Enhancing the maximum power of wind turbine using artificial neural network

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Article Info

ABSTRACT

Wind energy conversion systems (WECS) now play a significant role in meeting the world's energy needs. Several different approaches are used to try to increase the reliability of these renewable energy systems. Smart systems are designed to be more proactive to improve the performance of renewable energy equipment. Artificial neural networks (ANNs) have a variety of applications, including controlling renewable energy systems. Using optimal torque control (OTC) system based prediction techniques, a controller to monitor a maximum point of wind turbine output power (MPPT) is designed and modeled in this paper. MATLAB/Simulink package tools for neural networks are also used to design the controller and simulate it to achieve the necessary results and to obtain an appropriate analysis for the controller. The results show that the ANN is more active and delivers better output than the traditional controller.

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1. INTRODUCTION

The need to use environmentally friendly energies to mitigate the impact of global warming and the adverse changes it brings to the surrounding environment has become more important as energy use from burning petroleum or fossil fuels and other unclean fuel sources have increased [1]. One of the most significant renewable energies that has started to be used in this sector is wind energy. Wind turbines use a rotor to transform kinetic energy into mechanical energy [2]. Mechanical energy will be used to rotate the electrical component, the generator, which will convert mechanical energy to electrical energy [3]. Typically, the wind turbine has three blades that complement the rotors known as the fans.

The rotating part is held in place by a tall tower, which is used to fix it and deliver it to the required height. Magnets that pass through the static wire coil known as the solid component transform wind energy into electricity [4], [5]. The generation of alternating electricity occurs when a magnet moves through the stator. Then, alternating electricity is converted into direct electricity to charge the batteries, which act as electricity storage, or it can be fed to the grid by the inverter. Wind turbines consist of the rotor, blades, brake, mechanical gearbox, generator, whether synchronous or DC type, and tower. Wind turbine parts are shown in Figure 1. Based on Betz's law and Newton's laws of motion, a vacuum cylinder that enters the air from S1 and exits from S2 as shown in Figure 2, has a density of 1.22 kg/m^3 in normal temperature and pressure conditions [6].

Regardless of the open flow of wind turbine design, Betz law suggests that it can make the most of wind energy extraction. This rule was established by the principles of maintaining the momentum and mass of air flowing through a perfect engine that extracts energy from the air stream. A turbine can only absorb 16/27

(59.3%) of the kinetic wind energy, according to Betz's rule. In the peak range of 75% to 80% of the Betz limit, wind turbines have achieved practical benefits [7], [8].
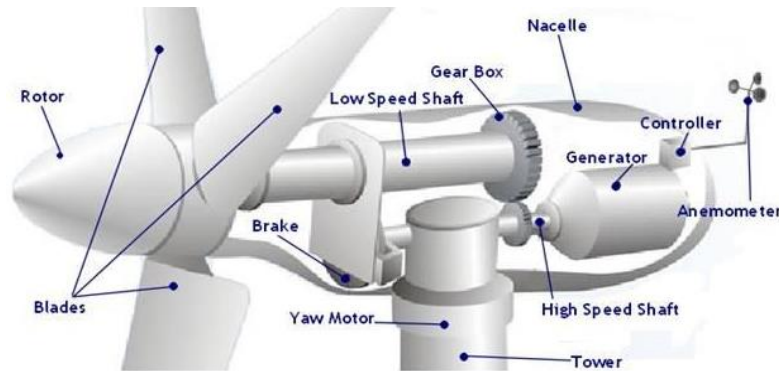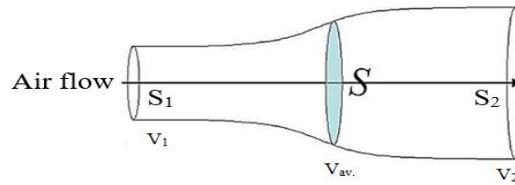

Figure 1. Wind turbine parts

Figure 2. Vacuum cylinder

2.   METHOD

The required research method included the components, hardware, and system simulation. The used wind turbine is modeled and simulated. The results are optimized using an artificial neural network (ANN). The modeling and simulation are based on MATLAB/Simulink.

2.1. Hardware description

The wind turbine that was used and simulated is 8.5 kW. The air density is assumed to be 1.22 kg/m^3. The wind turbine pitch angle used in the simulation is 2^0.

2.1.1 Modeling and implementation of wind turbine

The mechanical aspects of a turbine can be represented as: the mechanical power Pm produced by the turbine is:

$$P_m = 0.5\rho S C_p(\lambda, \beta) V_w^3 \tag{1}$$

Where ρ is the density of the air in (kg/m^3), S represents the turbine swept area, C_p represents the power coefficient, λ is the tip speed ratio, β is the pitch angle, and V_w represents the wind speed in (m/s) [9], [10]. In this work β is set to 2. The power coefficient C_p can be represented by the given (2):

$$C_p = A_1\left(\left(\frac{A_2}{\lambda_i}\right) - A_3\beta - A_4\right)e^{\frac{A_5}{\lambda_i}} + A_6\lambda \tag{2}$$

Where: A_1=0.5, A_2=116, A_3=0.4, A_4=5, A_5=-21, A_6=0.0068 and $\boldsymbol{\lambda}_i$ can be found as (3):

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

Shaft mechanical torque T_m can be found as (4):

$$T_m = \frac{P_m}{w_r} \qquad (4)$$

Where w_r is the wind turbine rotor speed. The tip speed ratio λ can be found as (5):

$$\lambda = \frac{w_r R}{V_w} \qquad (5)$$

Where R is the rotor radius of a wind turbine in meters (m). Table 1 represents the used wind turbine parameters in the simulation [11].

Table 1. The parameters of wind turbine

Parameter	Values
Output mechanical power	8.5 kW
Density of the air	1.22 kg/m^3
Base wind speed	12 m/s
Pitch angle	2 degrees

The mechanical power of the turbine is represented in Figure 3, concerning the rotor speed at different wind speeds [12]. Figure 4, depicts the mechanical wind turbine rotor torque as a function of wind speed for different wind speeds. The power factor C_p (λ) for different pitch angle values is shown in Figure 5. The optimum value of C_p is 0.39 corresponding to the deflection pitch angle $\beta=20$ of the turbine blades at $\lambda_{opt}=10$. There is a running point at which these optimal turbine characteristics, Pm, Tm, and Cp, produce an optimal wind turbine output power Pg for varied wind velocity values. This emphasizes the importance of using the MPPT control to reach the maximum power point, which must then be followed by any wind speed variations [13]-[16].
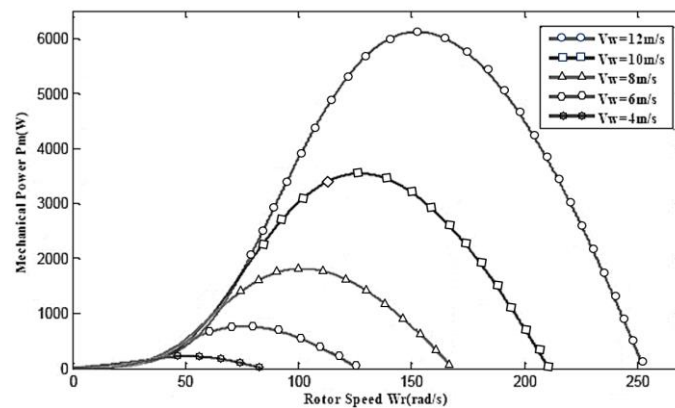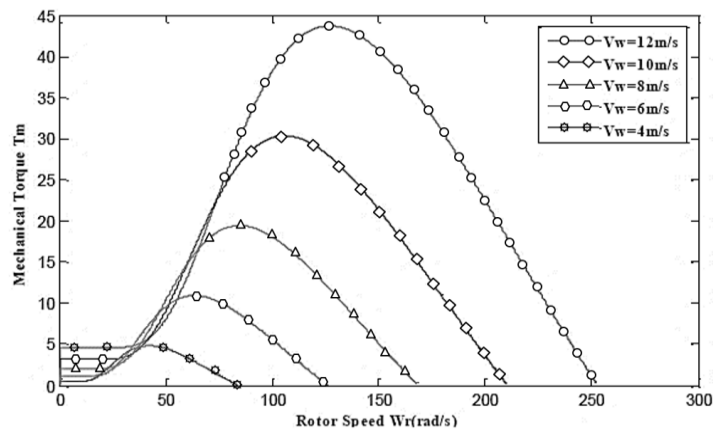

Figure 3. Wind turbine characteristics

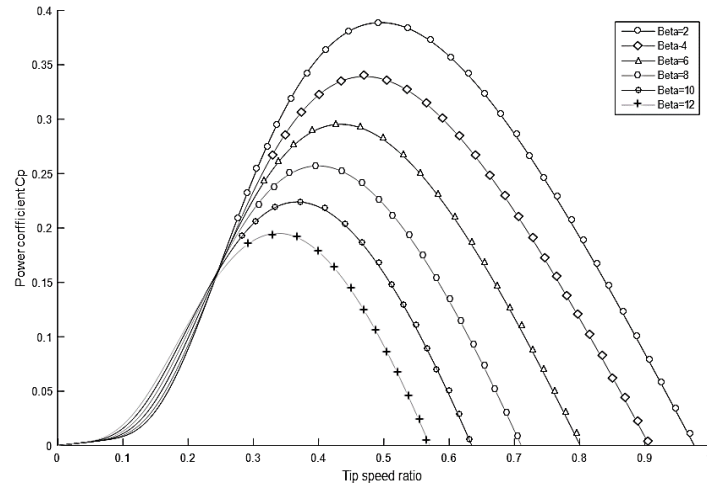Figure 4. Mechanical torque of wind with wind speed

Figure 5. Mechanical torque of wind with wind speed

2.1.2 MPPT controller algorithm

MPPT controllers should be used in wind energy conversion systems (WECS) because they play an important role in extracting the most power generated by the generator regardless of wind speed, and they are based on the theory of the MPPT system, which allows for optimal power point tracking [17]. MPPT wind systems make use of a variety of technologies, including direct and indirect methods. Indirect methods such as optimal torque control (OTC) and power signal feedback (PSF) use the characteristics of $C_{p\text{-}opt}$ and λ_{opt}. The MPPT algorithm and the ANN-based methodology for OTC are used in this analysis [18], [19].

2.1.3 Optimal torque control technique

It's a control method that works in the background. The goal of the OTC system is to keep generated torque constant for varying wind speeds, which necessitates a thorough understanding of the optimal power coefficient $C_{p\text{-}opt}$ and optimal λ_{opt} of the turbine features [20]. The mechanical power of wind speed and the optimum torque can be formulated in the following way using the optimum values of turbine features and in (1), (4), and (5):

$$V_w = \frac{w_{r.opt}R}{\lambda_{opt}} \tag{6}$$

$$P_{m.opt} = 0.5\rho\pi R^2 C_{p.opt} V_w^3 \tag{7}$$

$$P_{m.opt} = K_{opt}.w_{r.opt}^3 \tag{8}$$

$$T_{m.opt} = \frac{P_{m.opt}}{w_{r.opt}} \tag{9}$$

$$T_{m.opt} = \frac{K_{opt}.w_{r.opt}^3}{w_{r.opt}} \tag{10}$$

$$T_{m.opt} = K_{opt}.w_{r.opt}^2 \tag{11}$$

Where K_{opt} is a constant that is determined as (12):

$$K_{opt} = \frac{1}{2}\frac{\rho\pi R^5 C_{p.opt}}{\lambda_{opt}^3} \tag{12}$$

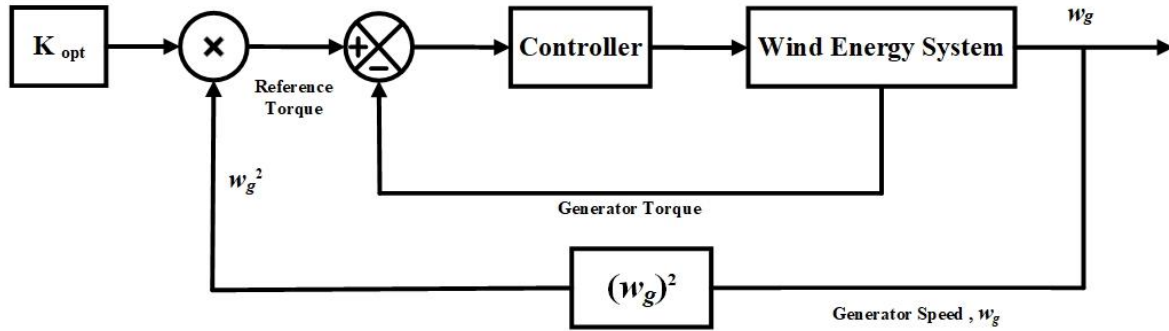Figure 6 shows a block diagram for the OTC method.

Figure 6. OTC method block diagram

3. MPPT based neural network

MPPT technology based on neural networks has recently been introduced as among the smart methods used with wind turbines to define and monitor the operating point roughly equivalent to maximum power regardless of wind velocity fluctuations [21]-[23]. In comparison to conventional control techniques, MPPT-based controller ANN is a powerful control method that does not necessitate a detailed understanding of the system's mathematical equation of model [24]. The function of artificial neurons can be illustrated and shown in Figure 7.
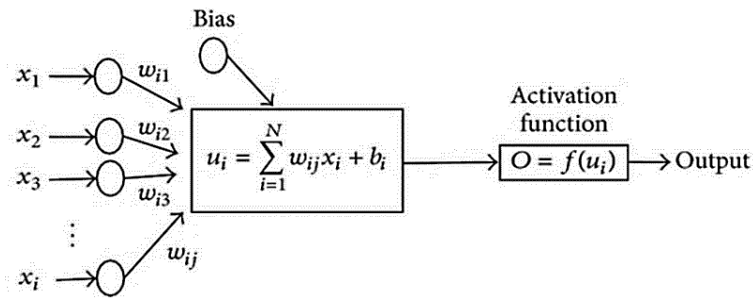

Figure 7. General pattern of a neuron

Where X is the neuron's inputs, w_i are the weights for the inputs, u_i is the input function. In the MPPT controller simulation, the suggested ANN's role is to predict the network electromagnetic torque Tem for each wind velocity value Vw using the learning outcomes of a set of data involving the Tem associated with each wind velocity value Vw [25]-[27].

4. RESULTS AND SIMULATION

The wind turbine system and the MPPT controller were implemented and simulated using MATLAB/Simulink. The MPPT controller behavior and tracking were modified utilizing ANN. Figure 8 shows the wind turbine simulation system. The simulation model is consisting of a wind turbine, gearbox, generator as a mechanical load, and the MPPT controller.

Figure 9 shows how wind speed V_w changed over two periods, from 10 m/s to 12 m/s, at t1=0 sec and t2=15 sec, respectively. Figure 10 represents how increasing wind speed affects the turbine's rotor. This will result in more turbine output power. Figure 11 shows the velocity variation of both the rotor and the wind turbine mechanical velocity. Figure 12 shows the power generated by this wind turbine. Figure 13 shows the maximum power point tracking by the MPPT controller. As observed in the curves, the response time of the neural network controller to changing wind speed is faster for the conventional controller, and the amount of energy produced using the intelligent controller will be greater.
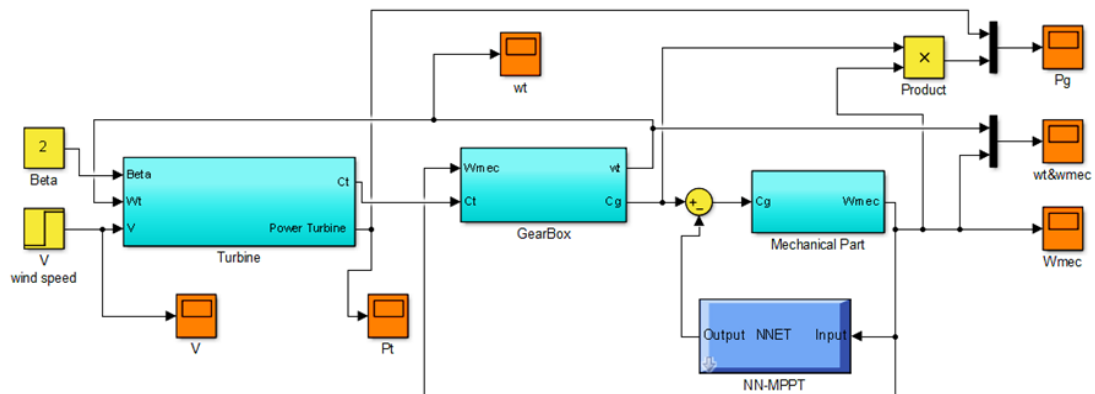
Figure 8. Overall wind turbine system simulation
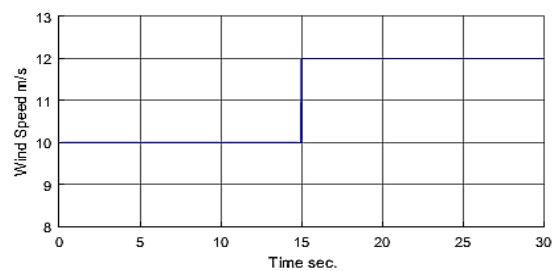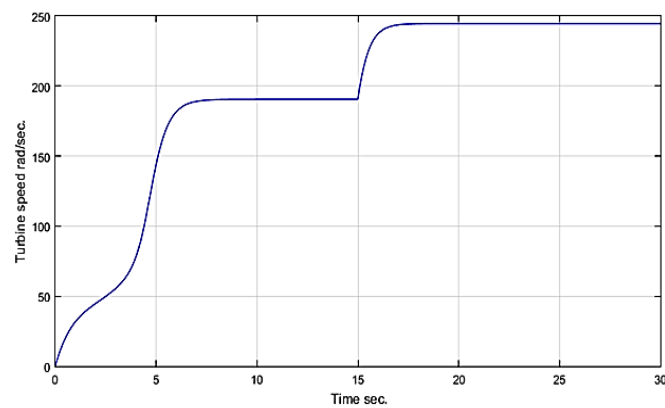

Figure 9. Wind speed m/s

Figure 10. Turbine speed development for various wind speed
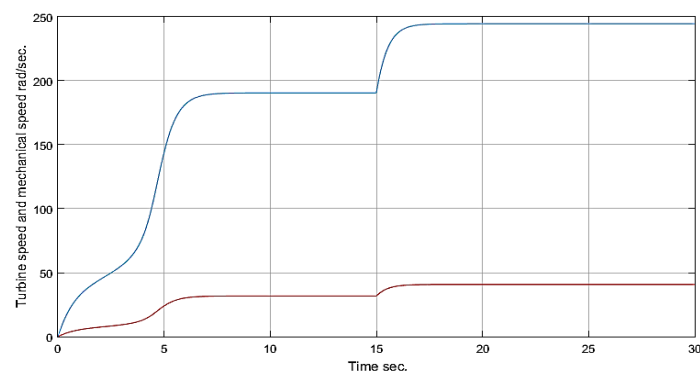

Figure 11. Rotor and mechanical speed for various wind speed
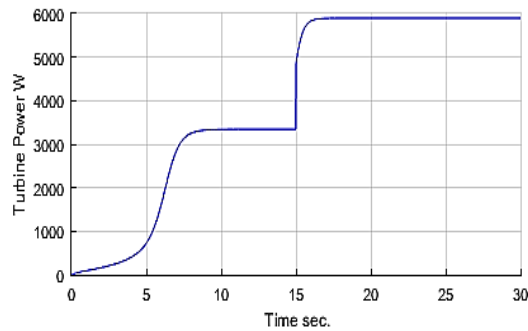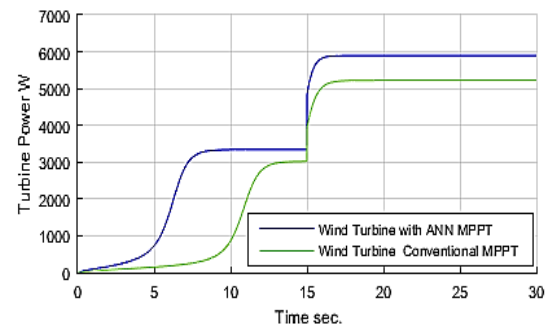
Figure 12. The wind turbine's output power

Figure 13. Comparison of wind turbine power of two controllers

5. CONCLUSION

The control design in this paper is based on the neural network program's prediction techniques. The OTC method was used to design this controller, which was then implemented using the MATLAB/Simulink program. The data and results of this controller's analysis represented tracking and extracting the maximum value of power generated by this wind turbine, and working to maintain that maximum value of power regardless of wind speed fluctuations that rotate the turbine's fins. When we look at the output power curves of the turbine system, we can see that the controller based on neural networks performed better in terms of performance and response than the traditional controller, which had a higher output power value and a faster response time.

ACKNOWLEDGEMENTS

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