

# Study on Optimization of Control Mechanism in Vertical Axis Wind Turbine

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## Abstract

**Objective-** This paper describes an attempt to streamline the execution of the Vertical Axis Wind Turbines (VAWT) utilizing dynamic sharp edge pitch control. **Methods/analysis-** 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. The outline of wind turbine picked here is an H-sort Darrieus VAWT which deals with the lift drive of the wind. **Findings-** 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%. **Applications:** The proposed design system is suitable for low wind speed areas which turbine is installed at lower heights.

**Keywords:** Active Pitch, H-Type, NACA 0018, Vertical Axis Wind Turbine

## 1. Introduction

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 energy system are a generator and wind turbine. The wind turbine can be ordered in two classes on the premise of the introduction of the pivot, to be specific, vertical hub wind turbines and flat hub wind turbines.

The VAWT offers some distinct advantages relative to HAWT, including easy installation and maintenance, low noise, and potentially simple blade design<sup>1</sup>. Also, the powers of the twist on the turbine edges take into account a further grouping into lift-constrain sort and the drag-compel sort. 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<sup>2</sup>, 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

Fixed Pitch-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 reliant upon the span of the turbine, the edge pitch sufficiency, the quantity of cutting edges and the airfoil profile<sup>3</sup>.

The project has been divided into the verticals namely mechanical, electrical and control system where the 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 theory is designed to control 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 the utilization efficiency of wind energy and reduced blade oscillation as compared to that of a standard FP-VAWT.

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At a global level, already installed wind plants generate up to 74000 MW of power and current estimates indicate that by 2030 wind energy could cover as much as 29% of world's electricity needs<sup>4</sup>.

There are two principle innovations in gathering wind vitality, the Horizontal Axis Wind Turbine (HAWT) and the Darrieus-sort (lift-based) Vertical Axis Wind Turbine (VAWT). HAWT has become a dominant design as it has very large turbines, but in conditions like in the mountains or inurban area; places which are highly susceptible to turbulent wind, VAWT offers a better solution. VAWT has more efficiency and self-starting capability which makes it more viable for the urban area which is not near to coastal regions. Also, VAWT can be easily installed on top of the roof as they have very small turbines.

## 2. Mechanical Vertical

The mechanical vertical comprises of the modeling of the structure formation and structure design elements. Initially, the modeling of the wind turbine is done to ensure the correct inputs to the system. After modeling of the system, designing of the structure is done with the help of 3D CAD software tools.

### 2.1 Dynamic Modelling

Basic straight models for the elements are acquired for the ostensible working conditions. A distinction is made between vertical axis turbines that operate using the drag-force of the wind on its rotor and those that employ lift forces to generate torque<sup>5,6</sup>. The variety of twist speed and also other principle working execution parameters of the VAWT requires induction of multi-direct models. A few first request Gains and time constants of these exchange capacities are resultants of these direct models. The rotor speed relies on upon the sharp edge pitch edge and wind speeds are communicated as far as rotor snapshot of idleness, rotor streamlined qualities and created torque attributes. The VAWT aerodynamics has been shown in Figure 1.

A single – mass linearized model of the VAWT in the neighborhood of an operating point ( $\Omega_o$ ,  $\theta_o$  and  $V_o$ ) is given by<sup>7,8</sup>:

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

Where:

- $\Omega_o$ : rated generator speed
- $\theta_o$ : operating blade pitch angle

- $V_o$ : operating wind speed
- $M_{T\omega} = \partial M_T / \partial \omega$  at  $V_o, \theta_o$
- $M_{T\theta} = \partial M_T / \partial \theta$  at  $V_o, \Omega_o$
- $M_{TVw} = \partial M_T / \partial V_w$  at  $\theta_o, \Omega_o$
- $M_{L\omega} = \partial M_L / \partial \omega$

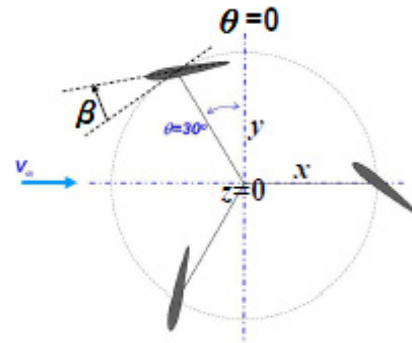


Figure. 1. VAWT Aerodynamics

The damping and firmness an impact of the turbine drive prepares are dismissed 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:

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

$$G_2 = M_{TVw} / (M_{L\omega} - M_{T\omega}) \quad (5)$$

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

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.

### 2.2 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.

We consider a Vertical Axis Wind Turbine (VAWT) incorporating mechanisms that enable independent pitching of individual blades. The blades are provided with servo linkages that can be independently regulated by adjusting pitch angle. Using pitch controls help in creating a greater force differential across the turbine. This will allow VAWT operation over a wide range of wind

speeds, improve tolerance to wind variations and permit the turbine to self-start.

**Table 1.** Design parameters

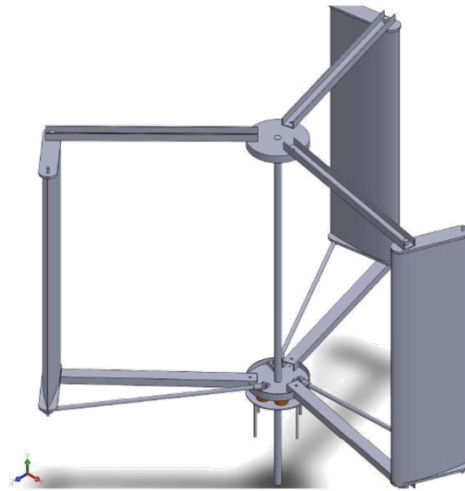
Power Performance initial estimation			
Design Parameters		Calculated Parameters	
Rotor radius (m)	0.75	Swept area (m <sup>2</sup> )	1.76
Blade Length (m)	0.75	Solidity	0.8
Blade Chord (m)	0.30		
Power Coefficient	0.40	Rated blade speed (m/s)	12
Tip speed ratio	2.5	Actual Rotational speed (rad/s)	12
Number of blades	3	Actual Rotational speed (rpm)	114.59
Air constants			
Air density (Kg/m <sup>3</sup> )	1.225		
Wind speed (m/s)	6	Available power Wind (W)	429.5
Conversion factors			
rad/s --> rpm	9.54		

Two sorts of linkages interface the sharp edge to the principle shaft. The rotor center arm interfaces the sharp edge's rotational pivot to the center point of the fundamental turning 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 0.15m 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. 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. The proposed control linkage mechanism is shown in Figure 2.

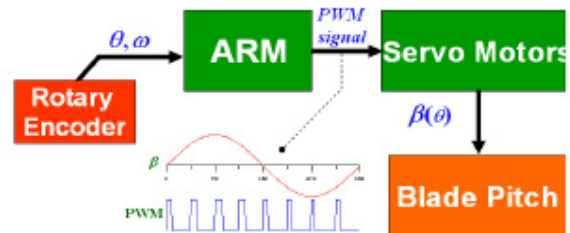
### 2.3 Control System Vertical

Individual control mechanism involves an addition of the rotary encoder to sensing part for measuring the rotating angle of the rotor. This enables the control unit to sense

the azimuth angle for obtaining optimal pitch angle at the position. At every time step, the microcontroller receives the position of each blade from rotary encoder and wind data from the wind indicator and the anemometer, and calculates optimal pitch angle to send PWM signal to the actuator. The pitch control block diagram is shown in Figure 3.



**Figure 2.** Proposed design with three rotor hub along with servo motor assembly in hub plate for blade pitch control.

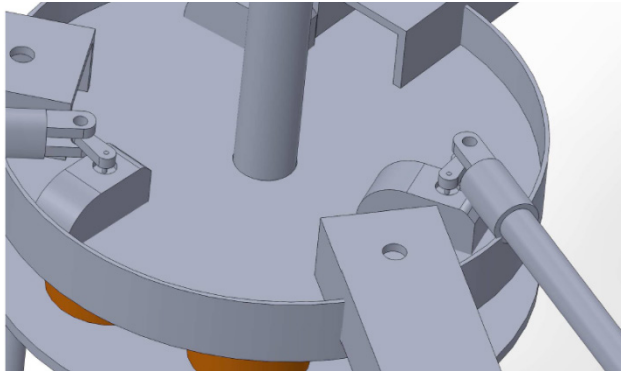


**Figure 3.** Pitch control

The control action is done by an MCU (ARM 7) with the assistance of three servo engines as appeared in Figure 4.

The MCU peruses the ideal pitch point at the position azimuth edge  $\theta$  with the assistance of rotational encoder to get the position of the sharp edge regarding the episode wind heading. PWM signals concerning the ascertained Pitch edge is then given to the servo motors to accordingly change the blade positions. Servo motors can transmit its rotating force directly to the blade by control linkage, and changing ratio of blade pitch angle can be increased by

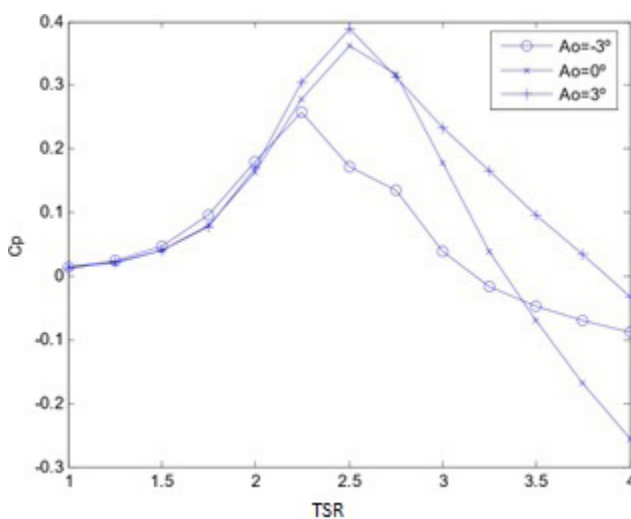
reducing the length of linkage. This makes it possible for a rapid response to the high-speed rotation of rotor<sup>5</sup>.



**Figure 4.** Servo motor mounting with control linkage

### 3. Result

A positive initial angle of attack broadens the range of angular speed operation and a negative shortens it. From Figure 5, we can see that at 2.5 tip-speed ratios (TSR) when  $A_0$  is at +3 degree,  $C_p$  is maximum which is 0.4 whereas, at  $A_0$  equal to zero degrees,  $C_p$  is 0.35. This leads to an increase in efficiency by 12.5%. It becomes interesting while fixing the maximum rpm. Further, as the torque is also influenced in the same way resulting in a lower maximum power coefficient and torque for negative angles of attack. For this design, the initial angle of attaching is set at zero degrees as according to this particular model, the advantages of a different angle of attack are only evident at higher tip speed ratios.



**Figure 5.** TSR vs.  $C_p$ , Power coefficient variation depending on Tip speed ratio.

### 4. Conclusion

The idea of individual sharp edge pitch control guarantees a noteworthy increment in the power coefficient of the VAWT. Small VAWT with individual blade pitch control converts more wind energy into electrical energy and are very suitable for households which are not near to coastal regions at lower heights. Furthermore, a research area in this topic includes the usage of the magnetic bearing and suspension to increase the power coefficient and ensure a frictionless rotational system with higher generation. The design and fabrication of wind power systems are to obtain an ultra-cost effective method of power generation with the considerable recovery of the power input.

### 5. Future scope of work

- Use of lightweight materials in the manufacturing of hub plates.
- Use of latest NACA profile, specially designed for VAWTs can help harness more energy and generate more lift.
- Automatic testing of viable points of operation without sensors.
- Enhancing the viability of the system by utilization of meteorological data logging techniques.
- Enhancement of electromagnetic flux induction by encasing coils within a resin coating.

### 6. Acknowledgement

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### 7. References

1. Dominy R, Lunt P, Bickerdyke A, Dominy J. Self-starting capability of a darrieus turbine. *Journal of Power and Energy*. 2007; 221(1):111- 120.
2. Zhang Z, Lixun L. Vertical axis wind turbine with individual active blade pitch control. *Asia-Pacific Power and Energy Engineering Conference*; 2012.
3. Kiwata K, Takahiro T. Performance of a vertical axis wind turbine with variable-pitch straight blades utilizing a linkage mechanism. *Journal of Environment and Engineering*. 2010; 5(1):213-25.

4. Paraschivoiu I, Trifu O, Saeed F. H-Darrieus wind turbine with blade pitch control. *International Journal of Rotating Machinery*. 2009; 1-7.
5. Pawsey NCK. Development and evaluation of passive variable-pitch vertical axis wind turbines [Ph.D. Thesis]. Australia: School of Mechanical and manufacturing Engineering, The University of New South Wales. 2002; 1-397.
6. Hantoro R, Utama IKAP, Erwandi, Sulisetyono A. An experimental investigation of passive variable-pitch vertical-axis ocean current turbine. *ITB Journal of Engineering and Technological Science*. 2011; 43(1):27-40.
7. Kader AA, Abdelmawla A. A novel control scheme for pitch regulated vertical axis wind turbine. *International Scientific Journal Environmental Science, Egypt*. 2015; 1-8.
8. Parvathy VM, Gnanambigai M. Stability analysis of the variable speed wind turbine using sliding mode control. *Indian Journal of Science and Technology*. 2015 Apr; 8(S7):467-70.