Controlled Operation of Wind Turbine during Wind Disturbances

Navjot Singh Sandhu, Shelly Vadhera and K. S. Sandhu

Abstract— Wind turbine a major component of wind power plant, is used to capture the kinetic energy associated with wind for converting it to electrical energy through generator. Performance of a wind power plant depends upon the power output of wind turbine under wind disturbances which may occur time to time. This paper includes a new Matlab/Simulink based proposal to control the output of wind turbine under wind variations. Simulated results as shown on two wind turbines, proves the effectiveness of new approach as proposed. Performance of wind turbine under controlled operation is found to be better as compared to uncontrolled operation.

Keywords— Controlled operation, Matlab/Simulink, Modeling, Wind energy, Wind turbine

I. Introduction

LOOKING the harmful effects and continuous depletion of conventional fossil fuels, scientists are searching for renewable sources of energy which are ecofriendly such as wind power and solar power. Out of these wind energy is found to be viable source of energy and its installation capacity as shown in table 1 is continuously increasing and presently reached at a significant level across the world.

Table. 1 wind energy installation worldwide

Year	Wind Energy Installation (MW)
2001	23900
2003	39431
2005	59091
2007	93889
2009	158975
2011	238126
2013	318105

In a wind energy conversion system, wind turbine captures the energy associated with the wind for driving generator [1-7], which in turn generates electric power. Many researchers [8-19] tried to analyze the behaviour of wind energy conversion system. Major issues and challenges related to wind turbine aerodynamics were discussed by [8]. Reference [9] tried to investigate the wind turbine resource potential with the help of seven small wind turbines and it was found that even for the same power rating, aerodynamic characteristics of selected wind turbine effects its production. New models to predict the mechanical torque of a wind turbine were proposed by [10]. Few researchers [11-18] tried to investigate the performance of wind turbine with wind speed variations. It was observed that rotor speed control by any technique may be helpful to control the performance of wind turbines, when subjected to wind variations. Efforts have been made for the comparison of different structures for wind energy system, as well as their mechanical, electrical and economical aspects. Reference [11] gave the comparison of variable-speed against constant speed wind turbine systems. In terms of energy capture, every researcher concluded that variable speed turbine will produce more energy than constant speed turbines. Based upon this fact, [12] proposed maximum power tracking algorithm for operating a wind turbine in variable speed mode. Some of the researchers [13-14] adopted the Matlab/Simulink models for the analysis of wind turbines when subjected to wind variations. Whereas [15-17] discussed the pitch control strategies for variable speed wind turbines. However such control when incorporated makes the system costly and complicated. Reference [18] discussed the analysis of a variable blade length wind turbine, which includes the effect of extending turbine blade when wind speed falls. Similarly [19] presents a review of the state of the art and present status of active aero elastic rotor control research for wind turbines. With the increasing size of wind turbine blades, the need for more sophisticated load control techniques has induced the interest for locally distributed aerodynamic control systems with build in intelligence on the blades. Such concepts are often named in popular terms ‘smart structures’ or ‘smart rotor control’. The review covers the full span of the subjects, starting from the need for more advanced control systems emerging from the operating conditions of modern wind turbine and current load reduction control capabilities. Such controls may require special designs for blades, accounting the stresses upon the flexible parts.

In the present paper, the Matlab/Simulink based model as

Navjot Singh Sandhu is doing M.Tech in School of Renewable Energy and Efficiency, National Institute of Technology Kurukshetra, Haryana-136119, India (ph: +919416528979; email: navjot_singhsandhu@yahoo.com.)

Shelly Vadhera is Associate Professor in the Department of Electrical Engineering, National Institute of Technology Kurukshetra, Haryana-136119 India phone: +919416377796; e-mail: shelly_vadhera@rediffmail.com).

K. S. Sandhu is Professor in the Department of Electrical Engineering, National Institute of Technology Kurukshetra, Haryana-136119 India (phone: +91-1744-9416314445; e-mail: kjssandhu@ yahoo.com).

developed for a wind turbine is used to control the output power during wind disturbances. A new model as proposed is found to be effective to control the performance of wind turbine. Simulated results as obtained are found to effective for controlled output.

II. Wind Turbine Modeling

Following equations are used to develop the wind turbine control concept as shown in Fig 1.

$$P = \left(1.963 C_p R^2 V^3\right) \quad \text{----------------} \ (1)$$

Where

C_p = Power coefficient
v = Wind speed (m/sec)
R = Blade radius (m)

The power coefficient (C_p) is a function of blade pitch angle β and tip speed ratio λ. Equation (1) may be used to define the power coefficient as a function of wind velocity.

$$C_P = \frac{k}{V^3} \quad \text{----------------} \ (2)$$

Where k= Rated Power/ (1.963R^2)

The tip speed ratio as defined as the ratio between wind speed and rotor speed, and is expressed as:

$$\lambda = \frac{\omega R}{V} \quad \text{----------------} \ (3)$$

This gives:

$$\omega = \frac{\lambda V}{R} \quad \text{----------------} \ (4)$$

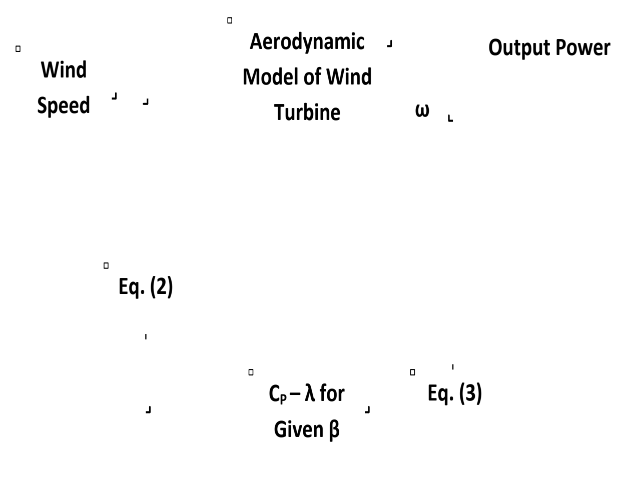

Fig. 1 wind turbine control concept

The general equation which may be used to define the power coefficient C_p is:

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_1} - C_3\beta - C_4\right).e\left(-\frac{C_5}{\lambda_1}\right) + C_6\lambda$$

With

$$\frac{1}{\lambda_1} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

Coefficient C_1 to C_6 , depend on the design wind turbine.

Fig. 2 shows the variation of power coefficient with tip speed ratio for different values of pitch angle.

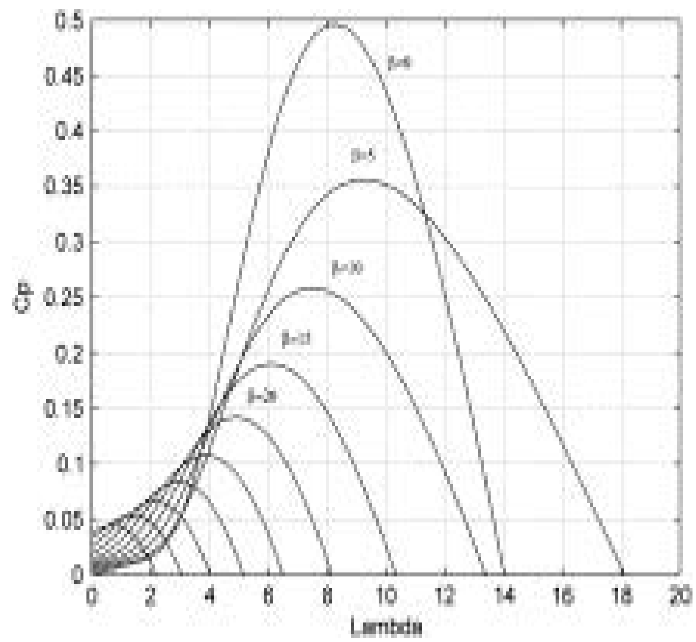

Fig. 2 variation of Cp with λ

III. Results and Discussions

The Matlab/Simulink model of wind turbine as developed is shown in Fig.3. Control unit is used to set the required speed as per Fig.1, using load adjustment. The model as shown may be used to control the output power during wind disturbances. Same model has been adopted for simulation results on two different wind turbines with randomly changing wind speeds. However, blade pitch angle during such simulations has been taken constant either zero or five degrees.

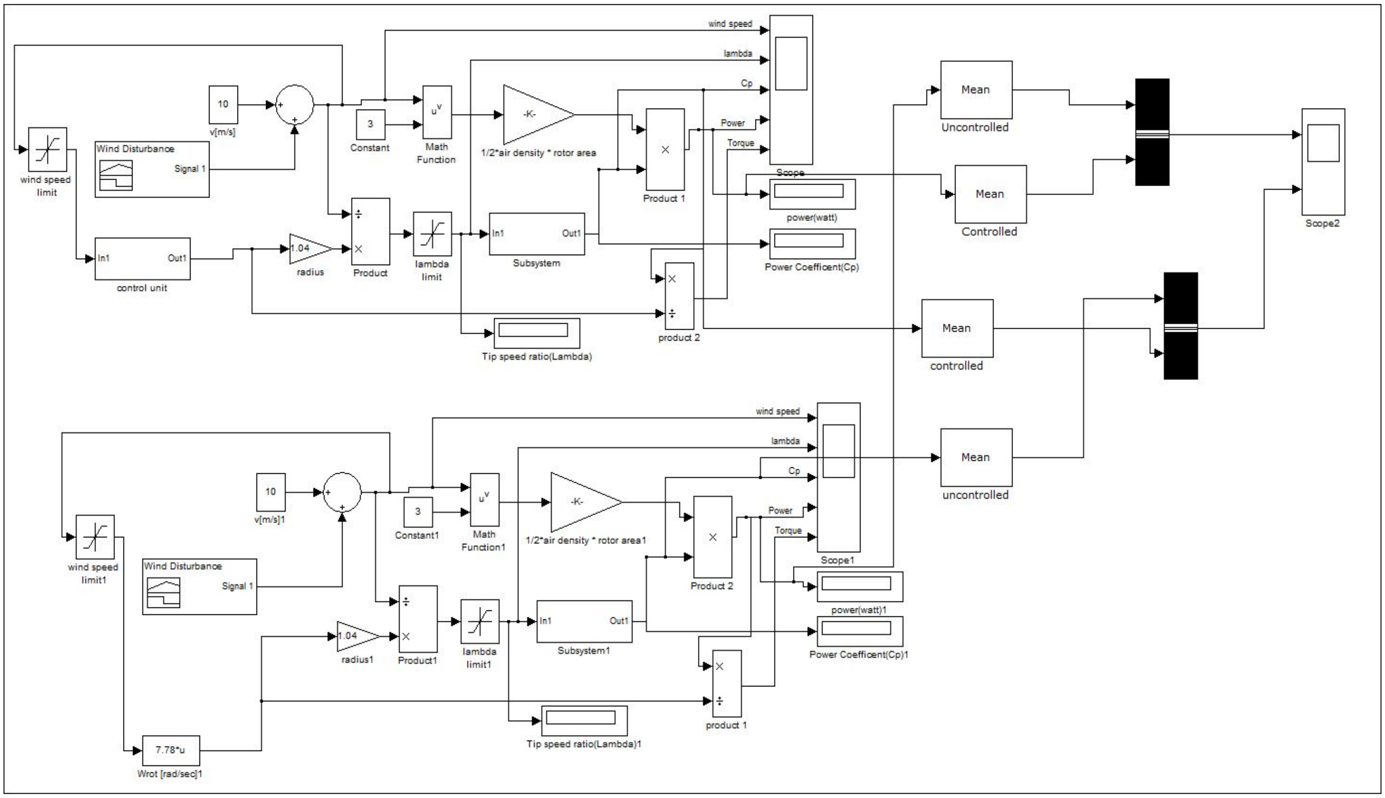

Fig. 3 simulink model of wind turbine

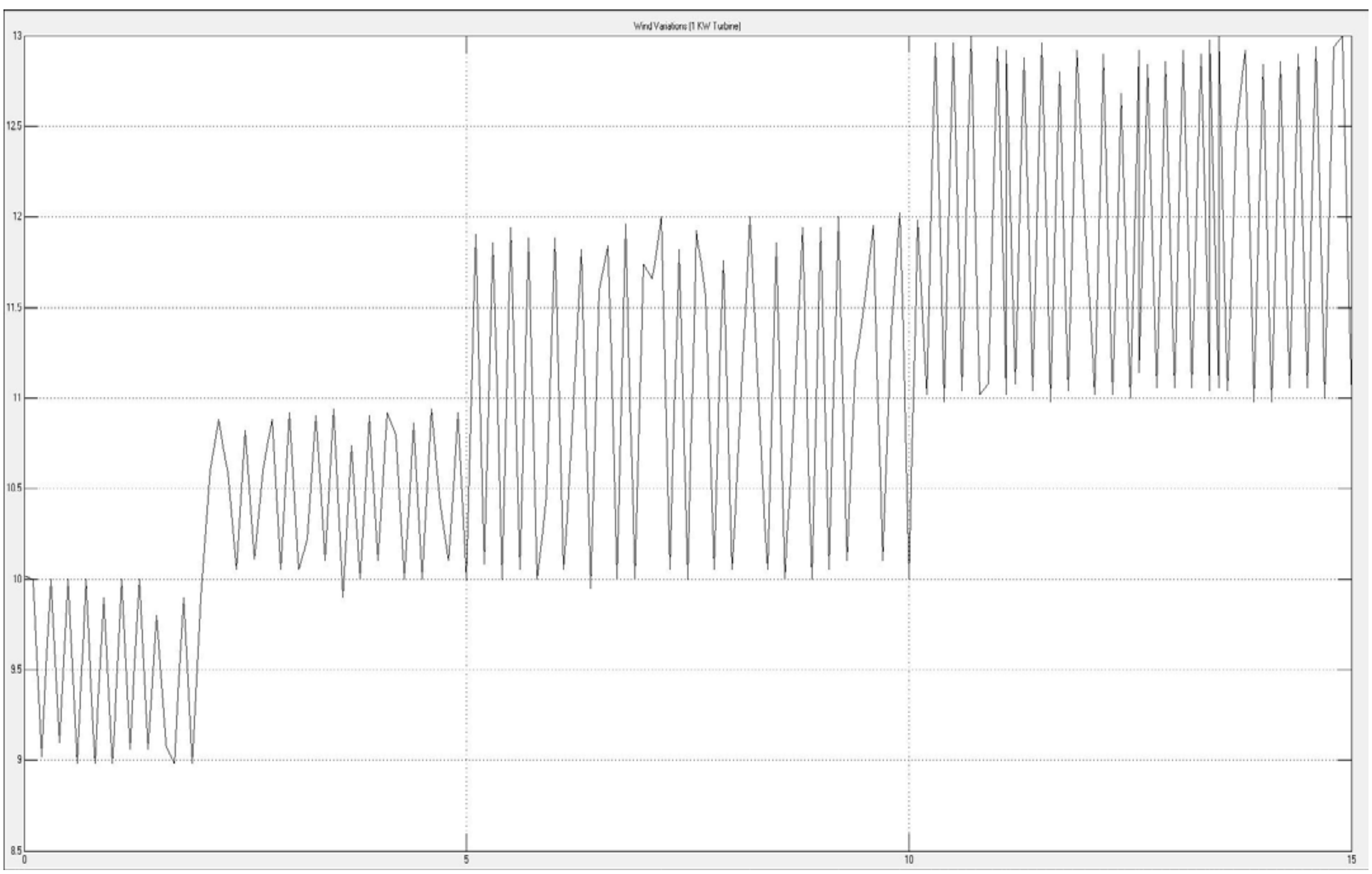

Fig. 4 randomly changing wind variations for 1KW wind turbine

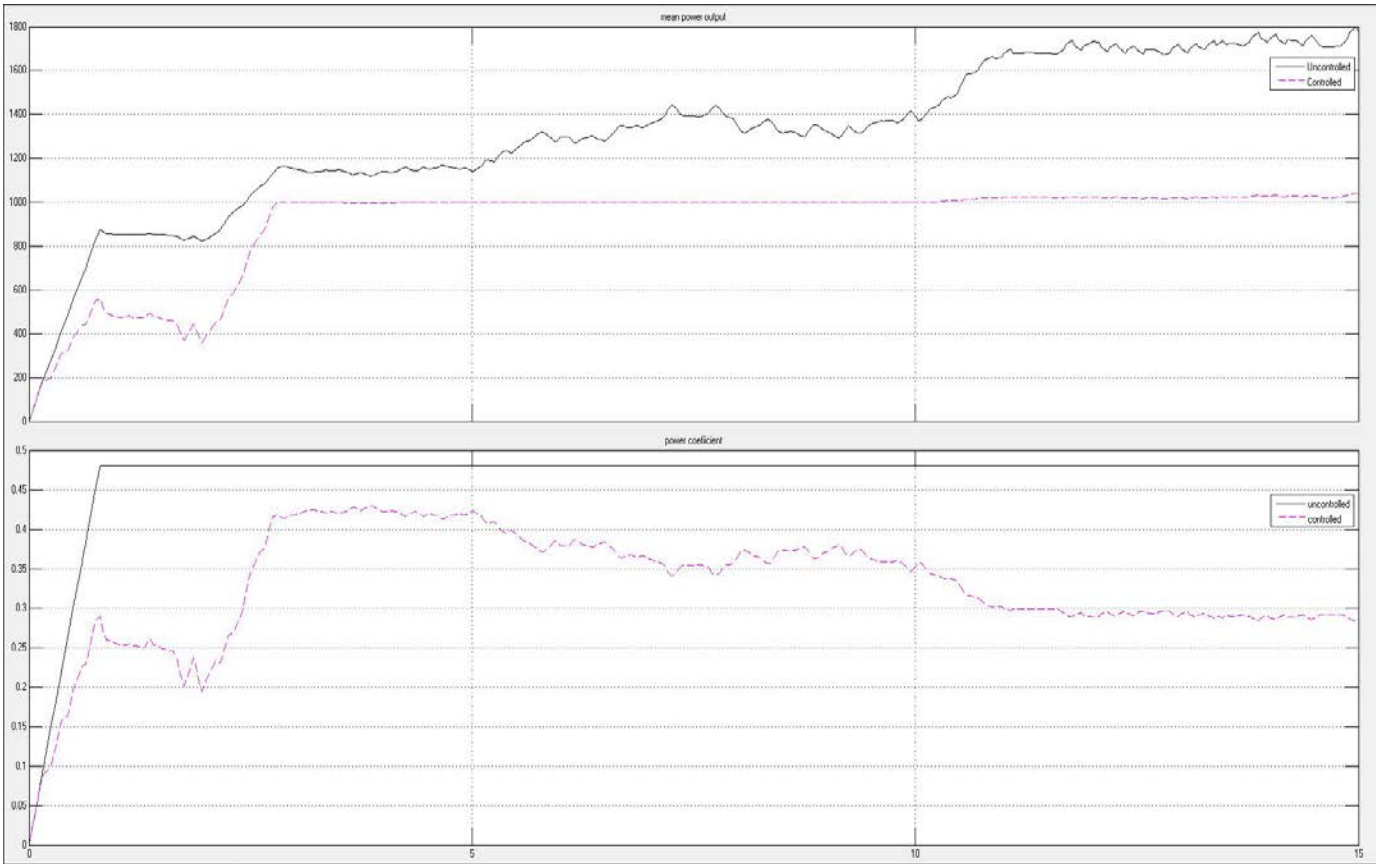

Fig. 5 effect of wind disturbances on output and power coefficient of 1KW turbine under uncontrolled as well as controlled operation with blade pitch angle as zero degree

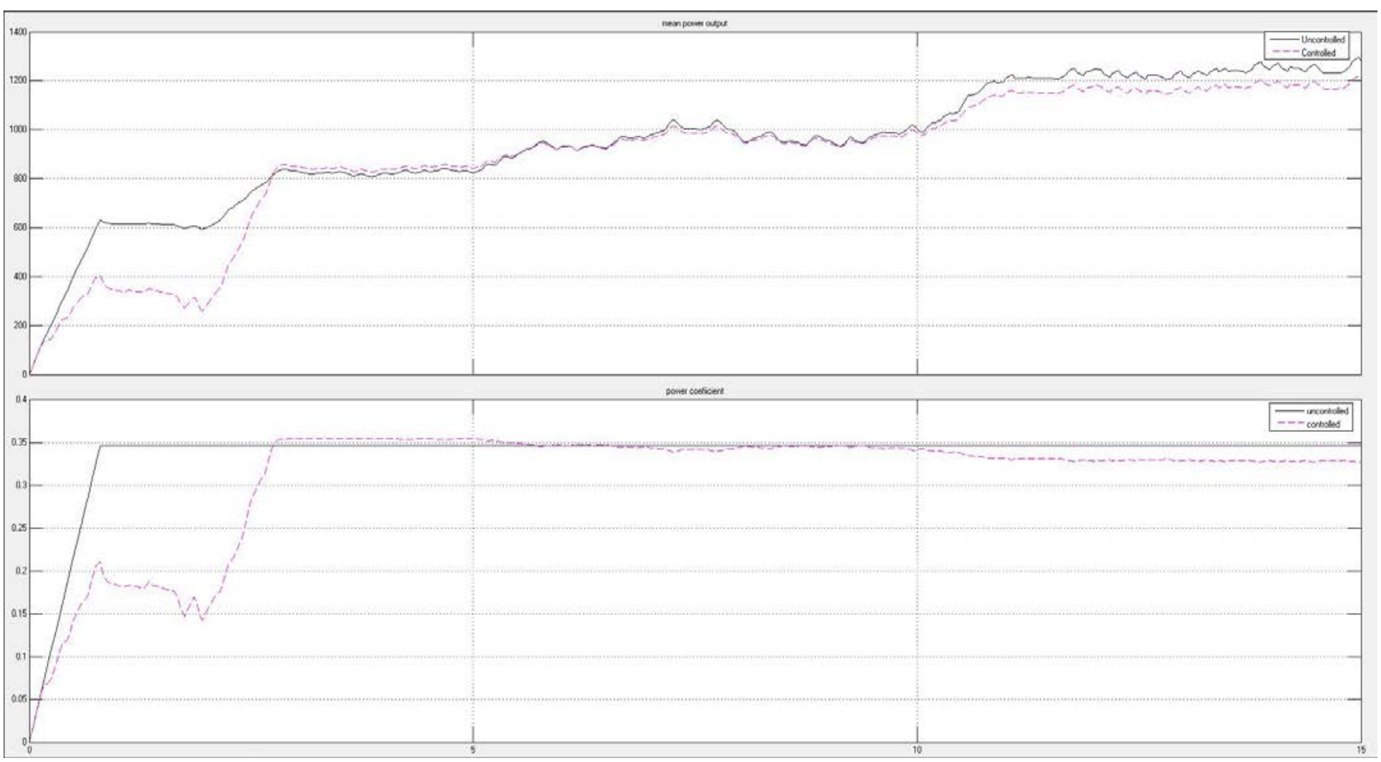

Fig. 6 effect of wind disturbances on output and power coefficient of 1KW turbine under uncontrolled as well as controlled operation with blade pitch angle as five degree

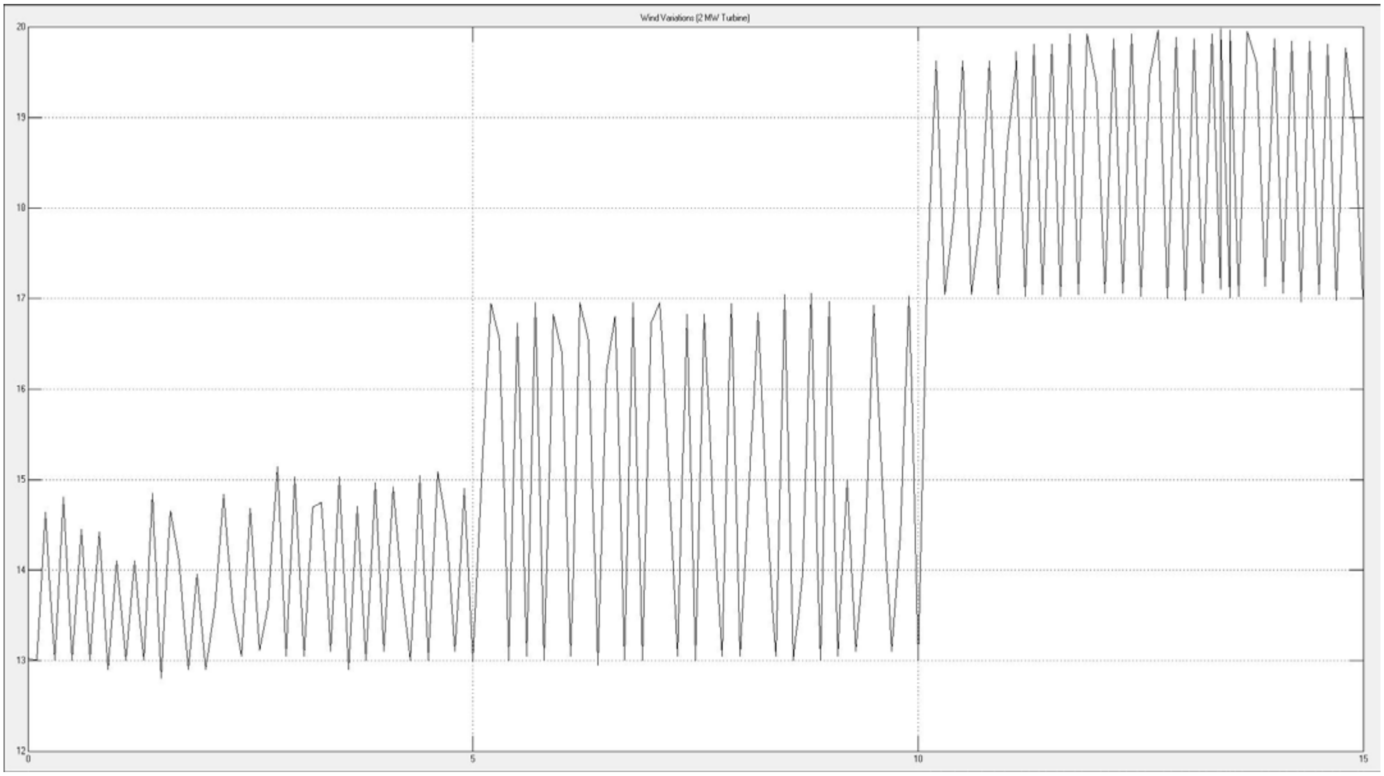

Fig. 7 randomly changing wind variations for 2MW wind turbine

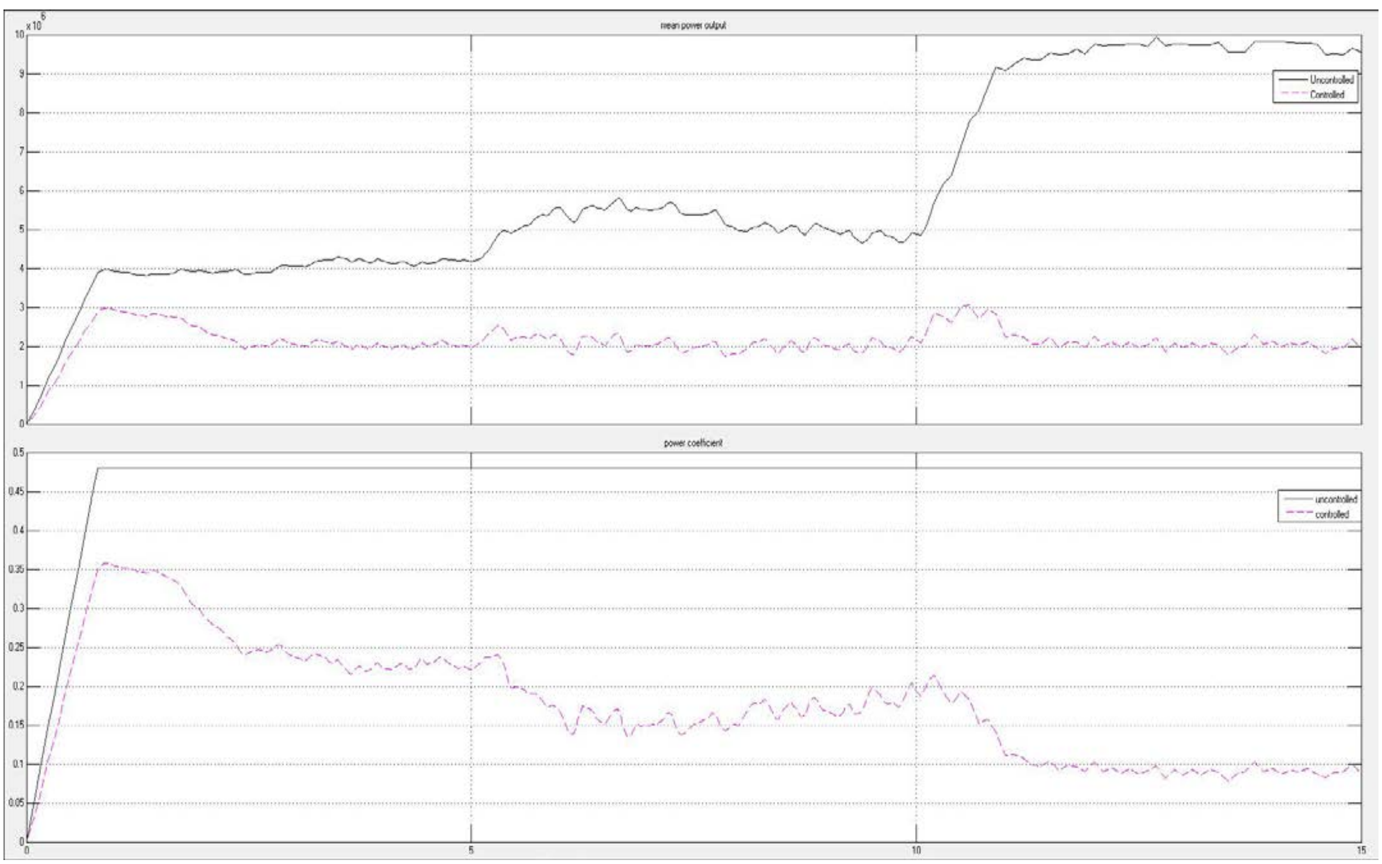

Fig. 8 effect of wind disturbances on output and power coefficient of 2MW turbine under uncontrolled as well as controlled operation with blade pitch angle as zero degree

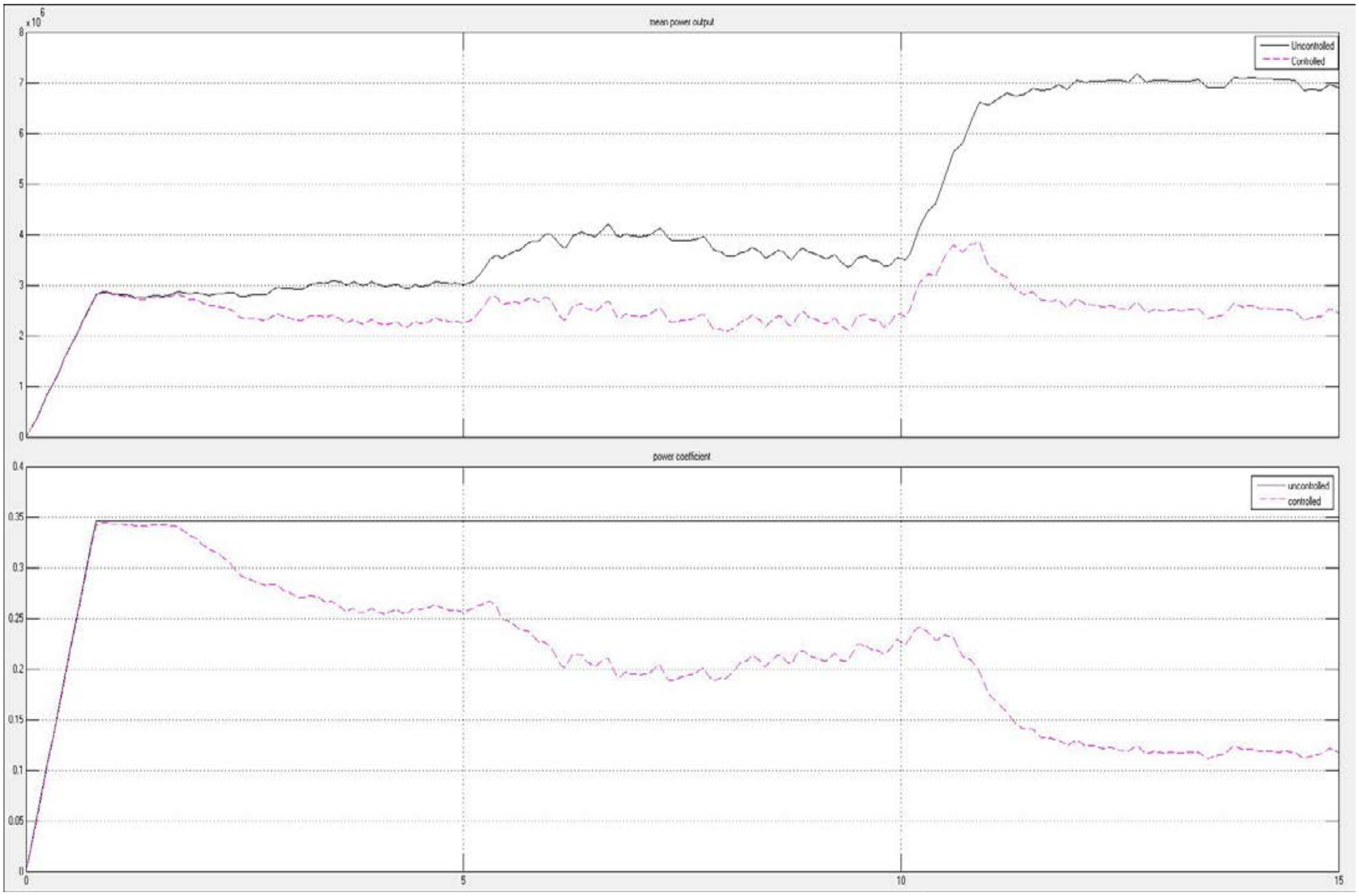

Fig. 9 effect of wind disturbances on output and power coefficient of 2MW turbine under uncontrolled as well as controlled operation with blade pitch angle as five degree

Fig.4 shows the randomly changing wind speed variations as adopted for simulation results on 1 KW turbine (Appendix 1). Wind variations have been taken as 9m/s to 10m/s, 10m/s to 11m/s, 11m/s to 12m/s &11m/s to 13m/s respectively for different time intervals. Fig. 5 & Fig. 6 shows the simulation results for mean power output & power coefficient of 1 KW wind turbine when operated with and without any control during such wind disturbances. Fig. 5 shows the performance under two modes, when blade pitch angle is taken as zero degree. As observed due to the controlled operation output power of wind turbine remains close to rated output even during wind variations, whereas it is not so in case of uncontrolled operation. However as shown in Fig. 6, the difference between power outputs for two operating modes decreases if blade pitch angle is increased to five degrees.

Similarly Fig. 7 shows the wind variations for simulation results on 2 MW wind turbine (Appendix 1). Wind variations have been taken as 13m/s to 15m/s, 13m/s to 17m/s & 17m/s to 20m/s for different time intervals. Fig. 8 & Fig. 9 show the variation of mean power output & power coefficient of 2 MW wind turbine when operated uncontrolled as well as with controlled operation.

As observed form Fig. 8 with blade pitch angle as zero degree, the power output of the wind turbine remains close to its rated value under controlled operation. Whereas it departs from its rated value under uncontrolled operation. Fig. 9 shows the simulation results indicating the effect of blade pitch angle on the output power & power coefficient of wind turbine under two operating modes. As observed form Fig. 8 & Fig. 9, the performance of the wind turbine appears to be better with zero degree blade pitch angle in contrast to five degrees.

Simulation results as obtained on two different wind turbines (Fig. 4 to Fig. 9) may be used to draw the following observations:

- Controlled mechanism as presented in the paper is found to be effective to control the output power of wind turbine even under randomly changing wind variations.
- Control mechanism as proposed is more effective with blade pitch angle as zero degree. This is desirable to maintain the simplicity of wind turbine blades.

IV. CONCLUSIONS

In the present paper, the Matlab/Simulink based model as developed for a wind turbine is used to predict the performance of wind turbine, with randomly changing wind disturbances. New control scheme as described is adopted to control the output power during wind variations. Comparison of simulated results as presented in the paper proves the effectiveness of proposed scheme.

APPENDIX 1

For 1KW Turbine

Turbine Data

Parameters	Value
Rated Power (kW)	1
Wind Blade Radius (m)	1.04
Rated Wind Speed (m/s)	10
Cut-in Speed (m/s)	4

For 2MW Turbine

Turbine Data

Parameters	Value
Rotor diameter (m)	21.4
Blade length (m)	9.0
Rated output (KW)	50
Cut in speed (m/sec)	4
Rated speed (m/sec)	10
Cut out speed (m/sec)	25

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Navjot Singh Sandhu was born in Haryana, India on 28th March 1990. He did his B.Tech (Mechanical Engg.) from UIET, Kurukshetra University, Kurukshetra. At present he is doing M.Tech (Renewable Energy System) from National Institute of Technology, Kurukshetra. His areas of Interest are wind energy, optimization techniques and energy auiditing.

Shelly Vadhera was born on 01 September, 1972. She received the B.E. (Electrical) degree from Thapar Institute Of Engineering and Technology, Patiala Deemed University, Patiala, M. Tech. (Power System) degree from Regional Engineering College, Kurukshetra University, Kurukshetra, India in 1994, 1998, respectively. She joined the Electrical Engineering Department of Regional Engineering College, Kurukshetra, as Lecturer in August 1998. Currently, she is Associate Professor in the Electrical Engineering Department. Her areas of interest are electrical machines, high voltage and power systems.

Kanwarjit Singh Sandhu was born in Haryana, India on 21st December 1957. He received the B.Sc. Engg. (Electrical), M.Sc. (Power System) and Ph.D (Electrical Machines) degrees from Regional Engineering College, Kurukshetra University, Kurukshetra, India in 1981, 1985 and 2001, respectively. He joined the Electrical Engineering Department of Regional Engineering College, Kurukshetra, as Lecturer in January 1983. Currently, he is Professor in Electrical Engineering Department, National Institute of Technology, Kurukshetra (Formerly Regional Engineering College, Kurukshetra), India. He has more than 60 international journals and about 70 conference publications in the area of Machines & Energy. His areas of interest include electrical machines, wind energy conversion, power quality, artificial intelligence and power systems.