Enhancing Performance of a Bicycle Wheel Wind Turbine Using a Wind-Lens

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Abstract: ***The following work deals with low cost and green energy production from wind by using a bicycle wheel wind turbine (BWWT) shrouded with wind-lens. A bicycle wheel wind turbine is a very simple wind turbine that is made, using a bicycle wheel and the blades are made up of plastic and fitted with the rims of the wheel. To increase the performance of the turbine a wind-lens is used which increases the wind speed striking the turbine blades by creating turbulence at the rear end. The design and analysis of the turbine were done using Autodesk Inventor and Ansys (fluent) software respectively. Finally, the whole set up was manufactured and an experiment was conducted at different wind speeds in order to check the performance of the wind turbine assembled with a wind-lens.***

Keywords: Green energy; Wind energy; Bicycle wheel wind turbine; Wind-lens; Turbulence

1. Introduction

Renewable energy resources (RES), involving natural phenomena such as sunlight, wind, tides, plant growth, and geothermal heat, as per the definition of the International Energy Agency [1], are the sources that can be derived from natural process and that gets replenished time and again. The lack of astute management and heavy usage of non-renewable resources, fossil fuels in particular, has led to environmental and climatic concerns such as global warming. The use of renewable resources will cut-off the root causes of aforementioned problems i.e. the release of toxic gases such as CO2 and CO etc. into the environment.

The need of the hour is to harness more and more energy from the sustainable energy sources efficiently and effectively without causing harm to the environment in order to meet the ever-growing energy demand of human civilization. For the application of an effective energy resource in future, keeping in mind the limitation of fossil fuels, the renewable energy resources are the safest keeping in mind the future generations. Furthermore, due to environmental issues, such as, global warming, etc., application of renewable and clean energy seems to be holding the key to the solution of these problems. In a survey done by United Nations Development Programme [2], it was found that in the year 2000, Renewable energy sources (RES) supply only 14% of the total world Energy demand. However, it was later found byFridleifsson IB [3]that the share of RESs is expected to increase very significantly (30–80%) in 2100.

In recent years, wind energy has become one of the most economical renewable energy technologies. Today, electricity generating wind turbines employ proven and tested technologies and provide a secure and sustainable energy supply. The technological development of recent years, bringing more efficient and reliable wind turbines, is making wind power more cost-effective. The drift towards this sector is showing positive results. In the Global Wind Report [4], GWEC stated "In 2015, global wind power capacity increased by 63,330 MW or 17.14% from 369,553 MW to 432,883 MW". However, comparing with overall demand of energy, the scale of wind power extraction is still small. The large area requirement, high installation cost and the turbulent nature of local wind have stalled the widespread use of wind turbines for power generation in many countries. OzgenerO_etal [5] stated that the world-wide potential for wind energy is estimated to be 26,000 TWh/yr, while a capacity of 9000 TWh/yr may be utilized due to economical and other reasons.In a review document published on 31st March 2010, KralovaI_etal [6] predicted the statistics of Global Wind Energy scenario by 2040: 4.7 in 2001, 44 in 2010, 266 in 2020, 542 in 2030, 688 in 2040(million tons of oil equivalent). Therefore, invention of a new wind power system is needed that produces more power output even in those areas where the speed of the wind is low and complex wind patterns are created. If by utilizing the fluid dynamic nature around a structure or topography we increase the wind speed, namely, if we concentrate the wind energy locally, the power output of a wind turbine will be increased as well.

Even after being very cheap and easy-to-build technology, Bicycle wheel wind turbine can serve as an effective practical application in the field of wind energy harnessing, which upon employment in the potential regions, where electricity transmission has not yet reached can mitigate the problems of the mass who are in dire need of electricity.

Kumar A_etal [7] of Policy Division Analysis of The Energy and Research Institute (TERI), India, in a study calculated that "At a mean wind speed of 4.5 m/s, the estimated value of net annual CO2 emission mitigation potential is the lowest (2874 kg) for GM-II model and highest (7401 kg) for SICO model in the case of diesel substitution. Similarly, for the case of electricity substitution for the same wind speeds, it is estimated at 2194 kg and 5713 kg, respectively, for the above-mentioned two experimented models".

The turbine is basically a horizontal axis wind turbine made from a bicycle wheel by wrapping adhesive plastic on appropriate spokes. The wrapped spokes work as blades which gyrate around the central hub of the bicycle wheel. A simple bicycle wheel turbine won't be sufficient to harness the required amount of energy at low wind speeds. So, a wind-lens attachment is added to the setup in order to increase the performance of the BWWT.

Wind-lens is a very simple and sophisticated technology that improves the wind turbine efficiency by active utilization of vortex shedding behind the brim which was first demonstrated by Prof. Yuji Ohya at Kyushu University. The shrouded wind turbine with a brimmed diffuser has demonstrated power augmentation by a factor of about 2–5 compared with a bare wind turbine, for a given turbine diameter and wind speed [8]. Next generation diffusers have been developed which show significant features like improved safety, reduction of acoustic noise and Doppler radar interference [9]. An aerodynamically optimum design of wind lens turbine was developed by Nobuhito Oka and his team [10]. Results of experimental research on a seven turbines array have shown no loss in performance with closely spaced rotors [11]. The wind lens profile was optimized by Liu J using computational fluid dynamics simulations [12].

2. Working

2.1. Working of Bicycle Wheel Wind Turbine

A bicycle wheel wind turbine is basically a horizontal axis, axial flow wind turbine made from a bicycle wheel in which certain pair of spokes are wrapped with adhesive polymer plastic to make them operate as turbine blades. When wind having sufficient kinetic energy strikes the blade, there is a change in momentum of air flow. This change in momentum imposes a force on the blade which drives it to rotate about its central axis, due to its structure. The spokes are aligned in such a way that they provide a twist angle, which facilitates even distribution of force at every radial cross-section of the blades, thus creating less stress concentration in the blades.

2.2. Working of Wind lens

A wind-lens is nothing but a brimmed ring attached to a diffuser and the wind turbine is placed at the smaller cross section area of the diffuser. A wind turbine's performance heavily depends upon the velocity of the wind striking the turbine blades. The power generated by a wind turbine can be given by [13],

$$P = \frac{1}{2} C_p \times \rho \times A \times V^3 \quad (1)$$

Where,
P = Power generated by wind turbine
Cp = Coefficient of Power
ρ = Density of Air
V = Axial component of velocity of air

The wind-lens technology creates a pressure difference between the rear and front end of the wind turbine with the help of the turbulence generated by the brim at the rear end (figure 1) and thereby, increasing the velocity of the wind striking the blades of the wind turbine. As a result of this, the power generated by a wind turbine increases many-fold.

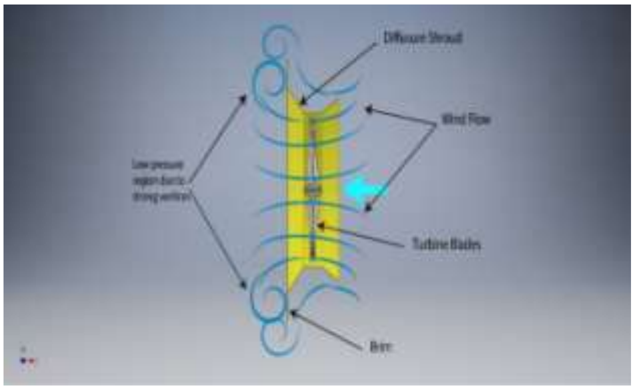

Figure 1: Schematic diagram of working of wind lens

3. Design and Simulation

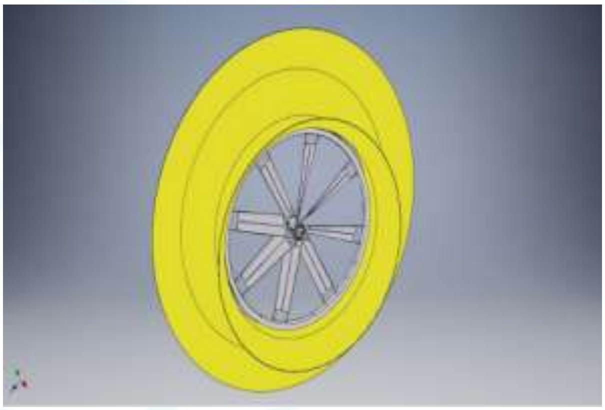

Figure 2: Wind lens model in Autodesk Inventor

At first a CAD model of the Wind-lens and Bicycle Wheel Wind Turbine was designed in "Autodesk Inventor" CAD software as shown in the figure 2. The simulation of above wind-lens was done using Ansys (fluent) software with a standard k-epsilon model and scalable wall function for near wall treatment and a turbulent intensity of 5% was used at both inlet and outlet. At the inlet, a velocity boundary condition having a value of 5.5 m/s and outlet pressure boundary having a pressure of 1 atmwas used. The following results were found from the simulation:

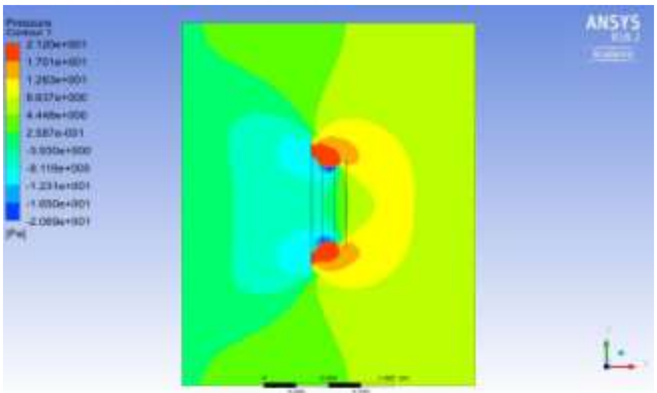

Figure 3: Pressure contour from the fluent analysis of the designed wind-lens at 5.5 m/s wind speed.

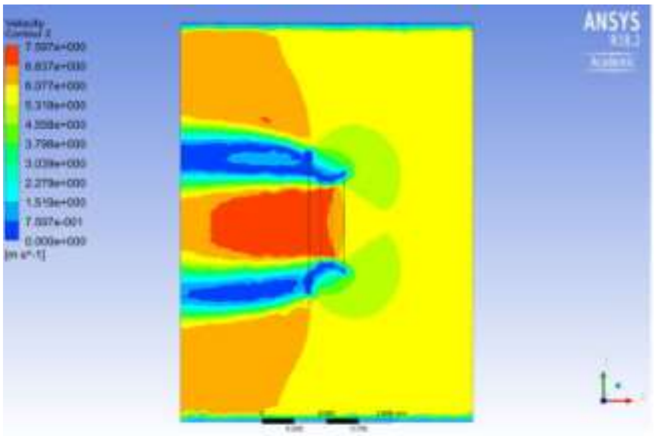

Figure 4: Velocity contour from the fluent analysis of the designed wind-lens at 5.5 m/s wind speed

In the figure 3, the simulation results for distribution of pressure around a wind lens at a wind speed of 5.5 m/s is shown. Figure 4 describes the velocity distribution around the wind lens at a wind speed of 5.5m/s. The above mentioned simulation was run at different inlet conditions to check increase in velocity of air striking the wind turbine after the wind lens was employed.

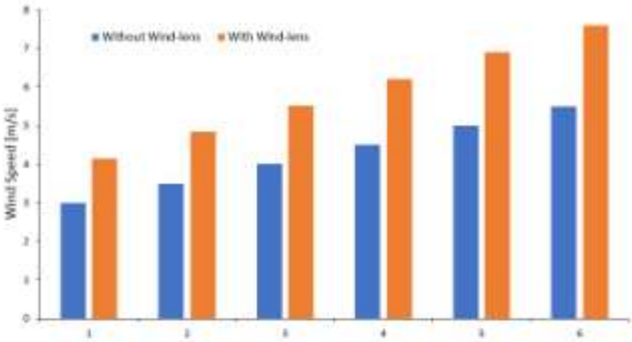

Figure 5: Comparison of wind velocity striking the turbine blades

It can be clearly seen from the simulation results in the figure 5, that after using wind lens the speed of air striking the BWWT blades is increasing and even the rate of increase is gradually increasing with increase in velocity.

4. Experimental Setup and Results

Figure 6: Experimental setup of Wind lens and Bicycle wheel wind turbine

Figure 6 shows the experimental set up with a wind lens and a bicycle wheel wind turbine. A wind turbine was made from a bicycle wheel of diameter 64 cm. The turbine blades having a surface area of 123.08 cm^2. and twist angle 34^0 were generated by wrapping adhesive plastics on selected spokes and the rest of the spokes were removed. Finally, both the wind turbine and wind lens were assembled and the assembly was mounted on a stand for testing.An experiment was conducted at different wind speeds in order to check the performance of the wind turbine.

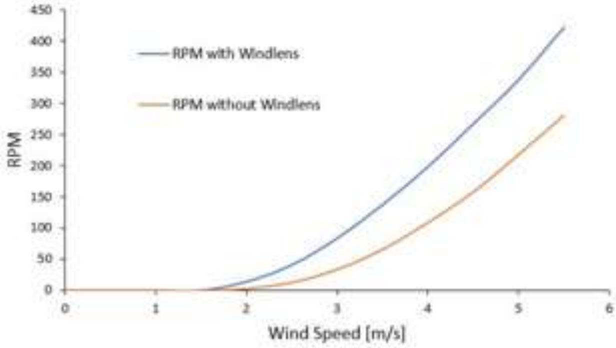

Figure 7: Experimental results on RPM at different wind speeds

Figure 7 and figure 8 contain two graphs relating the RPM and shaft power to wind speed for two cases, i.e., with the use of wind lens and without the use of wind lens. From the graphs it can be deduced that both RPM and shaft power increases with increase in wind speed; as with increasing wind speed the kinetic energy of wind striking the turbine increases. In the figure 9 a graph between electrical power and wind speed is shown which is obtained by coupling a turbine with a 1000 RPM DC generator.

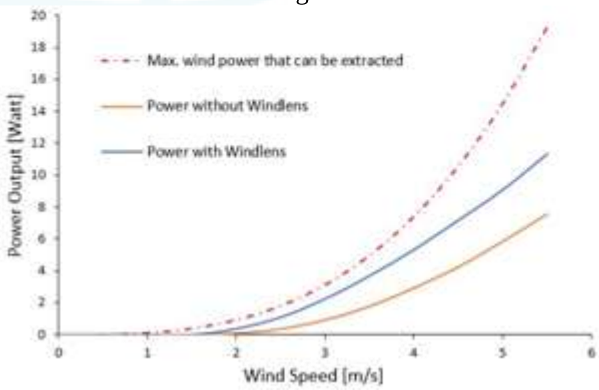

Figure 8: Experimental results on Shaft Power Output at different wind speeds.

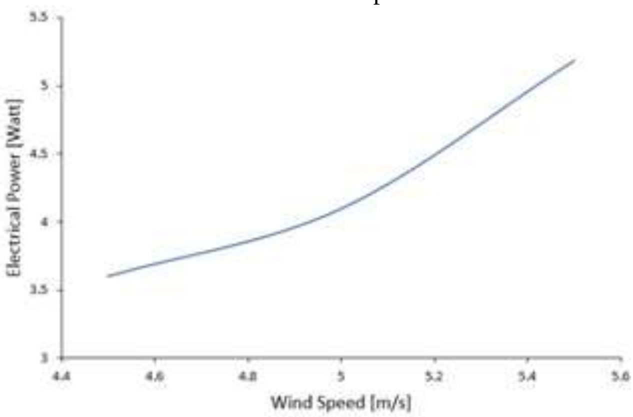

Figure 9: Electrical power output observed after using a 1000 RPM DC generator.

5. Future Scope

Figure 10: Multi-rotor Wind lens model in Autodesk Inventor

As the rotor diameter is very small and the wind speed considered for experimenting are almost around the rated wind velocity of many commercial wind turbines, the energy that can be extracted from the wind turbine is less. By increasing rotor size and for a higher wind speed of about 10 m/s or more, the turbine will be able to generate enough power to recharge a battery for storing energy or for any other small scale applications such as powering the street lights etc. A further modification can be done by using a multi-rotor system for generating more power from a single structure as shown in figure 10. These turbines owing tos its small size can be integrated with the prevailing technology (solar panels on a street light pole) to generate power for illuminating street lights even when the sun rises rarely in a cloudy day. This technology can be installed in the farthest surviving regions of Arctic and Antarctic where there is sunlight for a very minimal amount of time while the wind speed is sufficient.

6. Conclusion

Wind lens technique applied to a bicycle wheel turbine shows great potential for generating clean and environment friendly power at very low cost. The results obtained from the experiment was from a 1000 rpm DC generator at a maximum wind speed of 5.5m/s and manufacturing were subjected to human errors. Despite all these lacunae, we were able to generate 6.4 watts of power. So, at higher wind speeds of 10 to 12 m/s and proper manufacturing, the bicycle wheel turbine with a wind lens can generate enough power to charge a battery for storing power and provide backup for street light powered by solar panels during the dark hours or during the cloudy days.

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