

1 KW Vertical Axis Wind Turbine with a Direct Driven Pm Synchronous Generator

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ABSTRACT: Experimental results from a three bladed vertical axis wind turbine with a direct driven PM synchronous generator are presented. The H-rotor turbine, independent of wind direction, does not require any yaw mechanism. Furthermore, the variable speed, stall regulated turbine does not require pitch mechanism. The specifically designed directly driven generator eliminates the need for a gearbox. All electrical equipment, including generator, are placed on the ground. This reduces the weight that has to be supported by the structure and simplifies maintenance. Thus, the overall strength of this concept is simplicity.

I. INTRODUCTION

Darrieus turbines are well known Vertical Axis Wind Turbines with beautiful and unique curved blades, which remove centrifugal force on the blades. Vertical Axis Wind Turbines are one of the useful renewable energy systems. They have several advantages in comparison with conventional, propeller-type, horizontal axis wind turbines [1]. For example, conventional wind turbines have to be set into the wind direction to operate at maximum efficiency; however, VAWT operate independently of the wind direction. Moreover, the maximum power coefficient can be obtained at lower TSR compared to conventional wind turbines. Flow induced noise is therefore less than that of conventional turbines. Although VAWT have high performance and advantages in comparison with conventional wind turbines, the operations of VAWT are limited to use for laboratory experiments. Or, they are in parks as monuments or symbols for renewable energy systems. One of the disadvantages of the VAWT is weak self starting. In the case of low TSR, the average torque of the turbine is equal to almost zero or sometimes it's negative. Therefore, starting motors or engines are required. The other problem of the VAWT development is that the effective operation range is small. Although the maximum power coefficient of VAWT is almost the same order as the conventional ones, the band width of the TSR in the effective operation range is too narrow for electric power generators. This disadvantage reduces the net amount of the electricity generation per year. In order to improve on these disadvantages, we should consider flow fields around a VAWT. However, the flow field around a VAWT is complicated, because of the interactions of the large separated flow and wake itself. The flow field of VAWT is essentially unsteady, turbulent and separated flow. To simulate flow around a VAWT and estimate its aerodynamic performance, numerical flow simulations were carried out. To simulate large separated flow from turbine blades, the sub-grid scale turbulent model was adapted. The sliding mesh technique was also introduced to simulate the rotational blades. The numerical results were compared with the calculated results based on momentum theory.[1]

II. SITING

The idea behind this location was to construct the turbine in a well characterized wind site. The site has been equipped since 2010 with anemometers at various heights from 2 to 16 m. The wind shear average profile is therefore known in figure

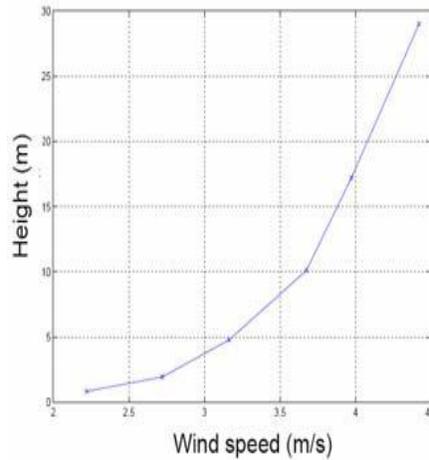


Figure1. Average velocity profiles due to wind shear[2]

The Weibull fit of the wind speed data gives a scale factor of 5.24m/s and a form factor of 1.94. Although the chosen site is not showing a high average wind speed, this wind regime. In particular, the average wind speed (6m/s) for a class turbine is attained during the three more windy months of the year during which the tests were conducted in figure

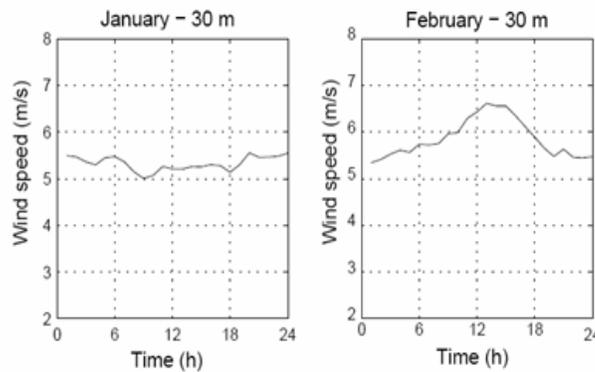


Figure2. Monthly averaged wind speed over a day from January to February

The terrain is such that it basically shows two main characteristic wind conditions, a less turbulent regime when the wind is blowing from the west direction (turbulence intensities below 10% at 6m height) and a highly turbulent regime when the wind is coming from the north over a forest with turbulence intensities of typically more than 20%. [3]

The turbulence intensities are calculated from an anemometer placed at 5m height and three rotor diameters upwind of the turbine and using the procedure from the BWEA Small wind turbine Performance and Safety standard [11].

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III. WIND TURBINE CHARACTERISTICS

III.a Turbine specifications [4]

In table 1 the most important design parameters are presented, electrical parameters excluded. The turbine is rated as a 1kW turbine at 5m/s. With its 920 mm height blades and diameter of 1m it

Rated rotational speed (m/s)	40
Rated tip blade speed (m/s)	26
Rated wind speed (m/s)	5
Number of blades	3
Swept area (m ²)	0.92
Hub height (m)	2.3
Turbine radius (m)	0.5
Blade length (m)	0.92
Chord length (m)	0.25
Solidity	0.25
Aerodynamic control	Stall
Blade airfoil section	NACA 0012

Table1. Turbine specification

The H-rotor consists on three blades with tapered NACA0012 wing sections connected to the rotating shaft through streamlined struts inspired by the NACA0025. The NACA0012 profile is used instead of the NACA0018 previously chosen due to the smoother stalling behavior of this section at high angles leading to less stall induced harmonics. The shaft, enclosed by a supporting tubular tower,[6] is directly connected to the rotor of the generator. One of the main benefits of this concept is its inherent simplicity which should limit the maintenance costs. Power absorption is limited by passive stall regulation controlled by the generator. The wind turbine is designed to be operated at a tip speed ratio of four but as soon as the wind speed reaches 10m/s the rotational speed is kept fixed to implement stall regulation and to limit the centrifugal forces acting on the blades and struts. The generator is specifically designed for high over load capacity (more than a factor of 2). It can slow down the turbine in strong winds which ensures a safe and reliable operation. An auxiliary winding in the generator's stator is used to start the turbine since the H-rotor is not self-starting with the current design.

III. b. Generator specifications

The generator used with this wind turbine is a direct driven permanent magnet synchronous generator. When using a direct driven generator, there is no need of a gearbox and associated losses are eliminated. Furthermore, the direct drive reduces the tensional constraints on the shaft imposed by Eigen frequency oscillations. By using high-energy permanent magnets the electric excitation of the rotor becomes unnecessary and rotor losses are thereby eliminated. The stator winding consists of circular cables, which gives an evenly distributed electric field in the cables and hence better use of the insulation material.

The generator was designed using a finite element method and extensive simulations gave the design parameters presented in table 2. The generator was constructed according to the geometrical parameters presented in this table.[5]

IV. a) Data acquisition and treatment

The data was acquired and stored using two oscilloscopes Tektronix TDS 2024 and TPS 2014. It corresponds to the wind speed data from the cup anemometer placed 3 rotor diameters upwind of the turbine and at 5m height, and to the currents and voltages for the three phases. Each data record is of 50s length. 50 sets of data are treated simultaneously and correspond to the same day under the same control rule. The sampling frequency is 50Hz. Each point corresponds to one instantaneous value for electrical power and one instantaneous value for the wind speed. The rotation speed is deduced from the electrical frequency of the generator knowing the number of poles. From the electrical power the mechanical power is given. Where is the mechanical friction coefficient due to the losses in the bearings, $f_{Cel}\eta$ is the electrical efficiency from the generator obtained from generator simulations, ω is the rotation speed in rad/s and J is the inertia[7](which has been evaluated as 240 Js²). From the deduced mechanical power. where A is the turbine swept area, ρ the air density and U the wind speed.

IV. RESULTS

actual C_p curve was obtained by the method of bins as classes of TSR as described in [18]. For this control rule, the probability density function of the TSR follows Figure 9 and the mean value of the TSR is 3.5. Hence, the results in terms of power coefficient will be accurate only in a small interval around 3.5. Instantaneous points lower than 3 and higher than 4 should not be taken into account. [8][13]

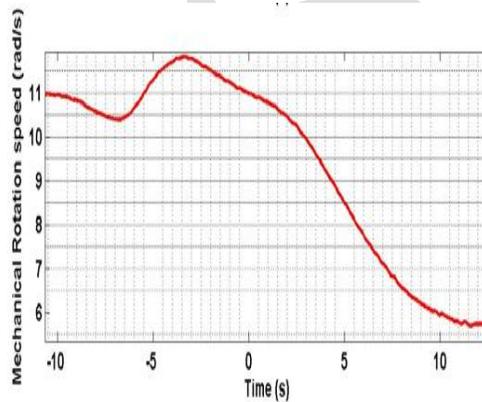


Figure3. Tip speed ratio distribution

Measurement results

In Figure, the wind speed can be seen as a function Of time. A time delay has been applied to the wind Speed data, Considering the distance between the Anemometer and the Wind turbine, the mean wind Speed, the time constant and The distance constant Of the anemometer. In Figure 5 the Turbine rotation Speed is plotted. The absorbed Electrical power is Shown in Figure 6 .The presented Data has been Averaged and smoothed using Sliding averages Over 0.2s.[9][12]

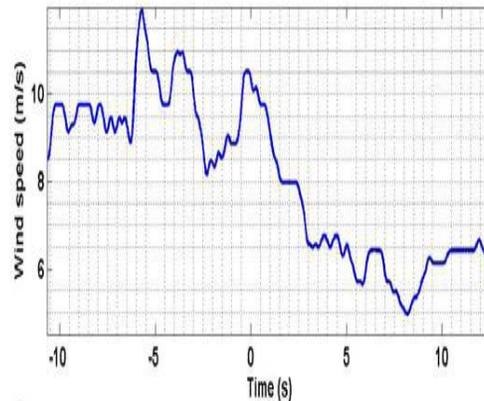
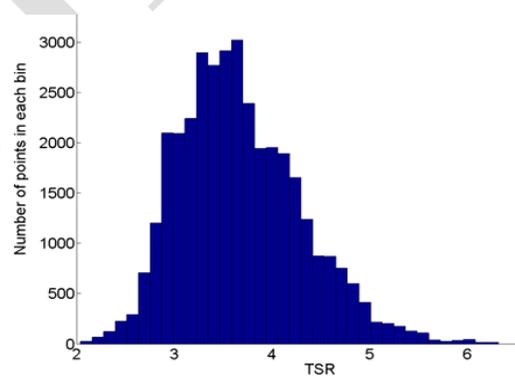


Figure4. Wind speed

V. ANALYSIS OF RESULTS

From Figure, during the first, more stable, 10 seconds, the average power is around 3.5 kW at an average wind speed of about 9.5 m/s. This gives a short-time electrical CP of 23 percent. From comparing the wind speed and the rotation speed in Figure 11, it is apparent that the rotational speed decreases as the wind speed decreases. As a result the electrical power is also decreasing. The high fluctuations present in the wind speed are noticed.[10][11]

As mentioned VI.a and considering Figure 6, the accurate part of the Cp curve is for a TSR around 3.5 [18]. This is very clear from the scattering of the data out of the range 3 to 4 in terms of tip speed ratios, see Figure 13. Therefore a Cp around 0.23 at a tip speed ratio of 4 can be estimated. In view of the high turbulent intensities this is a very decent result for a turbine of this small size. More tests will be conducted in less turbulent wind conditions, with a better control system and at higher and lower mean tip speed ratios. The wind measurement system will also be improved by placing several more accurate wind anemometers in a line and at different heights in front of the turbine.



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VIII. CONCLUSION

The construction and first experimental data of a vertical axis Wind turbine with a direct driven permanent magnet Synchronous generator has been presented. The first and aerodynamic efficiency has been shown. The turbine is reacting fairly well with respect to the highly turbulent wind conditions. Further tests will be made to fully characterize this H-rotor turbine.

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