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Experimental And Numerical Evaluation of Modified Micro – DVAWT Manufactured by Using Fusion Decomposition Modelling

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ABSTRACT

Due to the depreciation of fossil fuels and rising global warming the prices of derivated products from fossils are increasing which resulted in instabilities in the energy market. As a result, there is an increased research taking place in the area of renewable energies especially in the field of wind energy which is abundantly available on Earth. The horizontal axis wind turbines which are also known as lift based wind turbines are used extensively for the electricity generation from wind. This HAWT are not preferable where land availability is low and wind speed is high. Small scaled vertical axis wind turbines (VAWT) shows the best potential for power generation at low wind speeds at various topological conditions. In this work, a novel configuration of micro- DVAWT prototype is developed by using NREL profile for energy conversions on small scale at low wind speed. The wind tunnel investigations have been made on the micro – DVAWT scaled model which is manufactured using Additive Manufacturing (AM) technique such as Fused Decomposition Modelling (FDM). The design of micro- DVAWT is carried out in Solidwork. The FDM of scaled DVAWT is done by using polylacticacid(PLA) as filler material on a 3D printer. The experimentation is carried out in a wind tunnel and the performance of the prototype is analyzed using numerical methods.

KEYWORDS : AM, FDM, 3D printer, NREL, DVAWT, Renewable energy, PLA

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I. INTRODUCTION

In recentdecades, globally many policies are being made by many countries to decrease the usage of exhaustible energy resources like fossil fuels which resulted in an increase in demand for non – exhaustible energy technologies. As a result, the researchers are showing a great interest in these technologies and are being encouraged to researchfurther by investing billions of dollars for research on renewable energy technologies by many countries and organizations. Even though horizontal axis wind turbines (HAWT) keep on being the most prominent for huge scale power production, their partners, vertical axis wind turbines (VAWT), particularly Darrieus turbines, have gotten much consideration in recent decades for independent applications.

The simplicity of maintenance, blade manufacture simplicity, and lower working noises are only a portion of the benefits of VAWTs over regular propeller-type turbines. Furthermore, their operation is free of wind direction and they show higher efficiency in turbulent flow fields, making them fascinating.In spite of the expressed points of VAWT advantages, a few scientists have asserted that Darrieus-type turbines with fixed rotor geometry and straight blades parallel to the axis of rotation are not fit for self- starting.

Various rotor geometrieshave proposed by researchers to resolve the self-starting issue.Also various types of passive pitching and active pitching blade mechanisms, usage of various airfoils in the design of blades, usage of various metals and non - metals in their manufacturing, etc., also been covered by researchers in their work. Because of these issues, examinations concerning the performance of VAWTs can be disputable. Major difficulties are additionally unavoidable in studies related to their starting behavior.

In this work, a novel configuration of micro- DVAWT prototype is developed by using NREL profile for energy conversions on small scale at low wind speed. The wind tunnel investigations have been made on the micro – DVAWT scaled model which is manufactured using Additive Manufacturing (AM) technique such as Fused Decomposition Modelling (FDM). The design of micro- DVAWT is carried out in Solidworks. The FDM of scaled DVAWT is done by using poly-lactic acid (PLA) as filler material on a 3D printer. The experimentation is carried out in a wind tunnel and the performance of the prototype is analyzed using numerical methods. The obtained results are scaled to the four different scales by using Froude scaling laws and the Annual Energy Output (AEO) is calculated and stated.

II. PERFORMANCE EQUATIONS

The performance parameters and equations are used for the evaluation of the performance of the wind turbine. The performance equations used are the Tip Speed Ratio (TSR), the coefficient of performance (c_p), and annual energy output (AEO), The equations are as follows:

TSR = $\frac{\omega R}{V}$ ..…………………………. (1)

$c_p = \frac{P}{0 \cdot 5 \rho A V^3}$ ………………………… (2)

P = $c_p 0 \cdot 5 \rho A V^3$

AEO = 0.01328 $D^2 V^3$………………………… (3)

Where

ω = $\frac{2\pi N}{60}$,

N = rotations per minute

R = Rotor radius of wind turbine

D = Rotor diameter of wind turbine

V = mean wind speed

A = rotor swept the area

P = Rotor power

ρ = Density of air

A = D X H

H = Blade Span

The value of c_p is taken as 0.59 in this work since from Betz limit the maximum c_p = 0.59 and for many wind turbine c_p is typically 0.36.

III. GEOMETRIC MODELLING AND FDM OF TURBINE

A. Geometric Modelling:

The modeling of the micro – DVAWT is done by using Solidworks Part Design. NREL 817 airfoil is taken in the design of the micro- DVAWT. Figure 3 shows the isometric view of the micro – DVAWT modeled in Solidworks and figure 2 shows the dimensions of the blade alignment and figure 1 shows the dimensions of the modeled micro - DVAWT.

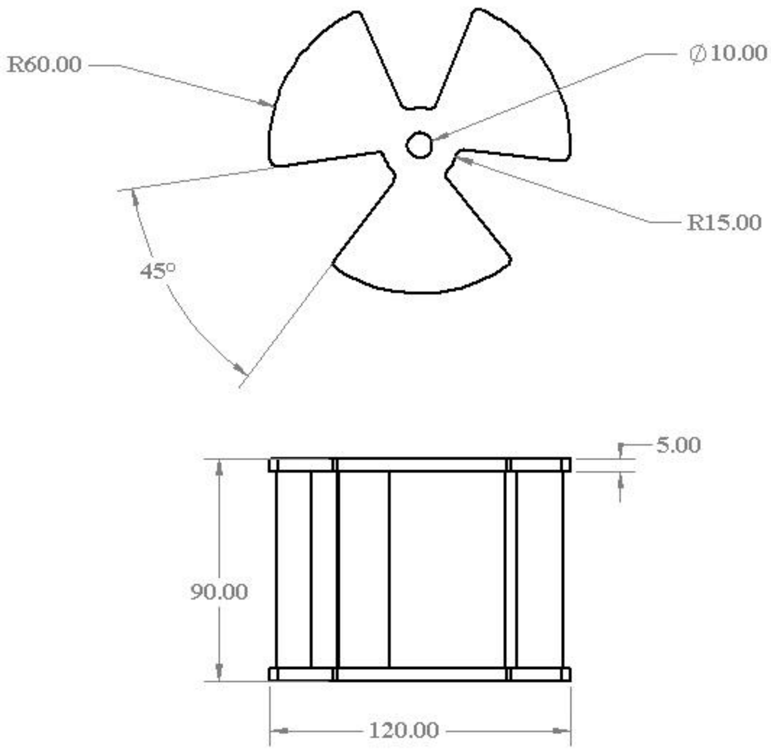


Fig. 1: Micro-Darrious vertical axis wind turbine dimensions

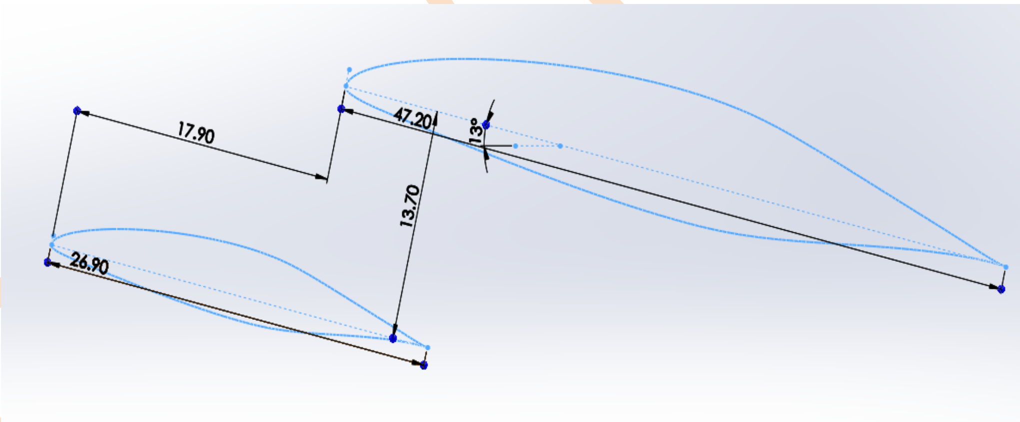


Fig. 2: Micro-Darrious vertical axis wind turbine blades alignment

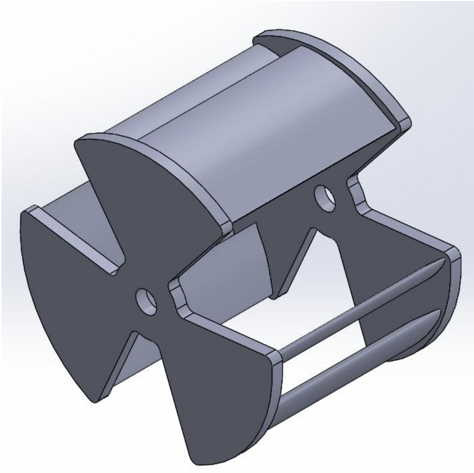


Fig. 3: Micro-Darrious vertical axis wind turbine isometric view

The modeled turbine is 3D printed using fused decomposition modeling (FDM) technique. Figure 4 shows the 3D printed scaled micro - DVAWT.

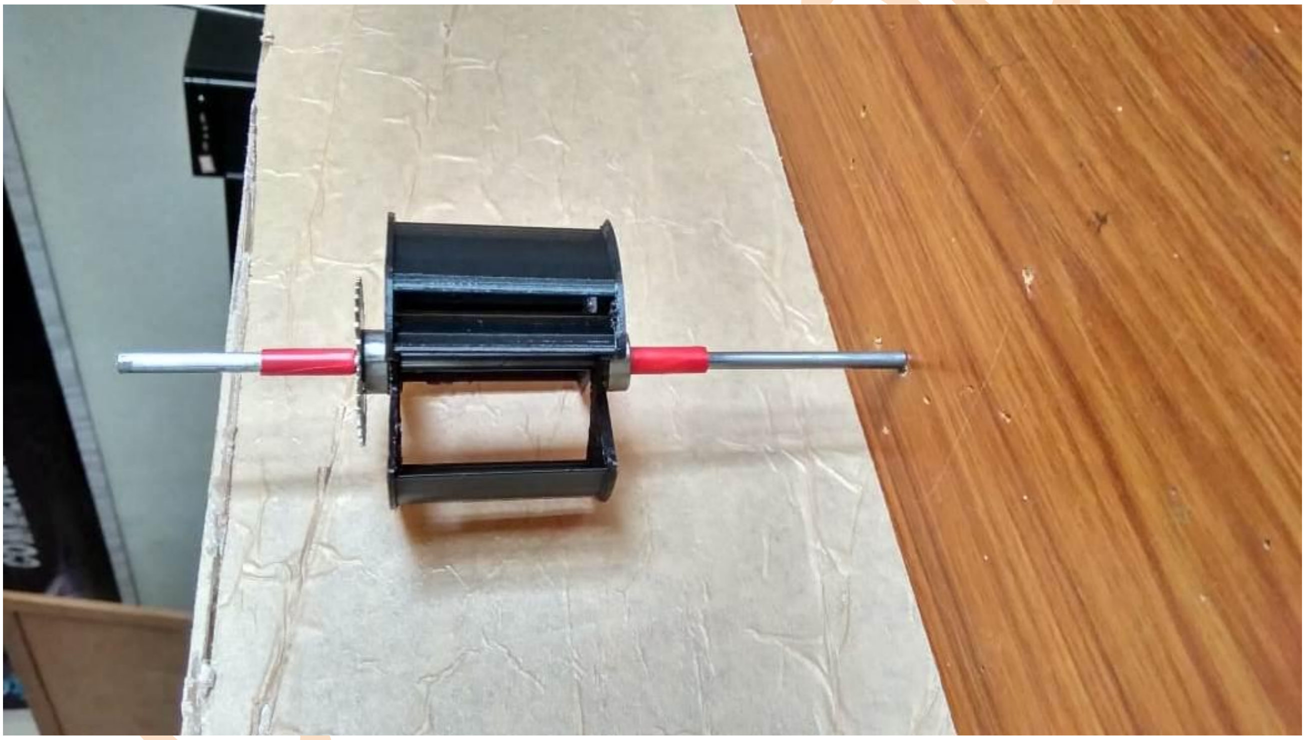


Fig. 4: Micro-Darrious vertical axis wind turbine Scaled model

The wind tunnel setup is created to take wind velocities from scaled micro – DVAWT. Fig.5 showing the wind tunnel setup.

Fig. 5: Testing of Micro-Darrious vertical axis wind turbin

IV. EXPERIMENTATION AND NUMERICAL EVALUATION

A. Experimentation of Scaled Model:

The scaled micro – DVAWT model is analyzed in an open circuit wind tunnel. Rotary encoders are arranged to the rotor shaft to measure the rotational speed of the turbine. Inlet wind velocity in the wind turbine is taken as a boundary parameter to measure the rotation of the wind turbine.The wind velocity is measured by using wane type anemometer. The rotational speed of the wind turbine is noted for five different wind velocities. The readings taken are represented in Table 1.

Table 1

Wind Velocity(m/s)	RPM
1.4	148
3.5	333.4
4.9	650
6	1452
6.5	1621
7.5	2461

The model is tested at ambient conditions of 28° C, 1 atmospheric pressure and relative humidity of 55%. The winding temperature from blower varied from 29.9° C to 31.2° C during experimentation.

B. Numerical Analysis of micro – *DVAWT scaled model:* The numerical analysis is done on the scaled micro – DVAWT to the values for the performance parameters by using the equations from (1) to (3). In the calculation the c_p value is taken as 0.59 which is maximum theoretical value from Betz law. The results obtained are tabulated in Table 2 and Table 3.

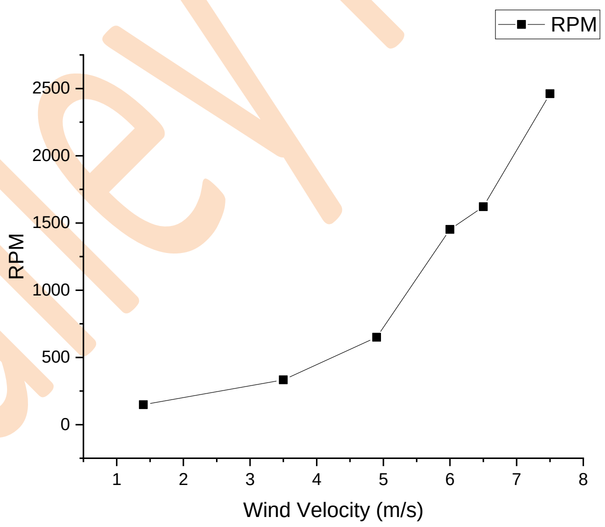
Table 2

Wind Velocity(m/s)	RPM
1.4	148
3.5	333.4
4.9	650
6	1452
6.5	1621
7.5	2461

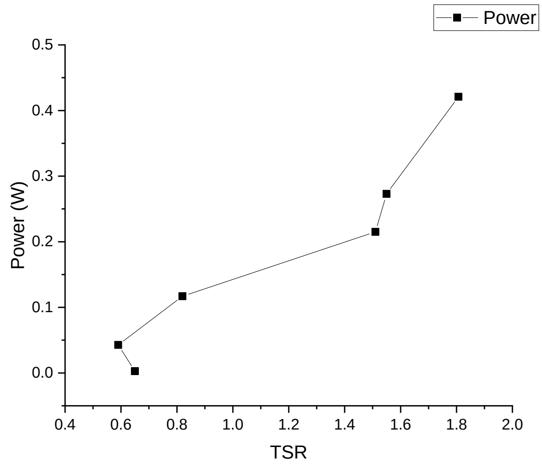
Table 3

TSR	Power(W)
0.65	0.0027
0.59	0.0428
0.82	0.117
1.51	0.215
1.55	0.273
1.807	0.421

Plots are plotted by taking wind velocity on X-axis and rpm on Y-axis and Power on Y-axis and TSR on X-axis. The plots are shown in Graph 1 and Graph 2. Graph 1 shows the variation of rpm with respect to wind velocity and graph 2 shows the variation of Power with respect to TSR.



Graph 1: RPM vs Wind Velocity



Graph 2: Power vs TSR

V. SIMILITUDE ANALYSIS

A. Similitude Analysis:

Thesimilitude analysis is done by using Froude scaling laws for different scaling factors considering the results of the current study. The scaling factor taken are shown in Table 4 based on the nomenclature of turbines.

Scaling factor = λ

Table 4

Nomenclature	**Scaling Factor (λ)**
Micro-scale wind turbine (µSWT)	1
Small-scale wind turbine (SSWT)	10
Mid-scale wind turbine (MSWT)	50
Large-scale wind turbine (LSWT)	100

λ = 1 represents the model studied in this work. Table 5 represents the Froude power scaling factors and Table 6 represents the rated power the prototype.

Froude Scaling factor for Rated Power = $\lambda^{3.5}$

The rated power is calculated at TSR = 0.65 where P = 0.0027 W and TSR = 1.807 where P = 0.421 W.

Table 5

Scaling Factor (λ)	Froude Power Scaling($\lambda^{3.5}$)
1	1
10	3,162.27
50	883,883.47
100	10^7

Table 6

Scaling Factor (λ)	Prototype Power(at TSR = 0.65, P = 0.0027 W)	Prototype Power(at TSR = 1.807, P = 0.421 W)
1	0.0027 W	0.421 W
10	8.538 W	1,331.31 W
50	2,386.48 W	372,114.94 W
100	27,000 W	4,210,000 W

B. AEO analysis for different blade span:

The Annual Energy Output Analysis (AEO) is carried out using Froude scaling laws for different scaling factors considering the results of the current study. Table 7 represents the Froude scaling rotor factors for AEO analysis and Table 8 represents the Froude scaling wind velocity factorsfor the prototype.

Froude Scaling factor for rotor diameter = λ

Froude Scaling factor for wind velocity = $\lambda^{0.5}$

Table 7

Rotor Diameter (m)	Scaling Factor (λ)	Froude Rotor Scaling (λ)
0.06	1	0.06
0.06	10	0.6
0.06	50	3
0.06	100	6

Table 8

Wind Velocity (m/s)	Scaling Factor (λ)	Froude Wind Velocity Scaling($\lambda^{0.5}$)
1.4	1	1.18
3.5	10	5.91
4.9	50	15.6
6	100	24.49

Table 9 represents the Annual Energy Output Analysis (AEO) in kWh/year for the respective rotor scales and are calculated for velocity scales having the values 1.18 m/s and 5.91 m/s since these are the common local wind velocities around the Globe.

Table 9

Froude Rotor Scaling (λ)	AEO (kWh/year) (at V = 1.18 m/s)	AEO (kWh/year) (at V = 5.91 m/s)
0.06	0.00007848	0.00986
0.6	0.007846	0.9868
3	0.1962	24.67
6	0.7848	98.68

Results Interpretation:

The micro- DVAWT wind turbine modeled using Solidworks and printed using FDM techniques shows a quite performance under very less wind velocity of 1. 4 m/s for the scaled model and 1.18 m/s for the prototype. The study is considered to be successful since the turbine scaled model started rotation at 1. 4 m/s wind velocity only. Further, the experimented model sustained wind velocity of 7.5 m/s which shows that it can function in areas with harsh wind conditions.

VI. CONCLUSION

The micro- DVAWT wind turbine modeled using Solidworks isscaled and 3D printed on MakerBot Replicatorusing PLA filling material. The printed scaled model is tested in a wind tunnel at wind velocities 1.4 m/s to 7.5 m/s and at ambient conditions of 28° C temperature, 1-atmosphere pressure and 55% relative humidity. The following are observations made from the experimental studies:

1. The minimum wind velocity at which the scaled model starts rotation is 1.4 m/s. At this velocity, the turbine accelerated from 0 to 148 rotations per minute.
2. The maximum wind velocity up to which the turbine showed a study increase in rotations per minute is 7.5 m/s. At this velocity, the turbine accelerated up to 2461 rotations per minute.
3. After increasing the wind velocity above 7.5 m/s the rotations per minute of the rotor going on increasing without increasing the wind velocity.
4. From points 1 to 3 we can say that the cut – in speed for the prototype is 1.4 m/s and cut – out speed is 7.5 m/s.
5. Now coming to the numerical calculations the conclusions derived are as follows:
6. The optimal power is 27 kW at cut-in speed and 4.21 MW at the cut – out speed for a prototype having a rotor of 6m diameter.
7. Also, the AEO for 6m diameter prototype at 1.18 m/s wind velocity is 0.7848kWh/year which is minimum and 98.68 kWh/year which is maximum.

The objective of the research to reduce the static torque and model a wind turbine which operates at low wind velocity is successful.

FUTURE SCOPE:

The assumption taken in the study is that the wind turbine coefficient of performance is 0.59 which should be calculated manually by load cells is left a task to be performed by the authors for future generations. If the prototype is to be made using this research the material sustainability for the considered prototype should be evaluated by using FEA simulation studies or experimentation which is also left a task to be performed by the authors for future generations.

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