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Exploring Blade Design and Size Optimization in Wind Turbines

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Abstract

Wind Turbines are a crucial power source of the future due to their high efficiency and renewability. The paper briefly discusses the history of wind turbines, different types of turbines currently in the industry, their importance in a sustainable and clean futures, as well as reviews past research work. This study investigates how blade length and windspeed affect the wattage produced by wind turbines through a software simulation. Windspeeds of four different locations of India were considered for the study. It was observed that having a longer blade with even average wind speeds is useful enough to run a windmill farm that is effective. For future works, other parameters for optimization like twist angle, rotational speed, pitch, and yaw can be investigated.

Keywords: Wind turbine, wind energy, renewable energy, sustainability, blade simulation

Introduction

Wind energy, a form of renewable energy, is generated by converting natural wind to electricity. It is a source of clean energy, does not increase climate change, and takes a short period to be renewed. Sustainable development goals (SDGs) help us choose what areas we want to impact. Wind energy creates a positive impact on several SDGs: affordable and clean energy, industry innovation and infrastructure, sustainable cities and communities, responsible consumption and production, climate action, and life on land. What this means is that companies making windmills have an option to choose among these SDGs to align their efforts with global sustainability goals and help mitigate global warming.

Wind turbines are made of several components including the low-speed shaft which directly connects to the blades and the hub. This hub takes the wind energy produced, slows it down, connects to a gearbox, then to a generator high-speed shaft, and finally reaches the power cables in a city. There are many different types of wind turbines, which include horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). Both of these depend on the blade length and size; these change with an increase and decrease in the HAWT and VAWT change. These are the two topics I will be verifying the importance of in this research paper. It has been noted that wind power technology is fully matured and commercially acceptable by the majority of nations, whether developed or developing [1,2].

The HAWT and VAWT windmills both focus on blade design and size to generate energy. The VAWT model of windmills is said to outperform the long-lasting most efficient windmill of the past, the HAWT model windmill, as the VAWT model windmill can generate more electricity at slower wind speed [3]. It can handle wind turbulence to keep the electricity generation at the same ability for as long as possible. The ability to dodge wind turbulence is extremely useful: wind turbulence can cause problems to electricity generation due to high turbulence as the productivity of the windmill reduces with an increase in wind shear [4]. When turbulence increases, a windmill becomes more susceptible to breaking with the force of the wind. This can be extremely expensive and time-consuming to fix for windmills that have a larger blade size and can catch more wind like the VAWT model. This is extremely dangerous as well, because if a windmill is going to fall and there is a power plant near it, it could fall on the power plant causing a huge short circuit for everyone who relies on the wind energy to run their homes; or there could be a large wildfire due to electricity in the open field where the windmill is present. When successful businesses like Mitsubishi are making a windmill they would choose windmills of the largest size to optimize for the most energy production. This tells us that the larger the windmill the more energy it can produce at the cost of materials and space.

The design of the windmill blades and size are the most important when manufacturing. The design of the blade has changed through history; the most modern, aesthetic, and power-efficient windmill is the three-blade, with yaw and pitch abilities to face the direction of the wind or to avoid turbulence. Wind turbine blades are easy to scale with only a few calculations in chord length, twist angle, etc. Most manufacturing industries are trying to be cost-effective by increasing the blade length rather than having minor efficiency increase by getting the optimum twist angle.

In this paper, we have explored wind turbines, their blade length, and their efficiency with different wind speeds. After exploring the history of the wind turbines, their designs, and industrial practices, we have experimented using windspeeds of four different places in India using an industrial simulation software. We have analyzed the ratios and provided a critical approach to using wind turbines as sources of renewable energy.

Literature Review

Windmills have been around for millennia since 644 AD (Anno Domina "The Year Of The Lord"), and during this time, the most common types of windmills were the 2-blade and the 4-blade. This is because the 2-blade windmills were extraordinarily cheap but not as effective due to less surface area covered by the blades, while the 4-blade design was too expensive but very effective and used by rich companies with huge energy requirements. Denmark, now a clean and green country, was one of the leading countries that focused on improving their wind energy generation [5, 6].

In a research review done by Rehman et al. [7], the researchers discuss how the efficiency of a wind turbine can be increased by redesigning the blades. They mention that wind speed usually increases with height, but it is important not to go beyond an optimal height due to structural constraints. The performance optimization can be done by maximizing the annual energy yield, which refers to increasing the capture of wind energy and maximizing electricity generation over a year. The paper also talks about minimizing blade loads, i.e., forces and stresses being applied on the blade to increase their life span. Other parameters like reducing the cost of generation of electricity and cutting the torque experienced by the blade can also increase the efficiency of the wind turbine.

In another research study done by Najar et. al [8], they talk about how to optimize the blade geometric design and optimization, aerodynamics analysis, wind turbine blade structural design and dynamics analysis. The particular airfoil S809 was tested in this experiment to give the range of the angle of attack between 6-14 degrees. The lift to drag (L/D) ratio over 1 is there in this range of angle of attack which produces more lift than drag thereby increasing the efficiency of the turbine. To increase the efficiency of wind turbine blades, studies have shown that having a curvature in the blades itself increases rotation speed and number, making the wind turbine effective in heavy as well as slow winds. The rotations of the wind turbine are much faster with the curved blade thereby giving a much higher efficiency. From the experimental results we can also see that inclined blades are less efficient than the straight blades which was against the online simulation used to form the hypothesis.

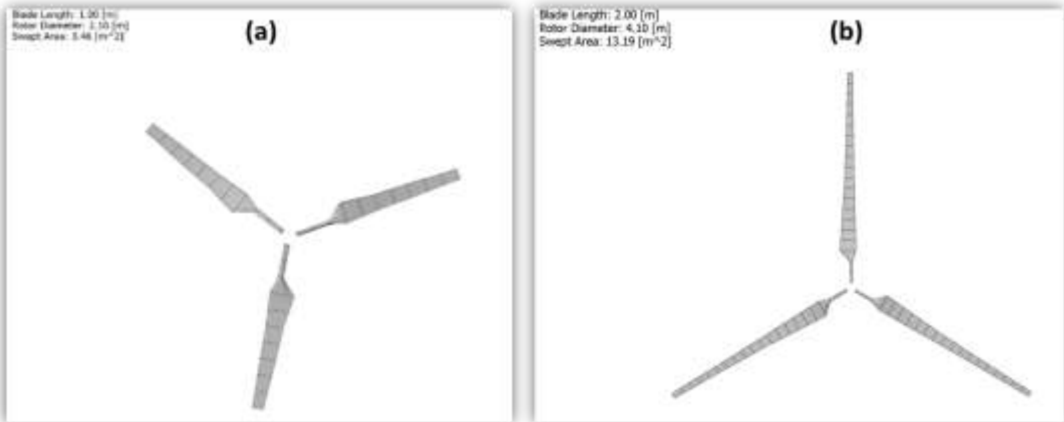
Methodology

In order to investigate the impact of length and windspeed on the performance of wind turbines, we used a publicly available simulation software, QBlade CE v2.0.7.7_beta. It is an engineering level software used in research and industry. This software shows the efficiency of curved blades as compared to straight blades and the efficency of these wind turbines in terms of power generation. The model used for the blade turbines is called the “Betz” model. This model simulates the maximum amount of energy a wind turbine can capture. It was invented by german physicist Albert Betz in 1919, which states that no wind turbine can capture more than 59.3% of the kinetic energy in the wind, called the betz coefficient [9].

The components used to make the wind turbine blades include: a HAWT mode button, airfoil design module, airfoil analysis module, polar extrapolation to 360 degrees, HAWT blade design, steady BEM analysis. A snapshot of the prepared model is shown in Figure 1. The HAWT blade design was used to design the blade and rest were used to analyse the efficiency of the wind turbine. The process of making the blade requires chosing a blade design from the blade airfoiltools.com [10]. The shape of the wind turbine is made following the required steps. Next step is to use the optimization tool to adjust the twist angle to 6 degrees after making the first blade. Then the wattage was checked and finally the same process was repeated to make 10 more segments. The first wind turbine was made of 1 meter length blades. Following a similar approach, a wind turbine with 2 meter long blades was made. We measured the chord values, which is the distance from the back edge of the blade to the leading edge of the blade. This gives us the exact total length for our blade, as shown in Figure 1 (a) and (b).

The wind speeds in four different parts of India was taken from the official meteorological website. The locations selected were Odisha (wind speed 1.6m/s), himachal pradesh (wind speed 11.2 m/s, Mumbai (wind speed 3.1m/s), Kerala(wind speed 11.2 m/s). The wattage of both the blades was measured with changing the speed of both wind turbines to match the windspeed of each of the four different Indian locations. The rotational speed of windmills in India is 10-20 per minute so as an average of 15 was taken to test all of our wind speed with the two considered blade lengths.

Figure 1: Blades of the wind turbine created in Qblade using the Betz model with a 6 degree twist angle optimization and a blade length of (a) 1m (b) 2m



4. Results and Discussion

Table 1 summarizes the findings from the experiment: the wattage is doubled when length of the blade and the windspeed are doubled. The influence of blade length on the wattage produced is extremely high. The graphs in Figure 2 and 3 show the wattage on the y axis and the windspeed on the x axis. The dot represents the accurate point of data at 11.2 m/s and the wattage it is producing. Doubling the blade length from 1m to 2m has almost doubled the wattage for the same windspeed. So it can be inferred that the longer the blade, the higher the wattage output. Testing the blade length at different windspeeds, it was observed that as the windspeed increases, without the increase of turbulence, higher wattage production occurs due to the increase of the air contact with the blades.

Table 1. Wattage(W) 1 and Wattage(W) 2 produced at different windspeeds for blade lengths 1m and 2m respectively with a twist angle of 6 degrees and rotational speed of 15 per minute.

Blade Length (m)	Wattage (W) produced at wind speed 1.6 m/s	Wattage (W) Wind speed 3.1 m/s	Wattage (W) Wind speed 11.2 m/s	Wattage (W) Wind speed 11.2 m/s
1	0.330	1.054	11.231	11.231
2	1.138	2.785	20.9	20.9

Figure 2: Power generated with a turbine of blade length 1m at 11.2 m/s windspeed

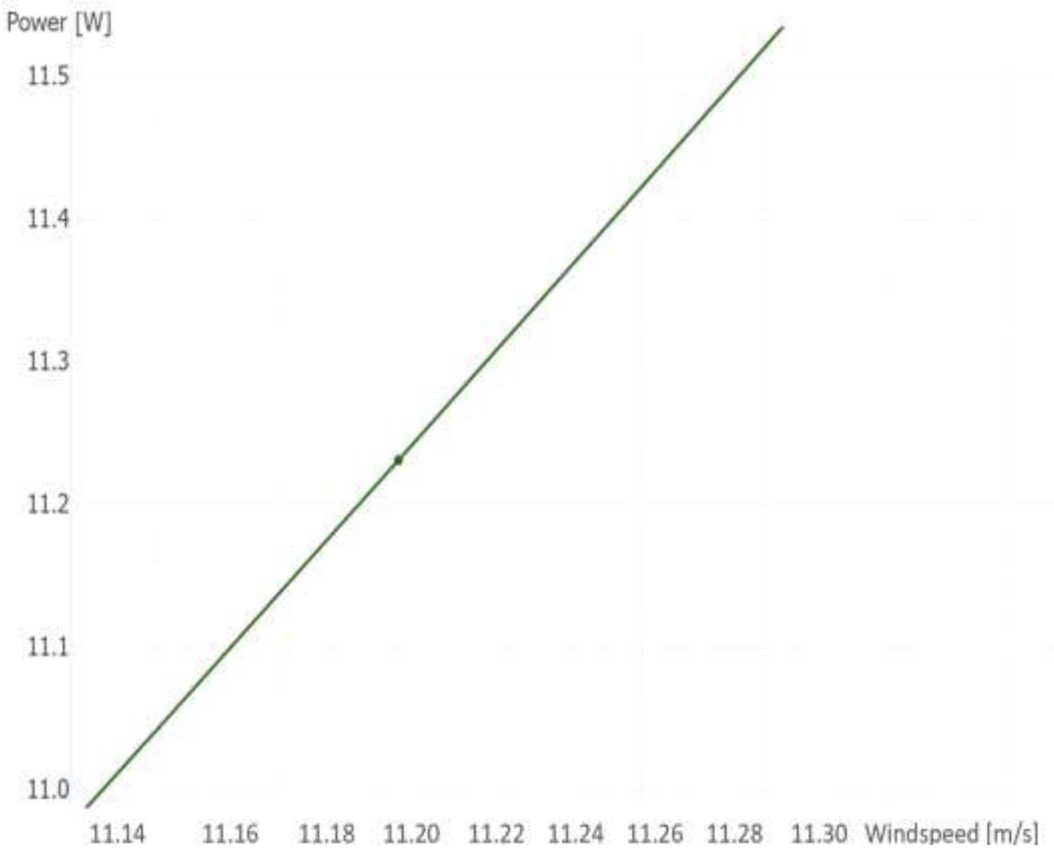
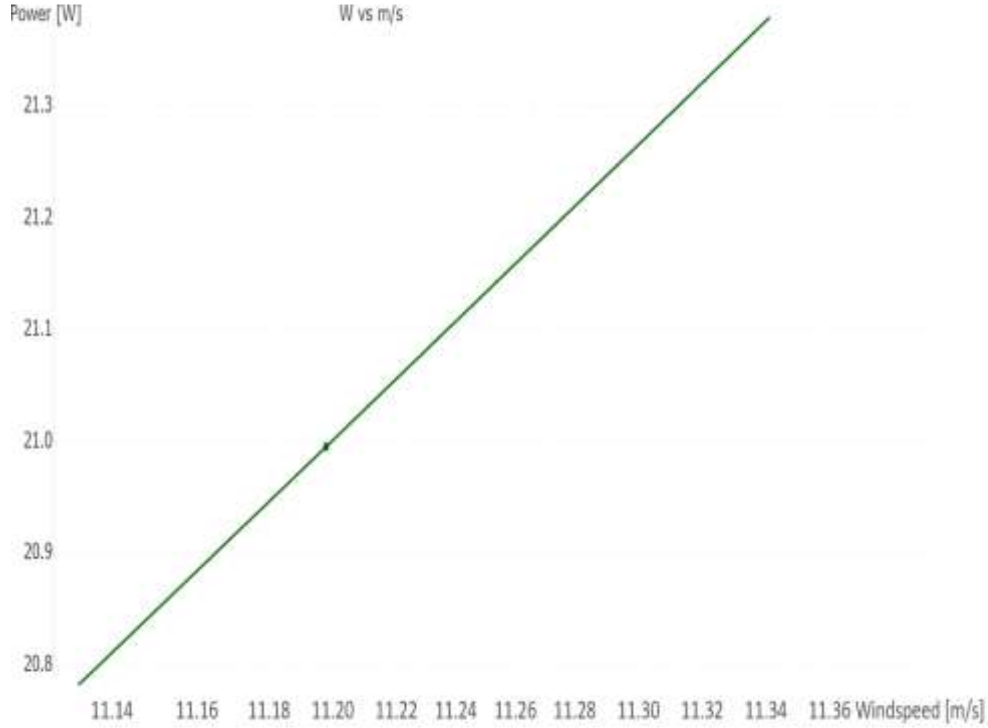


Figure 3: Power generated with a turbine of blade length 2m at 11.2 m/s windspeed



Blade optimization is one of the best ways to make wind turbines sustainable and more efficient. Blade optimization includes tweaking the twist angle, changing the blade, design, changing the chord length, and making the width optimal based on the other changes made. It can also be made hollow to reduce weight or use lighter materials. This also reduces carbon emissions as we are using less materials to make more energy.

Due to the sheer size of wind turbines the wattage per square km becomes less than that of fossil fuels which can slowly reduce the toal energy we have to power our world but the positive side of this is that researches show that windmills produce 11g of CO2 per killowatt/hour compared to 980g of CO2 per kilowatt hour produced by coal[11]. So if it means we have to use more resources and space to produce less carbon into the atmosphere in the long run it would be advisable for the world to switch to wind turbines as their main energy source. Estimates show that a single 5MW windmill requires 1300 metric tons of concrete to make. Which can put a dent in the number of resources we have for future development. Which can put a dent in the number of resources we have for future development. The best mitigation method of the problems of creating large windmills is to optimize each windmill to its finest possibility. Making tons of different heights of wind mills in one area to get maximum efficiency use the best possible generator, gearbox, speed-up shaft and slow down shaft to get the best power efficenty per windmill to get a neutral or carbon negative wind turbine farm.

The expense of creating wind turbines is extremely high. This is because of their large size and space requirements in order to harness maximum wind for energy. This is a huge barrier that prevent most companies from using wind turbines. If the government were to subsidise the production of wind turbines, they could cut down the use of fossil fuels by almost half as expenses are the main reason large companies dont invest in wind turbines for their main source of energy. This will further incentivise the research on more sustainable wind turbines.

Conclusion

In conclusion, this paper explores multiple aspects of wind turbines with a focus on optimization. Starting with the history and types of wind turbines, the paper presents a software simulation for power generation by varying blade lengths at various windspeeds. It was observed that the power generated almost doubles by doubling the blade length and increases with increase in windspeed. However, the only way you can increase the blade length is by slightly optimizing the design to match the blade length otherwise the overwhelming length will be inefficient. In the future adding new aspects to the simulation parameters, such as twist angle or blade design, to find the most optimized version of wind turbines.

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