# DESIGN AND STUDY OF WIND-SOLAR HYBRID SYSTEM FOR DOMESTIC APPLICATION

By

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## ABSTRACT

The Government of India has sanctioned funds for the production of 190 GW and this solution is a way to reduce the pollution levels. This support of the go-green initiative by the United Nations as well is a step forward in creating a better environment for the future generations to live in. The proposed work aimed at designing a wind-solar hybrid system for light load application. The tools like Qblade and solidworks were used to model and analyze the wind turbine system, the material used for the blade and hub was Balsa wood and the tower is a tripod type. The power output of 100 W at an average wind speed of 4.5 m/s has been targeted. The work also aimed at providing electricity to the rural area in India which amount to 25000 in number where, there is no provision for electricity, this solution may provide the electricity needs of such villages.

Keywords: Renewable Energy, Hybrid, Aerofoil Blades, Wind Speeds, Make-in-India, Qblade, Solidworks, Balsa Wood.

## INTRODUCTION

The use of alternative energy sources is gaining popularity worldwide with a lot of interest in particular being shown in efficiently harnessing wind energy and solar energy [5]. It is relevant to the Make-in-India concept. One of the biggest hurdles in using these alternative energy sources is their lack of consistency in terms of their dependency to deliver a fixed power supply.

In this paper, the focus is laid on using green and renewable forms of energy to provide electricity to certain areas where there electricity is still a dream.

The focus is laid on using theoretical equations and simulation to design a wind-solar hybrid standalone system that can be used in such applications [1].

## 1. Objectives

The objectives of the study are:

• To generate power through Wind-Photovoltaic Hybrid Power System with battery storage for light loads.

• To integrate the hybrid system to save on high fuel costs and to minimize noise.

• To Integrate Solar and Wind Technology into electrical system will result in higher efficiency [2], easier maintenance and increased reliability.

## 2. Literature Survey

C.N. Narayanswamy et al., (2006), proposed the availability of wind energy and its characteristics at selected locations and data collected from the wind monitoring department [12].

Vikram Singh et al., (2014), focussed their studt primarily on designing the blade for tapping power in the regions of low wind power density. This can be achieved by using wood [13] as the blade material which has good strength to weight ratio.

Shankar Bentur et al., (2011), demonstrated that wind energy is one the most widely used renewable energy resources. Wind turbines need to be reliable and be cost effective. At the same time, small-scale wind turbines must produce the required amount of power to meet the needs [14] especially in the areas with low wind speeds.

Kianoosh Yousef et al., (2009) explained the effects of jet width on blowing and suction flow control evaluated for an airfoil. Results of this study demonstrated that, when the blowing jet width increases [3], the lift-to-drag ratio rises continuously in tangential blowing and decreases quasi-

linearly in perpendicular blowing.

Y. Sudhakar et al, (2012) involved in putting a cylindrical rod upstream of the leading edge [5] in vertical translation movement in order to accelerate the transition of the boundary layer by interaction between the wake and the boundary layer.

U. Anand et al., (2003) Focused on increasing their aerodynamic efficiency [6] and operational range through active flow control with the help of blowing devices with constant or pulsed jets in their study.

Hansena et al. (2006) presented the state of the art in wind turbine aerodynamics and aero elasticity, thus the aerodynamic part starts with the simple aerodynamic Blade Element Momentum Method [8] and ends with giving a review of the work done applying CFD on wind.

Jang-Oh Mo and Young-Ho Lee (2012) have developed CFD investigation on the aerodynamic characteristics of a small-sized wind turbine of neural phase. Root design approaches considered the appropriate selection [9] of the angle of attack and the thickness.

## 3. Wind System Design

1) Average wind speed ($U_M$)

$$U_m = 1/(n-1) * \Sigma (U_i) \quad \text{(from 1 to n-1)} \tag{1}$$

$$U_m = 1/(12-1) * (37.34)$$

$$U_m = 3.43 \, m/s$$

2) Standard deviation ($\Sigma$)

$$\sigma^2 = 1/(n-1) * \Sigma(U_i - U_m) \tag{2}$$

$$\sigma = [1/(12-1)*(15.71)]1/2$$

$$\sigma = 1.19$$

| MONTHLY WIND SPEED (FOR 2014) | FOR A HEIGHT OF 10 m | FOR A HEIGNT OF 15 m |
|---|---|---|
| JANUARY | 2.32 | 2.78 |
| FEBRUVARY | 2.27 | 2.72 |
| MARCH | 2.37 | 2.84 |
| APRIL | 2.11 | 2.53 |
| MAY | 3.36 | 4.02 |
| JUNE | 5.24 | 6.38 |
| JULY | 4.99 | 5.98 |
| AUGUST | 4.39 | 5.27 |
| SEPTEMBER | 4.46 | 5.14 |
| OCTOBER | 1.92 | 3.32 |
| NOVEMBER | 2.79 | 3.45 |
| DECEMBER | 2.63 | 3.16 |

Figure 1. Wind Data for Hubli city

3) Shape parameter

a) $k = d_1 * (U_m)1/2$ \hfill (3)

where $d_1$ is site parameter = 0.94 (average)

$$k = 0.94 * (3.43)1/2$$

$$k = 1.48$$

b) $k = (\sigma/U_m) - 1.086$ \hfill (4)

$$k = (1.19/3.43) - 1.086$$

$$k = 3.34$$

4) Scale parameter

$$c = \frac{Um}{\Gamma\left\{\left(1 + \left(\frac{1}{k}\right)\right)\right\}} \tag{5}$$

$$c = \frac{3.43}{\Gamma\left\{\left(1 + \left(\frac{1}{3.34}\right)\right)\right\}}$$

$$c = 1.4306$$

5) Weibull density function

$$f(u) = \frac{k}{c} * \left(\frac{u}{c}\right)^{k-1} * \exp\left[-\left(\frac{u}{c}\right)^k\right]$$

$$f(u) = \frac{3.34}{1.43} * \left(\frac{4.11}{1.43}\right)^{3.34-1} * \exp\left[-\left(\frac{4.11}{1.43}\right)^{3.34}\right] \tag{6}$$

$$f(u) = 0.32$$

6) Power density factor in terms of Weibull

$$PowerDensity = \frac{Pavail}{A} = \frac{1}{2} * \rho * c^3 * \left(1 + \frac{3}{k}\right) \tag{7}$$

$$PowerDensity = \frac{Pavail}{A} = \frac{1}{2} * 1.22 * 4.56^3 * \left(1 + \frac{3}{3.34}\right)$$

Power density = $55.59 \, W/m^2$

7) Energy density

$$Energy \, Density = \frac{1}{2} * \rho * c^3 * \left(1 + \frac{3}{k}\right) * time \tag{8}$$

where Time is in seconds

$$Energy \, Density = \frac{1}{2} * 1.22 * 4.56^3 * \left(1 + \frac{3}{3.34}\right) * 8760$$

Energy Density = $486.968 \, kWh/m^2$

8) Wind speed corresponding to maximum energy ($U_{me}$)

$$Ume = c * \left[\frac{k+2}{k}\right]^{\frac{1}{k}} \tag{9}$$

$$Ume = 4.56 * \left[\frac{3.34+2}{3.34}\right]^{\frac{1}{3.34}}$$

$U_{me} = 5.24$ m/s

9) Maximum energy available from turbine

$$W = \frac{1}{2} * A * Ume^3 * f(Ume) * time \qquad (10)$$

$$W = \frac{1}{2} * 1.22 * 5.24^3 * 0.206 * 8760$$

W = 156 kWh/m²

10) Weibull density function for 15m hub height from ground

$$f(u) = \frac{k}{c} * \left(\frac{u}{c}\right)^{k-1} * \exp\left[-\left(\frac{u}{c}\right)^k\right] ... \qquad (11)$$

$$f(u) = \frac{3.34}{4.56} * \left(\frac{4.11}{4.56}\right)^{3.34-1} * \exp\left[-\left(\frac{4.11}{4.56}\right)^{3.34}\right]$$

f(u) = 0.283

The above equations suggest that for an average wind speed of 3.43 m/s for a pole height of 10m the maximum available energy is 156 kWh/m² which is sufficient for domestic lighting application. The wind speed which corresponds to maximum energy is 5.24 m/s. Figure 1 shows the Wind Data for Hubli city.

### 3.1 Energy Available

This excel sheet supports the therotical calculations of the energy available and the graphs show the available energy and maximum energy that can be obtained from the turbine for wind speed of 4 m/s. Figure 2 shows the Energy Available for Wind Speed.

### 3.1.1 Operating Characteristics

Electrical Rated Power (PR) = 100 W

Rated wind speed = 9 m/s

Cut in speed = 3 m/s

Furling speed = 12 m/s

$$\text{Capacity Factor} = \left\{ \left[ \exp\left[-\left(\frac{U}{c}\right)^k\right] - \exp\left[-\left(\frac{Ume}{c}\right)^k\right]\right] * \right.$$
$$\left. \frac{1}{\left[\left(\frac{U}{c}\right)^k - \left(\frac{Ume}{c}\right)^k\right]} \right\} - \exp\left[-\left(\frac{Ume}{c}\right)^k\right] \qquad (12)$$

Capacity Factor = 0.082

$$Normalized\ Power\ (P) = \left[\frac{Ume}{c}\right]^3 * Capacity\ factor \qquad (13)$$

$$Normalized\ Power\ (P) = \left[\frac{5.24}{4.56}\right]^3 * 0.082$$

Normalized Power = 0.63

Power Output From Turbine

$$Power\ Output = a + (b * 7.5^{3.34}) \qquad (14)$$

Where a & b are constants

$$a = 100 * \frac{3.34^{3.34}}{3^{3.34} - 9^{3.34}}$$

$$b = \frac{100}{9^{3.34} - 3^{3.34}}$$

$$Power\ Output = -2.44 + (0.066 * 7.5^{3.34})$$

Power Output = 62.79 W

### 4. Design of Blade

In this excel sheet (Figure 3), the data obtained from the above equations are used to obtain suitable dimensions of the blade for a particular requirement of wind speed of 4 m/s and expected power output of 100 W. Figure 3



Figure 2. Excel Sheet for Calculation of Wind Energy Available for Wind Speed of 4 m/s
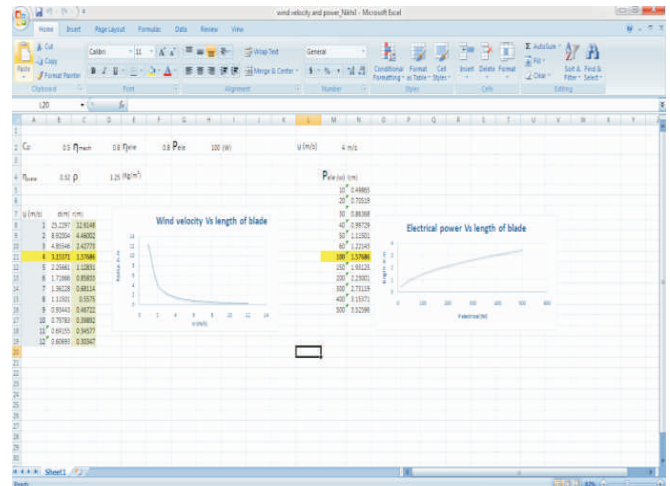


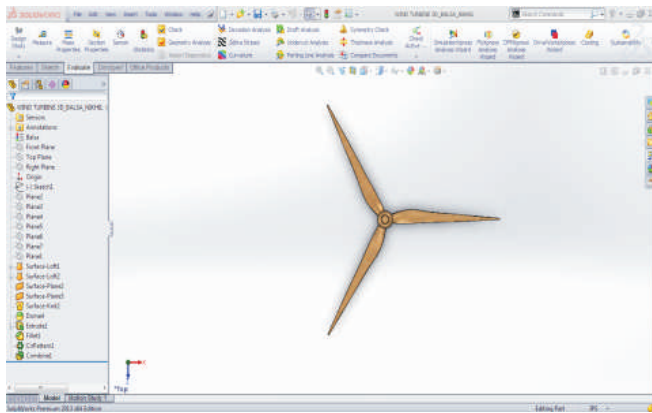Figure 3. Excel Sheet for Estimating Wind Power Based on Blade Parameters
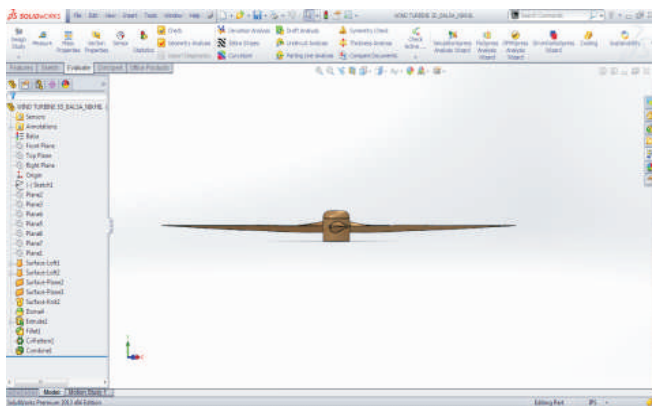
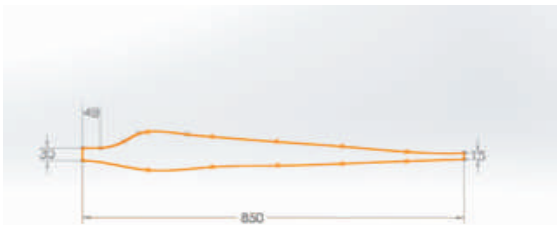Figure 4. Front View of CAD Model



Figure 5. Side View of CAD Model



Figure 6. Dimensions of Blade

| Name: | Balsa |
|---|---|
| Model type: | Linear Elastic Isotropic |
| Shear modulus: | 0.23 GPa |
| Yield strength: | $2e{+}007$ N/m$^2$ |
| Elastic Modulus: | 3 GPa |
| Density: | 0.13 g/cm3 |

Table 1. Properties of Basla Wood

shows the Blade Parameters, and CAD Model. Figure 4 shows the Front View of CAD Model and Figure 5 shows the Side View of CAD Model.

## 5. Solid Works Analysis

The solidworks analysis suggests that, the static displacement and the von-mises equivalent stress is not



Figure 7. Applying Boundary Conditions and Meshing

| Load Name | Load Image | Load Details | |
|---|---|---|---|
| Force |  | Entities: | 3 face(s) |
| | | Type: | Apply normal force |
| | | Value: | 115 N (X Component) |
| | | | 130 N (Y Component) |
| | | | 125 N (Z Component) |
| Pressure |  | Entities: | 3 face(s) |
| | | Type: | Normal to face |
| | | Value: | 1.0 |
| | | Units: | Atm |

Table 2. Boundary Conditions
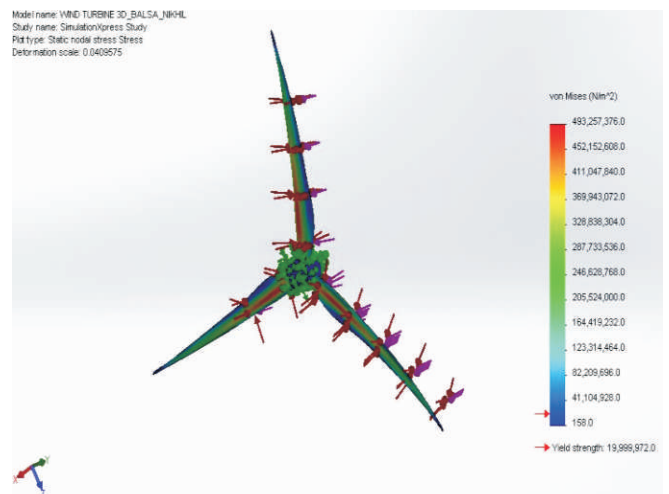


Figure 8. Von-Mises Equivalent Stress

too high and that the Balsa wood material [4] selected for the blade can withstand the loads and pressure it will be subjected to and can perform effectively. Table 1 shows the properties of Basla Wood and Table 2 shows the boundary conditions. Figure 6 shows the Dimensions of Blade. Figure 7 explains the boundary conditions and meshing. Figure 8 depicts the Von-Mises Equivalent Stress. Figure 9 shows the Static Displacement. Figure 10 the Graph shows the Foils Generated for Chord.

## 6. Qblade Software Simulation

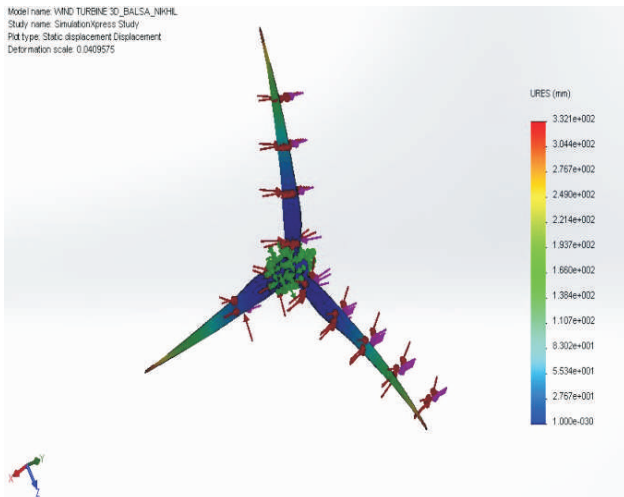From Figure 11 and Figure 12, the test foil and the NACA
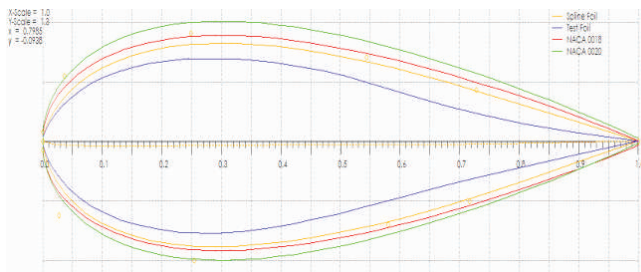
Figure 9. Static Displacement


Figure 10. Foils Generated for Chord Length of 100mm, Maximum Thickness of 18mm at 50mm from the Leading Edge
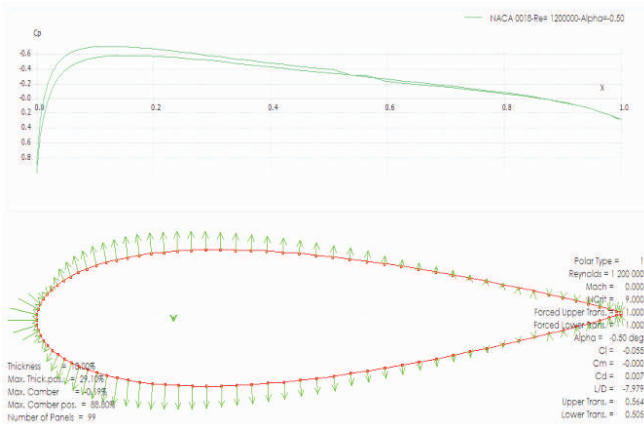

Figure 11. Pressure Distribution and the Graph of Co-efficient of Performance Against Position for NACA0018
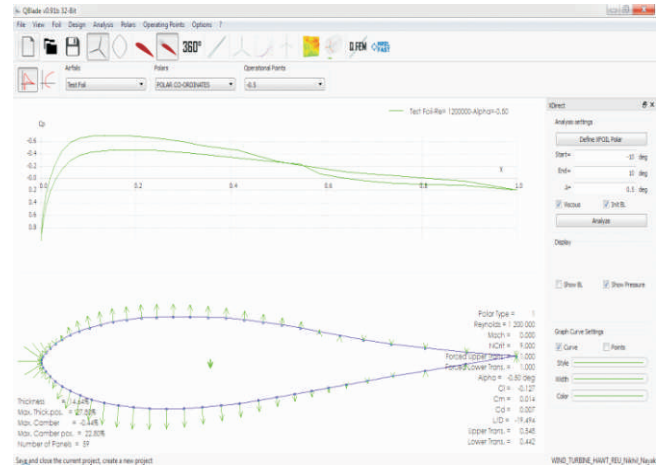

Figure 12. Pressure Distribution and the Graph of Co-efficient of Performance Against Position for Test Foil


Figure 13. System of Blades Generated
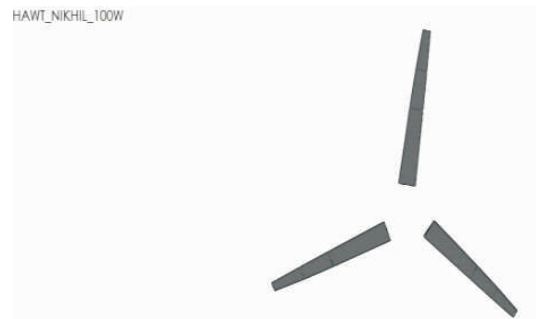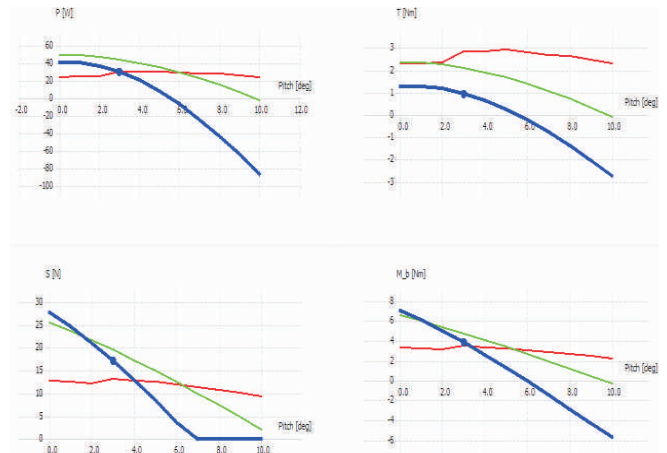

Figure 14. Impact of Pitch Angle for Different Rotor Speeds

0018 profiles have similar nature of graph for co-efficient of performance, but the pressure distribution is better in case of NACA 0018 profile. Keeping the cost of manufacturing and application [10] of the wind turbine in mind, the test foil can be preferred.

Figure 11 shows a comparison between the profile used to design the blade and that of a standard NACA 0018 and NACA 0020 aerofoil. Also, it shows the pressure distribution along the test foil along with a plot of $C_p$ (Co-efficient of performance) against the position. The angle of attack is -0.5$^0$ and also shows the maximum camber.

Figure 13 shows the blade system that was generated and imported to the software Qblade and the rotor diameter selected is 2m.

### 6.1 Graphs Obtained

Figure 14 shows 4 graphs that were obtained for different rotor speeds. The green colored line represents 100 rpm,

red colored line represents 200 rpm and the dark blue colored line represents the 300 rpm rotor speed. The graphs plotted against the pitch angle suggest that the power is maximum if the pitch angle is on the lower side
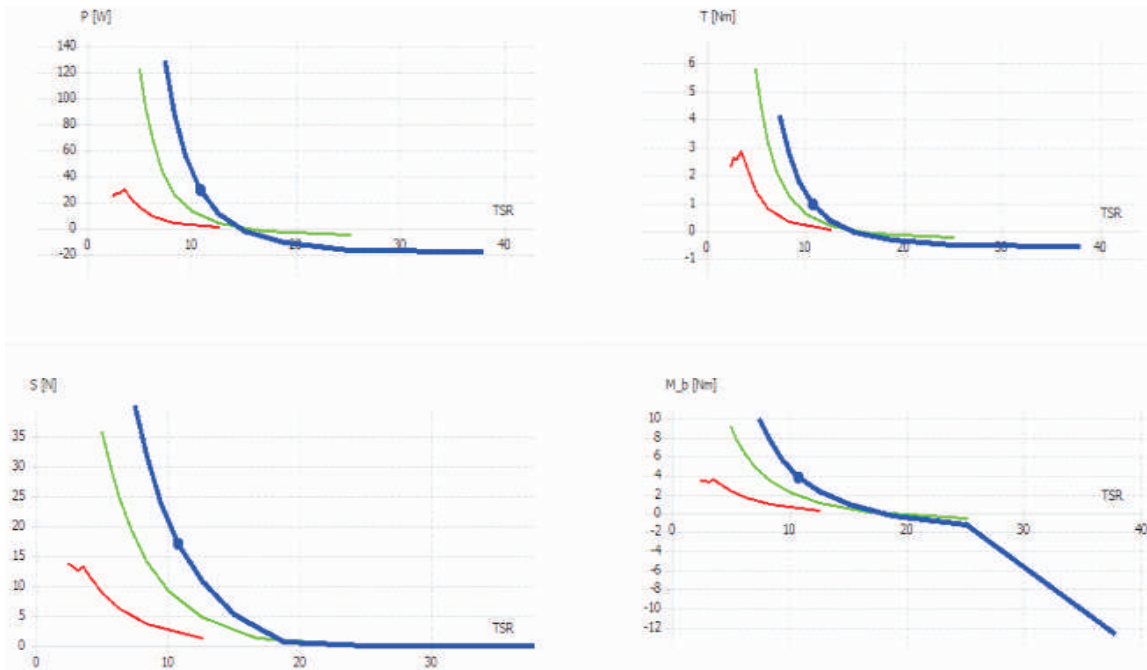


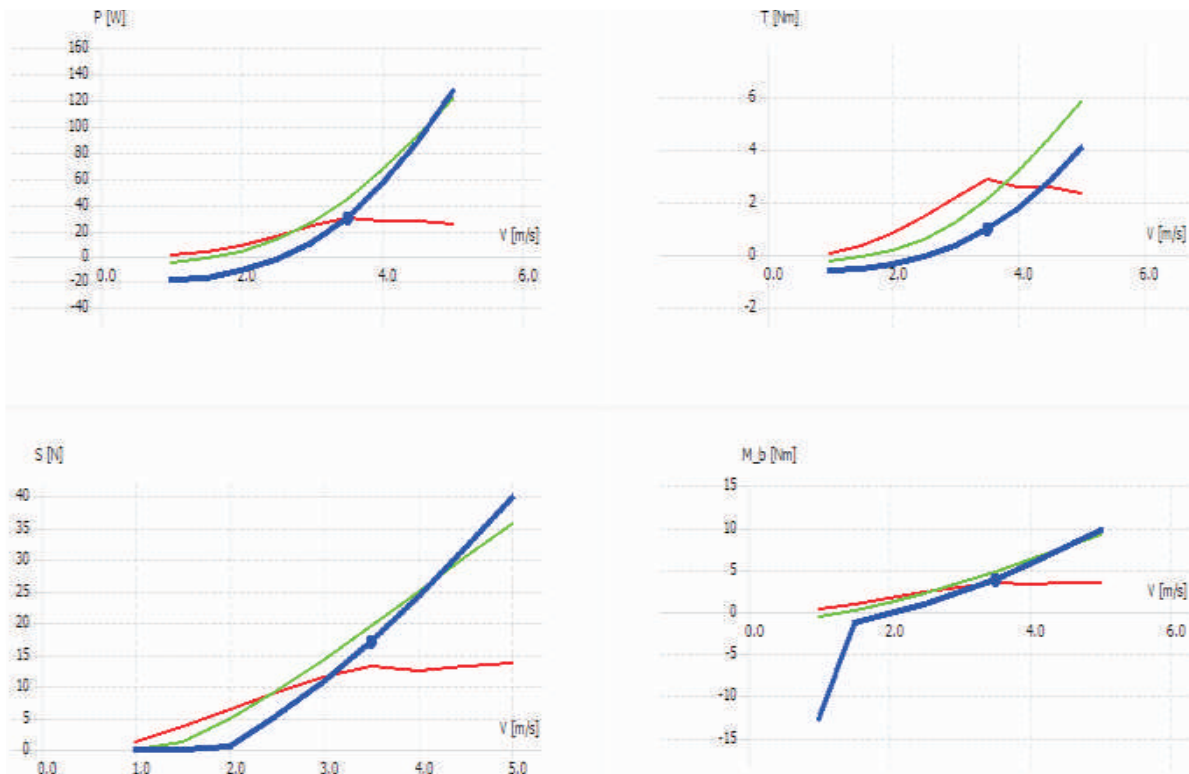Figure 15. Tip Speed Ratio Impact for Different Rotor Speeds



Figure 16. Wind Speed Impact for Different Rotor Speeds

and power reduces with increase in pitch angle. A similar trend is seen in other graphs as well for thrust force (S), bending moment (M_b) and Torque (T). Rotor speed of 200 rpm and pitch angle between $2^0$ to $4^0$ seems appropriate for the application.

Figure 15 shows 4 graphs that were obtained for different rotor speeds. The convention for rotor speeds remains the same as the previous figure. The graphs are plotted against T.S.R (tip speed ratio) suggest that, the power is high at low T.S.R and reduces with increase in T.S.R and becomes constant. A similar trend is seen in other graphs as well for thrust force (S), bending moment (M_b) and Torque (T). Rotor speed of 300 rpm and T.S.R on the lower side is appropriate for the application.

Figure 16 shows 4 graphs that were obtained for different rotor speeds. The convention for rotor speeds remains the same as previous figure. The graphs are plotted against different wind speeds suggest that, the power increases with increase in the wind speeds. The thrust force for the rotor speed of 200 rpm shows a linear nature and torque shows a dip after the wind speed of 3.8 m/s. Rotor speed of 300 rpm and the wind speed calculated for the given area 4 m/s suggests that, a power output of 60 W for rotor speed of 300 rpm.

Figure 17 is used to study the effect of different wind speeds on the angle of attack and its variation with the position. The graph suggests that, the angle of attack for the designed wind speed of 4 m/s dips drastically as the position increases and is marked in green color.
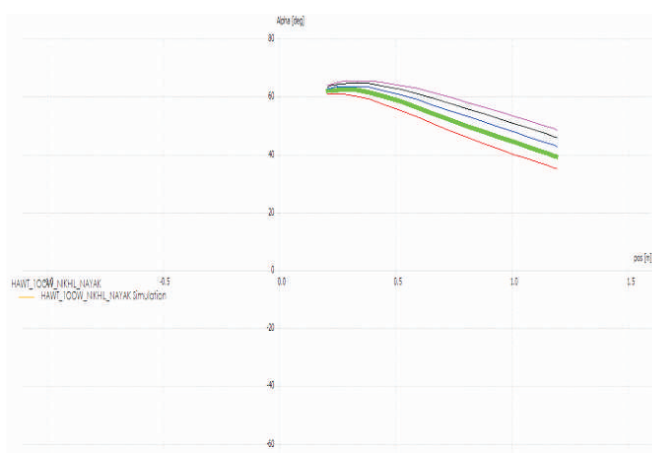


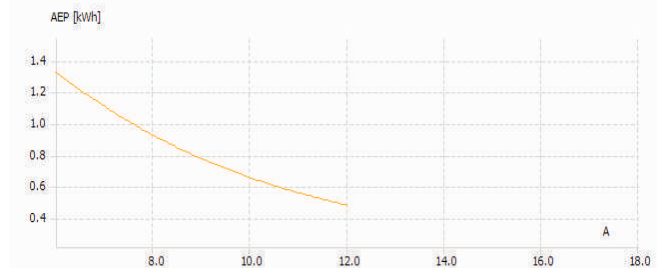Figure 17. Angle of Attack V.s Position for Different Wind Speeds



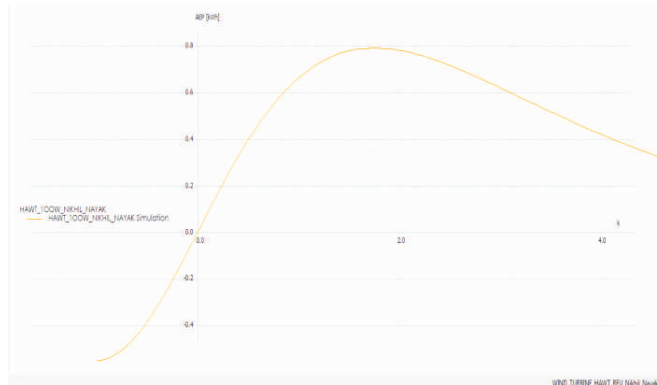Figure 18. Annual Energy Production Vs Scale Factor



Figure 19. Annual Energy Production Vs Shape Factor

## 7. Effect of Weibull Parameters

Figures 18 and 19 suggest the impact of shape and scale factors on the annual energy production and the inference that can be made is that the annual energy production is high for low scale factor and shape factor and the acceptable values [12] for the required power below 5.

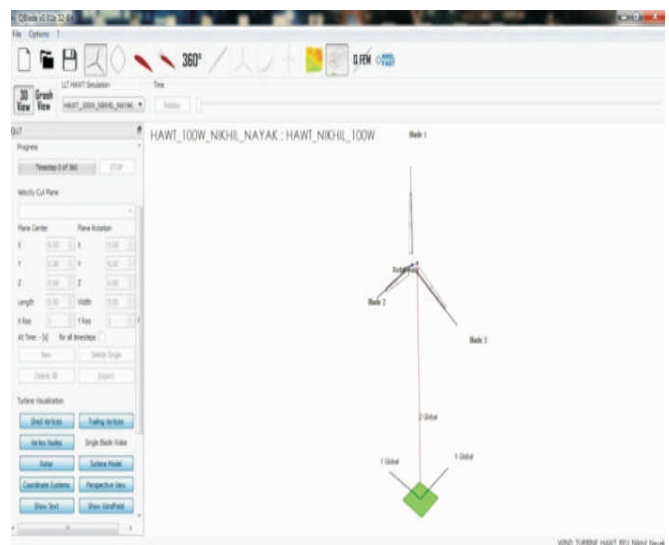Figures 20 and 21 show the model that was prepared
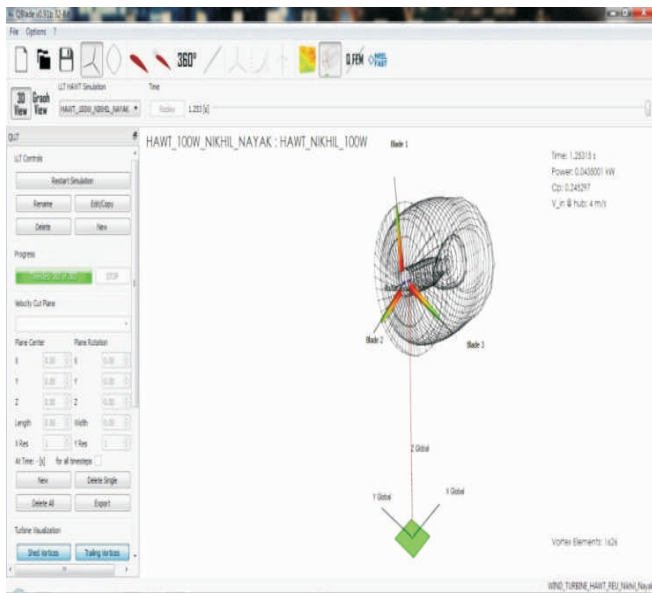


Figure 20. Hawt Simulation Setup

Figure 21. Simulation Results

using the Qblade software for the purpose of simulation. After subjecting to a simulation of time step of 360, it is observed that, the power obtained is 43.5 W for a wind speed of 4 m/s and a height of 10 m from the ground for the given area in Hubli.

From the Figure 22, it is clear that the horizontal axis wind turbine is a "lift based" turbine and the test foil has higher lift co-efficient when compared to the standard NACA profile.
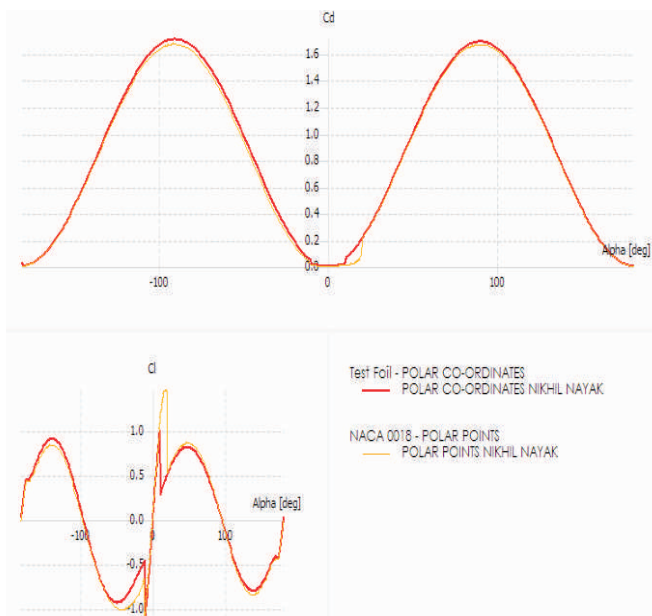


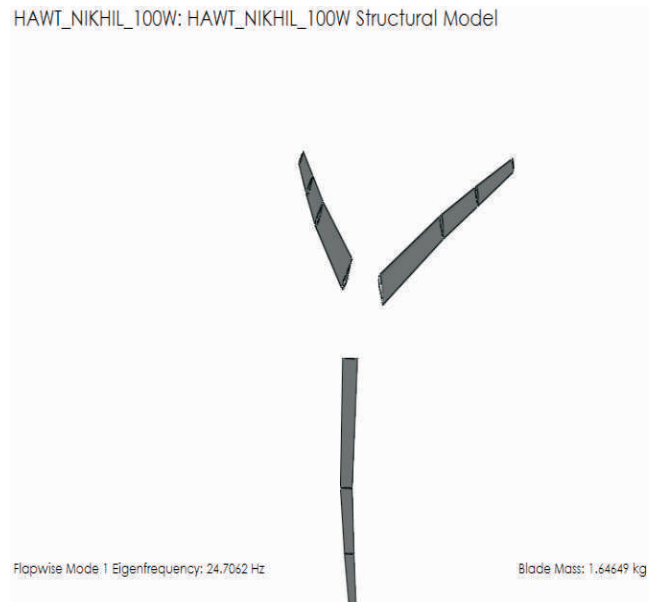Figure 22. 360° Polar comparison between test foil and NACA 0018



Figure 23. Flapwise Mode Shape



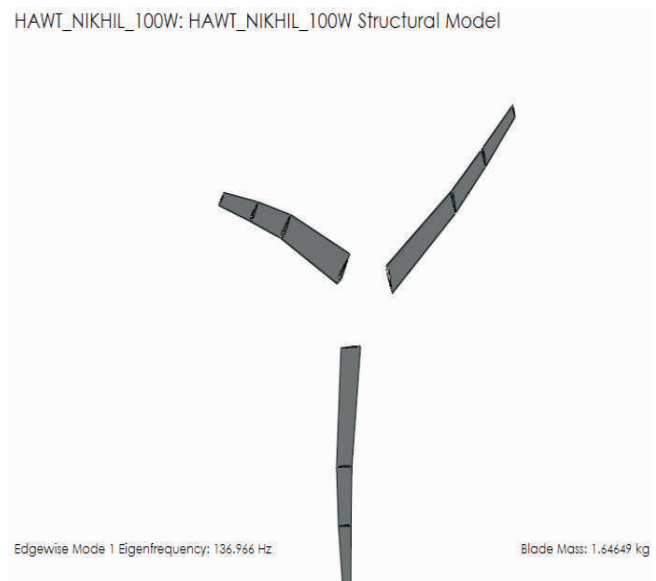Figure 24. Edgewise Mode Shape

## 8. Mode Shapes

Figures 23, 24 and 25 show different mode shapes for the blades along with the corresponding Eigen frequency along with the mass of the blade. The highest Eigen frequency was observed for the blades under torsional mode 1181.13 Hz and lowest under flapwise mode 24.70 Hz.

## 9. Proposed Tower

Triangular lattice towers consist of three legs positioned at

HAWT_NIKHIL_100W: HAWT_NIKHIL_100W Structural Model

Torsional Mode 1 Eigenfrequency: 1181.13 Hz
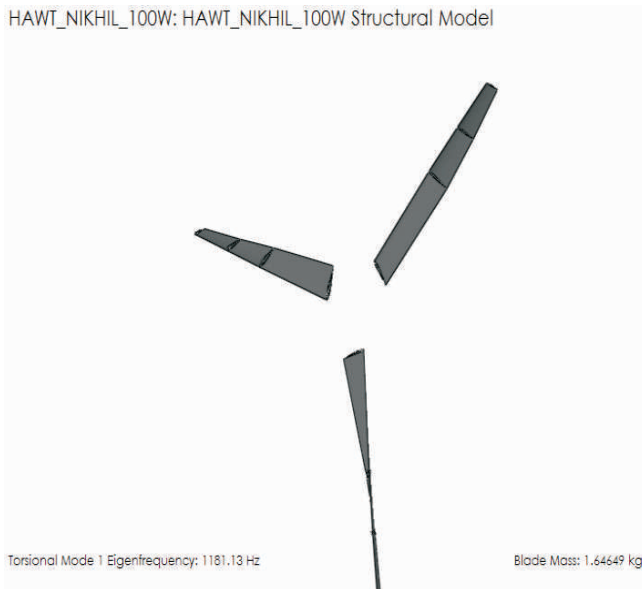
Blade Mass: 1.64649 kg
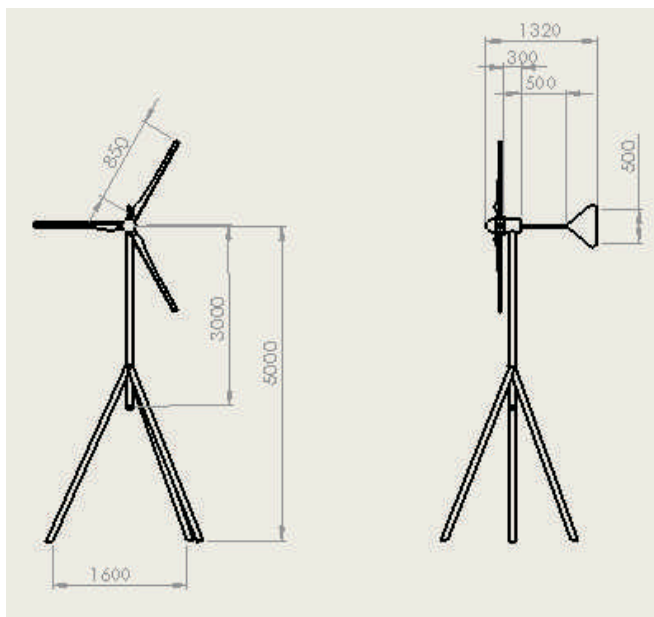
Figure 25. Torsional Mode Shape

Figure 26. Dimensions of Designed Wind Turbine in mm

the corners of an equilateral triangle. Figure 26 shows the Proposed Tower.

### 9.1 Solar Panel

Total load = 100 W

Period of operation = 12 Hours

Then, Total Watt-Hour = $100 \times 12 = 1200$ W.hr

The period of the solar panel exposed to the sun = 8 hrs.

(Between 9am and 3pm)

Therefore,

Solar panel wattage = 1200/8 = 1500 W

Hence solar panel of 150W will be needed for this design [15].

If solar panel of 15 W is to be use the number of panels to arrange in parallel to achieve 150 Watt will be:

Number of panels required = 150 W/15 W = 10

### 9.2 Charging Controllers

For this design of 100 W solar power supply,

$$P = IV \qquad (15)$$

where,

I = Expected charging current,

V = Voltage of the battery and = 12 V,

P = Power supply rating = 100 W,

I = 83 A

Charging controllers is not readily available in the market hence "Buck-Boost controller" will be used [11].

### 9.3 Inverter

Since the total load is 100 W, it is suggested to size the required inverter to be 150 W as designed for solar panel ratings.

Hence 150 W "PURE SINE WAVE" will be used.

### 9.4 Applications

For domestic applications, this wind turbine and solar panels can be used to engineer the required capacity requirements and accommodate the needs.

### Conclusion

The analysis from the tools like Qblade and solidworks support the calculations made and show that the material used for the blade Balsa wood and the tower, a tripod can withstand the loads acting on them and can be expected to produce a power output of 100 W for an average wind speed of 4 m/s. This may not be a significant amount of power, but it can be employed to ensure that remote areas can benefit from the solution proposed.

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