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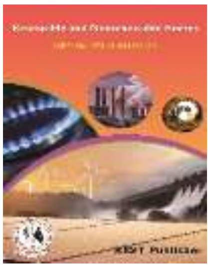

Maximizing the Performance Characteristics of The Wind Turbines at Different Pitch Angles

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Abstract: *In recent days utility of renewable energy sources is increased for various purposes and at varied locations under various conditions. Among all such sources wind source is one of the important sources being used extensively. The angle at which the surface of the blade contacts the wind is the pitch angle. In varying wind conditions, it is variable for optimum operation of the turbine and to prevent over speed and electrical over load in high winds. Pitch variation is allowed by gears in the hub of the rotor. It is proposed to analyse the effect of variations in pitch angles on wind turbines. The performance characteristics of the wind turbines by varying the pitch angle are implemented in MATLAB. The values of tip speed ratio of a wind turbine are estimated and coefficient of power is also evaluated. The coefficient of power is achieved at a particular tip speed ratio, pitch angle. By using Mat lab, the optimized output is obtained for interaction, the data can be plotted very easily, and graphical interactive tools can change the sizes, colours, scales etc.*

Keywords: *wind turbines, induction generator, pitch angles, tip speed ratio, coefficient of power.*

1. INTRODUCTION

Today India has one of the highest potentials for the effective use of renewable energy technology. One of the important energy sources is the wind energy. Most renewable sources are based on energy from the sun. Wind energy is the kinetic energy associated with the momentum of large mass of air. These motions results from uneven heating of the atmosphere by the sun creating temperature density and pressure difference. This wind energy is an indirect source of energy; it can be used to run a wind mill which is in turn drives a generator to produce electricity. [1]

Wind Energy Conversion System: The major components of a wind energy system include a wind turbine, generator, control system, gearbox, and interconnection apparatus. The kinetic energy produced by the wind is converted into mechanical energy by using wind turbine. The mechanical energy is converted into electrical energy by using generator. [2] Modern wind turbines can be categorized into two types:

They are

- Horizontal axis wind turbine
- Vertical axis wind turbine.

Here horizontal axis wind turbine is analysed.

Horizontal Axis Wind Turbine*:* Horizontal axis of rotation is parallel to wind stream and aero turbine plane is vertical facing the wind. The wind turbine with a horizontal axis is simple in principle, but the design of complete system is complex, especially a large one that will produce electric power economically is complex.[2]

Induction Generator: The induction generators used in fixed-speed wind turbines are very similar to conventional industrial induction motors. Induction generators are mechanically and electrically simpler than other generator types. They are also more rugged, requiring no brushes or commutators. In induction generators the magnetizing flux is established by a capacitor bank connected to the machine in case of standalone system and in case of grid connection it draws magnetizing current from the grid. It is mostly suitable for wind generating stations as in the case speed is always a variable factor.

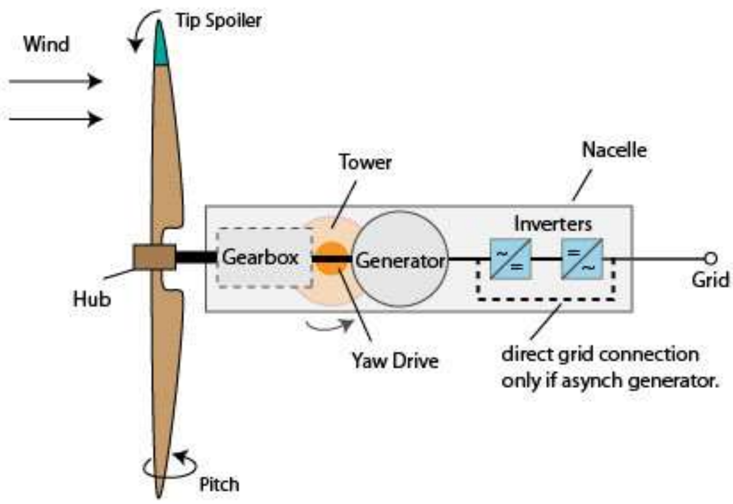

FIGURE 1. Horizontal axis wind turbine

2. COEFFICIENTS OF POWER CALCULATIONS DEPENDING ON THE SPECIFICATIONS

The output power of a wind turbine is determined by several factors. They are, rotor blade pitch angle, turbinespeed, size and shape turbine, and wind speed etc. A relationship between the output power and the mathematical model of the wind turbine of various variables constitute. The mathematical modelling enables control of wind turbines performance and also it is essential understanding of the behaviour of the wind turbine over its region of operation. [3]

Mathematical Formulation of Turbine Model
According to Newton's Law, we have:
$F = ma$ (1)
Thus, the kinetic energy becomes
K.E = mas… (2)
$K.E = \frac{1}{2} m v^2$ (3)
The power can be defined as:
$P = \frac{1}{2} \rho A v^3$ (4)
Wind power can be formulated as
$P_w = \frac{1}{2} \rho A V_w (V_u{}^2 - V_d{}^2)$ (5)
Tip speed ratio,
$\lambda = \frac{\text{blade tip speed}}{\text{wind speed}}$ (6)
Blade tip speed = $\frac{\text{angular speed of turbine } (\omega) * R}{\text{wind speed}}$

Where
R= radius of the turbine
ω = angular speed of turbine radians/seconds

$\lambda = \frac{\text{linear velocity of the rotor blade}}{\text{wind velocity}}$
But linear velocity
$= \frac{\text{the circumference of the swept area by the rotor blade}}{\text{time taken for one complete revolution}}$

i.e., linear velocity = $\frac{2\pi R}{T}$
We conclude that the tip speed ratio of the wind turbine can also write as:

$\lambda = \frac{2\pi R}{T * V}$
Were

R = length of the rotor blade
T = time taken for one complete oscillations of the wind turbine rotor blade

Substituting the equation (6) into equation (5), [4]

$C_p = \frac{(1+\lambda)(1-\lambda^2)}{2}$ (7)

Differentiate C_p with respect to λ and equate to zero to find the value of tip speed ratio (λ) that makes C_p as maximum, Now $\lambda = \frac{1}{3}$ substitute the equation (7) we get the maximum coefficient of power value. Thus the maximum value is $\frac{16}{27}$.

i.e. C_{pmax} = 0.59.

Theoretically the maximum coefficient of power is possible but practically it is not possible, because some mechanical and aerodynamic losses are present. The real world limit is well below the Betz limit with the values of 0.35 – 0.45 even in the best designed of wind turbines. The coefficient of power is not a static value. It varies with the tip speed ratio of the wind turbine. The wind turbines must be designed to operate at the optimal wind tip speed ratio (λ) in order to extract the power as possible from the wind stream. Theoretically high tip speed ratio is better in terms of efficient operation of the generator. There is some disadvantage in high tip speed ratio (λ) causes erosion of leading edges of the blades due to the impact of dust or sand particles found in the air. [5]

Power Coefficient Analysis: The coefficient of power is the most important parameter in the case of power regulation. To calculate the coefficient of power at a given wind speed, the ratio of the electricity produced by the wind turbine to the total energy available in the wind. It is the function of the tip speed ratio (λ) and the blade pitch angle (β) in degrees.

$C_p(\lambda,\beta) = C_1(C_2\frac{1}{\gamma} - C_3\beta - C_4\beta^x - C_5)e^{-C_6\frac{1}{\gamma}}$ (8)

Where the values of the coefficients C_1 - C_6 and x depend on turbine type, β is defined as the angle between the plane of rotation and the blade cross section chord. For a particular wind turbine type C_1 = 0.5, C_2 = 116, C_3 =0.4, C_4 = 0, C_5 = 5 and C_6 = 21 and γ is defined by

$\frac{1}{\gamma} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{1+\beta^3}$

Where β is the pitch angle of the blade in degrees, λ is the tip speed ratio of the wind turbine. It is observed that the value of coefficient of power is depends on the tip speed ratio of the wind turbine which also vary with the length of rotor blade.[5]

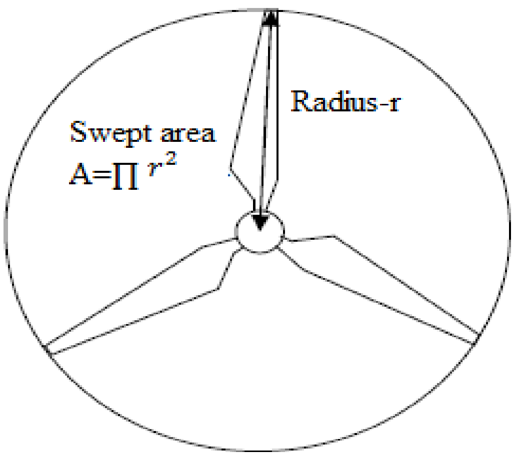

FIGURE 2.

The swept area of the wind turbine can be calculated from the turbine length of the rotor blade using the equation for the area of a circle.

Given date:
Length of the rotor blade, l = 42m
Wind speed, V =11m/seconds
Air density, ρ = 1.23kg/m^3
Coefficient of power, C_p = 0.4

Inserting the values for rotor blade length as the radius of the swept area into equation (9)

l = r = 42m

$A = \prod r^2$ (9)

Where

A = swept area of the wind turbine

R = radius

A = $\prod * (42)^2$

A = 5541.36 m^2[6]

Coefficient of power calculations depending on the specifications:

At time 12 seconds

λ = tip speed ratio

R = radius of the wind turbine= 42m

V = wind velocity = 11m/s

T = time= 12seconds

$$\lambda = \frac{2\prod R}{T*V}$$

$$= \frac{2*\prod*42}{9*14}$$

λ = 2

λ=2

TABLE 1: Calculated values of wind power and coefficient of power

β(0)	ϒ	Cp(λ,β)	Pm(MW)
0	2.15053	1.3937*10-3	0.013003
2	2.1783	1.5431*10-3	0.014431
4	2.3234	2.5725*10-3	0.024058
6	2.481	4.1491*10-3	0.038802
8	2.6406	6.2829*10-3	0.058758
10	2.8003	8.9738*10-3	0.083923
12	2.9603	0.01219	0.114001
14	3.1201	0.01586	0.148323
16	3.2808	0.01988	0.185918

Similarly for different values of tip speed ratio (λ=2, 4, 6, 8, 10, 12, 14) the wind power and coefficient of power are calculated by using the above formulas.

3. RESULTS

Graphical Representations:

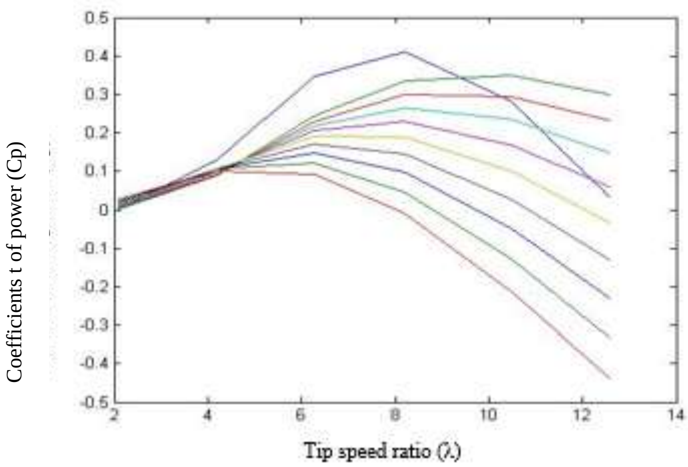

FIGURE 3: $c_p$verses λ with different pitch angles

The performance characteristic of the wind turbines is relationship between the coefficients of power verses tip speed ratio graphically shows. Increasing the pitch angle the coefficient of power is gradually decreasing. That means the coefficient of power depends on the pitch angle and tip speed ratio. The tip speed ratio increases and then coefficient of power also increases, but up to certain points only increases. The maximum coefficient of power is 0.41 at tip speed ratio 8 and then coefficient of power is decreasing gradually.

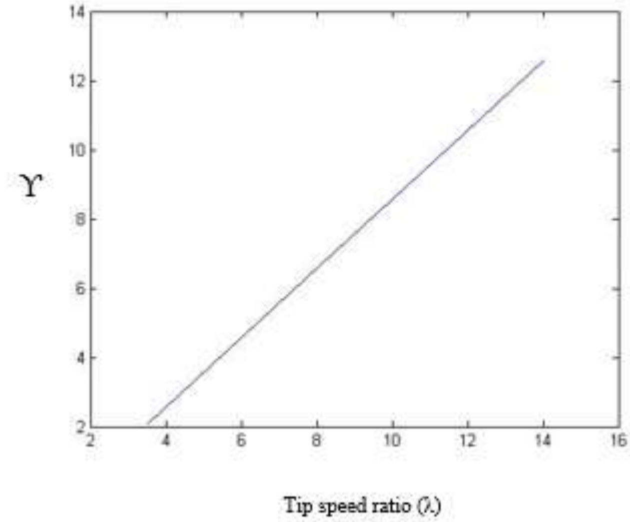

FIGURE 4: Υ verses λ with different pitch angles

The performance characteristic of the wind turbines is relationship between the gamma verses tip speed ratio graphically shows. Increasing the pitch angle the gamma is gradually decreasing. That means the gamma depends on the pitch angle and tip speed ratio. Gamma increases with increasing of tip speed ratio.

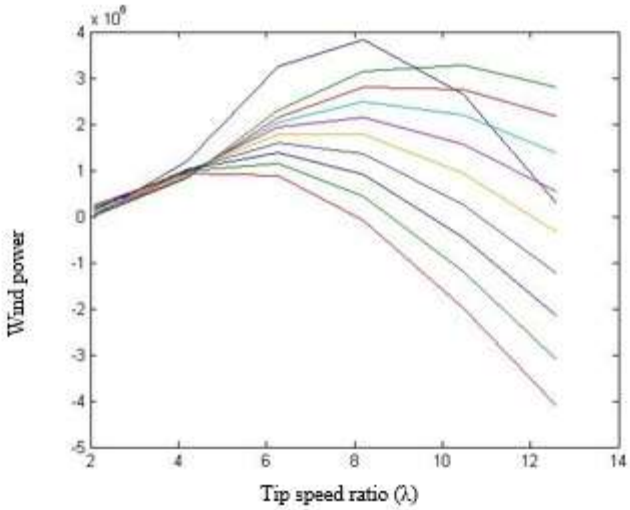

FIGURE 5: P_m verses λ with different pitch angles

The performance characteristic of the wind turbines is relationship between the coefficients of power verses tip speed ratio graphically shows. Increasing the pitch angle the coefficient of power is gradually decreasing. That means the wind power depends on the pitch angle and tip speed ratio. The tip speed ratio increases and then winds power also increases, but up to certain points only increases. The maximum wind power is 1.86MW at top speed ratio is 8 and then wind power is decreasing gradually.

4. CONCLUSION

The effects of variations in pitch angles on wind turbines are analysed. The graphical results of the coefficient of power Vs tip speed ratios, wind power Vs tip speed ratio, gamma Vs tip speed ratio by varying the pitch angles are obtained from MATLAB programming. The performance characteristics of the wind turbines are analysed and graphically shown by using the MATLAB. The maximum coefficient of power is 0.41 at top speed ratio 8 and then coefficient of power is decreasing gradually. Gamma is increased with increasing of tip speed ratio. The maximum wind power obtained in this work is 1.86MW at tip speed ratio 8 and then wind power is decreasing.

REFERENCES

[1]. “Renewable Energy Sources” by G.D. Rai.
[2]. “Wind Energy Hand Book” by Tony burton, Nick Jenkins and Ervin Bossonyi.
[3]. SachinKhajuria, JaspreetKaur, June 2012. “Implementation of pitch control of wind turbine using Simulink (MATLAB)”. ISSN: 2278 – 1323.
[4]. P.O.Ochieng, A.W.Manyonge., 2014. “Mathematical analysis of tip speed ratio of a wind turbine and its effect on power coefficient”. International journal of mathematics and soft computing vol.4, No.1 (2014), 61 – 66.
[5]. A.W.Manyonge, R.M.Ochieng, F.N.Onyango and J.M.Shichikha., 2012. “Mathematical Modeling of wind turbine in a wind energy conversion system”. Power coefficient analysis applied mathematical sciences, vol.6, no.91, 4527 -4536.
[6]. M. Rangheb., 2014, “wind energy conversion theory”, BETZ equation.
[7]. Eric Lu and Jessive Jin. 2011. “Planetary Gear”. CS285 Solid modelling.
[8]. Ageh, O. M., Hashim, N., Shamsudin, R., Che Man, H., Mohd Ali, M., Onwude, D. I., & Dasore, A. (2025). Optical imaging for food grain quality evaluation – recent advances and future perspectives. International Journal of Agricultural Sustainability, 23(1). https://doi.org/10.1080/14735903.2025.2569166
[9]. Dasore, A., Hashim, N., Shamsudin, R., Che Man, H., Mohd Ali, M., & Ageh, O. M. (2025). Comparative analysis of RGB and hyperspectral imaging for evaluating quality parameters of glutinous rice during storage. In Proceedings of the 2024 Brawijaya International Conference (BIC 2024) (pp. 46–58). Atlantis Press. https://doi.org/10.2991/978-94-6463-854-7_5
[10]. Dasore, A., Hashim, N. (2025). Backscattering Imaging. In: Sunil, C.K., Rawson, A., Chidanand, D.V., Shanmugasundaram, S. (eds) Emerging Non-destructive Technologies for Food Quality Analysis. Springer, Cham. https://doi.org/10.1007/978-3-031-95048-3_8
[11]. Tejes, P. K. S., Naik, B. K., Dasore, A., & Hashim, N. (2025). Multi-objective optimization of a three-fluid hollow fiber membrane dehumidifier for energy-efficient drying applications. Case Studies in Thermal Engineering, 75, 107036. https://doi.org/10.1016/j.csite.2025.107036
[12]. Sunkarwar, O. P., Naik, B. K., & Dasore, A. (2025). Experimental and numerical study of parallel flow evacuated U-tube solar collector with parabolic reflector: Impact of particulate matter. Journal of Solar Energy Engineering, 147(4), 041001. https://doi.org/10.1115/1.4067664