Indian Journal of Modern Research and Reviews

This Journal is a member of the *'Committee on Publication Ethics'*

Online ISSN:2584-184X

Review Paper

Study of Classification of Wind Turbines and Its Applications

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ABSTRACT

As a sustainable and clean energy source, wind turbines are becoming an essential part of renewable energy systems. Understanding the features, uses, and constraints of wind turbines requires an understanding of their classification. This study offers a thorough classification of wind turbines according to their generator type, application, and rotor configuration, number of blades, control systems, and axis of rotation. The study also looks at the many uses of wind turbines, such as small-scale wind energy systems, urban wind power, and offshore and onshore wind farms. The results of this study can help guide policy and decision-making in the field of renewable energy and offer insightful information about the design, development, and deployment of wind turbines.

Manuscript Info.

- ✓ **ISSN No:** 2584-184X
- ✓ **Received:** 28-01-2025
- ✓ **Accepted:** 23-02-2025
- ✓ **Published:** 24-03-2025
- ✓ **MRR:3(3):**2025;15-22
- ✓ **©2025, All Rights Reserved.**
- ✓ **Peer Review Process:** Yes
- ✓ **Plagiarism Checked:** Yes

How To Cite

Meshram HB. Study of Classification of Wind Turbines and Its Applications. Indian J Mod Res Rev. 2025;3(3):15-22.

KEYWORDS: Wind turbines; classification; horizontal axis wind turbines; vertical axis wind turbines; wind energy applications.

INTRODUCTION

The kinetic energy of the wind is converted by wind turbines into mechanical energy, which can subsequently be converted into electrical energy. They are essential in utilizing renewable energy, which lessens dependency on fossil fuels and fights climate change. Since wind energy doesn't directly emit greenhouse gases or pollute the air, it is regarded as one of the cleanest power sources. The basic idea behind how wind turbines work is that when wind blows, it passes over the turbine's blades, rotating them. A shaft carries this rotational motion to a generator, which generates energy. Wind speed, turbine size, and component efficiency are some of the variables that affect how much power is produced [1].

Man has harnessed the strength of the wind since the earliest known history. It was used earlier for moving ships and wind turbines to melt grain and pump water. The production of electricity from wind turbines began in the late 19th century and was designed by Professor James Blyth of Scotland, then the generator of 12 kW DC windmills constructed by Brush in the United States. The fastest-growing source of electricity in the world is wind energy. It can provide large volumes of energy to meet the needs of a population. It is a common source of electricity generation because of its zero fuel free characteristics. Once installed, almost zero costs can be used for wind turbines. In addition, it ensures a clean and green climate. Prof. James Blyth, a Scottish academic, performed wind energy experiments in July 1887 which resulted in a UK patent in 1891. Charles F. Brush produced electricity with a wind-powered system in the USA from 1887-1888, which was in operation until about 1900 in his home and laboratory. In the 1890s, the Danish physicist and inventor Poul La Cour designed electric wind turbines that were then used for the manufacture of hydrogen. They were the first of the new Small Wind Turbine shapes.

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In the first half of the 20th century, there was a common small wind turbine for lights of remote rural houses. In 1941, a variety of sites were investigated like Balaklava USSR, and in 1941 a 1.25 Megawatt (MW) experimental unit in Vermont, with larger units planned for connection to a distribution network.

The wind energy modem industry commenced in 1979 with the Danish manufacturers Kuriant, Vestas, Nordtank and Bonus manufacturing wind turbines as serial products. Early turbines of 20-30 kW each were small in line with current requirements. Since then, they have increased considerably by up to 7 MW of Enercon E-126, whereas the output of wind turbines has risen in so many countries.

Electricity in all developed countries began to expand exponentially in the 19th century. The major cities were using electricity in the early 1920s (Hau, 2000) and the diffusion of electricity in rural areas was slower, primarily on account of the cost of interconnection.

However, engineers realized that the back of the blades were critical from experience (Heymann, 1995). The work of three Danes: Hans Christian Vogt, Johan Irminger and Poul La Cour slowly contributed to a new hypothesis. Based on the variations on both sides of the blades, this new idea resulted in much improved construction. In sizes of 20 m rotor diameters and power outputs of 10–35 kW the Lykkegard wind turbines were built and about 120 were operative in Danish in 1920. (Maltha, 2005). Although these turbines had successfully been drawn by demand since World War I, the demand for wind turbines was disrupted by increasingly cheap oil and the connection of rural areas to the power plant. During World War II fuel prices were up again and interest in wind turbines was revived for a brief period, but the interest in electricity producing wind turbines dropped as soon as fuel prices fell.

The first age since wind turbine technology developed from the beginning of the 20th century up to the end of the Second World War. Classical windmill technology had a knowledge base, and the designs were focused on experience and experimentation. These designs ignored aerodynamic knowledge and were restricted to general and cost-effective materials.

However, there has already been voices advocating the consumption of wind energy to supply a wide spectrum of cheap fuel. In the early phases of the growth of the sector, most wind power schemes originated as private projects. The studies in the 1970s were primarily performed by technological stakeholders using a reduced version of the Gedser computer (10-15kW) (Krohn, 1999). Subsequently, serious turbine makers joined the scene in the late 1970s and early 1980s. In the '70s, the world was met with an oil crisis, which led to the huge reliance of developing nations on scarce energy supplies being inspired by many policymakers.

As a result, major government projects in the U.S., Denmark and Germany have been launched. The aim was to develop cost-effective wind turbines in these demonstration projects.

Industrial and Offshore Turbine Growth

The government, industry, and international joint research and development have led to important design changes and improved technological and economic efficiency. According to an assessment of wind turbines in Denmark by the Rise National Laboratory, cost per wind power unit was reduced from € 15.8cents to 5.7 cents per kWh between 1981 and 1995 due to improved turbine design and better positioning. Since then, the norm has been new generations of larger and better turbines. In 2003, the average costs for state-of-the-art wind turbines in the wind industry were € 804 per installed kW at a price of € 3.79 cents per KWh, which is 50% lower than the previous year.

The rise in turbine size has closely connected to better efficiency and cost reductions. Until mid-1980, turbines with a rotor diameter of approximately 20 meters were usually less than 100 kW. At the beginning of the 1990s, turbine sizes ranged from 0.5–1.5 MW to several hundred kilowatts. Averaging about 1170 kW of new turbines installed in 2002. In the same year, a major offshore project was launched in Denmark using 2-2.3 MW, while the average wind turbine scale reached 1.4 MW in Germany. The Sea Titan 10MW wind turbine designed by American energy technologies company AMSC is currently the biggest wind turbine in the world.

The direct-drive turbine, with 190m rotor diameter, has a rated power capacity of 10MW and hub height of 125m. The turbine design incorporates a high temperature superconductor (HTS) generator with a speed of 10 rpm making it much smaller and lighter than a conventional wind turbine generator. AMSC started developing the turbine in 2010 and completed the design in 2012. The generator for the wind turbine has been tested by the US Navy in harsh offshore conditions. AMSC is currently negotiating with potential partners to build and commercialize the Sea Titan 10MW wind turbines [2-3].

The Vestas V164 has a rated capacity of 8 MW, later upgraded to 9.5 MW. The wind turbine has an overall height of 220 m (722 ft), a diameter of 164 m (538 ft), is for offshore use, and is the world's largest-capacity wind turbine since its introduction in 2014. The power of a wind turbine has dramatically increased since the early 1980s

A wider variety of wind speeds can be controlled by variable speed turbines, which reduce the impact on the structure.

In the background of the upscaling of turbines, there has been more or less interest in offshore wind growth capacity. In Denmark, wind production onshore appears closely saturated in terms of sites with ample wind speeds and issues in densely populated areas with large turbines. MW-size turbines will dominate the countryside, so offshore development seems a prerequisite for wind development in Denmark to continue. In Germany, the situation is close.

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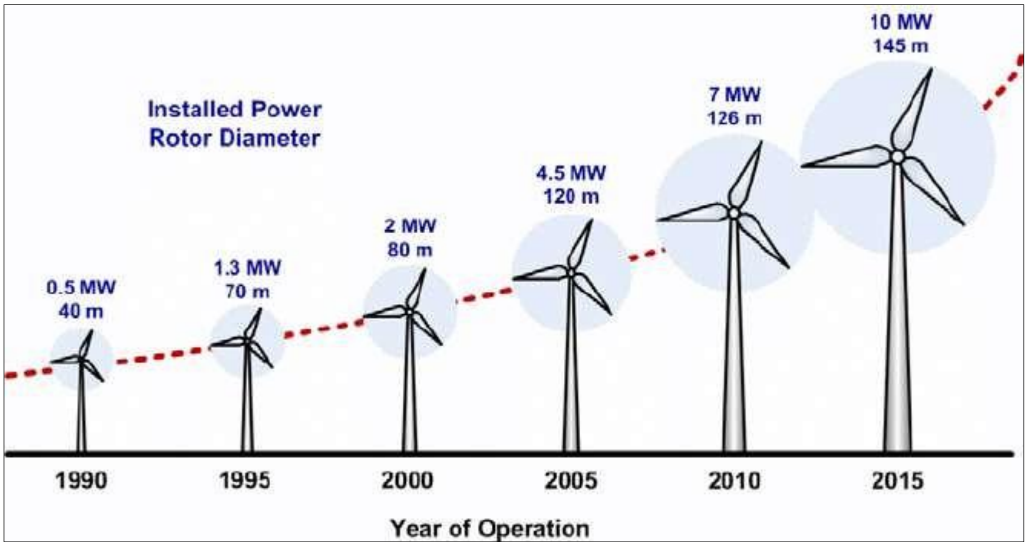

Fig. 1: Increase in rotor size of turbines (**Source**: https://cutt.ly/9jPwWBb)

A 400 MW offshore project was launched in 2012 in Denmark, which is 1300 MW of total power. Other coastal countries, such as Ireland, Netherlands, Sweden and the UK investigate or intend offshore wind resource extraction. The maritime environment is much more demanding and requires large-scale, fixed investment in building infrastructure and civilian engineering, ships, platforms, installation technology and transmission lines. The continued production of wind turbines and components onshore to be mostly the maintenance of industry, as the methodology is quite advanced. The production of wind power on and offshore faces grid integration challenges although there are technological, organizational and costs gaps [4].

Wind Turbines Classification

Wind turbines can be classified based on several factors, including their axis of rotation, size, and application.

1. **Classification by Axis of Rotatio**n
   i. **Horizontal Axis Wind Turbines (HAWT):** Most common type, with blades rotating around a horizontal axis.
   ii. **Vertical Axis Wind Turbines (VAWT):** Blades rotate around a vertical axis, often used in urban areas.

2. **Classification by Size**
   i. **Small Wind Turbines:** Typically used for residential or small commercial applications, with capacities up to 100 kW.
   ii. **Medium Wind Turbines:** Used for larger commercial or industrial applications, with capacities between 100 kW and 1 MW.
   iii. **Large Wind Turbines:** Used for utility-scale applications, with capacities exceeding 1 MW.

3. **Classification by Application**
   i. **Onshore Wind Turbines:** Installed on land, often in wind farms.
   ii. **Offshore Wind Turbines:** Installed in the ocean, often in deeper waters.
   iii. **Hybrid Wind Turbines:** Combine wind power with other energy sources, such as solar or diesel.

4. **Classification by Rotor Configuration**
   i. **Upwind Turbines:** Blades face into the wind, most common configuration.
   ii. **Downwind Turbines:** Blades face away from the wind, less common configuration.

5. **Classification by Control System**
   i. **Stall-Controlled Turbines:** Use blade stall to regulate power output.
   ii. **Pitch-Controlled Turbines:** Use blade pitch to regulate power output.
   iii. **Active Stall-Controlled Turbines:** Combine stall and pitch control systems.

Above all, the HAWT is the most powerful turbine concept in today's era [5]. According to this classification there are several examples of wind turbines. Some of discussed here.

1. Longer Blades Wind Turbine

By expanding the rotor's surface area, longer blades of wind turbines are intended to capture more wind energy and enable more effective wind energy harvesting. Especially in regions with moderate wind speeds, the blades can increase the turbine's ability to produce power.

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Previously the blades were about 120 feet per blade, but the rotor diameter of the "Siemens SWT - 6-0-154" (505 feet) is approximately 246 feet long and is 154 meters (505 ft.) long.

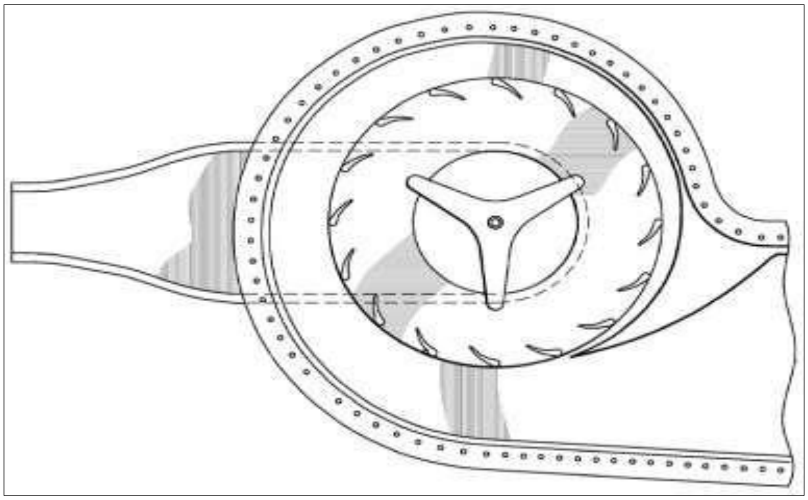

Fig. 2: Larger blade wind turbine (**Source**: https://cutt.ly/EjO7cgW)

The use of Aluminium and compost materials in their blades has contributed with a low rotating inertia, allowing for a speedy acceleration of wind turbines when the winds are recovering and retaining a high speed ratio. The blades are long and light because of the strategic placement of carbon fiber. In addition, some moving parts have been removed to minimize maintenance, such as transmission boxes, spirals, starter pins etc. The low-wind demand will hopefully increase these turbines [6].

2. Bladeless Wind Turbine

An original and cutting-edge method of capturing wind energy without the need of conventional blades is represented by bladeless wind turbines. Bladeless turbines use the vortex-induced vibrations (VIV) method to produce electricity rather than revolving blades. A turbine generates energy as wind passes over a conical or cylindrical structure, causing the turbine to vibrate. It is referred to as "Fuller wind turbine" in a relatively small compact unit.

This type of turbine provides a variety of fluid flow speeds. Its low maintenance costs because of no blades. For example, towers or poles can be installed in turbines, while generators on the base of the tower can be installed and easy maintenance is provided. In addition, the turbines need only be mounted high enough to eliminate close wind flow obstacles. Since no outer blades need a clearing of the ground, the tower can be shorter than those used for blade turbines. Example: Vortex Bladeless Turbine.

Fig. 3: Bladeless wind turbine (**Source**: https://cutt.ly/EjO7cgW)

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The screen also stops birds and bats, and prevents spinning blade visual pollution, while the proper construction will make the turbine almost invisible for the emissions of radar microwaves. The turbine could also be mounted on urban rooftops, due to infrastructure requirements. It only has a rotating section which is a turbine drive shaft and thus creates less noise [7].

3. Foldable Wind Turbine

It can supply energy in areas where electricity is not available. The Eolic folding wind generator is made of very lightweight materials that can be transported. It can be high enough in wind to actually produce electricity.

The building material includes ultra-light materials such as Aluminium and carbon fiber. It is in fact clean, Fold-up, nice and compact but practical, a lot of energy needs to be produced that regularly takes windy days. The electricity generated can be saved for future use in batteries. But this is just an idea that was not practically applied.

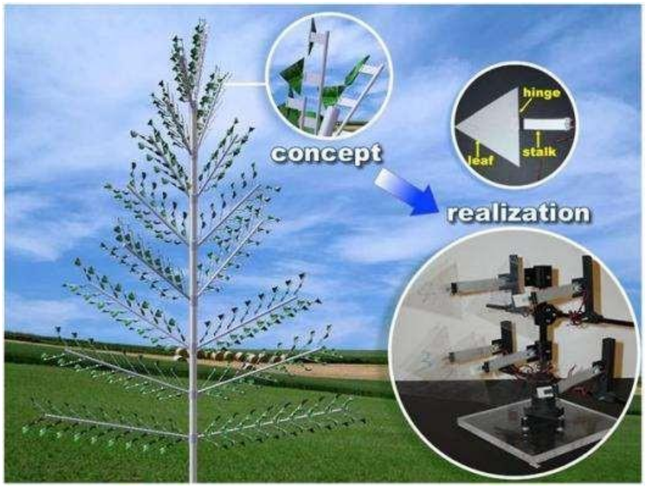

Fig. 4: Foldable wind turbine (**Source**: https://rb.gy/3ey4bi)

4. Piezo-Tree Wind Turbine

The wind turbines of the piezo-tree are like a living tree. This transforms wind energy into electrical energy through the shifting of the leaves. The flexible plate and film of the piezo-tree oscillate just like a leaf or flag can fly in the wind. On one side of the so-called leaf is an edge that is connected to a body of bluffs in a cylinder, and on the other side it is left free, but if the breeze swoops and hangs onto this body, the breeze leads to a vortex-shedding. The AC signal is pulled from the piezo leaf napping, which operates on a periodic bending model, and after rectification by a full wave bridge the electric energy will then be stored in a condenser.

Fig. 5: Piezo-tree wind turbine (Source:https://cutt.ly/fjO73G)

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The "Piezo-tree" which is a versatile piezoelectric material, is made from Polyvinylidene fluoride (PVDF). This PVDF can withstand unpredictable wind power. At first, the power level of the Piezo-Leaf Generator was not adequate. Then the end of the leaf was connected to a piece of plastic film, which increased its energy 100 times in the path of the air flux. As an effective and outstanding power manufacturer in different settings, the "piezo-tree" could be used [8].

5. Kite Wind Generator

The kite wind generator is designed by an Italian company, "KiteGen". These kites are lightweight and highly resistant and fly up to 2000 meters in height. They are like structures on giant poles, which spring from the funnel. These dragons come out of funnels when the wind blows. There are winches For each kites that release a pair of high- resistance control and angle cables. All of the light systems in the air were mounted and heavy on the ground were for power generation. The resulting structure including the base is much lighter and less costly, they say. They also offered versatility in terms of kite height. The height of the kite can be adjusted accordingly if the wind is strong at a certain height, to achieve maximum advantage in the wind. The spinning kitos causes the centre of KiteGen to rotate, and the rotation activates large alternators that generate a current. It also has an autopilot control system. This control system manages the flight pattern in order to produce full power either night or day. The best part is that the advanced radar system is mounted that can redirect kites within seconds if birds are identified [9].

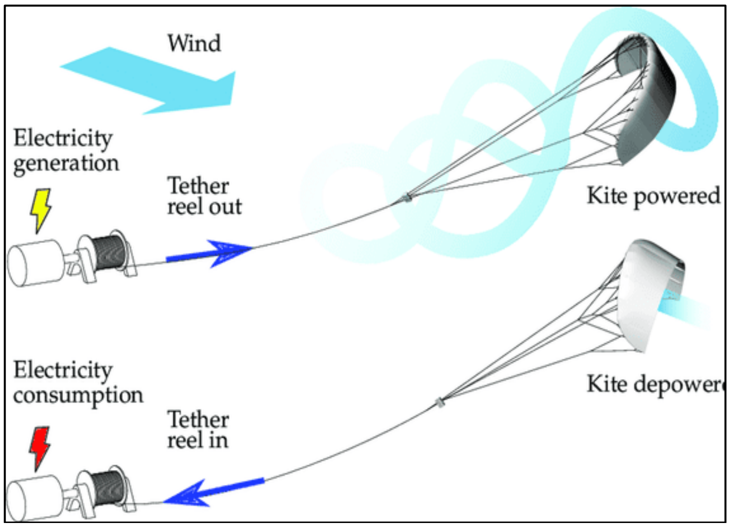

Fig. 6: Kite wind generator (**Source**: https://rb.gy/zzn3zh)

6. Concept of Bridge Wind Turbine

When cars drive under a bridge, the speed of the local wind is almost 20% higher. The wind quality is harnessed by researchers "Tiago Barros" and "Jorge Pereira" They built a bridge, which lights up at night with electricity produced by the cars pushing underneath the bridge every day. This is known as the Cross-Wind Bridge. The wind-cross bridge acts like an envelope for multipurpose.

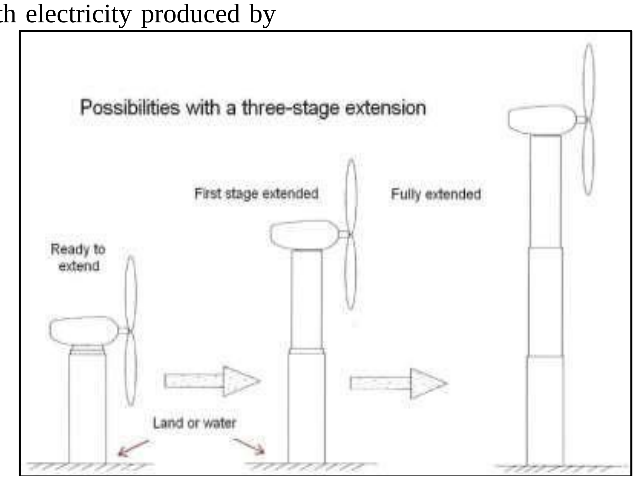

Fig. 7: Concept of Bridge (Source: https://inhabitat.com/files/windfreeways.jpg)

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A wind power system of 2,188 lightweight rotating panels catches a single form of envelope. The oblique angles of the route are located such that prevailing wind directions can be optimized. An electromagnetic belt is mounted on each panel and exchanges wind power in this concept. Due to the penetrated membrane used in the bridge cladding, this energy is projected in the auto industry to raise the green quotas by 35 percent [10].

7. The Folding Tower Wind Turbine

The "Parafold's" idea of a folding tower now needs no climbing system and is easier to build because cranes, excavators and vibrators are not required and the turbine can be lowered easily to service on the ground. The definition simplifies, efficiently, easily and effectively the construction of wind turbines. Earlier were also studied other folding towers with a hinge close to the base. However, they generated large volume loads and needed equipment to generate forces that exceeded these loads to increase the tower. More concrete than a typical tower also needed the concrete foundations. A Parafold’s Tower not only decreases construction costs, it reduces the cost of maintenance and repair, since it can be reduced to the ground easily [11].

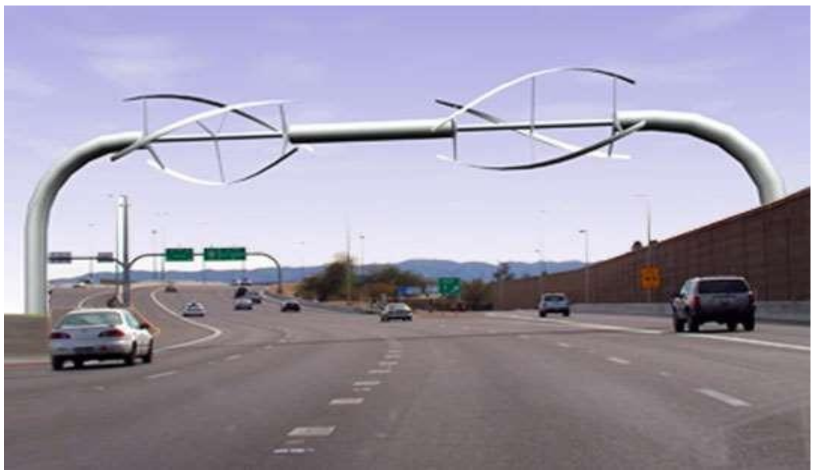

Fig. 8: Folding tower wind turbine (**Source**: https://cutt.ly/ijPqgX9)

8. Airborne Wind Turbines

An airborne wind turbine is a concept that supports a wind turbine without a tower in the air. Wind turbines may be installed at low or high altitudes, they are part of a larger class of airborne wind energy turbines (AWE), which have wind turbines of high altitudes. The bonded aircraft do not need to transport the generator mass or have a conductive bond while the generator is on the ground. If the generator is aloft, then a conductivity tether is used to transmit power to the ground or to the receiver by means of a microwave or laser. The benefit of the airborne turbine systems would be a virtually unbalanced wind, no slip rings or yaw mechanism, and without tower construction expenses.

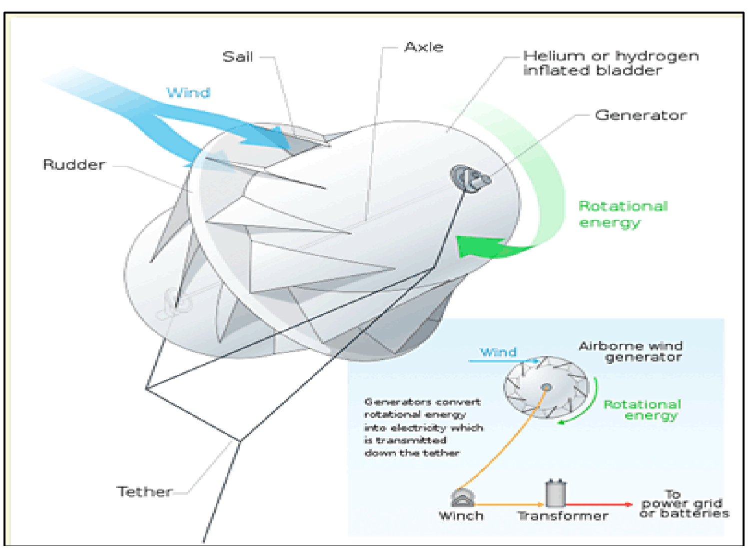

Fig. 9: Airborne wind turbine (**Source**: https://rb.gy/xhlzsj)

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Dinghies and 'helicopters' fall when there is a lack of wind; "kytoons" and "blimps' are the responses to this matter. Furthermore, bad weather such as lightning or thunderstorms could interrupt the use of the machines temporarily and possibly require them to be brought down to earth and protected [12].

Materials used

The trends in design and manufacturing keep on changing. The first turbine built cloth as its blades, but it continued to evolve until today when GRP was primarily used for rotor blades. However, between small and large turbines the materials used vary. To minimize costs, small machines prefer to use lighter castings. Many parts are Aluminium coated in small turbines, whereas steel-coated or forged in large machines satisfy the need for strength and fatigue. The bulk of rotor blades commonly used are made of fibre-reinforced plastic (GRP). Other tested materials include steel, various composites and carbon filament reinforced plastics (CFRP). The volume of small turbines is increasingly growing, requiring light but robust material. The elimination of the gearbox using variable speed generators increases the usage of magnetic generators on longer turbines to improve the magnetic material requirements [13-14].

CONCLUSION

There are lots of wind turbines according to their utilities and power needed. The results of this study show how different wind turbine designs and uses can be, and how crucial it is to choose the right kind and configuration for a given wind energy project. In addition to offering useful information for wind energy practitioners, academics, and politicians, the study's findings can influence policy and decision-making in the renewable energy industry. This study can be expanded upon in the future by examining the effectiveness and performance of various wind turbine combinations as well as novel and creative wind turbine designs. Studies can also look into ways to integrate wind energy into current energy systems and analyse the social, economic, and environmental effects of wind energy development.

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