Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2011
(ICMERE2011) 22- 24 December 2011, Chittagong, Bangladesh

ICMERE2011-PI-009

FEASIBILITY STUDY OF WIND POWER IN BANGLADESH BASED ON ANNUAL ENERGY CAPTURE

P. K. BANERJEE[1*] and MD. ARIFUJJAMAN[2]

[1]Department of Electrical and Electronic Engineering, Dhaka University of Engineering and Technology, Gazipur-1700, Bangladesh, palash2106@yahoo.com*
[2]Department of Electrical and Computer Engineering, University of New Brunswick, Fredericton, NB, E3B 5A3, Canada, marifujj@unb.ca

***Abstract**- Furling control method is the most common control method for small wind turbine industry to control the aerodynamic power extraction from the wind. A small wind turbine with furling mechanism and its resulting dynamics is modeled in Matlab/Simulink platform. The model is simulated to regulate the speed of the wind turbine at the optimum tip speed ratio thus ensures the maximum power extraction. Wind speed data and weibul distribution of Patenga, Cox's Bazar, Teknaf, Char Fassion, Kuakata, Kutubdia of Bangladesh is used in this research to determine the annual energy capture. The results of the simulations indicate that energy capture of a wind turbine depends not only on the control strategy but on wind speed and Weibul distribution. The results of the investigation lead to the conclusion that Kuakata has the highest potential of energy capture for such rated wind turbine and could be a viable solution for high penetration of wind power.*

Keywords: Peak power tracker (PPT), maximum power extraction, grid power, tip speed ratio (TSR) and load control.

1. INTRODUCTION

Recent development in wind turbine industry deploys different control strategies to maximize the energy capture from the wind turbine. Research indicates that a variable speed operation gives more energy than the fixed wind turbine so further research can be focused on the variable speed operation of wind turbine. In this paper firstly, the wind turbine is modeled using a second order furling dynamics, secondly, the annual energy capture from the system is investigated. Six sites of Bangladesh are selected: Patenga, Cox's Bazar, Teknaf, Char Fassion, Kuakata, Kutubdia. The paper is organized as follows: The first section is a short overview of the work presented in this research. In the second section the modeling of small wind turbine system components with furling dynamics is presented. A procedure to calculate the annual energy capture using weibull distribution is discussed in the third section and the fourth section contains the simulation results and discussion of the same. Finally, the findings of the investigations are highlighted in the conclusion.

2. MODELING OF SYSTEM COMPONENTS

A stand-alone variable speed wind turbine when connected to a load should be controlled to extract the maximum power. Dynamic modeling and simulation is required to determine the suitable controller of the wind turbine connected to a load. The wind turbine and the associated components have been modeled by the following equations.

The output power of the wind turbine can be expressed as

$$P_{aero} = 0.5\ \rho\ A\ Cp\ (\lambda)\ V^3 \quad (1)$$

The torque produced by the wind turbine is given by

$$T_w = P_{aero}/\omega_m \quad (2)$$

where, ω_m is the angular velocity of the wind turbine rotor (rad/s). Also, the tip speed ratio λ is given in terms of rotor speed, ω_m and wind speed, V (m/s) as

$$\lambda = R * \omega_m / V \quad (3)$$

where, R is the radius of the wind turbine rotor (m).
Substituting Eq. (1) and (3) in Eq. (2) the torque term can be expressed as

$$T_w = 0.5\ \rho\ A\ Cp\ (\lambda)\ V^3 / \omega_m = 0.5\ \rho\ A\ R\ Cp\ (\lambda)/\lambda * V^2 \quad (4)$$

The torque co-efficient is given by Ct (λ), which can be expressed as Cp (λ)/λ. When the wind speed increases, the wind turbine moves to an angle θ along its horizontal axis because of furling action. The effective wind velocity at the rotor plane will be V$\cos\theta$ [1]. Incorporating the furling action, the final expression of the torque is obtained as

$T_w = 0.5\ \rho\ A\ R\ Ct\ (\lambda)^*\ (V\cos\theta)^2$ (5)

The wind turbine considered is rated at 10kW and it incorporates furling mechanism. The wind turbine is based on a permanent magnet synchronous generator (PMSG). The permanent magnet synchronous generator has been modeled in the rotor reference frame. Assuming that zero sequence quantities are not present and applying Park's transformation, the terminal voltage of the PMSG in the rotor reference frame can be expressed as [2]

$$V^g_q = -(R^g + p\ L^g_q)\ i^g_q - \omega_r\ L^g_q\ i^g_q + \omega\ \lambda_m \quad (6)$$

$$V^g_d = -(R^g + p\ L^g_d)\ i^g_d + \omega_r\ L^g_q\ i^g_q \quad (7)$$

where, R^g is the stator phase winding resistance (Ω),
L^g_q is the stator inductance in the quadrature axis (H),
ω_r is the rotor angular velocity of the generator (rad/s),
λ_m is the flux linkage (V-s/rad),
p is operator d/dt.

The electromagnetic torque in the rotor reference frame is written as

$$T_e = (3/2)(P/2)\ [(L^g_d - L^g_q)\ i^g_q\ i^g_d - \lambda_m\ i^g_q] \quad (8)$$

where, P is the number of poles of the PMSG.
The relation between the angular velocity of the generator ω_r and mechanical angular velocity of the rotor ω_m can be expressed as

$$\omega_r = (P/2)\ \omega_m \quad (9)$$

The rotational speed and the torque produced by the wind turbine can be related as

$$T_w = J\ (2/P)\ p\omega_m - T_e + B\ \omega_m \quad (10)$$

where, p is the laplace operator.
A small friction term has been added in the generator to make the model more realistic. T_w is the torque produced by the wind turbine and serves as the input to the PM. The wind turbine considered has no gearbox.
The stator voltage of the PM can be expressed as

$$V_s^g = -(R^g + p\ L_g)\ i^g_q + \lambda_m\ \omega_r \quad (11)$$

The rectifier used in the model is of the uncontrolled type, hence the delay angle α of the rectifier is zero. As a result, the direct axis quantities i^g_d and V^g_d are zero[2].
In terms of rotor reference frame quantities and the assumption of non-existence of zero sequence current, the output power of the rectifier is expressed as

$$V_R\ I_R = (3/2)\ (V^g_q\ i^g_q + V^g_d\ i^g_d) \quad (12)$$

Since V^g_d and i^g_d are zero,

$$i^g_q = (V_R\ I_R)/(3/2 * V^g_q) \quad (13)$$

The simplified dc output voltage of the rectifier can be expressed as

$$V_R = (3*\sqrt{3}/\pi)\ V_s^g \quad (14)$$

And the current is given by

$$I_R = P_{load}/\ V_s^g \quad (15)$$

The power inverter is modeled assuming the basic principle of pulse width modulation (PWM) operation. A simple series RL load model is considered as a load.
The wind turbine is considered as a direct drive system. The generator is connected to the load through a rectifier and an inverter. The controller controls the value of load to maintain a desired output.

3. ENERGY CALCULATION

The standard wind probability models used in the wind resource assessment studies is the Weibull and Rayleigh distribution. The Weibull distribution is a special case of a generalized two-parameter Gamma distribution, while the Rayleigh distribution is a subset of Weibull distribution. The Weibull distribution is preferable due to its dependency on two parameters and is well accepted to give a good fit of wind data. However, Rayleigh distribution is very often used when a simplified calculation is desirable. Weibull distribution is characterized by its probability density function, $f(w)$ as follows [3]:

$$f(w) = \left(\frac{k}{c}\right)\left(\frac{w}{c}\right)^{k-1} e^{-\left(\frac{w}{c}\right)^k} \quad (16)$$

where, c is the scale parameter, k is the shape parameter, and w is the wind speed.
A wind turbine starts to produce power at cut-in wind speeds and stops at cut-out wind speed. The annual (365 days) energy capture of the wind turbine can be expressed as.

$$E_g = \int_{w_{cut-in}}^{w_{cut-out}} 8760 P_g(w) f(w)\, dw \quad (17)$$

where, $P_g(w)$ is the power generated at any particular wind speed and 8760 is the number of hours in a year.
It can be seen from eqn (17) that the energy capture of a wind energy conversion system is greatly dominated by the wind speed distribution. The energy capture is a dictating factor for potential investors and is meaningful for evaluating turbine performance.

4. SIMULATION RESULTS

The system described above was simulated using Matlab-Simulink^{TM} blocks and the simulation diagram is presented in Fig. 1. A simple RL load was considered. To calculate the energy from the wind turbine a power curve was first produced by employing several wind speed and observing the corresponding output power. Fig. 2 depicts the power curve found by the simulation. It is obvious that after the rated wind speed (12 m/s) the power falls due to the furling action. The obvious task of the furling control activates after the rated wind speed. The task of the furling control is of particular important. This is because it can reduce both mechanical and electrical overstress on the turbine thus increasing the lifespan of a particular system. Moreover, a small wind turbine system is always very much subjected to initial cost and lifetime of the associated assembly. Furling control can effectively increase the lifetime and could help more penetration of a small wind turbine to the end user.

After determination of the power curve, the wind speed distribution of the selected sites are plotted and presented in Fig. 3. Based on the wind distribution, the energy for each site is calculated as presented in Section 3. The results are plotted in Fig. 4. It is noticeable that Kuakata has the highest potential of energy capture in year compared to the other sites of Bangladesh. This leads to an imperative conclusion that such rated wind turbine is greatly feasible for Kuakata.

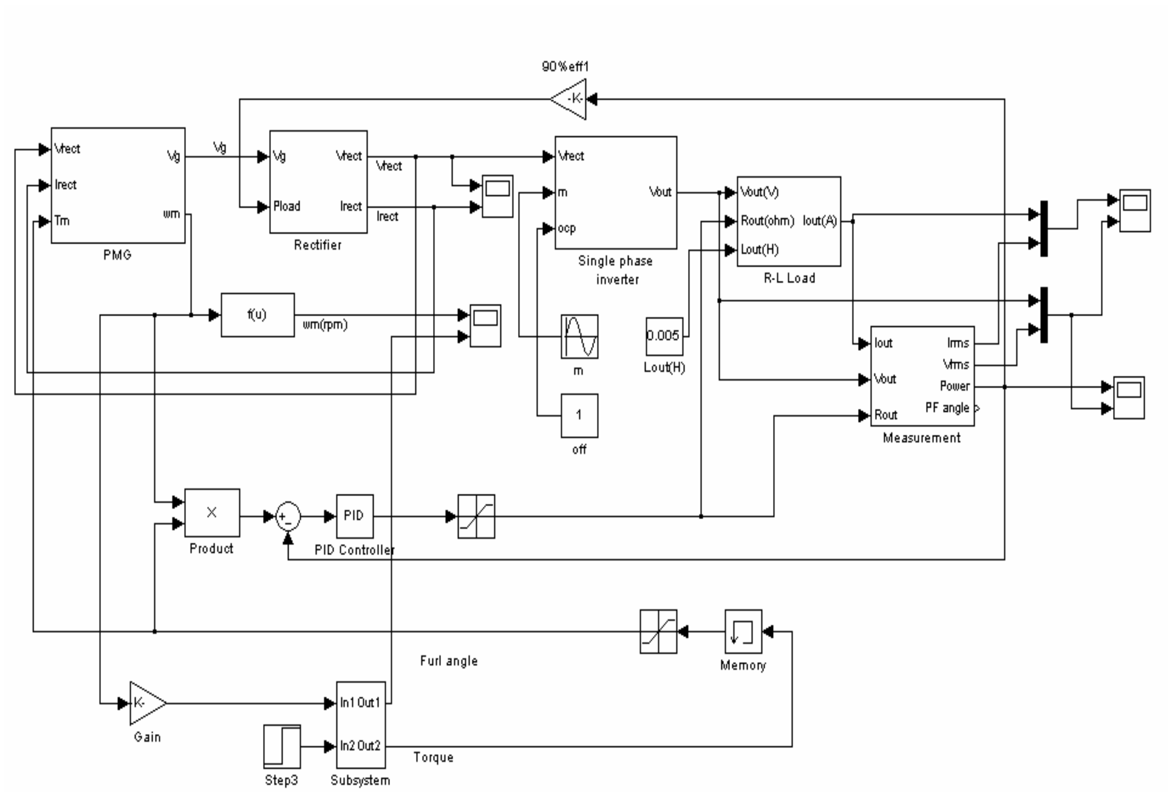

Fig. 1 Simulation model of the wind turbine

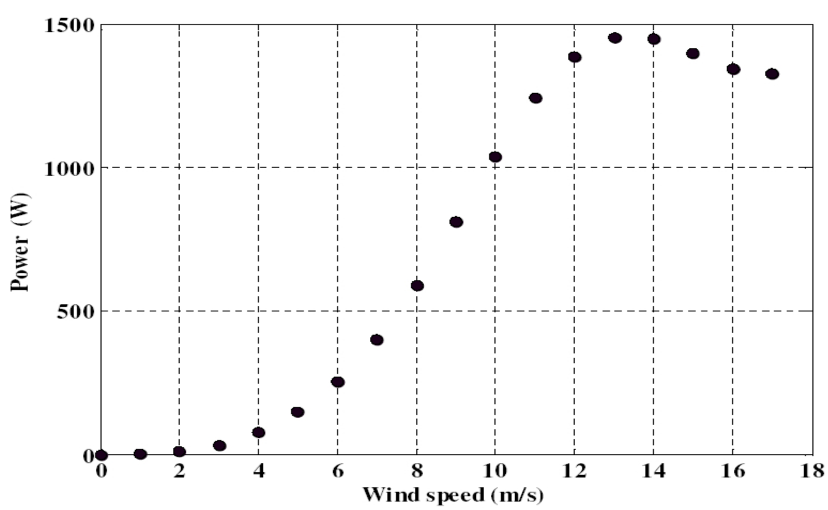

Fig. 2 Variation of power production of the wind turbine with wind speed

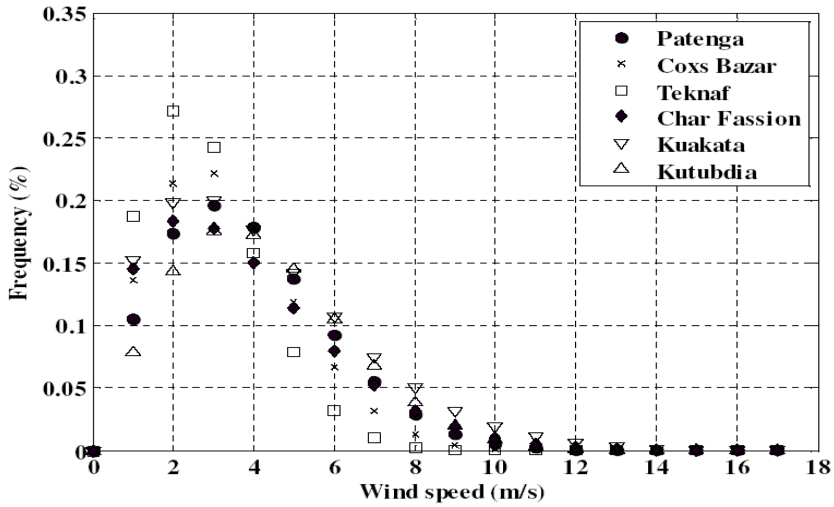

Fig. 3 Wind speed distribution of the selected sites

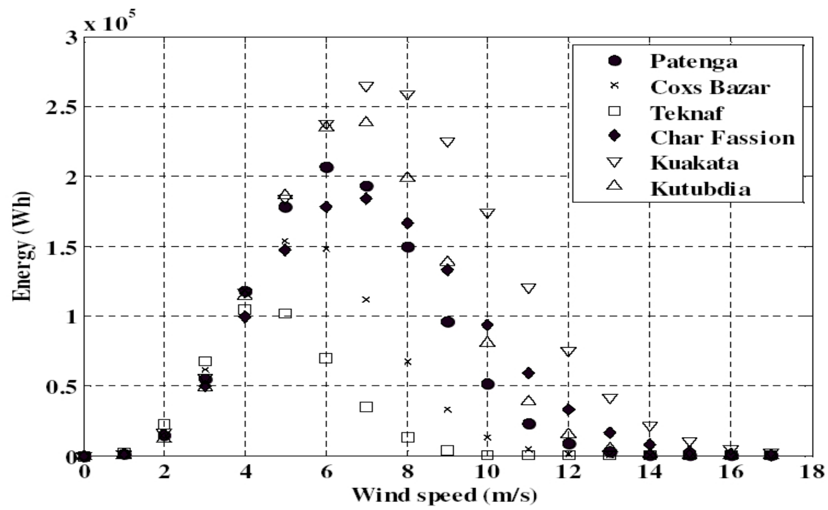

Fig. 4 Variation of annual energy capture of the selected sites

5. CONCLUSIONS

The paper has discussed the dynamic modeling of a small wind turbine with furling dynamics and the energy is calculated using the weibull distribution. Furling action was initiated with rated wind speed and effectively reduces the power production. Wind speed distribution of eight sites of Bangladesh is used to determine the annual energy capture. It is found that Kuakata has the highest potential to capture of annual energy and leads to a possible implementation site in Bangladesh.

6. REFERENCES

[1] Bialasiewicz, J.T. "*Furling control for small wind turbine power regulation,*" Industrial Electronics, 2003. ISIE '03. 2003 ,pp. 804 – 809.

[2] Borowy B.S.; Salameh, Z.M. "*Dynamic response of a stand-alone wind energy conversion system with battery energy storage to a wind gust,*" IEEE Transactions on Energy Conversion, vol. 12, Issue: 1, March 1997.pp.73 -78.

[3] Paul Gipe, "Wind power for home and business: Renewable Energy for the 1990s and Beyond," Chelsa Green Publishing Company, White River Junction, Vermont.

[4] http://www.bpdb.gov.bd

[5] http://www.lged-rein.org/database

[6] http://www.sdnbd.org/wind