MODELING OF WIND TURBINE FOR WIND ENERGY CONVERSION SYSTEM

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Abstract- This paper presents a study of wind turbine in wind power generation system for real time modeling. We are at era when there is gradual reduction in fossil fuels and environmental pollution is of main concern. Due to this reason we are focusing on non-conventional/ renewable energy resources. Nowadays penetration level of wind power in power system is increasing day by day. The main reason for higher penetration of wind power is its higher conversion efficiency. But before inserting wind power in power system it is necessary to estimate the power output which we are going to obtain from WECS. Few parameters on which power output from Wind turbine (WT) depends, are wind turbine radius, air density, swept area of blade, wind speed and pitch angle. If these parameters are known, wind power output can be estimated.

In the present paper, a mathematical model is developed to study the parameters that affect the electrical power generated by the wind turbines. The considered parameters are turbine swept area, air density, wind speed, and power coefficient as a function of pitch angle and blade tip speed. This study shows that the operational parameters has a direct effect on the generated power which will lead the utilities to select the dimension and designs of wind turbine to obtain the estimated wind power.

Keywords: WECS, Wind turbine, DFIG, Tip-speed ratio, pitch angle, swept area, aerodynamic modeling, radius, and penetration level.

I. INTRODUCTION

The use of wind energy is almost as old as 10,000 years ago. In earlier days, wind energy was used for sailing boats, grinding mills, water pumping etc. With the continuous gust in inventions and discoveries in means and methods of improving utilization of available resources, during the scientific age a seed of generating electricity from wind was sown in mind of many researchers of those ages. Wind power has additional advantages of availability, pollution free, cheapness and its easier handling. The system which transforms wind energy into other form of useful energy is known as wind energy conversion system (WECS). The mechanical energy produced by wind energy is usually used as prime mover for electricity generation. The intermittency of wind often creates problems when used to supply up to 20% of total electricity demand, but as the proportion increases, a need to upgrade the grid, and a lowered ability to supplant conventional production can occur. The question that has to be asked is how wind power will affect the whole electrical grid, in particular the network to which it is usually connected to. The blades use engineered airfoils, matched to the alternator, that capture the wind's energy. Most modern wind generators use three blades, the best compromised between the highest efficiency possible and the balance provides with the multiple blades. Together, the blades and the hub, they are attached to the rotor, which is the collector of the system, intercepting winds that pass by.

The parameters which we need to consider while modeling the WT are radius of wind turbine blade, air density, material of WT blades, wind speed tip speed ratio (which is the ratio of angular speed of wind turbine to the wind speed), and power coefficient (which is the ratio of mechanical power output to the power contained within the wind) which is the function of tip speed ratio and pitch angle. Using these parameters, the wind power which we are going to obtain, can be estimated.

II. AERODYNAMIC MODELLING METHODS

There are basically three methods of aerodynamic modeling which are: I.) Simple thumb rule II.) Modeling based on the standard mathematical equation for cp curve which is function of λ and β III.) Approximate modeling of wind turbine to vary Cp and Cq as function of wind speed.

A. SIMPLE THUMB RULE

This modeling usually uses equation shown below for obtaining the power output versus wind speed. The ramp is provided to the wind speed and the power coefficient to obtain the curve. The curve obtained using the MATLAB programming using equation is shown in the below figure. This curve is used in order to find the optimum tip speed ratio at which we can obtain the optimum power output. The various values which are considered for obtaining this plot are mention in table 1.1

$$\text{Pm} = \left(\frac{1}{2}\right) * (\text{Pa} * \text{Cp} * \text{v}\infty^3)$$

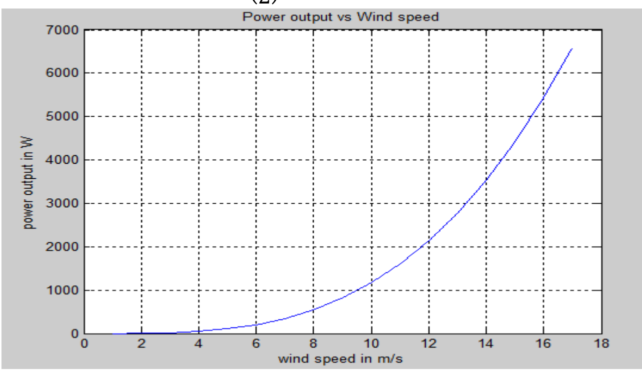

Fig.1: Coding result for power versus wind speed

B. MODELING BASED ON THE STANDARD MATHEMATICAL EQUATION FOR CP CURVE WHICH IS FUNCTION OF λ AND β:

A more generalized model, which implement the variation of power extraction coefficient with the variation in the pitch angle and the tip speed ratio. The mathematical equation of power coefficient is given by:

$$Cp(\lambda,\beta) = c1 * \left\{\left(\frac{c2}{\lambda i}\right) - (c3 * \beta) - (c4)\right\} * (e^\wedge - \frac{c5}{\lambda i})\} + c6 * \lambda$$

Where,

$$\left(\frac{1}{\lambda i}\right) = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

C1	C2	C3	C4	C5	C6
0.5176	116	0.4	5	21	0.0068

Table.1: values of parameters of WT

With this values the maximum value of cp is 0.48 when β=0 for λ=8.1, here wind speed assumed is 30m/s. The value of cp is required to keep at its maximum value in order to attain the maximum power output from the turbine. With the variation in wind speed, or tip speed ratio (λ), or any variation in pitch angle (λ), the corresponding value of cp also changes. Thus it is necessary to keep the track of cp to its maximum value $c_{p,\ max}$ in order to attain the maximum power output.

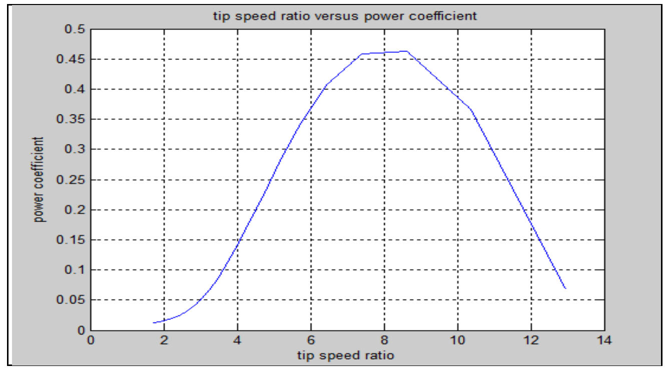

Fig 2: Coding result of Cp versus λ

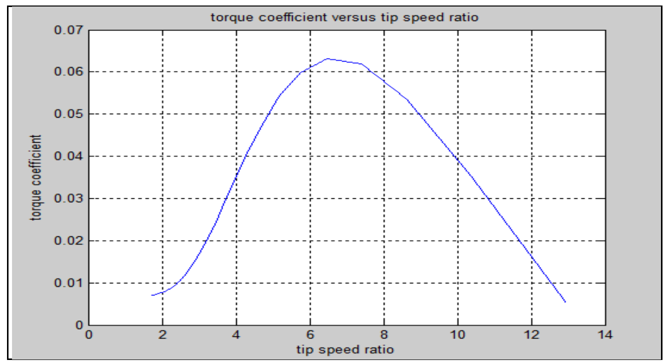

Fig 3: Coding result for Cq versus λ

C. APPROXIMATE MODELING OF WIND TURBINE TO VARY CP AND CQ AS FUNCTION OF WIND SPEED:

If the power performance of the wind turbine is to be evaluated, it's Cp (λ,β) can be obtained from manufacturer and look-up table to evaluate the power coefficient for different values of tip speed ratio and pitch angle. It the rotational speed, ω_0, and pitch angle, β are known, ($\omega=\omega_0$ and $\beta=\beta_0$ for constant rpm) then the mechanical power output can be evaluated at any upstream wind speed. But sometimes full cp (λ,β) data are not present in that case equation of Pm is not applicable in order to attain power performance evaluation. According to Justus [30], for any pitch angle, a good approximate value of cp as a function of the wind speed can be found by following equation.

$$Cp = Cpm\left[1 - F\left(\frac{um}{u} - 1\right)^2 - G\left(\frac{um}{u} - 1\right)^3\right] \quad uc \le u \le ur$$

$$Cp = Cpm\left[\frac{ur^3}{u^3}\right] \qquad ur \le u \le uf$$

The value of f and g can be obtained by the boundary condition given in equation (3.12) and (3.13), by using the fact that the power coefficient cp is 0 at the cut in speed and power coefficient is rated, Cpr at the rated speed.

$$Cp\ (uc) = 0 = Cpm\left[1 - F\left(\frac{um}{u} - 1\right)^2 - G\left(\frac{um}{u} - 1\right)^3\right]$$

$$Cp(ur) = Cpr = Cpm\left[\frac{ur^3}{u^3}\right]$$

Combining these equations gives the value of f and g in the matrix form as shown in the below figure as:

$$\begin{bmatrix} F \\ G \end{bmatrix} = \begin{bmatrix} \left(\left(\frac{um}{uc}\right)-1\right)^2 & \left(\left(\frac{um}{uc}\right)-1\right)^3 \\ \left(\left(\frac{um}{ur}\right)-1\right)^2 & \left(\left(\frac{um}{ur}\right)-1\right)^3 \end{bmatrix} * \begin{bmatrix} 1 \\ 1-Cpr \end{bmatrix}$$

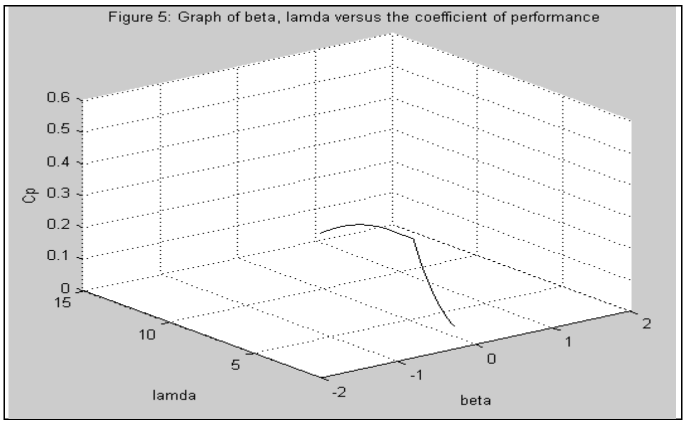

Fig 4: Coding result for cp versus λ

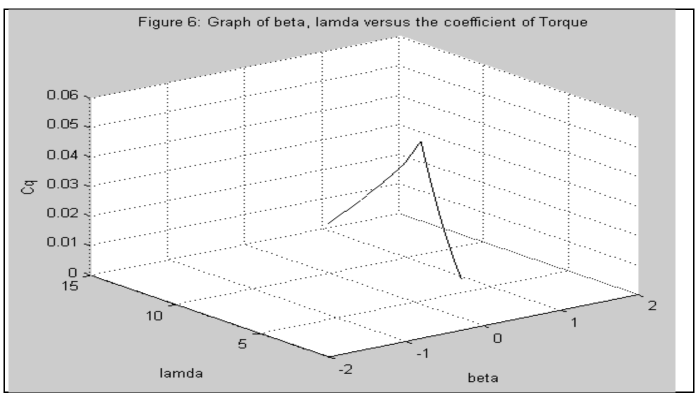

Fig 5: Coding result for Cq-λ

The mechanical power output which is obtained from the approximate model of the aerodynamic system as function of wind speed is plotted in the below figure:

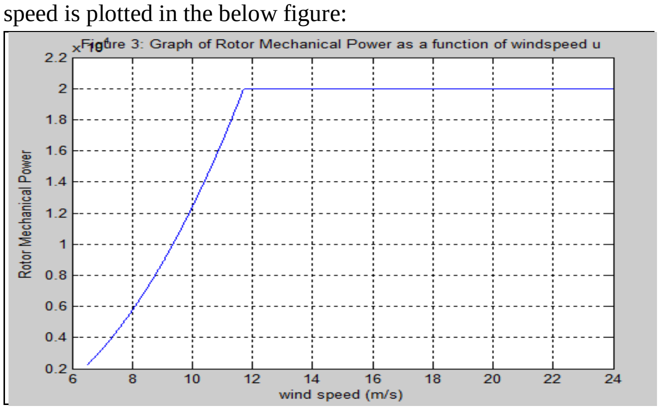

Fig 5: Mechanical power output versus wind speed curve

I. EFFECT OF VARIOUS PARAMETERS ON POWER COEFFICIENT:

The parameters, whose effect on the power output is obtained, are wind turbine radius, air density and pitch angle.

A. VARIATION IN TURBINE POWER OUTPUT WITH VARIATION IN TURBINE RADIUS:

Power output is directly proportional to the turbine radius. If the turbine radius increases the turbine power output also increases.

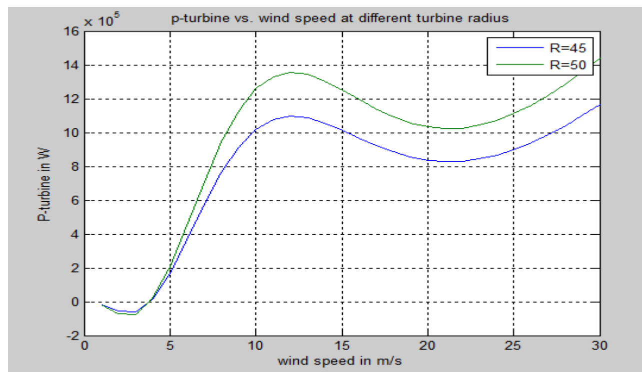

Fig 6: Coding result for Pm vs. W at different R

B. VARIATION IN TURBINE POWER OUTPUT WITH THE VARIATION IN AIR DENSITY:

If the air density increases the torque-wind speed curve shifts upward.

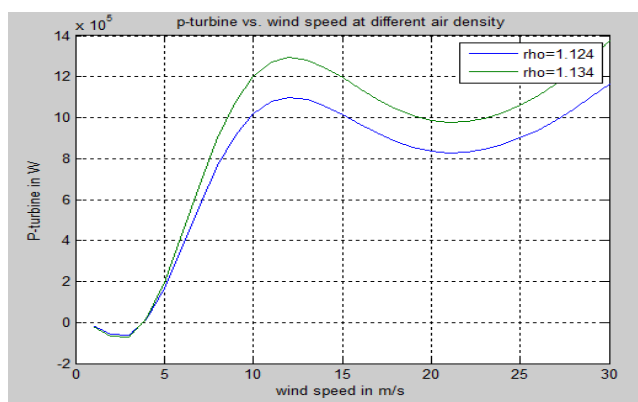

Fig 7: coding result for Pm vs. W at diff. ρ

C. VARIATION IN POWER CP-λ CURVE DUE TO VARIATION IN PITCH ANGLE:

As mentioned before the cp is function of pitch angle and tip speed ratio. The variation in power coefficient due to pitch angle is shown in the below fig.

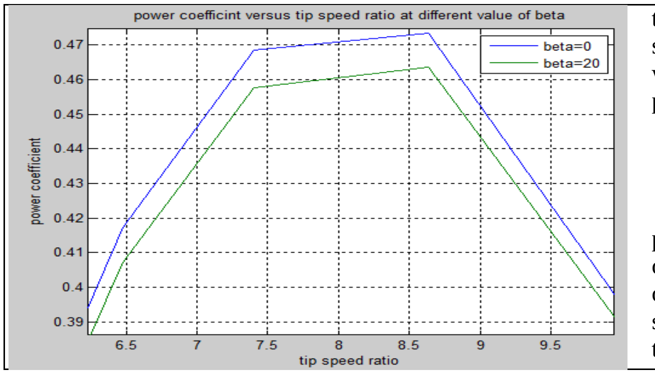

Fig 8: Coding result for Cp-λ at different β

This wind turbine is mechanically coupled to generator. The main competition is between the PMSG and DFIG. Here if this wind turbine is connected to the DFIG then active power output which is obtained from stator and rotor side is plotted in the below figure.

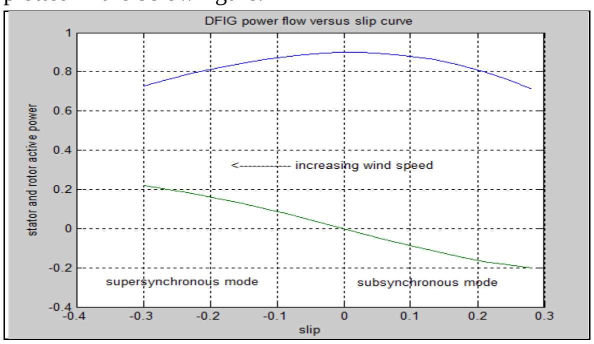

Fig 9: DFIG power flow versus slip curve

Table – 2
General details

Rotor diameter	45m
Area swept	2,124 m^2
Number of blades	3
Power regulation	Pitch/Opti-Speed
Air brake	Full blade pitch
Cut-in wind speed	6 m/s
Nominal wind speed	15 m/s
Cut-out wind speed	25 m/s
Nominal output	850 kW
Power coefficient	0.48

(Source: [3])

III.SIMULATION RESULTS AND DISCUSSION

Estimation of electrical power output can be obtained if the dimensions of Wind turbine along with the climatic condition are known. The wind turbine dimensions which are to be considered directly affect the mechanical power output. The wind turbine starts producing mechanical power output when wind speed reaches cut-in speed. And it went to stall regulation when wind speed reaches the cutout speed (after stall regulation the power output remains fixed).

IV.CONCLUSION

The good exploitation of wind energy may increase penetration of wind power in power in power system. The higher order modeling of wind will help to predict the amount of power output. The main parameters which are used are turbine radius, swept area, diameter of wind turbine, wind speed, pitch angle and tip-speed ratio.

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