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Design of a Wind Turbine for Self-Renewable Electric Vehicle

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ABSTRACT

The project aims to design a wind turbine from which the wind energy is caused by the relative motion between vehicle and the wind. By using the auxiliary power sources electric vehicle itself generates the electric power required to drive the vehicle during dynamic condition. Compared to conventional fuels used in modern vehicles the energy storage capacity of this is very low, due to the lack of capability of storing sufficient amount of energy to run the vehicle for a long time. The efficiency and performance of electric vehicles are better than the engine driven vehicles. Utilizing the wind energy caused by the relative motion between the vehicle and the wind by auxiliary power source like horizontal, vertical wind turbines can generate the electric power required to drive the vehicle during running condition.

Keywords: *Electric vehicles; Wind energy; Wind turbine; Renewable energy.*

1.0 Introduction

Decrease in resources of fossil fuels, worldwide deployment of electrical vehicles has feasibly come into existence. India is also a leading name in producing electric vehicles. In order to compete with combustion engines electric vehicles efficiency has to be increased. As we are generating total capacity of nearly 31141.36MW of electricity from wind energy, if we can utilize the wind turbine technology or conceptualization in order to generate electricity during the vehicle motion it may results in higher efficiency of the vehicle. Initially the vehicle utilizes the stored energy electrical energy from the battery and converted into mechanical energy which moves the vehicle forward .When the car starts moving then generation takes place, using a wind turbine setup.

2.0 Working Principle of Wind Turbine

2.1 Betz's law

Betz's law states that kinetic energy in the wind is limited to a maximum conversion of 16/27 or 59% into mechanical energy using wind turbine.

3.0 Wind Energy

Wind driven generators are based on 1st law of thermo-dynamics (Daniel S. and Gaunden, 2011) states that energy can only be transformed from one form to another and can neither be created nor be destroyed. Newton's 3rd law states that action and reaction on one body on another are equal and opposite, can be used for analyzing wind speed on the vehicle.

3.1 Selection of aerofoil

NERL series aero foils are widely used aero foils for modern horizontal axis wind turbines and also blade configuration is most popular and efficient. The aerofoil selection is done on the basis of optimum lift to drag ratio for specific wind speed. Also we need to determine an optimum angle of attack for the theses aero foils which are on placing together in specific place and specific angle are going to form the full blade geometry. Selection of optimum angle is given by figure 1.

For our further analysis, take a value of Angle of attack (AOA). The optimum angle of attack is determined 0.2 from the figure 2. From figure 1 and 2, it is clear that 0° AOA is the optimum for our selected aerofoil as it shows maximum value of lift to drag ratio.

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Figure 1: Angle of Attack vs Lift To Drag Ratio Plot

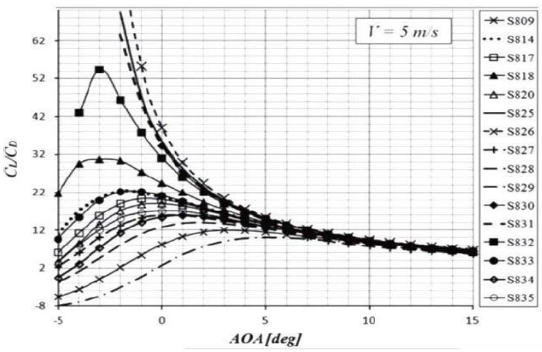


Figure 2: Plot between Angle of Attack v/s Lift to Drag Ratio

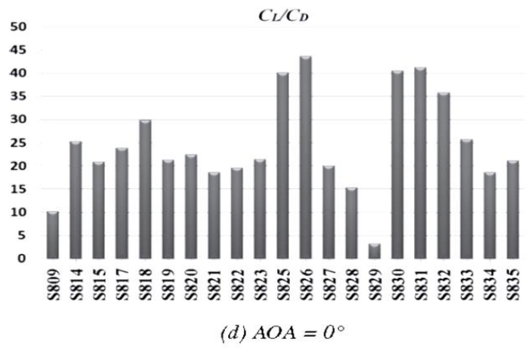


Table 1: Top-Section Coordinates of Aerofoil NERL S8260

X	Y	Z
0	0	0
0.0125	0.02307	0
0.025	0.03981	0
0.0375	0.05093	0
0.05	0.06296	0
0.075	0.08333	0
0.1	0.09722	0
0.15	0.12222	0
0.2	0.13704	0
0.25	0.14815	0
0.3	0.1537	0
0.35	0.14815	0
0.4	0.13518	0
0.45	0.11852	0
0.5	0.0963	0
0.55	0.08056	0
0.6	0.06667	0
0.65	0.05185	0
0.7	0.04074	0
0.75	0.0287	0
0.8	0.02037	0
0.85	0.01204	0
0.9	0.00556	0
0.95	0.00185	0
1	0	0

Table 2: Bottom Section Coordinated of Aerofoil NERL S8260

X	Y	Z
0	0	0
0.0125	-0.03704	0
0.025	-0.0463	0
0.0375	-0.04907	0
0.05	-0.04907	0
0.075	-0.04352	0
0.1	-0.03981	0
0.15	-0.03333	0
0.2	-0.0287	0
0.25	-0.02593	0
0.3	-0.02315	0
0.35	-0.02037	0
0.4	-0.01852	0
0.45	-0.01667	0
0.5	-0.01481	0
0.55	-0.01296	0
0.6	-0.01111	0
0.65	-0.00926	0
0.7	-0.00741	0
0.75	-0.00556	0
0.8	-0.0037	0
0.85	-0.00278	0
0.9	-0.00185	0
0.95	-0.00093	0
1	0	0

**Data gathered from UIUC Airfoil data site (https://m-selig.ae.illinois.edu/ads.html)*

3.2 Generation of full blade geometry

For generation of full blade geometry we are taking the configuration which takes different aerofoil at different segment of the blade span. From our selected aerofoil S818 aerofoil will be at root regime, S825 will be at middle and S826 will be at tip of the full blade geometry. For optimum blade configuration we have to consider two parameters, chord length(c) of each aerofoil. For a 4 bladed design, λ should be greater than 4 and the most common value chosen is 6.

Rotor radius = R

No. of blade = N

Lift coefficient = Cl

Angle of attack = α

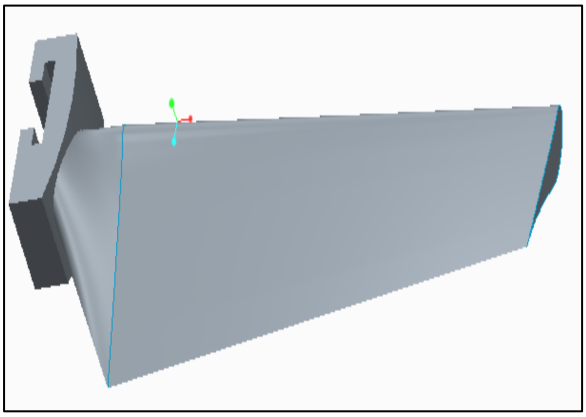
Designed tip speed ratio =λ_r

$$c_r = \frac{8\pi r}{NC_{LDesign}}(1 - cos\phi_r) \quad ...(1)$$

$$\beta = \phi_r - \alpha \quad ...(2)$$

$$\phi_r = \frac{2}{3}tan^{-1}(\frac{1}{\lambda_r}) \quad ...(3)$$

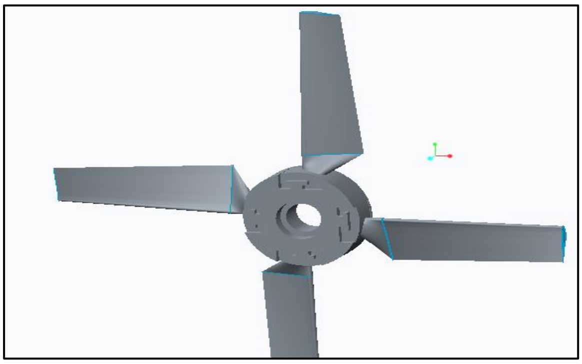
Figure 3: Fully Generated Blade



3.3 Rotor design

Wind turbine rotor design typically includes airfoil selection, design of blade for optimum performance in wide range of flow conditions, determination of pitch angle of the blade and number of blades and hub of the rotor as shown in figure 3.

Figure 4: CAD Model for the Rotor



4.0 Computational Fluid Dynamic Analysis

Figure 5: Creation of Work Envelop

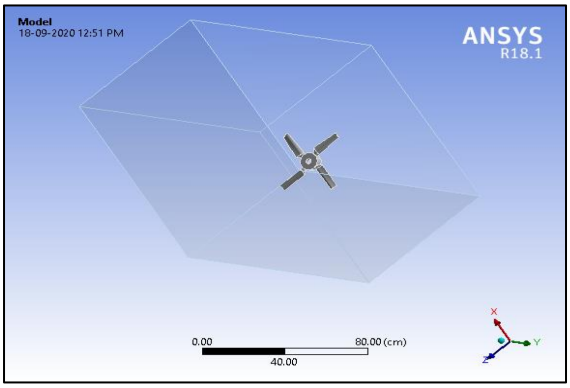
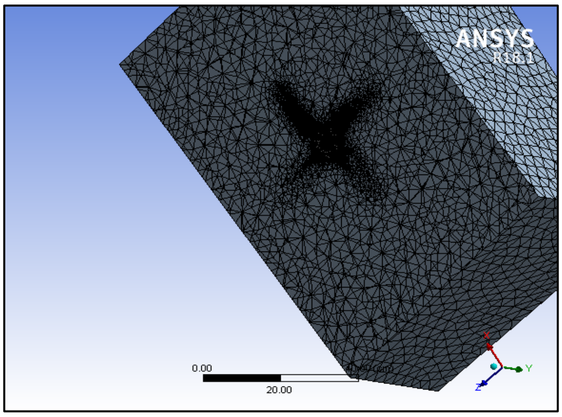


Figure 6: Generation of Mesh



4.1 Generation of work envelop and mesh

Table 3: Mesh Specifications

Number of nodes	191399
Number of elements	896540
Orthogonal quality	0.85

5.0 Results

Using the optimal tip speed ratio of 6 the theoretical calculations were carried out for different wind speeds. The results given by figure 7 and table 4. Also theoretical analysis was carried out using different tip speed ratios for a fixed wind speed of 8 m/s and the results of it are presented by table 5.

Table 4: Variation of Performance Parameters of Wind Turbine with Wind Speed at $\lambda = 6$

Wind Speed (ms^{-1})	Normal force (N)	Torque (Nm)	Power (W)
4	1.2411	0.01524	1.624
6	2.5966	0.03112	7.4985
8	4.7648	0.06475	15.845
10	7.48	0.10364	28.0154
12	10.555	0.15111	48.2451

The plots reflect the theoretical variation of normal force, torque and power with wind speed. The torque was almost constant in the tip speed ratio range of 0 to 2. For tip speed ratio beyond 2, the torque rises steeply and reaches a maximum value at tip speed ratio of 4.7 and then decreases. Above a tip speed ratio of 9, if the flow is forcefully rotated by MRF approach, it produces a torque which opposes the motion. This is because as the tip speed ratio increases beyond 6 the angle of attack continuously decreases and above a certain value it becomes negative. This leads to the production of forces and moments in opposite direction.

Figure 7: Pressure Contour

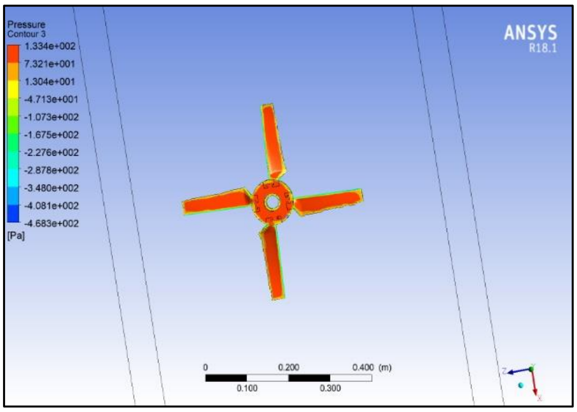


Table 5: Variation of Torque and Power with Tip Speed Ration for 8m/s

Tip Speed Ratio	Torque(Nm)	Power(W)
0.5	0.0047	0.17010
1	0.01145	0.3901
1.5	0.01212	0.6845
2	0.02229	1.3899
2.5	0.03244	2.9454
3	0.04900	5.2478
3.5	0.06211	7.7109
4	0.07324	10.311
4.5	0.07721	12.54
5	0.07722	13.9
5.5	0.07399	14.571
6	0.06840	14.587
6.5	0.06112	13.545
7	0.04964	13.101
7.5	0.04444	11.27
8	0.03064	8.2106

6.0 Conclusions

In this analysis, a small Horizontal Axis Wind Turbine was designed and computational analysis is done on same. The blades were designed using BEM theory and a CAD model was generated based on it. The blades were designed such that the angle of attack at each section remains constant and equals to the value corresponding to minimum CD/CL. The tip speed ratio was found to vary from 4 to 7 in the wind speed range of 4 to 9m/s with the optimum tip speed ratio of 6 achieved somewhere between 7 and 8m/s. The flow field corresponding to these speeds indicated no flow separations along the span of the blade. Between 3 and 4m/s the flow field corresponding to experimental tip speed ratio indicated flow separations at three sections and the in the remaining part of the blade the flow was fully attached. Thus even though the performance predicted by CFD simulations alone was not achieved in the real case the performance of the wind turbine in the wind speed rang of 3 to 9m/s was found to be acceptable. Thus additionally we can conclude that the specified wind turbine can operate in local wind condition and will produce sufficient torque.

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