Electrical Power Engineering

Wind Power Plant:

Generating electricity from the wind requires that the kinetic energy of moving air be converted to mechanical and then electrical energy, thus the engineering challenge for the wind energy industry is to design cost effective wind turbines and power plants to perform this conversion. The amount of kinetic energy in the wind that is theoretically available for extraction increases with the cube of wind speed. However, a turbine only captures a portion of that available energy (see the Figure 1).

Specifically, modern large wind turbines typically employ rotors that start extracting energy from the wind at speeds of roughly 3 to 4 m/s (cut-in speed). A wind turbine increases power production with wind speed until it reaches its rated power level, often corresponding to a wind speed of 11 to 15 m/s. At still-higher wind speeds, control systems limit power output to prevent overloading the wind turbine, either through stall control, pitching the blades, or a combination of both.

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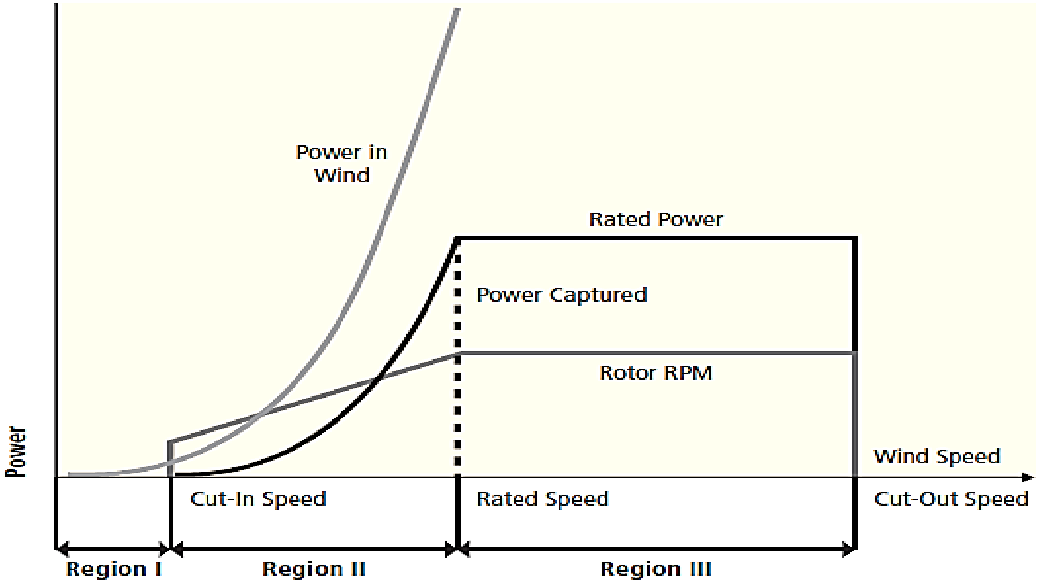
Most turbines then stop producing energy at wind speeds of approximately 20 to 25 m/s (cut-out speed) to limit loads on the rotor and prevent damage to the turbine's structural components.

In the 1970s and 1980s, a variety of onshore wind turbine configurations were investigated, including both horizontal and vertical axis designs (see the Figure 2). Gradually, the horizontal axis design came to dominate, although configurations varied, in particular the number of blades and whether those blades were oriented upwind or downwind of the tower.



(Figure 1)

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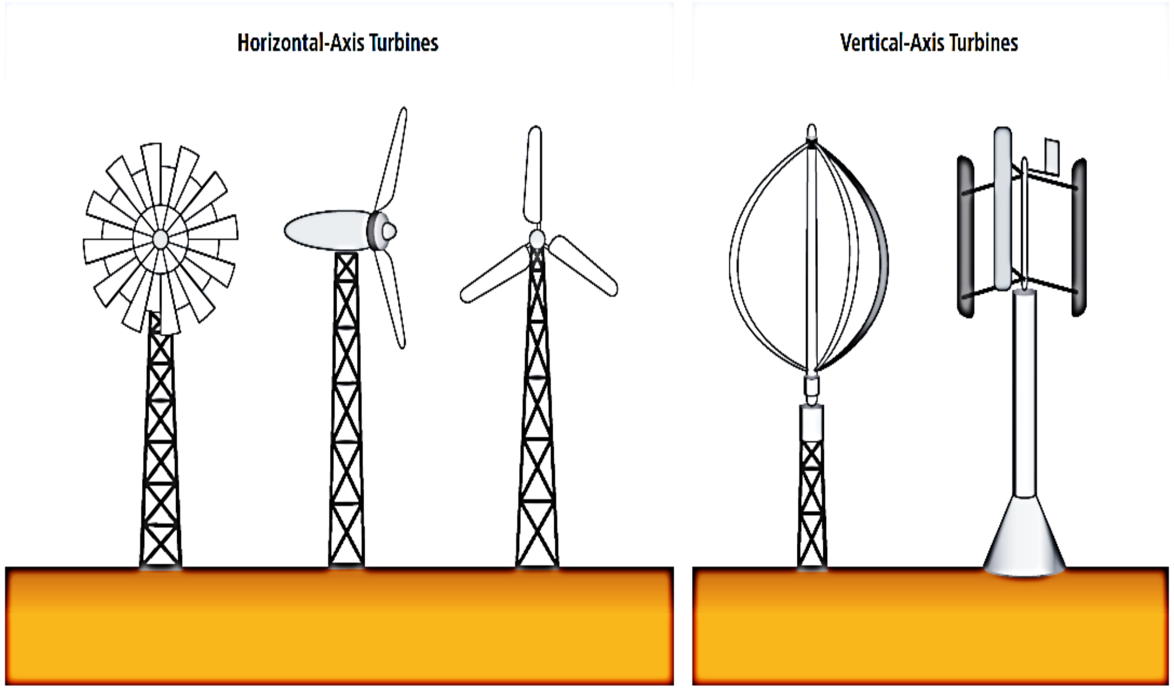
After a period of further consolidation, turbine designs largely centered (with some notable exceptions) around the three-blade, upwind rotor; locating the turbine blades upwind of the tower prevents the tower from blocking wind flow onto the blades and producing extra aerodynamic noise and loading, while three-bladed machines typically have lower noise emissions than two-bladed machines. The three blades are attached to a hub and main shaft, from which power is transferred (sometimes through a gearbox, depending on design) to a generator.



(Figure 2)

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The main shaft and main bearings, gearbox, generator and control system are contained within a housing called the nacelle. Figure 3 shows the components in a modern wind turbine with a gearbox; in wind turbines without a gearbox, the rotor is mounted directly on the generator shaft.

In the 1980s, larger machines were rated at around 100 kW and primarily relied on aerodynamic blade stall to control power production from the fixed blades. These turbines generally operated at one or two rotational speeds. As turbine size increased over time, development went from stall control to full-span pitch control in which turbine output is controlled by pitching (i.e., rotating) the blades along their long axis.

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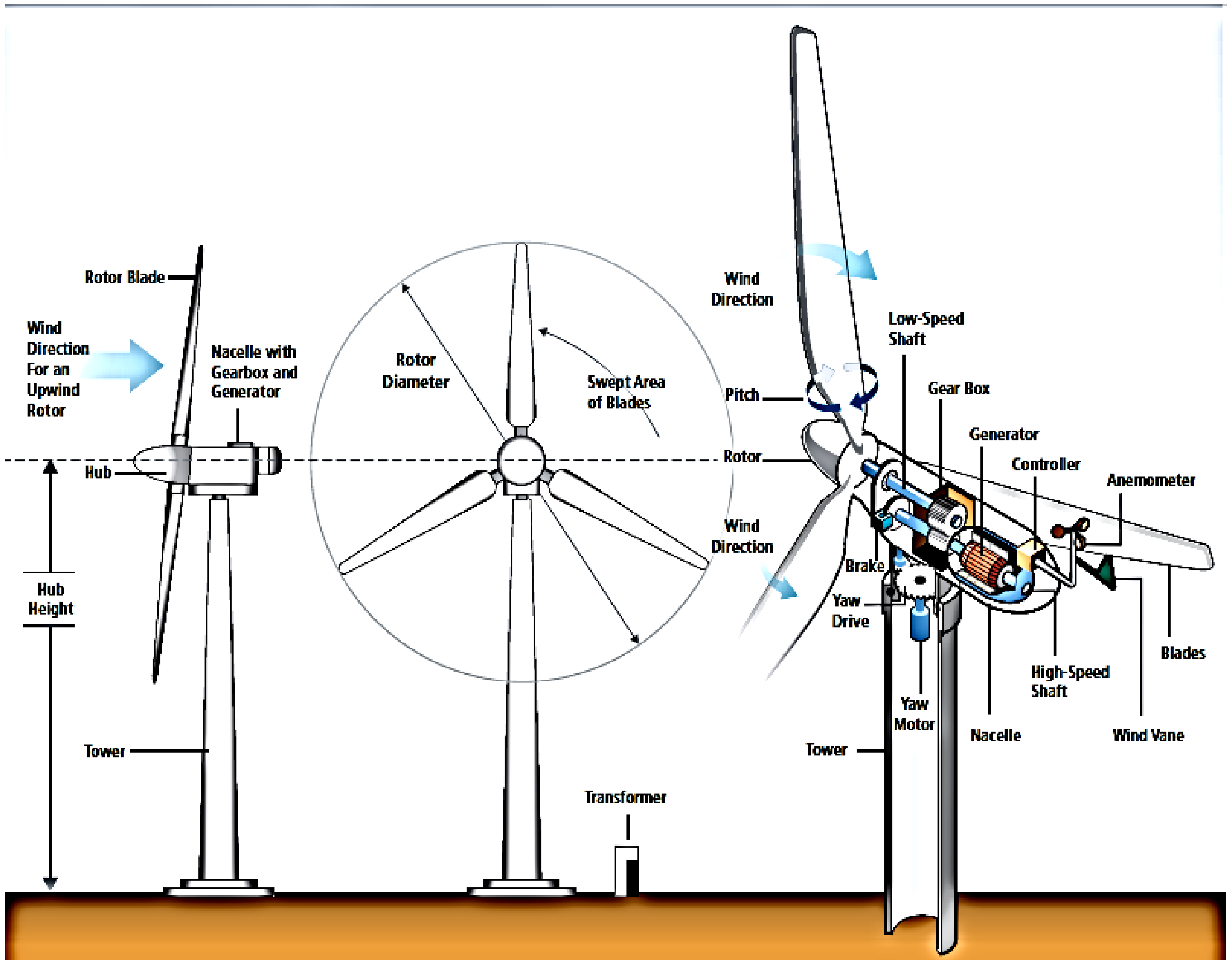

Figure (3)

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Over the past 30 years, average wind turbine size has grown significantly (Figure 4), with the largest fraction of onshore wind turbines installed globally in 2009 having a rated capacity of 1.5 to 2.5 MW; the average size of turbines installed in 2009 was 1.6 MW (BTM, 2010). As of 2010, wind turbines used onshore typically stand on 50- to 100-m towers, with rotors that are often 50 to 100 m in diameter; commercial machines with rotor diameters and tower heights in excess of 125 m are operating, and even larger machines are under development. Modern turbines operate with rotational speeds ranging from 12 to 20 revolutions per minute (RPM).

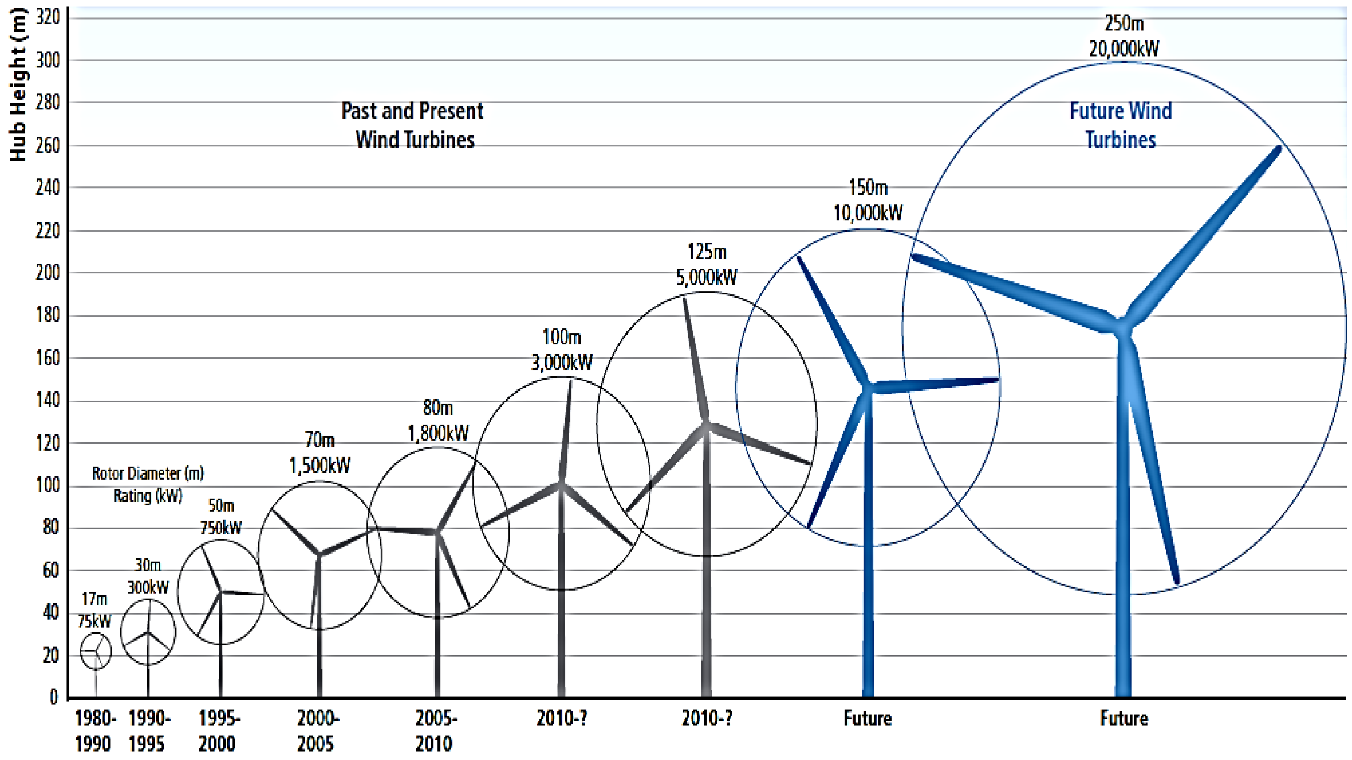

Figure (4)

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From an electric system reliability perspective, an important part of the wind turbine is the electrical conversion system. For large grid-connected turbines, electrical conversion systems come in three broad forms. Fixed-Speed Induction Generators were popular in earlier years for both stall-regulated and pitch-controlled turbines; in these arrangements, wind turbines were net consumers of reactive power that had to be supplied by the electric system.

For modern turbines, these designs have now been largely replaced with variable-speed machines. Two arrangements are common, Doubly-Fed Induction Generators and Synchronous Generators with a full power electronic converter, both of which are almost always coupled with pitch-controlled rotors.

Thanks