Development and Field Trials of Ultra Low Wind Speed Vertical Axis Wind Turbine (VWAT) for Home Application

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Abstract

Objectives: The turbine is of 1.5 m diameter and two bays of 0.5 m length blades NACA 0015 airfoil profile is used for the fabrication of hydrofoil blades. Glass fibre reinforced poly pipeline is used for the fabrication of the blades. The blades are assembled to a 50mm KTEC pipe to form a 1.5 m diameter ring. 200 watts ultra low speed Permanent Magnet Alternator (PMA) was used with suitable electronic circuit and battery backup. Methods/Statistical Analysis: Field trials were conducted in the salt extraction filed of Chemfab Industries at Marakkanam. Since the initial results are encouraging and proves the technology of the concept, it is proposed to develop more turbines. Findings: In this paper development and results of the field trials of an ultra low wind speed vertical axis wind turbine are presented. Application/Improvements: This type for use in the coastal areas with larger dimensions to harvest higher green energy.

Keywords: AC DC Converter, Chopper Circuit Application, Home Turbine, Hydrofoil Blades, PMA, VWAT

1. Introduction

As the global population increases the need for electrical energy also increases exponentially, hence non-conventional and non-polluting means of producing energy, without affecting the environment has been of greater significance in recent times. The Horizontal Axis Design has been used in the wind mills.

By using multiple blades in the turbine, the kinetic energy of the wind is converted to mechanical energy. The traditional wind turbines occupy a larger space and the noise levels are not controllable. Also these turbines cut the speed of the wind and generate energy. A turbine which works along with the wind direction is preferable as this would occupy less space and low noise levels. Ultra low speed vertical axis wind turbines are designed to operate even at low wind velocities as low as 1 m/s. For reducing the loss of transmission of electrical power the ultra low speed vertical axis wind turbine is preferred for localized power generation and distributors.

The Horizontal Axis Wind Turbine are extensively installed in various places the major difficulty is installation is perpendicular to the wind direction. But the vertical axis turbines position is independent and the major advantage is the operation takes place to any wind direction. VAWT is further classified as lift and drag turbines depending on the predominant force. Of the two lift turbines are more efficient. For Multi-Directional uniform wind speed an optimal Wind Turbine Micrositing VAWT has been done by

2. Design Criteria

2.1 VAWT Basics

Figure 1 shows an Off – Shore Wind farm installed with a number of horizontal axis wind turbines.
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Basics of VAWT are given in 3. VAWT concept has different blade shapes. Large amount of forces experienced by the turbine rotors, require the Troposkien (Nearly Parabolic) shape as the ideal shape. The centrifugal force is translated through the blade is directed to the shaft. Large rotational speeds warrant for the use of large diameter turbines. The turbine has decreasing radius at both the ends. When the speed is less, no power is generated. H-Darrieus or Musgrove developed vertical axis turbine with straight blades and the power is generated over entire surface area. In this additional strength is required to withstand the centrifugal forces.

Parts of VAWT are:
- vertical Structural assembly
- Shaft
- Blades and support members
- PMG and AC/DC converter

Thickness of the blades takes care of the loads. The shape of the turbine blades determines how the wind energy is converted to torque about the axis of the turbine. The development of the turbines was based on symmetrical standard air-profiles. Experimental data on the performance of the turbines with these profiles is not yet available. For small Reynold’s number (with non-availability of data) small diameter turbines are developed.

Figures 2a and b show the Two Dimensional and Three Dimensional schematic diagram of Vertical Axis Wind Turbines.

2.2 Basics of Aerodynamics

The aerodynamics involved in HAWT is more complicated than the VAWT. The reason is in VAWT the axis of rotation is perpendicular to wind direction. The turbine works independent of wind direction and the angle of attack is more as can be seen in Figure 3.

Depending on the wind speed level, the speed can be varied by the turbine control system. The angular velocity and the tip speed ratio \( \lambda \) of the turbine given in equation (1). This parameter represents as factor of the

\[
\lambda = \frac{R \omega}{V_{\text{inf}}}
\]

where the tip speed as \( R \omega \) and the free stream velocity is \( V_{\text{inf}} \).

The viscous behavior of air is measured by Reynolds Number:
The energy produced in the turbine represents the performance coefficient. The height times of the diameter is equal to the bluff area of the turbine. At a certain Reynolds number, the tip speed ratio is plotted by $\lambda$.

3. Flow Conditions

Wind velocity conditions are important for the working of VAWAT which are given in the following sections.

3.1 Angle of Attack

A wide range of angles of attack experienced by the turbine the blades experiences while starting to reaching the high rotational speeds in the site conditions. Increase in speed, results in the decrease in angle of attack. Increase in speed has less influence on the free stream flow. The blade will be optimized for a vertical axis turbine operating at a tip speed ratio of 3. A Large angle of attack is desirable to vary the azimuth angle of the turbine. This is desirable at early design stages to allow the blades to extract energy from the air flow from the up wind side.

Figure 4 Shows the NACA 0015 Aerofoil Profile for turbine Blades.

3.2 Condition for Stall

An increased angle of attack results in airflow separation for a wing. This allows for increase in the angle of attack by shifting the tailing edge in the forward direction. Further an increase in angle of attack shift the separation to the leading edge. This phenomenon is called deep stall. At very low Reynolds numbers separation can occur at the air foils nose right away. If the air foil is in deep stall, this condition will be maintained for some time, even if the angle is decreased again. This will cause a hysteresis loop. This phenomenon has a strong negative influence on the performance of the blade, because in the loop the lift is low and the drag remains high. The angle at which deep stall occurs dependents on the Reynolds number and the nose radius. In the VAWT application of air foils large angles of attack are encountered. At the operating tip speed ratio this phenomenon therefore should be avoided or its influence should be kept as small as possible.

3.3 Dynamic Stall

Dynamic stall is a phenomenon that occurs at air foils with rapid changing angle of incidence which is identified by vortex flow variation over surfaces with less pressure. Dynamic stall is used in the design of helicopter and fighter aircraft. These are used for wind turbines also. The vertical axis wind turbine has stall when the change of angle of incidence is large and at low TSR. The stall occurs when the blades complete a circle and there is influence of lower level and upper level of blades. First visualization of the dynamic stall for the VAWT was done by have studied the dynamic stall at high Reynold’s number. With TSR 1 - 8, blades made of 0021 profile.

The first vortex flow exists both at the leading edge and opposite direction at the trailing edge. A confirmation to the effect was made on a NACA 0018 blade Darrieus turbine. This condition exists at low TSR as the large incident angles. Dynamic stall is of less significance for ratios, above 4. Increase in noise, vibrations and blade fatigue result.

3.4 Reynold’s Number

Small turbines operate at low Reynold’s number. NACA 0015 profile the maximum lift co-efficient and are used in practice for small turbines. Some research works were performed on VAWT by. The chord length and wind speed were the parameters studied.

3.5 Virtual Camber

have studied the curvilinear and rectilinear flow conditions. In rectilinear flow, Symmetric profiles
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Performance depend on camber and incident angle. The influence of the curvilinear flow field on the blade chord to turbine radius ratio, if large, effect of curvilinear flow conditions are increased. The lift curve is shifted upwards by camber. This causes the trend to shift to the left side. These factors are not yet established for VAWT.

4. Fabrication of VAWT

4.1 Fabrication
The fabrication of the turbine involves the fabrication of blades of size NACA 0015, 100 mm chord length KITEC pipes are used for fixing the blades.

The dimensions of the turbine were:
- Height: 1000 mm
- Diameter: 1500 mm

First, the helical profile is formed on the outer surface of 200 mm diameter pipe, then a template of the shape of the air foil used was made. By using this template, the profile was built using FRP. The FRP is arranged in layers sandwiched between resins.

5. Testing
Testing the turbine was the important part of this work. The tests were carried out in different places like Marakanam, Roof top of the college premises. Wind speeds were recorded using Anemameter. Figure 5. Shows Aerofoil Profile for Turbine Blade. Three dimensional Hydrofoil Blade Profile designed using solid works 10 is shown in Figure 6.

Figure 5. Hydrofoil profile for turbine blade.

Figure 6. Fabricated turbine.

6. Results and Discussion
The testing of the turbine revealed that the turbine output increased as the wind speed increased. The results of the test were tabulated and the following graph was obtained.

7. Conclusion
The results of tests conducted on our VAWT at different conditions reinstated that the VAWT rotor is a high speed device of greater efficiency compared to horizontal axis wind turbines. It seems likely that this device will find use in the conversion of wind energy to electric power especially if used on a large scale in conjunction with the grid. In fact a 200 kW turbine driving a generator is currently being tested in Canada. With such large devices it is quite feasible to have adequate control systems for starting and controlling the operation. In India, the mean wind speeds are high during certain period of time and at such times it would be feasible to economically convert wind energy to electric power for grid augmentation. And at times when the wind speed is found to be low, the practical use for wind power is likely to do direct water pumping for drinking water and minor irrigation purposes. The water pumping application generally implies high starting torque and low control costs. Hence it appears, at least from our testing experience, that VAWT turbines are likely to be of much use in the Indian context.
This paper deals with only the preliminary testing aspects of our model and based on the upcoming tests, further improvements to improve the operational efficiency will be incorporated.

8. References

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