

# International Journal of Innovative Research in Science, Engineering and Technology

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## Design and Fabrication of Small VAWT for Turbine Tree using PVC Blades

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**ABSTRACT:** In the contemporary world the population is increasing and the demand for conventional source of energy is also increasing. Also these sources are diminishing in the near future. This leads to increase in cost of consumption. There is increase in cost of electricity due to less supply and more demand. So there is a need for alternate sources of energy. In this regard a new approach is made to harness the wind energy from the moving vehicles in highways, railway tracks and truck application to generate electricity. Turbine tree is a concept in which a number of small vertical axis wind turbines (VAWT) are mounted on a single arrangement and coupled to obtain high power output. Presently metals and composites are being used as material for blades in turbines. So, use of alternate materials other than metals in wind turbines yet to be researched. Also Integration of wind turbines in vehicles and road yet to be thoroughly researched and tested.

**KEYWORDS:** Small VAWT, Turbine tree, Truck application, Integration of wind turbines.

### I. INTRODUCTION

The use of wind turbines has risen rapidly in recent years because of the potential that they offer for carbon free power generation. Winds are usually unsteady with high levels of turbulence for significant proportions of the time, resulting in air flows characterized by rapid changes in speed and direction. It has been pointed out several times in literature that vertical axis wind turbines (VAWT) may be more appropriate for urban applications because of several distinct advantages it presents over the conventional horizontal axis wind turbines (HAWT). These advantages include no need to include a yawing mechanism to adjust the rotor to the changing wind direction, ease of maintenance due to the location of the gearbox – generator system at the base of the turbine, as well as potentially better performance in unsteady and skewed wind conditions. Also, as turbines are becoming bigger, the maintenance of equipment's grows more complex and costs much higher. Compared with HAWTs, Darrieus vertical axis wind turbines (VAWTs) have more technological advantages, providing an alternative for the wind power technology; hence Darrieus VAWTs are catching more eyes. Nevertheless, most of wind turbine design currently focuses on HAWTs, researches on Darrieus VAWTs have lagged significantly behind those on HAWTs, which have greatly hindered the development of VAWTs. Accordingly, this paper reviews the main basic research methods and their corresponding applications in Darrieus VAWTs, aiming to let more experts know the current research status and provide some guidance for relevant researches. However, very little work has been carried out into the effects of VAWT performance in unsteady wind conditions

#### Objectives:

Based on the problem definition for the project, the following objectives are set so as to achieve in the project work.

1. To design and fabricate a turbine tree using vertical axis wind turbine (VAWT) that could generate power under relatively low wind velocities.
2. Analyse how different geometry of the wind turbines would affect the output power of the wind turbine.

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3. Compare the operation of turbines with respect to the numbers of attached blades in the turbine.
4. The conceptual model for wind tree is to be fabricated.

## II. RELATED WORK

**T. Hayashi, Y. Li and Y. Hara**<sup>[1]</sup>: Two types of control were implemented: constant rpm and constant load torque. When subjected to a step change in wind speed from 10m/s to 11m/s under constant rpm control, the VAWT torque was observed to respond almost instantaneously and attained a steady state in less than 3s.

**S. J Kooiman, S.W. Tullis**<sup>[2]</sup>: experimentally tested a VAWT within the urban environment to assess the effects of unsteady wind on aerodynamic performance. Independence of the performance in directional fluctuations was seen while amplitude-based wind speed fluctuation decreased the performance linearly.

**Scheurich, F and Brown**<sup>[3]</sup>: Different fluctuation amplitudes were investigated for three blade configurations: straight, curved, and helical. Both straight and curved blades exhibited considerable variation in blade loading which is also observed in steady wind results. Helical blades perform much better with the unsteady CP tracing the steady performance curve quite well.

**Arti Tirkey, Yamini Sarthi, Khemraj Patel, Ritesh Sharma, Prakash Kumar Sen**<sup>[4]</sup> found that Power drawn from each blade. Assuming each blade draws a certain amount of power from the wind, a higher number of blades would draw more energy from the wind.

**Mithun Raj K and Ashok S**<sup>[5]</sup>: System Vertical axis wind turbine can be installed on the median of the roads so that the wind from both sides of the median will act tangentially in opposite direction on both sides of the turbine thereby increasing effective wind speed acting on the turbine

## III. CONCEPT OF WIND TREE

It was observed that by placing multiple turbines on a single tree the power output could be increased. Therefore, wind tree is a concept based on vertical axis wind turbine for power generation in which number of wind turbines are coupled in a single arrangement and due to the reduced size of blades so they can be easily rotated due to the impact of forced air. With the help of generators power is generated and stored with the help of battery. The main advantage is that; it is economically eco-friendly. The hand sketch is shown in fig 1 and Fig 2 shows the CAD model of wind tree concept.

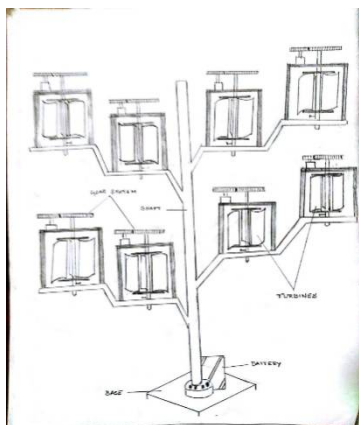


Figure 1 Hand sketch of Wind Tree

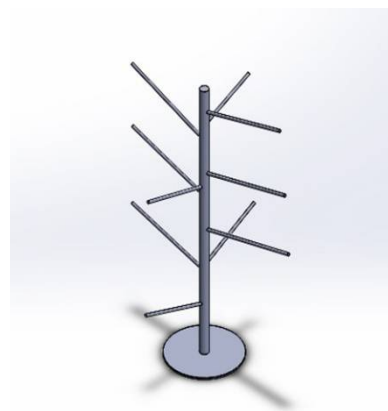


Figure 2 CAD model of Wind tree concept without VAWT

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The concept of wind tree can overcome the drawback of unidirectional flow of wind. When turbines are placed alternately it rotates for any direction of the wind i.e. wind tree becomes omnidirectional.

## IV. DESIGN OF VAWT FOR TURBINE TREE

Based on the above selected concept of VAWT for turbine tree, the theoretical calculations are carried out for different iterations of turbines. Multiple turbines can be placed at different location on the turbine tree to obtain the higher power output.

### Power Available

$P_{av} = \frac{1}{2}(\rho A v_m^3)$ , Assuming,  $\rho = 1.205 \text{ kg/m}^3$  we get

$$P_{av} = 0.6025 A v_m^3 \text{ watts}$$

Writing in terms of the propeller diameter. We have  $A = d \times h \text{ m}^2$

For the model under consideration, diameter( $d$ ) = 192mm, height( $h$ )=255mm &  $V_m = 5 \text{ m/s}$

Therefore  $P_{av} = 13.01 \text{ kWh}$

Considering Betz coefficient

$C_p = 0.593$ , where  $C_p$  = Coefficient of performance (Betz's Limit). Therefore, Mechanical power  
 $P_m = 0.593 * 13.01 = 7.71 \text{ kWh}$

### Gear ratio:

Number of teeth on driver gear =  $T_1 = 56$ , Number of teeth on driven gear =  $T_2 = 15$

Diameter of driver gear = 80mm, Diameter of driven gear = 20mm

Speed of driver gear =  $N_1$ , Speed of driven gear =  $N_2$

$$\text{Velocity ratio} = \frac{N_1}{N_2} = \frac{D_2}{D_1} = \frac{20}{80} = 0.25$$

Therefore, Output power =  $P_o = P_{av} * 0.25 = 7.71 * 0.25 = 1.92 \text{ KWh}$

Therefore, theoretical output power is 1.92 KWh.

Taking Betz equation into consideration, the mechanical power available and output power for different possible wind speed is calculated.

**Table 1. Output power for various wind speeds**

Wind speed(m/s)	Power available(watt)	Mechanical power available (watt)	Output power (watt)
2	0.2313	0.1371	0.0342
3	0.7808	0.4630	0.1157
4	1.8508	1.0975	0.2743
5	3.615	2.1436	0.5359
6	6.2467	3.7042	0.9260

### Torque available:

We have, Speed( $N$ ) =  $\frac{v * 60}{\pi * D} = \frac{5 * 60}{3.142 * 0.192} = 497.35 \text{ rpm}$

We have,  $P = \frac{2\pi NT}{60}$

$$T = \frac{P * 60}{2\pi N} = 0.0411 \text{ Nm}$$

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### Force acting on the shaft is:

Further, we have, relation between force and torque as,

$T = F \times r$ , Where  $r$  = radius of the wind turbine, which equals to 0.0961m.

$F = 0.42 \text{ N}$

For design safety, considering the wind speed of 10m/s, we have,

Speed (N) =  $\frac{v_m \times 60}{\pi \times D} = 994.71 \text{ rpm}$

We have,  $P = \frac{2\pi NT}{60}$

$T = \frac{P \times 60}{2\pi N} = 0.1645 \text{ Nm}$

### Shear stress on the shaft:

The diameter of the shaft is 6mm. To check the design safety of the shaft, neglecting the radial loads,

The equation for checking the torsional strength of the shaft is,

$$\frac{T}{J} = \frac{\tau}{r}$$

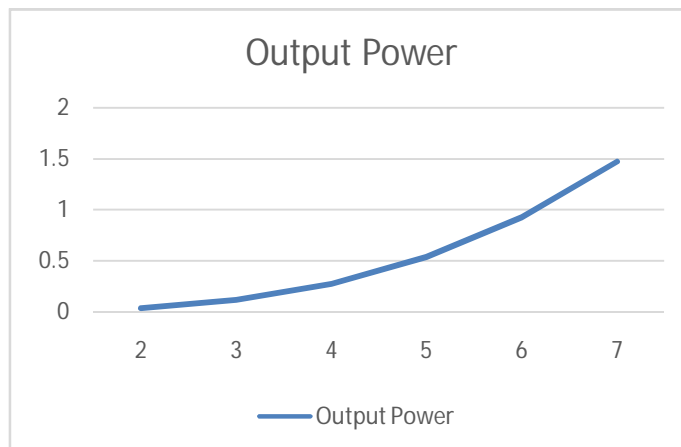
$$\tau = \frac{T \times r}{J}$$

$$\tau = \frac{16 \times T \times d}{\pi \times d^4}$$

Substituting the values,  $T = 0.1645 \times 10^3 \text{ N-mm}$ ,  $d = 6 \text{ mm}$ .

We get  $\tau = 3.878 \text{ N/mm}^2$

### Power curve:



The above graph shows the power curve for theoretical calculations. From this we can observe that, as the wind speed increases the power generation also increases.

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### Comparison of GI sheet and PVC material:

The PVC is chosen over GI sheet for blade material because of following reasons given in table 2

**Table 2. PVC v/s GI**

.N	GI sheet	PVC
	Blade fabrication is difficult	Blade fabrication is easy
	Surface appearance changes with environmental factors	Surface appearance doesn't change with environmental factors
	Blade geometry can be altered easily	Blade geometry cannot be altered easily
	It can be easily corroded when exposed to moisture	It cannot be corroded
	Durability is less when compared to pvc	Durability is more
	Cost of fabrication is more	Cost effective

### Power developed from Wind Tree:

The above calculations are carried out for a single c shaped blade vertical axis wind turbine. But wind tree consists of more number of turbines mounted on the branches. Considering power output from all the turbines, the total power output from the turbine tree is calculated by making assumptions.

#### Assumptions for calculating power:

1. All the turbines are assumed to generate same power output.
2. The efficiency of all the turbines are assumed to be same.
3. Effect of rotation of one turbine on the another is neglected.
4. The mechanical losses of all the turbines are considered to be same.
5. The pressure losses at the blades of all the turbines are equal.
6. Coefficient of performance for all the turbines is assumed to be same.

The power calculated for single turbine with wind speed of 5m/s is KWh.

Assuming the total number of turbines mounted on the turbine tree is 15, we get  $P_{total} = 15 \times 1.92$

$$P_{total} = 28.8 \text{ KWh}$$

## V. ANALYSIS OF A BLADE USING ANSYS AND WIND TUNNEL

The below figure 3 shows the contours of static pressure acting on a single blade of unit length for wind velocity of 7m/s at temperature 288.16 K. The blades are meshed to analyze. The node size is 7022 and elements are 6742. The boundary conditions are applied on the blade surfaces to analyze static pressure.

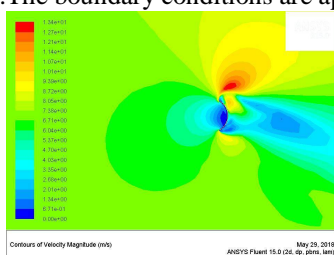


Figure 3 Static pressure analysis

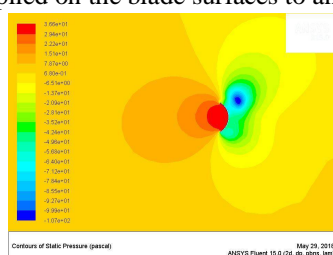


Figure 4 wind velocity analysis

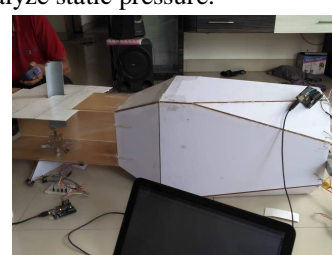


Figure 5 Testing of blade under wind tunnel

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From the analysis it can be found that the maximum pressure of 36.6 pascal will be acting on the blade inner surface. the outer surface will have low pressure so there is the pressure difference created results in drag force. hence the blade rotates. so the inner surface should have designed to withstand that pressure. The PVC material used in this project has rated pressure of 392.26kPa. So, the blade material used in this project is safe from the point of pressure acting on the blade. The above figure 4 shows the contours of velocity magnitude for 7m/s wind speed. The nodes and elements remain the same for this analysis also. From the above analysis we can found that the tip of the blade experiences higher velocity of 13.4 m/s, so tip of the blade should be as smooth as possible. The wind velocity comes to least at inner surface of blade and gradually moves through the C curve. So, the C curve should be designed with at most importance. The forces acting on single blade of VAWT for various angles and at different wind speeds is determined using wind tunnel. Fig 5 shows the experimental set up of wind tunnel. The blade is mounted in the test section of the wind tunnel and the wind is blown at different wind speeds. The different forces acting on the blade i.e.  $F_x$  = Drag force,  $F_y$  = Side thrust and  $F_z$  = Downward force, are obtained using 3 strain gauges.  $F_x$  and  $F_y$  are the components which are responsible for the rotation of the rotor. Therefore, the resultants of  $F_x$  and  $F_y$  for different wind speeds are tabulated below.

**Table 3. Wind speed v/s Resultant force on blade**

45degree		60degree		90degree	
Wind Speed (m/s)	Resultant Force (N)	Wind Speed (m/s)	Resultant Force (N)	Wind Speed (m/s)	Resultant Force (N)
2	0.022	3.5	0.098	<b>3.8</b>	<b>0.088</b>
3.4	0.107	<b>4.8</b>	<b>0.176</b>	<b>5.2</b>	<b>0.166</b>
4.4	0.171	<b>6</b>	<b>0.276</b>	6.2	0.256
<b>5</b>	<b>0.310</b>	7.2	0.357	7.3	0.322
5.4	0.301	7.9	0.427	7.8	0.410

From the above table it can be observed that for an average wind speed of 5m/s, the resultant force for 45degree is maximum i.e. 0.310N when compared to other angles. Therefore, mounting the blade at an angle of 45degree gives the maximum rotational force and hence maximum output power.

## VI. FABRICATION OF VAWT USING PVC

A PVC pipe of 75 mm diameter is taken and cut vertically at 120deg to fabricate the blade. The burred edges are removed. Smooth blade is fabricated. Holes are made for blades using drilling machine. Two metallic round plates are taken. Holes are made at 120deg in the two rotors using drilling machine. Collar is fabricated according to required dimensions. L-clamps are used to fasten blades to the rotor. Stainless steel shaft of 15inch length and 6mm diameter is used. The blades along with metallic plates are mounted on the shaft. Frame is fabricated using MS brite. Two nbc bearings are mounted into the frame at top and bottom by transition fit. Gears of 80mm and 20mm are used for drive system. Small DC generator is coupled to the shaft using gears to generate the electricity. Fig 6 shows the final assembled model for VAWT.

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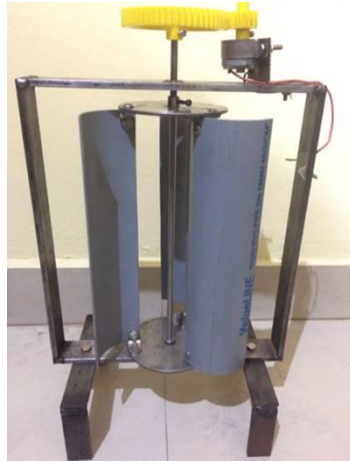


Figure 6 Fabricated model of small VAWT Figure 7 Fabricated model of small VAWT in highway median

## VII. RESULTS AND DISCUSSIONS

The testing of VAWT is done for highway power generation and truck application in Mysuru – Bengaluru highway and the following observations are noted directly from multi-meter for various wind and vehicle speeds. Experimental results are calculated and tabulated below. Fig 8 shows the wind speed reading.



Figure 8 Anemometer reading in highway

### Experimental Observations and results:

Note: All calculations are done using average wind speed of 5 m/s.

Table 4. Wind speed and power output for highway power generation

Wind speed (m/s)	Turbine (rpm)	Voltage (V)	Current (mA)	Power (KWh) $P=V*I$
3	130	0.53	-	-
4	178.6	0.75	38.7	0.1050
5	201.5	0.96	79.2	0.2736
6	440	1.66	98.6	0.5892

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**Table 5. Wind speed and power output for application in Automobiles**

Vehicle speed (Kmph)	Voltage (V)	Current (mA)	Power (W)	Power (KWh) P=V*I
30	2.415	101.25	0.2445	0.8802
40	3.845	120.55	0.4635	1.6686
50	6.46	133.8	0.8643	3.1140
60	7.425	141.85	1.0532	3.7916
70	10.84	144.75	1.5690	5.6487
80	11.35	150.1	1.7036	6.1330

**Experimental calculations:**

Following are the experimental calculations done for various application for the above observations.

**1. For highway power generation:**

For an average wind speed of 5 m/s, Observed voltage V = 0.96 volts

Observed current I = 73.2 mA

Therefore, Output power obtained  $P_o = V * I = 0.27$  KWh

Assuming there are 15 turbines mounted on tree,  $P_o = 15 * 0.27 = 4.05$  KWh

**2. For truck application:**

For an average vehicle speed of 50 kmph, Observed voltage V = 6.46 volts

Observed current I = 133.8 Ma

Therefore, Output power obtained  $P_o = V * I = 3.1140$  KWh

**3 Efficiency of turbine:**

$$\begin{aligned} \text{Efficiency of the turbine } (\eta) \text{ is given by } \eta &= \frac{\text{Experimental output power}}{\text{Theoretical output power}} \\ &= \frac{0.27}{1.92} \\ &= \mathbf{14.06\%} \end{aligned}$$

From the above experimental calculations, it can be observed that the wind tree yields around **4.05KWh** assuming that 15 turbines mounted on wind tree whereas, the single model of VAWT for truck application gives the power output of **3.1140KWh**. For a single turbine, the efficiency is **14.06%**.

## VIII. CONCLUSION

It is possible to outline a VAWT framework that enhanced power yield when contrasted with the past projects. From the obtained results, the recommendations of new design aspects to improve the system and efficiency are provided.

- At wind speed of 5 m/s the output power accounts for 0.27 KWh. Hence once can easily obtain an output of 4.05 KWh by mounting around 15 turbines on tree.
- Inefficient wind speed was the huge impact getting the required power output, minimum speed of 5 m/s is required to have acceptable output power taking in consideration 14.03 of efficiency between theoretical and experimental results.
- Even though the design of Vertical Axis Wind Turbine is made there is a never ending process to always improve upon inventions and new designs. Wind turbines are a start for society to lessen the damage done to the earth by not using energy sources that produces pollution.

Hopefully the project could propel research and testing on VAWT frameworks and give knowledge for different gatherings to finish additional testing and enhance productivity and execution of vertical axis wind turbines.



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### Future scope of work

A more efficient Wind turbine can be developed using the following measures:

- Optimizing the design of blades so as to give better aerodynamics.
- Using a more efficient alternator which produces more voltage for low rpm.
- Using more effective drive mechanisms to increase rpm for alternator input and hence can have higher power output from the alternator.
- This turbine can also be fixed near high speed railway tracks in order to get more energy output.

To gain the best power gain in the concept of green energy, it is strongly recommended having some solar panels attached to the tree. Below figure 9 is recommended design sketches having the solar panels.

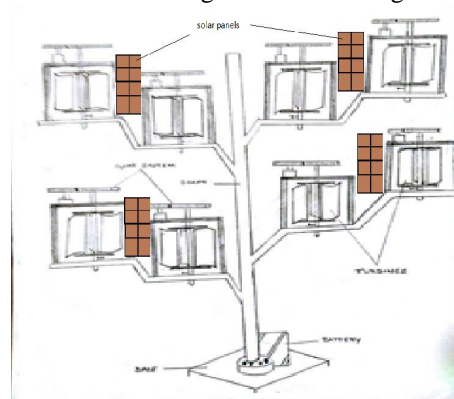


Figure 9 Wind tree with solar panels to power street lights

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