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Analysis on the Performance Characteristics of the Wind Turbine Gear Box at Different Pitch Angles

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Abstract: ***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 analyze the effect of variations in pitch angles on wind turbine gearbox. The performance characteristics of the wind turbine gearbox by varying the pitch angle are implemented in MATLAB. The planetary gear box is used at pitch angle of 6 degrees which can produce 2.1MW/ blades power. 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. Gear ratio is estimated. 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, colors, scales etc.***

Keywords: wind turbines, planetary gearbox, and induction generator, pitch angles, tip speed ratio, coefficient of power, gear ratio.

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
1.vertical axis wind turbine.
2. Horizontal axis wind turbine
Here horizontal axis wind turbine is analyzed.

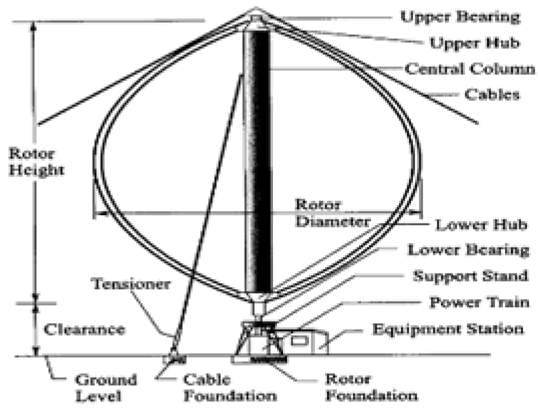


Figure 1: Horizontal axis wind turbine

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.[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.

2. Coefficients of power calculations depending on the specifications

The output power of a wind turbine is determined by several factors. They are (1) rotor blade pitch angle (2) turbine speed, (3) size and shape turbine, (4) wind speed etc. a relationship between the output power and the mathematical model of the wind turbine of various variables constitute. The mathematical modeling enables control of wind turbines performance and also it is essential understanding of the behavior of the wind turbine over its region of operation.[3]

Mathematical Formulation of Turbine Model

According to Newton's Law, we have:

$$F = ma \quad (1)$$

Thus, the kinetic energy becomes

$$E = mas\ldots \quad (2)$$

$$E = \frac{1}{2} mv^2 \quad (3)$$

The power can be defined as:

$$P = \frac{1}{2}\rho A V^3 \quad (4)$$

Wind power can be formulated as

$$P_w = \frac{1}{2}\rho A V_w (V_u^2 - V_d^2) \quad (5)$$

Tip speed ratio,

$$\lambda = \frac{\text{blade tip speed}}{\text{wind speed}} \quad (6)$$

$$\text{Blade tip speed} = \frac{\text{angular speed of turbine } (\omega) * R}{\text{wind speed}}$$

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:

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

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

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

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

Differentiate C_p with respect toλ 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 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.

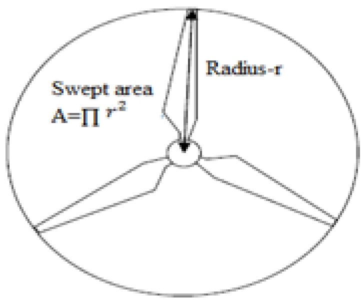
$$C_p(\lambda,\beta) = C_1\left(C_2\frac{1}{\gamma} - C_3\beta - C_4\beta^x - C_5\right)e^{-C_6\frac{1}{\gamma}}$$

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.[5]

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 data:

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

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

Where

A = swept area of the wind turbine

R = radius

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

A = 5541.36 m^2[6]

2.1 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

$$\lambda = \frac{2*\Pi*42}{12*11}$$

$$\lambda = 2$$

λ=2

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.

Table 1: calculated values of wind power and coefficient of power

B	ϒ	Cp(λ,β)	Pm(MW)
0	2.1505	1.4051*10-3	0.006374
2	2.1782	1.543*10-3	0.006529
4	2.3229	2.5681*10-3	0.0116
6	2.4809	4.149*10-3	0.0188
8	2.6404	6.2808*10-3	0.02849
10	2.9601	0.01219	0.40705
12	2.9601	0.0121	0.00005
14	3.1201	0.0158	0.000071
16	3.28009	0.0198	0.000009

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. Planetary Gear Box

The gearbox is used in the 2.1MW machine is planetary system which is the effective system for the maximum power generation. Planetary gearboxes are look like to the solar system. The components of a planetary gear box include a sun gear, ring gear and planetary gears. The sun gear is the central gear which is fixed in the center, ring gear which is the outer ring, and the planetary gears which rotate around the sun gears and mesh with both the sun gear and ring gear.[7]

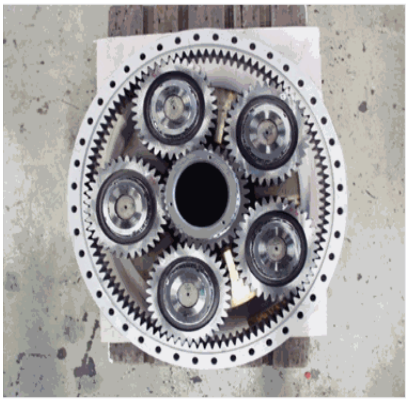


Figure 2: Planetary Gear Box

Gear Ratio:

The gear ratio of an epicyclic gearing system is mainly three basic components are:

- Sun: central gear
- Planet carrier: it is meshed with the sun gear
- Ring gear: an outer ring with inward facing teeth that mesh with the gears

The overall gear ratio of planetary gear can be calculated using the below two equations, representing the sun-planet and ring- planet interactions respectively.

$$N_s W_s + N_p W_p - (N_s + N_p) W_c = 0$$

$$N_a W_a - N_p W_p - (N_a - N_p) W_c = 0$$

Where,

W_s, W_a, W_c, W_p, is the angular velocity of the sun gear, annulus, planet carrier, and planet gears respectively, and N_s, N_a, N_p is the number of teeth of the sun gear, annulus, planet gears respectively.

The gear ratio of a gear train, also known as its speed ratio, the gear ratio is the ratio of the angular velocity of the input gear to the angular velocity of the output gear. The gear ratio can be calculated directly from the number of teeth on the gears in the gear train. [7]

$$\text{Gear Ratio} = \frac{\text{velocity of driver}}{\text{velocity of driven}} \qquad (10)$$

$$= \frac{V_1}{V_2}$$

Where

V1= velocity of driver

V2= velocity of driven

Gear ratio=v1/v2

Gear ratio= 0.6

V1=14 to 25 m/s

Velocity of driven is calculated by using the above formula

V2=v1/G.R (11)

At velocity of driver 14 m/s

V2=v1/G.R

=14/0.6

V2 = 23.33 m/s

Similar calculations are done from 14 to 25 m/s the results are tabulated:

Gear Ratio = 0.6

Table 2: Calculations of velocity of driven

Velocity of driver(v1) m/s	Velocity of driven(v2) m/s
14	23.33
15	25
16	26.6
17	28.3
18	30
19	31.66
20	33.33
21	35
22	36.66
23	38.33
24	40
25	41.66

Gear Ratio = v1/v2

V1=14 m/s

G.R= v1/v2

At angular velocity of driver 14 m/s

G.R=14/23.33

G.R= 0.6

Similar calculations are done from 23.3to 41.6 m/s the results are tabulated:

Table 3: Calculations of gear ratio

Angular velocity of driven(v2)m/s	Gear Ratio(G.R)
23.33	0.6
25	0.56
26.6	0.526
28.3	0.494
30	0.466
31.66	0.442
33.33	0.42
35	0.4
36.66	0.38
38.33	0.365
40	0.35
41.66	0.336

4. Results

Graphical Representations:

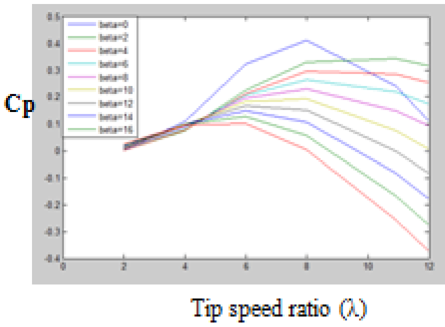


Figure 3: C_p verses λ with different pitch angles

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 is increases and then coefficient of power is 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.

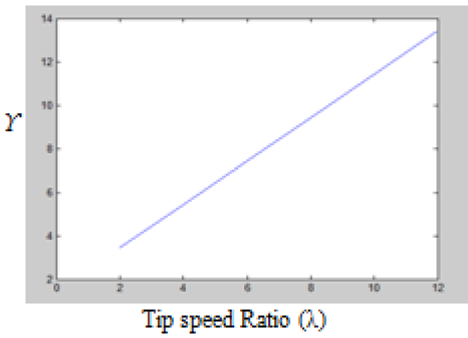


Figure 4: γ verses λ with different pitch angles

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.

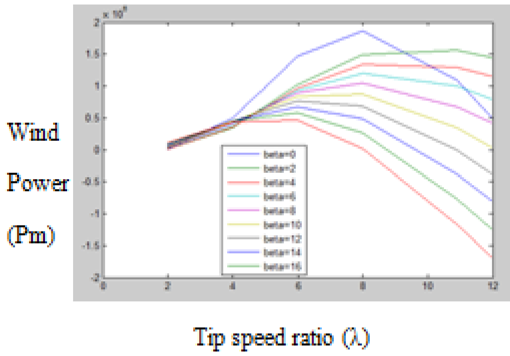


Figure 5: P_m verses λ with different pitch angles

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

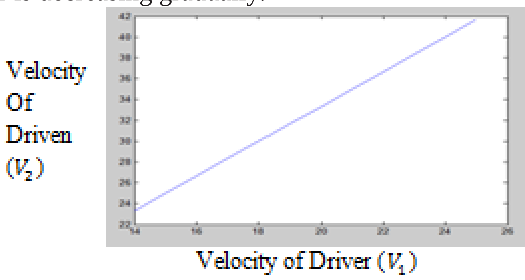


Figure 6: velocity of driven verses velocity of driver at fixed velocity of driver.

The performance characteristics are drawn between the angular velocity of driven and angular velocity of driver by fixed gear ratio. The gear ratio is fixed at 0.6, the angular velocity of driver increases gradually then angular velocity of driven also increases.

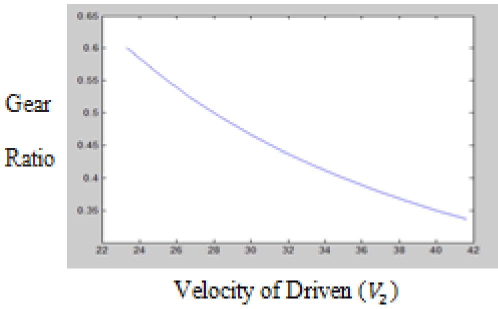


Figure 7: gear ratio verses velocity of driven at fixed velocity of driver

The performance characteristics are drawn in between the angular velocity of the driven and gear ratio at fixed angular velocity of driver at 14 m/s. Angular velocity of driver at14m/s is fixed, the angular velocity of driven is increasing gradually the gear ratio value is gradually decreasing state. Hence the gear ratio is inversely proportional to the angular velocity of driven.

5. Conclusion

The effect of variations in pitch angles on wind turbines and gearbox are analyzed. 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. And gear ratio is also calculated by using the velocity of driver to velocity of driven. The performance characteristics of the wind turbines and gear box are analyzed and graphically shown by using the MATLAB. The maximum coefficient of power is 0.41 at tip 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 gradually. Angular velocity of driven is increased gradually with increasing in angular velocity of driver. The gear ratio is inversely proportional to the angular velocity of driven.

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