VERTICAL DUCTING AND VERTICAL-HORIZONTAL COAXIAL BLADE COMBINATION EFFECTS ON THE PERFORMANCE OF VERTICAL AXIS WIND TURBINE (VAWT)

Abdul Latif Manganhar*, Saleem Raza Samo**, Mohammad Ramzan Luhur***, Altaf Hussain Rajpar****

ABSTRACT

Horizontal wind flow ducting of wind turbines is not new in the turbine history. It is conventionally applied with horizontal axis wind turbines to accelerate wind at turbine section to generate more power from low-speed wind. In few cases vertical axis wind turbines are integrated with wind accelerating duct structures to improve their power generation performance. This technique has been proved effective in low-speed wind zones and reviewed mostly to improve efficiency and environmental characteristics of VAWT. The present study experiences vertical ducting of VAWT with horizontal inflow and vertical outflow. A Vertical Cylindrical House was fabricated with horizontal inlet door and vertical opening. Auxiliary wind source (low-speed open type wind tunnel) was used to inlet wind in the house changing the direction and velocity. Three rotor systems a/ Savonius Four Bladed VAWT, b/ Horizontal Blade-Vertical Axis Rotor(HB-VAR) and c/Vertical-Horizontal Coaxial Blade Combination, were developed and tested in the fabricated rotor house. Results of three setups were compared and concluded that vertical ducting of VAWT is more beneficial with vertical–horizontal coaxial blade combinations and can be preferred for low wind conditions.

Keywords:- *Blade combination, Horizontal inflow, Low-speed wind ,Savonius rotor, VAWT, Vertical Duct, Vertical outflow*

1. INTRODUCTION

The performance improvement of wind generators is the first priority of wind energy experts. There are two option in this regard, either more efforts be on turbine design or the power of incoming wind be enhanced. For later option, ducting or funneling concepts are introduced mostly in HAWTs and in few cases of VAWTs, to accelerate and guide wind before it strikes on the rotor. Literature shows that sites for wind flow intensities, worldwide, required for power production are very less. Major portion of the world has wind less than 5m/s, which is in sufficient for power generation [1]. The suggestions are that the wind power generators should be located near the more populated zones, unfortunately more populated zones increase turbulence intensity in wind flow [2]. In urban area wind is always changing its speed, and direction is rarely uniform. VAWTs are reliable since they are omni-directional and can be more effective in the complex urban terrains to harness the wind energy [18]. More effective systems are required to generate power, in such sites. Recommendations from researchers are that the systems to be located near or in the urban zones may be integrated with such techniques that may improve the quality of wind flow and increase striking power of incoming wind. Converging diverging ducts were introduced as integral part of wind rotors to obtain a higher energy density [3-6]. Ducting and shrouding the rotor highlighted the importance of such wind accelerating techniques. Comparative studies were conducted with and without ducts [7,8] and it was claimed that integration of ducting techniques multiplied the power performance of the bare rotor. The positive results from low speed and turbulent wind improving techniques provided new direction to the researchers in the field of wind power generation. Flow converging ducts and

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diffuser geometries were studied [9,10] to optimize their effects on the rotor performance. Surprising results were came forward with increasing power factor more than double as compared to the bare cases of wind turbines [11]. Wang, et al [12] used scoop to utilize lower winds and claimed that such techniques increase the catchment of wind and improve performance of wind turbine at lower wind speeds.

The performance improvement of straight bladed vertical axis wind turbine was claimed, with the use of guide vane row, 1.5 times higher than the same rotor without the attachment of any guide vane [13].

H40 turbine was assembled on vertical shaft [14] with vertical duct to study ducting effect on its performance. In this setup wind enters horizontally and leaves vertically. Upper end of the duct was designed to perform as diffuser and the blades were fixed at the throat. 80% improvement in its performance was claimed.

A building integrated vertical axis wind turbine was developed and tested by [15]. In this system wind enters horizontally and leaves the duct vertically after shifting its energy to the vertical rotor. Carcangiu and Montisci [16] developed an innovative system suitable for wind power generation in urban areas. The wind energy conversion system was installed on the roof of the building. They claimed through analysis that the developed system can satisfy the energy demands of a common building. Omni-directional-guide-vane (ODGV) was designed and analyzed to in house Vertical Axis Wind Turbine [17, 19]. According to the claim, the ODGV accelerated and concentrated the low speed incoming wind resulting two times increase in the rotational speed of the rotor.

The objective of above researchers was, mostly, to search ultimate wind accelerating geometry of duct and its beneficial integration with the rotor. These efforts were intended to bring low-speed wind zones in the working range of VAWT. In the present work vertical ducting of VAWT and vertical-horizontal coaxial blade combination effects on its performance are taken into consideration.

2. MATERIAL AND METHODS

The test setup shown in Fig.1, comprises,

- A four blade savonius rotor
- A vertical rotor in housing cylinder
- Fan type horizontal blade set with concentrator cap
- Instrumentation(hotwire anemometer and tachometer)
- Low-speed subsonic open-type wind tunnel

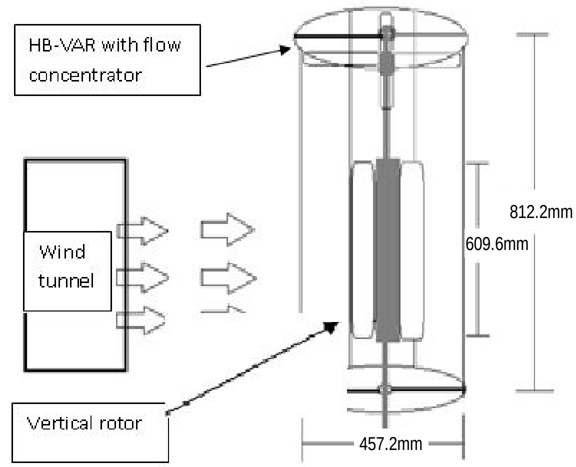

Fig 1: Test Setup Drawings

2.1 Rotor Dimensions

- Diameter = 440mm = 0.44m
- Height = 609.6mm = 0.609m
- Swept area = $0.268m^2$
- Blade size = 0.2032m x 0.6096 = $0.124m^2$
- Aspect ratio = h/d =0.6092/0.2032=3

2.2 Cylinder dimensions

- D_c(diameter of cylinder) = 0.4572m
- H_c(height of cylinder) = 0.8122m
- h_i(horizontal inlet) = $0.124m^2$
- v_o(vertical opening) = $0.164m^2$

2.3 Horizontal Blade-Vertical Axis Rotor(HB-VAR) with Flow Concentrator Cap

- H_{rd}(horizontal blade rotor diameter) = 0.443m
- H_{ra}(horizontal blade rotor area = $0.164m^2$
- Concentrator blockage area = $0.041m^2$
- Net Swept area of HB-VAR = $0.123m^2$

3. TESTING METHODOLOGY

The performance of a four blade savonius rotor (savonius VAWT) was tested in following ways,

1. VAWT without vertical duct
2. VAWT with vertical duct.
3. Horizontal Blade-Vertical Axis Rotor(HB-VAR) with vertical duct
4. Combined VAWT and HB-VAR with vertical duct

The VAWT performance without duct was studied at the initial stages by changing the direction of wind beam from origin of rotor to the tip of blade.

Effects of ducting the rotor were analyzed by in-housing the rotor in a vertical cylinder with horizontal opening for inward wind flow and vertical opening for outward flow, as shown in fig.2.

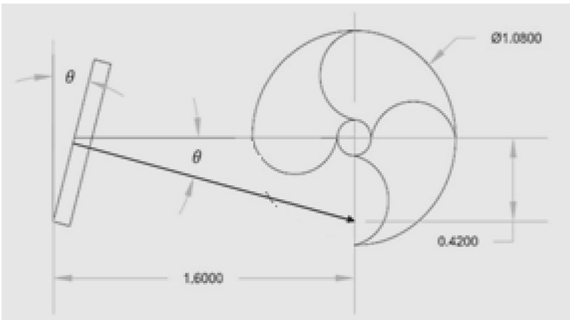

Fig.2: Positions, dimensions and orientation of the rotor, duct, slot and wind source

Two rotor setups, Savonius VAWT and HB-VAR, were fixed on same vertical shaft.

The performance of HB-VAR with vertical duct was studied separately and then combined with VAWT, where vertical cylinder was acting as an agent to modify wind direction and the power. This typical rotor setup and in-housing geometry as shown in fig.3 was used to study the performance of the proposed system. Out flow of subsonic wind tunnel provides the microclimate to the project. Outflow velocity variations up to 0.1 was observed through anemometry techniques which indicates free stream turbulence in the wind source. Mean values of inlet velocity and corresponding rotor rpm were rounded off and used for further analysis to minimize error occurrence.

Fig 3: Test setup

4. PERFORMANCE CALCULATIONS

The mathematical model to determine the power available in the wind beam of swept area A is;

$$P_w = \tfrac{1}{2} \rho A V^3 \qquad (1)$$

Where,

P_w = the power available in the wind beam of cross-sectional area A(Watts),

ρ = the density of wind (kg/m^3)

A = the swept area of Savonius rotor (m^2)

V = the speed of wind(m/s)

The limiting power co-efficient of any design of rotor, determined by Betz [18], is Cp (max) = 0.59.

According to this limit, no turbine can extract power from wind more than this value. The value of Cp varies from design to design. The real achieved value of Cp, even in the best designed wind turbines is well below the Betz limit. It is not more than 0.45 [18]

Hence, the power co-efficient needs to be incorporated in wind power equation (1) to determine extractable power from the wind beam that hits the rotor, and is given by;

$$P_m = \tfrac{1}{2} \rho A V^3 \, Cp \qquad (2)$$

Where,

P_m = the extractable mechanical power,

Cp = co-efficient of performance of the rotor and

$\frac{1}{2}\rho A V^3$ = the power of upstream wind (P_w) that hits the rotor.

Turbines are usually characterized by performance curves, which give Cp as a function of Tip Speed Ratio (λ).

$$\lambda = (\omega \times R)/V \qquad (3)$$

Where,

ω = the angular velocity of Savonius rotor and

R = the radius of the Savonius rotor.

Cp as a function of λ curves for many turbines are shown in Fig.4.

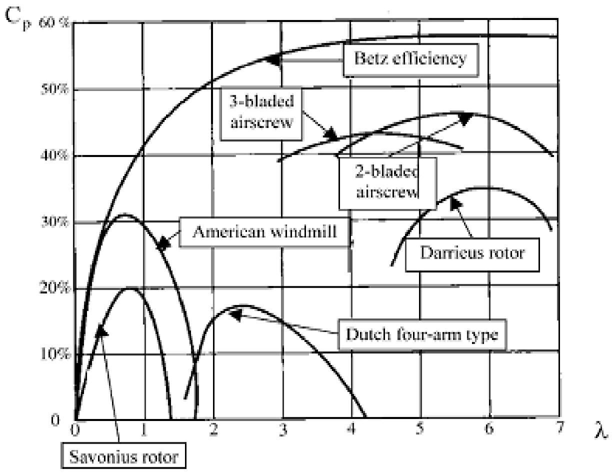

Fig. 4: Characteristic curves of many conventional wind machines

5. RESULTS & DISCUSSIONS

5.1. VAWT Without Vertical Duct

Performance of Simple VAWT was analyzed in terms of rpm with respect to angle made by wind beam, (i) by changing its direction from origin of rotor to the tip of blade at constant wind velocity V=5m/s to search the best flow direction and then (ii) by varying wind velocity from 1 to 10m/s with the searched best wind direction.

From fig.5, we can estimate that the most effective wind beam angle is 30° with which it hits the blade near its tip, at which maximum rpm 172 are recorded. Further increase in the angle causes reduction in rpm. Fig.6 shows the values of tip speed ratio(λ) with respect to wind direction for this rotor at 5m/s constant wind velocity. The value of λ=0.79, recorded at ϴ =30°, coincides with Cp = 0.19 in figure 4, which indicates the performance co-efficient of this VAWT, whereas, fig.7 shows the performance of VAWT without duct at ϴ =30° with respect to wind velocity.

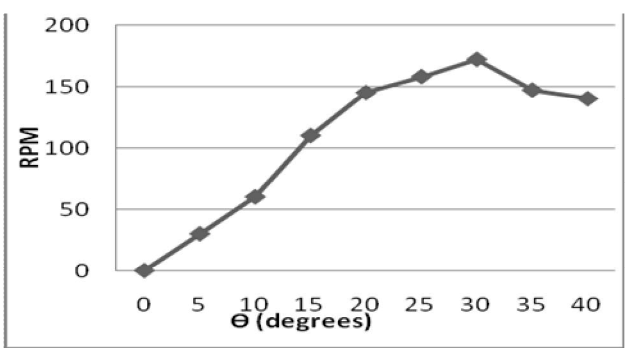

Fig. 5: Performance VAWT without duct with respect to wind direction at V= 5m/s.

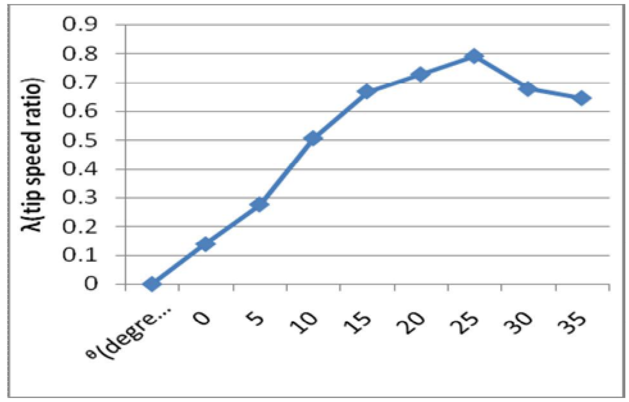

Fig. 6: Performance of VAWT without duct in terms of tip speed ratio with respect to wind direction at V= 5m/s.

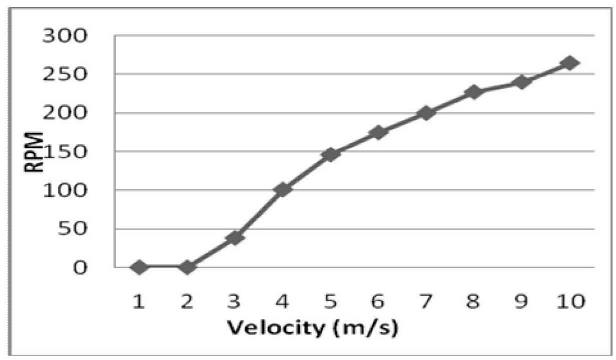

Fig. 7: Performance of VAWT without duct at ϴ=30° with respect to wind velocity

5.2 VAWT with Vertical Duct.

In this test performance of VAWT was studied at a constant wind beam angle ϴ=30° with respect to wind velocity.

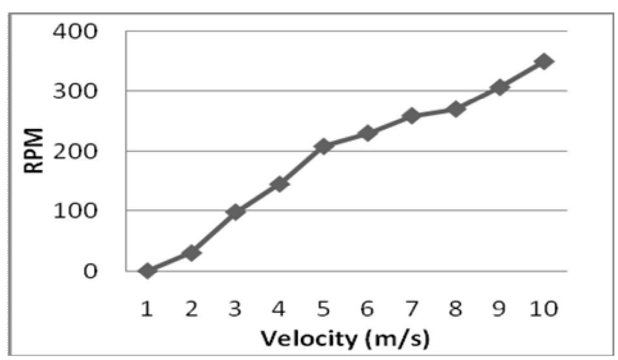

Fig. 8: Performance of VAWT with vertical duct with respect to wind velocity.

fig. 8 indicates improvement in the performance of VAWT with integration of vertical duct. This performance improvements can be indicated through fig.9, where RPM-1 indicates the case without duct and

RPM-2, with duct showing 42% improvement at 5m/s and 32% at 10m/s.

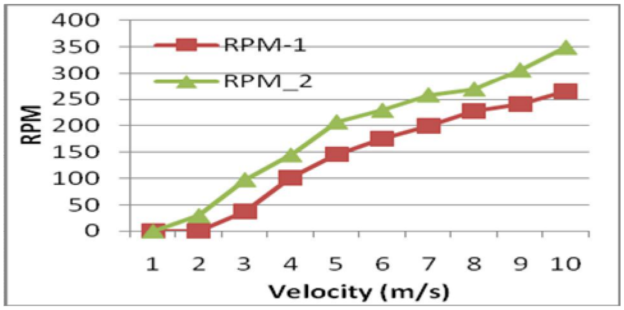

Fig. 9: Performance comparison of VAWT with and without vertical duct

5.3 Horizontal Blade-Vertical Axis Rotor(HB-VAR) with Vertical Duct

In this case, performance of HB-VAR was checked with vertical duct at wind direction (ϴ=0) with respect to velocity.

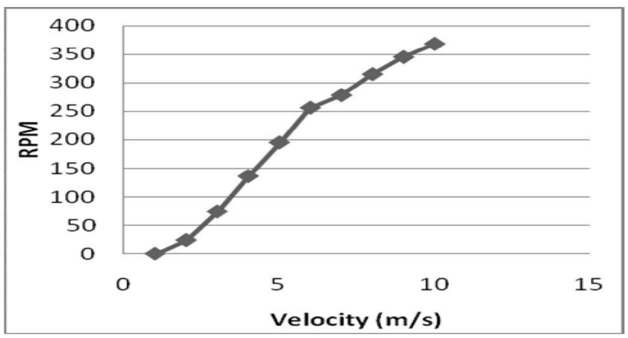

Fig.10: Performance of HB-VAR with vertical duct at ϴ=0 with respect to velocity

According to fig.10 the HB-VAR with vertical duct performs very well. Comparative performance is shown in fig.11 which indicates more better performance of HB-VAR in higher winds i.e, 38%, 5% greater than first and second case respectively.

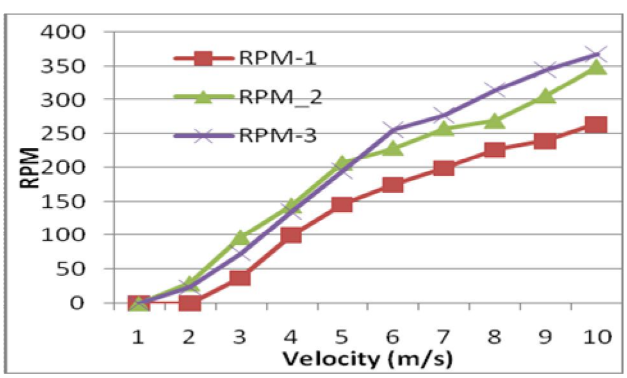

Fig. 11: Comparative performances of VAWT without duct (RPM-1), with duct(RPM-2) and HB-VAR(RPM-3)

5.4 COMBINED VAWT AND HB-VAR WITH VERTICAL DUCT

Effect of HB-VAR on the performance of VAWT inside the vertical duct was studied with respect to wind direction and velocity. It should be noted that the cap below the HB-VAR reduces vertical wind flow path and develops neck to concentrate the rising wind near the tip of blade resulting improvement in the performance of system.

Fig.12 indicates the performance of combined rotor system with respect to wind velocity. 409rpm at 10m/s were recorded which shows 54% greater performance as compared to bare VAWT. The performance comparison is shown in fig.13.

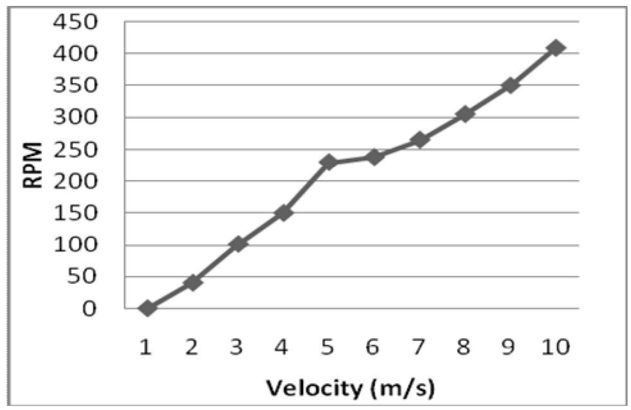

Fig. 12: Performance of the combined system with respect to wind velocity.

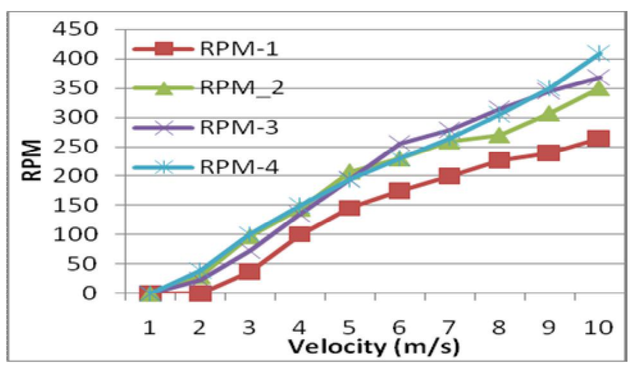

Fig. 13: Performance comparison of above four cases

6. CONCLUSIONS

The present study concludes following important observations.

- Co-efficient of performance estimated for the developed VAWT was Cp=0.19.

- The performance of VAWT with integration of vertical duct increases 42% and 32% at 5m/s and 10m/s respectively.
- Performance of HB-VAR is more better in higher winds i.e, at 10m/s, was 38% and 5% greater than VAWT without duct and VAWT with duct respectively.
- The performance of combined rotor system with respect to wind velocity was appreciable. 409rpm at 10m/s were recorded which shows 54% greater performance as compared to bare VAWT

6.1 RECOMMENDATIONS

Vertical ducting of VAWT is preferable for low wind conditions and will be more beneficial with vertical–horizontal coaxial blade combinations if proper wind direction be maintained with the help of any wind guiding and concentrating mechanism. This technique is better to improve efficiency and environmental characteristics of Vertical Axis Wind Turbine.

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