Maximum energy capture of variable speed variable pitch wind turbine by using RBF neural network and fuzzy logic control

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Abstract - This paper in order to get the maximum power as wind turbine output, for variable input wind velocities, we use the pitch controlling of wind turbine. One of the natural disadvantages in Conventional wind turbine is, the wind is non-linear. So that, we can get the speed of the turbine also as changing and may rotate with dangerous speeds. And to get the maximum output power from the wind turbine the rotation of turbine must be at rater speed. So to get the constant rated speed of wind turbine at wind variations, we need to control thepitch angle of turbine i.e. pitch control is required. By designing of the pitch controller, the turbine speeds are controlled as rated speed. If the wind speeds below the rated speed, then the power generated without pitch controller i.e. pitch angle is at its maximum. If the wind speed above the rated speeds, in order to get the maximum power output and to protect the blades from dangerous speeds, we use pitch control. This system of controlling will helps to run the wind turbine very efficiently and gives maximum power as output. In this paper, the RBF neural network and fuzzy logic controller is used for variable operating modes of variable speed variable pitch wind turbine. In addition in this study, radial basis function of neural network is good for non-linear systems and fuzzy logic controller has been successfully applied to identify disturbance wind in turbine input. Thusoutput power has been regulated in optimal and nominal range by pitch angle control. This proposed paper was first tested with MATLAB/SIMLINK and then used for 5MW wind turbine.

Key words— Variable speed variable pitch wind turbine, generator pitch control, radial-basis function (RBF) neural network (NN), transition mode of operation, fuzzy logic controller, varying wind speed.

I. INTRUDUCTION

Wind turbine is the one of the oldest energy conversion devise from mechanical energy to electrical energy. This devices were used in past windmills as fundamental energy conversion devices. The wind gives the input to windmills or wind turbines as input and the mechanical energy can beobtained. In the next step this mechanical energy can be converted to electrical energy by using alternators. Because of day by day environmental pollution has been increasing problems and the economic benefits of fuel savings, there wind turbines has been installed as wind energy power systems. So thisWind energy in the world, is currently the fastest-growing source for generation of electrical energy. Due to the wind power is eco-friendly,Wind power as an energy source,has been increased its share in electrical energy generation in all over the world.Especially in central parts of Europe and on the west coast of the U.S. Globally. So the wind derived power is the fastest growing energy source. India is in 5th place in top production of wind energy in the world. The installed capacity's growth rate of wind energy has been increasing more than 25% annually in the world.

In the recent years the variable speed variable pitch controlled wind turbines are used in all over the world. Due to wind which is input to wind turbine is non-linear i.e. its magnitude is changing respectively. Due to this effect the speed of turbine rotor will also changes. To extract the maximum power from wind turbine we need to rotate the turbine at rated speeds [1]. If the turbine speed is rated then the efficiency of conversion of energy is high [2], which is desirable. So when the wind speed is above rated speed, the blade pitch angle is increased to keep the rotor speed at its rated value so the output power is maximum [3]. So this pitch angle controller will give the stable output power and this pitch control is one of the most commonly used control techniques to regulate the output power and rotor speed of wind turbine [4]. In this paper, pitch controllerwilldevelop by using two control techniques, they are radial basis function neural network [5] & [6] and fuzzy logic controller[7] & [8].

The linear approximation in various widespread cases is not valid [9] and the accuracy of system modeling decreases significantly. Thus Artificial Neural

Networks(ANNs) [10] are capable of modeling very complex functions. Thus ANNsare mathematical representations, inspired by the functioning of the human brain. In addition they keep in check the curse of dimensionalityproblem that bedevils efforts to model nonlinear functions with large numbers of variables.

Due to random and non-linear nature of the wind turbulence, the ability of Radial Basis Function (RBF) Neural Networks (NNs) in the modeling andcontrolling of this turbine is used. In this study, widespread changes of wind have been present, so pitch controlling by using RBF artificial NNs is used. In addition in this study, fuzzy rules have been successfully extracted from fuzzy logic controller to control the widespread wind speeds. In addition a new genetic fuzzysystem has been successfully applied to identify disturbance wind in turbine input. Thus outputpower has been regulated in optimal and nominal range by pitch angle regulation [11]. Results indicatethat the new proposed fuzzy logic controller rule, output performs are best than earliestmethods in controlling the output during wind fluctuation. Simulation results ofthese two methods have verified and comparison of these two methods will be discussed finally.These twocontrollers have reached its demands with higher accuracy in wind turbine for variable wind speeds.
In this study first we will declare components of wind turbine modeling in section II. The control strategy and objectives are discussed in section III.Pitch control of wind turbine by using RBF neural networks and fuzzy logic controllerwill discuss in SectionIV. In section V we will completely assert with simulation results. Finally wewill compare these two control methods in section VI as conclusion.

II. WIND TURBINE MODELING

The modeling of wind turbine is mainly depends on the study state characteristics of wind turbine with respect to output power of wind turbine [12]. In this modelling we will discuss varies parameters relative to the wind turbine and their characteristic equations. So than we can study the characteristics of wind turbine. The flow rate of mass of wind turbine is a constant for the turbine cross-section (0), at the wind turbine rotor cross-section (1), and for the turbine downstream cross-section (2), and is given by [13],

$$\text{Mass}\, m = \rho A_0 V_0 = \rho A_1 V_1 = \rho A_2 V_2 \quad (1)$$

In this modelling of wind turbine represents the power captured by the turbine from the wind. The power available in wind is Pw, in an area, A, is given by:

$$P_w = \frac{1}{2}\rho A V_w^3 \quad (2)$$

Where, $\rho$is the density of air and $V_w$is the velocity of wind. But the turbine captures only a part of this power, this is considered as the turbine power, Pm, as,

$$P_m = \frac{1}{2}\rho A V_w^3 C_p \quad (3)$$

$$P_m = P_w \times C_p \quad (4)$$

$$C_p(\lambda, \beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{\frac{-C_5}{\lambda_i}} + C_6\lambda \quad (5)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (6)$$

$C_1 = 0.5176, \quad C_2 = 116, \quad C_3 = 0.4$

$C_4 = 5, \quad C_5 = 21, \quad C_6 = 0.0068$

Where $\lambda = \frac{\Omega R}{V_w - \dot{d}}$

Where V_w is the wind speed, C_p is the performance coefficient, Ω is the rotor speed of wind turbine.λAnd β are function of tip-speed ratio and pitch angle. The power coefficient $C_p$is a nonlinear expression which uses λ and β as its variables. The value of $C_p$is maximum when the tip-speed ratio (λ) is at its nominal value and at pitch angle is at zero i.e. $\lambda_{nom}$and $\beta = 0$.Its graph is shown in Fig.1. From the steady-state operation of wind turbine, the output power is maximum i.e. nominal output power occurred at the tip speed ratio is nominali.e.at λ_{nom}.

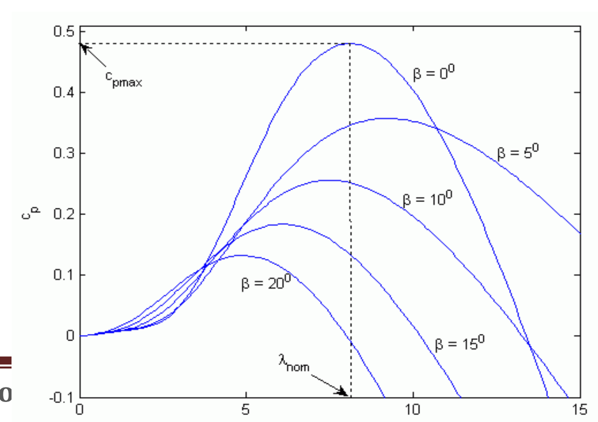

Fig.1. power coefficient varies with tip speed ratio.

From the Fig.1 the power coefficient C_p, represents the fraction of power in the wind captured by the turbine from the wind energy, and the power coefficient's theoretical value is maximum of 0.48. The power coefficient can be expressed by as the equation (5).

III.CONTROL STRATEGY AND OBJECTIVES

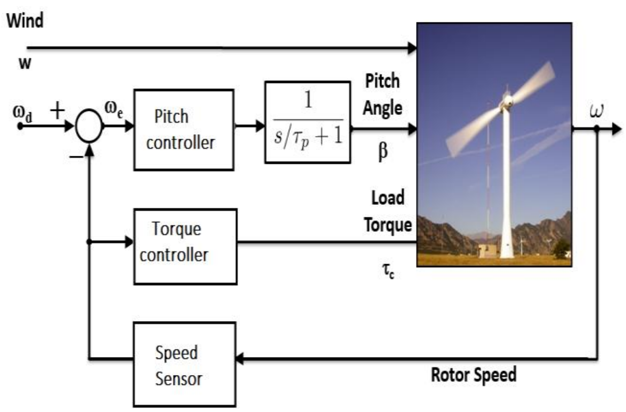

Fig.2. Wind turbine controllers.

In this section we study that when the pitch control have to applies. Wind turbine is naturally nonlinear and it varies with time. So the Aerodynamic torques of wind turbine depends on nonlinearly on wind speed. So as the wind varies then pitch angle also has to vary, to extract the maximum output power.

The cut-in speed of wind is given as 3 m/sec and the cut-off speed of wind is 25 m/sec i.e. if the wind speed is below 3 m/sec then the wind turbine won't rotate and I the wind speed is more than 25 m/sec then we intentionally stop the rotation to protect the blades of wind turbine not to damage [13]. So, if the wind speed is between these two limits then the smooth transaction can be achieved.

Generally if the rotor of wind turbines speed is more than rated value (1800 rpm or 1.2pu) then we have to apply the pitch controller. If we increase the pitch angle then the wind force on the wind turbine will reduces so the torque on wind turbine decreases.

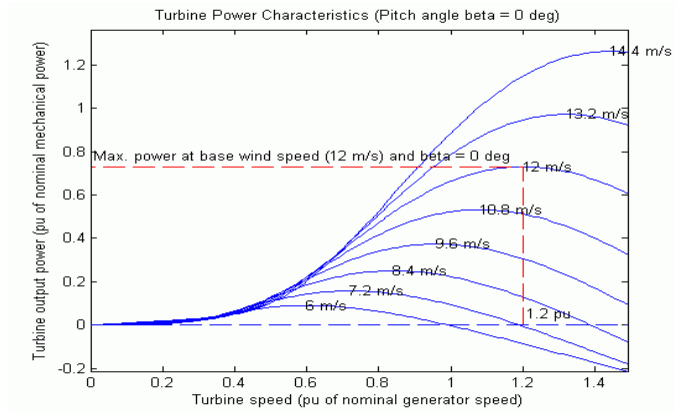

Fig.3. Non-linear characteristics of wind turbine

The base speed of wind is given as 12 m/sec. at base speed the maximum power can be obtained, when the turbine speed is 1.2pu as shone in fig.3. at these when the wind speed increases then the speed of turbine also increases (more than 1.2pu) then output of wind turbine will reduces as shone in Fig.3. So it is required to run the wind turbine at rated speed i.e. 1.2pu then only we can get maximum output power at wind speeds greater than 12 m/sec. so the variation of pitch angle with respect to wind speeds will explain bellow.

The non-linear wind conditions can be divided into four stages they are given as,

1. If wind speed is low (< 3m/sec), the generator is not connected to grid.
2. If the wind speed is medium (between 3 m/sec to 12 m/sec), the generator is connected, but does not produce maximum power.
3. If the wind speed is higher (between 12 m/sec to 25 m/sec), the generator is connected to grid and produces maximum power.
4. If wind speed is very high (more than 25 m/sec), the generator is disconnected from grid and the turbine is stopped.

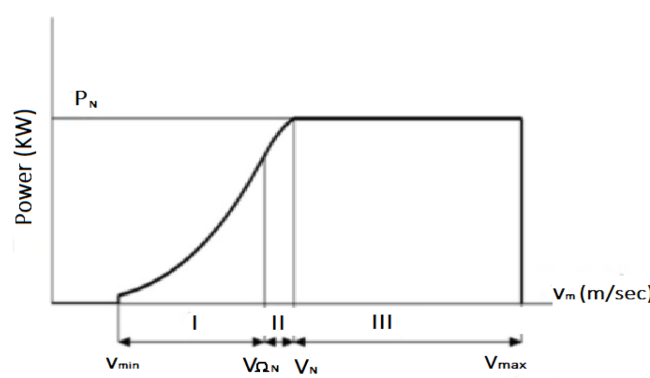

Fig.4. Output power vs turbine speed

From the Fig.4

- In Region 1, the wind speed and the generator torque are below rated. So the blade pitch angle is held constant at the optimal value that gives maximum aerodynamic torque. This is called torque control. Here the output power of wind turbine is below nominal value and is proportional to square of wind speed.
- In Region 3, the wind speed is at or above (12 m/sec) then the rotor speed will exceeds rated speed so pitch controller will come in to picture. So as the pitch angle changes till the speed of rotor reaches to rated value i.e. 1.2pu. So the output power will be nominal value.
- In Region 2, this region is the smooth transaction between two regions. In this region both the rotor speed and aerodynamic torque are tends to rated.

IV.PITCH CONTROL DESIGN USING RBF NEURAL NETWORKAND FUZZY LOGIC CONTROLLER

A. Pitch Control Design Radial Basis FunctionNeural Networks:

Neural networks can be used for dealing non-linear problems as an excellent mathematical tool. These neural networks have been use to get the desired response by updating the weights of the neurons. As the number of neurons are high the accuracy of the system also high. So we use more neurons as possibly high.

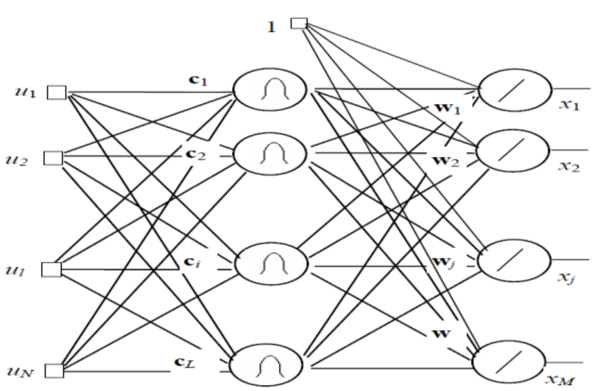

Fig.5. Two-Point radial basis function.

Radial basis function (RBF) neural networks are feed-forward networks.The training of the weights of neurons by using supervised training algorithm. The radial basis function neural networks have only one hidden layer with high number of neurons. The activation function of RBF is taken as basis function.The hidden layer is having activation functions as nonlinear characteristics. These hidden layer output is directly connected to the output layer. The output layer is having a linear activation function as shown inFigure. 5.

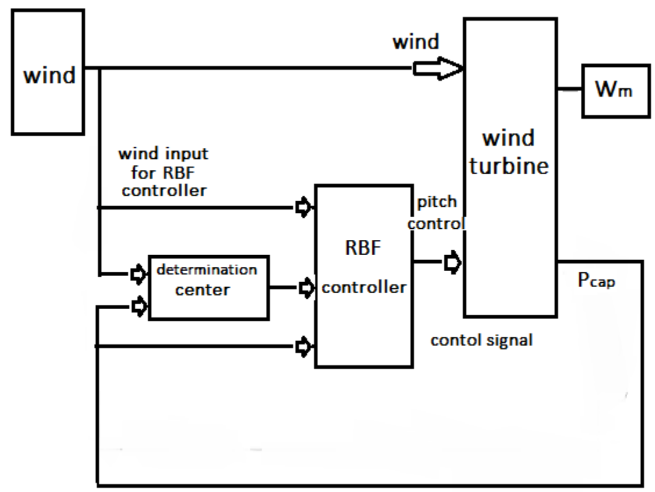

Fig.6 (A). Pitch control algorithm using RBF NN.

From fig.6 (A) shows theblock diagram of RBF controller[14], designs the pitch angle controller using neural network, the results show that the power output is stable during high wind speeds, and protecting the turbine blades from the over rotating speeds.

The rotor speed of the wind turbine depends on the pitch angle and input wind speed. The change of rotor wind speed can be given in as bellow.

$$\dot{\Omega} = f(V_w, \Omega, \beta) \tag{6}$$

The governing equation of rotor speed in this mode is given by

$$\dot{\Omega} = \frac{\frac{1}{2}\rho\pi R^5 \frac{C_p(\lambda,\beta)}{\lambda}(V_w)^2}{(J_R + J_G)} - \frac{1}{(J_R + J_G)}(T_{nom} + K_t\Omega) \tag{7}$$

From the equation 6 and 7 the change of rotor speed is the function of wind speed, pitch angle and the rotor previous speed. By using this pitch angle controlling we have to maintain the turbine speed as rated so the output of wind turbine will be nominal.The block diagram of pitch control of wind turbine by using RBF neural network can be given below.

B. Pitch Control by using Fuzzy Logic Controller (FLC):

The control algorithm of a process that is based on fuzzy logic or a fuzzy inference system is defined as fuzzy controller. One of the most advantage with fuzzy logic controller is that, this controller does not need any mathematical model for the plant, like any other conventional controllers as exists. Fuzzy logic controller is also nonlinear control, which gives robust performance for linear as well as nonlinear plants, with input parameter variation. So the fuzzy logic controller is the best adaptive controller[15].The pitch controlling ofwind turbine by using fuzzy logic controller is be given by Fig.6 (B).

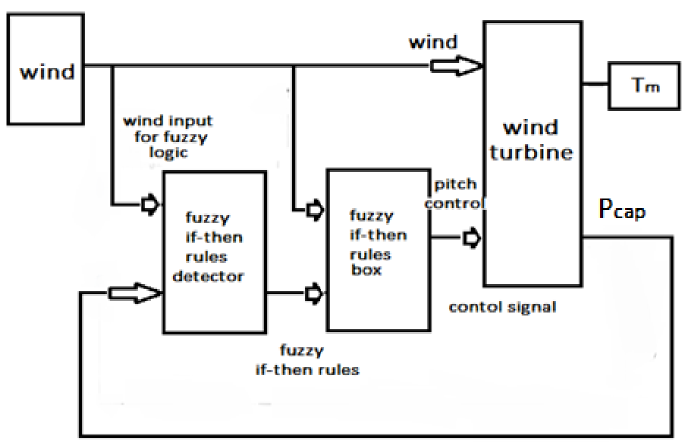

Fig.6 (B). Pitch control by using fuzzy logic controller.

The fuzzy logic controller has the two inputs and one output. The inputs are one is wind speed and another one is error between turbine rotor speed and rated rotor speed. The output is taken as pitch angle given to wind turbine. The first input has five membership functions. Which are classified as 1. Very low speed 2. Low speed 3. Medium speed 4. High speed 5. Very high speed. The error is classified as 1. Negative error 2. Zero error 3. Positive error. The output is divided as 1. Very low pitch 2. Low pitch 3. Medium pitch 4. High pitch and 5. Very high pitch.The mapping of fuzzy logic inputs and output is based on if then rules. The rules are given below in table.1. The overall pitch controlling of wind turbine is depends on these if then rules.

Table.1. Fuzzy logic if-then rules

AND LOGIC	N.E	Z.E	P.E
V.L.W	V.L.P	V.L.P	L.P
L.W	V.L.P	L.P	M.P
M.W	L.P	M.P	H.P
H.W	M.P	H.P	V.H.P
V.H.W	H.P	V.H.P V	V.H.P

V.SIMULATION RESULTS

The pitch control of variable speed variable pitch angle wind turbine gave the following results by using radial basis function neural networks and fuzzy logic controller they are explain below.If the wind speed is belongs to region III for example 18 m/sec from Fig 7(A) and Fig 7(B),as the rotor speed gone more than rated rotor speed (more than1.2pu), at this rotor speeds, the captured output power gone below the nominal value, so as to compensate this effect and bring back the energy capture to maximum, the pitch controller has activated.

As the pitch controller by using RBF Neural Network or Fuzzy Logic Controller comes to picture, in both controllers the pitch angle was increased i.e. the deflection of blades increases.So that, the torque and the rotor speed decreased.

Here the pitch angle is increased up to the rotor speed reaches to rated speed i.e. 1.2pu. At this rated rotor speed we got the nominal output power which is our aim.The output wave forms for the wind speed 18 m/sec are given in fig.7 (A & B).

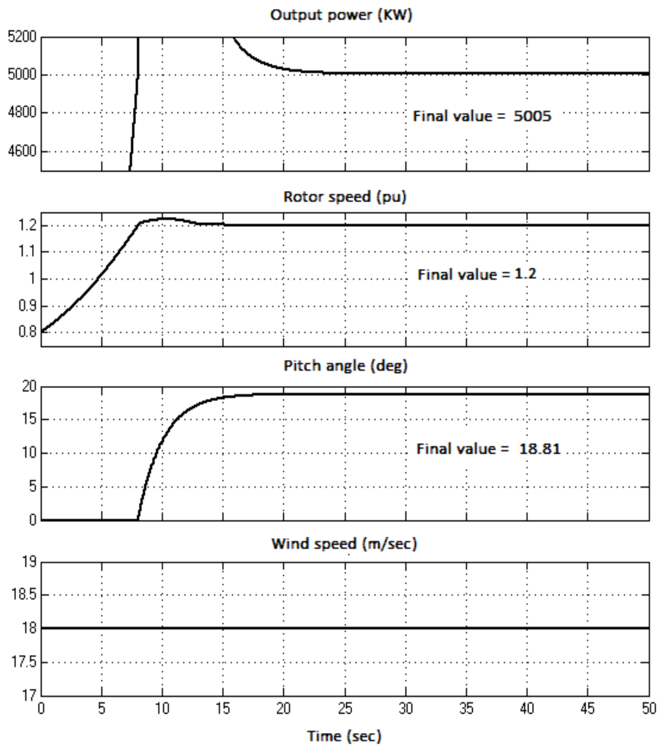

Fig.7. (A). Pitch controller by using RBF neural network for the wind speed 18 m/sec.

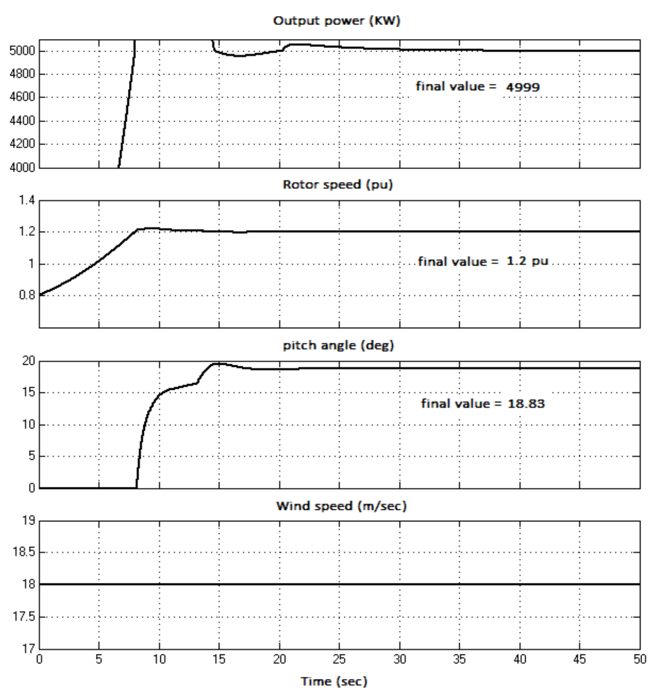

Fig 7. (B). Pitch controller by using fuzzy logic controller for the wind speed 18 m/sec.

If we give the wind speed as ramp signal which changes its magnitude with respect to time linearly [16], from Fig.8. (A) and Fig 8. (B), still the rotor speed reaches to its rated value, the pitch controller was in inactive mode. So the pitch angle was zero, after some time as the wind speed increases continuously the rotor speed also increased rom minimum to rated and then more than rated.

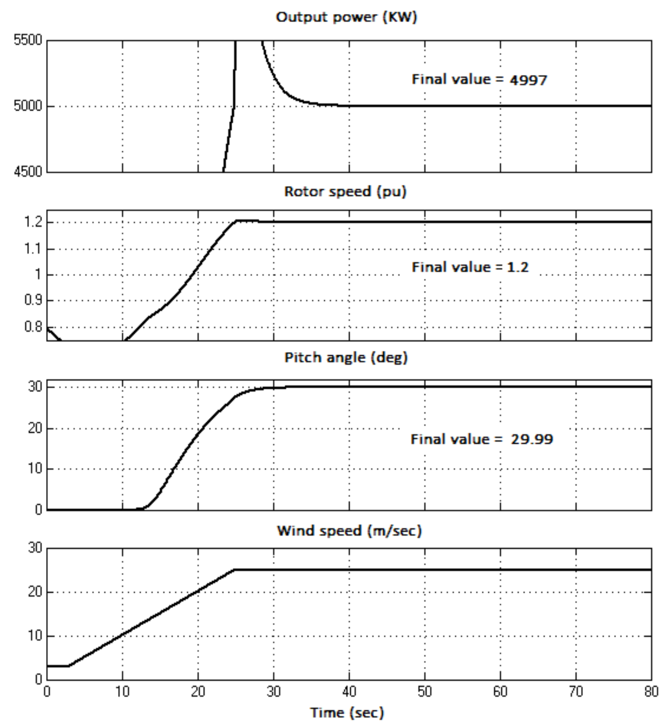

Fig 8. (A). Pitch controller by using RBF neural network for variable wind speeds.

So as the rotor speed reached more than rated speed, the pitch controller activated. So the pitch angle increases linearly up to rotor speed decrease and reach to rated. The maximum value of pitch controller for the wind speed 25 m/sec is 30° (in degree).

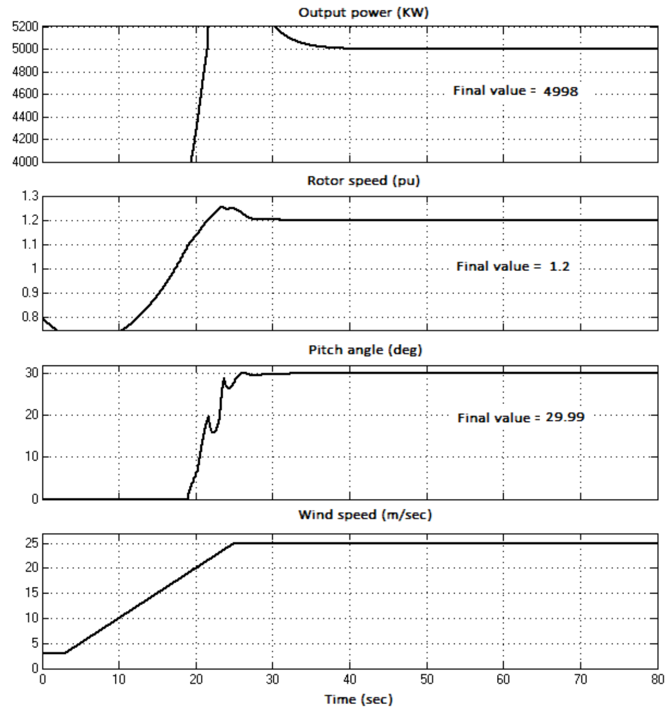

Fig 8 (B). Pitch controller by using fuzzy logic controller for variable wind speeds.

VI. Conclusion

The controllability of wind turbine is necessary for extract the maximum power. Because of wind energy is one of the world's fastest increasing renewable energy source of clean and eco-friendly. In this paper, two new method of controlling the pitch angle of wind turbine are introduced. These two models have same input i.e. wind speed. As the wind is nonlinear the wind turbine controlling is investigated. As plotted from the above simulationresults, the controllers change pitch angle of turbine blades to achieve most nominal output power.According to comparison results, RBF Neural Network Controller and fuzzy logic Controller have been compared using difference between the power outputs. As it is demonstrated Fuzzy logic Controller hasthe better response than RBF neural network. These two controllers had trained with full rang optimal value of wind turbine input-output successfully. The fuzzy logic controller optimally produced accurate rules or curve betweeninput and output. Thus it is clear that output power of wind turbine was nominal and obtained by using pitch controller only. Forthis method a limitation is that we need a computer with high speed of operation to give results as early as possible.

In this paper, blade pitch position control has been submitted by two smart controllers duringwind input was nonlinear. Practically, both the approaches gave acceptable results. But consequently,considering the desired values in training, fuzzy logic controller gave better results than the other type.

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