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Aerodynamic Factors Affecting Wind Turbine Power Generation

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Abstract

The potential of wind energy in this power starved county is the brightest one among all others, owing to its free availability even at various remote places. In this paper, a matlab model is developed to study the aerodynamic factors that affect the wind turbine power generation and this simulink model is valid for wide range of wind turbines. It is tested for vestas Type V27, V39 and V52 wind turbines. The study observes that the operational parameters has a direct effect on the generated power which will lead the designer to focus on priority factor that should be considered for optimizing the new generation wind turbines.

***Keywords**:* wind Energy; wind turbine; Aerodynamic factors; Gearbox.

I. Introduction

For all renewable energy sources in India, Wind Electric Generation (WEG) is the largest in terms of installed capacity. India holds a wind energy potential of more than 45000MW, out of which 14000MW is technically feasible now but India secures fourth position globally with a capacity of 8698MW(2007-08). Poor performance of WEG's installed will have serious negative impact on new developments.

Wind turbines are classified on the basis of their axis in which the turbine rotates into horizontal and vertical axis wind turbines. Horizontal axis wind turbines are considered more commonly because of their ability to collect maximum amount of wind energy for the particular time of day and season. Wind turbines coupled with generators convert wind energy to electrical energy. All vestas RRB turbines are equipped with microprocessor-controlled optimal pitch regulation ensuring continuous and optimal adjustment of the angles of the blades in relation to the prevailing wind, thus generating maximum power.

The energy conversion for modern wind turbines will be of fixed speed & variable speed. In Fixed speed machines, the generator is directly connected to the main supply grid. The frequency of the grid determines the rotational speed of the turbine rotor, which in turn is converted into the generator rotational speed through gear box. The generator speed depends on the number of pole pairs and the frequency of the grid. In variable speed machines the generator is connected to the grid by an electronic inverting system or the generator excitation windings are fed by an external frequency from an inverter. The rotor will operate with variable speed adjusted to the actual wind speed situation.

II. Proposed mathematical model

The wind turbine component rotor consists of blades for converting wind energy to an intermediate low speed rotational energy. The generator component consists of electric generator, control electronics & gear box for converting the low speed rotational energy to electrical energy.

A. Wind stream Power

The kinetic energy in air of an object of mass m moving with speed ν is equal to:

$$E = \frac{1}{2} m \nu^2 \qquad (1)$$

The power in the moving air (assuming constant wind velocity) is equal to:

$$P_{wind} = dE / dt = \tfrac{1}{2} m v^2 \qquad (2)$$

Where m is the mass flow rate per second. When the air passes across an area A (e.g. the area swept by the rotor blades), the power in the air can be calculated as(Mukund, R. 1999)

$$P_{wind} = \tfrac{1}{2} \rho A v^3 \qquad (3)$$

Where ρ is the air density. Air density varies with air pressure and temperature in accordance with the gas law:

$$P = P / RT \qquad (4)$$

Where, ρ – Density of air in kg/m^3
T – Temperature
R – gas constant

The pressure and temperature varies with the wind turbine location. Some publishers give formula for air density as a function of the turbine elevation above sea level H:

$$\rho = \rho_0 - 1.194 \times 10^{-4} H \qquad (5)$$

Where $\rho_0 = 1.225$ kg/m^3 is the air density at sea level at temperature T = 288 K.

B. Mechanical Power Extracted from the Wind

The air energy cannot be transferred into mechanical energy with 100% conversion efficiency by any energy converter. The power extracted from the air stream by any energy converter will be less than the wind power P_{wind} also because the power achieved by the energy converter P_{ww} can be computed as the difference between the power in the moving air before and after the converter.

The extracted mechanical power from the air stream by the energy converter is equal to:

$$P_{ww} = C_p \, Pwind = C_p \, \tfrac{1}{2} \rho A v^3 = 16/27. \, Pwind \qquad (6)$$

Where the coefficient $C_p < 1$; Actual maximum power coefficients can be between 0.15 to 0.593 for different rotor designs & is defining as the ratio of the mechanical power extracted by the converter to the power in the air stream is called the power coefficient (Betz's factor.). The coefficient is equal to $C_p = P_{ww} / P_{wind.}$

The power coefficient of real converters C_p achieves lower values than that computed above because of various aerodynamic losses that depend on the rotor construction. The rotor power coefficient is usually given as a function of two parameters: the tip-speed ratio λ and the blade pitch angle θ. The blade pitch angle is defined as the angle between the plane of rotation and the blade cross-section chord and the tip-speed ratio λ is defined as

$$\lambda = u / v = \omega R / v \qquad (7)$$

Where u = tangential velocity of blade tip
ω = angular velocity of rotor
R = rotor radius

Summing up the above, it can be seen that the mechanical power P_{ww} extracted from the wind converter and the torque τ_{ww} for the given rotor and for the given wind velocity v, rotor angular velocity ω and the blade pitch angle θ can be computed as

$$P_{ww} = C_p (\lambda, \theta) \, P_{wind} = C_p (\lambda, \theta) \, \tfrac{1}{2} \rho A v^3 \qquad (8)$$

$$\tau_{ww} = P_{ww} / \omega = C_\tau (\lambda, \theta) \, \tfrac{1}{2} \rho A v^2 R \qquad (9)$$

The rotor power and torque coefficients in these models can be utilized in the form of look-up tables or in the form of a function. Often, for a given blade, the characteristics of the drag C_d and the lift C_1 ratios as functions of the blade pitch angle are available. In such a case, the rotor power coefficient C_p can be defined as a function of these quantities. Such a function which is defined as

$$C_p(\lambda, \theta) = 16/27[1 - C_1/ N\lambda]^2 \left[e^{(-C2}/\lambda^{1.29)} - (C_d / C_1)\, \lambda\right] \quad (10)$$

Where,

N - Number of blades,
C_d / C_1 - average drag-to-lift ratio of blade airfoil,
$C_{1,}\, C_2$ - coefficients

III. Proposed Simulation model

Power from a given rotor would be controlled by quantities viz. air density ρ, turbine swept area A, air velocity v and power coefficient C_p. The Matlab/Simulink model is developed to observe how these quantities affect the generated power from wind turbine. Koçak (2008) focused entirely on wind speed persistence during weather forecast, site selection for wind turbines and synthetic generation of the wind speed data. This model is valid for wide ranges of wind turbines. It is tested for V27, V39 and V52 turbines and compared the results. The specifications of wind turbines are given in Table 1. A Matlab/simulink model is shown in Fig.1and power output curves are shown in figure 2-6.

Table 1. The specifications of V27, V39 & V52 wind turbines (Vestas wind systems2000)

Details	**Vestas Type V27**	**Vestas type V39**	**Vestas Type V52**
Rated Power output	225 KW	500 KW	850 KW
Cut-in wind speed	3.5 m/s	4 m/s	4 m/s
Rated wind speed	14 m/s	15 m/s	16 m/s
Cut-out wind speed	25 m/s	25 m/s	25 m/s
Rotor Diameter	27m	39m	52m
Swept area	573 m^2	1735 m^2	2124 m^2
Number of Blades	3	3	3
Power Regulation	Pitch	Pitch	Pitch/Optispeed

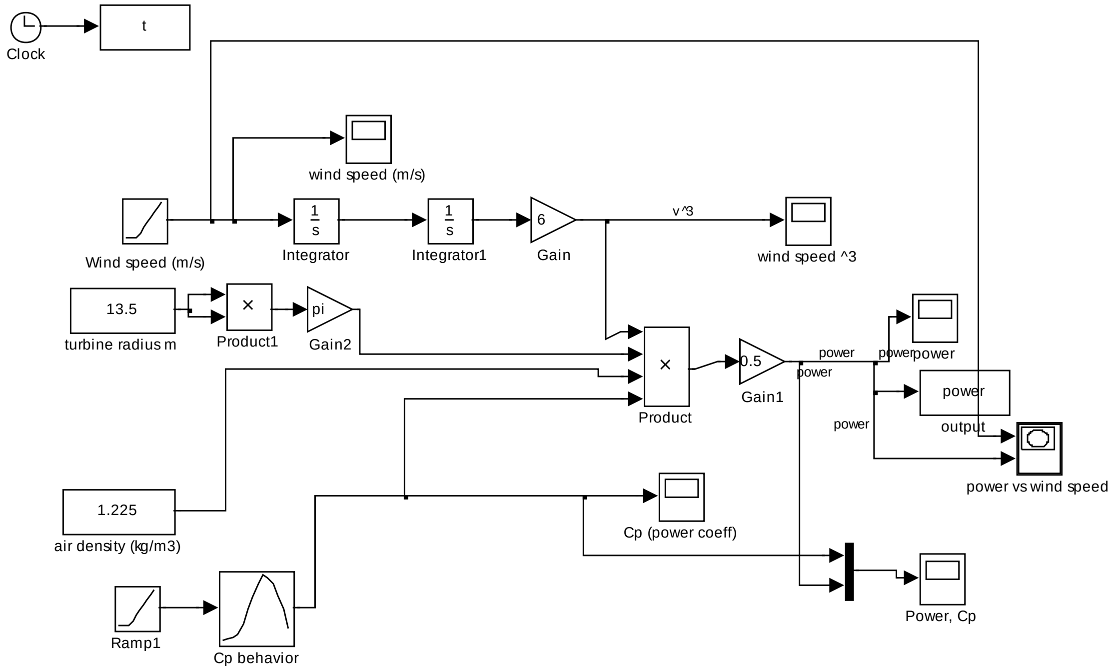

Fig.1. Matlab/simulink model

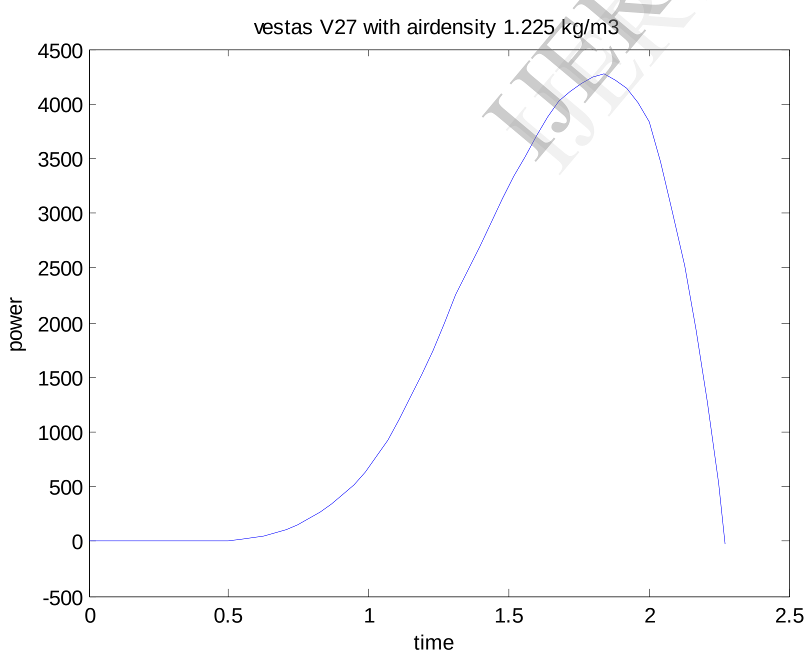

Fig2**.** Power Output curve for vestas V27 with air density 1.225 kg/m^3

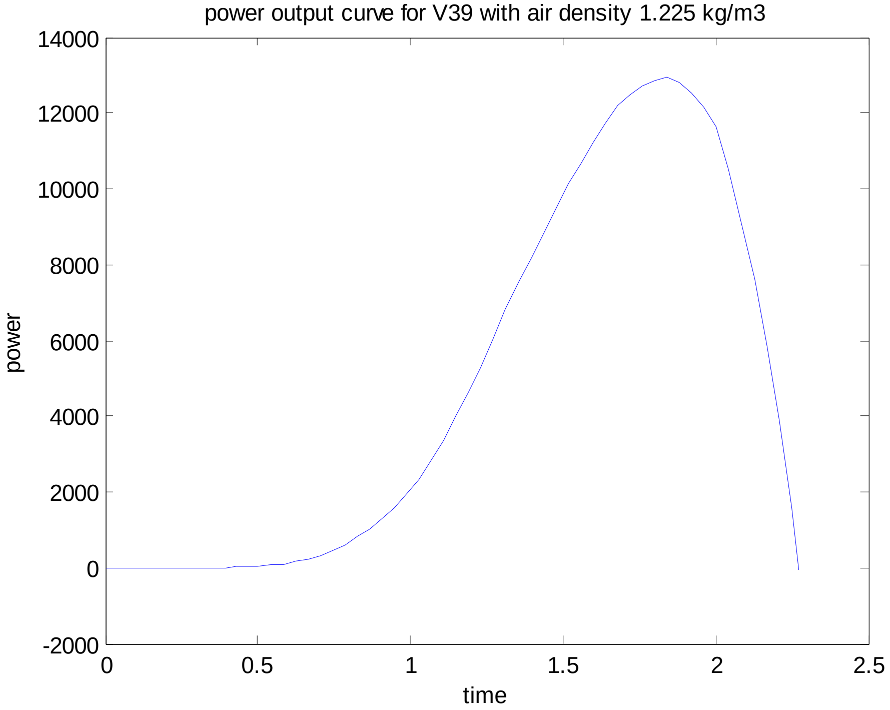

Fig3. Power Output curve for vestas V39 with air density 1.225 kg/m^3

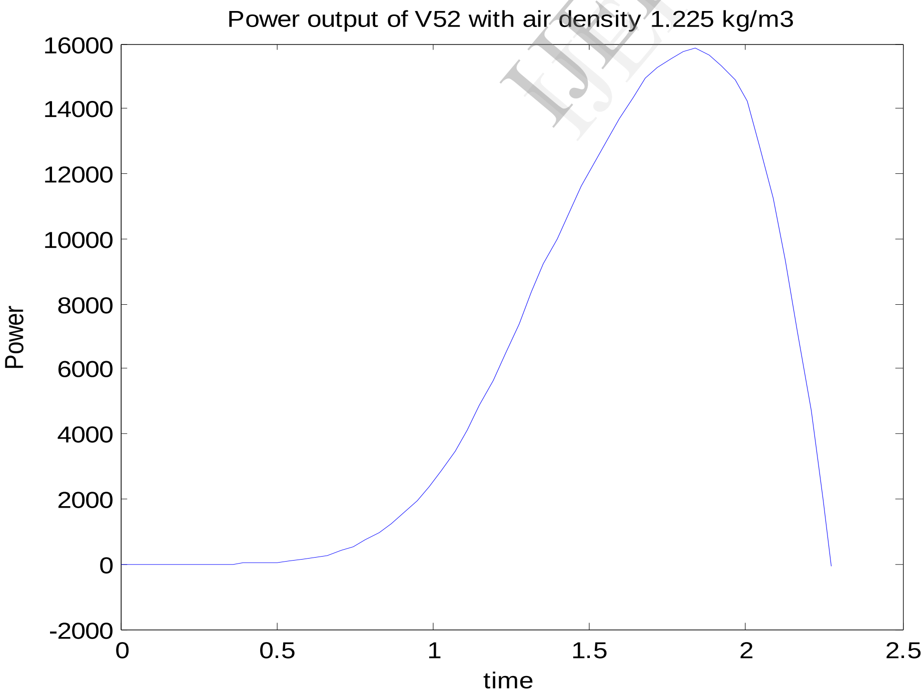

Fig4. Power Output curve for vestas V52 with air density 1.225 kg/m^3

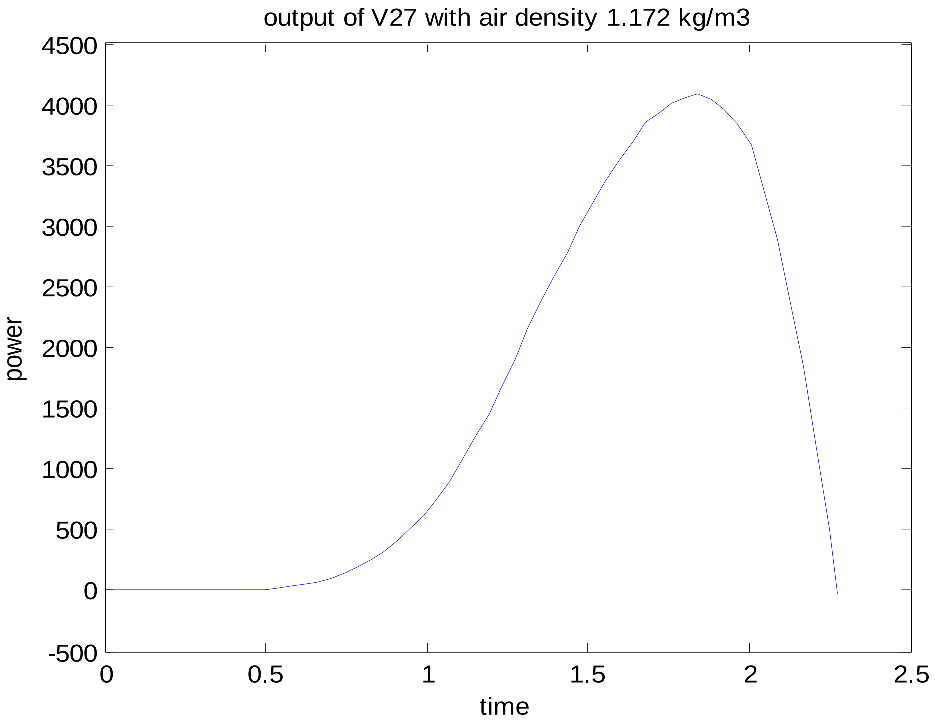

Fig5. Power Output curve for vestas V27 with air density 1.172 kg/m^3

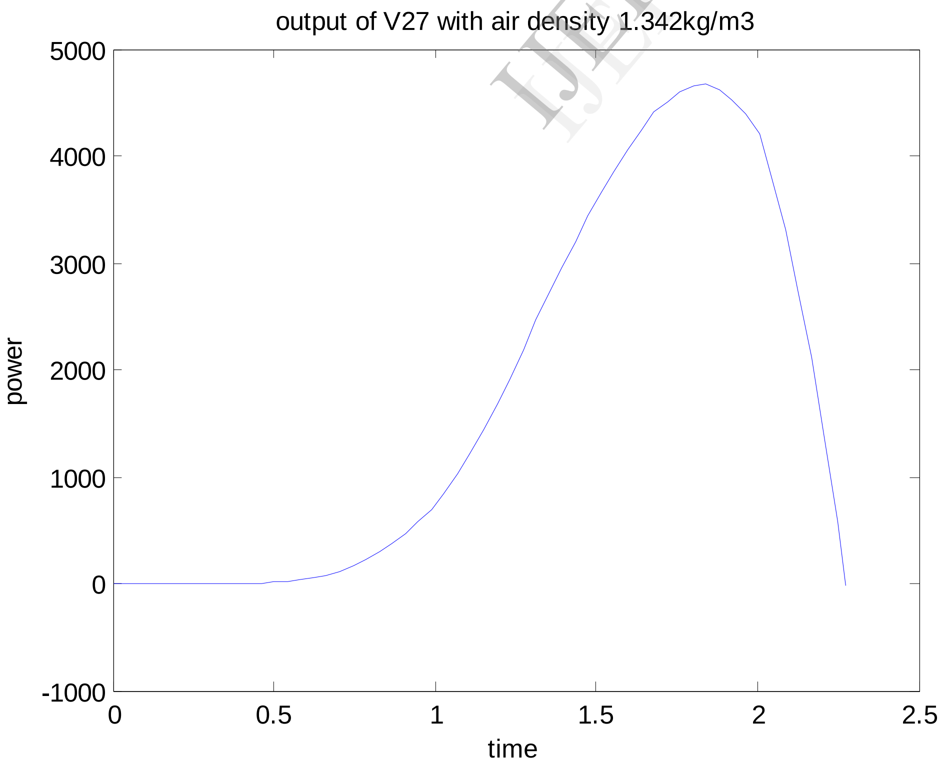

Fig 6. Power Output curve for vestas V27 with air density 1.342 kg/m^3

IV. Results and Discussion

Wind turbines are optimized by considering swept area and wind speed in terms of local area conditions to extract maximum power. The output power of a wind turbine is directly proportional to cube of wind speed and swept area of its blades. The larger the diameter of its blades, the more power can be extracted from the wind. In this paper, power output of three Vestas wind turbines V27, V39 and V52 with different diameters 27m, 39m and 52m respectively with same air density 1.225 kg/m^3 are compared in Fig. 2,3 &4. The power output of Vestas V52 type is greater than V39 and V27 types.

Khalfallah, M. and Koliub, M. 2007 shown that Wind speed has a significant effect on wind turbine performance. The power available in the wind is directly proportional to the cube of wind speed and swept area of blades. As swept area of blades increases, the available power also increases. The output of a wind turbine is also directly proportional to air density. As air density increases, the available power also increases. It can be observed from Fig.2, 5&6 for Vestas type V27 with different air densities.

V. Conclusion

Many factors have to be considered while manufacturing wind turbines i.e., turbine swept area, air density, wind speed and power coefficient as a function of pitch angle and blade tip speed. Air density has a significant effect on wind turbine performance. As air density increases, the available power also increases. The power output of wind turbine is directly related to swept area of blades. As swept area of blades increases, the output power also increases. |The good exploitation of wind energy may enhance the renewable power generation capabilities and participate in generating at good costs.

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