Nature of Wind Turbine Power

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***Abstract*—Wind is merely air in motion. Wind turbine convert kinetic energy from the wind that passes over the rotors into electricity. In this paper a wind electrical system is designed using induction generator in PSCAD (Power System Computer Aided Design) software. Here a simulation approach is adopted to observe the nature of power obtained from the wind turbine. From the study it is seen that the turbine power is dependent on air density, area of the rotor and wind speed**

***Index Terms*— Air density, rotor area, wind electrical system, wind speed, wind turbine power.**

I. Introduction

The conventional energy sources are limited and have pollution to the environment. So more attention and interest have been given to the utilization of renewable energy .Wind energy is the fastest growing and most promising renewable energy sources among them due to economically viable. During last two decades; the high penetration of wind turbines in the power system has been closely related to the advancement of the wind turbine technology and the way of how to control. Doubly-fed induction machines are receiving increasing attention for wind energy conversion system during such situation [1].

Recently, due to incremental rate of environmental concern, wind energy development has experienced a significant of interest and considerable attention all over the world. Large wind turbines with the wind power of MW levels are becoming more and more attractive to offshore wind firm, and a number of wind firms of rated capacity of hundreds of MW level are going to be connected to the existing power system in near future. Due to its simple construction and low maintenance cost, wind turbines based on induction generators are mostly used [2].

Modern wind turbines fall into two basic groups: the horizontal-axis variety and the vertical-axis design, like the egg beater-style Darrieus model, named after its French inventor. Horizontal-axis wind turbines typically either have two or three blades. These three-bladed wind turbines are operated "upwind," with the blades facing into the wind. Wind turbines transform kinetic energy in the wind to electricity. Almost all commercial wind turbines are 'horizontal axis' machines with rotors using 2 or 3 airfoil blades. The rotor blades are fixed to a hub attached to a main shaft, which turns a generator – normally with transmission through a gearbox. Shaft, generator, gearbox, bearings, mechanical brakes and the associated equipment are located inside the nacelle on top of the tower. The nacelle also supports and transfers structural loads to the tower, together with which it houses all automatic controls and electric power equipment. The wind turbine automatically yaws the nacelle to the direction facing the wind for optimal energy production. The turbines are stopped at very high wind speeds (typically 25 m/s) to protect them from damage. Rotors may operate at constant or variable speed depending on the design. Modern MW-size machines are all variable speed concepts. Typical rotor speeds at rated power range from 15 revolutions per minute and up – a factor, which influences the visual impact. The larger the rotor the lower the rotational speed in order to keep the blade tip speed in the optimal range – 60-80 m/s. Power output is automatically regulated as wind speed changes to limit loads and to optimize power production. The present "state of the art" of large wind turbines has:

- Power control by active stall or pitch control (in both cases pitching blades) combined with some degree of variable speed rotor, and
- A two-speed asynchronous generator, or a gearless transmission to a multipole synchronous generator and power electronics.

Wind turbines range in capacity (or size) from a few kilowatts to several megawatts. The crucial parameter is the rotor diameter – the longer the blades, the larger the area swept by the rotor and thus the volume of air hitting the rotor plane. At the same time the higher towers of large wind turbines bring rotors higher above the ground where the energy density in the wind is higher. Totally, larger wind turbines have proven to be more cost-efficient due to improvements in designs and economics of scale, but also with a higher energy production per swept m^2, due to the higher towers and better aerodynamic design [3]- [4].

In this paper model of a wind electrical system has been designed using induction generator. This system has been developed with the help of PSCAD (Power System Computer Aided Design) software. The nature of the turbine power is observed with the developed model. This paper will help in studying the factors affecting wind power generation.

II. Factors Affecting Wind Power

For designing a wind firm the following factors should be considered:

A. Power in the Wind

The total power that is available to a wind is given as

$$P=1/2\ \rho\ AV^3$$

where ρ is the air density in Kg/m^3, A is the exposed area in m^2, and V is the wind velocity in m/sec. The density is a function of pressure, temperature and relative humidity. Wind power varies as the cube of wind velocity.

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B. Wind Statistics

Wind is highly variable power source and there are several methods of characterizing this variability. Most common is the power duration curve. Another method is to use a statistical representation, particularly weibull function.

C. Load Factor

There are at least two major constraints on wind turbine design; one is to maximize the average power output. The other is to meet the necessary load factor requirement of the load. Load factor is not of major concern if the wind electric generator is acting as a fuel saver on the electric network.

D. Seasonal and Diurnal Variation of Wind Power

Seasonal and diurnal variation has significant effect on wind. Load duration data are required to judge the appropriate effects. Diurnal variation is less with increased height.

E. Effect of Height

Wind speed increases with the height because of the friction at earth surface. The rate of increase is given by

$$V/V_o = (Z/Z_o)^{1/7}$$

where V is the predicted wind speed at height Z and V_0 is the wind speed at height Z_o.

F. Variation with Time

For most applications of wind power, it is more important to know about the continuity of supply than the total amount of energy available in year. In practice when the wind blows strongly, e.g. more than 12 m/s there is no shortage of power. Difficulties appear, however, if there are extended periods of light or zero winds [5].

III. Description of the Developed Circuit

The external wind, Es is fed to the Wind Source by regulating the Variable Real/Integer Input Slider. In Wind Source various types of wind characteristics such as gust, ramp, noise and damping can be used with mean wind speed. After this, the wind speed Vw , from the Wind Source is given to the input of Limiter. If the wind speed is between the upper limit and lower limit of the Limiter then it outputs a duplicate of the input signal.The output wind from the Limiter is fed to the input Vw of the Turbine. The Pitch angle is controlled in the Governor and by the Beta output of the Governor this controlled signal is fed to the Beta input of the Turbine. The mechanical speed of the machine is given to the W input of the Turbine through Real Constant. The Pg output of the Governor is connected with the P output of the Turbine. The output torque Tm of the Turbine is fed to the input torque T of the Induction Generator. The per-unit speed, 1.01 of the induction generator is given to the W input of the Induction Generator by using Real Constant. Another Real Constant 1 is used as an input in the S terminal of the Induction Generator to run the machine in speed control mode. Phase A, Phase B, Phase C of the Induction Generator are connected with the Voltage Source and RMS meter by Node Loop and other necessary model. By adding graphs with Vw ,P ,Beta ,Te,Tm ,Pout ,Qout and output of RMS meter their nature can be obtained.

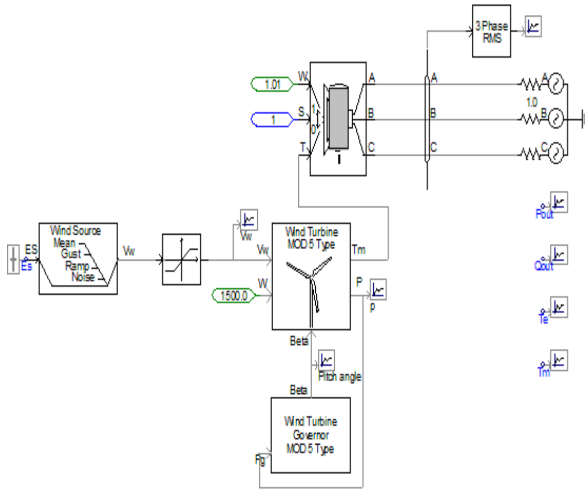


Fig. 1. Model of a wind electrical system with induction generator

IV. Analysis of Results

A. Variation of Turbine Power with Air density

Three graphs for output power of a turbine used in the wind electrical system with Induction Generator are shown in figure 2. The turbine output power; P (p.u) graphs are plotted as a function of air density. The air density is varied from 1.165 kg/m^3 to 1.225 kg/m^3. When air density is 1.165 kg/m^3 the maximum output power is 0.095032 p.u, for air density 1.204 kg/m^3 the maximum value of power is 0.098214 p.u and for 1.225 kg/m^3 air density the value is 0.099927 p.u . So from these three graphs it is observed that with the increase in air density the maximum value of turbine output power also increases in case of wind electrical system modeled with Induction Generator.

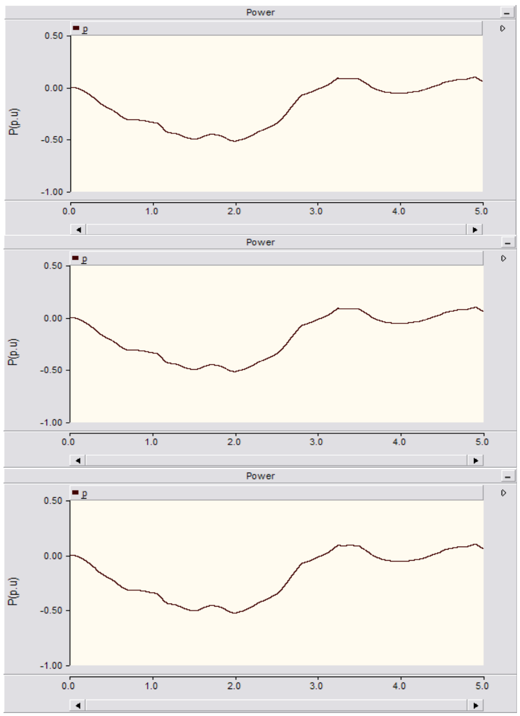


Fig. 2. Variation of turbine power with air density

B. Variation of Turbine Power with Rotor Radius

Three graphs for output power of a turbine used in the wind electrical system with Induction Generator are shown in figure 3. The turbine output power; P (p.u) graphs are plotted as a function of rotor radius. The rotor radius is varied from 15 m to 17 m. When rotor radius is 15 m the output power is minimum and maximum output power is obtained at 17 m. So from these three graphs it is observed that with the increase in rotor radius the value of turbine output power increases in case of wind electrical system modeled with Induction Generator.

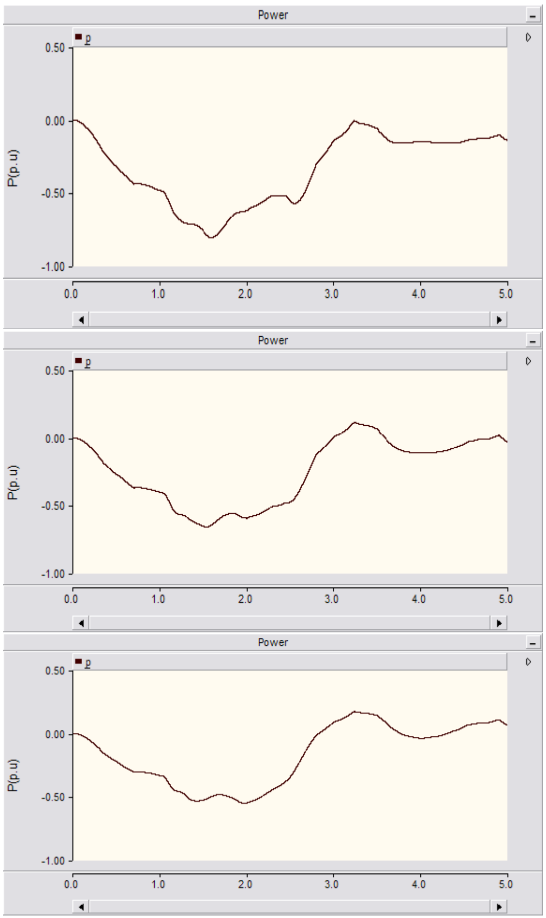
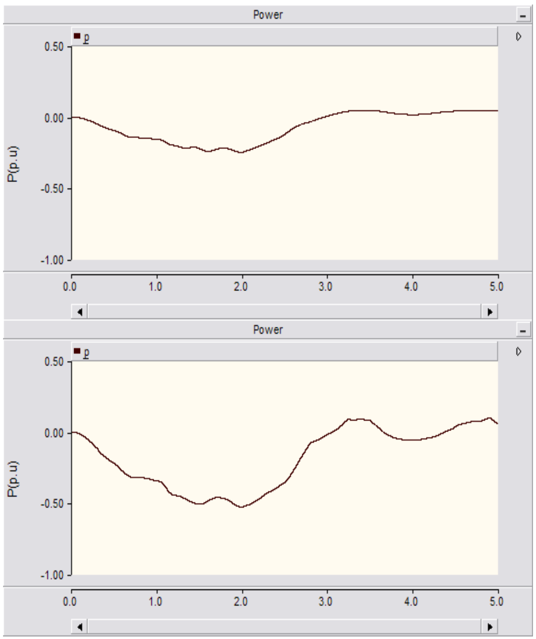


Fig. 3. Variation of turbine power with rotor radius



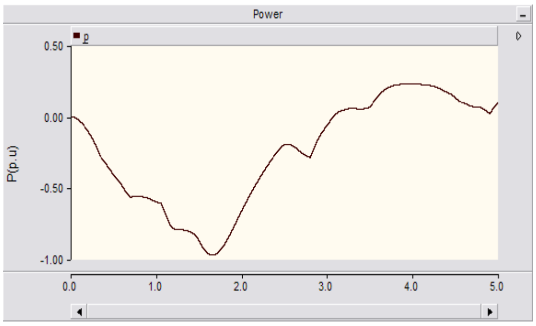


Fig. 4. Variation of turbine power with wind speed

C. *Variation of Turbine Power with Wind Speed*

Three graphs for output power of a turbine used in the wind electrical system with Induction Generator are shown in figure 4. The turbine output power; P (p.u) graphs are plotted as a function of wind speed. The mean wind speed at reference height is varied from 3.33 m/s to 6.67 m/s. When wind speed is 3.33 m/s the maximum output power is 0.042105 p.u, for wind speed of 5 m/s the maximum value of power is 0.099927 p.u and for 6.67 m/s wind speed this value is 0.229699 p.u. So from these three graphs it is observed that with the increase in mean wind speed at reference height the maximum value of turbine output power also increases in case of wind electrical system modeled with Induction Generator.

V. Discussion

Power performance measurements have always been an important issue in relation to wind energy. The influence of the parameters is even more important today, where the area of rotor disk is significantly increased since modern wind turbine became commercially available.

The wind comes in contact with the wind turbine and rotates the blades of the turbine. Then kinetic energy of wind will be converted by the turbine. So, power will be generated at the output of the turbine. Various parameters affect the output power. Air density, rotor area and wind speed are some important parameters which affect the turbine power. The variation of wind turbine output power with air density, rotor radius and wind speed are shown in this paper. Here it is seen that as the air density increases the output power also increases. The exposed area of the turbine is a function of the radius of the turbine. As the radius of the turbine increases the area of the turbine also increases. With the increase in rotor radius the amount of power also increases. Again, it is observed that with the increase in mean wind speed at reference height the maximum value of turbine output power also increases. So, the turbine output power is directly proportional to the air density, area of rotor and wind speed.

VI. Conclusion

In this work different turbine power graphs are obtained from the circuit. From the graphs a relationship is found among wind turbine power, air density, rotor area and wind speed. This relationship can be justified from the formula of wind power related with air density, rotor area and wind speed.

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