Wind turbines

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Content:

1 .Introduction:

A wind turbine is a device that converts the kinetic energy of the wind into electrical energy. It is a type of renewable energy technology used to generate electricity from the wind. Wind turbines operate on the principle that the kinetic energy of moving air can be harnessed to turn the blades of a turbine, which then drives a generator to produce electricity.

People have been using wind energy to propel sailboats, pump water, and power windmills since prehistoric times. Vertical axis windmills were used in grain mills that date back to the 13th century in China and the 10th century in Persia. Prior to the development of the steam engine, the primary energy sources were water and wind mills. Grain grinding was a common practice in the Netherlands using windmills. A variety of designs were employed, from the shorter post mills to the taller mills with revolving tops that maintain the blades perpendicular to the flow of the wind. Since 1850, early immigrants in the United States have made extensive use of water pumping windmills. The ancient windmills were all made of wood. The majority of windmills were made of metal by 1900. To differentiate them from the contemporary windmills that produce electricity, all of these varieties are referred to as farm windmills. Charles F. Brush constructed the first wind turbine in history to produce electricity in Cleveland, Ohio, in 1888. His home was supplied with an average of 12 kW of electricity produced by the 17 m diameter turbine rotor for nearly two decades. For every wind turbine revolution, the DC dynamo generator made 50 turns. The rotor consisted of 144 separate cedar wood vanes. When compared to contemporary turbines of the same size that can currently generate more than 100 kW of electricity, the Charles turbine was, however, inefficient. Generally speaking, farm windmills move slowly due to their vast number of vanes. Compared to farm windmills, modern wind turbines may generate power more efficiently since they have two or three vanes and rotate more quickly.

From small turbines for home or small-scale use to enormous utility-scale turbines that can be a part of wind farms, wind turbines are available in a variety of sizes and designs. Since wind energy doesn't release greenhouse gases or other pollutants linked to traditional fossil fuels, it is regarded as a clean and sustainable energy source.

Wind power has become an increasingly important part of the global energy mix as efforts to transition to renewable energy sources continue.

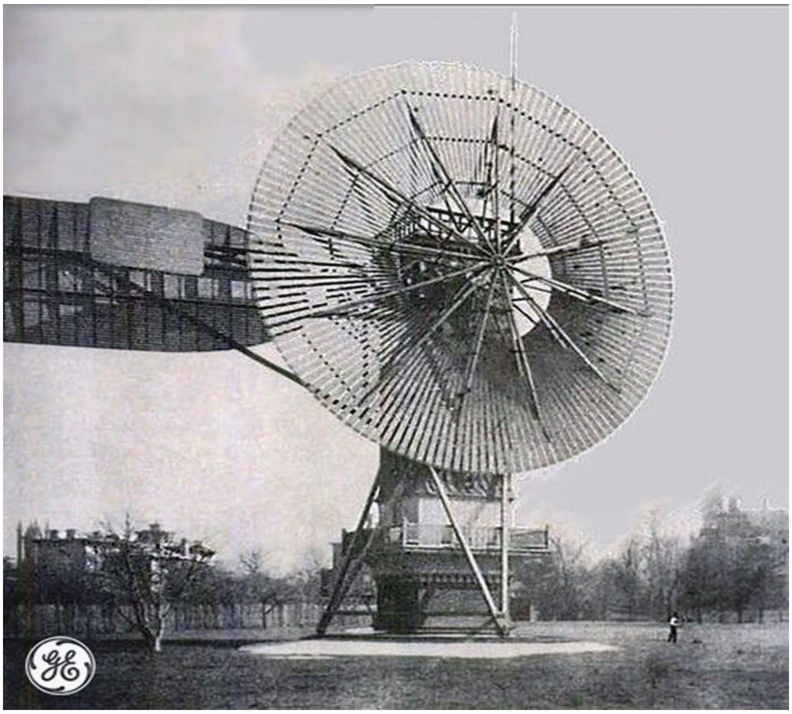


Fig (1.1): Charles wind turbine; the first turbine to generate electricity in 1888.

2. ***History of Wind Turbines:***

1. Ancient Beginnings:

The use of wind energy dates back thousands of years. Early civilizations utilized wind power for activities such as grinding grain and pumping water. Simple windmills with vertical-axis designs were among the first structures built to harness wind power.

2. Persian Windmills:

In the 7th century, Persian windmills were documented to have been used for grinding grain and pumping water. These windmills had vertical-axis designs and were an important precursor to more advanced wind turbine technologies.

3. European Windmills:

Windmills became widespread in Europe during the Middle Ages. These were primarily used for milling grain and draining marshes. The iconic Dutch windmills, with their horizontal-axis design, became popular in the 17th century and played a crucial role in various industrial applications.

4. Electricity Generation:

The transition from mechanical power to electricity generation started in the late 19th century. Pioneers like Charles F. Brush and Poul la Cour experimented with electricity-generating windmills.

5. Smith-Putnam Wind Turbine:

The Smith-Putnam wind turbine, erected in 1941 in Vermont, USA, is considered one of the first large-scale wind turbines designed for electricity generation. It had a capacity of 1.25 megawatts (MW) and was in operation until 1945.

6. 1970s-1980s: Modern Wind Power Emerges:

The modern era of wind power began with the oil crises of the 1970s. Countries sought alternative energy sources, and advancements in technology led to the development of more efficient and cost-effective wind turbines. The Danish Risø research station played a key role in advancing wind turbine technology.

7. Horizontal-Axis Wind Turbines:

The development of the horizontal-axis wind turbine (HAWT) with a three-blade configuration became the standard design. These turbines proved to be more efficient and reliable than earlier designs.

8. Global Expansion:

In the late 20th century and early 21st century, wind power gained momentum globally. Countries invested in large-scale wind farms, and the technology continued to improve, with larger turbines and increased energy output.

9. Offshore Wind Farms:

Recent decades have seen the growth of offshore wind farms, harnessing stronger and more consistent winds over open water. Offshore wind is becoming a significant contributor to global renewable energy capacity.

Today, wind turbines are a vital part of the renewable energy landscape, providing a clean and sustainable source of electricity as the world continues to transition away from fossil fuels.

3. *Main types of wind turbines:*

There are two main types of wind turbines: horizontal-axis wind turbines (HAWT) and vertical-axis wind turbines (VAWT). Each type has its own set of advantages and disadvantages.

1. Horizontal-Axis Wind Turbines (HAWT):

- Upwind Turbines: The rotor faces into the wind, and the wind hits the blades first.
- Downwind Turbines: The rotor faces away from the wind, and the wind hits the tower first.
- Most commonly used in modern wind farms.
- The three-bladed design is prevalent.

2. Vertical-Axis Wind Turbines (VAWT):

- The main rotor shaft is arranged vertically.
- Can accept wind from any direction without the need for a yaw mechanism.
- Different designs include Savonius, Darrieus, and helical turbines.
- Less common in large-scale commercial applications but may be suitable for certain environments.

Each type has its own advantages and drawbacks, and the choice between them depends on factors such as wind conditions, space constraints, and application requirements. The horizontal-axis wind turbine is the more common type in large-scale wind farms, while vertical-axis turbines may find applications in smaller installations or unique environments.

Fig. (3.1): Horizontal versus vertical axis wind turbines.

3. *Advantages and disadvantages of horizontal and vertical axis wind turbines:*

- **Horizontal axis wind turbines Advantages**:

A) Since it is positioned atop a tall tower and faces winds that are faster than those on the ground, it can generate more power.

B) Because the blades can be adjusted for optimal power conversion and operate perpendicular to the direction of the wind, they are more effective at turning wind speed into a rotating motion.

- **Horizontal axis wind turbines Disadvantages**:

A) Due to the tower's height, massive blades, hefty gearbox, and electric generator that must be positioned at the top, there were considerable upfront building and installation costs.

B) Maintain the rotor perpendicular to the wind by requiring a yaw mechanism.

C) Because every moving item is at the top of the tower, maintenance is more challenging.

D) Unsuitable in confined areas or cities.

- **Vertical axis wind turbines Advantages:**

A) It can function in any wind direction, therefore facing the wind is not necessary.

B) Capable of operating at minimal wind speeds. Long curved propellers are designed to be pushed by a small amount of wind.

C) No need to be positioned in a tower or at an extremely high altitude. It is therefore appropriate for urban areas and small spaces.

D) Require less maintenance cost because all moving parts are near the ground.

E) Less expensive during fabrication and installation.

- **Vertical axis wind turbines <u>Disadvantages</u>**:

A)Efficiency at Low Wind Speeds: VAWTs generally have lower efficiency at low wind speeds compared to horizontal axis wind turbines (HAWTs). This is because they may struggle to start turning in very light winds.

B)Less Established Technology: The technology of horizontal axis wind turbines is more advanced, and they are more frequently and extensively used. Conversely, there are fewer commercially viable designs for vertical axis wind turbines, and they are still in the early stages of development.

C)Complexity and Maintenance: Some designs of VAWTs can be more complex and require more maintenance compared to HAWTs. The moving parts of a vertical axis turbine may be more exposed to wear and tear, potentially leading to increased maintenance requirements.

D)Limited Scalability: When compared to horizontal axis wind turbines, vertical axis wind turbines are frequently less scalable. As the size of the turbine increases, the engineering challenges and efficiency issues can become more pronounced.

E)Wind Shadow Effect: VAWTs can create a wind shadow behind them, which may reduce the efficiency of other turbines in close proximity. This effect can limit the number of turbines that can be installed in a given area.

F)Higher Turbulence: Vertical axis turbines can experience higher levels of turbulence, which may affect their performance and structural integrity over time.

G)Noise Generation: In residential or other noise-sensitive environments, certain vertical axis wind turbine designs may generate more noise than their horizontal counterparts.

H)Limited Commercial Availability: Vertical axis wind turbines are not as extensively available in the commercial market as horizontal axis turbines, as of the cutoff date of January 2022, to the best of my knowledge. This reduces the alternatives available to people wishing to invest in wind power.

4. Main parts of wind turbines:

The main parts of a wind turbine include:

Rotor Blades: Large blades that capture the kinetic energy from the wind. They are connected to the rotor hub and spin when the wind blows.

Rotor Hub: The central part to which the rotor blades are attached. It connects the blades to the main shaft.

Pitch control: Pitch control is the process of changing the pitch angle of the wind turbine's blades to maintain the required levels of rotor speed, rotor torque, and electrical energy output. This is one method of designing a "constant-speed" wind turbine, and it can be used electrically (motor) or mechanically (hydraulically). Currently, the latter is primarily utilized because it can regulate each blade separately. Since pitch control can restrict operation levels to the maximum of a particular machine, it is also a safety feature.

Nacelle: The housing or casing that sits atop the tower and contains the main components, such as the gearbox, generator, and other control electronics.

Generator: Converts the kinetic energy captured by the rotor blades into electrical energy. It is usually housed in the nacelle.

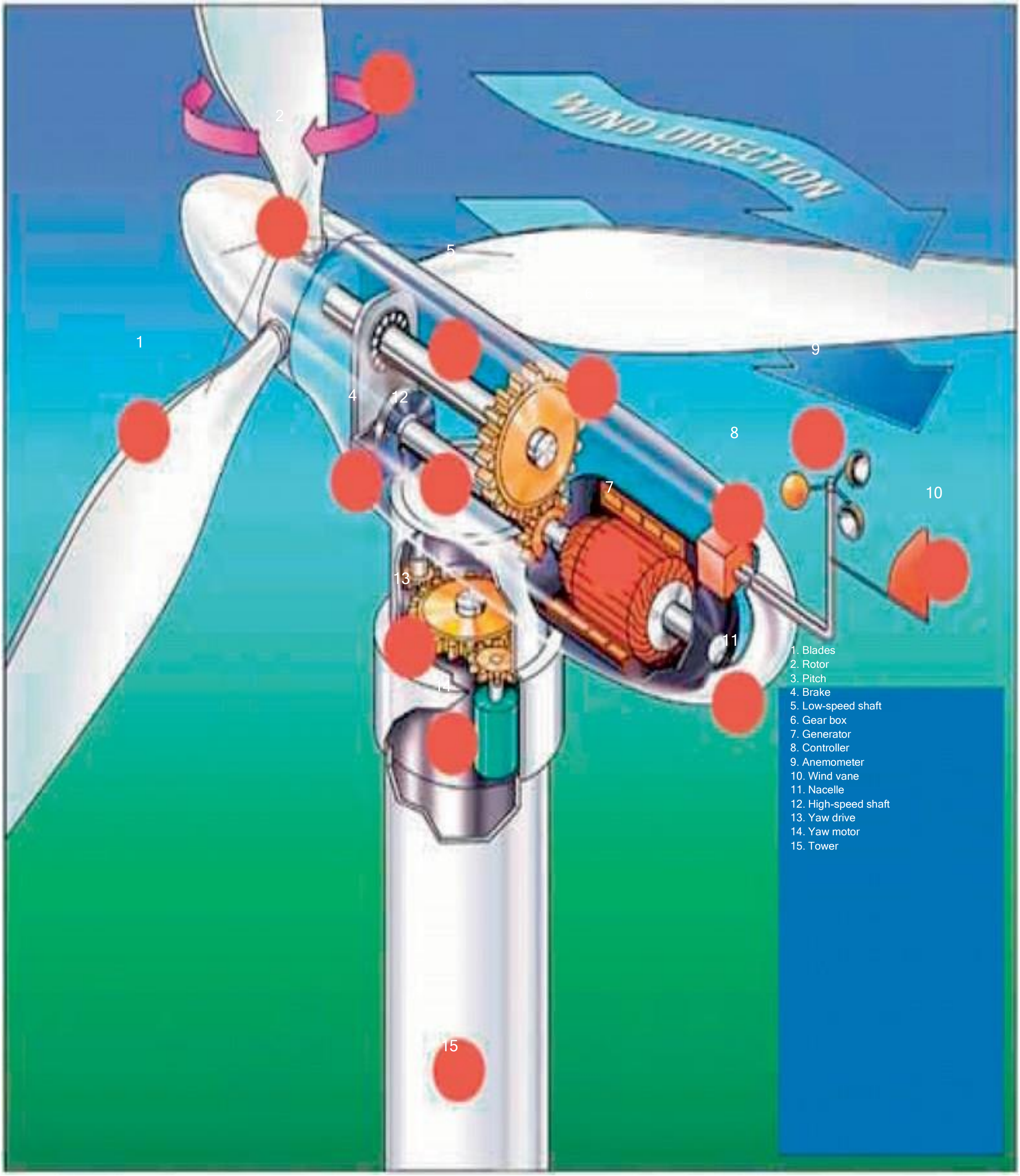
Gearbox: If the turbine has one, the gearbox is responsible for increasing the rotational speed of the rotor blades to a level suitable for electricity generation.

Yaw System: The mechanism that allows the nacelle to turn and face the wind. This helps optimize energy capture.

Tower: The tall structure that supports the nacelle and rotor blades. Towers vary in height based on the size of the wind turbine.

Anemometer and Wind Vane: wind direction and speed measuring devices, which assist the turbine in reorienting itself to produce the most energy.

Brakes and Safety Systems: These are necessary in the event of heavy winds or maintenance requirements in order to control and halt the rotor. Sensors and controllers are also included in safety systems to monitor different parameters. These parts function as a unit to capture wind energy and transform it into electricity for use in a variety of applications.



Fig(5.1) shows the main parts of wind turbine generators

5.Conclusion:

Remarkable advances in wind turbine design have been possible due to developments in modern technology. The advanced wind turbine technologies have been reviewed as follows:

1. Numerous variables, including site selection, height, wind generator selection, wind velocity, and wind power potential, have been regarded as objective functions of probabilistic models. The system's energy output is ascertained using these mathematical models for the wind turbine.
2. It was discovered that the Rayleigh distribution, Weibull, and Markov chain model could all accurately forecast the site's wind speed data. Meteorological data is needed to select a windy location for wind power generation and to deploy wind generators.
3. Vibration issues with wind turbines are examined using both theoretical and experimental techniques. The Miner summation, a linear Goodman fit, and rain flow counts are utilized to predict the lifespan of wind turbine blades. The comprehension of different loads utilized for design and fatigue damage is aided by the structural dynamic and aeroelastic aspects.
4. To detect noise in the aerofoil, aeroaccoustic experiments are performed.
5. Wind turbine operational parameters are identified using computer-based supervisory control.
6. The stabilization of big wind farms is achieved by the employment of static reactive power compensator. Grid-related problems are analyzed using simulation models and parato analysis.
7. An essential component of a structural examination of wind turbines is wind field modeling.
8. The aerodynamic forces operating on the rotor blade are calculated in aerodynamic modeling using blade element moment theory.
9. To maintain the wind turbine's operational characteristics within the designated range, control system modeling is employed. The wind energy sector has a bright future ahead of it because to these advancements and expanding trends in wind energy. With this advancement in technology, wind turbines may be constructed to provide the most power at the lowest possible cost.

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