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Design & Implementation of Small Wind Power Plant

Chetan D Patil[1], Sayali S Khatangale[2],Ashwini A Kekare[3], Gundhar A Chougule[4], Anurag A Sutar[5]

Assistant Professor[1, 2, 3,4,5,]

Department of Electrical Engineering,

Sharad Institute of Technology College of Engineering, Yadrav-Ichalkaranji, Kolhapur, Maharashtra, India.

Abstract— This Paper describes about the wind power and its potential that can be harnessed in the future to meet the current energy demand. Here detailed description of the wind turbine and the wind generation is to be done in this project. Power generation of around 500w to 1 kw by using horizontal windmill is to be undertaken. Now-a-Days most of the wind turbines are equipped with a Permanent Magnet Synchronous Generator (PMSG) combined with AC-DC-AC converter to extract the kinetic energy of the wind and convert it into electrical energy. Same ways in this project Permanent magnet DC generator (PMDC Generator) combined with DC-DC Buck boost converter is used. The DC-DC converter is connecting between generator and the electrical grid in order to control the wind turbine shaft speed and consequently the generated power. These converters have an intermediate

Keywords-wind energy, pmsg, dc-dc converter, ac-dc-ac converter

1. Introduction

Renewable Energy Sources are those energy sources which are not destroyed when their energy is harnessed. Human use of renewable energy requires technologies that harness natural Phenomena, such as sunlight, wind, waves, water flow, and biological processes such as anaerobic digestion, biological hydrogen production and geothermal heat. Amongst the above-mentioned sources of energy there has been a lot of development in the technology for harnessing energy from the wind. Wind energy is not a constant source of energy. It varies continuously and gives energy in sudden bursts. About 50% of the entire energy is given out in just 15% of the operating time. Wind strengths vary and thus cannot guarantee continuous power. It is best used in the context of a system that has significant reserve capacity such as hydro, or reserve load, such as a desalination plant, to mitigate the economic effects of resource variability. Some 80% of the global wind power market is now centered in just four countries—which reflects the failure of most other nations to adopt supportive renewable energy policies. Future market growth will depend in large measure on whether additional countries make way for renewable energy sources as they reform their electricity industries. Renewable energy is the energy which comes from natural resources such as sunlight, wind rain, tides and geothermal heat. These resources are renewable and can be naturally replenished. Now the increasing demand on electrical energy and environmental concerns, a considerable amount of effort is being made to generate electricity from renewable sources. Climate chances, high oil prices, have been leading to most governments' awareness of global issues. Wind turbine can be used to harness the energy available in available in airflows. Current day turbine ranges from around 600kw to 5mw of rated power. Nowadays renewable energy as the wind, sun, water, geothermal heat and biomass, supply 19% of the global final energy consumption. (Fig. 1.1)

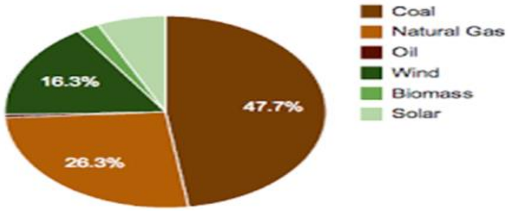

Fig.1.1 - Renewable energy share of global final energy consumption in 2016

Research Motivation:

Wind is one of the most abundant renewable sources of energy in nature. The economical and environmental advantages offered by wind energy are the most important reasons why electrical systems based on wind energy are receiving widespread global attention.

Growth of Installed Wind Turbine Power

Due to the increasing demand on electrical energy, a considerable amount of effort is being made to generate electricity from new sources of energy. Wind energy is now achieving exponential growth and has great potential. For example, Fig. 1.2 illustrates the installed wind turbine power in worldwide. According to the Fig.1.2, installed capacity of wind energy system has multiplied fourfold worldwide from 2007 to 2013 and by 2018.

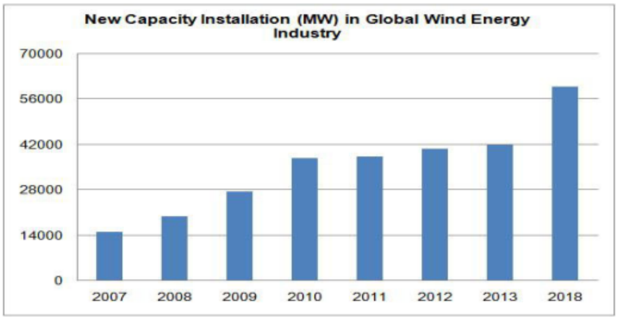

Fig. 1.2 Installed wind turbine power world wide

In some countries and regions wind has become one of the largest electricity sources. For example, in Portugal, in 2009, the wind generation was 15% of the total consumption and represented 51.8% of the renewable energy sources in the country capacity.

Environmental Advantages of Wind EnergyNow-a-days, we have faced with environmental disasters that threaten our well-being and existence. Rising pollution levels and dramatic changes in climate demand a reduction in environmentally damaging emissions. One of the major sources of air pollution is fossil fuel combustion in power plants for producing electricity. Reduced carbon dioxide (CO_2) emissions, reduced use of nonrenewable energy, reduced sulfur dioxide (SO_2) emissions, wind power uses less land.

2. Literature Survey

This Paper describes about the wind power and its potential that can be harnessed in the future to meet the current energy demand. With detailed description of the wind turbine and the wind generator focus has been given on the interconnection of the generators with the grid and the problems associated with it. The use of power electronics the circuitry and their applications have also been emphasized. In the end a voltage stability analysis has been done with respect to various models of the wind turbines to find the best way to clear faults and have optimum output. Generic three-phase AC-DC-AC converter, converter control methods for wind power generation. Neeraj Pareta Electrical Engineering & PAHER, Naveen Sen Electrical Engineering &PAHER India [1] The use of renewable energy increased greatly just after the first big oil crisis in the late seventies. At that time, economic issues were the most important factors, hence interest in such processes decreased when oil prices fell. The current resurgence of interest in the use of renewable energy is driven by the need to reduce the high environmental impact of fossil-based energy systems. Harvesting energy on a large scale is undoubtedly one of the main challenges of our time. Future energy sustainability depends heavily on how the renewable energy problem is addressed in the next few decades. Although in most power-generating systems, the main source of energy (the fuel) can be manipulated, this is not true for solar and wind energies. The main problems with these energy sources are cost and availability: wind and solar power are not always available where and when needed. Unlike conventional sources of electric power, these renewable sources are not “dispatchable”—the power output cannot be controlled. Daily and seasonal effects and limited predictability result in intermittent generation. Smart grids promise to facilitate the integration of renewable energy and will provide other benefits as well Eduardo F. Camacho, Tariq Samad, Mario Garcia- Sanz, and Ian Hisken [2]

1 Aerodynamics System

A brief introduction to the aerodynamics of wind turbines

Wind turbine power production depends on interaction between the wind turbine rotor and the wind. The first aerodynamic analyses of wind turbines were carried out by Betz and Glauer in the late 1920s and early 1930s.

Power available in the wind is given by:

The kinetic energy in air of mass "m" moving with speed V is given by the following:

$$\text{Kinetic energy} = V*m \qquad (2.1)$$

The power in moving air is the flow rate of kinetic energy per second.

$$\text{Power} = (\text{mass flow rate per second}) \qquad (2.2)$$

$$\text{Mass flow rate per second} = \rho*A*V$$

$$\text{Power} = (\rho*A*V)$$

$$P_{wind} = \rho*A*V^3 \qquad (2.3)$$

Betz,s low proved that the maximum power extractable by an ideal turbine rotor with infinite blades from wind under ideal conditions is 0.5926 times of the power available in the wind i.e. Betz limit. In practice, wind turbines are limited to two or three blades due to a combination of structural and economic considerations, and hence, the amount of power they can extract is closer to about 50% (0.5 times) of the available power. The ratio of extractable power to available power is expressed as the rotor power coefficient Cp.

1.2 Rotor power coefficient (CP) calculation

The actual power extracted by the rotor blades is the difference between the upstream and the downstream wind powers.

$$P_{wind} = \rho*A*V^3*Cp \qquad (2.4)$$

$$P_{wind} = \rho*A0.59 \qquad (2.5)$$

Where, P_{wind} is the power in W, ρ is air density in kg/, Cp a dimensionless factor called power coefficient, A is area swept by the rotor blades, (where R is the rotor blade radius) and V the wind speed in m/s. The power coefficient is related to the tip speed ratio λ and rotor blade pitch angle θ.

1.3 Aerodynamic Torque Calculation.

In aerodynamic model gives a formula for the mechanical torque on the wind turbine shaft as follows.

$$T_{mech} == \rho*A*Cp(\theta, \lambda). \qquad (2.6)$$

1.4 Tip-Speed Ratio Calculations

The tip-speed ratio or TSR, denoted by λ, is the ratio of the blade-tip linear speed to the wind speed. The TSR determines the fraction of available power extracted from the wind by the wind turbine rotor.

1.5 Pitch angle control

In this method, blades are turned out or into the wind as the power output becomes too high or too low, respectively. Rotor blade pitch is varied to control both the rotational speed and the coefficient of performance. At high wind speeds the

mean value of the power output is kept close to the rated power of the generator. Thus, power is controlled by modifying the pitch-angle, which modifies the way the wind speed is seen by the blade. This method has the advantages of good power control, assisted start-up and emergency stop. This is the most commonly used in variable-speed wind turbines.

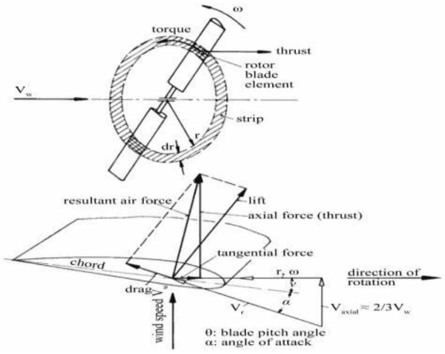

Fig 2.4 Blade pitch angle and angle attack

2. Wind Turbine Power Characteristics

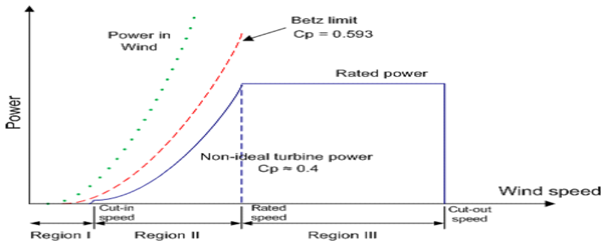

Fig 2.5 Power curve for a large wind turbine

•Cut-in speed - The wind speed at that the turbine begins to get power.

•Rated speed - The wind speed at that the wind turbine arrives at appraised turbine Control. Ordinarily this could be frequently, nonetheless not consistently, the maximum power.

•Cut-out speed - The wind speed at that the turbine is pack up to stay masses and generator control from arriving at harming levels

3. Proposed System & Mechanical Design Aspects

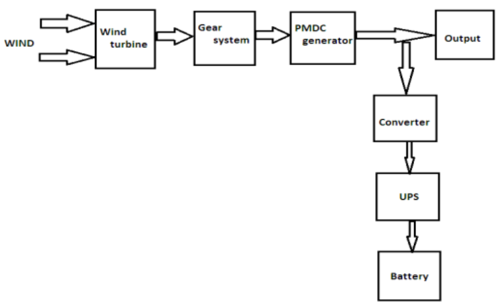

Fig 3.1 Block diagram

The block diagram consists of wind, wind turbine, generator, converter, UPS and battery and then eventually battery. As shown in fig 3.1. Wind strikes on the blades of wind turbine. The blades are specially designed, its construction and working is explained further. The wind velocity increases with respect to height. The blades are placed at 120 degrees apart from each other; the pitch angle is decided on basis of calculation made in chapter 2. Blades are of wooden material. Gear system used in the model is of ratio 1:1.5, shaft used is about 22 inches and bearings used are of two types thrust bearing and ball bearing. This assembly helps in connecting wind blades the tail and the generator for exact working co-ordination between the wind turbine rotating and the generator to work accordingly to get output.The generator used is Permanent magnet DC generator with 24 volts 5 ampere DC specification, with 100 RPM and having love-jaw coupling. Tower is 60 inches tall cubical in structure with length and width 12812 inches. The block diagram explains that with strikes on the blades i.e. with turbine, it starts rotating. The direction of rotating part is controlled by tail its gives way with respect to wind. As the turbine rotates the gear system operates and generator starts working and eventually output is obtained. This output is not constant due to wind speed. So, use of converter is done. The converter is buck boost converter. It is DC to DC converter which gives constant 12-volt output. With the use of 12-volt battery energy is stored and output is obtained.

3.1 Blade design-

Blade designed is of tamarind wood. Their dimensions are as shown in fig 3.2. they are specially designed so that maximum wind can be trapped. Such three blades are designed according to the burnolz principle. The blades are placed 120 degrees apart with constructional highlight of slight cross. Fig 3.2 shows complete dimension of wind and its pitch angle is decided on basis of study discussed

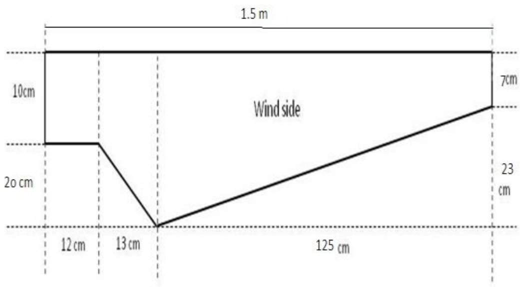

Fig 3.2 Blade design

3.2 Gear system

A gear ratio is a direct measure of the ratio of the rotational speeds of two or more interlocking gears. As a general rule, when dealing with two gears, if the driving gear (the one directly receiving rotational force from the engine, motor, etc.) is bigger than the driven gear, the latter will turn more quickly, and vice versa. We can express this basic concept with the formula Gear ratio = T2/T1, where T1 is the number of teeth on the first gear and T2 is the number of teeth on the second. The gear with ratio 1:1.5 is used.

3.3 Shaft and bearing

A shaft is a rotating machine element, usually circular in cross section, which is used to transmit power from one part to another, or from a machine which produces power to a machine which absorbs power. The various members such as pulleys and gears are mounted on it.The material used for ordinary shafts is mild steel. When high strength is required, an alloy steel such as nickel, nickel-chromium or chromium-vanadium steel is used. Shafts are generally formed by hot rolling and finished to size by cold drawing or turning and grinding. Shaft of about 22 inches is used. Fig 3.4 shows shaft used in model

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Fig 3.3 Shaft

Like other bearings they permit rotation between parts, but they are designed to support a predominately axial load. Fig 3.4 shows thrust bearing. A ball bearing is a type of rolling-element bearing that uses balls to maintain the separation between the bearing races.

3.4 Tower

Tower is designed with iron material with 7 feet in height and cubicle in structure with 1*1 feet width and length. The blades through shaft and gear and mounted on tower. The generator is set on one fourth position of tower. This is done in order to prevent the upper area from carrying weight so that tail can operate without any load. Fig 3.7 shows tower design and location of generator is shown in picture.

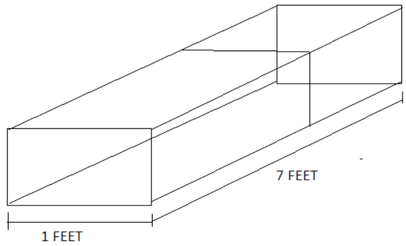

Fig 3.4 Tower design

3.2.5 Tail

Tail is a special construction attached to the nacelle to get wind direction and allow the wind turbine rotate according to wind direction. It changes the location of turbine with respect to wind. Thus, this model can rotate turbine in 360 degrees. Fig 3.5 shows tail of wind mill.

Fig 3.5Tail

4. Electrical System

4.1 Motor

A simple DC generator may be constructed in a variety of ways depending upon the relationship and interconnection of each of the magnetic field coils with respect to the armature. The two basic connections for a self-excited DC machine are the "Shunt Wound DC Generator", were the field winding is connected in parallel with the armature, and the "Series Wound DC Generator", were the field winding is connected in series with the armature. Each type of DC generator construction has certain advantages and disadvantages.

Shunt Wound DC Generator – In these generators, the field (excitation) current, and hence magnetic field, increases with operating speed as it is dependent upon the output voltage. The armature voltage and electrical torque also increase with speed. The shunt-wound generator, operating at a constant speed under varying load conditions, has a much more stable voltage output than does the series-wound generator. However, as the load current increases the internal power loss across the armature causes the output voltage to decrease proportionally.

As a result, the current through the field decreases, reducing the magnetic field and causing voltage to decrease even more and if load current is much higher than the design of the generator, the reduction in output voltage becomes so severe resulting in large internal armature losses and overheating of the generator. As a result, shunt wound DC generators are not normally used for large constant electrical loads.

Series Wound DC Generator – The field (excitation) current in a series-wound generator is the same as the current the generator delivers to the load as they are both in series. If the connected load is small and only draws a small amount of current, the excitation current is also small. Therefore, the magnetic field of the series field winding is too weak and the generated voltage is also low. Likewise, if the connected load draws a large current, the excitation current is also high. Therefore, the magnetic field of the series field winding is very strong, and the generated voltage is high. One main disadvantage of a series-wound DC generator is that it has poor voltage regulation, and as a result, series wound DC generators are not normally used for fluctuating loads.

Both Shunt Wound and Series Wound self-excited DC generators have the disadvantage in those changes in load current causes severe changes in generator output voltage due to armature reaction and as a result, these types of DC generators are seldom used as wind turbine generators. However, a “compound” connected DC generator has a combination of both shunt and series windings incorporated into a single generator and which can be so connected as to produce either a “short-shunt compound DC generator” or a “long-shunt compound DC generator”. This type of self-excited DC generator design allows for the advantages of each type to be included into one single DC machine.

Another way to overcome the disadvantages of a self-excited DC generator is to allow the field windings to be externally connected. This then produces another type of DC generator called a Separately Excited DC Generator.

As the name suggests, a separately excited DC generator is supplied by an independent external DC power source for the field winding. This allows the excitation current to produce a constant magnetic field flux regardless of the load conditions on the armature. With no electrical load connected to the generator, no current flows and only the generators rated voltage appears at the output terminals. If an electrical load is connected across the output, current will flow and the generator will begin to deliver electric power to the load.

A separately excited DC generator has many applications and can be used in wind turbine generator applications. However, DC generators for wind turbine applications have the disadvantage that a separate direct current power source is needed to excite the shunt field. However, we can overcome this disadvantage by replacing the field winding with permanent magnets, creating a Permanent Magnet DC Generator or PMDC Generator.

Permanent Magnet DC Generator can be considered as a separately excited DC brushed motor with a constant magnetic flux. In fact, nearly all permanent magnet direct current (PMDC) brushed motors can be used as a permanent magnet PMDC generator, but as they are not really designed to be generators, they do not make good wind turbine generators because when working as a simple DC generator, the rotating field acts like a brake slowing down the rotor. These DC machines consist of a stator having rare earth permanent magnets such as Neodymium or Samarium Cobalt to produce a very strong stator field flux instead of wound coils and a commutator connected through brushes to a wound armature as before.

The most common type of DC generators for wind turbines and small-scale wind turbine systems used to charge batteries is the permanent magnet DC generator, also known as the Dynamo. Dynamos are a good choice for newcomers to wind power as they are large, heavy and generally have very good bearings, so you can mount fairly hefty rotor blades directly onto their pulley shaft.

Old style diesel truck or bus dynamos are a better choice for wind turbines as they are designed to generate the required voltage and current at slower speeds with the emphasis on efficiency rather than on maximum power. Also, most bus and truck dynamos can generate power up to 500 watts at 24 volts which is more than enough to charge batteries and power lights for a small-scale low voltage system.

Other types of PMDC motors that are suitable for wind power DC generators include traction motors used in golf carts, fork lifts and electric cars. Usually these motors are 24, 36 or 48 volt types with high efficiencies and power ratings. One of the main disadvantages of a permanent magnet DC generator, is that these machines have commutating brushes that carry the full output current of the generator so DC machines used as dynamos and generators require regular maintenance as the carbon brushes used to extract the generated current quickly wear out and produce a lot of electrically conductive carbon dust inside the machine. Therefore, AC alternators are sometimes used.

4.2 Converter (buck boost converter)

The buck–boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is equivalent to a fly back converter using a single inductor instead of a transformer. Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, from an output voltage much larger (in absolute magnitude) than the input voltage, down to almost zero.

The inverting topology

The output voltage is of the opposite polarity than the input. This is a switched-mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the switching transistor. One possible drawback of this converter is that the switch does not have a terminal at ground; this complicates the driving circuitry. Neither drawback is of any consequence if the power supply is isolated from the load circuit (if, for example, the supply is a battery) because the supply and diode polarity can simply be reversed. The switch can be on either the ground side or the supply side.

A buck (step-down) converter combined with a boost (step-up) converter

The output voltage is typically of the same polarity of the input, and can be lower or higher than the input. Such a non-inverting buck-boost converter may use a single inductor which is used for both the buck inductor and the boost inductor, sometimes called a "four-switch buck-boost converter", it may be used in multiple inductors but only a single switch as in the SEPIC and Cuk topologies.

The basic principle of the buck–boost converter is fairly simple, while in the On-state, the input voltage source is directly connected to the inductor (L). This results in accumulating energy in L. In this stage, the capacitor supplies energy to the output load.

While in the Off-state, the inductor is connected to the output load and capacitor, so energy is transferred from L to C and R.

Compared to the buck and boost converters, the characteristics of the buck–boost converter are mainly:

Polarity of the output voltage is opposite to that of the input.

The output voltage can vary continuously from 0 to $-\infty$ (for an ideal converter). The output voltage ranges for a buck and a boost converter are respectively V_i to 0 and V_i to ∞.

4.3 Battery

The lead–acid battery was invented in 1859 by French physicist Gaston and is the oldest type of rechargeable battery. Despite having a very low energy-to-weight ratio and a low energy-to-volume ratio, its ability to supply high surge currents means that the cells have a relatively large power-to-weight ratio. These features, along with their low cost, make it attractive for use in motor vehicles to provide the high current required by automobile starter motors.

As they are inexpensive compared to newer technologies, lead–acid batteries are widely used even when surge current is not important and other designs could provide higher energy densities. Large-format lead–acid designs are widely used for storage in backup power supplies in cell phone towers, high-availability settings like hospitals, and stand-alone power systems. For these roles, modified versions of the standard cell may be used to improve storage times and reduce maintenance requirements. Gel-cells and absorbed glass-mat batteries are common in these roles, collectively known as VRLA (valve-regulated lead–acid) batteries. In this project 12 volt battery is used. Fig 3.10 shows lead acid cell battery.

5. Mechanical Design Implementation

5.1 Blades

Fig 5.1 Baldes

Wooden blades were designed with study of velocity and pitch angle ratio. Material used is tamarind wood. Such material is selected from economical point of view and weight point of view.

5.2 Shaft and gear system-

The gear system and shaft are mounted as shown in fig. The shaft length was decided on basis of generator location and gear system is kept longitudinal.

Fig 5.2 Shaft & Gear

5.3 Tail

Tail is constructed with the help of iron material and specially designed so that turbine gets the wind direction.

Fig 5.3 Tail

5.4 Tower

Tower is so designed which helps in setting the generator into it and thus this reduces weight on nacelle and movement in 360 degrees becomes easy. Tower is made up of iron plates forming rectangular plus cubicle structure. Model acts as a hybrid model because horizontal wind turbine is constructed but the generator is kept below in the tower as in vertical axis wind turbine. Height of tower is about 7 feet and it is so decided by checking wind velocity of that particular area.

5.5 Converter

A buck boost converter which is DC to DC converter, for variable input it gives constant DC output. The generator output is variable i.e. 4 volt to 5 volt, this output is fed as input to converter which gives constant output of 12 volt DC. The construction is mentioned.

6. Economics of Small Wind Power Plant

Sr. No.	Material	Specifications	Cost
1	Dynamo	1	3500/-
2	Metal Pipe	10 feet	1000/-
3	Metal Materials	35-40 feet	5000/-
4	Cables	20 feet	1500/-
5	Blades of wind turbine	3	4000/-
6	Ball bearing & thrust bearing	2	1500/-
7	Nuts & blots	-	1000/-
8	Converter	-	2000/-
		Total	20000/-

7. Result

Sr. No.	Parameters	Proposed System	Other Windmill
1	Rated O/P (KW)	1 KW	0.8KW
2	Generator Type	PMDC	PMSC
3	Rotor Diameter	11 Feet	10 Feet
4	Tower Height	40m	70m
5	Rotating Speed	20-100 (RPM)	5 0-400 (RPM)
6	Rated Wind Speed	3-5 m/s	7-10 m/s
7	Cut Wind Speed	1.5	1.5

8. Conclusion

In conclusion, while wooden blade windmills offer the advantages of sustainability's, aesthetical and potential local sourcing they also pose challenges related to durability, weight, manufacturing, complexity and performance. Further research and development are necessary of wooden tables challenges and unlock the full potential of wooden blade wind turbine technology

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