بسم الله الرحمن الرحيم

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Postgraduate (Pre-master) Course

Generation of Electrical Power from Renewable Resources

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Wind Power system

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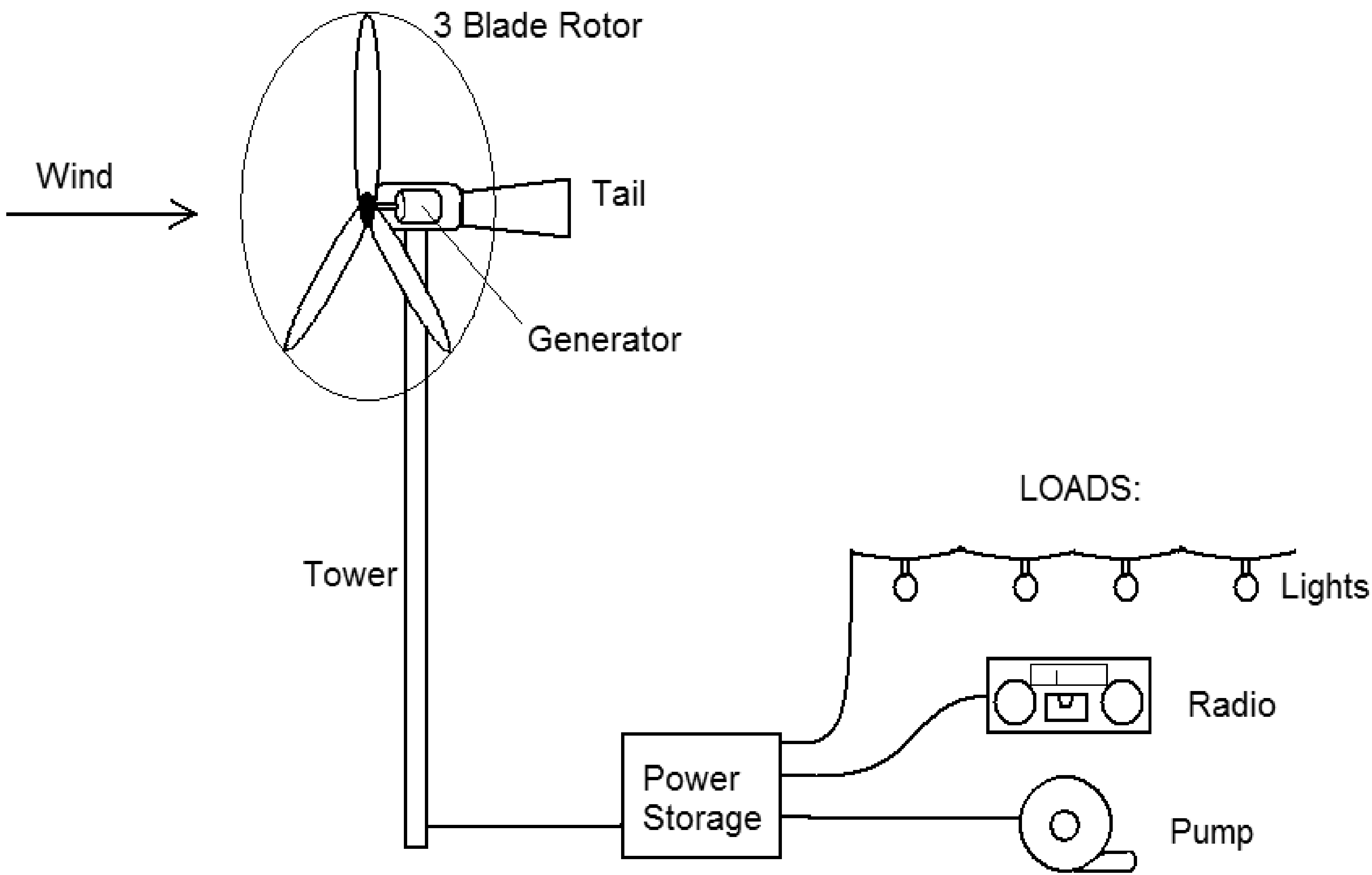
System Components

The wind power system is comprised of one or more units, operating electrically in parallel, having the following components:

1. the tower.
2. the wind turbine with two or three blades.
3. the yaw mechanism.
4. the mechanical gear.
5. the electrical generator.
6. the speed sensors and control.



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1. Tower

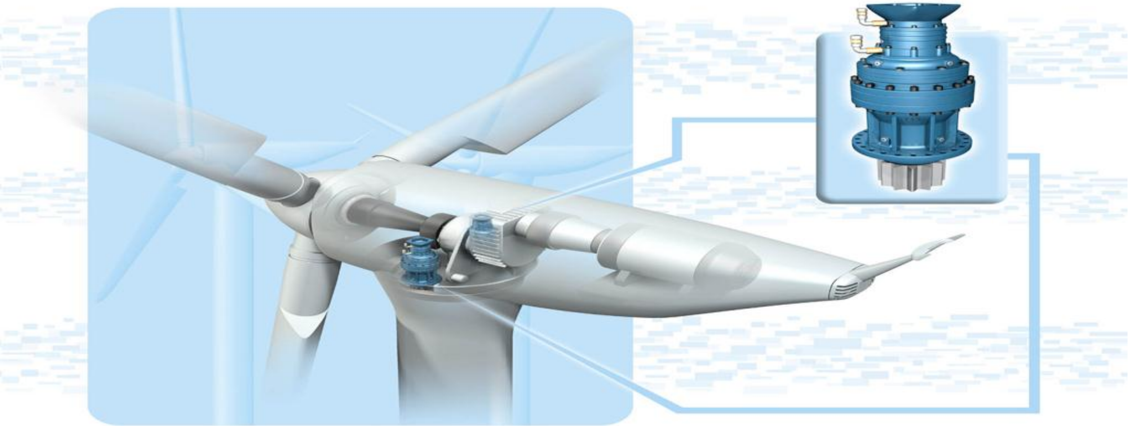
- The wind tower supports the turbine and the nacelle containing the mechanical gear, the electrical generator, the yaw mechanism, and the stall control.
- The height of tower in the past has been in the 20 to 50-meter range.
- For medium and large size turbines, the tower is slightly taller than the rotor diameter.
- . Small turbines are generally mounted on the tower a few rotor diameters high.

2. Turbine Blades

- The turbine blades are made of high-density wood or glass fiber and epoxy composites.
- Modern wind turbines have two or three blades.
- The steady mechanical stress due to centrifugal forces and fatigue under continuous vibrations make the blade design the weakest mechanical link in the system, protects the blades, and also protects the electrical generator from overloading and overheating.

3. Yaw Control

- The yaw control continuously orients the rotor in the direction of the wind.
- Theoretical considerations dictate free yaw as much as possible. rotating blades with large moments of inertia produce high gyroscopic torque during yaw, often resulting in loud noise.
- Too rapid yaw may generate noise exceeding the local ordinance limit. Hence, a controlled yaw is often required and is used.



4. Speed Control

- Large wind turbines being installed today tend to be of variable speed design, incorporating the pitch control and the power electronics.
- Small machines on the other hand must have simple, low cost power and speed control. The speed control methods fall into the following categories:

  * no speed control whatsoever.

  * yaw and tilt control.

  * pitch control.

  * stall control.

Speed Control Categories

Stall control	Pitch control	yaw and tilt control	no speed control
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.	changes the pitch of the blade with the changing wind speed to regulate the rotor speed.	the rotor axis is shifted out of the wind direction when the wind speed exceeds the design limit.	In this method, the turbine, the electrical generator, and the entire system is designed to withstand the extreme speed under gusty wind.

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System Design Features

1. **Number of Blades.**

- This is the first determination the design engineer must make.
- Wind machines have been built with the number of blades ranging from 2 to 40 or more.
- The major factors involved in deciding the number of blades are as follows:

  * the effect on power coefficient.
  * the nacelle weight.
  * the design tip-speeds ratio.
  * the structural dynamics.
  * the cost.
  * the means of limiting yaw rate to reduce gyroscopic fatigue.

2. Rotor Upwind or Downwind

- Operating the rotor upwind of the tower produces higher power as it eliminates the tower shadow on the blades.
- This also results in lower noise, lower blade fatigue, and smoother power output.
- The downwind blades, on the other hand, allow the use of free yaw system.
- It also allows the blades to deflect away from the tower when loaded.
- Both types are used at present with no clear trend.

3. Horizontal Axis Versus Vertical Axis

- Most wind turbines built at present have a horizontal axis.
- The vertical axis Darrieus machine has several **advantages:**

a) it is omnidirectional and requires no yaw mechanism to continuously orient itself toward the wind direction.

b) its vertical drive shaft simplifies the installation of the gearbox and the electrical generator on the ground, making the structure much simpler.

- **Disadvantages:**

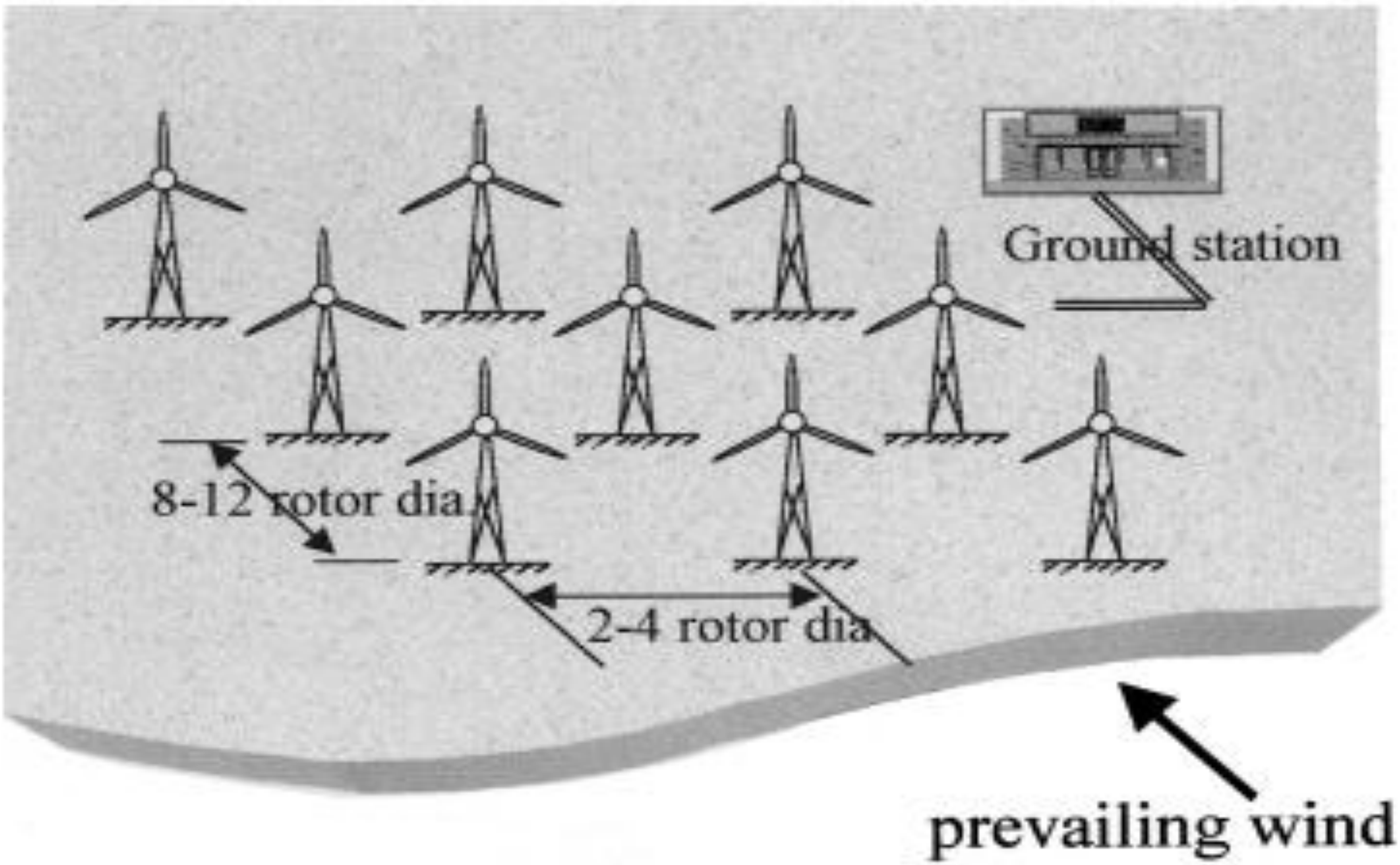
a) it normally requires guy wires attached to the top for support. This could limit its applications, particularly for the offshore sites.

b) Overall, the vertical axis machine has not been widely used because its output power cannot be easily controlled in high winds simply by changing the blade pitch.

4. **Spacing of the Towers**

- The spacing of the towers depends on the terrain, the wind direction, the speed, and the turbine size.
- The optimum spacing is found in rows 8 to 12-rotor diameters apart in the wind direction, and 1.5 to 3-rotor diameters apart in the crosswind direction.
- A wind farm consisting of 20 towers rated at 500 kW each need 1 to 2 square kilometers of land area.
- The average number of machines in wind farms varies greatly, ranging from several to hundreds depending on the required power capacity.

Optimum tower spacing in wind farms in flat terrain



Power Generated by Wind Power

- Wind turbines with rotors that are about 8 feet in diameter) may peak at about 1,000 watts (1 kilowatt; kW), and generate about 75 kilowatt-hours (kWh) per month with a 10 mph average wind speed.
- Turbines smaller than this may be appropriate for sailboats, cabins, or other applications that require only a small amount of electricity.
- For wind turbine farms, it’s reasonable to use turbines with rotors up to 56 feet in diameter. These turbines may peak at about 90 kW, and generate 3,000 to 5,000 kWh per month at a 10 mph average wind speed, enough to supply 200 homes with electricity.

- Homes typically use 500-1,500 kilowatt-hours of electricity per month.
- Depending upon the average wind speed in the area this will require a wind turbine rated in the range 5-15 kilowatts.

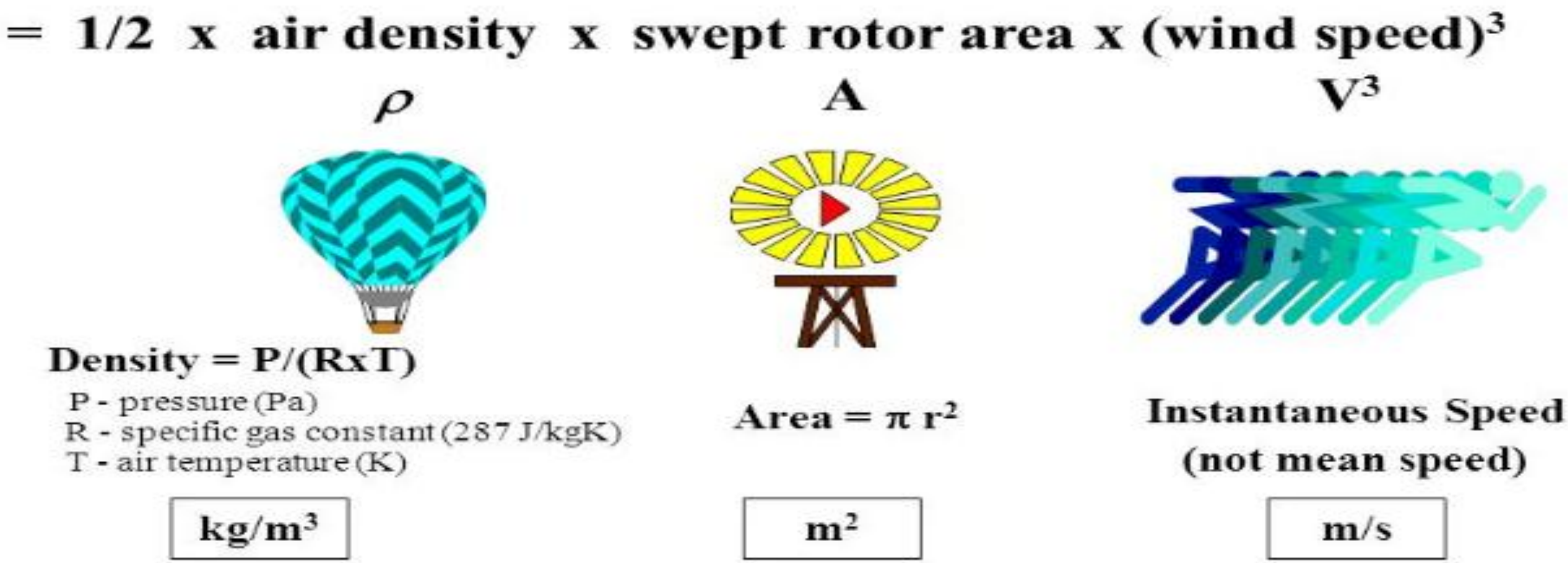
Fundamental Equation of Wind Power

- **Wind Power depends on:**

  * amount of air (volume).

  * speed of air (velocity).

  * mass of air (density).



Efficiency in Extracting Wind Power

- **Betz Limit & Power Coefficient:**
- Power Coefficient (Cp), is the ratio of power extracted by the turbine to the total contained in the wind resource Cp = Pt/Pw.

- Turbine power output

$$P_T = ½ * \rho * A * v^3 * Cp$$

- The Betz Limit is the maximal possible Cp = 16/27.
- 59% efficiency is the efficiency is the BEST a conventional wind turbine can do in a conventional wind turbine can do in extracting power from the wind

Example

- How much power a wind turbine with 50 meters long blade can generate with a wind speed of 12 m/s. The site of the installation is about 1000 feet above sea level. Assume 40% efficiency (η).

Air density is lower at higher elevation. For 1000 feet above sea level, ρ is about 1.16 kg/m^3

$$\text{Power} = \tfrac{1}{2}(\rho)(A)(V)^3(\eta)$$

$$= 0.5(1.16)(\pi 50^2)(12)^3(0.4)$$

$$= 3.15 \times 10^6 \text{ Watt}$$

$$= 3.15 \text{ MW}$$

where we assumed the turbine efficiency is 40%.

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Electrical Generators

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Wind Turbine Generators

- The function of the blades is to convert kinetic energy in the wind into rotating shaft power to spin a generator that produces electric power.
- Generators consist of a rotor that spins inside of a stationary housing called a stator.
- Electricity is created when conductors move through a magnetic field, cutting lines of flux and generating voltage and current.
- While small, battery-charging wind turbines use dc generators, grid-connected machines use ac generators as described in the following slides:-

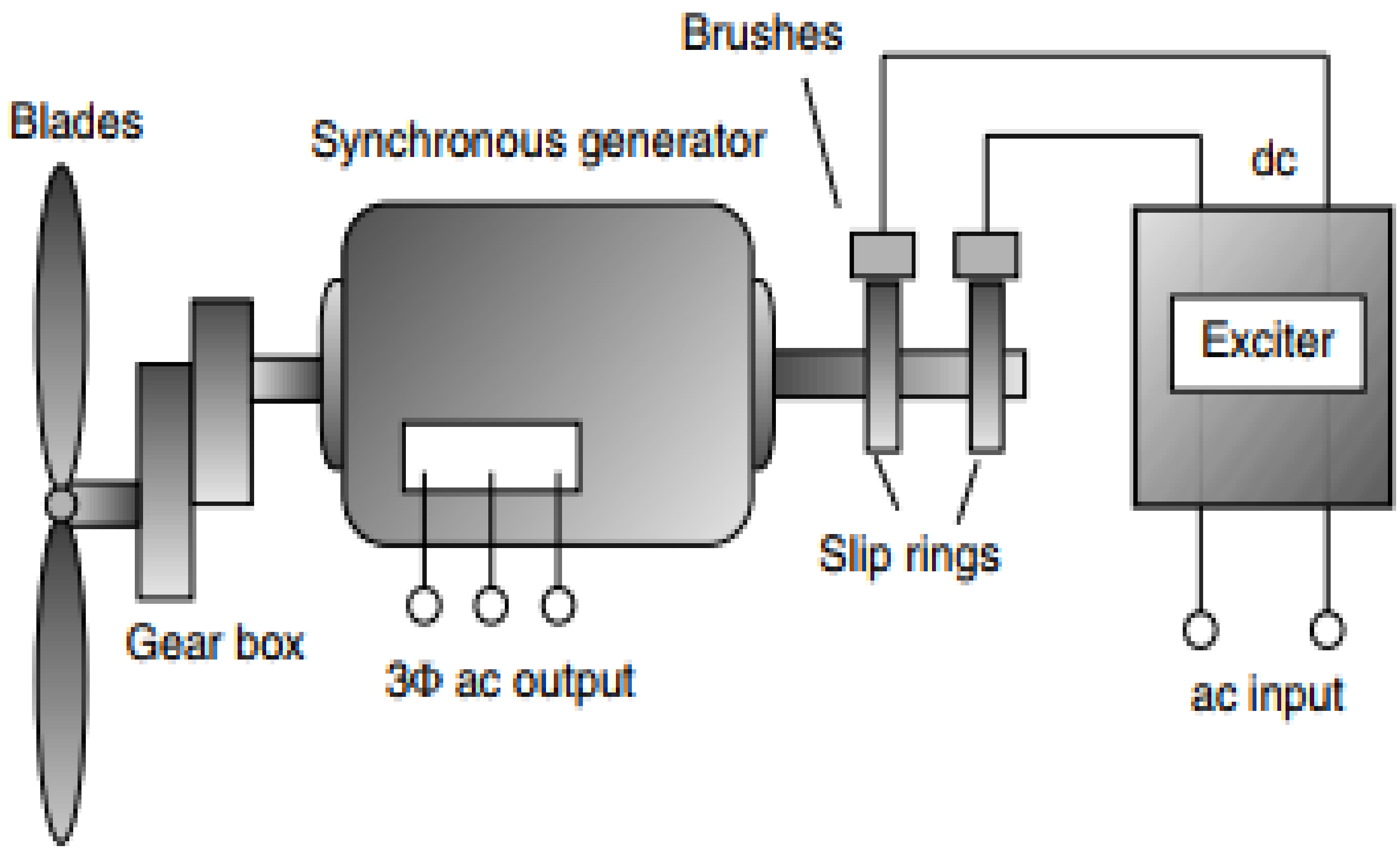
1. Synchronous (Permanent Magnet Generators)

- Synchronous generators are forced to spin at a precise rotational speed determined by the number of poles and the frequency needed for the power lines.
- Their magnetic fields are created on their rotors.
- While very small synchronous generators can create the needed magnetic field with a permanent magnet rotor, almost all wind turbines that use synchronous generators create the field by running direct current through windings around the rotor core.

- Synchronous generator rotors needs dc current for their field windings creates two complications:

1) DC has to be provided, which usually means that a rectifying circuit, called the exciter, is needed to convert ac from the grid into dc for the rotor.
2) This dc current needs to make it onto the spinning rotor, which means that slip rings on the rotor shaft are needed, along with brushes that press against them.

A three-phase synchronous generator needs dc for the rotor windings

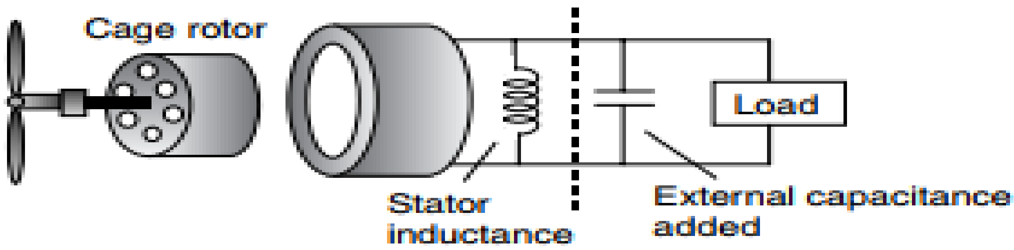


2. Asynchronous (Induction Generators)

- Most of the world's wind turbines use induction generators rather than the synchronous machines.
- In contrast to a synchronous generator (or motor), induction machines do not turn at a fixed speed, so they are often described as asynchronous generators.
- While induction generators are uncommon in power systems other than wind turbines, their counterpart, induction motors, are the most prevalent motors around using almost one-third of all the electricity generated worldwide.
- In fact, an induction machine can act as a motor or generator, depending on whether shaft power is being put into the machine (generator) or taken out (motor).

- Both modes of operation, as a motor during start-up and as a generator when the wind picks up, take place in wind turbines with induction generators.
- As a motor, the rotor spins a little slower than the synchronous speed established by its field windings, and in its attempts to catch up it delivers power to its rotating shaft.
- As a generator, the turbine blades spin the rotor a little faster than the synchronous speed and energy is delivered into its stationary field windings.

- The key advantage of asynchronous induction generators is that their rotors do not require the exciter, brushes, and slip rings that are needed by most synchronous generators.
- This means that they are less complicated and less expensive and require less maintenance.
- Induction generators are also a little more forgiving in terms of stresses to the mechanical components of the wind turbine during gusty wind conditions.



Site Selection

- **Technical Factors Affecting Site Selection:**

1. High average annual wind speed.
2. Low cost of construction.
3. Close distance from utility line or customers.
4. Surface roughness.
5. Prevailing wind direction.

Improved capacity Factors

1. **Performance improvements due to:**

   * better siting. * larger turbines.

   * technology advances. * higher reliability.

2. **Capacity factors > 35% at good sites.**

Future Technology Development

- **Improving Performance:**
- Capacity: higher heights, larger blades, superconducting magnets.
- Capacity Factor: higher heights, advanced control methods (individual pitch, smart-blades), site-specific designs.
- **Reducing Costs:**
- Weight reduction: 2-blade designs, advanced materials, direct drive systems.
- Offshore wind: foundations, construction and maintenance

- **Improving Reliability and Availability:**
- Forecasting tools (technology and models).
- Dealing with system loads Dealing with system loads.

- **Advanced control methods, materials, preemptive diagnostics and maintenance.**
- Direct drive – complete removal of gearbox.