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Neural Network Based Pitch Controller

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Abstract -The neural network pitch controller has been introduced in this paper to regulate wind turbine power above the rated wind speed. The changing rate of generator speed is used in this neural network pitch controller as well as the difference between the rated and current generator speed. Matlab/Simulink has been used for simulations and it has been shown that the suggested pitch controller regulates generator power as the rated power.

***Keywords*:** neural network, pitch controller, wind turbine

1. Introduction

Wind energy has widely grown during the last decades and is nowadays the most competitive form of renewable energy. Control plays a very important role in modern wind energy system. Wind turbine control enables a better use of the turbine capacity as well as the alleviation of aerodynamics and mechanical loads [1,2]. Variable-speed wind turbine operates in two primary regions, below-rated power and above-rated power. When power production is below the rated power, the turbine operates at variable rotor speed to capture the maximum amount of energy available in the wind [2]. In above rated power region, the primary objective is to maintain a constant power output. This is generally achieved by decreasing to capture the amount of wind energy, which is done by varying the blade pitch angle. In this paper, a new method using neural networks to control a blade pitch angle is proposed. The neural networks have been used to design nonlinear control systems. This neural network pitch controller is used to maintain a constant power in above rated power region. Finally, the 5MW wind turbine model of NREL is used for Matlab/Simulink simulations.

2. The Control Region of Wind Turbine System

Using a wind turbine for production of electrical energy requires reliable operation. Especially at high wind speed fluctuations from the wind result in large mechanical loads of the turbine. Therefore an active control system is often used to realize a long lifetime of turbine and produce high quality power or increase energy capture. In control engineer in terms, the wind turbine is a dynamic system excited by a disturbance input, the wind, and measurement noise. Basically, the control design objectives are: maximization of energy capture in partial load, limiting and smoothing of electrical power in full load, and minimization of the turbine transient loads and thereby maximization of the turbine lifetime in both partial and full load.

The turbine is normally operated between a lower and upper limited wind speed. A typical power curve is shown in Fig. 1. It can be started at a cut-in wind speed (Vmin), and shut down at a cut-off wind speed (Vmax). When the wind speed drops too low, the produced energy by the turbine is not enough to compensate for the consumed energy by the turbine, the turbine is then stopped. When the wind is too high it is again stopped since it would be uneconomic to construct the turbine to be robust enough to operate in all wind speeds. Variable-speed wind turbine operates in two primary region, below-rated power and above-rated power. When power production is below the rated power, the turbine operates at variable rotor speed to capture the maximum amount of energy available in the wind [2]. In above rated power region, the primary objective is to maintain a constant power output. This is generally achieved by decreasing to capture the amount of wind energy, which is done by varying the blade pitch angle.

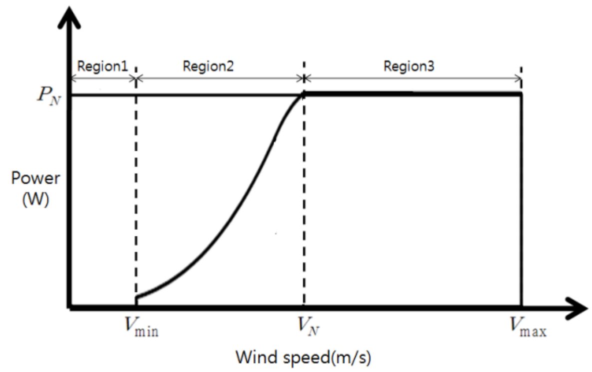


Fig. 1. Operation modes of a wind turbine

At low wind speeds in the region 2, the operational point of the turbine should be held at the maximum point on the Cp surface. The turbine rotational speed w, should be adjusted to obtain a constant tip-speed ratio, resulting in maximum turbine efficiency. The rotor power increases with the cube of the wind speed whereas the turbine rotational speed changes linearly proportional to the wind speed.

In the region 3, the rotational turbine speed reaches the speed limit. The wind turbine is controlled to prevent the turbine rotational speed from varying. The operation at optimal tip-speed ratio is not possible at all wind speeds. At higher wind speeds the speed limitation ensures that the tip-speed ratio reduces, this can be done by control-ling blade pitch angle.

3. Proposed Method

The purpose of this controller is to maintain the rated power above the rated wind speed by adjusting the pitch angle of the rotor blades. The power coefficient and the turbine's tip-speed ratio are strongly influenced by blade pitch angle and their relationships are strongly nonlinear. Neural networks have been proved a successful method in control of dynamic systems. In fact, control of nonlinear systems is a major application area for neural networks. Their approximation capabilities of neural net-works made them a popular choice for implementing general purpose nonlinear controllers [3].

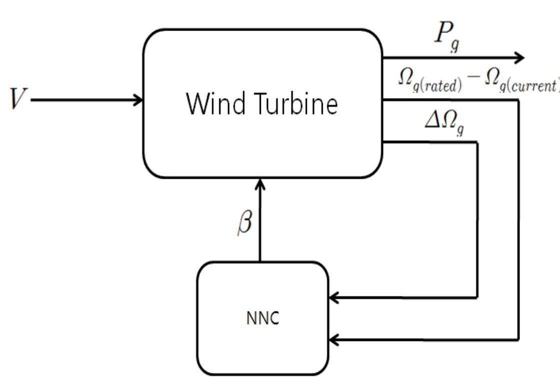


Fig. 2. Block diagram of wind turbine system using NNC

3. 1. Multi-layer Perceptron Networks

Multi-layer perceptron cover a large group of feed-forward neural networks with one or more layers of neuron. In most applications, MLP networks having three layers have been used. Neurons in input layer have a pure linear activation function, but some nonlinear activation functions such as logarithmic and tangent sigmoid functions are used in the neurons in hidden and output layers. An architectural scheme for an MLP network having only one hidden layer is illustrated in Fig. 3.

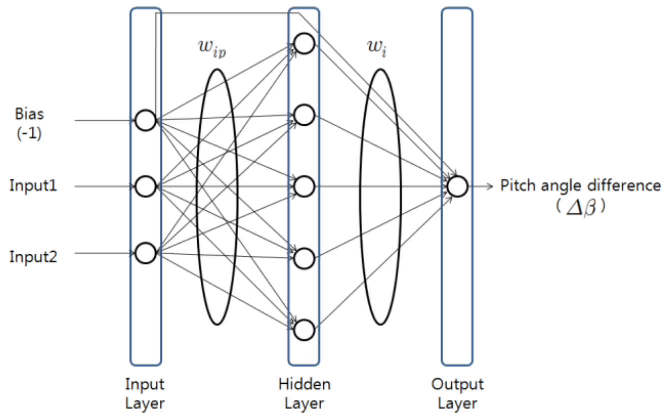


Fig. 3. Structure of a neural network pitch controller

The neural network pitch controller has two input, 5 neurons in a hidden layer, and one output. The two inputs are the current speed and the changing speed rate of wind generator. And one output is the changing difference pitch angle. Training process and calculations in the neurons and layers occur by using input–output equation given in (9). Training process of the back propagation algorithm runs according to the following steps [4-6].

Step 1: Initialize all weights at random.
Step 2: Calculate the output vector.
Step 3: Calculate the error propagation terms.
Step 4: Update the weights by using Eq. (1) and (2).
Step 5: Calculate the total error ‘‘E” by using Eq. (3) and (4).
Step 6: Iterate the calculation by returning to Step 2 until the total error is less than the desired error

$$w_{ip}(t+1) = w_{ip}(t) + \frac{\alpha}{l}\sum_{n=1}^{l} X_{pn} f_1^{'}(net_i) E_{in} w_i \qquad (1)$$

$$w_i(t+1) = w_i(t) + \frac{\alpha}{l}\sum_{n=1}^{l} E_{in} f_2^{'}(net) Z_{in} \qquad (2)$$

where w_{ip} is the connection weight between the i_{th} neuron in the hidden layer and p_{th} neuron in the input layer, w_i is the connection weight between the i_{th} neuron in the hidden layer and the input layer. And α is the learning rate and l is learning size and

$$E(n) = f_2(n) - \overline{Y}(n) \quad n = 1,2,...,l \qquad (3)$$

$$E_{total} = \frac{\sum (E(n))^2}{l} \quad n = 1,2,...,l \qquad (4)$$

And f_1 and f_2 ,the transfer functions of hidden and output layer's neuron, are as follows

$$f_1(u) = \frac{1-e^{-u}}{1+e^{-u}}, \quad f_2(u) = u \tag{5}$$

3. 2. Neural Network Based Pitch Controller Algorithm

In Fig. 4, the flowchart of neural network pitch controller algorithm is presented. For starting up, the first phase is classified in three cases whether the current generator speed is greater, equal or less than the rated generator speed. Additionally the changing rate of generator speed is considered in determining to increase or decrease pitch angle β. For example, when current generator speed is greater than rated speed , the changing rate of generator speed is once more considered to increase the pitch angle. If the changing rate of generator speed is also increasing , then the pitch angle is determined to increase. Otherwise the pitch angle is not changed. Decreasing the pitch angle has also same procedure when current generator speed is smaller than rated speed . And when current generator speed is equal to rated speed, the pitch angle changes proportionally to the changing rate of generator speed. The pitch angle is increased when the changing rate of generator speed is positive .

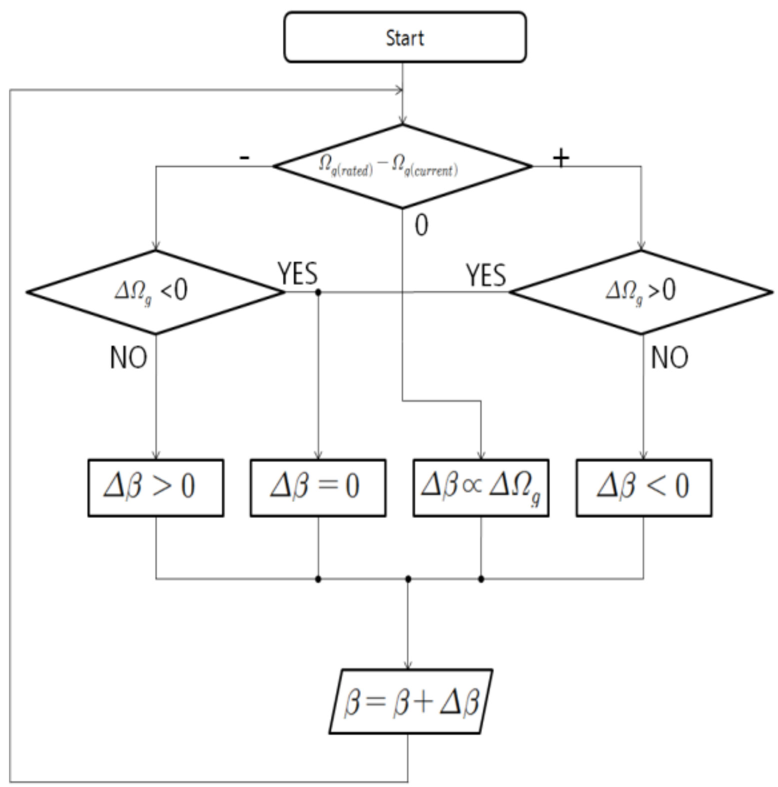


Fig. 4. Flowchart of the neural pitch controller

4. Simulation Results

The proposed control scheme is simulated using Matlab/Simulink. The 5-MW wind turbine model of NREL is used for simulations. Characteristic data about the 5-MW wind turbine model of NREL used in this paper can be seen in [7]. Basically the main idea is that, blade pitch can be changed to regulate power above the rated wind speeds. This section verifies the performance of the proposed neural pitch controller by looking into the responses of the wind turbine model to the above rated wind speed. Two cases, which are step wind speed and randomly varying wind speed, are used for simulations as shown in Fig. 6.

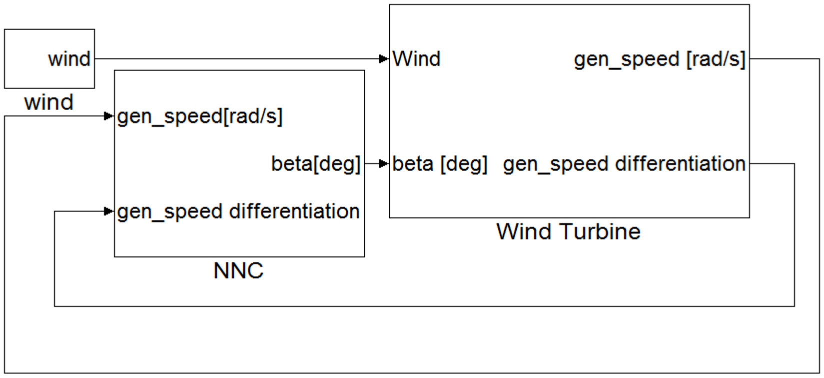
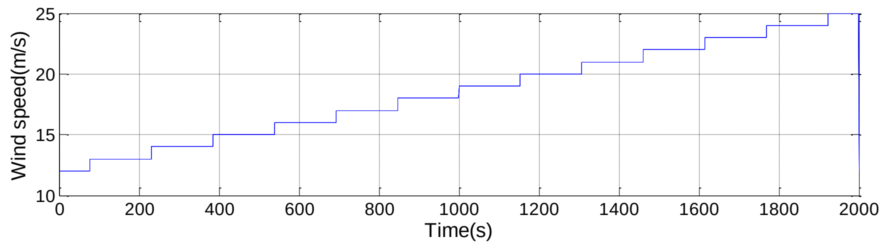
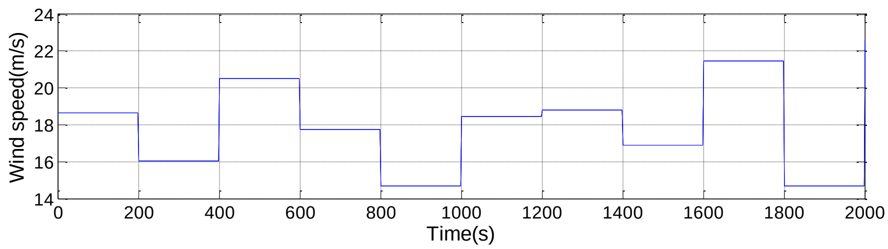


Fig. 5. Matlab/simulink model of the neural pitch controller



(a)



(b)

Fig. 6. Step wind speed (a) and randomly varying wind speed (b)

As seen in Fig. 8, the power produced in both cases are regulated to the rated power of the turbine by changing the pitch angle according the neural network controller results (Fig. 7).

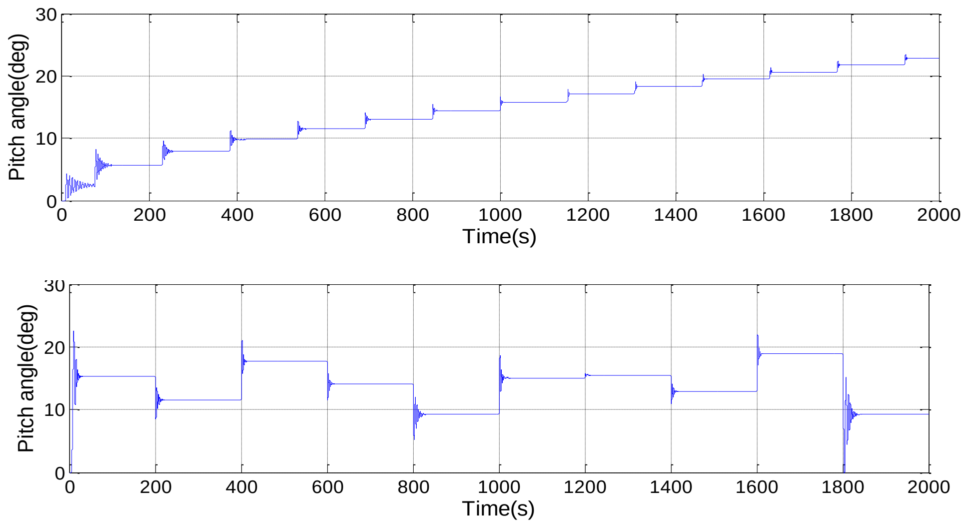


Fig. 7. Pitch angle β produced by the NNC

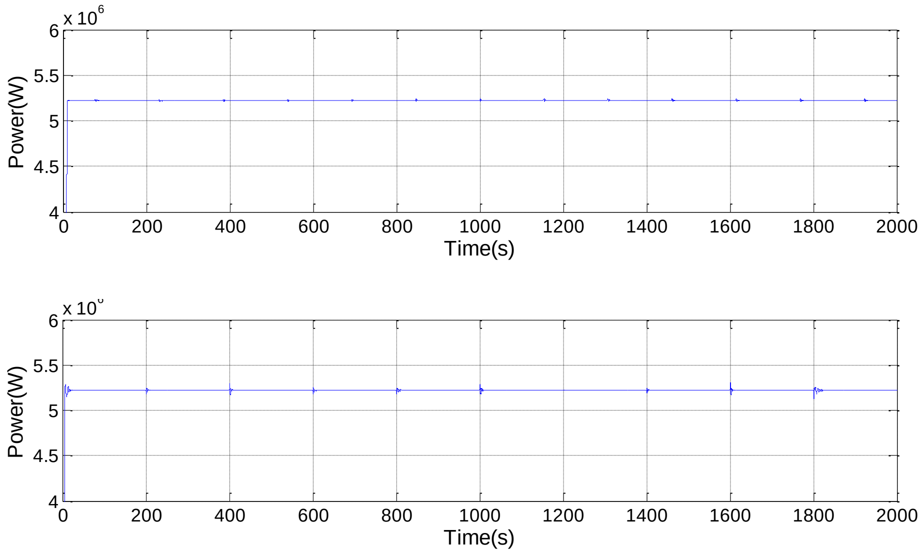


Fig. 8. Power outputs

5. Conclusion

In this paper, a neural network pitch controller is introduced to regulate the power above the rated wind speed. The neural network pitch controller exhibits a good performance regulating the rated power above the rated wind speeds. The generator speed changing rate is used additionally for the input of neural pitch controller as well as the difference between current and rated generator speed. The 5-MW wind turbine model of NREL is used in this paper and Matlab/simulink is used for simulations. Small problem has been shown in a rapid wind change, where small oscillation is occurred in pitch angle. Except this problem, the presented model has been shown to provide good performance.

Acknowledgements

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References

Rao, P., Crow, M.L., & Yang, Z. (2000). Statcom Control for Power System Voltage Control Applications. *IEEE Trans. on Power Del.*, 15, 1311-1317.

Norouzi, A.H., & Sharaf, A.M. (2005). Two Control Schemes to Enhance the Dynamic Performance of the Statcom and SSSC. *IEEE Trans. on Power Del.*, 20, 435-442.

Qin, J., & Saeedifard, M. (2012). Predictive Control of a Modular Multilevel Converter for a Back-to-Back HVDC System. *IEEE Trans. on Power Del.*, 27, 1538-1547.

Tu, Q., Xu, Z., & Xu, L. (2011). Reduced Switching-Frequency Modulation and Circulating Current Suppression for Modular Multilevel Converters. *IEEE Trans. on Power Del.*, 26, 2009-2017.

Tu, Q., Xu, Z., Chang, Y., & Guan, L. (2012). Suppressing DC Guan Voltage Ripples of MMC-HVDC Under Unbalanced Grid Conditions. *IEEE Trans. on Power Del.*, 27, 1332-1338.