Review paper on Diffuser Augmented Wind Turbine (Wind Lens Turbine)

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Abstract - *For the last few years a great deal of research work has been done in the field of wind energy to improve the performance of small wind turbines for domestic application. In this paper, a new approach of wind turbine is discussed which consists of a diffuser shroud with a broad-ring brim at the exit periphery and rotor blades inside it with various researches studied giving an overview of it. Here, the improved effects of diffuser have on the overall performance of a small wind turbine system been studied. Besides, the effect of the diffuser shape had on the wind speed was analysed by experimental setup as studied in following researches and found that the wind speed in the diffuser is greatly influenced by the diffuser open angle, flange height, body length, throat position and inlet shroud shape and so on. The wind speed is increased near the inlet region of the shrouded diffuser. As a result, the output power co-efficient in many studies show increase by a factor of 2.5 to 5 times that of a conventional wind turbine.*

Key Words: Diffuser Augmented Wind Turbine, Wind Lens Turbine, Blade design, CFD

1. INTRODUCTION

In order to develop the energy resources for the present as well as future, so many researches have been under implementation where wind energy is found to be emerging and one of the most potential sources to produce energy. Due to combustion of huge amount of fossil fuels worldwide for power production is causing numerous environmental problems such as acid rain, global warming, smog and climate change. In recent years, to reduce the worldwide dependence on fossil fuels, interest in renewable energy technology has been increased.

The wind lens turbine is a modification of the horizontal wind turbine created by Professor Ohya from the Kyushu University as an attempt to be more efficient in production of electricity and less invasive to both humans and nature. As the normal wind turbine does, the wind lens harnesses the energy of the wind but has a few modifications in order to increase efficiency as well as the impact on the environment. Studies have shown that the Wind Lens can have between two and five times more output of power compared to the wind turbine due to the way it harnesses more wind. The diffuser shape and the brim combined creates more efficiently placed and accurate airflow. This results in a higher amount of energy that is produced.

As the power generated by a wind turbine is proportional to the swept area and the third power of the wind speed. Therefore, for effectively increasing the power output we need to enlarge the swept area or increase the wind speed. This can be achieved by adding flanged diffuser as shown in Fig 1. to the wind turbine, thus, generating separations behind it where low-pressure region draws more wind through the rotor blades as compared to a bare wind turbine. This ultimately increases blade rotation and amount of energy generated.

Fig 1. CAD Assembly of Wind Lens Turbine

2. LITERATURE SURVEY

Yuji Ohya and Takashi Karasudani presented a paper [1] in which they developed a new wind turbine system which consists of a diffuser shroud around the wind turbine with a broad brim at the exit periphery i.e. Wind Lens. They started with the experiments on diffuser shaped structure which showed acceleration of wind speed at the entrance and then they carried out experiments on long type diffuser and brimmed short diffuser, where long type diffuser further showed increase in wind speed. Their first prototype was a long type brimmed diffuser wind turbine with L/D =1.47 and h/D = 0.5 having rated power of 500 Watt. Remarkable increase in power output coefficient of about 4 to 5 times that of BWT (Bare or Conventional Wind Turbine) was achieved because of a strong vortex formation which creates low pressure region behind the broad brim drawing more mass flow of wind through the diffuser. They also made two compact brimmed diffuser wind turbines with L/D = 0.1 to 0.4, h/D = 0.1, D_h/D = 13% and clearance of 10mm having rated power of 5kW. Through output performance test, they achieved about 2 to 3 times increase in output power compared to BWT.

Yuji Ohya [2] presented a paper in which 3 and 5 B-DAWT (Brimmed Diffuser Augmented Wind Turbine) placed in close vicinity in an MRS (Multi-Rotor System) were investigated. B-DAWT with fixed parameters as rotor of 510 mm, L/D ratio = 0.22, h/D ratio = 0.1 whereas s (gap width)/D_{brim} was varied from 0.01 to 0.3. Investigation was carried out in a wind tunnel with approaching wind speed of 6 m/s and Reynolds number taken as $1.7*10^5$. Influence in each other's power output by using WLT in MRS was observed. Whereas, the largest increase in the total power output of about 10% and 20% was seen in 3 and 5 B-DAWT at s/D_{brim} = 0.2 and lower pressure was observed due to the acceleration of leading vortices near the gaps which means more air flows into the turbine.

Hasim A. Heikel in the paper [3] investigated the effect of diffuser flange inclination which was varied from -15° to +15° with a step of 5° and the diffuser flange depth inside at the exit of the diffuser ranging from 0 to 0.06 with a step of 0.02. Investigation was carried out on a CFD model having rotor diameter 1160 mm and flange diameter 1608.5 mm in ANSYS Fluent 16.2 at the wind speed of 8 m/s and 10 m/s. It was confirmed that due to formation of low-pressure region behind rotor, there was increase in both wind speed and power produced. When the diffuser flange inclined at little angle in positive and negative angle, a larger lower pressure region was observed, thus, more streamlines at the diffuser outlet and increase in C_p. The location of the vortex was fixed in Y-direction at negative diffuser flange inclination whereas there was increase in vortex location ranging from 22% to 45% at positive diffuser flange inclination. The maximum percentage increase of both C_p and C_m of 28% was obtained at TSR = 5.6 and diffuser flange angle of +10°. Whereas, decrease in C_p was observed when the diffuser flange depth goes deeper at the diffuser outlet with a reversed flow occurred at the depth of 0.08.

Raju Govindharajan in the paper [4] observed that the increase in wake formation behind the brimmed diffuser create low pressure region behind the turbine which draws more wind flow to strike on rotor blades results in augmentation of torque. They investigated optimization of mass flow rate through turbine of various diffusers with straight, curved, bumped and stepped configuration. It was observed that bumped and curved diffusers had more static pressure rise compared to another diffuser configuration.

Shuhei Takahashi in the paper [5] investigated the blade tip vortices of a B-DAWT by conducting a three-dimensional numerical simulation using a large eddy simulation (LES). In order to focus on blade tip vortices, they used a moving boundary technique to simulate flow around a rotating blade. A long type and a compact type WLT with rotor diameter 380 mm and 2500 mm respectively were taken for investigation. They found that due to induced counter rotating vortices between the blade tips and the inner surface of the diffuser, the blade tip vortices were weakened. In both cases of long type and compact type WLT, it was observed that blade tip vortex and induced vortex are mutually weakened whereas they dissipate before reaching the end of diffuser in long type WLT. Also, the compact type WLT generated stronger blade tip vortices compared to BWT. Jei Liu in the paper [6] presented an optimization method for the shape design of the axis symmetric wind lens with a goal for velocity augmentation and drag force reduction using Genetic Algorithm (GA) and CFD method. Optimization of 200kW WLT was done having throat radius of 9062mm and diffuser length 3780mm at a wind speed of 12m/s. From the result, it was observed that optimized WLT has a longer inlet segment and a smaller windward area compared to original WLT and it also showed a good performance at other wind speed as well.

Peace-Maker in the paper [7] studied that the optimized plain conical diffuser reduced the cut-in wind speed of the rotor more than that of BWT, and it gives power output about 2.5 times that of BWT. Therefore, it can be used in low wind speed areas where BWT cannot be operated. The optimized plain conical diffuser is less inert and response to wind speed and its direction is more as compared to that of flanged diffuser. Also, production cost is less compared to flanged diffuser due to addition of flange.

Aly M. El-Zahaby presented a paper [8] in which development and analysis of 2D-axis-symmetric CFD model of B-DAWT was done to increase the generated power. GAMBIT software was used for 2D CFD diffuser model grids whereas, ANSYS Fluent was used for flow field analysis. This study mainly focuses on the effect of diffuser flange angles which was varied from -25 to 25 with fixed other diffuser parameters. Validation of presence of vortices behind rotor which creates low pressure region and thus, increase in wind speed near diffuser entrance was observed. While at diffuser flange angle of 15, maximum diffuser entrance wind velocity was reached with 1.953 times increase in power generation compared to BWT viz., 5% more than normal flanged diffuser.

T. Saravana Kannan in the paper [9] investigated the effect of wind speed on different shapes of flanged diffuser using software like SOLIDWORKS for 3D modelling and ANSYS Fluent for CFD simulation. Total four concepts were analysed where diffuser opening angle was varied from 4° to 20°; use of splitter within the diffuser to direct and avoid separation and cause vortex inside the diffuser wall; use of solid cone shaped separator to get optimum air pressure at the wake of diffuser and minimize separation of flow in the diffuser and lastly using a bigger diffuser along with cone shaped splitter to ensure smooth flow inside the diffuser. About 61.25% increase in the wind speed was obtained with diffuser configuration having diffuser opening angle of 16° and 0.5m splitter with splitter opening angle of 4°.

S. A. H. Jafari and B. Kosasih in the paper [10] carried out CFD simulations on a 300W AMPAIR WT having rotor radius of 650mm with a simple frustum diffuser shrouding. The diffuser was modelled with different L/D and H/D ratio in order to understand the effect of length and area on power augmentation. It was suggested to keep swept area equal to the outlet of the diffuser for economically extracting the desired power from the WLT. It was found that with a high area ratio, greater pressure reduction at the exit of the diffuser is achieved with greater degree of separation which can be overcome by using longer diffuser.

Toshio Matsushima in the paper [11] studied the effect of diffuser's shape had on the wind speed showing how it was greatly influenced by the diffuser length and its expansion angle in a WLT. They simulated the wind speed passing through the diffuser by varying the parameters like diffuser main body length from 2m to 4m, entrance diameter, expansion angle from 0 to 12 with a step of 4 and flange height from 0.1m to 0.5m with fixed rotor diameter of 1m. About 1.7 times increase in wind speed was obtained which was observed near the diffuser entrance which then resulted into 2.4 times increase in power output compared to BWT.

Nobuhito Oka in the paper [12] developed an optimum aerodynamic design method for WLT (Wind Lens Turbine) which is based on quasi-three-dimensional design method and genetic algorithm. It consists of two parts: meridional viscous flow analysis and two-dimensional blade element design. Investigation for aerodynamic performance and flow field showing difference between the optimum and conventional design, was carried out using wind tunnel and 3D Reynolds-averaged Navier-Stokes simulations. It was observed that the optimum design was very efficient in extracting wind energy by achieving significant improvement in the output power coefficient outperforming the Betz limit which is the theoretical maximum power output coefficient for conventional wind turbine. Also, it was found that performance enhancement of WLT can be done by simultaneous optimization of the spanwise blade loading distribution and wind lens shape.

Peter J. Schubel and Richard J. Crossley presented a review paper [13] which provides detailed knowledge about modern wind turbine blade design. Following points where highlighted: To reduce efficiency losses, it was suggested to avoid low TSR which increases wake rotation and has to be selected between 6 to 10 for three blade HAWT, selection of an aerofoil shape with high lift to drag ratio and need of specialised tip geometries; designing of rotor blades based on BEM method according to Betz limit; XFOIL free software which is generally used to accurately calculate lift to drag ratio; details about chord length and angle of twist distribution in rotor blades and also introduction to aerodynamic control surface concepts like aileron style flaps, camber control, active twist and boundary layer control.

Magdi Ragheb and Adam M. Ragheb in the paper [14] presented the detailed derivation of Betz limit and also described an optimal TSR for a wind turbine. From their research, they noted that turbulent wake is formed when a rotor blade passes through the air stream and if at that instant, next blade is passed then it will not be able to extract power from the wind efficiently and also high vibration stresses may induce. Whereas, it the rotor rotates slow, the air hitting each rotor blade would no longer be turbulent, thus, blocking the wind stream. Therefore, for extracting energy from a wind turbine, it is necessary to allow wind stream from high speed to low speed region.

Qiyue Song and William David Lubitz in the paper [15] investigated the impact of tip loss, hub loss and drag coefficient on a Bergey XL1 small WT having rated power of 1kW and rotor diameter of 2.5m using BEM method. The procedure followed for the BEM method is as follows first spanwise dividing the blade elements for calculating forces and momentum on each element assuming they are different from each other and axial flow induction factor is constant, then calculating total forces and moments acting on blade by integrating those elements and finally calculating power coefficient to evaluate the overall performance of WT. Software like XFOIL and MATLAB was used for predicting aerofoil performance and produce continuous functions of the lift and drag coefficients versus angle of attack respectively.

Bumsuk Kim in a study [16] investigated aerodynamic design and performance of 3MW class blade with rotor diameter of 94.8m using BEM method and CFD analysis which was carried out in ANSYS ICEMCFD V11.0. Quantitative comparison of data like thrust force, power coefficient and mechanical power was done. To improve the estimation of wall shear stress in the viscosity sub layer, Wilcox model, BSL (Baseline) model and SST (Shear Stress Transport) model was used where SST model is known for accurately predicting the size of vortex formed behind rotor and also to trace location of separation point due to adverse pressure gradient.

L. Tenghiri in the paper [17] presented a design methodology for the rotor blades of a small wind turbine having rated power of 11kW and rotor radius 3.5m. Design parameters like wind speed, tip speed ratio (TSR) and angle of attack were to be optimized. Then using optimum rotor theory, optimum blade shape was determined i.e. chord length and twist angle distribution. It was observed that high TSR have many drawbacks such as noise generation, excessive rotations of rotor and vibration problems, thus, TSR of 6 was selected. Design angle of attack of 4.5 °which as to be selected slightly lower than optimum angle of attack of 5 ° where maximum lift to drag ratio occurs was selected. Then using QBlade software, wind blade performance parameters like power coefficient and power produced were determined.

Emre KOC in the paper [18] compared the performance of a HAWT with rotor diameter of 2m from QBlade software and CFD results in ANSYS Fluent. 3D CAD model was created using parameters like optimum chord length and twist angle distribution obtained from QBlade software in CATIA for analysis. Further, performance analysis was performed on QBlade software and ANSYS Fluent for obtaining power and torque curves versus TSR graphs for comparison. Maximum power coefficient and torque of 0.48 and 31Nm respectively from QBlade software whereas 0.45 and 28Nm respectively from CFD result was obtained, thus, showing good agreement. It was concluded that BEM method which is used in QBlade software for analysing WT does not take account of turbulence because of which its result where higher than CFD results.

M. Rajaram Narayanan in a research [19] made an attempt to increase the efficiency of wind turbine blades through dimples on the surface of it. Dimples are considered to be very efficient in reducing air drag and increasing lift which can be observed in golf balls. So, the surface of turbine blades was integrated with dimples of various shape and arrangements which were then analyzed using CFD to obtain optimum combination. Wind Turbine with rated power of 1.5MW was to be analyzed and it was found that nearly 1.4MW power at the wind speed ranging 12–20m/s was generated which shows about 15% increase in efficiency due to addition of dimples on the surface of Wind Turbine.

Lachlan Clements and Ashfaque Chowdhury in the paper [20] performed some wind tunnel tests on a BWT and WLT to determine its performance by measuring TSR and Betz law efficiency in turbulent environment. Two types of aerofoil design namely, NACA 4415 and NACA 63-425 were also studied to see whether performance relies on blade shape or WT design in such situations. About 30%-40% increase in TSR and Betz law efficiency for both the aerofoil designs was obtained in the non-turbulent and turbulent scenario. NACA 63-425 performed marginally better than NACA 4415 and on average 50%-60% increase in efficacy was observed in both scenario for NACA 4415.

G. Ramya and N. Balakumar in a paper [21] presented an overview on wind turbine generator technologies by highlighting their advantages and drawbacks. They suggested the doubly fed induction generator (DFIG) which equipped with fault ride through capacitor for medium and large wind turbines whereas permanent magnet generators for small wind turbines. The analysis also showed a trend from fixed speed, geared and brushed generators to variable speed, gearless and brushless generators which reduced system weight, cost and failure rates.

3. CONCLUSION

This paper provides a good overview of wind lens turbine, its advantages over conventional wind turbine and its scope. So, for designing an optimum wind lens turbine, there are various parameters to be varied like diffuser length, throat diameter and its position, opening angle, brim height, flange angle and its shape as discussed in the papers [1-12]. Also, it is necessary to design an optimum rotor blade which can capture more wind energy, thus, increasing efficiency is discussed in the papers [13-19]. In the paper [20], it is shown how a wind lens turbine may perform in turbulent conditions whereas in the paper [21], study on various generators showing its advantages based on which specific generator can be selected for a particular purpose.

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