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# Designing, Fabrication, Testing and Performance Evaluation of a Straight Bladed Darrius Type Vertical Axis Wind Turbine

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***Abstract*****—**Designing, fabrication, testing and evaluation of vertical axis straight bladed Darrius type wind turbine are done. Calculations are carried out for a specified load, then Darrius type wind turbine, having the capacity to drive that load is designed. The airfoils of turbine are symmetrical with good lift to drag ratio. Initially turbine with fixed blade is designed, fabricated and its performance evaluated in lab with real wind. Efficiency has been calculated by testing the turbine with and without load

***Keywords*****—**Darrius, VAWT, HAWT , design

## I. Introduction

Wind power considered to be giant sustainable power resource is becoming progress progressively more critical in worldwide strength regulations in response to speedy weather adjustments. Therefore, the wind electricity plants are enhancing and developing countries arranging funds for harnessing a huge amount of wind electricity. Wind electricity considered to be the cleanest assets of energy and has been used for electricity for numerous hundreds of years. Wind is really a derivative of sun power. According to researchers, approximately 1% of solar's power obtained at earth floor is changed to wind electricity [1].Stress zones are created in atmosphere through choppy heating and cooling of the surface of earth. This glides air from excessive stress zones to zones of low stress. Air get high kinetic energy which may be converted to mechanical or electrical energy. Studies reveals that the total wind power that can be harnessed is 61 TW [2]. To obtain this power a massive wide variety of industrial wind turbines had been designed within the global. So, developing market for wind power exists and unique forms of wind turbine generators, have been made inclusive of vertical axis wind turbine (VAWT), horizontal axis wind turbine (HAWT), Darrius kind wind turbine, Savonus type turbine. Each of the turbines have a few upsides and downsides. HAWT are greater costly to supply than VAWT, due to high-priced substances and comparatively complex designs [3]. The next downside is that HAWT are used best in the regions of non-stop wind. One of the main drawbacks is that unequal gravitational force is acting at all airfoils of HAWT. On the opposite hand, benefits related to VAWT are numerous for instance:

- VAWTs can function in regions wherein HAWT **aren't** very useful. This is because the axis of rotation of blades is independent of wind current.
- VAWT does not yaw in direction of wind.
- VAWT has sturdy design and is capable of withstanding extraordinarily wind velocities.
- Price of VAWT is low as compared to HAWT due to straight-blade design.
- They can function even in turbulent wind flow.
- VAWT has easy Maintenance due to the fact they're at very low height from the surface of earth.

On the opposite hand, HAWT has higher efficiencies than VAWT [4]. Therefore, VAWTs are much less common and are not extensively commercially to be had. The efficiency of VAWT can be improved with certain modifications in design. The more particular intention for the paper is designing, constructing and testing a vertical axis wind turbine of Darrius type for a selected electrical load.

## II. APPROACH AND METHODOLOGY

Darrieus type vertical axis wind turbine consisting of three blades is chosen. The turbine includes base, central shaft, generator, circular assisting plates, springs and different add-ons. The airfoils are kept at an angle of one hundred twenty degrees. The airfoils are placed on the edges of assisting plates. The assisting plates are constructed from acrylic sheet and its job is to support the airfoils. The turbine's shaft is made of steel and its function is to rotate assisting plates and airfoils. First of all, wind transfers its energy to the blades which in turn transfer it into assisting plates. Energy from the plates is transferred to the shaft. From the shaft it is transferred into generator via pulley and generator finally change it into useful electrical energy.

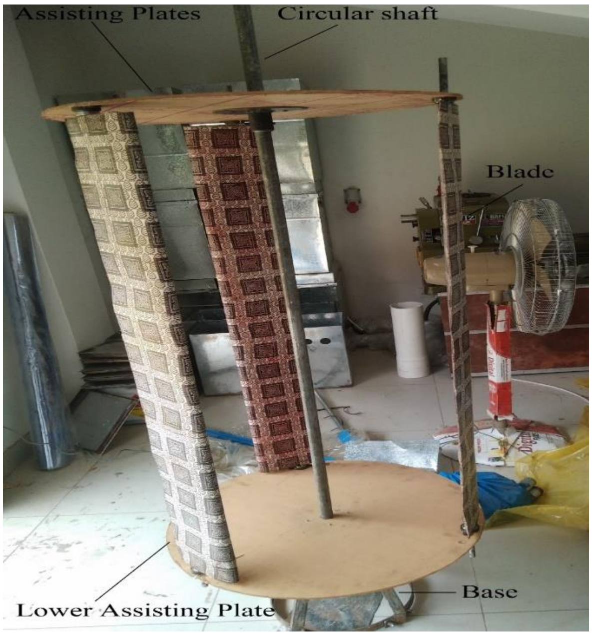


Figure 1. Figure 1 Turbine at rest

Turbine Airfoils

The airfoil selected for the paper is NACA 0018. The geometry of airfoil is symmetrical which provide extra lift to the blade. This geometry is too simple to be fabricated at any simple workshop.

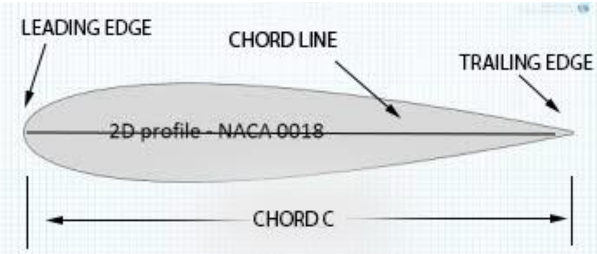


Figure 2. Figure 2 NACA 0018 Airfoil

**Mathematical calculations of Aerodynamic evaluation of the NACA 0018**

Table 1 indicates the performance of the blade on aerodynamics basis for 360°. Table shows that when the wind angle attacking the blade is 0°, simply the pressure existing is drag. Lift force increases with increase in relative angle of attacking wind. Lift is maximum at 45° angle and lowers with further increase in angle. The most lift force on the airfoil at an angle of 90° to the wind [5].

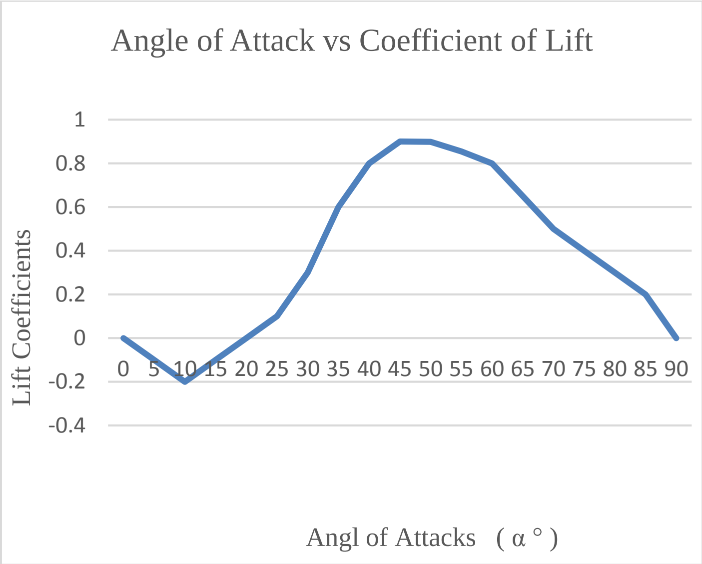


Figure 3. Coefficient of lift vs angle of attack

Phenomena occurring in blades of Darrieus turbines are:

**a) Change in angle of attack**

The pace of the wind at upstream and downstream of wind turbine isn't always identical [6]. So, the angle at which wind attacks the blades varies constantly. Fig. 4 demonstrates complete process. [7]

TABLE I. LIFT AND DRAG COEFFICIENTS OF NACA 0018

| **(α°) Angle of Attack** | **($C_L$) Lift Coefficient** | **($C_D$) Drag coefficient** |
|---|---|---|
| 0 | 0 | .0385 |
| 1 | -.0045 | .0387 |
| 2 | -.0154 | .0391 |
| 3 | -.0233 | .0399 |
| 4 | -.0368 | .0410 |
| 5 | -.0577 | .0425 |
| 6 | -.0839 | .0443 |
| 7 | -.1182 | .0463 |
| 8 | -.1501 | .0489 |
| 9 | -.1584 | .0489 |
| 10 | -.1423 | .0574 |
| 11 | -.1125 | .0800 |
| 12 | -.0767 | .1230 |
| 14 | .0085 | .1580 |
| 16 | .1051 | .1960 |
| 18 | .2070 | .2380 |
| 20 | .3111 | .2820 |
| 22 | .4172 | .3290 |
| 25 | .5775 | .4050 |
| 30 | .8550 | .5700 |
| 35 | .9800 | .7450 |
| 40 | 1.0350 | .920 |
| 45 | 1.0500 | 1.07550 |
| 50 | 1.0200 | 1.2150 |
| 55 | .9550 | 1.3450 |
| 60 | .8750 | 1.4700 |

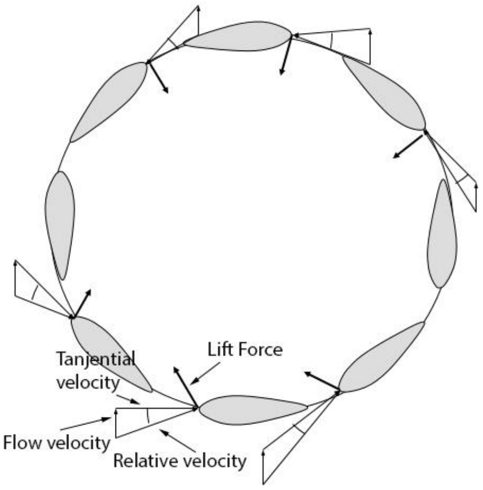


Figure 4. Turbine airfoils during rotation

**Flow velocity: Velocity of wind received by turbine.**

Relative velocity: Vector sum of tangential and flow velocities.

Tangential velocity: Velocity that is tangent to the airfoil.

Figure 5. illustrates that the angle of attacking wind is not uniform but varying thoroughly as it passes through the turbine. Therefore, both the lift and drag forces varies. These forces stronger at one point and weaker at others and are further explained in this figure [8]. The upwind and downwind shown in figure 6.

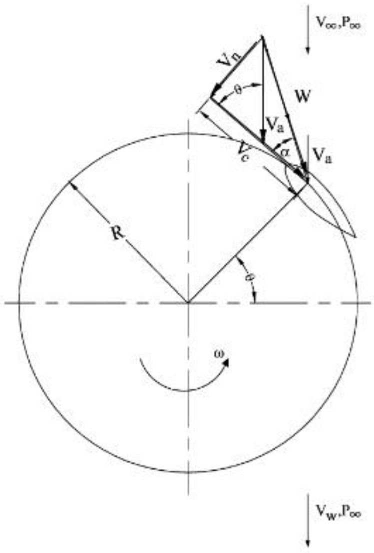


Figure 5. Lift and drag Forces

$\boldsymbol{V}_{\infty}$ Is in axial direction and has two components.

$\boldsymbol{V_c} =$ Chordial component of velocity

$\boldsymbol{V_n} =$ Normal component of velocity

Derivation

Both of the above components can be derived in the following way.

$V_c = v_a cos\theta + r\omega$------------------ **(1)**

$V_n = v_a sin\theta$------------------------- **(2)**

$$v_a = \frac{V_\infty + V_W}{2}$$

$\boldsymbol{V}_{\infty}$= wind speed at turbine inlet

$\boldsymbol{v_a} =$ Wind axial flow velocity inducing through turbine

$\boldsymbol{v_W} =$ **Wind Velocity of wake** = velocity at turbine outlet.

$\boldsymbol{V_W}$ *is equall to* $\boldsymbol{v}_{\infty}$ - $\mathbf{v_a}$

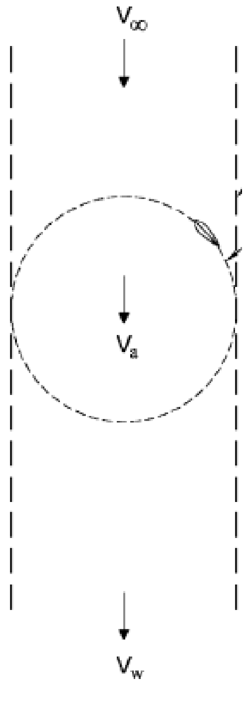


Figure 6. upwind and downwind

$\boldsymbol{\omega} =$ turbine angular velocity

$\boldsymbol{R} =$ **Turbine** radii

$\boldsymbol{\theta} =$ Angle of azimuth

Formula for attacking angle of wind can be calculated as

$$\alpha = \tan^{-1} \left({}^{v_n}/_{v_c}\right) \text{------------------------ } \mathbf{(3)}$$

Putting values

$$\alpha = \tan^{-1} \times \left[ \frac{\sin\theta}{\left(\frac{\frac{R\omega}{v_\infty}}{\frac{v_a}{v_\infty}}\right) + \cos\theta} \right] \text{------------------ } \mathbf{(4)}$$

**Change in Relative Flow Velocities**

As relative velocities of flow are given by [9]

$$W = \sqrt{v_c{}^2 + v_n{}^2} \text{--------------------------- } \mathbf{(5)}$$

Inserting values

$$\frac{w}{v_\infty} = \left({}^{W}/_{v_a}\right) \times \left({}^{v_a}/_{v_\infty}\right) =$$

$$\left({}^{v_a}/_{v_\infty}\right) \sqrt{\left[\left(\frac{\frac{R\omega}{V_\infty}}{\frac{V_a}{V_\infty}} + Cos\theta\right)\right]^2 + Sin^2\theta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(6)}$$

**Change in Tangential and Normal Components of Forces**

Both components of forces i.e. Varies during 360° rotation of the blades. Normal and tangential sections of drag and lift forces on the airfoil are provided in figure 7.

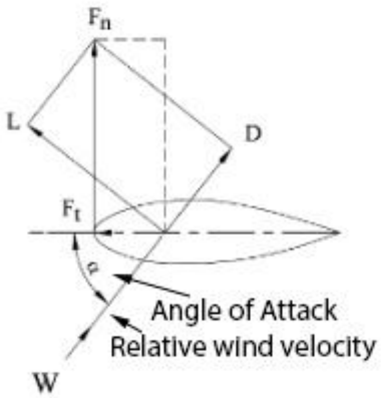


Figure 7. Angle of Attack of wind

$\boldsymbol{C_t}$ Shows the difference of tangential components of lift and drag force.

$\boldsymbol{C_n}$ Shows the difference between components of lift and drag forces that are normal.

**Mathematical Calculations**

$$C_T = C_1 \text{Sin}\alpha - \text{C}_\text{D} Cos\alpha \text{------------------------ } \mathbf{(7)}$$

$$C_n = C_1 \text{Cos}\alpha - \text{C}_\text{D} Sin\alpha \text{--------------------- } \mathbf{(8)}$$

$\mathbf{F_t}$ Show **the** sum of tangential forces and is equal to

$$F_t = C_t \times \frac{1}{2} \rho \times \text{C} \times \text{H} \times \text{W}^2 \ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(9)}$$

$\boldsymbol{F_n}$ Shows net normal forces.

$$F_n = C_n \times \frac{1}{2} \times \rho \times \text{C} \times \text{H} \times \text{W}^2 \text{------------- } \mathbf{(10)}$$

**ρ** is density of air

**C** is chord′s lenght of airfoil

**H** is turbine′s height

**W** shows relative flow velocities

**Mathematical calculations**

Design calculations for a single blade are given below in figure. 8 (a) and 9 (b).


Figure 8. A single blade (a)

For calculating $V_c$ we fine RPS
As

Rev/mint $= 166$
Hence
Rev/second $= {}^{166}/_{60}$
Rev/mint $= 2.8$
Turbine Diameter $= 0.60$ m
Circumference of turbine $= \pi$ D

Circumference of turbine = $3.140 \times 0.60$ m = S
Circumference of turbine = 1.93 m
Speed of turbine = $2.80 \times 1.90$ m/s
Speed of turbine = $V_c = 5.320$ m/s
$V_c = chordial\ component = 5.32$ m/s
$v_n = normal\ component = 4\ m/s$
Tip Speed Ratio = $5.32/4$
Tip Speed Ratio = 1.4


Figure 9. A single blade (b)

As

$$tan\alpha = \frac{Perpindicular}{Base}$$

Putting value

$$\alpha = \tan^{-1}\left(\frac{4}{5.32}\right)$$

$\boldsymbol{\alpha} = 36.94°$

It is the angle of attacking wind to the blade.

### Design of the Project

Calculations for 50 watts of a turbine and wind of 7 m/s speed were done by using the formula

$$power = \frac{1}{2} C_P\ \rho A v^3 \ldots\ldots\ldots\ldots\ldots\ldots \text{(A)}$$

$$C_P = .300$$

Air density at temperature 30°C = 1.22 $kg/m^3$

$V = velocity\ of\ wind = 7\ m/s$

The following dimensions were calculated after putting all of the values in the power formula.

## III. RESULTS

Wind turbine of these dimensions was fabricated and was tested in the wind of $4\ m/s$ speed in the laboratory. The following results were obtained.

### Results for Unloaded Turbine

Initially results of turbine for no load were obtained in Table II and results for loaded turbine in Table III.

TABLE II. RESULTS FOR UNLOAD TURBINE

| Rev/mint | Open Circuit Voltage(volts) |
|---|---|
| 164 | 185 |
| 168 | 187 |
| 171 | 191 |
| 172 | 192 |
| 169 | 186 |
| 161 | 181 |
| **REV/MINT** (Average) unloaded = **167** | **VOLT**(Average) unloaded = **187** |

### Results for loaded turbine

TABLE III. RESULTS FOR LOADED TURBINE

| Height of Turbine (meter) | Diameter of Turbine (meter) | Chord's length of Blades (meter) | Area of Turbine ($meter^2$) |
|---|---|---|---|
| 1.250 | .620 | .1240 | .76880 |

A light bulb of power 5 watts was connected to the turbine. Current, voltage and RPM were measured.

Now calculating power

As we know that

$Power = Voltage \times Current$

$P = V \times I$

$P = 90 \times .0226$

$P = 2.34\ Watts$

The below table IV as shown below.

TABLE IV.

| REV/MINT | Closed Circuit Generator Voltage (volt) | Current (Amp) |
|---|---|---|
| 121 | 89 | .025 |
| 122 | 92 | .026 |
| 122 | 92 | .028 |
| 125 | 94 | .03 |
| 131 | 95 | .035 |
| 123 | 93 | .03 |
| 121 | 89 | .029 |
| 120 | 89 | .029 |
| 119 | 88 | .028 |
| **Rev/Mint** (Average) Loaded = **122** | **VOLT**(Average) Loaded = **91** | **CURRENT**(Average) = **0.026** |

### Efficiency of the Turbine

As turbine was designed for a power of 5 watts and it is generating 2.34 watts so its efficiency is

$$\text{Efficiency} = \frac{2.34}{5} \times 100$$

$$\text{Efficiency} = 46.8$$

The figures 10 and 11are shown the tubine base and Led light energized by turbine respectively.


Figure 10. Turbine Base

Figure 11. Led light energized by turbine

## CONCLUSION

Non-directional nature, high lift and easy maintenance enable vertical axis Darrius type vertical axis wind turbine to be used in area of high wind speed for power production. VAWT, Due to simple mathematical and aerodynamics calculations and easier manufacturing processes can be easily made at any local workshop.

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