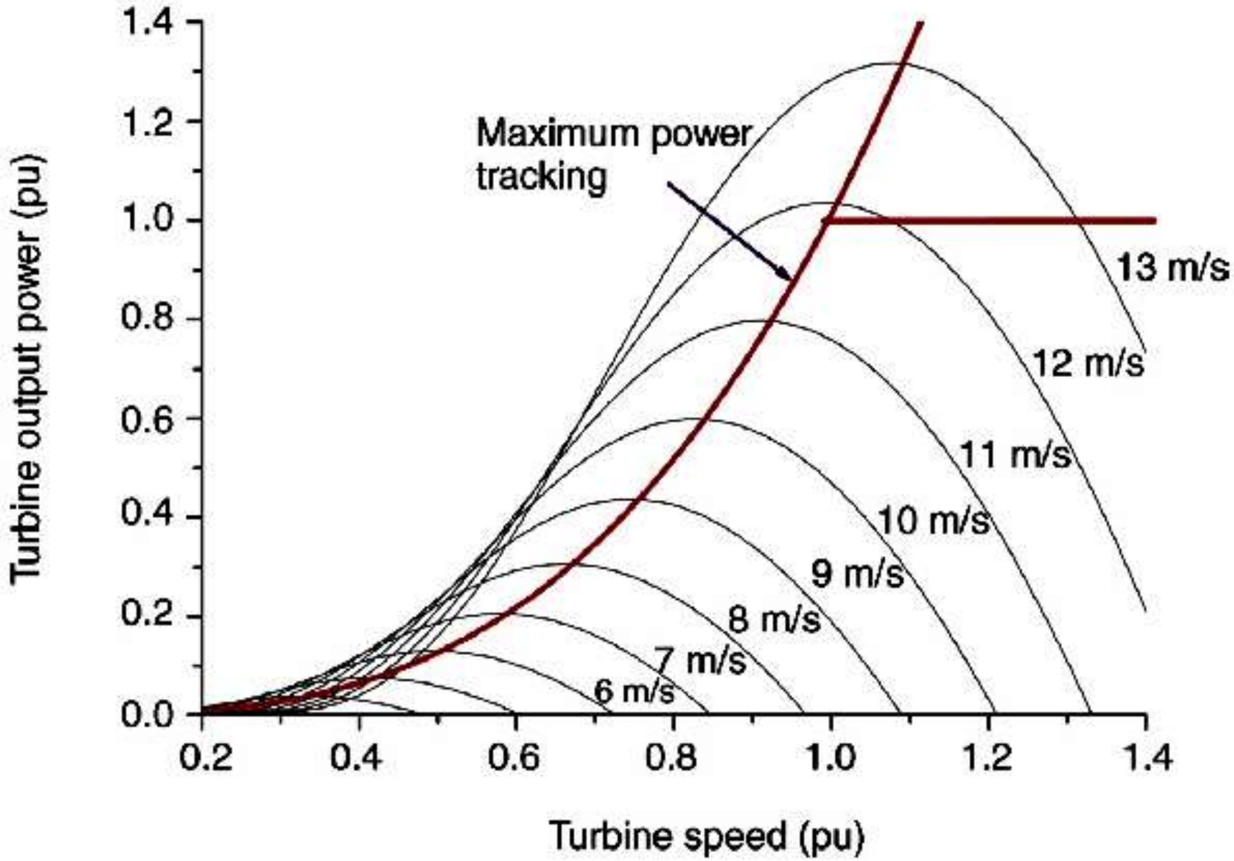

Figure 4.12 Turbine characteristic with maximum power point tracking.

End of Wind Power Generation—Part 1
Course Work