

# Design and Manufacture of Low-Cost Micro Wind Turbine Rotor

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**ABSTRACT:** In this study, design, implementation and power performance analysis of a horizontal axis micro wind turbine (HMWT) system are presented. The blades are designed using Q-BLADE software. The airfoils chosen are FX-84-175 for root section and S803-nr for midspan and tip of the blades. Blades and hub are manufactured on CNC machine using light weight Balsa wood because of its strength, durability and stiffness. Due to some restrictions, carving and finishing of the blades are done manually. Stepper motor of Nema-23 configuration is used as a generator. Power performance analysis of the HMWT is carried out for different wind speeds. Comparison of theoretical values of power calculated by Q-BLADE, which uses Blade Elemental Theory and the actual experimental values of power obtained is done. The experimental power measurement is performed using anemometer and millimetre setup. The generated power could not reach up to the expected level because of the low wind speeds and manual finishing of blades. However accurate machining of the blades would make system much more efficient. The system still can light up to one CFL.

**KEYWORDS:** Airfoils, Balsa wood, blades, Power, Q-blade, turbine, Wind energy.

## I. INTRODUCTION

Today's major research area is based on finding alternatives to fossil fuels. Wind energy contributes significantly towards renewable energy production. Micro wind turbine is generally located in urban areas, where the wind is not strong, due to presence of buildings and another obstacle. At low wind speeds, modern commercial wind turbines have low efficiency for electricity generation. This research hence aims to design a new small wind turbine blade that is suitable for practical applications. The micro power generation is also thought to be a more practical alternative in terms of overcoming the non-reliability of the grid as well as being isolated or far away from the electrical grid, non-connected to it, which is the case in some secluded villages and areas in the world. In that sense, and in order to achieve a micro power generation, small scale wind turbines can be used in residential areas.

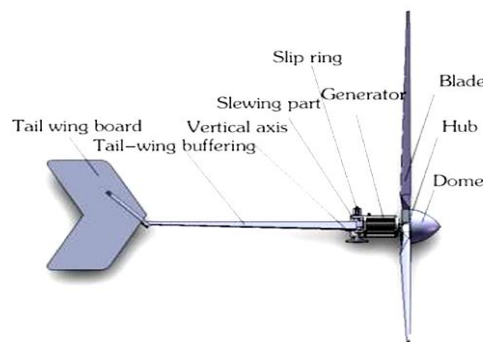


Figure 1. Construction of micro wind turbine

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**Blades:** Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

**Controller:** The controller starts up the machine at wind speeds of about 3.5 to 8 m/s and shuts off the machine at about 29 m/s. Turbines cannot operate at wind speeds above about 29 m/s because generators can be overheated.

**Generator:** Usually an off-the-shelf induction generator is used that produces AC electricity.

**Rotor:** The blades and the hub together are called the rotor.

**Tower:** Towers are made from tubular steel or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

## II. METHODOLOGY

Initially a brief survey about design parameter of wind turbine blade was performed. Based on the survey, selection of airfoil sections at root, midspan, tip section was decided. In the preliminary design calculation, dimensions of the blade, chord length along the length, angle of twist etc. was calculated. Based on design calculations blade was modeled in Q-BLADE software and a simulation on power generation was carried out. Simulation results was used to decide the final geometry, and design of the blade. Taking the final design into consideration, the blades and the hub was machined and carved out of Balsa wood. Blades and hub were assembled with the help of fasteners combinedly called as rotor. The rotor was coupled with generator and a real time power generation data was extracted using combination of tachometer, multimeter, and anemometer setup. A simulation of power generation with final rotor design was carried out. Measurement of power generation with the manufactured rotor was carried out. Results from experimental measurement and simulation was compared.

## III. DESIGN PARAMETERS

### A. Selection of airfoil:

In this work the FX84-W-175(For root section) and S803-nr (for midspan & tip) profile is chosen for modelling the micro wind turbine blade because of its best lift-drag ratio, good strength properties, good stall characteristics and small centre of pressure movement across large speed range, and also its roughness has little effect. This profile has more starting torque at low wind speed. Airfoils are shown in figures below.

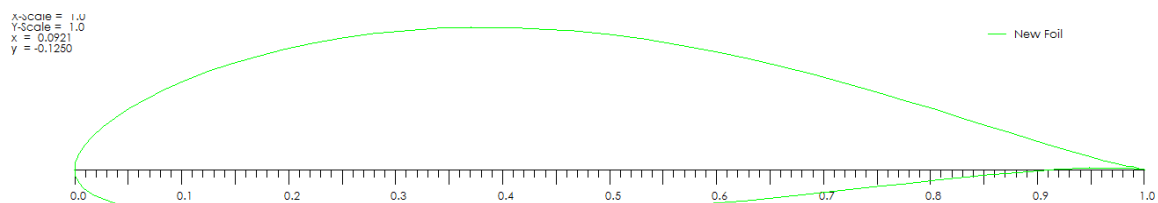


Figure 2. FX84-W-175

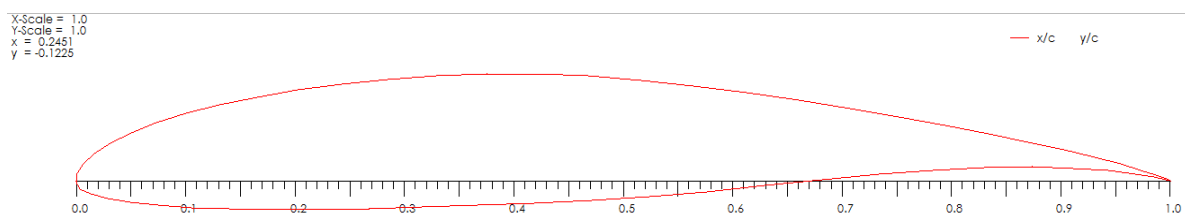


Figure 3. S803-nr

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**B. Selection of blade material:**

Balsa wood is used for its high efficiency in Micro wind turbine blades. Balsa wood is of good natural durability which may be expected to resist both decay and termite attack for at least 20 years. Balsa wood exhibits variable grain structure making it easy to shape. It has low weight & good strength when compare with other wood.

Table.1 Properties of Balsa wood

Young's modulus	Density	Passion ratio
3000 MPa	163 kg/m <sup>3</sup>	0.38

**C. Wind power Vs tower height:**

The energy in the wind increases with the cube of the wind speed ( $P \sim v^3$ ), and wind speed increases with height. An increase of just 26% in wind speed means twice of power is available in the wind. Double the wind speed and you will harvest almost eight times as much power. A small additional investment in tower height may therefore be worth it. The tower height is chosen 2 m installed on rooftop of total height of 9 m.

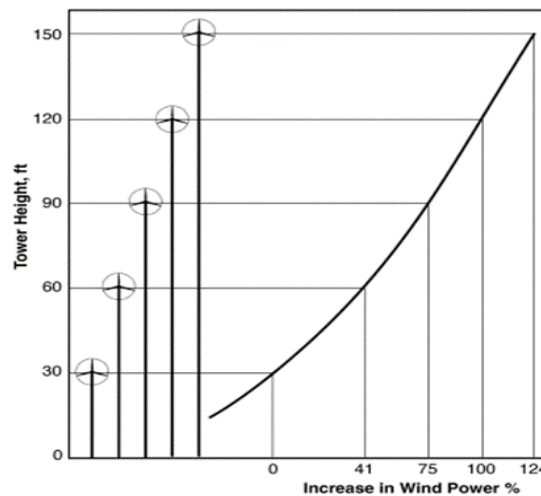


Figure 4. Wind Power vs. Tower Height

## IV. CALCULATIONS

**A. Blade design calculation:**

Assumptions made in calculation of blade design is given in below table:

Table 2. Design considerations

Sr. No	Description	Units
1	Power requirement(P)	600 W
2	Power Coefficient (Cp)	0.4
3	Velocity (v)	12 m/s
4	Density of air ( $\rho$ )	1.2kg/m <sup>3</sup>

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5	Hub radius (r)	0.056 m
6	Angle of attack ( $\alpha$ )	4.5(S803 nr)

- To find area  
 $P = 1/2 \times \rho \times A \times C_p \times v^3$   
 $600 = 1/2 \times 1.2 \times A \times 0.4 \times 12$   
 $A = 1.44 \text{ m}^2$
- To find radius  
 $A = \pi r^2$   
 $r = 0.68 \text{ m}$
- To find angular velocity  
 $\omega = 2\pi n / 60$   
 $\omega = 157.07 \text{ rad/s}$
- To find Tip speed ratio  
 $\lambda = r \times \omega / v$   
 $\lambda = 8.9$
- To find Reynolds number  
 $Re = \rho \times v \times d / \mu$   
 $Re = 987594.55$
- To find blade twist angle  
 $\varphi = (2/3) \times \tan^{-1} (1 / \lambda Local)$   
 $\varphi = 35.831^\circ$
- To find chord length  
 $C = (8\pi \times r / B \times CL) \times (1 - \cos\varphi)$   
 $C = 0.063445 \text{ m}$

Table 3. Blade chord length and twist angles at different radius along the blade

Blade section	Cross section no	Air foils	Radius (r) in m	Local ratio ( $\lambda$ )	Lift coefficient (CL) max	Twist angle ( $\varphi$ )	Chord length (C) in m
Root	1	circular	0.056	0.7331	1.4	35.831	0.063445
	2	FX84-W-175	0.112	1.4662	1.4	22.859	0.05265
	3		0.168	2.1994	1.4	16.297	0.04041
Midspan	4	S803-nr	0.224	2.9325	1.5	12.551	0.02990
	5		0.28	3.6656	1.5	10.171	0.02458
	6		0.336	4.3988	1.5	8.5373	0.02080
	7		0.392	5.1319	1.5	7.349	0.01799
	8		0.448	5.8650	1.5	6.449	0.01584
	9		0.504	6.5982	1.5	5.7445	0.01414
Tip	10		0.56	7.3313	1.5	5.1775	0.0127
	11		0.616	8.0644	1.5	4.7118	0.01163
	12		0.672	8.7976	1.5	4.3226	0.01068

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### B. Tail design calculation:

The design of the tail is of triangular shape. The material use for tail is stainless steel. The height of the tail fin is about 548.6 mm and the base width is around 274.3 mm. The thickness of the tail is 2 mm. The tail is connected to the PVC pipe of 500 mm length and 20 mm in diameter.

Calculations of tail design is given as follows-

- Swept area
  - $A = \pi r^2 = c \times 2c$
  - $A = 1.45 \text{ m}^2$
- Tail area
  - Ta = 5% of sweep area
  - $Ta = 0.072 \text{ m}^2$
- Length
  - $L = 0.75 \times R$
  - $L = 0.525 \text{ m}$
- Centre of pressure
  - $X = 1/3 \times c$
  - $X = 0.091 \text{ m}$
- Base of triangle
  - $b = c$
  - $b = 0.0274 \text{ m}$
- Height of triangle
  - $h = 2c$
  - $h = 0.0548 \text{ m}$

## V. DESIGN AND MANUFACTURING

### A. Blade and rotor section:

According to blade calculation and airfoil chosen, the blades are modelled in Q-BLADE. The manufacturing of blades is carried out on 3-axes CNC machine. The carving and finishing of blades are performed manually to give the exact chord length to blade. The blade and rotor models are shown in below figures.

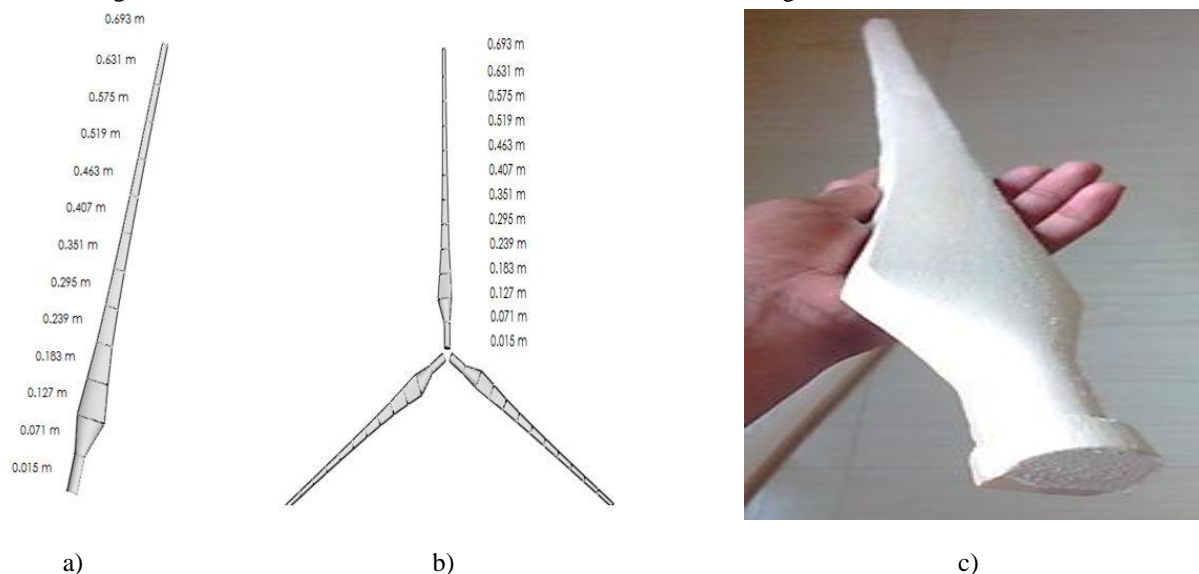


Figure 5. a) blade section b) rotor section c) Manufactured Blade

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### B. Hub:

The hub consists of two plates, a front plate and a back plate. The main purpose of hub is to hold the rotor. The hub diameter is taken as 90 mm to accommodate the calculated swept area. The hub should be light in weight and simpler to manufacture. The material chosen for hub is Balsa wood itself.

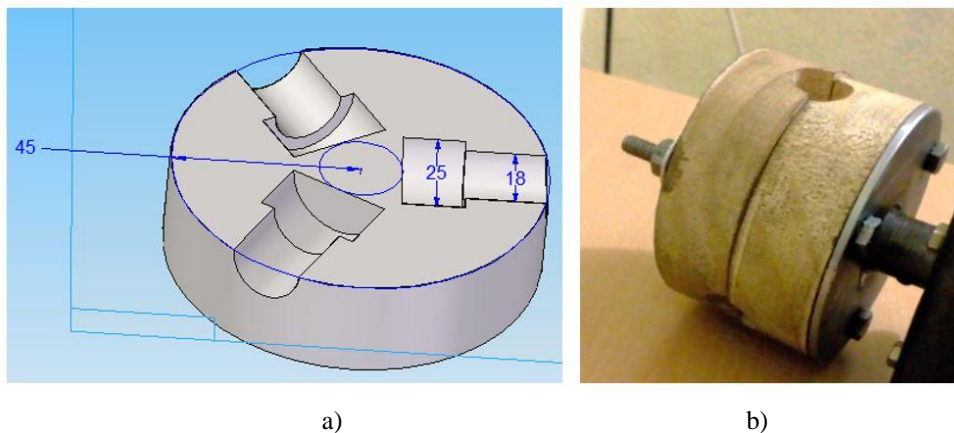


Figure 7. a) Hub modelled in CATIA b) Manufactured hub

### C. Assembly of micro wind turbine:

The stepper motor of torque 10.1 kg-cm and shaft diameter 6.35 mm was mounted on bracket and fastened together. The blades and hub assembly were coupled to motor with the help of coupling. The tail was connected to motor bracket. The tail helps the turbine to change direction for optimum power development. The total cost of manufacturing the HMWT comes under 4000 Rs.



Figure 8. Manufactured HMWT assembly

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## VI. RESULTS AND DISCUSSION

### A. Experimental power measurement:

The maximum power obtained from the experiment is 7.28 watts at 6 m/s wind speed. The power at surveyed wind speed i.e., 12 m/s could not be measured practically due to lower wind speeds.

### B. Q-BLADE simulation result:

The power obtained in software at 12 m/s is 490 watts, which is closer to our estimated power.

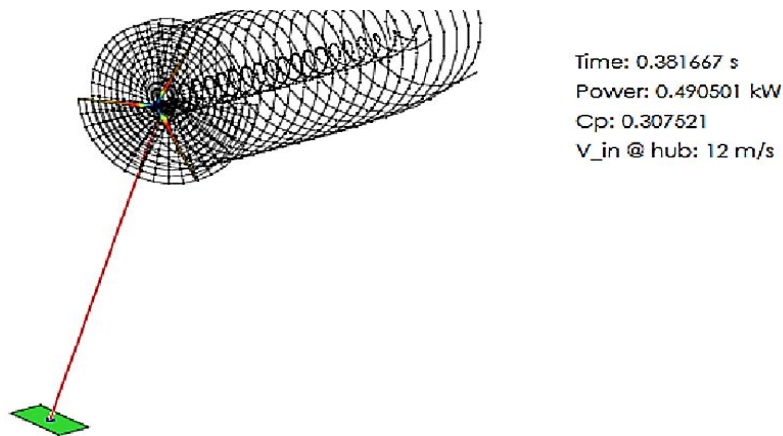


Figure 9. Rotor simulation in software

### C. Graphs obtained from software:

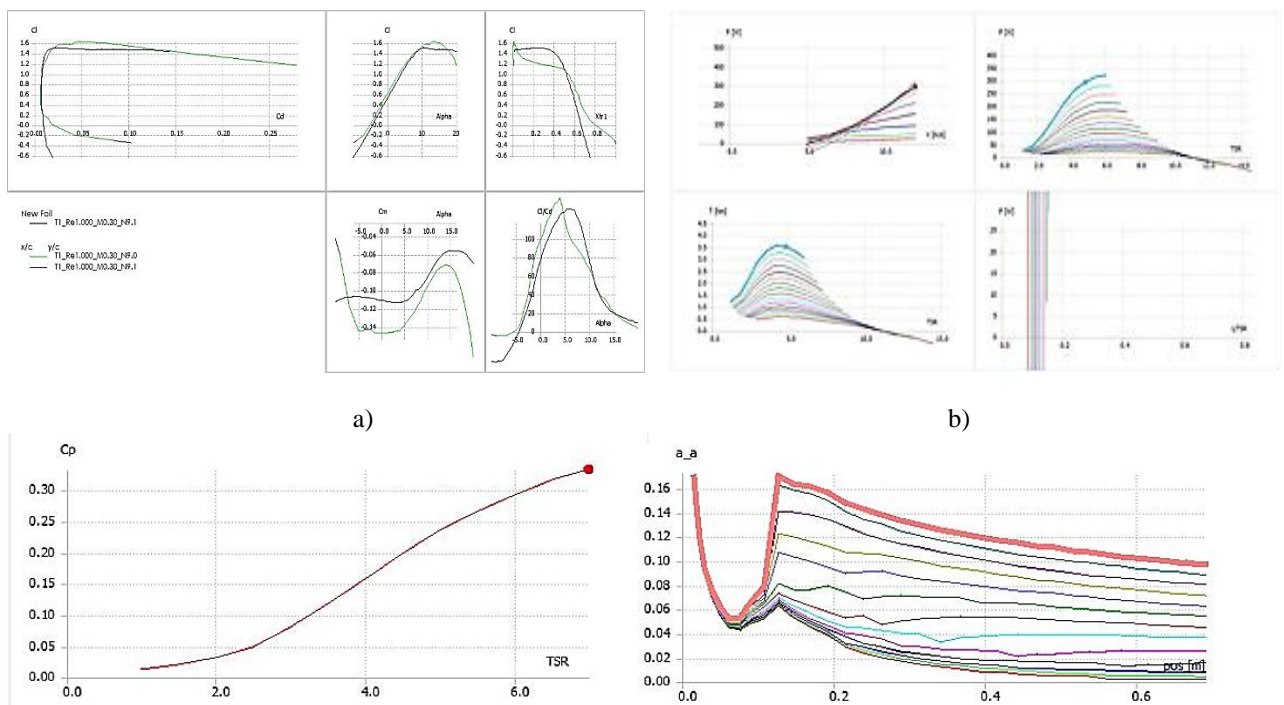


Figure 10. a)  $C_l$  vs.  $C_d$ ,  $C_l$  vs.  $\alpha$ ,  $C_l/C_d$  vs.  $\alpha$  b)  $P$  vs.  $V$   
c)  $C_p$  vs.  $TSR$

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### D. Power comparison:

The comparison of power of Q-BLADE and the actual power against different wind speeds is plotted in the below figure. The maximum power obtained from simulation is 160 watts at 12 m/s. The maximum power obtained by experiment is 7.2 watts at 6 m/s wind speed.

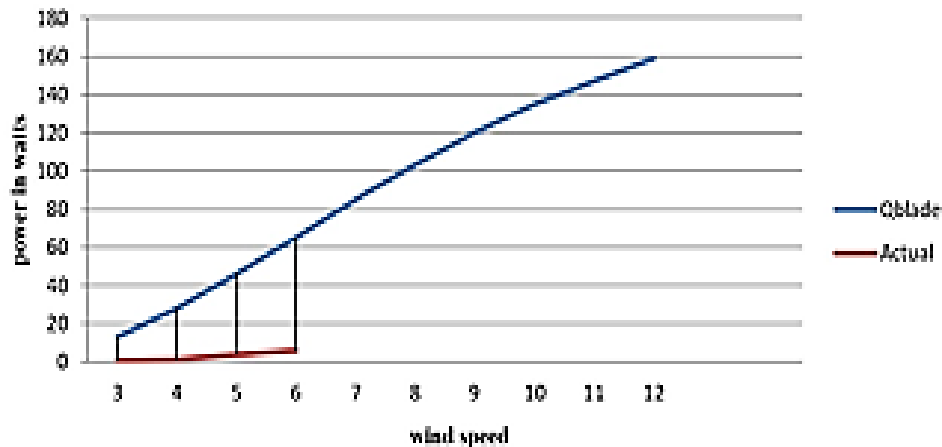


Figure 13. Power comparison against wind speeds

### E. Conclusion:

The following conclusions were reached from the HMWT.

- The power measurement is done using the anemometer, and multimeter setup. The generated power could not reach up to the expected level because of low wind speeds and manual finishing of blades.
- Stepper motor is used as generator minimizing the overall production cost. Accurate machining of the blades would make system much more efficient.
- The HMWT began electricity generation at 2.9 m/s cut-in wind speed with the employed blade form.
- The power comparison of the HMWT was obtained.
- Nevertheless, the developed system can still be installed on rooftops of rural areas with as little investment as 4000 Rs. The system can light up one CFL.
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