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Performance analysis of wind turbine systems under different parameters effect

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Abstract
In this paper, simulation models are used to study the performance of small power systems based on different weather parameters. The results are extracted using Matlab software program for analyzing the performance of two wind turbines: Whisper-500 3.2KW and NY-WSR1204 600W which have the same type of permanent magnetic alternators (three phase and 16 poles). Different parameters can affect on the performance of wind turbines which are: the wind speed air density, air pressure, temperature and the length of blades for wind generators. The mathematical results related the previous mentioned parameters are analyzed in order to determine the sensitivity of input power on the output of wind generators.

Keywords: Wind generator; Whisper-500; NY-WSR1204; Wind speed; Air density; Air pressure; Air temperature.

1. Introduction
The basic goal of calculating effect of air's parameters in mechanical power (that later become electrical output power) is to show the generating sensitivity of wind generator to air characteristics variation at any wind speed value. Then create database for air effect of mechanical power to use it in practical tests, installation, electrical generation, usefulness of wind station with air's parameters of its location and compare the economic profit to electrical wind station installation with its costs and losses.
In the last years MATLAB/Simulink has become the most used software for modeling and simulation of wind systems [1]. Wind turbine systems are an example of such dynamic systems, containing subsystems with different ranges of the time constants: wind, turbine, generator, power electronics, transformer and grid.
In 2008, the United States became the nation with the largest wind power generation infrastructure [2]. As wind turbine power generation proliferates, designs are needed which are both efficient and minimally disruptive to surrounding communities, particularly in terms of additions to background noise. Design optimization is therefore needed to resolve the conflicting considerations of maximum power production and minimum noise generation. Horizontal Axis Wind Turbines (HAWTs) have become the predominant configuration for harnessing wind power, exemplified in the General Electric 1.5sle wind turbine, a model rated at 1.5MW. The wind turbine rotor is the mechanism which interacts directly with the wind in order to convert it into energy, and is also the main contributor to wind turbine noise. Therefore the present work will focus on optimization of the aerodynamic and aero acoustic properties of the wind turbine rotor. The main improvement over that work is the incorporation of a variable airfoil shape across the rotor and fixed *y*-coordinates of the Bezier curve control points.

The authors are using the facilities of MATLAB environment for simulation, optimization and sensitivity analysis of small power generating systems based on renewable energies [3], however, the modeling, simulation and analysis of a large variety of systems based on renewable energy and to manage these systems, the software MATLAB was expanded with the RegenSim library. This library was designed to implement the above functions for hybrid systems based on renewable energy sources, but also their components interfacing with components from other libraries, particularly those of MATLAB Simulation Power Systems library.

Basic components of RegenSim library are: Wind generators, PV generators, Hydro generators and Storage devices. Each of these components was basically modeled on studies of mathematical models and has associated specific parameters. The interfacing with MATLAB libraries components was realized in order to make a thorough study of the modeled hybrid system from local automatic control systems to the centralized operational management system. Except for Storage device component, each of the other three components has, as input parameters, the specific primary source of energy and, through interconnection with different types of measurement and display blocks of MATLAB, voltages, currents, powers and energy flows from the system, depending on the nature of the consumer, can be watched. The Storage device component was designed with the primary function of serving as a buffer to store the energy produced by renewable sources, from its terminals being directly supplied the DC consumers and the AC through the inverter blocks. At the batteries level can be monitored by using measure and display blocks from MATLAB, the size and state of battery charge (SOC), the terminal voltage or currents absorbed by consumers. One of the advantages of MATLAB software is that libraries offer a wide range of basic components for modeling the consumers. Thus, it can be modeled both single-phase or three phased consumers with different powers, nature and types (e.g.: resistive, capacitive or inductive consumers).

The utilization of wind energy for power generation purposes is occupying a great share in the electricity market worldwide and becoming increasingly attractive [4]. The good exploitation of wind energy may enhance the renewable power generation capabilities, maximize its capacity factor, and participate in generating electricity at good costs. Many factors have to be considered during manufacturing or installation of wind turbines, i.e., (turbine swept area, air density, wind speed, and power coefficient as a function of pitch angle and blade tip speed).

Renewable energy including solar, wind, tidal, small hydro geothermal, refused derived fuel and fuel cell energies is sustainable, reusable and environmentally friendly and clean[5]. With the increasing shortage in fossil fuels, and pollution problems renewable energy has become an important energy source. Among the other renewable energy sources wind energy has proven to be one of the most economical one. Earlier Constant speed WECS were proposed to generate constant frequency voltages from the variable wind. However, Variable speed of Wind Energy Conversion System (WECS) operations can be considered advantageous, because additional energy can be collected as the wind speed increases. Variable speed WECS must use a power electronic converter. They are classified as full power handling WECS and partial power handling WECS. In full power handling WECS, the power converter is in series with the induction or synchronous generator, in order to transform the variable amplitude/frequency voltages into constant amplitude/frequency voltages and the converter must handle the full power. In a partial power handling WECS, the converter processes only a portion of the total generated power (e.g. slip power) which poses an advantage in terms of the reduced cost converter of the system and increased efficiency of the system. This paper is focused on partial power handling WECS using DFIG. A dynamic steady state simulation of WECS is essential to understand the behavior of WECS. This paper explores steady-state characteristics of a typical variable-speed that uses doubly fed induction generators using MATLAB.

2. Modeling of wind turbine

The turbine is a wind energy conversion system. It consists of an induction generator and other electrical control power requirements. The wind turbine is effected by many parameters whether internal (electrical connection, rotor size, copper and iron losses, efficiency of wind generator and blade shape) or external (wind speed, weather parameters, location and height of wind tower). The mechanical power is given in equation (3). This equation describes the relation between the input mechanical power with wind speed variation and other variables (air pressure, air density and temperature). The variation range of these variables is used to cover the atmosphere effect on the mechanical power. Electrical power (Pe) is approximately 0.7 of mechanical power. The parameters are measured at the same site of installed wind turbines (University of Anbar Campus/ Ramadi- Iraq).

$$Pw=(1/2)\rho\times A\times V^3 \quad (1)$$

but

$$P=Cp\times Pw \quad (2)$$

therefore

$$P=(1/2)\rho\times A\times Cp\times V^3 \quad (3)$$

and

$$Pe=P-PL \quad (4)$$

where: Pw = wind power, P = mechanical power in watts, Pe = electrical output power, PL= power losses in wind turbine, ρ = air density in kg/m^3, A = swept area in m^2, Cp =power coefficient of wind turbine, V = wind speed in m/s.

Mechanical power of wind turbine is directly related to the wind speed as well as to the swept area of its blades. It should notice that the power is proportional to the cube of the wind speed and the square of the radius of the rotor blades. If the radius of the rotor blades is doubled, the swept area is quadrupled. Also, the efficiency needs to be considered due to blade size and shape, number of blades, pitch angle, rotor speed, alternator efficiency, gear losses and other such factors. If the wind speed is reduced by half (1/2), the power is reduced to 1/8 of the original power. Thus, a light wind contains little power, so remember to use a larger table fan for the experiments. It will produce much better results [6].
Albert Betz was a German Physicist and a pioneer of wind turbine technology. He found out that we can only harvest, at maximum, 16/27 or 0.593 of the power from the wind. This number is called the Betz coefficient and is the theoretical maximum efficiency that a wind turbine can harvest from the wind [7].
The wind turbines activity to convert power from mechanical to electrical is depend on power losses like mechanical, electrical and iron losses. Generally wind turbine converts (90-70) % of the mechanical power into electricity. Therefore, the wind turbine would be convert (59-41) % of the available wind energy into electricity.

2.1 Blade length effect
The effect of increasing the blade length is shown in Figure 1 with constant air density equal to 1.225 kg/m^3. From this figure it can be seen that as the blade length increased from 0.8m to 1.8m, the mechanical power increased from approximately 700W to 3550W at wind speed of 12m/s which is rated speed. Table 1 shows the standard classification system for wind turbines and effect of diameter of power rating of wind generating [8]. The diameter of swept area is twice of blade length which represent radius of swept area.

Table 1. Standard classification system for wind turbines

Scale	swept area diameter	Power rating
Micro	Less than 3 m	50 W to 2 kW
Small	3 m to 12 m	2 kW to 40 kW
Medium	12 m to 45 m	40 kW to 999 kW
Large	46 m and larger	More than 1.0 MW

Figure 2 and Figure 3 show the relation between mechanical and electrical powers respectively versus the blade length at fixed wind speed of 12m/s. from these figures, it is clear that the larger the length of its blades cause more power can be extracted from the wind.

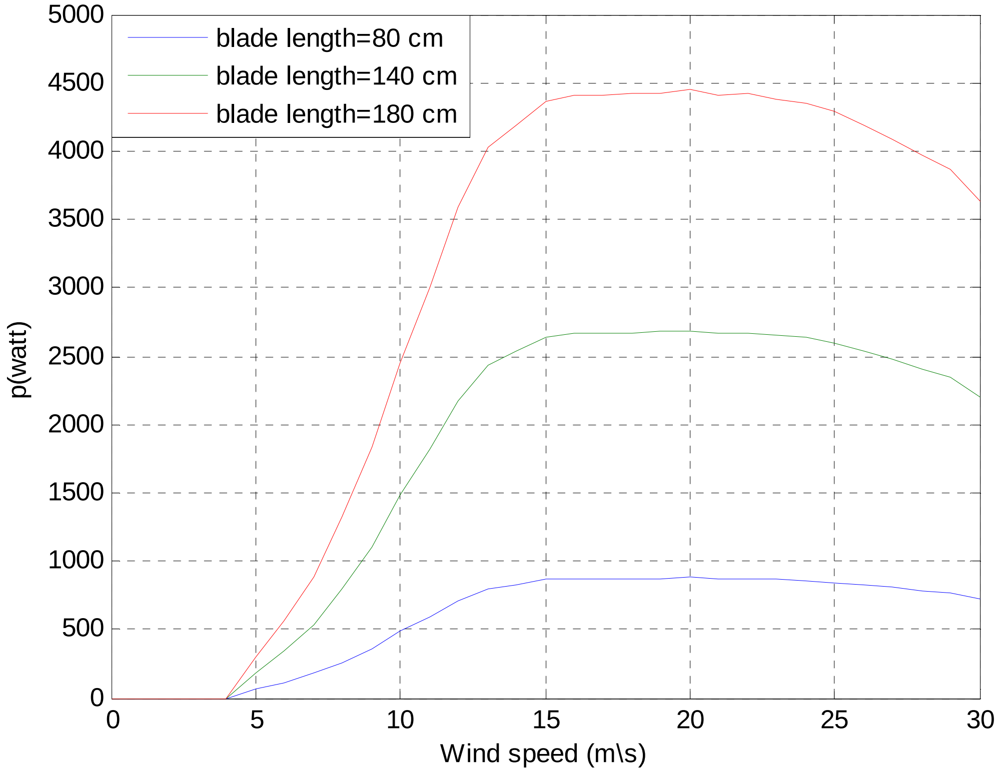

Figure 1. Blade length effect of mechanical power

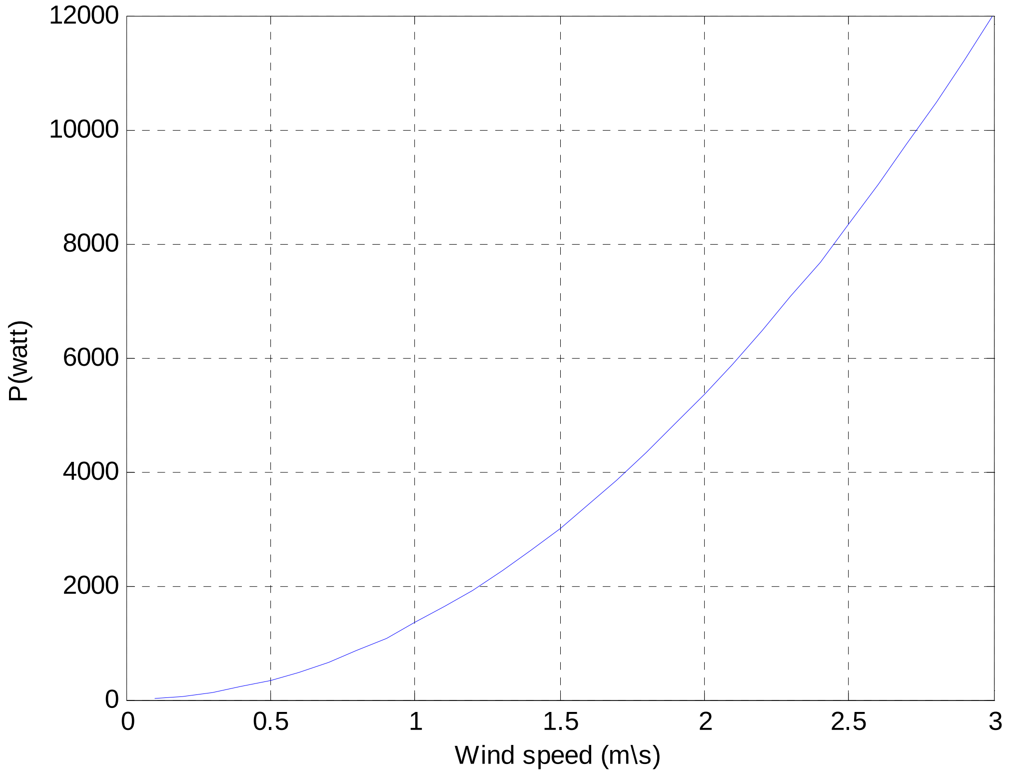

Figure 2. Mechanical power versus the blade length (wind speed=12m/sec)

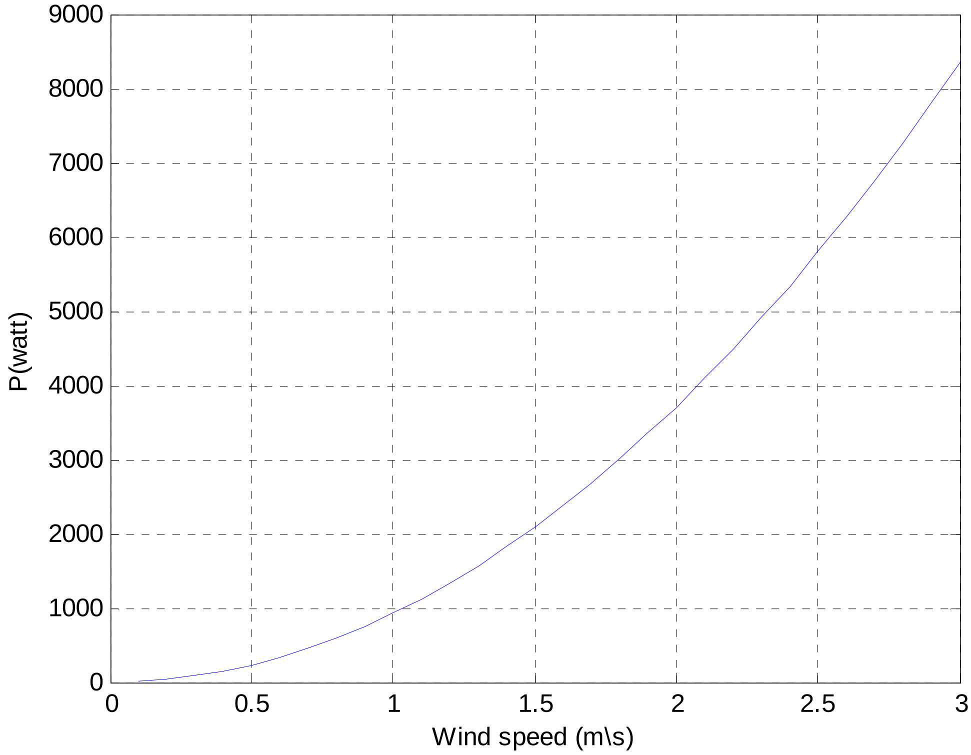

Figure 3. Electrical power versus the blade length (wind speed=12m/sec)

As example in Whisper-500 wind generator has 1.8 m blade length, the mechanical power is 3550 and electrical output power is equal 3200w. As the same way in NY-WSR1204 wind generator has a blade of 0.8 m, the mechanical power is 700w and electrical output power is equal 600w

2.2 Wind speed

The mechanical power (P) is harnessed with the wind speed (V). The wind speed of air is a measure of activity of wind generator and it has a greatest effect on the mechanical power (see equation (1)). The wind turbine is characterized by the dimensional curves of the power coefficient (Cp) as a function of both the tip speed ratio (λ) and the blade pitch angle (B). The result is shown in Figure 4.

$$Cp=Cp(\lambda,B) \quad (5)$$

In order to fully utilize the available wind energy, the value of (λ) should be maintained at its optimum value. Therefore, the power coefficient corresponding to that value will become at maximum value. The tip speed ratio (λ) can be defined as the ratio of the angular rotor speed of the wind turbine to the linear wind speed at the tip of the blades; that is to say the behavior of mechanical power effectiveness by wind speed is determined by power coefficient [9].

$$\lambda=\omega t\times r/V \quad (6)$$

where: r = wind turbine rotor radius, V = wind speed, ωt = mechanical angular rotor speed of the wind turbines.

Initially, wind speed is not useful until it reach to cut in speed of 4 m/s then the power begin initiates and grows with wind speed increasing. When wind speed increases up to 14m/s, the stability of mechanical power can be observed while the drop of mechanical power starts at cut off speed of 25m/s as shown in Figure 5.

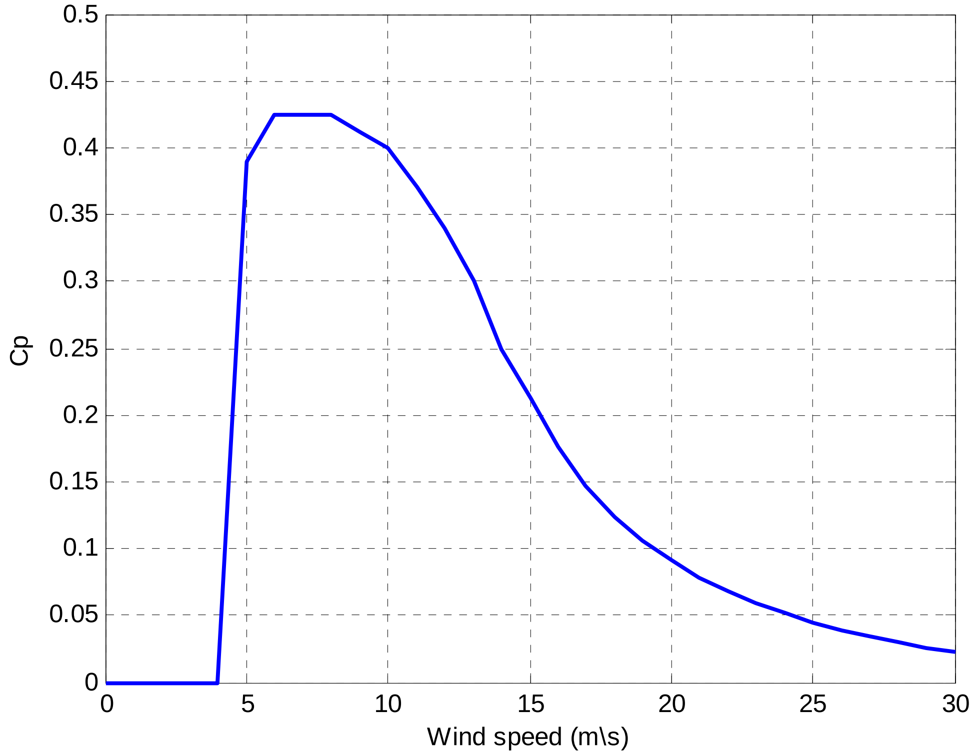

Figure 4. Power coefficient as a function with wind speed

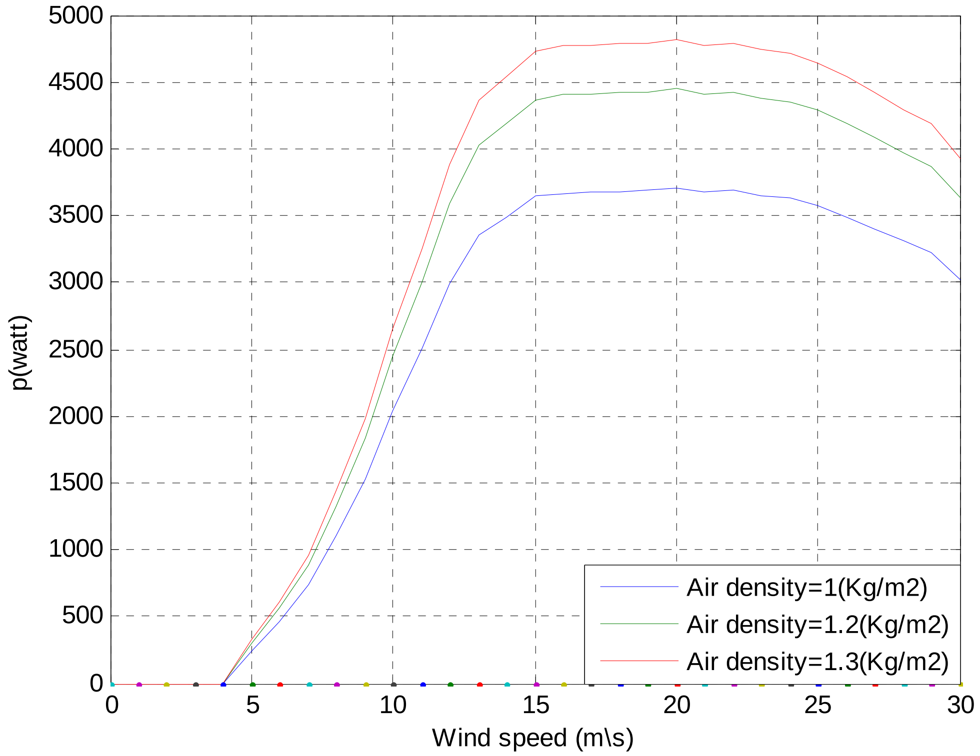

Figure 5. Air density effect of mechanical power of Whisper-500 wind generator

2.3 Air density

An air density effect of mechanical power is remarkable and clarifies the wind stations work under air density variation with constant wind speed. Mechanical power of wind generator is directly proportional to air density. As air density increases the available power also increases show that in Figure 6.

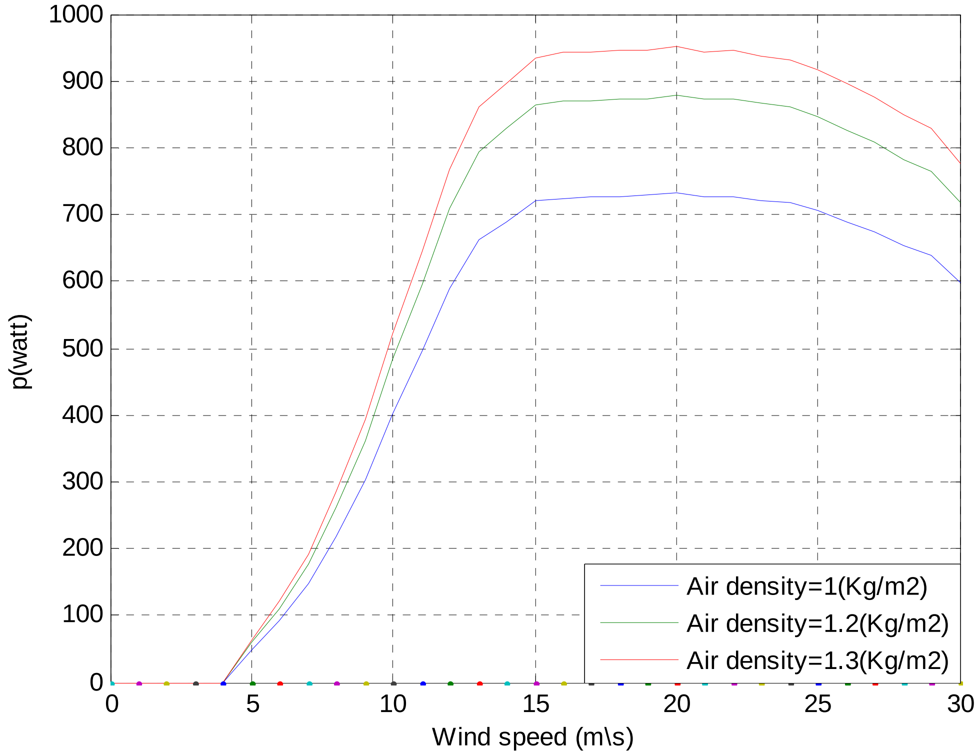

Figure 6. Air density effect of mechanical power of NY-WSR1204 wind generator

Air density is a function of air pressure and temperature. It increases when air pressure increases or the temperature decreases. The effect of these parameters (Pressure and temperature) on the mechanical power is shown in Figures 7 and 8 at constant temperature of 25^0C. The first figure is for Whisper-500 wind generator, while the second figure is for NY-WSR1204. From both figures it is clear that the power increases as the air pressure increases for both models.

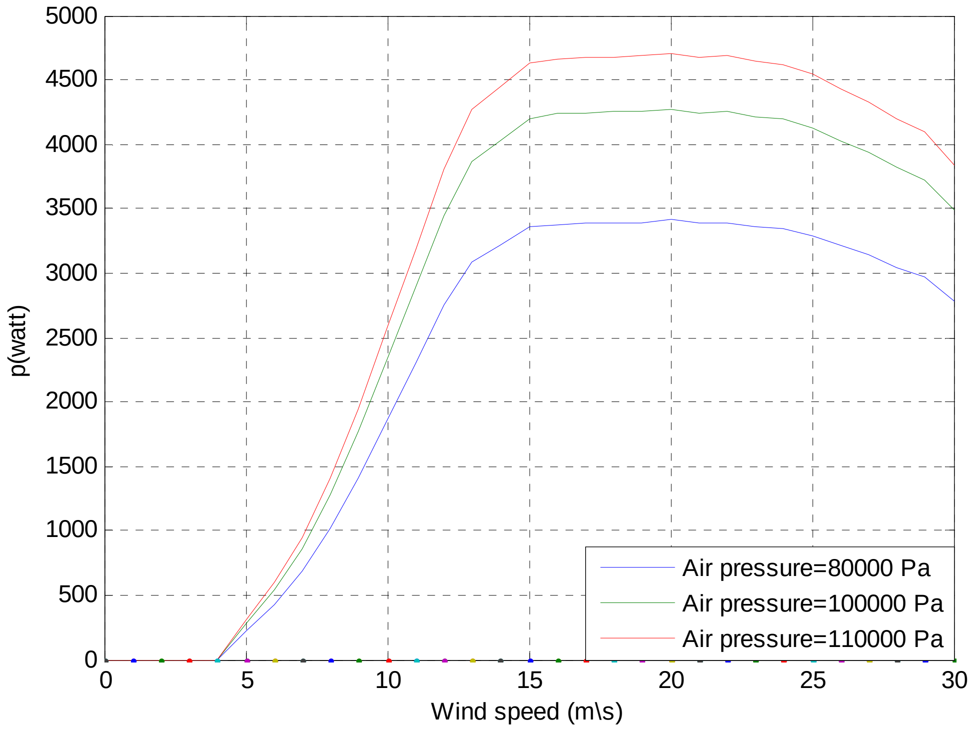

Figure 7. Air pressure effect of wind power for Whisper-500 wind generator (^{0}C=25)

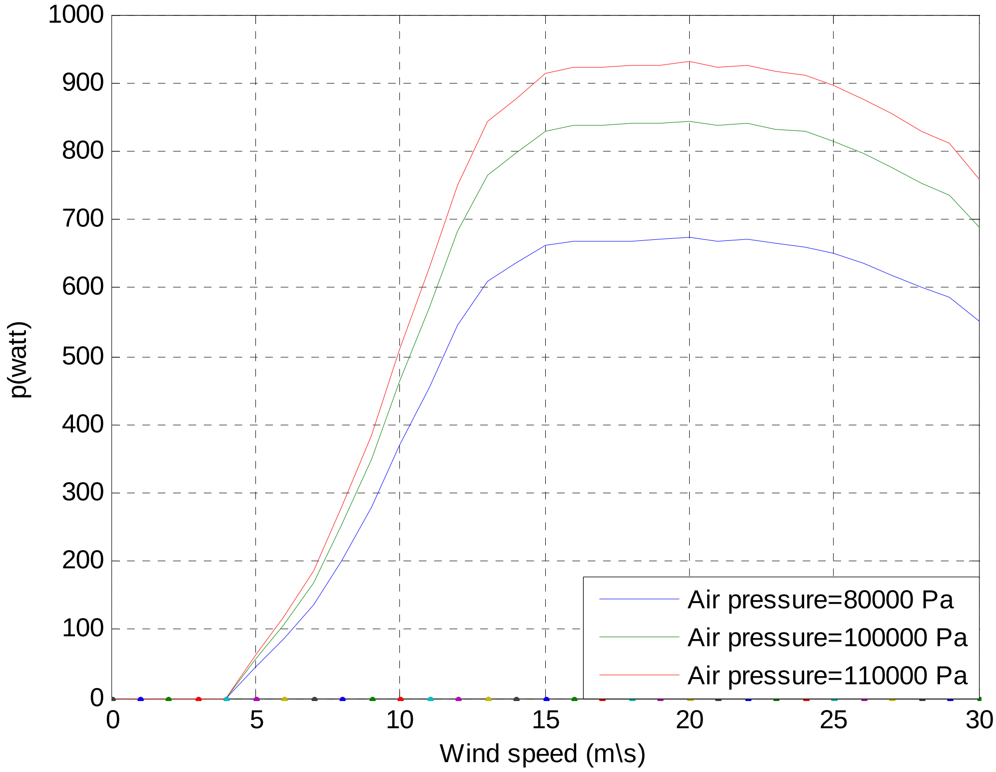

Figure 8. Air pressure effect of wind power of NY-WSR1204 wind generator (^{0}C=25)

Figures 9, and 10 show the effect of temperature on the power with constant pressure equal 100000 Pa for both models.

Both temperature and pressure decrease with increasing elevation. Therefore changes in elevation produce a profound effect on the generated power as a result of changing in the air density. To understand air density effect it is important to understand how it is changed with air status. Air density simply the mass of the molecules of the ideal gas in a certain volume, which may be mathematically derived in equation (4) [10].

$$\rho = pa/(R \times T) \tag{7}$$

where: ρ = air density, kg/m^3, pa = air pressure, Pascals (Pa), R = specific gas constant = 287 for dry air, T = temperature, deg K = deg C + 273.

As an example, using conditions of P = 100000 Pa and T = 25 deg C, the air density be calculated as: D=100000/(287×(25+273))=1.169 kg/m^3

This example has been given for the dry air to clarify the effect of temperature and pressure and moisture in the air in air density and consequently electrical generation is changed with this effect that necessary to be taken in account of any electrical calculation.

3. Conclusion

In this paper, a simulation Matlab model for wind turbines is presented as a useful tool for practical utilization. According to the results, there is a high effect of air characteristics on the mechanical and electrical power. Many effects have to be considered during the analysis of wind turbine performance, like the turbine blade, wind speed, air density, pressure, temperature, and power coefficient. The environment's parameters has a massive effect on the generated power, which will lead the researchers to concentrate on it with highest priority.

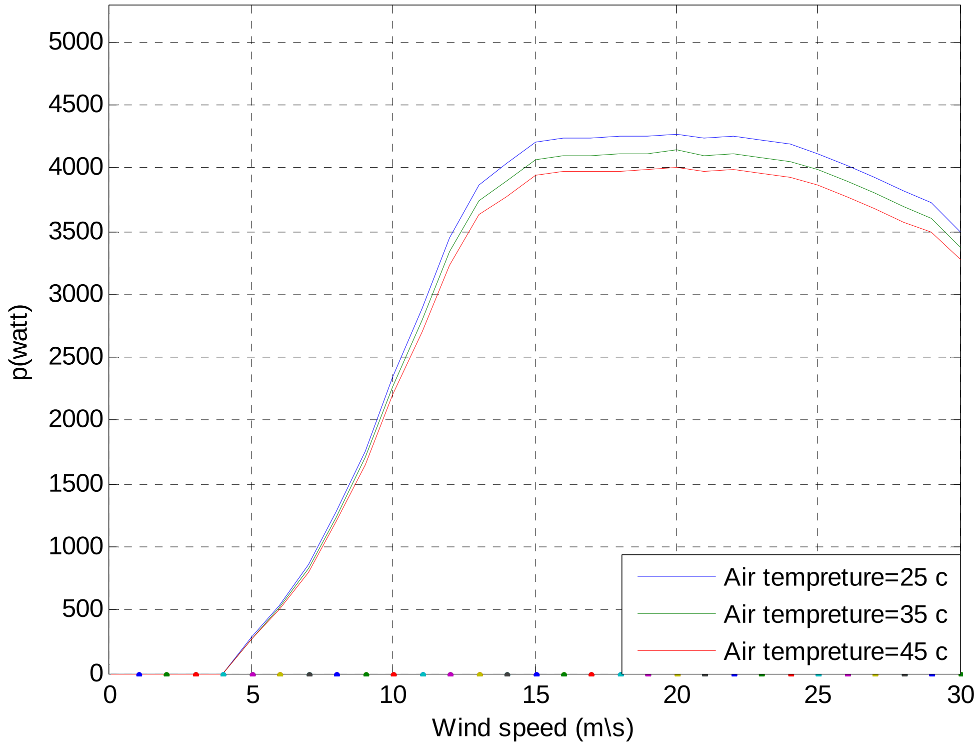

Figure 9. Air temperature effect of wind power of Whisper-500 wind generator

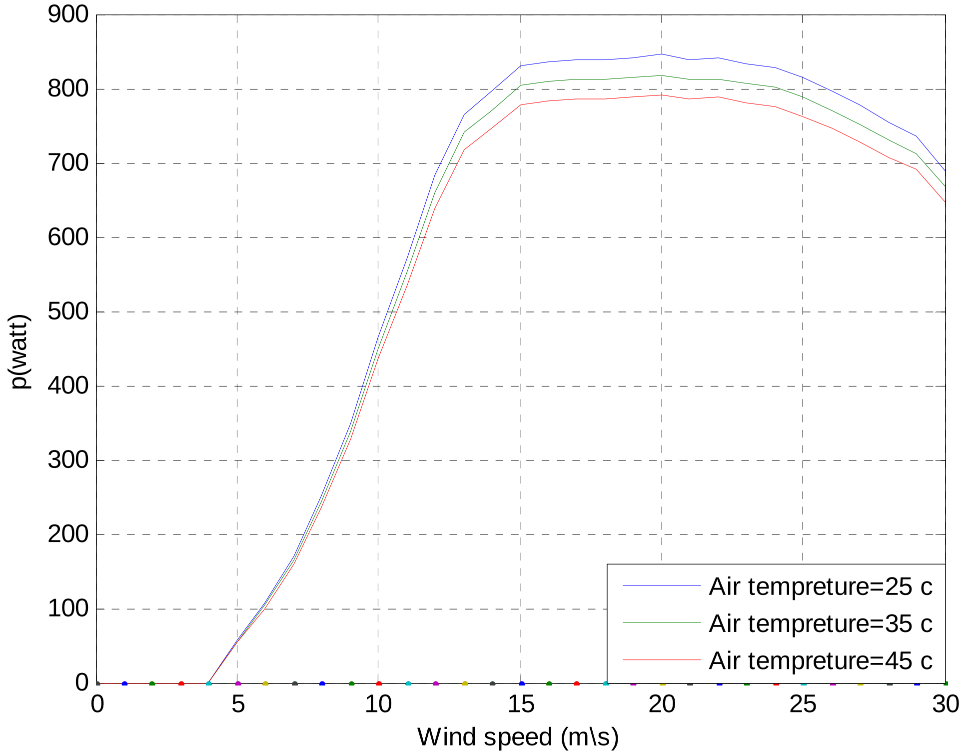

Figure 10. Air temperature effect of wind power of NY-WSR1204 wind generator

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