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# Design, Modelling and Comparative Analysis of a Horizontal Axis Wind Turbine

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**Abstract -** *This project objectifies the design, modelling, comparative simulation of a Horizontal Axis Wind Turbine. Wind energy is epitomized as a significantly viable form of clean renewable energy. Due to rapid increase in global energy requirements supplemented by the decrease in fossil fuel reserves, this form of energy is gaining significant prominence. Unlike nuclear power or thermal energy, wind energy does not emit, a long lasting hazardous and radioactive byproduct. This project emphasizes on hybrid electrification of domestic households with minimum cost, to ease the conventional electricity utilization and contribute toward demoralizing integration of fossil fuels in our daily lives leading to a prosperous sustainable future. Considering multiple design theories, various airfoils have been compared using Qblade. The wind turbine has been modelled using Solidworks. The structural integrity of the wind turbine has been justified with the use of Ansys. Following the design, various simulations using Solidworks flow and Qblade have been performed to validate the analytical design. The most efficient airfoil shape and turbine design has been determined and simulated in real world conditions to find real power and efficiency generated.*

***Key Words*: *Design, Modelling, Simulation, Horizontal Axis Wind Turbine, Fossil fuels, Renewable energy.***

## 1.INTRODUCTION

The evolution of wind energy production over the past decade has surpassed all expectations. From a mere production of 159 Gw in 2009 to a gargantuan leap of 651 Gw in 2019 [1], renewable energy has become the epitome of clean energy and is well on the way to replace fossil fuels. Scientists estimate that being exposed to particle matter developed from burning fossil energy is responsible for 18.3 percent of worldwide deaths in the year 2018. [2] The overall wind energy sector expanded approximately 19.8% in the year 2019, with around 60.2 GW of new production capability added to the worldwide electricity grid. India specifically added 2.4 Gw of wind power in 2019 [3].

Designing a power generating Horizontal Axis turbine is a complex process. Several theories are taken into considering while designing a turbine. One of the more significant ones being the blade element momentum theory (BEM). It is the foundation of any wind turbine design as emphasized by several researchers [4-7]. The BEM aids us with ideal predictions and comparisons. A rough understanding of the system can be gained by practicing this simple approach first, before more complex blade element and strip theories are

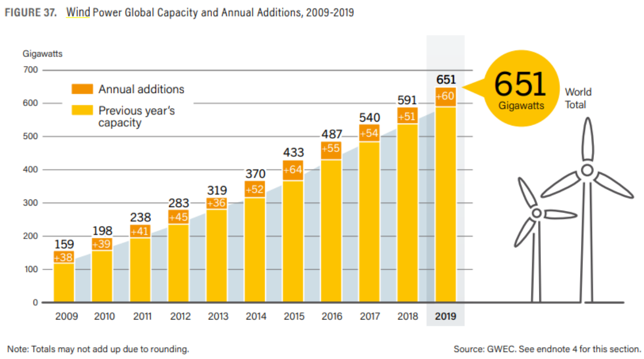


**Fig -1:** Wind energy trends across the world. [1]

used. The various construction materials used for the manufacture of advanced wind turbines are discussed [8-14]. Composite materials such as carbon nanotubes, carbon fiber, fiberglass impregnated with polyester or alternatives like epoxy resin greatly improves efficiency over conventional materials.

Qblade is a specifically designed software for analysis of wind turbine blades [15-18]. Tools such as Qblade aid in reassuring the numerical design's validity by providing real world simulation results according to the inputs provided, precise results were calculated using Qblade with little to no deviation from the numerical design analysis, thus good precision is concluded in the researches cited above. Structural analysis is useful in finding the maximum loading conditions of the blade and tower. CAD software such as Solidworks or CREO is employed for modelling and analyzed in FEM software to determine various structural parameters such as tower width and blade thickness to ensure good structural integrity [19-21].

In developing countries like India, shortage of electricity is a very commonly seen issue. Electricity shortages impact a substantial setback on the Indian industries, reducing revenue by 7.7% on an average. [22] Over the past years, considerable focus has been directed toward implementation of renewable energy in India. This research project contributes to the production of clean energy at a substantially lower design cost due to its hybrid design, thus favoring small scale industrial or domestic use.

## 2. Methodology

### 2.1 One Dimensional Theory –

A modular representation of a stream tube is made use of to evaluate the power produced from an optimal rotor, the action of the blowing air force on the propellers, and the influence of the turbine impeller action on the field of wind. This theory takes in consideration, a regulating setup, where the bounding limitations are itself the exterior boundaries of the model and both cut sectors of the flowing liquid stream. The only applicable motion is beyond the boundaries of the demonstrated model. The rotor, depicted by an 'actuating disc' creates a discontinuous force in the tube with liquid moving within. [23]
The Betz limit, $Cp_{max}$ = 16/27 (59%), is the upper limit of theoretically achievable coefficient of performance.

Assumptions –
•Uniform, non-compressible fluid motion.
•No frictional drag.
•homogenous action of force over the rotor area.
•An immobile wake.

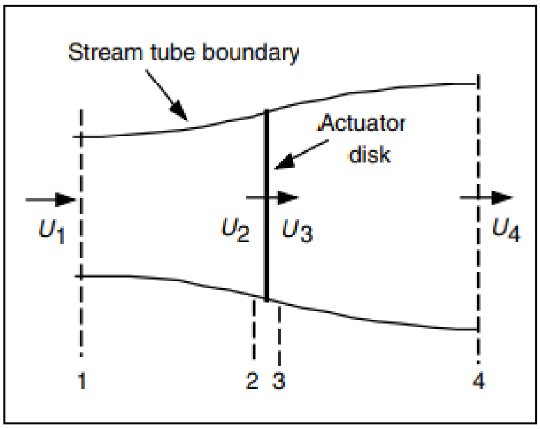


**Fig -2:** Stream Tube Model [23]

### 2.2 Blade Element Momentum Theory –

These forces influencing upon the wings of a wind turbine may alternatively be demonstrated as a derivative of lift coefficient, drag constants and the approaching wind for each different imaginary section. For the analysis of this theory, the blade is considered to be fractionated into X sections and each section is analyzed individually.

Assumptions –
- There is no relationship amidst the blade sections (eliminates radial flow)
- Acting forces at the sections of blade are evaluated by the Cl, Cd constants corresponding to a particular geometric form of airfoil assigned to the wing [23].

## 3. Analytical Design

Wind energy observations from over 3 locations with varying altitudes are recorded using a Vane Anemometer, to get a triangulated average.

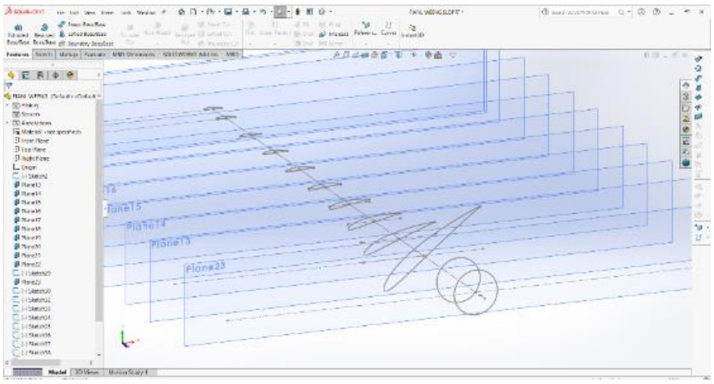

**Fig -3:** BEM sections from CAD model

### 3.1 Wind Observations (m/s) -

a. $V_{avg}$ = 6
b. $V_{design}$ = 8.5
c. Cut in velocity = 4.2
d. Cut out velocity = 18

### 3.2 Design Considerations –

a. Power Required = 1 KW
b. Coefficient of Performance (Cp) = 45 %
c. Mechanical Efficiency ($\eta$) = 85 %
d. Number of blades = 3
e. Tip Speed Ratio = 6 [23]

| Suggested blade number, B for different tip speed ratios, λ | |
|---|---|
| λ | B |
| 1 | 8-14 |
| 2 | 6-12 |
| 3 | 3-6 |
| 4 | 3-4 |
| > 4 | 1-3 |

**Fig -4:** Ideal Tip Speed Ratio to blade number

### 3.3 Rotor Calculations –

**a. Power –**

$$P = C_p * \eta_{mech} * \pi * \frac{1}{2} * \rho * R^2 * V^3$$

$$1000 = 45\% * 85\% * \pi * 0.5 * 1.225 * R^2 * 8.5^3$$

$$R = 1.487\, m \approx \underline{1.5\, m}$$

**b. Swept Area –**

$$A = \pi * R^2$$

$$A = \pi * 1.5^2 = \underline{7.068\, m^2}$$

**c. Wind Power –**

$$P_w = \frac{1}{2} * \rho * A * V^3$$

$$Pw = 0.5 * 1.225 * 7.068 * 8.5^3$$

$$Pw = \underline{2658.63\, W}$$

**d. Blade Power –**

$$P_b = Cp * Pw * \eta_{mech}$$

$$P_b = 0.45 * 2658.63 * 0.85$$

$$P_b = \underline{1016.92\, W}$$

**e. Efficiency of energy transformation –**

$$\eta = \frac{P_b}{P_w}$$

$$\frac{1016.92}{2658.63} = \underline{38.25\%}$$

**f. Angular Speed –**

$$\omega = \frac{\lambda V}{R}$$

$$\omega = 6 * \frac{8.5}{1.5}$$

$$\omega =$$

**g. Rotor Speed –**

$$\omega = \frac{2\pi N}{60}$$

$$34 = \frac{2 * \pi * N}{60}$$

$$N = \underline{324.67\, RPM \approx}$$

**h. Torque –**

$$\tau = \frac{30}{\pi} * \frac{P_{out}}{N}$$

$$\tau = \underline{29.38\, Nm}$$

### 3.4 Ideal Blade Design according to BEM –

**Table -1: Ideal Blade Design**

| SR. No. | r/R | C/R | Wind Approach ($\varphi$) | Pitch of Section ($\theta p$) |
|---|---|---|---|---|
| 1 | 0.1 | 0.276 | 43.6° | 36.5° |
| 2 | 0.2 | 0.175 | 25.6° | 18.4° |
| 3 | 0.3 | 0.120 | 17.6° | 10.5° |
| 4 | 0.4 | 0.090 | 13.4° | 6.6° |
| 5 | 0.5 | 0.074 | 10.8° | 3.4° |
| 6 | 0.6 | 0.064 | 9.0° | 2.1° |
| 7 | 0.7 | 0.055 | 7.7° | 0.8° |
| 8 | 0.8 | 0.046 | 6.8° | -0.2° |
| 9 | 0.9 | 0.043 | 6.0° | -1.1° |
| 10 | 1.0 | 0.040 | 5.4° | -1.4° |

## 4. Software Modelling and Analysis

### 4.1 CAD Models and Renders –

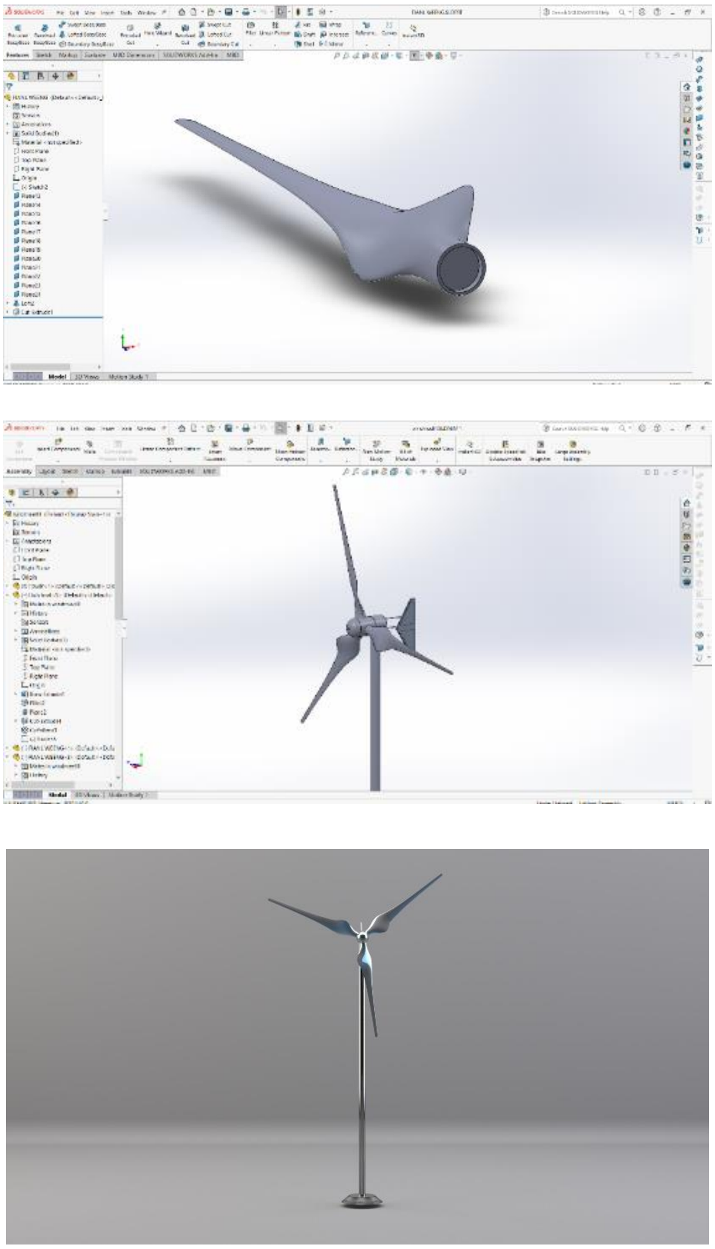

**Fig -5:** CAD Models and Renders

### 4.2 CAD Models and Renders –

**Table -2:** Material Assignment

| SR. No. | Part | Material | Weight |
|---|---|---|---|
| 1 | Hub | AISI4130 | 56.6 kg |
| 2 | Blades | A-Glass Fibre | 8.35 kg x 3 |
| 3 | Hub Rear | AISI4130 | 31.3 kg |
| 4 | Yaw Rods | AISI4130 | 1.8 kg x 2 |
| 5 | Yaw | PVC | 500 g |
| 6 | Tower | AISI4130 | 412.3 kg |
| Total | - | - | 529.35 kg |

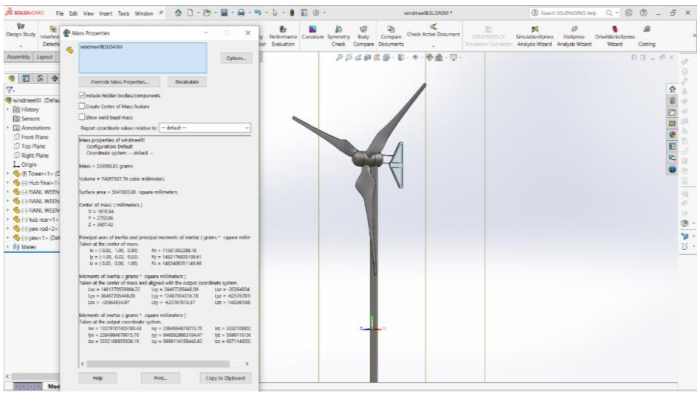

**Fig -6:** Solidworks Mass Properties

Solidworks Mass properties validate the above material table at mass **529.30 kg**

### 4.3 Structural Analysis –

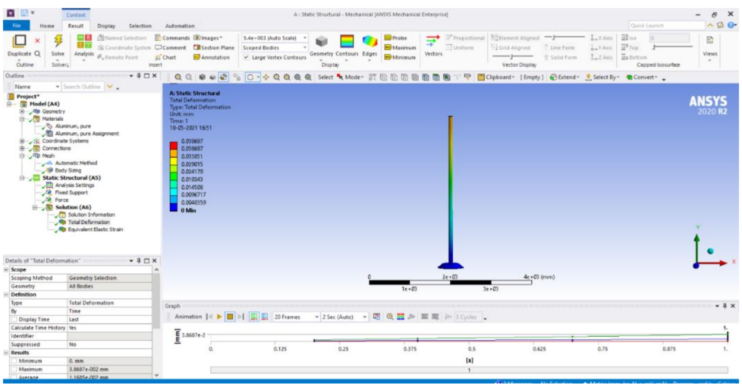

**Fig -7:** Structural Analysis of the tower in ANSYS

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Force applied = 5500N (550 kg)
Maximum deformation observed = 0.038 mm
Thus, the results confirm that the design is **safe.**

### 4.4 Aerodynamic Analysis –

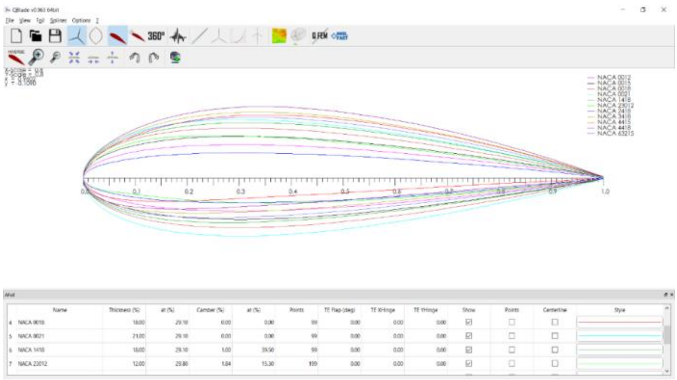
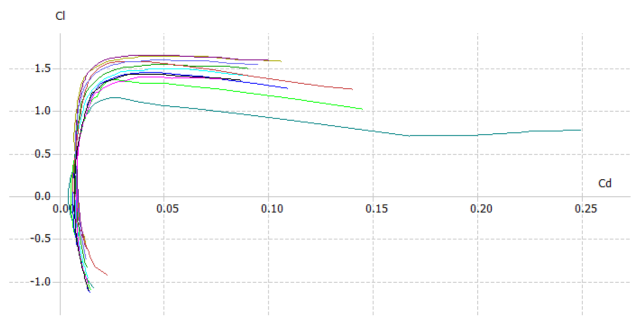


**Fig -8:** Airfoil Comparison in Qblade

**Symmetrical –**
National advisory committee for aeronautics.
0012
0015
0021
0018
**Cambered –**
1418
2418
3418
4418
**Special –**
4415
23012
63215



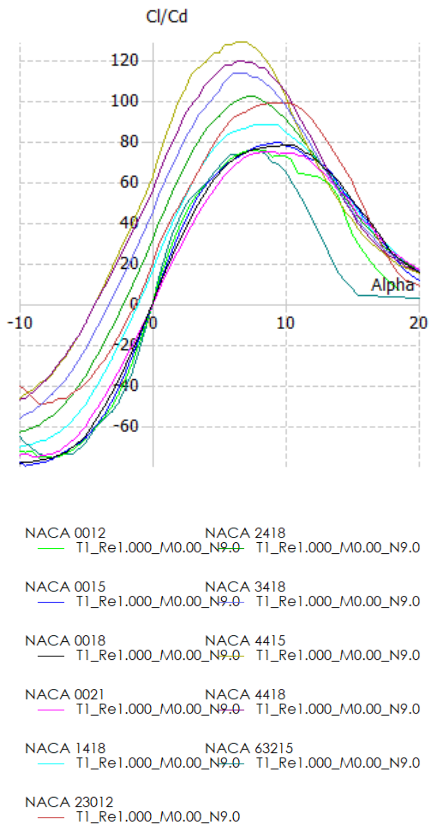




**Fig -9:** Technical Airfoil Comparison in Qblade

Graphs in observation –
Cl/Cd = Glide Ratio
Cl/α = Coefficient of lift vs the Angle of Approach of Wind
Coefficient of lift/Coefficient of drag/α = Glide Ratio vs the Angle of Approach of Wind (Attack)

### 4.5 Rotor Design –

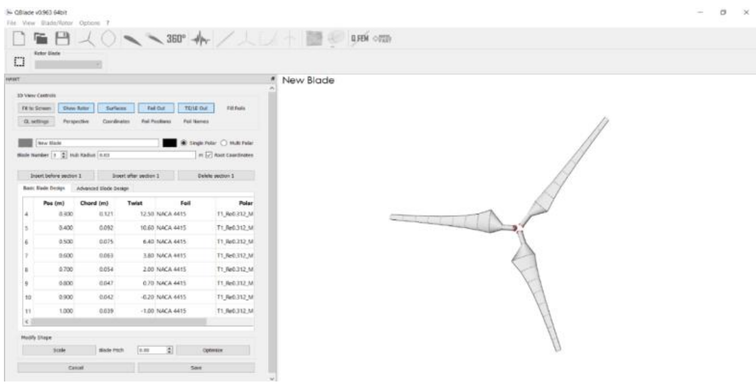



**Fig -10:** Rotor Design in Qblade

The rotor design section of Qblade requires the designer to input the various design parameters of the blade, according to the BEM, if applicable. Once the basic blade shape is completed, sectional twist and airfoil is to be assigned to each individual section. This rotor design is used in the final simulation.

## 5. Simulations

### 5.1 Solidworks Flow Simulation –

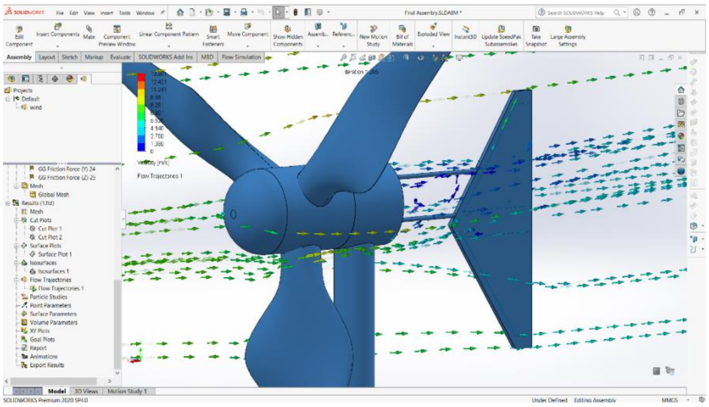


**Fig -11:** Flow Trajectories

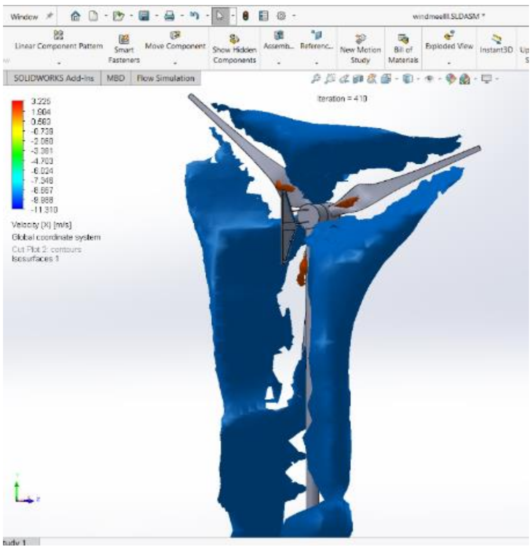


**Fig -12:** Drag force observed

Input Velocity = -8 m/s (X direction)
Drag force Observed = 3 m/s (X direction)

### 5.2 Qblade Aerodynamic Simulation –

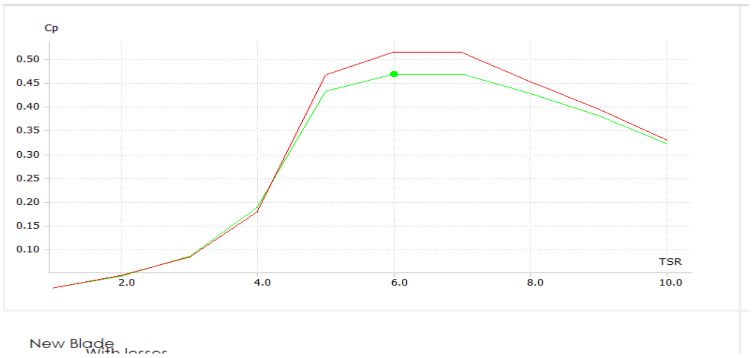



**Fig -13:** Cp Simulation

The coefficient of performance simulation verifies the analytically found Cp, that is 0.45 or 45%.

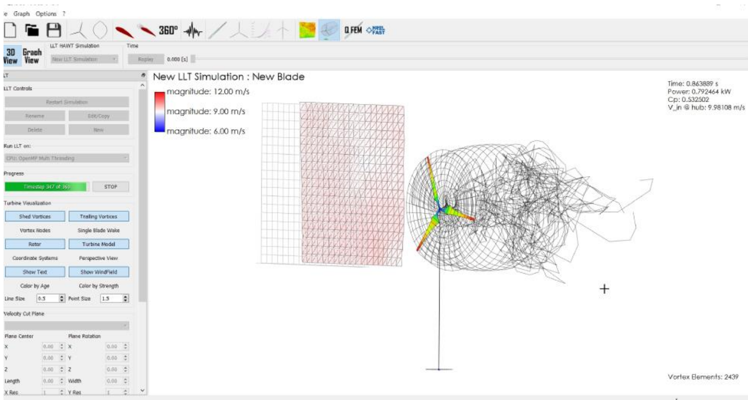



**Fig -14:** Qblade real world conditions simulation

Power results considering the following losses –

- Wake loss
- Tip loss
- Wind Drag
- Weight action of rotor
- Wind compressive force
- Fluid friction losses

## 6. Results and Discussions

Upon creating a varying wind-field from 8 meter per second to 12 meter per second, the program performs simulation of turbine in corresponding generated wind-field. Qblade aerodynamic simulation proves that in real world conditions, the turbine can produce about 800 W/h of power at the generated wind field in varying conditions.

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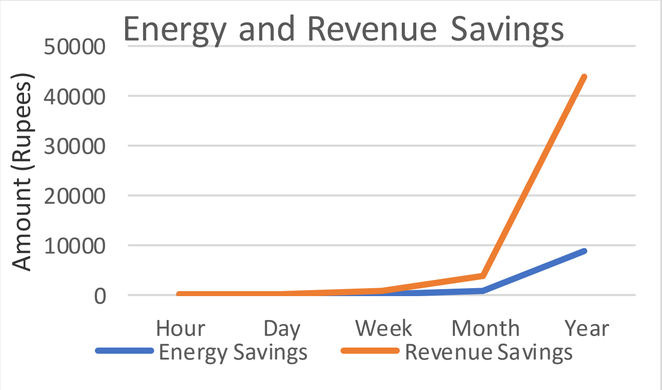
**Table -3:** RPM vs Power generated

| SR. No. | Wind Velocity (m/s) | RPM (Rev/m) | Energy generated* (W) |
|---|---|---|---|
| 1. | 4 m/s | 160.4 | 122.67 |
| 2. | 5 m/s | 190.98 | 206.98 |
| 3. | 6 m/s | 229.18 | 357.67 |
| 4. | 7 m/s | 267.38 | 567.97 |
| 5. | 8 m/s | 305.57 | 847.82 |
| 6. | 8.5 m/s | 324.67 | 1016.92 |

**Table -4:** Potential Energy and Revenue Savings

| Time Frame | Approx. Energy Savings | Approx. Revenue Savings |
|---|---|---|
| Per Hour | 1 KW | ₹5 |
| Per Day | 24 KW | ₹120 |
| Per Week | 168 KW | ₹840 |
| Per Month | 720 KW | ₹3600 |
| Per Year | 8760 KW | > ₹43,800 |



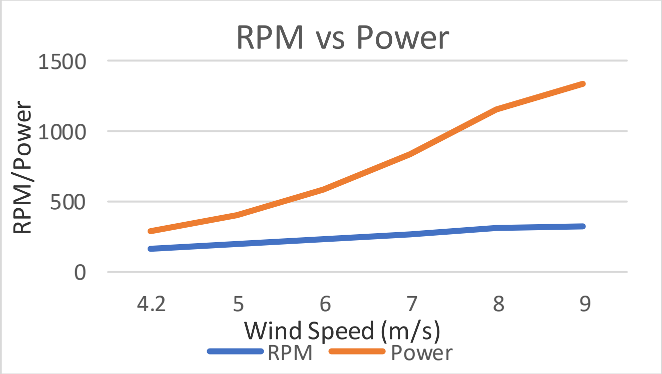




**Fig -15:** Energy revenue and RPM power graphs

## 7. Conclusions

In conclusion, a Wind Turbine of Horizontal Orientation is designed. Power produced from the blow of air, being a clean source of energy, there are no hazards of electricity production by a wind turbine. These turbines neither emit any toxic nor they have any specific productivity time, making these a superior alternative to fossil fuels and solar power.

The wind turbine is analytically designed and then the results were verified using multiple simulation Softwares. The structural analysis was done using Ansys. The environmental flow analysis was done using Solidworks Flow. The Aerodynamic analysis was done using Qblade (MATLAB).

The theoretical efficiency was found out to be 38.25% which is a 7% improvement over standard HAWT efficiency. The simulation results determined a power of 750-800 W at mean speed, including losses. This power is more than enough for domestic purposes to save a chunk of electricity bills. The turbine can also pitch
in at the time of power failures, thus saving productive time and loss of data.

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