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Efficient Maximum Power Generation and Correlation by Using Vertical Axis Wind Turbine

[1]*V. Malathy and* [2]*M. Balasubramanian*

[1]Department of Electrical and Electronics Engineering,
University College of Engineering-Ariyalur, Ariyalur, India
[2]Department of Mechanical Engineering,
University College of Engineering- Ramanathapuram, Ramanathapuram, India

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Abstract: This paper aims to attain maximum electricity power by using newly designed model of vertical axis wind turbine. To model the vertical axis wind turbine a new design has been adopted and performed various parameter as a function of different wind speed. The same model has been simulated with finite element method (ANSYS) and has performed various parameters with respect to different wind speed. The obtained experimental result from varying conditions was found to be excellent and resulted in frictionless and noiseless model. The finite element method using ANSYS software was modeled and compared with the experimental results. The finite element method results were found to have fairly agreeing with the experimental results with respect to different wind speed. The proposed design of model of vertical axis wind turbine has generated more power compared to horizontal wind turbine.

Key words: Vertical axis winds turbine · Horizontal wind turbine · Finite element method

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INTRODUCTION

Wind power is one of the renewable energy, which is most widely used to produce more electricity now-a-days. Modern wind turbines have been produced rated power in the range around from 600 kW to 6 MW. Different wind turbines such as horizontal axis wind turbine, vertical axis wind turbine, Darrieus vertical wind turbine, technology green energy wind turbine, pitch blade wind turbine and invisible wind turbine has been used to produce different range of power.

Ali Varda and Ilknur Alibas [1] investigated rotor type model in a wind tunnel measurement system. Rotation rates for each rotor model were determined based on wind speed. Power coefficient values were calculated using power and tip speed rates of wind. They reported that, the proposed model has produced maximum power when compared to existing rotor type model.

Andrew Kusiak, Wenyan Li and Zhe Song [2] developed a five different model of wind turbine with different weights control condition and have evaluated the wind turbine performance. These weights were adjusted with respect to the variable wind conditions and operational requirements.

Cumali Ilkilic, H useyin Aydin and Rasim Behcet [3] performed various renewable source method and finally reported that, wind energy method is most suitable energy source among renewable sources.

Jung-Hun Park, Hyun-Yong Park, Seok-Yong Jeong, Sang-Il Lee, Young-Ho Shin and Jong-Po Park [4] used computational algorithm for to find model characteristics of rotating blades.

Kazumasa Ameku, Baku M. Nagai and Jitendro Nath Roy [5] designed prototype wind turbine blades with a thin airfoil and a tip speed ratio of 3.

Mazharul Islam, David S.K. Ting and Amir Fartaj [6] analyzed the aerodynamic model of Darrieus type straight bladed wind turbines and reported that it had better performance than double-multiple stream tube model, free-Vortex model and the Cascade model.

Shawn Armstrong and Stephen Tullis [7] analyzed that the Helical blade shapes for vertical axis wind

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Corresponding Author: V. Malathy, Department of Electrical and Electronics Engineering,
University College of Engineering-Ariyalur, Ariyalur, India.

turbines can reduce load fluctuations during turbine operation; however, a helix has complicated three dimensional geometry that can be difficult to manufacture resulting in expensive blades.

Shun-zhang Chen and Lu-ping Li [8] used finite element method to analyze dynamic characteristics of wind turbine blade under the rotational and irrotational conditions. It was shown that the first five mode shapes of every condition were similar with each other.

Kamoji, Kedare and Prabhu [9] tested Helical Savonius rotors having a twist of 90° and tested in an open jet wind tunnel for overlap ratios of 0.0, 0.1 and 0.16. Tests were carried out to study the influence of overlap ratio, aspect ratio and Reynolds numbers on the performance of helical Savonius rotors.

Seungmin Lee, Hogeon Kim and Soogab Lee [10] said about three rotor configurations, 2-bladed single, 4-bladed single and counter-rotating rotor and were compared using numerical method. The method used here was based on vortex lattice method and was validated with measurements of the NREL phase-VI rotor. The calculated shaft torque was found to be in good agreement with the experimental results.

K. Pope, I. Dincer and G.F. Naterer A [11] said Savonius design and Zephyr VAWT benefit from operational attributes in wind conditions that are unsuitable for airfoil type designs. This paper analyzes each system with respect to both the first and second law of thermodynamics. The aerodynamic performance of each system is numerically analyzed by computational fluid dynamics software, FLUENT. A difference in first and second law efficiencies between 50% and 53% is predicted for the airfoil systems, whereas 44% - 55% differences are predicted for the VAWT systems.

R.N. Sharma and U.K. Madawala [12] concluded that the concept would be feasible if the cost of the rotor could be kept less than 4.3 times the cost of a standard rotor with fixed length blades.

Yuwei Li and Kwang-Jun Paik [13] computed the effect of wind speeds (5, 10, 15 and 25 m/s) at a fixed blade pitch angle of 3° with constant rotational speed using unsteady Reynolds-Averaged Naviere Stokes (RANS) and Detached Eddy Simulation (DES) turbulence models, both showing little difference in the average forces and moments.

This paper has been adopted a new model of vertical axis wind turbine and evaluates the performance of the wind energy. The performance are evaluated in the areas where wind is stronger and more constant, such as offshore and high altitude sites preferred location for wind farms.

The new model of vertical axis wind turbine has been designed and adopted to generate high power than horizontal, vertical and other wind turbine. The general type of vertical axis wind turbine components and model is shown in Fig. 1. The newly modeled vertical axis turbine blades and arrangement are shown in Fig. 2. Finite element simulation has been carried out in a newly modeled vertical axis wind turbine blade and stress and strain are evaluated. The finite element simulation of stress and strain profile is shown in Fig.3.

Dynamic Analysis: In dynamic analysis it has been evaluated with respect to load or field conditions which are varying with time. The system can be uniform or non-uniform rotation. The dynamic load includes oscillating loads, impacts, collisions and random loads.

Design Calculations

Power Calculation

Power (P) is obtained by using (1),

$$P = \frac{1}{2}\rho U^3 \tag{1}$$

Rotor radius (R) is obtained by using (2),

$$P = c_P \eta \frac{1}{2}\rho \pi R^2 U^3 \tag{2}$$

The maximum power can be obtained by using (3)

$$P_{\max} = \frac{16}{27}\rho A V_1^3 \tag{3}$$

Airfoil Data Calculations:

The Chord (c) value is determined by using (4),

$$c = \frac{8\pi r \sin\varphi}{3BC_l \lambda_r} \tag{4}$$

The Pitch angle (ϕ) value is determined by using (5),

$$\phi = \tan^{-1}\left(\frac{2}{3\lambda_r}\right) \tag{5}$$

The Tip speed Ratio value is determined by using (6),

$$\lambda \frac{\omega R}{U} \tag{6}$$

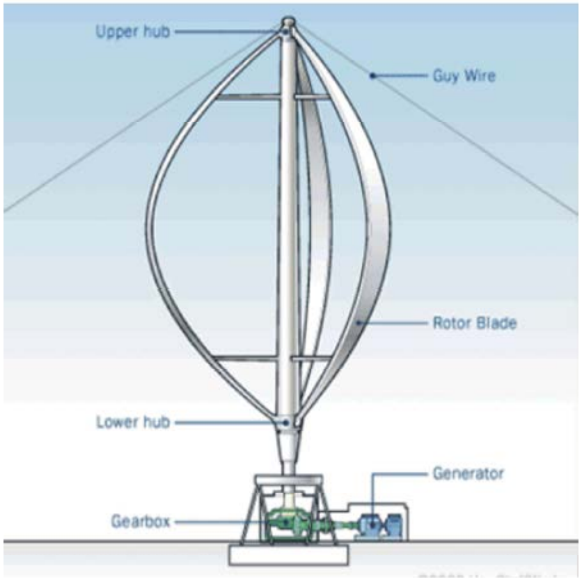

Fig. 1: General type of vertical axis wind turbine

Fig. 2: New model type of vertical axis wind turbine

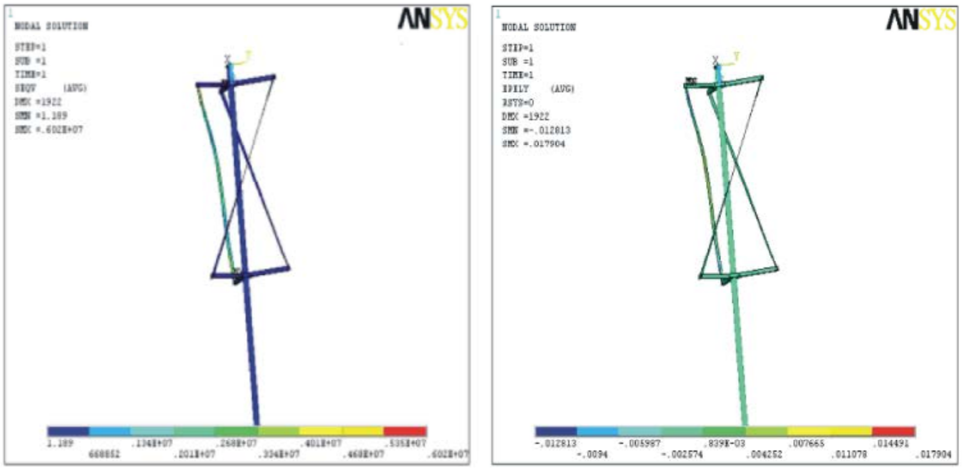

Fig. 3: Illustration of stress and strain profile of vertical axis wind turbine

Table 1: Chord value and Blade angle at various locations

Non dimensional radius Ratio (r/R)	Chord value(c) at particular position of radius (in m) [non-linearized]	Chord value(c) at particular position of radius (in m) [linearized]	Twist angle(β) at the particular position of radius (in degrees) [non-linearized]	Twist angle(β) at the particular position of radius (in degrees) [linearized]
0.08	6	1.955	28.19	17.5
0.166	3.73	1.841	15.59	15.5
0.25	2.63	1.727	9.84	13.5
0.33	2.02	1.612	6.769	11.3
0.416	1.632	1.498	4.787	9.0
0.5	1.366	1.383	3.451	7.0
0.583	1.175	1.269	2.48	4.8
0.666	1.0328	1.155	1.761	3.2
0.75	0.917	1.040	1.182	1.0
0.833	0.8277	0.926	1.002	-1.2
0.96	0.7525	0.817	-4.302	-5.0
1	0.69	0.697	-4.582	-5.2

Table 2: Theoretical calculation of thrust, torque and power

S.No.	Wind speed (m/s)	Thrust (kN)	Torque (Nm)	Power (kW)
1	5	44.40	13.11	691.93
2	7	87.03	25.7	1660
3	10	170.6	52.45	5470

Table 3: Comparison of theoretical and simulation values

S. No.	Wind speed (m/s)	Blade Velocities	Theoretical values (m/s)	Simulation values (m/s)
1	5	Velocity Magnitude	55.0	54.53
		Tangential Velocity	52.7	54.8
		Axial Velocity	3.35	4.0
		Relative Velocity	52.80	54.0
2	7	Velocity Magnitude	77.0	78.09
		Tangential Velocity	74.86	77.04
		Axial Velocity	4.669	5.669
		Relative Velocity	77.31	78.09
3	10	Velocity Magnitude	110.0	108.96
		Tangential Velocity	105.48	107.5
		Axial Velocity	6.67	8.66
		Relative Velocity	110.45	108

Table 4: Comparison of vertical axis wind turbine results with existing horizontal axis wind turbine results

		Vertical Axis wind Turbine			Horizontal Axis wind Turbine		
S.No.	Wind speed (m/s)	Torque (Nm)	Thrust (N)	Power (kW)	Torque (Nm)	Thrust (N)	Power (kW)
1	5	13.11	44.40	650	12.05	40.05	400
2	7	25.7	87.03	1450	23.89	80.68	900
3	10	52.45	170.6	1600	48.88	161.09	1200

The Angular Velocity is determined by using (7),

$$\omega = \frac{2 * 3.14 * N}{60} \tag{7}$$

Similarly the chord and blade twist values for various locations of blade are calculated and tabulated as shown in Table 1.

Rotor Calculations:

The Relative velocity is determined by using (8)

$$U_{rel} = U\sqrt{1 + \lambda^2} \tag{8}$$

The Tangential velocity is determined by using (9)

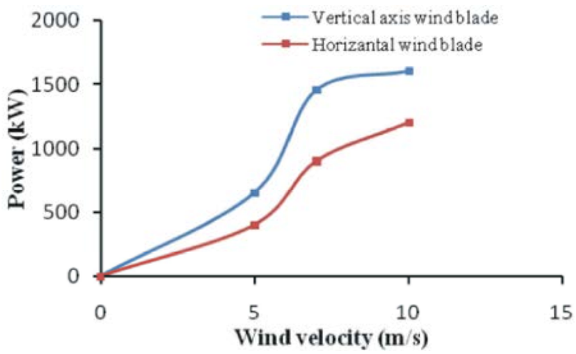

Fig. 4: Illustration of power output with respect to wind speed at different wind blade

$$U_t = \omega r \tag{9}$$

The Axial velocity is determined by using (10)

$$U_{axi} = V(1-a) \tag{10}$$

Performance and Load Calculations

The Thrust is determined by using (11)

$$dF_N = \sigma\pi\rho \times \frac{U^2(1-a)^2}{\sin^2\psi}(C_L\cos\psi + C_D\sin\psi)rd \tag{11}$$

The Torque has been find out by using (12)

$$dQ = \sigma\pi\rho \times \frac{U^2(1-a)^2}{\sin^2\psi}(C_L\sin\psi - C_D\cos\psi)r^2dr \tag{12}$$

Similarly for various values of wind speeds the calculation is done and tabulated as shown in Table 2.

Comparison of theoretical values and simulation values are shown in Table 3.

The thrust, torque and power values are calculated for vertical axis wind turbine and compared with the existing values of horizontal axis wind turbine and it is shown in Table 4.

The power output of vertical axis wind turbine results are compared with existing horizontal axis wind turbine results and is shown in Fig. 4.

CONCLUSION

The proposed design model of vertical axis wind turbine has produced electric power more than 25 % when compared to horizontal axis wind turbine model. This type of model can be installed very easily at any location. The proposed model has can be run without any noise and it is harmless at any location.

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