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EFFECT OF SHROUD ATTACHMENT ON POWER GENERATION ON A HORIZONTAL AXIS WIND TURBINE

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Abstract - *The abundance in availability of wind energy has inspired researchers to work more towards the improvement on wind energy production technologies. There are various methodologies, designs and technologies through which the wind energy is efficiently converted into the useful power. One such approach was the attachment of a shroud around a horizontal axis wind turbine which enhances the air mass inflow at the turbine blades and also the velocity profile varies along the blade length. The effects of these on power generation and efficiency is to be studied. The present work throws light on optimising the shroud design on varying various design parameters such as the area ratio, nozzle and diffuser lengths*

Key Words*: *Wind energy, Computational fluid dynamics, Blade element momentum theory, Horizontal axis wind turbine, shroud, Dynamometer.

1. INTRODUCTION

As a base model horizontal axis wind turbine of rotor diameter 2m with aerofoil profile of NACA 4412 was chosen[9]. Numerical analysis was carried out on Ansys fluent to study the performance characteristics. For the experimentation purpose the model was scaled down by a factor of 0.25. The performance characteristics of the scaled down model was determined by carrying out CFD analysis. This scale down model was placed inside the optimised shroud design and the numerical analysis on shrouded wind turbine was performed. In order to verify the working of the turbine inside the shroud, experimental analysis for shrouded and unshrouded wind turbines was carried out. The performance characteristics of the shrouded and unshrouded wind turbine was analysed as well as experimental and numerical values were compared.

2. BLADE ELEMENT MOMENTUM THEORY

Blade element momentum theory basically is the one that contains the momentum theory and blade element theory concepts in it in order to obtain a aerodynamically effective blade design. The horizontal axis wind turbine design parameters were obtained analytically by BEM method. The steps followed is listed as follows.

1. A design tip speed ratio, λ, the desired number of blades, B, the radius, R, and an airfoil with known lift and drag coefficients are as function of angle of attack need to be chosen.
2. The blade is divided into known number of sections in order to have an efficient design. Each section distance from hub is calculated and given as ‘r’.
3. The calculation starts with guesses for induction factors a and a’, from flow conditions a new induction factors are calculated.
4. Once the induction factors value is guessed angle of relative wind is calculated as,

$$\varphi = \frac{2}{3}\tan^{-1}(1/\lambda ri) \quad (1)$$

Where, $\lambda ri = \lambda(r/R)$

5. For the chosen airfoil type for the turbine blade design, NACA 4412 the angle of attack at maximum Cl/Cd value is 5.25 and is kept constant. Corresponding Cl and Cd values are 1.05 and 0.00785 respectively.
6. From the value of angle of relative wind obtained at step 4, a new induction factor values are obtained by the following formula,

$$a = \frac{1}{1+4(sin\varphi)^2/\sigma Cl\ cos\varphi} \quad (2)$$

Where, solidity, σ = cB/2πr

$$a' = \frac{1-3a}{4a-1}$$

7. Having guessed for axial and angular induction factors, iterative solution procedure is followed. If the newest induction factor are within an acceptable tolerance of the previous guesses, then the performance can be calculated. If not, then the procedure starts again at step 4.
8. The chord length for each blade element is calculated as,

$$c = \frac{8\pi r}{B\ Cl}(1 - cos\varphi) \quad (3)$$

9. The twist angle that is to be given for elements of blade depends on the angle of attack and the angle of relative wind.

$$\varphi = \theta t + \alpha \quad (4)$$

10. Once the axial and angular induction factors are calculated relative velocity value is calculate with the formula,

$$Urel = \frac{U(1-a)}{sin\varphi} \quad (5)$$

11. The value of induction factors, relative velocity and angle of relative velocity is calculated for each section following the steps mentioned above.

12. The torque on each blade element is calculated by the formula,

$$dQ = \frac{1}{2} B\rho Urel^2 (Cl\ sin\varphi - Cd\ cos\varphi) crdr \qquad (6)$$

dQ is the differential torque values which is summed up in order to get the total torque on the blade.

12.The power coefficient is obtained by, $Cp = \sum_{i=1}^{N} \left(\frac{8d\lambda r}{\lambda^2}\right) F \sin^2\varphi\ (cos\varphi - \lambda\ sin\varphi)(sin\varphi + \lambda cos\varphi) \left[1 - \left(\frac{Cd}{Cd}\right) cot\varphi\right] \lambda i^2$

Once the blade design is be optimised for one design tip speed ratio (TSR) its performance characteristics in all the TSR are studied and corresponding power coefficients (Cp) are plotted against the TSR values as shown in the fig.1.

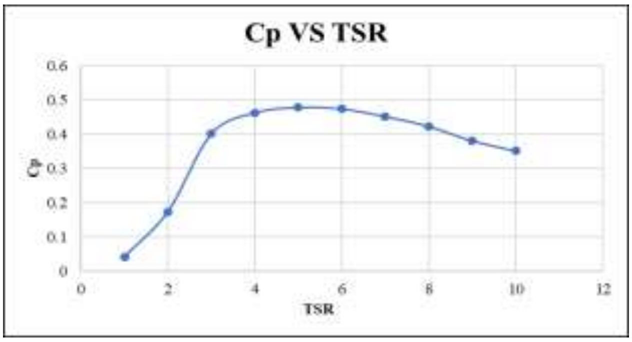

Fig.1. Plot of power coefficient vesus TSR.

3. NUMERICAL ANALYSIS

In order to study the aerodynamic performance characteristics of the wind turbine its analysis was carried out in ANSYS fluent software. The 3D CAD model was imported in to the fluent set up and was placed in a cylindrical external domain of radius 1m. The unstructured grid was applied on the turbine rotating disk area and external flow domain surrounding the turbine and due to the Boolean operation the turbine was merged into the external domain. Different sizes of grids were used to obtain grid independency of the analysis results. In the meshed geometry the domain entrance was defined as “velocity inlet” and exit was defined as “pressure outlet” boundary conditions. The shear stress transport K= omega turbulence model was used for the analysis. Varying the rotational speed of the turbine the torque values were obtained and power coefficient was calculated. The obtained results are shown in the plot fig.2 below.

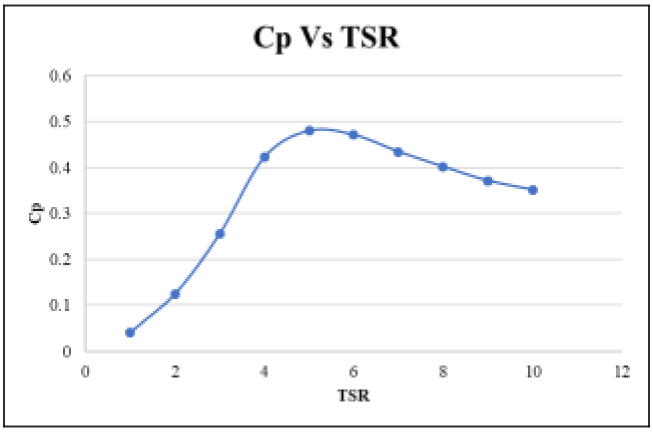

Fig.2 Plot of Cp versus TSR for values obtained from numerical analysis.

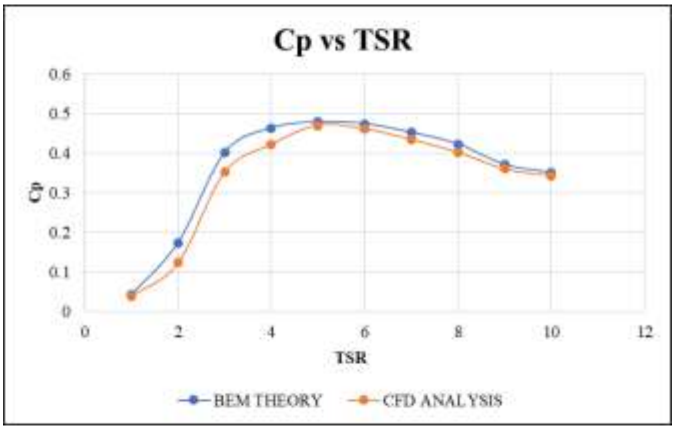

Fig.3. The comparison of numerical analysis values and analyticla values.

As seen in fig.3. on comapring the values obtained by analytical method and numerical analysis method it can be inferred that the values obtained by BEM method has higher values as it doesnot account for the tip losses as in CFD analysis.

4. SHROUD DESING OPTIMIZATION

The concept of conservation of mass-flow through a pipe states that the velocity of the flow is inversely proportional to the cross-section area of the pipe for a given density.

ρ*A*U=constant

This concept was used to develop a shroud which will increase the velocity of air at the turbine blades hence producing more power for the same inlet velocity. But adding to this concept, we are trying to analyse the performance of the blade inside the shroud. The shroud was divided in three major parts: a converging section, a curved housing and a divergent section. In order to reach the most optimum design, essentially four geometrical parameters were considered, namely (a) converging section length L_1 , (b) converging section half cone angle Θ_1, (c) diverging section length L_2 and (d) diverging section half cone angle Θ_2. These parameters were optimised using CFD simulations. The effect of each of these was extensively studied on the velocity augmentation and to achieve optimal design. The results were verified experimentally.

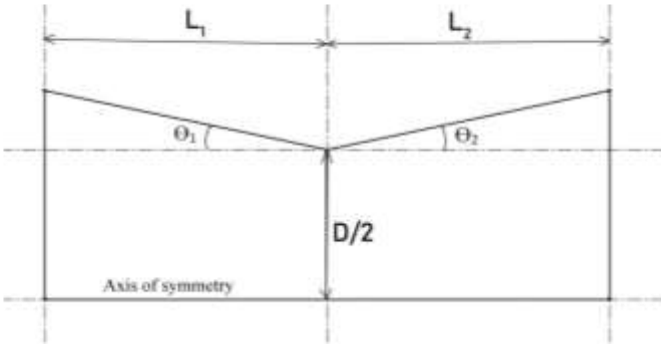

Fig.4 Conceptual drawing of the shroud design.

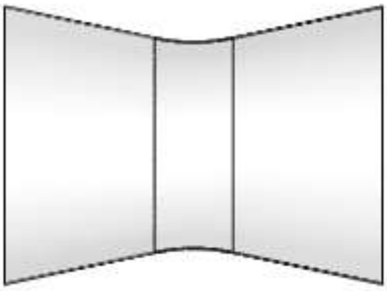

Fig.5 Shroud design.

For the numerical anaysis of the shrouded wind turbine the procedure mentioned for the bare turbine is followed. The fig.6. shows the shrouded turbine in the external cylindrical domain.

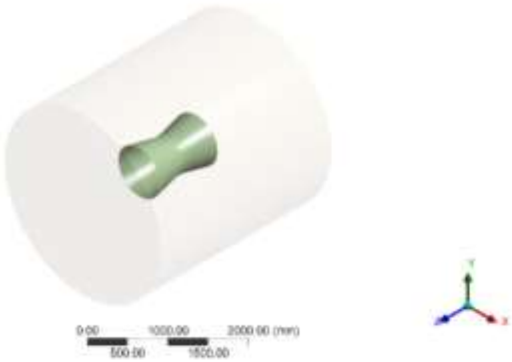

Fig.6 Shrouded turbine in an external domain.

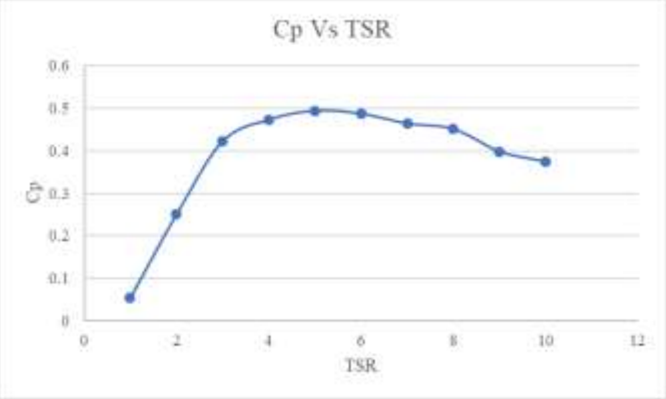

Fig.7 Plot of power coefficient versus TSR for shrouded wind turbine.

5. EXPERIMENTAL ANALYSIS

The turbine was fixed in the shroud with the help of attachment links. The motor was attached to the turbine in order to control the rpm of the turbine. To calculate the generated torque, a Rope brake dynamometer was used. The setup was kept in the flow region with a velocity of 4m/s and the torque value and the rpm were observed.

Digital manometer- used to measure velocity at different parts, Digital Tachometer- to measure the RPM of the turbine blade, Electrical generators- to control the rpm of the turbine, Rope brake dynamometer, Test turbine blades, Shroud, Attachment links are the various apparatus used for the experimentation set up.

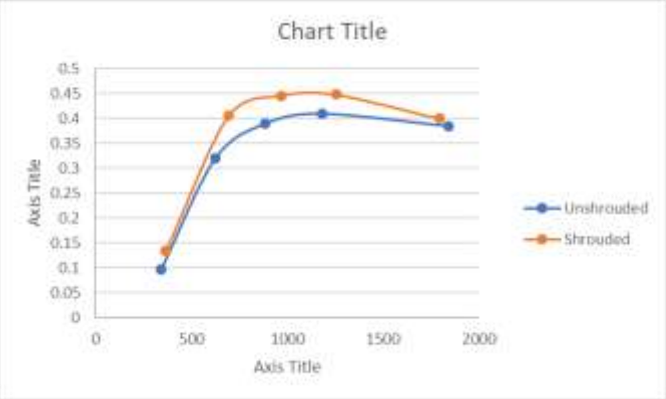

Fig.7. Comparison of shhrouded and unshrouded performance curve.

From the experimentation we were able to practically analyze the behavior of the turbine blade inside the shroud. it was observed that the turbine gives higher efficiency inside a shroud due to the variation of the velocity inside the shroud. as the velocity increases from the hub to the tip, the turbine blade produces higher torque with slight increase in rpm which affects the generated power. this leads to overall increase in the power hence increasing the efficiency. The graph (fig.7) shows a comparison between the efficiencies of shrouded and unshrouded wind turbine.

6. CONCLUSION

It was observed in the simulations as well as in the experimental analysis that for a given velocity at the turbine blade, the power efficiency of a shrouded wind turbine was higher than a unshrouded turbine. This happened due to the wind velocity profile inside the shroud which clearly showed that if the averaged velocity at the turbine blades is taken equal to the wind velocity at the blades of unshrouded wind turbine, more power is produced by shrouded wind turbine. The error percentage shows that there were a lot of mechanical and electrical losses which can be reduced by slight modifications in the design of the hub as well as choosing good quality generators.
The Design of the turbine blades as well as the design of the shroud can be modified to achieve higher power outputs. Using proper gear mechanism can also enhance the power generation

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