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Vertical Axis Wind Turbine

Pranit Nagare
Mechanical Engineering
Don Bosco Institute of Technology
Kurla, India
nagare.pranit@gmail.com

Arnav Nair
Mechanical Engineering
Don Bosco Institute of Technology
Kurla, India
arnav.r.nair@gmail.com

Rammohan Shettigar
Mechanical Engineering
Don Bosco Institute of Technology
Kurla, India
shettigarrammohan@yahoo.in

Pratibha Kale
Mechanical Engineering
Don Bosco Institute of Technology
Kurla, India
pratibhakale13@yahoo.com

Dr. Prasanna Nambiar
Mechanical Engineering
Don Bosco Institute of Technology
Kurla, India
prasannanambiar@hotmail.com

***Abstract*—Increasing demand for energy in recent years has seen a rise in development of alternative energy sources. Wind being one of the most abundant and easily available sources is an excellent alternative to conventional energy sources.**

Vertical Axis Wind Turbines (VAWT's) are of two type's viz. Darrieus (lift based) and Savonius (drag based). The problem associated with Darrieus is the lack of self-starting while the Savonius has a low efficiency. In order to overcome these flaws, an innovative design has been created by incorporating both the types into one single unique structure not tested before.

In this design, the Darrieus blades are helically twisted to get even torque distribution. The Savonius blades are of half drum type and at the center of the assembly. This unique design allows the use Savonius as a method of self-starting the wind turbine which the Darrieus cannot achieve on its own. There are 3 Darrieus blades placed circumferentially and 2 Savonius couples attached perpendicular to each other along the shaft. The cross-section of the Darrieus blades is of NACA- 4415.

The objective is to eliminate the need for external motors for self-starting purposes and study the performance of the model. The testing of the model was carried out for different wind velocities. Initially the Darrieus and Savonius blades were tested independently and then the new model which combines the two designs was tested.

Keywords*— *Wind Turbine, Vertical Axis Wind Turbine, Darrieus, Savonius, VAWT, Helical Blades

I. Introduction

Existing wind turbine designs are divided in 2 parts: Horizontal Axis Wind Turbine (HAWT) & Vertical Axis Wind Turbine (VAWT).

HAWT's the height at which their mechanisms are located is disadvantageous for servicing. They require a mechanical yaw system to orient them. As potential power generation is related to the swept area of the rotor, more power requires a larger diameter. The blades experience large thrust and torque forces, so size is limited by blade strength.

A VAWT does not need to be oriented into the wind and the power transition mechanisms can be mounted at ground level for easy access. The perceived disadvantage of the VAWT is that they are not self-starting. Currently, VAWT are usually rotated automatically until they reach the ratio between blade speed and undisturbed wind speed (Tip Speed Ratio or TSR) that produces a torque large enough to do useful work.

II. Background Study

A. Turbine size as a function of power required

The power of the wind (P_w) is proportional to air density (ρ), area of the segment (A) of wind being considered, and the natural wind speed (u). At standard temperature and pressure (STP = 273K and 101.3 KPa),

$$P_w = 0.647Au^3 \quad (1)$$

A turbine cannot extract 100% of the winds energy because some of the winds energy is used in pressure changes occurring across the turbine blades. The mechanical power (P_m) that can be obtained from the wind with an ideal turbine is given as:

$$P_m = ½ \rho (16/27\ Au^3) \quad (2)$$

The constant 16/27 from equation (2) is referred to as the Betz coefficient. Equation (2) can be re-written as

$$P_m = C_p P_w \quad (3)$$

The coefficient of performance(C_p) depends on wind speed, rotational speed of the turbine and blade parameters such as pitch angle and angle of attack. [5]

B. Wind Speed, Tip Speed Ratio and Solidity

The first step in wind turbine design is to select an operating tip speed ratio (λ) which can be expressed by

$$\lambda = \omega r/V_\infty \quad (4)$$

Which is the ratio of the rotational velocity of the wind turbine ωr and the freestream velocity component (wind speed V_∞) [8].

Once λ has been chosen, the geometry of the VAWT can be defined through a dimensionless parameter known as the solidity (σ).

$$\sigma = Nc/d \quad (5)$$

which is a function of the number of blades N, the chord length of the blades (c), and the diameter of the rotor (d) [6].

III. PROBLEM STATEMENT AND PROPOSED SOLUTION

A. Problems Identified

On studying the literature the problems found with VAWT's were as follows:

- The Darrieus design had the problem of not self-starting due to lack of lift generated at low speeds and uneven torque distribution while rotating
- The Savonius while self-starting has very low efficiency

The uneven torque distribution of Darrieus has been addressed in a design known as Quiet Revolution turbine which is based on Dr. Gorlov's Helical Turbine.

B. Proposed Solution

For solving the uneven torque distribution, the blades of Darrieus will be made in a helical twist. The Savonius assembly will be incorporated in the middle which will provide the starting torque for the assembly which should solve the problem of self-starting. The solution will be tested by making a scaled down model which will be tested for different wind velocities.

C. Steps to be taken

- Designing the blades
- Analysis of blades
- Prototype manufacturing
- Testing

IV. ANALYSIS AND DESIGN

A. Design Details

1) Darrieus Blades Calculations:

Based on the calculations of Gorlov [1], the following dimensions were chosen C = Chord Length of aerofoil cross-section= 30 mm, Taking L/R ratio as 3, Radius (R) = 100 mm, Height (L) = 300 mm, S = Solidity = $(n*C)/D_1$ = 0.45, δ = 56.80, ϕ = 750, TSR= 4. The calculations are as follows:

TABLE I: DARRIEUS CALCULATIONS AT 4 TSR

v(m/s)	Torque(N/m)	omega	N rpm	Power
1	0.000516266	40	381.9718634	0.020650632
2	0.002065063	80	763.9437268	0.165205058
3	0.004646392	120	1145.91559	0.557567072
4	0.008260253	160	1527.887454	1.321640468
5	0.012906645	200	1909.859317	2.581329039
6	0.018585569	240	2291.831181	4.460536579
7	0.025297025	280	2673.803044	7.083166883
8	0.033041012	320	3055.774907	10.57312374
9	0.04181753	360	3437.746771	15.05431096
10	0.051626581	400	3819.718634	20.65063231
11	0.062468163	440	4201.690498	27.48599161
12	0.074342276	480	4583.662361	35.68429264

Fig. 1. Shows the variation of theoretical power produced with variation in velocity. The cut in speed which is the minimum velocity at which power is produced is approximately 2.5 m/s.

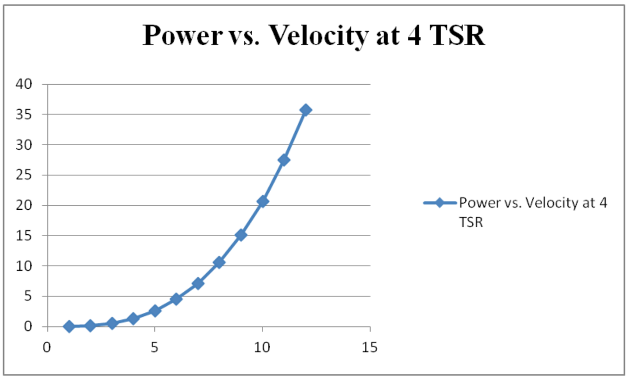

Fig. 1. Power vs. Velocity at 4 TSR

2) Savonius Calculation*:*

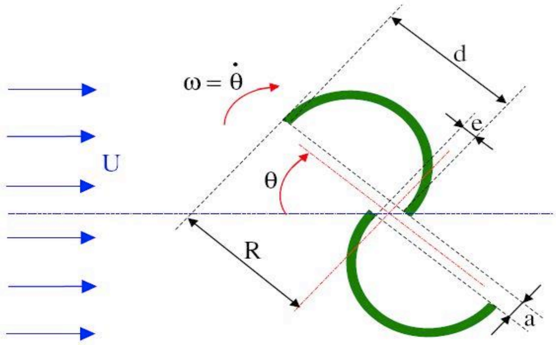

Fig. 2. Scheme of Savonius rotor [3]

Darrieus blade need about 5 mph of wind speed so that enough torque is generated to spin the turbine [2]. In order to make our hybrid design work at any wind speed, we need to design Savonius blades which would provide that amount of torque. Selecting steel can as material, following were the dimension obtained [3]:

D= 100 mm
R_0= 50 mm

Using Empirical Relations:
2d-e=D and m = e = (d/6), we get
e = a = 54.5454 mm
d = 327.2724 mm
H = 200 mm

$P_{max}= C_p\ \rho\ R_0 H(V_w\text{^}3)$
where, C_p= power coefficient =0.3
ρ = density of air = 1.225
we get,
P_{max} = 0.459375 W

Generally, assuming Tip speed ratio = 1

$\lambda = (\omega R_0)/V_W$
Torque = $P_{max}/\omega = 4.59375 * 10^{-3}$ N-m

3) Shaft Selection*:* Considering buckling and standard size available for material MS C-40; let d = 80 mm

4) Bearing Selection*:* Bearing chosen was roller bearing with no. Z809 which was based on the shaft diameter. The bearing has 8 mm internal diameter and 22 mm external diameter.

5) Motor Selection*:* Motor chosen was Direct Current Permanent Magnet motor with voltage rating 12 V and RPM rating 6500 to match with the highest maximum theoretically calculated RPM of the turbine.

B. Analysis

In order to select an appropriate profile for Darrieus blades, an initial study was done to determine the standard profiles usually used for wind turbines. These profiles were then analyzed in a MATLAB code [4]. The profile selected was NACA- 4415.

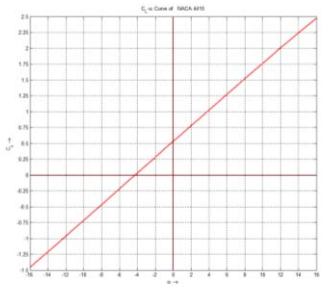

Fig. 3. C_L-α graph for NACA – 4415 [4]

Once decided, this profile was then tested on ANSYS FLUENT 14.5 to verify if the results achieved through the code were valid or not. Even with the following crude mesh the results were close enough to provide validation.

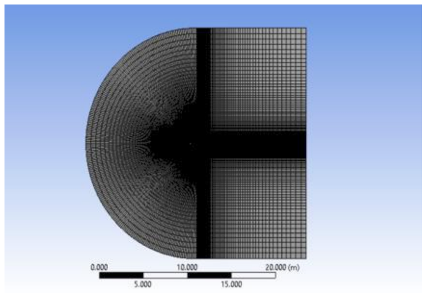

Fig. 4. Meshed Model of NACA – 4415

The profile was tested at different angles of attack to check the CL- α characteristics.

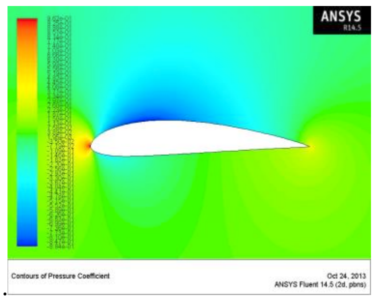

Fig. 5. Pressure Coefficient at α = 0

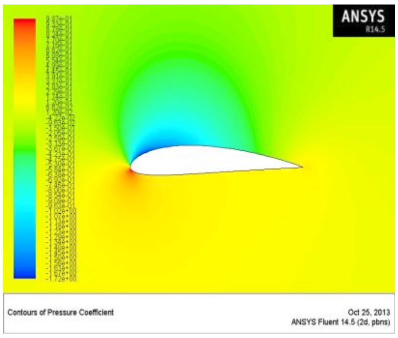

Fig. 6. Pressure Coefficient at α = 6

The obtained characteristics were found to be matching with the suggested characteristics. Thus once validated the NACA-4415 profile was finalized for the Darrieus blades.

V. TESTING

A. Objectives of testing

To test the power output, efficiency and tip speed ratio at different wind velocities, the wind turbine was subjected to wind from a wind tunnel in order to study the performance of the design.

B. Phases of testing

To study the performance of the model it is necessary that the performance of the Darrieus and Savonius blades should be known independently. To accomplish this, the testing is done in 3 phases. The Savonius is tested first, then the Darrieus and then the combined assembly.

C. Instruments used for testing

Wind Tunnel was used to analyze the performance of wind turbine at different velocities. Anemometer was used to measure the wind velocity. The power output was measured using resistors, multi-meter. Digital tachometer was used to measure the rotational speed of the rotor.

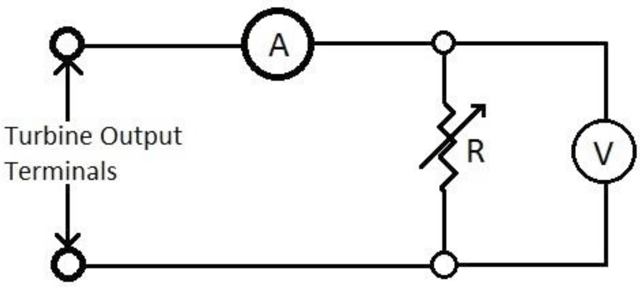

Fig. 7. Electric Circuit for measuring power output

Fig. 8. Experimental Setup

VI. RESULT

A. Savonius Blades Testing

The Savonius blades are tested independently. The results are as follows.

TABLE II. RESULTS FOR SAVONIUS BLADES

Sr. No.	R (ohm)	V (m/s)	N (RPM)	Voltage (V)	Current (A)	Power (W)	Torque (N-m)	Available Energy (W)	Efficiency (%)	TSR
1	5	7.9	240	0.15	0.03	0.0045	0.00017897	6.03972775	0.07450667	0.1591392
2	10	7.9	250	0.21	0.021	0.00441	0.00016837	6.03972775	0.073016536	0.16577
3	50	7.9	270	0.43	0.0086	0.0037	0.00013073	6.03972775	0.061227925	0.1790316
4	5	9.3	420	0.22	0.044	0.00968	0.00021999	9.85337325	0.098240468	0.2365699
5	10	9.3	405	0.34	0.034	0.01156	0.00027245	9.85337325	0.117320228	0.228121
6	50	9.3	390	0.6	0.012	0.0072	0.00017622	9.85337325	0.073071423	0.219672
7	5	10.5	980	0.5	0.1	0.05	0.00048699	14.1809063	0.352586775	0.4889111
8	10	10.5	1030	0.87	0.087	0.07569	0.00070142	14.1809063	0.53374586	0.5138556
9	50	10.5	1050	1.6	0.032	0.0512	0.00046543	14.1809063	0.361048858	0.5238333
10	5	12.688	875	0.46	0.092	0.04232	0.00046165	25.02163	0.169133665	0.3612501
11	10	12.688	1070	0.87	0.087	0.07569	0.0006752	25.02163	0.302498278	0.4417573
12	50	12.688	902	1.4	0.028	0.0392	0.00041482	25.02163	0.156664454	0.3723973
13	5	14.868	1350	0.58	0.116	0.06728	0.0004757	40.2618518	0.167106074	0.4756356
14	10	14.868	1350	0.9	0.09	0.081	0.0005727	40.2618518	0.201182997	0.4756356
15	50	14.868	1350	2.1	0.042	0.0882	0.00062361	40.2618518	0.21906593	0.4756356

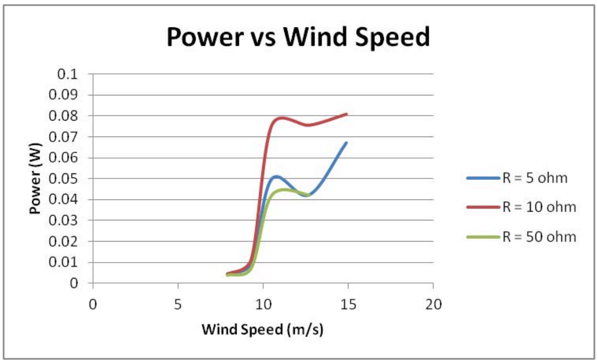

Fig. 9. Power vs. Wind Speed for Savonius Blades

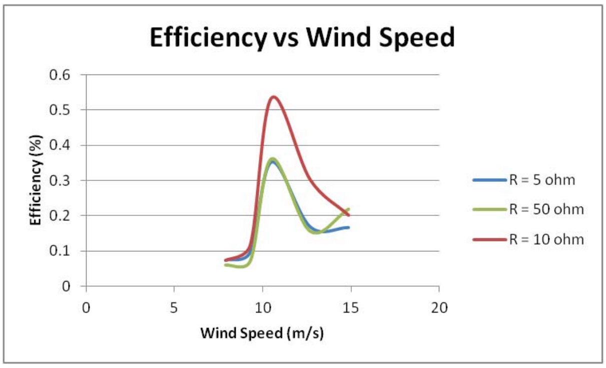

Fig. 10. Efficiency vs. Wind Speed for Savonius Blades

Maximum power output was found out to be 0.081 W for 10 ohm resistor at wind speed 14.868 m/s.

The Maximum efficiency was found out to be 0.53374586 % for 10 ohm resistor at wind speed 10.5 m/s.

B. Darrieus Blades Testing

While testing only Darrieus blades, the rotational speed of the turbine was too low to test the turbine for different wind speeds. Hence there are no results available for the Darrieus Blades.

C. Combined Assembly Testing

For the combined assembly, for various wind speeds, the results are as follows.

TABLE III. RESULTS FOR COMBINED ASSEMBLY

Sr. No.	F (Hz)	R (ohm)	V (m/s)	N (RPM)	Voltage (V)	Current (A)	Power (W)	Torque (N-m)	Available Energy (W)	Efficiency (%)	TSR
1	30	5	9.3	208	0.11	0.022	0.00242	0.000111053	29.56012	0.008186706	0.2343168
2	30	10	9.3	208	0.13	0.013	0.00169	7.75533E-05	29.56012	0.005717162	0.2343168
3	30	50	9.3	208	0.33	0.0066	0.002178	9.99474E-05	29.56012	0.007368035	0.2343168
4	35	5	10.5	700	0.13	0.026	0.00338	4.60888E-05	42.542719	0.007944955	0.6984444
5	35	10	10.5	700	0.2	0.02	0.004	5.4543E-05	42.542719	0.009402314	0.6984444
6	35	50	10.5	700	0.3	0.006	0.0018	2.45443E-05	42.542719	0.004231041	0.6984444
7	40	5	12.69	921	0.169	0.0338	0.005712	5.91999E-05	75.06489	0.007609683	0.7604831
8	40	10	12.69	912	0.265	0.0265	0.007023	7.34977E-05	75.06489	0.009355239	0.7530517
9	40	50	12.69	972	0.5	0.01	0.005	4.90999E-05	75.06489	0.006660904	0.8025946
10	45	5	14.87	1214	0.207	0.0414	0.00857	6.73797E-05	120.78556	0.007095054	0.8554394
11	45	10	14.87	1214	0.34	0.034	0.01156	9.089E-05	120.78556	0.009570681	0.8554394
12	45	50	14.87	1214	0.62	0.0124	0.007688	6.04466E-05	120.78556	0.006365	0.8554394

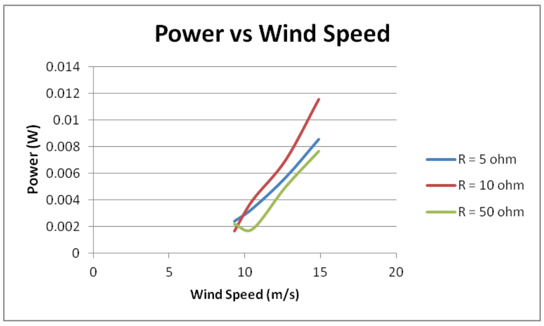

Fig. 11. Power vs. Wind Speed for Combined Assembly

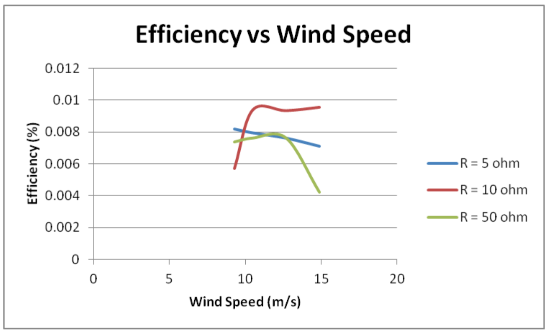

Fig. 12. Efficiency vs. Wind Speed for Combined Assembly

Maximum power output was found out to be 0.01156 W for 10 ohm resistor at wind speed 14.868 m/s.

The Maximum efficiency was found out to be 0.009570681% for 10 ohm resistor at wind speed 14.868 m/s.

VII. Conclusion

From the results obtained, we can conclude that the Darrieus blades were not performing as anticipated and in fact, it was causing a resistance when used in a combined assembly. The probable cause for this may be that the design of the blades was improper and may depend upon many other factors which we failed to take into consideration because of lack of literature.

The Savonius blades were rotating at the desired speed but were less efficient than we expected. This may be because of the higher RPM rating of the motor, thus producing lower voltage. Also there might be some losses related to the scaling down of a design similar to the scale factor of the hydro-turbines.

From the testing of the turbine, it was evident that the combined assembly, including both the types of the blades, was self-starting, completing one of our objectives successfully.

From the results obtained, it can be seen that the power output of the combined assembly is increasing with the wind speed and may yield more power at higher wind speeds. Unfortunately, that trend couldn't be found out because the highest possible wind speed that could be obtained by the wind tunnel was reached. However, the efficiencies appear to be decreasing, but for 10 ohm resistance, it is seen to be increasing again. However, due to flaw in our Darrieus blade design, the result may not be conclusive.

In case of Savonius blades, it is very evident that the efficiency reaches its peak value at wind speed 10.5 m/s and then starts decreasing. Also after the wind speed of 12.866 m/s, it again starts to increase. The trend of the efficiency curve after the 15 m/s needs to be found out using a wind tunnel having higher capacity.

Even the power output of the Savonius blades show similar behaviour as that of the efficiency. It increases up to 10.5 m/s and then starts decreasing up to 12.866 m/s and then again starts increasing.

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