Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2021
(ICMERE 2021) 12 – 14 December 2021, Chattogram, Bangladesh

ICMERE 2021-PI-158

DEVELOPMENT AND PERFORMANCE OPTIMIZATION OF VERTICAL AXIS WIND TURBINE USING AVP

Md. Mahmodul Alam[1], Irfan Ahmed[2], Md. Golam Rasul Joy[3*], Maksud Kamal[4], Md. Tahmid Anim[5], Tanjila Islam[6], Iftekhar Amin[7] and Samiul Alam[8]
[1]Department of Energy Science and Engineering, Khulna University of Engineering and Technology, Bangladesh
[2, 3*, 4, 5, 6, 7]Department of Mechanical Engineering, Bangladesh Army University of Science and Technology, Bangladesh
[8]Department of Mechanical Engineering, Khulna University of Engineering and Technology, Bangladesh
Mahmod.kuet.me@gmail.com, irfan_ahmed@baust.edu.bd, golamrasul.me15@gmail.com*, maksud82255@gmail.com, tahmidanim2426@gmail.com, tanasha1316@gmail.com, iftekhar@gmail.com, samiulpranto5@gmail.com

Abstract- *This investigation focuses on the development and performance optimization of Vertical Axis Wind Turbine (VAWT) by using Asymmetric Vortex Provider (AVP). This experiment has been carried out at BAUST campus, Saidpur where the local velocity is much lower than the coastal areas. The objective was to build a VAWT with a very low starting speed as well as performance optimization which have been accomplished by using 6 blade section AVP made of PVC. This study shows that after using AVP, this VAWT is capable of producing power at very low wind speed under different conditions. It also depicts that using AVP doesn't increase the moment of inertia whereas it increases the RPM tremendously at any wind speed along with the turbine efficiency. The RPM was measured and compared at different conditions and it shows that at the same wind speed, the rpm of VAWT with AVP is much higher than the rpm of VAWT without AVP. The local velocity of the turbine is also increased by using AVP. This whole investigation suggests that, AVP can be a solution for those areas where wind speed is not enough to rotate the turbine blade to produce electric power.*

Keywords: VAWT, AVP, Starting Speed, Local Velocity and RPM.

1. Introduction

Wind power is a clean and environmentally friendly energy source. The two major classifications of wind turbines are: Horizontal axis wind turbine (HAWT) and Vertical axis wind turbine (VAWT) [1]. There are two main types of VAWTs called: drag driven VAWT (Savonius type) and lift driven VAWT (Darrieus type) [2]. The reason for concentrating on the VAWTs idea is to more readily comprehend its future possibilities of being an option in contrast to HAWTs. Further learning of the benefits and burdens of the idea can likewise assist with finding application regions that are particularly reasonable for VAWTs. Likewise, by drawing information from existing VAWTs, the opportunities for building admirably working turbines are in increments.

Basically, that heap of models had an even center, at this point in a comparable period (1931) Georges Jean Marie Darrius arranged one of the most notable and typical kinds of VAWT, that really bears his and Afghanistan in the period from the seventh to 10th century. These windmills were fundamentally used to siphon water or to squash wheat. They had a vertical turn and used the drag as a piece of wind power. The primary windmills worked in Europe and awakened by the Middle East ones had a comparable issue, at this point they used an even turn. Thusly, they substitute the drag with the lifting power, making their makers in like manner the oblivious pioneer of smoothed out highlights. This is one reason for them is for low productivity. The breeze turbines utilized in the USA during the $19th$ century. They had countless steel-made cutting edges and addressed a tremendous monetary potential due to their enormous amount [3]. The early pioneers engaged with the improvement of wind turbines quite a long time back applied VAWTs to the processing of grain, an application where the upward hub of the grindstone could be effectively associated with the VAWT rotor. A lot of amazing review articles have been distributed in the past specifying the recorded improvement of wind turbines of various types [4]. Vertical pivot wind turbine power age hardware can be situated at ground level, which makes for simple upkeep. Likewise, VAWT are Omni-directional, which means it should not be pointed towards the breeze to deliver power. At long last, there is potential for enormous force with VAWT on the grounds that their size can be expanded significantly. Right off the bat, limit layer influences starting from the earliest stage the air stream occurrence on the VAWT, which sometimes prompts conflicting breeze designs. Besides, VAWT are self-beginning; at present, an external force source is needed to begin turbine pivot until a specific rotational speed is reached. The fundamental goal of the work is to plan and assemble a self-beginning vertical hub wind turbine [5].
The main objective of this postulation is to plan and assemble a Darrius Vertical Axis Wind Turbine with AVP to deliver clean energy at low air speed areas.

2. Methodology

In this turbine different methods were follower for this turbine to get the optimum design in this project and all the methods were includes this chapter. For achieving this project, two different ways were followed.

1. Performance analysis.
2. Design analysis.

2.1 Design parameters of VAWT

The following parameters were considered of this project

2.1.1 Turbine swept area

The circled area as blades sweeps through air is called swept area. The swept area of straight-bladed VAWT is:

$$A = 2RH \quad (1)$$

2.1.2 Number of Blade

Reason for using 8 blades are-To increase the swept area. To harness maximum amount of air. To increase the solidity of turbine.

2.1.3 Tip speed ratio

The most important factor in wind turbine design is tip speed ratio which is defined as the ratio of the tangential speed at the blade tip to the actual wind speed, i.e.:

$$TSR = \omega R / u\ \infty \quad (2)$$

Each rotor design has an optimal tip speed ratio at which the maximum power extraction is achieved [6].

2.1.4 Turbine Aspect ratio

$$\text{Aspect ratio} = \frac{\text{blade height}}{\text{rotor radius}}$$

High aspect ratio ensures high rotational speed for the same power than rotor torque and vice versa [6].

2.1.5 Turbine solidity

$$\text{The solidity } \sigma = \frac{\text{the total blade area}}{\text{the projected turbine area}}$$

for straight bladed VAWTs is calculated with:

$$\sigma = \frac{B * c}{R} \quad (3)$$

2.1.6 Mass moment of inertia

Angular acceleration = Aerodynamic moment / Mass moment of inertia [6].

2.2. VAWT Design analysis methodology:

The design strategy is as follows:

2.2.1 Forces acting on VAWT blades and rotor

The forces acting on each rotor blade is displayed in figure (1).
The centrifugal force is defined as: $F_c = m \times R_{rotor} \times \omega^2$. This force is always pointing outwards w.r.t the rotational axis and acts in opposite of the radial force [6].

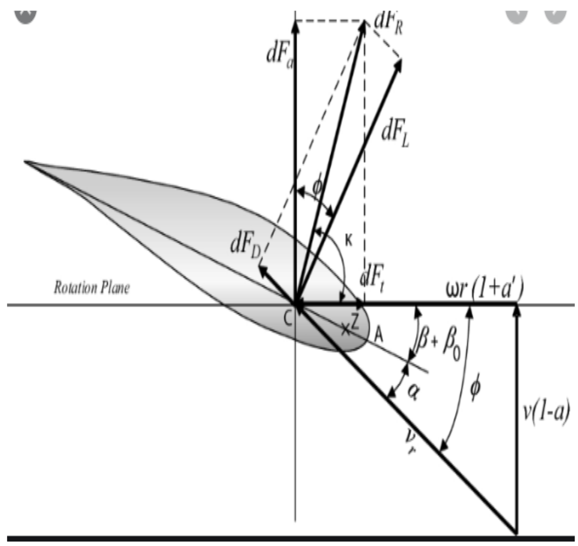

Figure 1: Aerodynamics forces acting on rotor blade.

2.2.2 Material Selection

Proper material has to be selected for proper job to ensure a rigid and long-lasting structure of the constructed model. Wrong selection of material could lead to faulty results and bad impact on economic value of the project.

3. Setup Details

This contains all the construction information about AVP and other parts of the turbine.

3.1 Material selection:

The output power from the turbine have to cover total expenses of the project for cost-benefit analysis. The materials for each part, measurement and total unit is listed in the table.

Table 1: Material Selection

Parts Name	Materials	Quantity	Total Unit
Shaft	Mild steel	4 feet	1
Blade	PVC pipe	4 feet	8
Bearing	Mild steel		2
Nut Bolt			40
Bearing cap	Mild steel		2
Elbow joint			16
AVP holder round ring	Mild steel		4
AVP PVC board	PVC sheet		6
Flat bar	Mild steel	8 feet	6
Strip	Plastic	5	5

Stand	Mild steel	3 kg	1
Motor		1	1
Pulley		1	1
Belt		1	1
Wire		1	1
Light		1	1

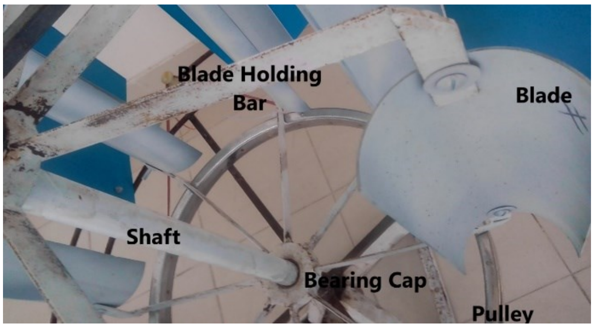

Figure 2: Different parts of turbine section.

3.2 Construction

This is the rotating body of the turbine connected to the generator with belt pulley system. The different parts of the turbine are shown in the figure (2). The main parts of the turbine are:

3.2.1 Shaft

A 4 feet long solid mild steel circular rod with diameter of 1 inch as shaft has been used. This is the backbone of the structure which carry all the axial load (weight of the body) and bending load caused by the air flow.

3.2.2 Bearing

It connects the rotating turbine blade and pulley through bearing cap with the stationary shaft. Inner diameter of the bearing is 1 inch and outer diameter of the bearing is 3 inches.

3.2.3 Bearing cap

This is used as bridge between bearing and blade holding bar. The blade holding bar is welded in the bearing cap. Inner diameter is 3 inch and the outer diameter was 3.5 inch. This was made in center lathe machine.

3.2.4 Blade holding bar

This rectangular bar is used to hold the turbine blade and the pulley.

3.2.5 Turbine blade

This is the main power extracting device of the turbine. Length of the blade is 12 inch and the cord length is 6.28 inch. This blade is attached to the blade holding bar by nut bolt.

3.2.6 Pulley

This is the largest pulley of the turbine having 17-inch diameter. It is attached with the blade holding bar.

3.2.7 Generator

A six-volt DC generator is used which efficiently generate current at 5200 RPM. A small DC light, a voltmeter in parallel and an ammeter series was connected with generator to measure power. Anemometer, Tachometer and Multi-meter was also used for the measurement procedure.

3.3 AVP

There are four main parts of the AVP section.

3.3.1 Ring holding flat bar

Cross sectional area of the square bar is 1 cm^2. 18-inch-long 8 flat mild steel bars were used to hold the circular AVP blade supporting ring rigidly.

3.3.2 Circular AVP blade supporting ring

Cross sectional area of the square bar is .25 cm^2 and dimension is .5cm×.5cm. Two rings were used to provide support to the AVP blade through the blade holding notch as shown in the figure (3). The diameter of the outer ring is 36 inch and diameter of the inner ring is 30. Four rings were used to hold the blade. Two of them used to support the upper side and two of them used to support the lower side.

3.3.3 Blade holding notch

This are the small flake of mild steel which dimension was 2cm×.25cm×5cm. It was a drilled hole at middle of its width and 4 cm along its length from welded point.

3.3.4 AVP blade

Six AVP blade was used symmetrically around the shaft. Dimension of each blade was 18inch×12inch (height × width).

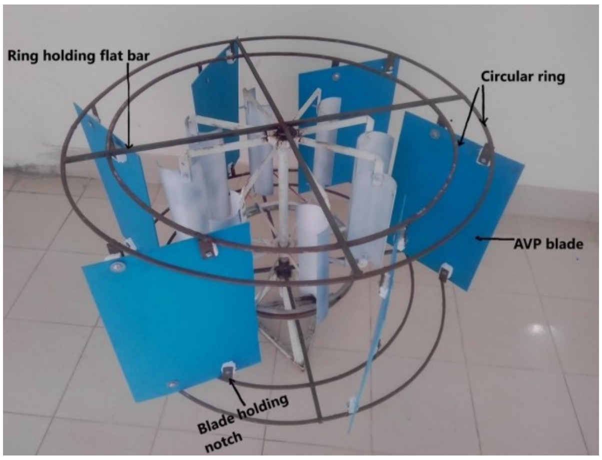

Figure 3: Different parts of AVP section.

The velocity profile around the turbine blade with AVP is given bellow:

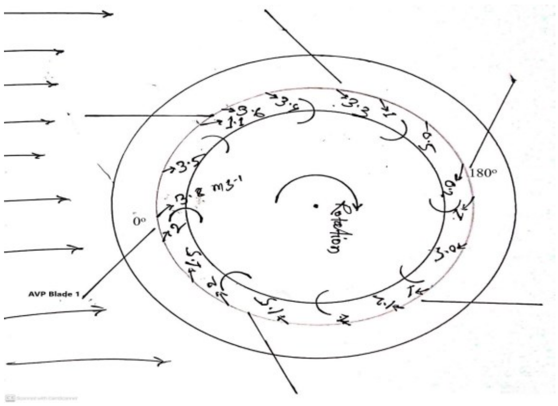

Figure 4: Velocity profile around Turbine blade with AVP at 3 m/s air stream air flow.

4. Experimentation and Data Analysis

Designing a vertical axis wind turbine with very low starting speed was focused. Also improving the efficiency and performance was the primary concern. After completing the construction of the wind turbine, some test experiment had been run with artificial sources of air flow. After running some experiment, the following results have been found;

Starting wind speed without load and without AVP= 1.9 m/s

Starting wind speed with load without AVP= 2.3 m/s

Starting wind speed without load with AVP= 1.6 m/s

Starting wind speed with load with AVP= 2 m/s

Table 2: The change of RPM by using AVP for the same wind speed without load

Wind speed(m/s)	RPM without AVP	RPM with AVP
1.5	0	21
1.7	24	33
2	36	43
2.5	47	55
3	56	64
3.5	62	78
4	70	88
4.5	80	104

After using the AVP, self-starting ability of the turbine improved which will provide additional advantage to generate power all over the year.

The RPM of the turbine increased after using AVP as shown in figure (5) and figure (6). The RPM of the wind turbine is proportional to the wind speed. A straight line can be obtained from the graph by which RPM could be determined of the turbine at wind speed.

The RPM of the turbine reduces a little bit while connected with load.

Both curves are almost similar to the curves in fig except decrease in RPM for the same wind speed. The RPM of the turbine decrease due to extra load connected to it.

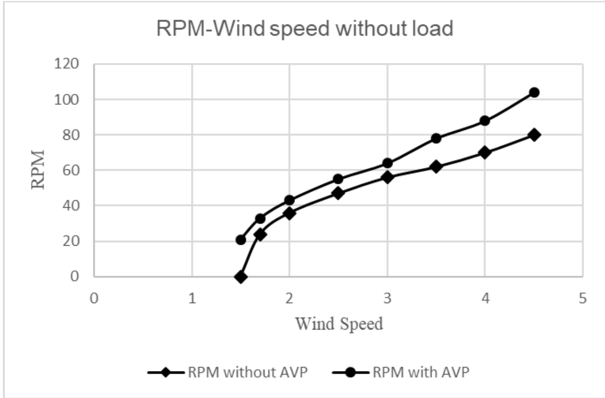

Figure 5: RPM-wind speed without load without AVP.

Table 3: The change of RPM by using AVP for the Same Wind Speed with Load

Wind speed(m/s)	RPM with AVP	RPM without AVP
2	19	12
2.5	34	23
3.5	54	48
4	69	62
4.5	89.3	78.5

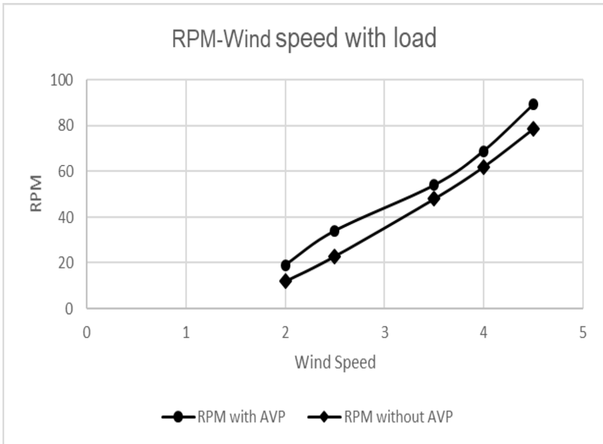

Figure 6: RPM-wind speed without load with AVP.

The speed of the turbine should keep two-third of the wind speed for maximum speed according to the betz low. But the inertial of the rotating parts are too huge to obtain that speed for maximum efficiency. The bearing is another reason for the speed lack of the turbine as the turbine rotor wasn't very free to rotate at high RPM. For self-starting requires more wind speed while connected with load.

Table 4: Power Output at the Load Terminal with AVP

Wind speed (m/s)	RPM with AVP	Voltage (V)	Current (mA)	Power (mW)
2	19	.3	1	.3
2.5	34	.7	1	.7
3.5	54	1.1	1	1.1
4	59	1.6	1	1.6
4.5	89.3	2	1	2

4.1 Data Analysis

The voltage-RPM characteristic curves of a wind turbine show the generation of voltage in dynamo with rotational speed of the turbine.

The turbine starts producing voltage at 10 rpm of turbine speed. The amount of produced voltage will increase until cut of speed than start reducing again relatively with increasing RPM of the turbine. This will create an exponential line in both RPM-voltage curve and RPM-power curve of the turbine.

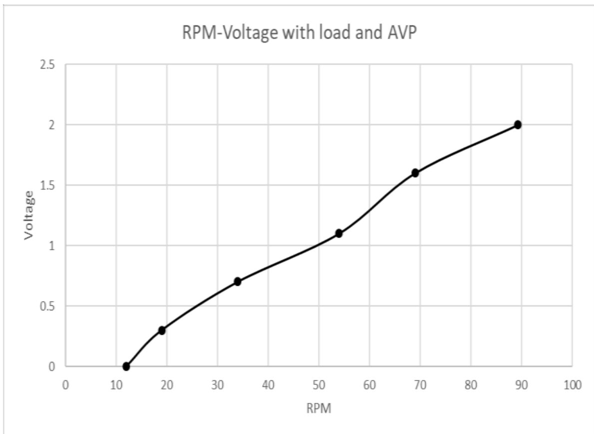

Figure 7: RPM-wind speed with load and AVP.

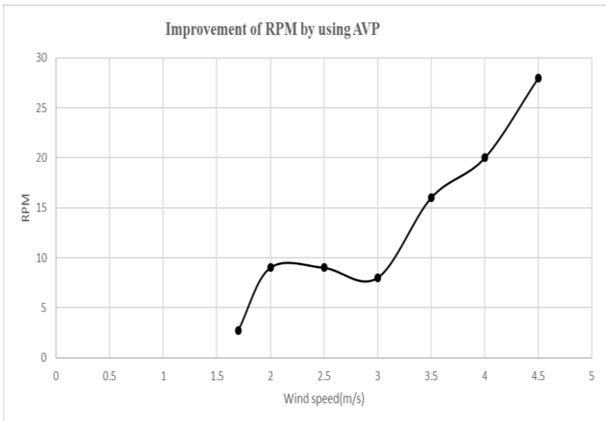

Figure 8: Improvement of RPM by AVP.

The RPM is increased using AVP as it's changed the wind direction towards the turbine blade. As the energy equation of wind is:

Wind energy= .5 ρ A V^3

From the equation it can be said that if the wind speed increases twice, the energy of wind will increase 8 times more. When the wind velocity become triple, total energy will increase 27 times more.

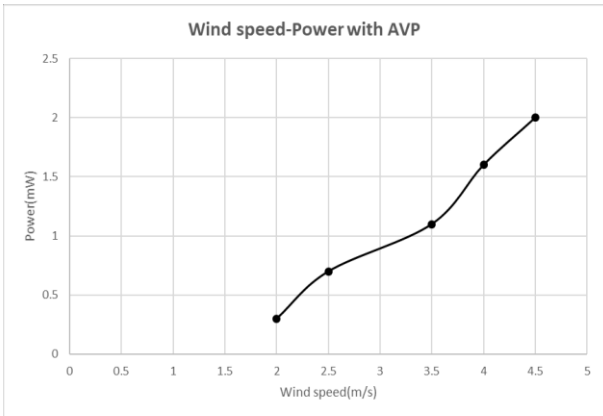

Figure 9: Improvement of power by AVP.

The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds.

5. Discussion

Air flow aren't available everywhere without off shore area. So self-starting capability at low wind speed of this VWAT is more suitable for use over HWAT. This turbine is capable of producing power at very low wind speed from 2.5 m/s and cut off speed of the wind turbine is around 8.5 m/s. The wide range of operating air flow will help to produce power all over the year. The generator run most efficiently at operating wind speed of 4.5 m/s.

Gaining an optimum speed ratio to obtain efficient rpm range of the generator has been a failure. In spite of having enough rotation of the turbine, current didn't induce at the generator winding. But the generator was a 4-pole permanent magnet dc generator, few voltages induced at the generator. The generator has been run at maximum 2800 RPM while the generator produced 2V.

Also, the belt was not tight enough, few amounts of sleep occurs on the both pulley which is another reason behind the low speed ratio. The turbine was running at standard air pressure and temperature during the measurement.

The AVP of the turbine affect the turbine efficiency a lot. The turbine couldn't produce enough electricity due to faulty pulley and generator but the AVP helped turbine to gain high velocity increment. This experiment proved the tremendous potential of AVP in wind turbine technology

6. Conclusion

To increase the flow rate of wind through the turbine, AVP (Asymmetric Vortex Provider) was used. It helps to increase the RPM of turbine & Rate of wind flow in a circular direction. It also increases the efficiency of turbine. The effect of mass moment of inertia is less and it is possible to reduce more by using proper material selection. There is limited option for bird strike which makes it more ecofriendly then HAWT. The all-out cost of the task was sensible for the VAWT size and for the monetary conditions in contrary. VAWT is also very much eco-friendly, easy to transport & less amount of space is needed over a HAWT. Also this AVP can be used to provide safety during storm, change the angle of attack and control the amount of air flow throughout the turbine.

7. REFERENCES

[1] B. G. -Newman. Actuator-disc theory for vertical-axis wind turbines. Journal of Wind Hngineering and Industrial Aerodynamics, 15:347-355, 1983.

[2] Savonius SJ. The S-Rotor and its applications. MechEng 1931;53(5):333–8).

[3] M. D’Ambrosio, M. Medaglia, “Vertical Axis Wind Turbines: History, Technology and Applications”, Master thesis in Energy Engineering, Hogskolan Halmstad, May-2010

[4] Ellabban, Omar; Abu-Rub, Haitham; Blaabjerg, Frede (2014). "Renewable energy resources: Current status, future prospects and their enabling technology" pp 748–764 history. The Environmental Magazine, Jan–Feb, 2005.

[5] Lunde P. Windmills: from Jiddah to Yorkshire. January/February. Vol. 31 (1), 1980.

[6] Palash Jain, Abhishek, “Analysis and Prediction of Vertical Cycloidal Rotor Wind Turbine with Variable”, Conference paper, IIT Kanpur, 2015.

8. NOMENCLATURE

All the dimensions used are in SI unit.

Symbols	Descriptions
ϑ	Mean wind speed
P	Theoretical power of the turbine
$\dot{m}$	Air mass flow rate
A	Swept Area
Cp	Coefficient of power
I	The wind turbulence intensity
σ_u	Air standard Deviation
R	Turbine rotor radius
H	Height of turbine \ Blade length
λ	Turbine tip speed ratio
ω	Angular speed
c	chord length
u_r	Wind velocity at the rotor
B	Number of blades
C_d	Blade drag Coefficient
C_l	Blade lift Coefficient
C_N	Normal force coefficient
C_t	Tangential force coefficient
C_T	Thrust coefficient
C_Q	Torque coefficient
N_θ	Number of stream tubes
AVP	Asymmetric vortex provider
F_N	Normal force
F_T	Tangential force
$P_{mech,out}$	Turbine Mechanical output power
σ_u	Air standard Deviation
T	Thrust force