Performance Analysis of Aerodynamic Design for Wind Turbine Blade

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Abstract - *In spite of the endowed abundant wind energy resource which can be harnessed for various applications especially in core Northern region of the country, Nigeria is still faced with challenges of the required technical know-how for appropriate integration. Thus, in this paper, a numerical study has been carried out to investigate the aerodynamic performance of designed blade of a wind machine which is to be installed at Faculty of Engineering, Federal University Dutsin-Ma (FUDMA). The system was designed by modelling differential equations of the aerodynamic block and then simulated in MATLAB SIMULINK environment. A computer program was also written in Matlab to carry out parametric study on the effect of varying parameters such as wind speed (v) and tip speed ration (λ) on the performance of the wind turbine. The whole analysis was done using the meteorological data of Dutsin-Ma in Katsina State, Nigeria. Increase in generated power was noticed with increase in wind speed at cut-in speed of 3m/s and maximum power coefficient of 0.48. The results obtained which corroborates with those found in literatures. It also shows that at a wind speed of 9m/s, the energy needed to efficiently power the whole Faculty (150kW) could be achieved. As such, the wind turbine blades can efficiently convert the energy in the wind to electricity by varying the wind speed of the location. Furthermore, this work is an important reference material for wind turbine design in Dutsin-Ma and its environs.*

Key Words: Wind Energy, Wind Turbine, Power Generation, Simulation, Modelling, Dutsin-Ma

1. INTRODUCTION

The need and importance of clean, abundant alternative source of energy cannot be over emphasized due to the negative effects posed by the use fossil fuels on life and environment. In Nigeria, especially in the dry season, the availability of sufficient water for the hydro-electric power plants affects the generation of electricity. Climate change coupled with low rainfall and drought leads to evapo-transpiration which reduced water volume as well as hydro-electric power generation and transmission capacities [1]. Thus, the need to explore alternative sources of these fossil fuels such as wind and solar is essential. Wind energy is currently one of the most economic and growing source of renewable energy globally due to its availability [2]. Wind turbine blade is one of the most important components of a wind power system. Many methods have been proposed to improve the aerodynamic efficiency of the blade. In addition, to capture more wind energy and ensure efficient use of this energy, the size of wind turbine blades has to increase. The world's largest installed wind turbine blade length has reached more than 100 meters [3]. [4] Conducted a parametric study to determine the various factors affecting the performance of a wind turbine that can be improved, in order to eliminate losses and achieve better performance. The factors recommended include: type of wind turbine and material, number of blades, wind flow directions, blade surface conditions, shape and geometry of blades, length of blades, altitude, suitable site, wake effects, aerodynamic loads and other design parameters. The economic analysis of small wind turbine was investigated by [5]. Findings from their study suggested € 3000.00 as the realistic cost of small wind turbine. Moreover, they added that the rotor should be optimized for low wind speed by reducing the blade mass and ensuring rotation with acceptable tip speed ratio (TSR) to minimize noise. To enhance wind harnessing capability of areas with low wind speed, [6] worked on the aerodynamic design of a horizontal axis micro wind turbine blade using NACA4412 profile. Betz-Joukowsky limits theory for wind turbine optimization, and multiple iterations for aerodynamic parameters calculations were applied. The coefficient of power obtained increased by 30%, when the optimized blade and thickness were reduced by 24% and 44% respectively. [7] Added that, poor performance due to the laminar separation bubbles on the blade is one of the major challenge faced by small wind turbine operating at low wind speed. [8] Investigated the aerodynamic design of turbine blade. The maximum coefficient of wind energy utilization obtained was found to be 0.42 which is 2.4% higher than a result obtained from similar study. [9] Carried out a study to control wake effect activity in order to optimize the efficiency of wind farm. It was found that optimizing the pitch variation of the turbine lead to increase in power generation by 4.5%. The characteristics of turbine spacing in a wind farm using an optimal design process was studied by [10]. The spacing between the first and second turbine was found to be responsible for the optimal increment on the wind farm efficiency. [11] Developed a numerical code based on blade Element Momentum (BEM) theory. This novel development enables the wind turbine power coefficient in the designed wind speed to be maximized, as well as the performance of the wind turbine. [12] also developed optimal design performance software for a wind turbine. The result obtained for CP and λ were compared with result obtained using commercial software (GH-bladed), and were found to be in agreement in all values. Similarly, [13] evaluated the annual energy output and capacity factor of small-medium sized wind turbine in some selected location of Oyo State, Nigeria. The wind turbine with a cut-in speed of about 2.5m/s and moderate rated wind speed was found to be suitable for the locations. [14] Conducted walk-through energy audit to ascertain the overall power consumption of a faculty building. They recommended from their study that, any alternative source of energy that is worth 150kW can be used to power the whole building. The thrust of this research work therefore, is to design and analyze the performance the blade of a wind turbine that will serve as alternative source of energy to the faculty.

2. Methodology

Aerodynamic block is responsible for the extraction of power from the wind in form of kinetic energy needed to drive the blades. The modelled aerodynamic wind turbine blade was designed and simulated in MATLAB SIMULINK environment as shown in Fig 1.

The aerodynamic design was described by the tip speed ration (TSR), power coefficient (CP) and Torque. The kinetic energy that it extracted from the wind was used to propel the wind turbine blades. Betz's law stated that 59.3% is the maximum power that can be extracted from a wind turbine [15]. The power accessible from the WT is proportional to the cube of the wind speed (v). Thus, the power output was calculated from the equations given as:

$$P_{blade} = \frac{1}{2} \times CP(\lambda, \beta) \times v^3 \times \rho_{air} \times A \quad (1)$$

Where ρ_{air} is the density of air in kg/m^3, A is swept area in m^2, v is wind speed in m/s and CP is the power coefficient. The CP is usually expressed as function TSR (λ) and pitch angle (β) and is given below as follows [16]:

$$CP(\lambda, \beta) = C_1\left(\frac{C_2}{\gamma} - C_3\beta - C_4\right)e^{\frac{-C_5}{\gamma}} + C_6\lambda \quad (2)$$

Where $C_1 = 0.5176$, $C_2 = 116$, $C_3 = 0.4$, $C_4 = 5$, $C_5 = 21$, $C_6 = 0.0068$ and γ is defined as:

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

The value of CP varies depending on the type of blades, TSR and other design factors of the turbine. The TSR (λ) is the ratio of the blade tip speed to the free wind speed and is expressed as follows:

$$\lambda = \frac{\omega R^2}{v} \quad (4)$$

Where ω is the rotor angular velocity in rad/s and R is the radius of the rotor. The rotor torque developed by the turbine is defined as:

$$\Gamma = \frac{P_{blade}}{\omega} \quad (5)$$

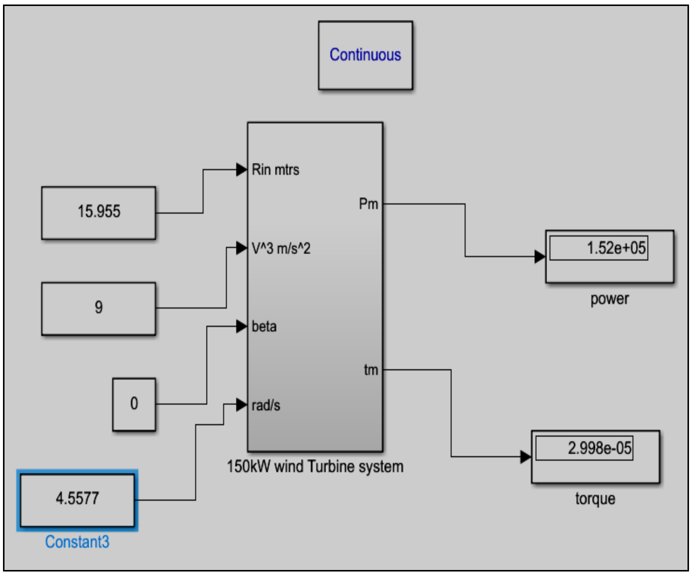


Fig 1: 150kW wind turbine blade model in Simulink

3. Results and Discussion

The aerodynamic block Simulation schematic was performed as depicted in Fig 2. By varying v and λ from 1-12m/s and 1-13 respectively, the power curve revealed that the maximum power output could be generated at a wind speed of 12m/s as depicted in Chart -1. Furthermore, the result also showed an increase in power with increase in the wind speed. It was also noticed that the wind turbine started to produce useful work from a cut-in speed of 3m/s. However, the output energy needed to power the whole faculty building as proposed in current research could be attained at wind speed of 9m/s.
Chart -2 depicted the tip speed ratio-CP curve which shows that the theoretical maximum power coefficient reaches 0.48. This signifies that the designed blade has a very high wind energy utilization coefficient. The results obtained followed the trends of those obtained by [6] and [9].

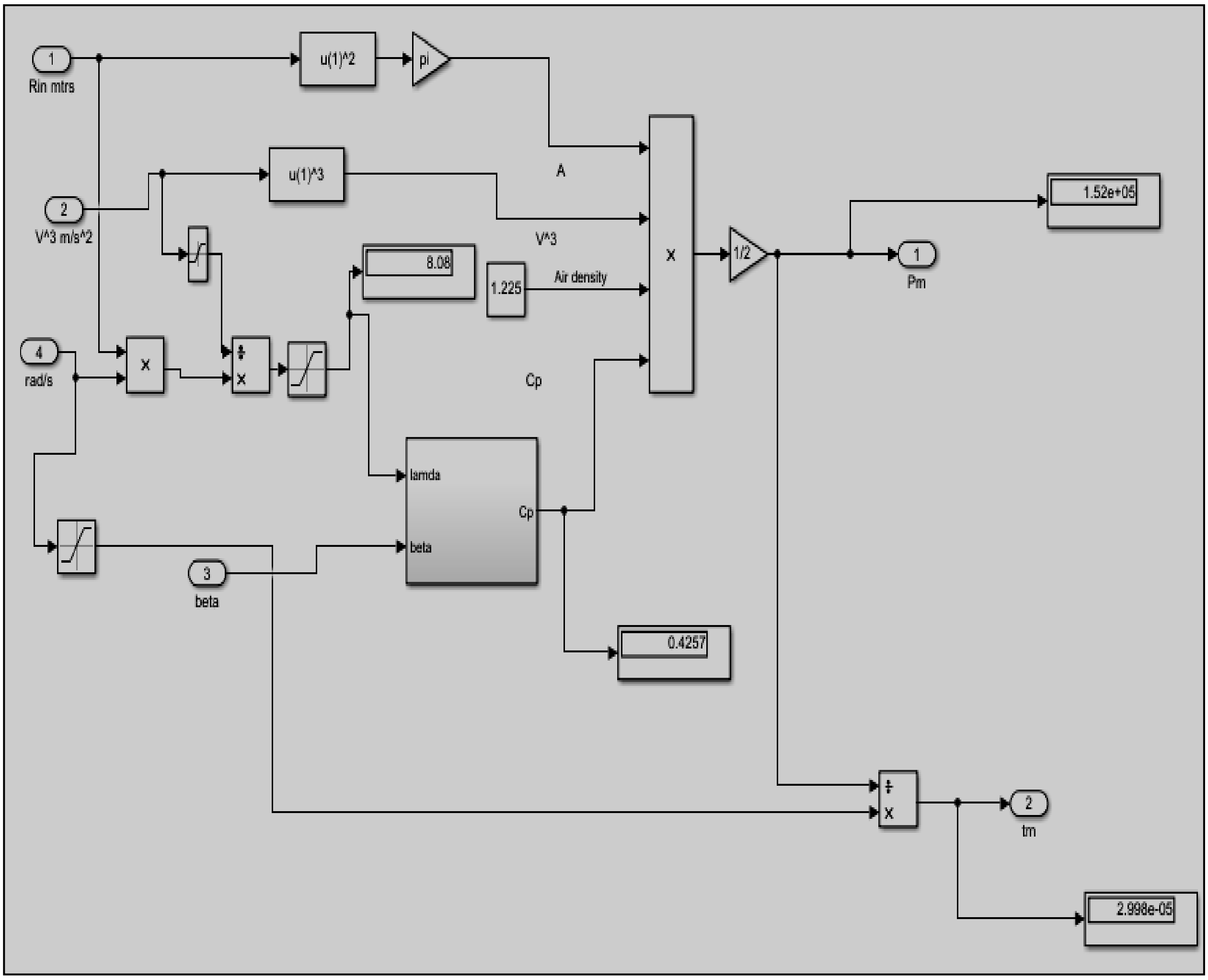
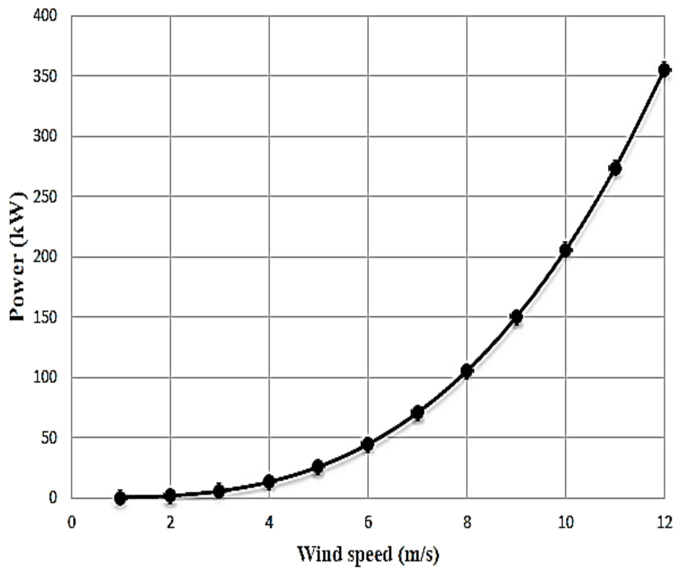
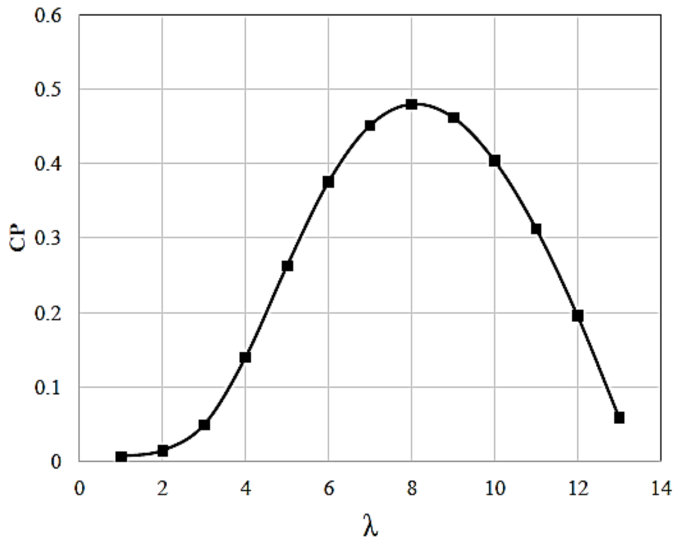


Fig - 2: Aerodynamic block Simulation schematic diagram



Chat -1: Power curve



Chat -2: Tip speed ratio-CP curv

4. CONCLUSIONS

In this study, a computational analysis of the aerodynamic design of a wind turbine blade was carried out to investigate the effect of ν and λ on the performance of the turbine blade. The analysis disclosed that the generated power increases as the wind speed increases, and the turbine blade started to produce useful work from a cut-in speed of 3m/s. It also shown that the generated energy needed to power the whole faculty is attained at 9m/s, and the blade has a very high wind energy utilization coefficient. Thus, the designed wind turbine blades can efficiently convert the energy in the wind to electricity. Furthermore, the study will facilitate and aid the design of a complete and functional wind turbine in any location of Dutsin-Ma in Katsina State of Nigeria. It is also recommended that the Mechanical and Electrical blocks should be modelled in order to have a complete designed wind electricity generation system.

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BIOGRAPHIES

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