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Analysis of the Spiral Bladed Vertical Axis Wind Turbine using Subsonic Wind Tunnel

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--ABSTRACT--
In order to meet the high energy requirements, there is need for the evolution of small-scale vertical axis wind turbine (VAWT) for the use in domestic energy generation. This study is aimed at conducting experimental analysis of spiral bladed VAWT for its performance evaluation. The analysis was carried out using low speed open-circuit subsonic wind tunnel. Firstly, the wind tunnel was tested for accurate measurement on the basis of the available airfoil models at different wind speeds. After that, 3D printed models of spiral bladed vertical axis wind turbines with two and three blades geometries were tested at different wind speeds. Drag force on the spiral bladed VAWT was measured through the pressure difference at upstream and downstream around the VAWT model. Torque and the generated mechanical power were evaluated for the two and three bladed VAWT models through the geometric data and the rotational speed in RPM. The cut-in speed of both the models was achieved as 1.81m/s and cut-off speed for two and three bladed VAWT models was 11.8 m/s and 13 m/s respectively. The pressure difference (downstream vs upstream) for two bladed VAWT model was subsequently less than the three bladed model which gives rise to torque generation in case of three bladed model. However, mechanical power generated was observed to be high for two bladed VAWT model.

KEYWORDS: Low Subsonic Wind Tunnel, Spiral Bladed Vertical Axis Wind Turbine, Vertical Axis Wind Turbine, Wind energy.

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I. INTRODUCTION

The current increase in energy demand and diminishing of fossil fuels attracts the production of energy through renewable resources. Wind energy is one of the lowest-priced energy technologies, highly efficient renewable energy resource, Environment friendly and uses little land. With growing wind-energy technologies, research is carried out for utilizing VAWTs for off shore power generation instead of horizontal axis wind turbines. Our study is focused to the analysis of the spiral bladed vertical axis wind turbines experimentally using wind tunnel after fabricating prototype using 3D printing approach and performance analysis of the turbine. Regarding wind turbine design, there are several approaches to analyze the flow field around the wind turbine. The basic approaches are divided into three main methods, including the computational aerodynamics methods, computational fluid dynamics (CFD), and experimental measurements. Very insignificant research was conducted on the effects of flat plates on the performance of the Lift type VAWT [1].

The key purpose of their work was to determine the effects and the flow properties of a flat plate deflector system which is placed at the lower side of the upwind of a two straight-bladed VAWT through 3D simulation. The fluid flow around a static airfoil with a range of set Angle of Attacks (AOA) has been used as a test and validation case by [2]. CFD simulations have been performed to obtain the flow field data around the airfoil at several selected reference-points, and these data are used to calculate the AOAs around this static airfoil and compared with the set AOAs. Effects of design factors such as, types of wind turbines, numbers of turbine blades, height to radius ratios, and design modifications were analyzed by using CFD-based simulations within a virtual wind tunnel by [3]. The VAWTs were performed to investigate effects of the design factors on mechanical performance under wind speed conditions from 1 m/s to 6 m/s. The Savonius-type VAWT, with cover-added pattern and perpendicular double layers, yield great mechanical performance. A Rotor House (RH) for vertical axis wind turbine was proposed by [4]. It has been shown that the RH utilizes free stream wind parcel of the area nearly double than the swept area of rotor and amplify velocity magnitude in the rotor zone up to 1.52 times the value of free stream velocity. Rotor house accelerates flow of wind in the area of rotor by creating venturi effect, and passes the flow over the effective location of rotor blade located within the structure. Rotor house improves the power coefficient of rotor from 0.125 to 0.218. Before using wind tunnels for precise measurement of the behavior of the flow, corrections and calibrations are of prime importance to decrease its uncertainties. The first time an atmospheric boundary layer type wind tunnel was calibrated [5], in which the intensity of turbulence was achieved as 0.02% and the gradient of axial pressure achieved was 0. Standard methods and verification items for a wind tunnel (low speed open-circuit) operating at environmental conditions were developed by the researchers of the Singapore, Denmark and Argentina being operated at wind speeds lesser than 27 ms-1 [6]. The turbulent intensity of flow was achieved as approximately 1% and flow uniformity was in the range of 0.5% to 3%.

Laser Doppler Velocimeter (LDV) was used by [7] to carry out successive research to calculate the un-steady flow through a VAWT having straight-blades, where a wind tunnel with circular cross section and flow uniformity of 1.2% was used at the free stream wind speed of 8.0 ms-1 and intensity of turbulence was kept less than 0.5%. It was observed from the results that by increasing tip speed ratio (TSR) the range of low wind velocity expands. It was observed that as the number of blades was increases from 2 to 5 there was a decrease in the power coefficient from 0.410 to 0.326 by [8]. Moreover, the performance of the wind turbine was merely dependent on the blade's pitch angle, and at pitch angle of 6o the maximum power coefficient was found to be [9]. Tests were made in an open cross-section type test section wind tunnel for the their newly developed VAWT of Savonius type [10], which was named as SSWT. The static torque coefficients increased due to modification of blade's arc geometry, furthermore, it also reduced the influences of negative torque. This modification led to the enhancement of the power produced over the modified Bach type by 3.3%, Banish by 6.9%, semi elliptical by 19.2%, and conventional SSWTs by 34.8%. Impacts on VAWT's performance was investigated experimentally in a open channel low speed wind tunnel using PIV at steady and un-steady wind conditions by [11]. When VAWT was operated, performance of wind turbine was improved at the TSRs higher as compared to that power coefficient is maximum in the steady wind. Although, the use of VAWT is still limited because these are not capable of self-start and are less efficient.

II. METHOD AND MATERIALS

In order to experimentally analyse the behaviour of the spiral bladed VAWT's two dimensionally similar models of the two and three bladed wind turbines were first designed using Solidworks 2015 software, those models were then physically built using AFINIA 3D printer. Each of the wind turbines were having a height of 200 mm and diameter of 100 mm, these dimensions for the models were selected as per the dimensions of the test section of the available wind tunnel. Then, the models were tested for determination of the power, torque, and RPM by varying the wind speed in the wind tunnel. Models of the spiral bladed VAWT's were then brought up for the experimental analysis in the Aerodynamic Laboratory at Mechanical Engineering Department Mehran UET, Jamshoro. TecQuipment AF100 low subsonic wind tunnel was used for analysis having square shaped test section with 305mm × 305mm × 600mm dimensions. Results were obtained by varying the wind speed, while RPM of the turbine were measured using laser tachometer.

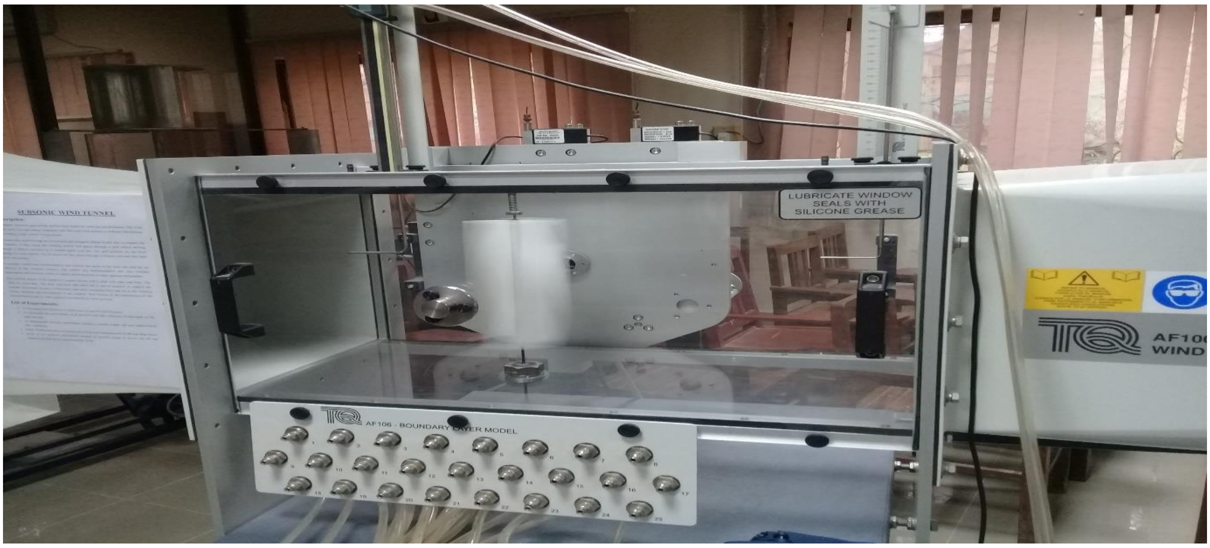

Fig.01. Experimental Setup for Wind Turbine Model in AF100 Subsonic Wind Tunnel

Figure. 01. Shows the model of two bladed vertical axis wind turbine mounted in subsonic wind tunnel. Upstream and Downstream pressure values are measured by connecting the tubes to the pressure gauges at the top of the test section to the instrument panel at variable the wind speed.

III. RESULTS AND DISCUSSIONS

Following results were obtained from the experimental setup:

Table No.01: Results for the two bladed vertical axis wind turbine model

Sr. No.	Upstream Wind Speed (m/s)	Rotational Speed (RPM)	Upstream Pressure (Nm^{-2})	Downstream Pressure (Nm^{-2})	Force (N)	Torque (N-m)	Power (Watt)
1	1.81	670	1	1	0	0	0
2	3	803	5	2	0.06	0.003	0.252
3	5	1250	15	9	0.12	0.006	0.785
4	7	1665	29	10	0.38	0.019	3.313
5	9	2081	51	22	0.58	0.029	6.319

Table No. 01 shows the pressure values at upstream & downstream region of the model and rotational speed in RPM with respect to the upstream wind velocity. At cut-in speed, the rotational speed of the wind turbine was achieved as 670 RPM. Drag force was calculated by multiplying the area of the turbine to the pressure difference created across the wind tunnel test unit. Drag obtained at cut-in speed is zero because of no pressure difference, then it increases linearly with the wind speed. Torque and mechanical power are calculated on the basis of the drag force.

Table No.02: Results for the three bladed vertical axis wind turbine model

Sr. No.	Upstream Wind Speed (m/s)	Rotational Speed (RPM)	Upstream Pressure (Nm^{-2})	Downstream Pressure (Nm^{-2})	Force (N)	Torque (N-m)	Power (Watt)
1	1.81	540	1	1	0	0	0
2	3	640	5	1.5	0.07	0.0035	0.23457
3	5	1010	15	8	0.14	0.007	0.74037
4	7	1320	29	9	0.4	0.02	2.7646
5	9	1650	51	20	0.62	0.031	5.35642

Table No. 02 shows the pressure values at upstream & downstream region of the model and rotational speed in RPM with respect to the upstream wind velocity for three bladed model. At cut-in speed, the rotational speed of the wind turbine was achieved as 540 RPM, which is low as compared to the two bladed model.

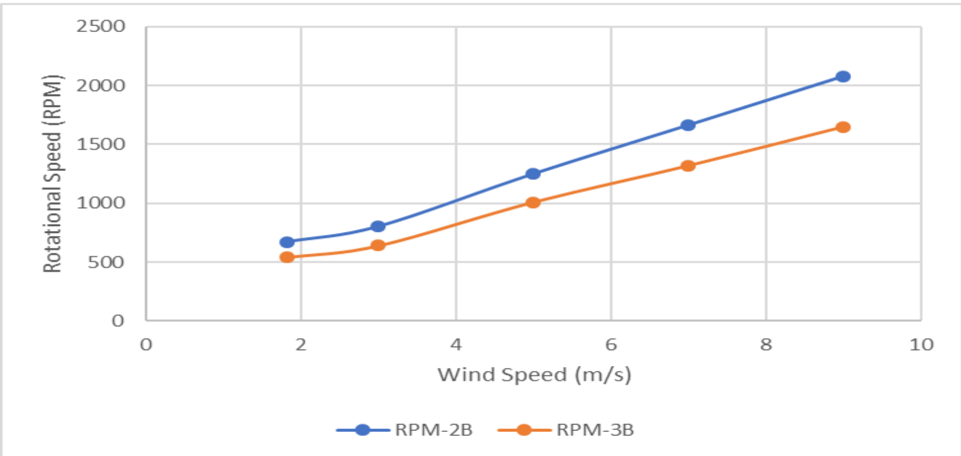

Fig.01. Relation between Wind Speed and Rotational Speed

The figure.01. shows the relationship between the upstream wind speed and rotational speed. It is clear from the graph that the rotational speed is greater in case of the two bladed wind turbine model as compared to the three bladed wind turbine model. The wind turbines started to rotate at a cut-in speed of 1.81 m/s so the graphs show no any value of rotational speed before achieving cut-in speed.

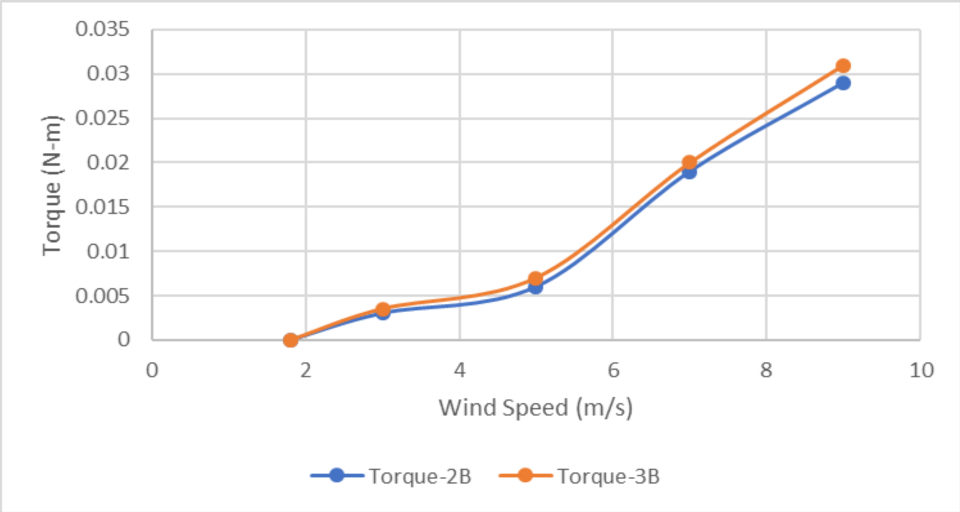

Fig.02. Relation between Wind Speed and Torque Generated

It could be inculcated from figure.02, that the torque generated in case of the three bladed wind turbine model greater as compared to the two bladed one that is because of the fact that there is higher pressure difference generated because of more number of blades which causes the pressure loss.

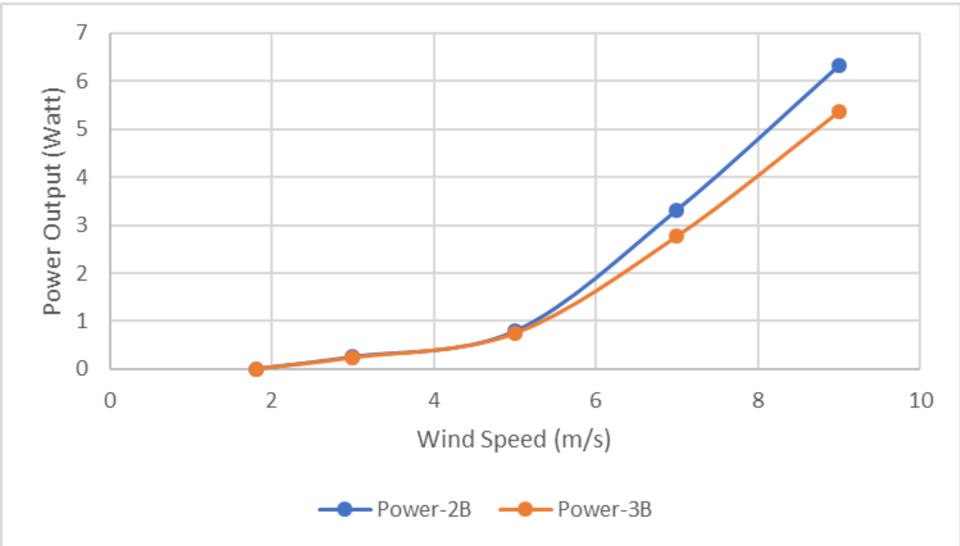

Fig.03. Relation Between Wind Speed and Power Output

Figure.03 show that the power generated in case of the two bladed wind turbine model is higher than that of the three bladed wind turbine model.

IV. CONCLUSION

It is concluded from the above results that although there is significant pressure drop in case of vertical axis wind turbine with three blades which leads to more torque generation, but output power of the two bladed vertical axis wind turbine model high because of a greater number of RPM generated in this case.

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