Micro Vertical Axis Wind Turbine Design Integrated with Wind Accelerating Techniques

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Abstract: Power generation from natural wind is the crucial issue due to rapid depletion of non-renewable energy resources and their pollution demerits. Most observers agreed that long-term economic growth will require technical innovation to make wind energy more competitive with other forms of energy. One among the key trends is the push to improve productivity. Vertical axis wind turbines are capable of extracting power from wind regardless of direction of natural wind flow. Very less work is devoted to improve the characteristics of wind to make it more useable for power generation. Major portion of the research is related to the wind energy system design that caters the domestic needs. A micro vertical axis wind turbine system with integrated wind accelerating techniques is proposed. At the outer of the turbine a wind accelerating convergent duct with larger wind area is proposed, that will perform as a nozzle action to accelerate the natural wind when it strikes on the front half portion of the turbine blades. Proposed micro wind turbine is also integrated with satellite dish type parabolic structure, mounted at the top of the turbine. The parabolic concentrator surface is coated with sun rays reflecting mirrors, sunlight striking on paraboliod surface is directed to words a heat absorbing hollow cylinder, erected at the center of the paraboliod concentrator. Hollow cylinder is the path channel for air leaving the turbine. Air molecules passing through this channel will be heated up, moving rapidly up word creating momentum in air leaving from the turbine. Design of the proposed vertical axis wind turbine system integrated with wind accelerating techniques and experimental study of wind accelerating duct composed of various section is reported in this research work.

Keywords: Vertical Axis Wind Turbine, Converging duct, Solar-thermal air heating.

I. INTRODUCTION

The social and economic development of any country depends upon the availability of energy at cheapest rate. Fossil fuel depletion rate and their prices, population growth rate and technological development created adequate demand of energy for sustainable economic growth. Though, unlimited renewable sources are available but still waiting for their efficient use. As regards the Pakistan's position is concerned it has approximately 152 million populations with 2.5% growth rate per annum. The current energy requirement reported as 58 million tons of oil equivalent (MTOE) per annum and will increase exponentially with population growth and economic activities [1]. Among 152 million populations nearly 68% of total resides in rural areas and about 50% of total rural areas population is enjoying electricity facility not more than 12 hours a day.

Looking at continuous drain of fossil fuels and global warming, many countries have common goal to develop clean and sustainable energy for future prospects of human beings and protection of earth. Wind energy utilization has attracted researchers for decades and will continue to grow in the future. Since 2008 United States become the number one having the wind power installations [2].

At present, research on power generation from the natural wind is the vital issue among all renewable energy sources due to its environmental friendly nature and availability in abundance [3-5]. Wind power generation system uses speed and density of wind in terms of kinetic energy that can be converted in to mechanical energy though wind turbines. Wind turbines are classified by its shaft orientation such as Horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT) conventionally known as Darrieus (Lift type) and Savonius (Drag type). Hybrid turbine consists of two types of turbine on the same shaft such as turbine based on straight bladed darriesus turbine along with double step savonious turbine. Hybrid vertical axis has much better self-starting characteristics and better conversion efficiency at higher flow speed reported in [6-8], such type of turbine cannot be used at micro-level for domestic needs.

The main focus of the researchers in renewable source of energy is to develop wind turbine power generation system suitable for windy areas where available wind possesses speed more than the cut-in speed of wind turbine i.e. greater than 3m/sec. As it is estimated that major locations of our country as well the world possesses natural wind speed less than the required amount to run the turbine, therefore it is

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essential to integrate wind energy systems with wind accelerating options to make them suitable for low windy areas [9-10].

In the present research study main focus is to introduce wind accelerating techniques that can improve the natural wind characteristics for electrical power generation. A vertical axis wind turbine energy generation system integrated with wind accelerating techniques is proposed, in this reach work proposed VAWT system will work on less than 3 m/s cut-in speed of air. There may be various ways to accelerate the natural wind but in this study two options are being taken in to consideration. (1) Converging duct to cover surroundings of the turbine to improve natural wind speed. (2) Solar-thermal air heating system used to heat-up the air leaving the turbine to create vacuum effect for incoming natural free stream air towards the turbine.

II. TURBINE DESIGN

Whenever cost or reliability is much more important, Savonius type vertical axis turbine produces higher torque and have lower cut-in speed as compared to horizontal axis turbine. Vertical axis turbines are simple and require very low maintenance, no pointing mechanism is required for wind direction. The multi-blade drag-type VAWT is a modified version of windmill type VAWT, initially turbine consists of 12 blades mounted on the cylindrical hub of the turbine. Proposed VAWT design consists of a shaft, shaft housing cylinder, blade housing cylinder bearings and supported frame. In general turbine design blades are often fixed with the shaft, but in this design blades are mounted on a separate cylindrical hub seated on a plate fixed at upper end of the shaft and the lower end of the shaft is connected with generator to convert mechanical energy in to electrical power generation. This design project is estimated for 400 watt power generation at moderate natural wind velocity. Turbine rotor specifications are shown in Table **1**. Generally the rotor height is kept greater then rotor diameter, in this design we proposed smaller rotor height for various reasons (1) whole surrounding area of the turbine is completely covered with the wind accelerating duct in order to improve the natural wind velocity more than 200 times (2) swept volume of the turbine is kept same by improving the swept area of the duct i.e. blade length is enhanced. (3) Maximum nozzle effect of convergent duct can be achieved at smaller rotor height.

Table 1: Vawt Rotat Specifications

VAWT rotor specifications	
Rotor height	609 mm
Number of Blades	12
Diameter of the shaft (d)	20 mm
Rotor Diameter (D)	762 mm
Blade Chord Length	381 mm
Diameter of the paddles for fixing the plate	30 mm
Plate diameter for housing rotor cylinder	711 mm
Thickness of plate	6.3 mm
Length of the shaft	914 mm
Inner cylinder dia for housing shaft	76 mm
Ball bearing	2
Swept area	1196 mm^2

Front view of the turbine integrated with wind accelerating duct is shown in Figure **1**.

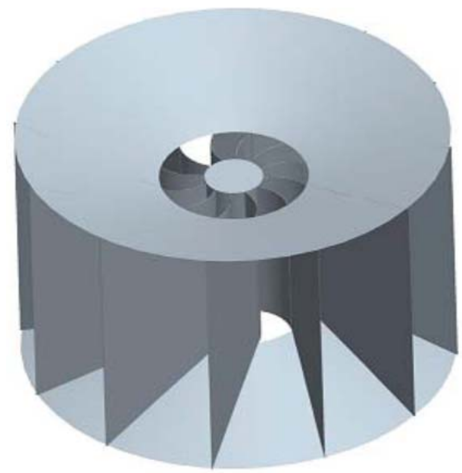

Figure 1: Turbine with integrated duct.

Natural wind with any direction of flow can enter in to the turbine. Figure **2** shows the cylindrical rotor on which turbine blades are fixed at equal length of pitch circle diameter of rotating circular cylinder.

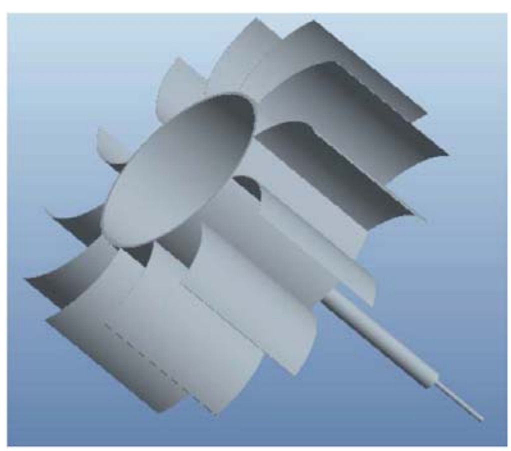

Figure 2: Cylindrical rotating hub.

Figure **3** shows a circular plate fixed on the sleeve of diameter 30 mm and height 101 mm mounted on the upper end of the rotating shaft for fixing the cylindrical rotating hub. Two ball bearings are introduced at both ends of the shaft supported by a fixed frame; whole system is rested on supporting frame for its balancing and vibration control.

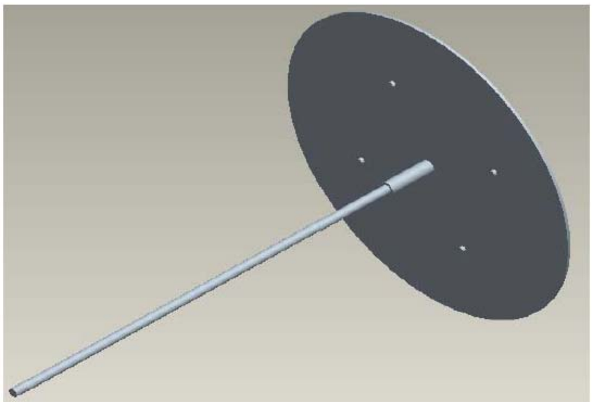

Figure 3: Rotor housing plate and sleeve.

Power output from a wind turbine is calculated as given in Eq. (1).

$$P = 0.5\, Cp\, \rho A_s\ U^3 \quad (1)$$

Where P is the power (W) output from the wind turbine, C_P is the power coefficient, ρ is the density of air (kg/m^3), As= (Height ×Diameter) = (Hs× Ds), is the rotor swept area (m^2) U is the free stream velocity of the wind (m/s) The tip peripheral velocity of the rotor V= $\omega_s \times R_s$ [ω_s is the angular velocity of rotor and R_s = (Ds/2) is the radius of the rotor]. Tip Speed Ratio (TSR) of a turbine is defined in Eq. (2)

$$\text{TSR} = \lambda = \frac{V}{U} \quad (2)$$

Turbines are usually characterized by performance curves, which give C_p as a function of λ (Betz theory) that for a horizontal axis wind turbine, the power coefficient is always inferior to the theoretical value of 0.593. In fact, the best modern machines have maximum value of less than 0.5 [7].

The aspect ratio (A_α) represents the height (H_s) of the rotor relatively to its diameter (D_s). This is also an important criterion for the performances of a Savonius rotor as estimated in Eq. (3).

$$A_\alpha = \frac{H_s}{D_s} \quad (3)$$

III. WIND ACCELARATORS

Limited efforts were devoted to improve the characteristics of natural wind to make it more useable for energy generation. Few efforts were made to accelerate the wind in horizontal axis wind turbines by introducing wind ducts, so for no such efforts have been made for improving the efficiency of the vertical axis wind turbines.

In the present research study main focus is introducing the wind accelerating techniques that can improve the wind characteristics for electrical power generation. Proposed VAWT for power generation will work on less than 3 m/s cut-in speed of air.

1. Converging Duct

The areas where speed of natural wind is not sufficient to rotate the turbine and is less than the required cut-in speed of turbine, wind accelerators provide good option. In this research work vertical axis wind turbine is proposed to be ducted. Accelerated wind stream is guided to hit the near tip of blades at right side of the shaft only. This is made possible by adjusting axis of wind duct with blade tip. Numbers of ducts are proposed to cover 100% of free stream wind coming from all directions in all seasons of the year. A single proposed duct is shown in Figure **4**. Area at inlet of duct for free stream velocity is 4.62 m^{2}and area at outlet of the duct is 0.37m^2

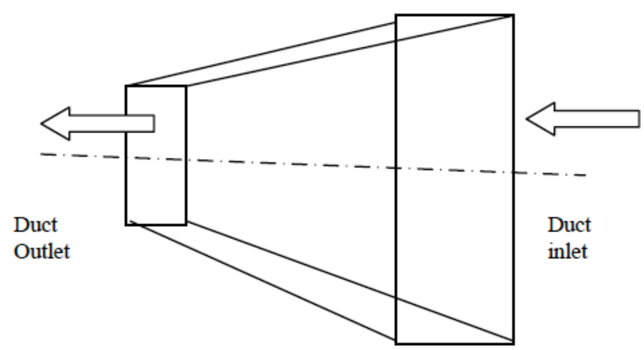

Figure 4: Wind duct.

Natural wind velocity is considered to follow the Bernoulli's flow conditions as given in Eq. (4).

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2 \quad (4)$$

Where P_1 is the pressure, V_1 is the velocity of the free steam wind at inlet of the duct ρ is the density of the free steam wind. P_2 is the pressure, V_2 is the wind velocity at outlet of the duct.

2. Solar-Thermal Air Heating System

This is another integrated part of the VAWT system located at upper bowl like cavity in the designed system. Sami spherical surface of the bowl like cavity will be coated with solar reflecting materials as shown in Figure **5**.

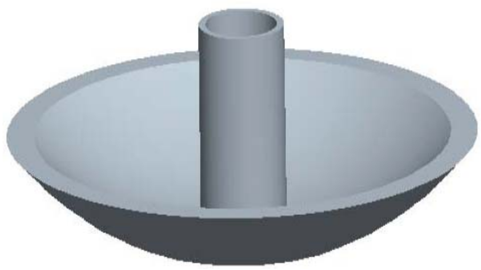

Figure 5: Solar-thermal air heating system.

The reflector of our experimental device consists of a parabolic concentrator of 4.52 m opening diameter. Its interior surface is covered with a reflecting layer which reflects solar rays on the cylindrical heat absorbing surface placed at the focal position of the concentrator. The concentrator is posed on a directional support according to two axes to ensure the follow-up of the sun [12].The surface S of a paraboloid of diameter of opening D whose focal distance f is given by Eq. (5).

$$S=\frac{8\pi}{3}f^2\left\{\left[1+\left(\frac{D^2}{4f}\right)^2\right]^{3/2}-1\right\}-\frac{8\pi}{3}f^2\left\{\left[1+\left(\frac{d^2}{4f}\right)^2\right]^{3/2}-1\right\} \quad (5)$$

The surface of opening of a paraboloid is expressed in Eq. (6).

$$S_o=\frac{\pi}{4}(D^2-d^2) \quad (6)$$

The circular cylinder of external diameter (d) mounted at the center of the paraboliod will act as a heat absorbing surface along the whole length (L) is given by Eq. (7).

$$S_a=\pi dL \quad (7)$$

The cylindrical heat absorbing surface is a stainless steel of a diameter of d, thickness 20 mm and the absorption coefficient of the absorber is 0.9 and thermal conductivity is of 20W/mk. The geometrical concentration C_g of this model is given in Eq. (8).

$$C_g=\frac{S_o}{S_a} \quad (8)$$

IV. RESULTS AND DISCUESSSION

This paper elaborate the design process of VAWT project that will be locally manufactured and tested in the laboratory of mechanical engineering department of Quaid-e-Awam University of Engineering, Science and Technology Nawbashah, Shaheed Benazirabad, Pakistan. At this stage of research design process is proposed, aerodynamics effects are not studied, however preliminary study of solar energy available in the form of temperature readings were carried out in the May, 2011. The weather station model was placed in open atmosphere in the free space of the laboratory to monitor ambient temperature during the day all data was recorded at 60 minutes time interval, temperature variation for a typical day is shown in Figure **6**.

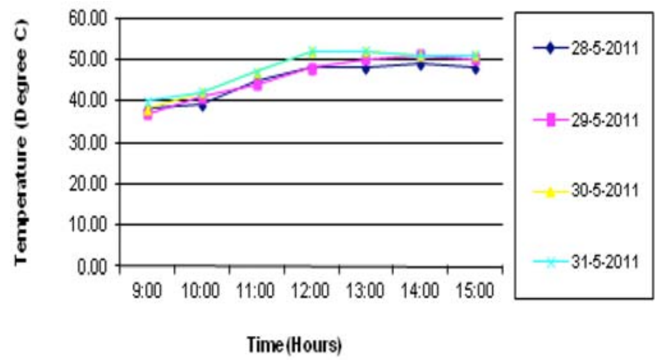

Figure 6: Variation of ambient temperature during the daytime.

Location of the city Nawabshah in global map is significant where solar energy is in abundant quantity, in summer time during the month of May ambient temperature reaches about 50 degree centigrade that will help us in making this project successful [13]. Figure **6** shows the plot of ambient temperature versus time and it was found that temperature initially increases from 9 am and reaches the maximum value between 13-14 hours.

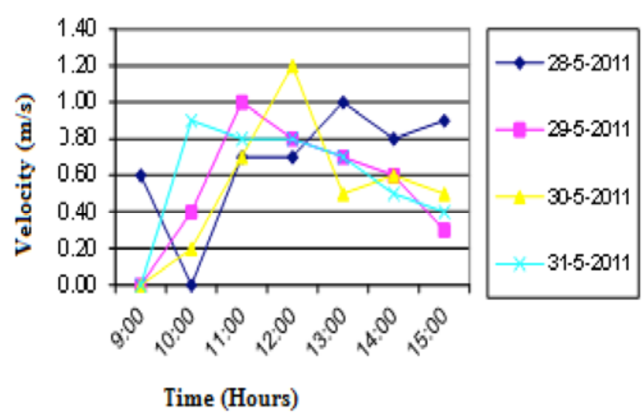

Figure 7: Variation in wind velocity during the day time.

The trend of the wind velocity was found to be varying every day at an average rate Wind velocity was recorded ranging from 0.02 to 2.5 m/s during the period of this experimentation Readings of the natural wind velocity during the month of May, 2011 was recorded as shown in Figure **7**. Natural Wind velocity trend is not attractive for the project, however we require the cut-in speed for proposed wind not less than 2m/s. To mitigate this problem we designed a separate wind accelerating duct as shown in Figure **8**.

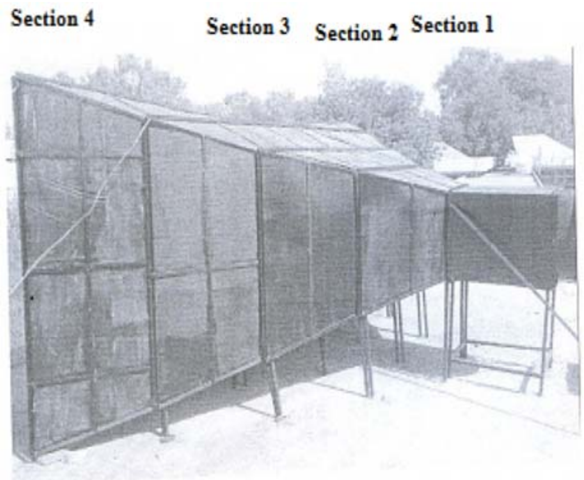

Figure 8: Wind accelerating duct.

Wind accelerating duct consists of four sections of varying inlet/outlet cross-sectional area of the duct; free stream enters from the section 4 and leaves at section 1. To validate the proposed VAWT system development, experimental data recorded in the month of April, 2011 for the section 1 of the duct is presented here. Table **2** shows the increase in velocity of the free stream wind at section1 of the duct.

During sunny daytime average wind velocity is about 1.3m/s can be improved at average rate of 4.07 m/s as shown n Table **2**. Overall effect of free stream wind acceleration is shown in Table **3**.

Table **3** shows the performance parameter of the various sections of the duct column no 3 shows the factor at which the inlet velocity is multiplied with outlet velocity. Column 4 shows the rate at which the factor of velocity amplification increases between two consecutive sections and column 5 shows effect of increase in inlet area of the duct on percentage increase in velocity per unit area. From this preliminary research study it is proposed that this project of VAWT will be a successful effort and contribute nationally to meet the ongoing energy crisis of the community.

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Table 2: Wind Velocity Variation at Section 4 of Duct

Time (Hours)	Wind Velocity at duct inlet(v_i) (m/s)	Wind velocity at duct exit (v_o) m/s	Increase in velocity $\Delta v = (V_o - V_{i})$	% increase in velocity
9.00	1	3.1	2.1	310
10.00	1.49	4.8	3.31	322
11.00	1.13	3.9	2.77	345
12.00	1.78	5.5	3.72	309
13.00	2.08	5.8	3.72	279
14.00	0.91	2.9	1.99	319
15.00	0.87	2.5	1.63	287

Table 3: Performance of Various Sections of the Duct

Section No (i)	Inlet duct area m^2	Factor of velocity amplification at outlet (V_{iexit}/V_{iinlet})	Performance rate($V_{(i+1)}$-V_i) $0<i<5$	% increase velocity/m^2
1	7.31	1.8	-----	-----
2	41.63	2.6	0.8	200
3	21.94	2.93	0.33	166
4	29.26	3.12	0.19	145

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