

Optimization of vertical axis wind turbine on individual blade pitch control

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ABSTRACT

This paper describes an attempt to optimize the performance of the Vertical Axis Wind Turbines (VAWT) using active blade pitch control. The design of wind turbine chosen here is an H-type Darrieus VAWT which works on the lift force of the wind. Active Pitch controlled VAWT with individual pitch control of each blade along with vertical roller bearings in the system is done to obtain maximum coefficient of power harnessed from the wind turbine setup and increase the efficiency by 12.5%. The aerodynamic model is chosen based on the surface profile and NACA 4 digit series was found to be the most suitable category under which NACA 0018 aerofoil design parameters have been chosen for the VAWT blade design, based on the previous research.

KEY WORDS: H-type, vertical axis wind turbine, active pitch, NACA 0018.

1. INTRODUCTION

The most available form of renewable energy is wind thus, the fastest-growing renewable energy source is wind energy. Wind energy is promising in areas where power supply is difficult such as isolated islands or challenging geographical altitudes. Compared to the day time limitation of solar energy harvesting, wind energy harvesting has a clear advantage over it considering coastal areas throughout India. Components of an ideal wind power system are wind turbine and generator. The wind turbine can be categorized in two classes on the basis of orientation of rotation, namely, vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT). The VAWT offers some distinct advantages relative to HAWT, including easy installation and maintenance, low noise, and potentially simple blade design. Also, the forces of the wind on the turbine blades allow for a further classification into lift-force type and the drag-force type. Through further and well-targeted research, increased attention has been paid to the known VAWT drawbacks, such as difficult or impossible self-starting and a somewhat less overall efficiency than an HAWT, low cost to performance ratio and inefficient utilization of wind energy. Thus, comes the need of a variable pitch controlled VAWT which overcomes the drawbacks of FP-VAWT. H-type lift type Darrieus turbine is chosen to optimize based on the approaches mentioned in this paper as it was found that performance of a wind turbine is dependent upon the blade pitch angle amplitude, the size of the turbine, the number of blades and the aerofoil profile.

The project has been divided into the verticals namely mechanical, electrical and control system where mechanical system comprises of the blade profile design, selection of material for the blades, hubs, linkages and the vertical axis shaft and their respective dimensions as per the information. The electrical system includes the rotor and stator assembly with an elaborate description of their respective configuration, the servo motor assembly to each linkage connecting the blade and the central hub. Finally, the control system layout is designed where the pitch angle of each blade is controlled by the servo motor via the linkage connecting the blade to the central hub. The advantages of such an approach are improved start-up torque, increased utilization efficiency of wind energy and reduced blade oscillation as compared to that of a standard FP-VAWT.

2. MECHANICAL VERTICAL

Dynamic Modeling: Simple linear models for the dynamics are obtained for the nominal operating conditions. The variation of wind speed as well as other main operating performance parameters of the VAWT necessitates derivation of multi linear models. Several first order transfer functions are resultant of these linear models. The rotor speed with respect to both effective blade pitch angle and wind speed and gains and time constants of these transfer functions are expressed in terms of rotor moment of inertia, rotor aerodynamic characteristics and generated torque characteristics. The VAWT aerodynamics has been shown in fig.1.

A single – mass linearized model of the VAWT in the neighborhood of an operating point (Ω_o , Θ_o and V_o) is given by:

$$J_{T\omega} \dot{\omega} = [M_{T\omega}] \omega + [M_{T\theta}] \theta + [M_{TVw}] V_w - [M_{L\omega}] \omega \quad (1)$$

Where, Ω_o : rated generator speed, Θ_o : operating blade pitch angle, V_o : operating wind speed, $M_{T\omega} = \partial M_T / \partial \omega$ at V_o , θ_o , $M_{T\theta} = \partial M_T / \partial \theta$ at V_o , Ω_o , $M_{TVw} = \partial M_T / \partial V_w$ at θ_o , Ω_o , $M_{L\omega} = \partial M_L / \partial \omega$.

The stiffness and damping effects of the turbine drive train are neglected in the above model. The transfer functions $\omega(s)/\theta(s)$ and $\omega(s)/V_w(s)$ are derived from the above model such that:

$$\omega(s)/\theta(s) = G_1/(T_{C1}S+1) \quad (2)$$

$$\omega(s)/V_w(s) = G_2/(T_{C1}S+1) \quad (3)$$

Where the gains G_1 , G_2 and the time constant T_{C1} are given by:

$$G_1 = M_{T\theta} / (M_{L\omega} - M_{T\omega}) \tag{4}$$

$$G_2 = M_{TV} / (M_{L\omega} - M_{T\omega}) \tag{5}$$

$$T_{C1} = J_T / (M_{L\omega} - M_{T\omega}) \tag{6}$$

Values of G_1 , G_2 and T_{C1} are computed by evaluating the partial derivatives of the torque characteristics at constant pitch angle and at constant wind speed.

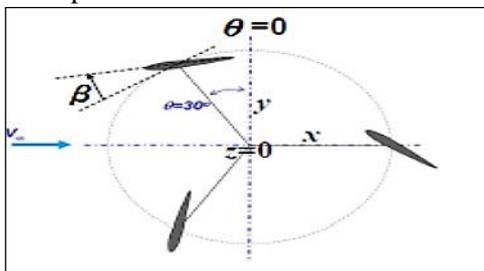


Fig.1. VAWT aerodynamics

Design: The design comprises of 3 blades of the NACA 0018 profile. The NACA 0018 profile states 18% of maximum thickness at 30% of chord length and belongs to the symmetrical series of airfoils. The design parameters are given in table 1.

Table.1.Power Performance initial estimation

Design Parameters		Calculated Parameters	
Rotor radius (m)	0.75	Swept area (m ²)	2.2
Blade Length (m)	0.75	Solidity	0.8
Blade Chord (m)	0.30		
Power Coefficient	0.17	Rated blade speed (m/s)	12
Tip speed ratio	2.5	Actual Rotational speed (rad/s)	12
Number of blades	4	Actual Rotational speed (rpm)	114.59
Air constants			
Air density (Kg/m ³)	1.225		
Wind speed (m/s)	6	Power Available from wind (W)	529.2
Conversion factors		Power output (W)	89.964
rad/s --> rpm	9.54		

Two kinds of linkages connect the blade to the main shaft. The rotor hub arm connects the blade's rotational axis to the hubs of the main rotating shaft. The other type which is the control linkage connects the servo motor fixed on the rotor hub plate to the blade at a distance of .15m from the rotor hub arm. Both types of links are riveted at the points connecting the blades whereas the shaft link is fixed to the main hub and the servo link is directly connected to the servo motor's shaft as shown in the figure. The main rotational shaft bears idler plate which has a vertical roller bearing assembly and the rotor hub plate having servo motor assembly and the same bearing assembly.

Control System Vertical:

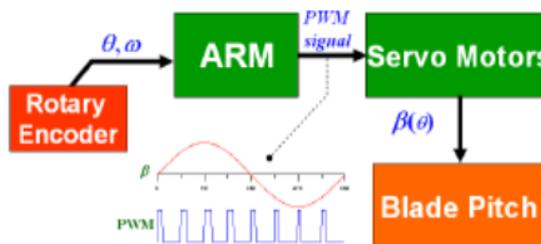


Fig.2. Pitch control

The control action is done by a MCU (ARM 7) with the help of three servo motors. The MCU reads the optimal pitch angle at the position azimuth angle, θ with the help of rotary encoder to obtain the position of the blade with respect to the incident wind direction. PWM signals with respect to the calculated Pitch angle is then given to the servo motors to accordingly change the blade positions. The pitch control block diagram is shown in fig 2. Servo motors can transmit its rotating force directly to blade by control linkage, and changing ratio of blade pitch angle can be increased by reducing the length of linkage. This makes it possible for a rapid response at the high speed rotation of rotor. The proposed control linkage mechanism is shown in fig. 3.

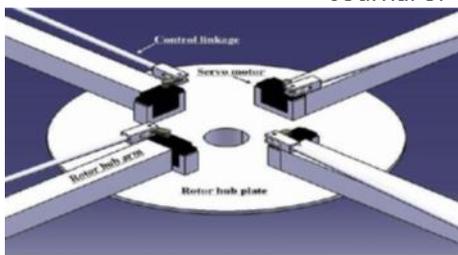


Fig.3. Proposed design with three rotor hub arms instead of four

3. RESULT

A positive initial angle of attack broadens the range of angular speed operation and a negative one shortens it. From fig. 4 we can see that at 2.5 TSR when A_0 is at +3 degree C_p is maximum 0.4 whereas at A_0 equal to zero degree C_p is 0.35. This increase the efficiency by 12.5%. This is interesting when fixing the maximum rpm. Furthermore the torque is influenced the same way resulting in a lower maximum power coefficient and torque for negative angles of attack. The initial angle of attack for our design will be set at 0 degrees as the advantages of a different angle of attack are, according to this model, only evident at higher tip speed ratios than the intended for the model.

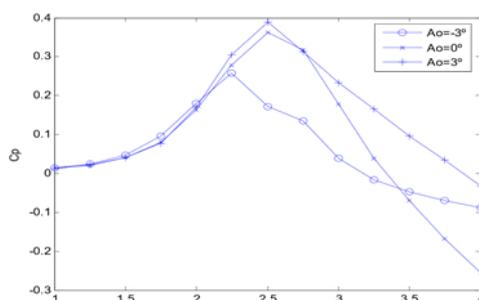


Fig.4. Power coefficient variation depending on Tip speed ratio

4. CONCLUSION

The concept of individual blade control ensures a significant increase in the power coefficient of the VAWT. Furthermore, a research area in this topic includes the usage of magnetic bearing and suspension to increase the power coefficient and ensure a frictionless rotational system. The design and fabrication of wind power systems is to obtain an ultra-cost effective method of power generation with considerable recovery of the power input.

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