Experimental investigation into the effect of obstructions placed in the downstream of a straight blade VAWT

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***Abstract* - The straight blade vertical axis wind turbine is widely used in urban locations for small scale power generation. The presence of obstructions like buildings, roofs in the downstream of a vertical axis wind turbine produces anti torque on the turbine and reduces its rpm. This paper presents the experimental investigation of the effect of obstructions placed in the downstream of a straight blade vertical axis wind turbine. The experiment is conducted in an open blower for various wind speeds and geometries of the obstruction plate. This study is helpful for fixing the location of small vertical axis turbines on top of buildings in urban locations**

Keywords-* *VAWT, Obstruction effect, wake flow

I. .INTRODUCTION

With the recent surge in the cost of non renewable energy resources, people have started to rely on wind energy for small scale power generation just like the case of solar power. Horizontal axis wind turbine (HAWT) is widely used in the wind energy market because of its high power generation capacity. In spite of the popularity of HAWT, vertical axis wind turbine (VAWT) is still used in developed countries like America, France etc. This is because of the economy of fabrication, ease of mounting, placement of generator on ground and Omni directional feature of VAWT. The simplest turbine in the vertical axis category is H-type straight blade turbine. The experiment was conducted using a three bladed H-type VAWT. This was chosen to avoid stalling. [6].

H-type VAWT comes under Darrieus VAWT which operates using the lift force generated by the blades. There are two forces acting on the turbine- lift force and drag force. When the wind is in the leeward side, lift force is higher than the wind ward side and vice versa. This pressure difference produces a force and pulls the aerofoil. This principle which is also known as Bernoulli's principle is the basis of straight blade vertical axis wind turbine. With the increase of the angle of attack of the blade, the distance travelled by the air in the leeward side will increase. Most studies conducted so far used symmetrical aerofoil for the blade cross section. But for this experiment, the unsymmetrical aerofoil NACA 4415 was chosen for the cross section of the blade. It produces lift even at zero angle of attack. Straight blade vertical axis wind turbine is commonly used for small scale power generation like theatres, restaurants, motels etc. Wake aerodynamics of the vertical axis wind turbine is very complicated and inherently unsteady. The wake of vertical axis wind turbine consists of shed and trailed vortices. Chenguang He [5] conducted a study on wake region and observed strongest wake contraction occurs at the leeward side and the strongest wake expansion at the extreme windward side of the rotor.

The location of the turbine such as building tops, tanks, etc is very crucial to the performance of the turbine. Experimental studies have given much importance to the upstream conditions of the turbine. Dageyoum Kim[1] conducted a study on the improvement of efficiency using an upstream deflector. In the present study, the variation of efficiency of the turbine due to the placement of an obstruction or a deflector in the downstream of the turbine is investigated. The efficiency varies because of the Omni directional property of this kind of wind turbines. Factors such as the location of the obstructions, the dimensions of the obstructions and the angle of slanting roof have an effect on the turbine rpm and reduce its efficiency. In urban environment, wind velocity is comparatively less than other high wind velocity zones, and also the turbulence level is high. To study these conditions, open blower test is preferred to wind tunnel analysis.

II. EXPERIMENTAL SETUP

Experiments were conducted using open blower setup available in Madras Institute of Technology (MIT) Chennai. The rpm of the blower can be varied using the control mechanism (regulator) installed in the blower. The regulator used was a silicon controlled rectifier based 7-stepper. Calibration of the blower was the first step of the experiment. Calibration was done using a Pitot static tube connected to a pressure scanner. The computation of velocities at various points in the flow field was done by measuring the total and static pressures at various points. It was found that the velocity at different points varies and turbulence level was comparable to that of urban environment. The model was placed outside the blower in an open atmosphere. Since the experiment was conducted at very low speeds the static pressure was assumed to be the atmospheric pressure. The rpm of the turbine was found for each free stream velocity condition.

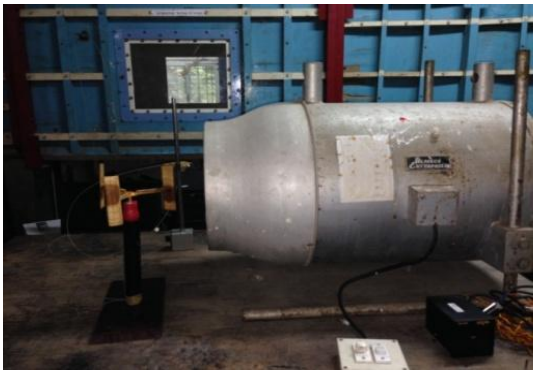

Fig.1 Open blower and mini VAWT for testing

The maximum velocity (v) achieved using the blower was 9m/s at an rpm of 1250. The minimum velocity achieved was 2.75m/s at an rpm of 468. Tests were carried out for about 6 low free stream velocities- 2.75, 3.67, 4.77, 5.1, 6 and 9 m/s. Test were conducted on the mini vertical axis wind turbine, the prototype of which was designed for Indian metrological conditions. It was a three bladed turbine. The aerofoil profile used for the blade design was NACA 4415 and it was connected to a strut. It is a fixed pitch angle turbine with the pitch angle as 95 degree. Diameter of the turbine was 18 cm and blade length was 10cm.The chord length of the blade was only 1.6cm and solidity was 1.5. [Fig-1]

The blade was well polished. In a vertical axis wind turbine mass of the turbine plays a major role. The mass was calculated to be 25gm including 3 connecting struts. The obstruction plate was made of wood and well polished in order to avoid frictional effects. Three obstruction plates were made for three different heights (H) 20cm, 40cm and 80 cm. The width of the obstruction plate (W) was kept constant as 20cm. Sensor ST18-3008PA was used for measuring the rpm of turbine. For measuring the rpm, a metal strip was placed in the blade. The Sensor senses the metal placed in the blade each time the particular blade with the metal strip passes over the sensor. The RPM was indicated using RC2100 indicator

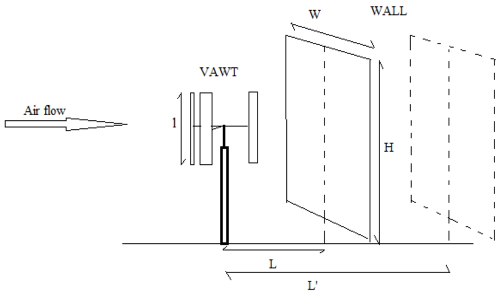

Fig.2. Schematic diagram, arrangement of obstruction plate

The experiment was conducted in four phases. Phase-I : the wind velocity is kept constant at 9 m/s and the distance of the obstruction is varied .Phase-II: the distance of the obstruction is kept constant at 20 cm and the velocity is varied .Phase-III: velocity and distance is constant, but the size of the obstruction is varied. Phase-IV: the free stream velocity, the distance (L) and the H/W ratio is kept constant and the roof angle is varied. For every experiment rpm of the turbine was measured and the torque was calculated.[Fig-2]

III. OBSERVATION AND RESULTS

The rpm of the mini vertical axis wind turbine for different free stream velocity conditions was observed and the torque was calculated for each rpm. The maximum torque produced by the turbine for the maximum free stream velocity of 9m/s was 0.309N. The graph between the free stream velocity and torque of the turbine was plotted [Fig-3,4]. The effect of the distance between the axis of the wind turbine and obstruction plate on the rpm of the turbine was studied. Maintaining the velocity (9m/s) as constant, the test was carried out with 3 obstruction plates with H/W=1, H/W=2, H/W=4, where H is the height of the obstruction plate and W is the width of the plate. Throughout the study, the distance of obstruction from centre of the turbine (L) was made non-dimensional by dividing the value with the turbine blade length (l). It was observed that H/W was significant for low L/l values. With the increase of L/l, the effect of the size of obstruction got reduced. This was because of the fact that the blockage produced by obstruction plate affected the wake flow of the turbine and resulted in a shear layer formation which in turn reduced the air velocity behind the turbine. When the distance from the turbine was increased, the wake region diminished and so the effect got reduced. The effect was significant only at strongest tip vortex region. With the increase in distance the strength of tip vortex reduced. It was also observed that the downwind released tip vortices were much weaker due to the induction of upwind wakes.[Fig-5]

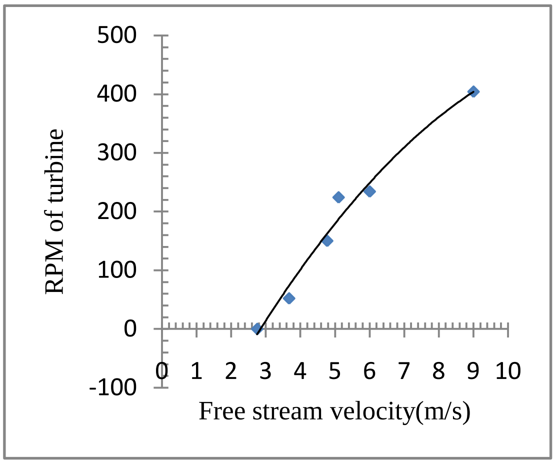

Fig.3 Variation o rpm with respect to free stream velocity

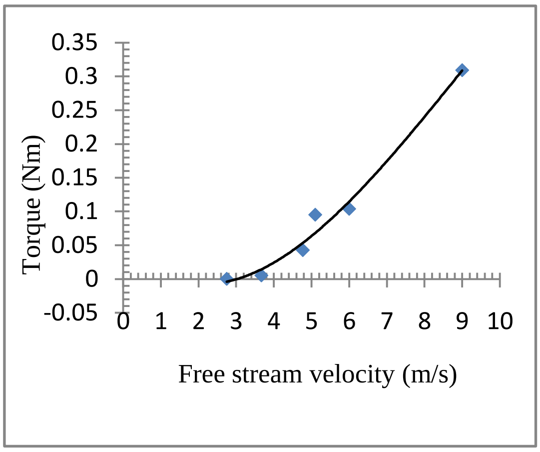

Fig.4 Calculated torque variation for turbine for different free stream conditions

In the second study H/W was made constant and the effect of different free stream velocity at different L/l conditions on the turbine rpm was observed. It was noticed that the effect of L/l on turbine efficiency was higher at high velocities.[Fig-6]Detailed analysis of the no effect point was studied. No effect point is L/l at which there is no effect on obstruction in turbine rotation. At the H/W 1, 2, 4 the minimum L/l is 4.5, 4.2, and 3.8 respectively.

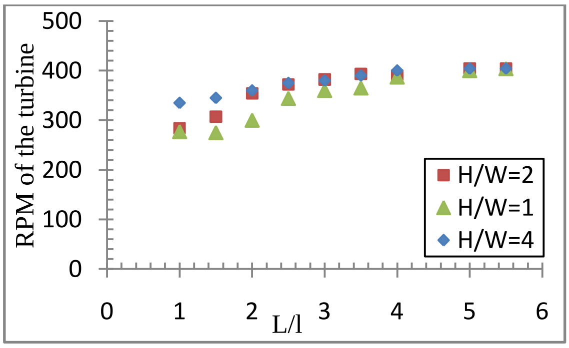

Fig.5 Effects of L/l on RPM of turbine at different H/W conditions

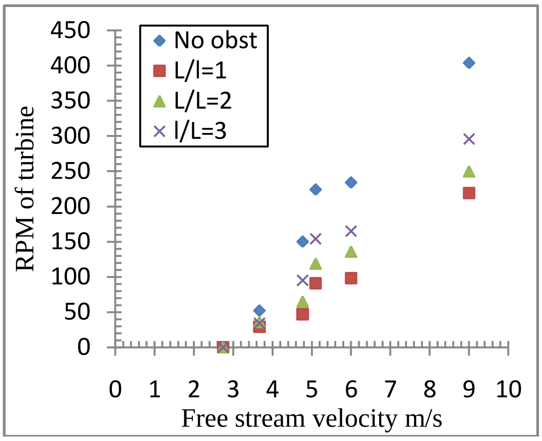

Fig.6 Effects of free stream velocity on RPM of turbine at different L/l conditions

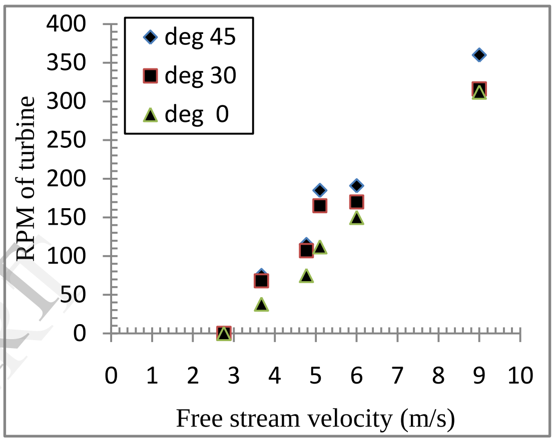

Fig.7 Effects of free stream velocity on RPM of turbine at different angle of obstruction plates

Slanted roof also would create a disturbance in turbine wake flow region. It depends on the semi cone angle of slanted roof, as that angle increases flow disturbances also increases and results the reduction in the coefficient of the turbine. [Fig-7]

IV. CONCLUSION

The effect of an obstruction placed in the downstream of the turbine for different conditions and different dimensions of obstruction plates, on the rpm of the turbine was investigated. And preferable minimum L/l was proposed for fixing the location of turbine. These data may be useful for fixing the location of turbine over the buildings in urban conditions for small scale energy production. Besides the presence of nearby building, the chimneys of houses, advertisement boards, nearby beams in the downstream of turbine may also reduce the turbine rotation. This study was limited for specific model of turbine and velocity range that were considered very less. Throughout the study the wind direction was same but in reality the wind direction will change based on the weather conditions.

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