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Maximum Power Extraction from PMSG Wind Turbine Based On Neural Network Predictive Controller

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Abstract

In this paper, robust control is considered to extract optimum wind energy power from wind turbines and to minimize fluctuations in output parameters by regulating the pitch angle. Wind turbines drive Permanent Magnetic Synchronous Generator (PMSG), which is directly integrated by autonomous controllers. However, as wind power contributes to the distribution grid, the significance of a constant power wind turbine output is increasing. PMSG also has a Variable Pitch System (VPS) wind turbine with systems to monitor the turbine axis orientation angles towards the skyline and the wind. The modelling and MATLAB simulation of the PMSG VPS Neural Network Prediction Controllers (NNPC) which is used to forecast plant potential performance is illustrated. Its architecture is simulated by simulation of wind speeds at 11.5-14 m / s on a linear baseline controller. PMSG based wind turbine VPS was simulated to test the planned NNPC pitch angle outputs, resulting in continuous performance.

Keywords: *Pitch angle, PMSG, NNPC, Variable Pitch System, MATLAB*

1. Introduction

Wind turbines are controlled by the particular wind speed where power of generator is brought to its nominal value. This speed has the name of nominal wind speed and the range of values of wind speed above this threshold is called nominal power mode. The torque limit reduces the coefficient of wind turbine power at wind speeds that are similar to the rated wind speed [11]. This corresponds to the maximum increase depending on the direction and true speed, consumed power by the wind. The pitch control is to rotate around its longitudinal axis to bound aerodynamic torque and thus to avoid performance around its nominal value. Pitch control must be carried out by minimizing mechanical pressure and changing the generator torque during pitching. Wind turbine control is of particular concern since fluctuations of wind speed and pitching induced vibrations lead to changes in the generated energy which, while increasing the burden of fatigue, reduce the quality of this energy.

For both blades, the angle of the pitch may be independently or identically changed. The first case, where each blade's pitch angle can be set independently, is known as individual pitch control, the latter case is called collective pitch control [2].

The PMSG turbine drive has become one of the utmost favorable configurations for small wind turbine [1, 16]. The control systems are equipped with the pitch angle control and the generator speed control. For regulation of the pitch angle wind signals and generator power are used as inputs [3, 17]. The constant output power will adjust the pitch angle slightly [2]. In conditions over the wind speed range, pitch angle adjustment is required when the rotary speed is maintained constantly [4]. Slight variations in the angle of the pitch will affect constant power output. In actual fact, the effect on the grid power supply of the wind turbine from the pitch angle control is important to study [10]. To predict future plant output, NNPC, which is applied in the PMSG based VPS wind turbine, uses a non-linear neural network (NN) model [9].The control inputs are then calculated by NNPC that optimizes the system's performance over the future.

This paper presents an overview of the wind turbine based on PMSG and also relies on the varying control unit to meet the power requirements of PMSG wind turbine. Simulated results in the modelling and simulation of the NNPC will examine the capability of the proposed strategy under variable and steady wind direction. Its performance is analyzed with the help of MATLAB software.

2. Modelling of Wind Turbine

Wind power is transformed into kinetic energy, followed by wind turbines into electricity. The current system aerodynamics confines the extracted power from the atmosphere. The PMSG database model is presented. The idea is built upon PMSG's steady state wind turbine characteristic [7]. This includes converters, wind turbines, PMSG, the conversion of wind energy and gearboxes (see figure 1).

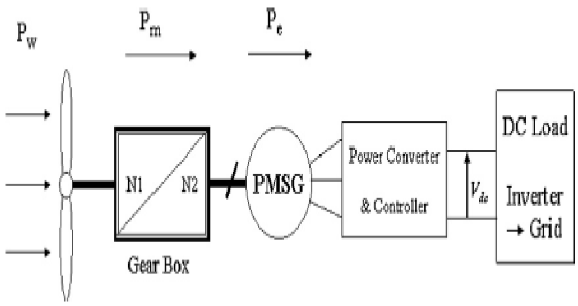


Figure 1. Configuration of wind generating module

The extracted power is usually placed in the following form [18]

$$P_t = 1/2\ \rho V^3\ ACp(\beta,\lambda) \qquad (1)$$

Where ρ and A are respectively the air density and the swept area, V is the wind speed (m/s). Cp is a power coefficient that changes depending on the pitch angle β and the tip speed ratio λ. This is defined as [5]

$$\lambda = R\ \omega/v \qquad (2)$$

The mechanical torque Cm on the rotor turbine can be attained from equation

$$C_m = (P_t)/\omega = 1/2\ \rho AV^2\ Cp(\beta,\lambda) \qquad (3)$$

With a one degree of convergence of the freedom of movement of wind turbines, as shown in Figure 2, the mechanical equation is shown by the [19]

$$d\Omega/dt = 1/J(C_m - C_{em} - f\Omega) \qquad (4)$$

Where f represents the coefficient of viscous friction (Nms rad^{-1}), Ω represents mechanical rotor speed (rad s^{-1}), C_m represents mechanical torque (N m), J represents the inertial moment (kg m^2), C_{em} represents electromagnetic torque (N-m).

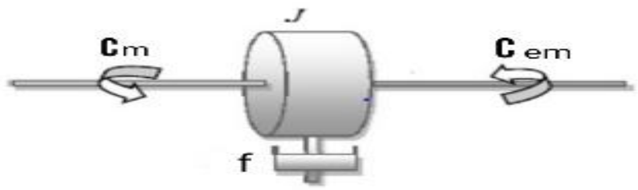


Figure 2. Model of freedom of wind turbines

To transform wind power into mechanical torque, wind turbines are used. The mechanical torque of the turbine can be extracted from the wind generated mechanical power of the turbine. This reality is that the turbine's wind speed is not zero. The power coefficient (Cp) of the turbine is instead used. The power coefficient is the pitch angle (β) and the speed tip (β) [6]. The pitch angle is the blade angle of the turbine, while the ratio of rotational speed to wind speed is known as the speed of the tip [8]. The Betz limit is known as the maximum energy coefficient (Cp).The power coefficient is given by [4]

$$C_P((\lambda,\beta)= \alpha \sin[(\pi(\lambda+0.1))/(18-0.3(\beta-2))]- 0.00184(\lambda -3)(\beta-2) \qquad (4)$$

Where $\alpha = (0.5-0.0167(\beta-2))$

The maximum C_p value is attained by the certain selecting the maximum power from wind turbines to the optimum efficiency level. The overall C_p ($C_{p\ max} = 0.48$) value for $\beta = 0^o$and for $\lambda = 8.1$ is reached.

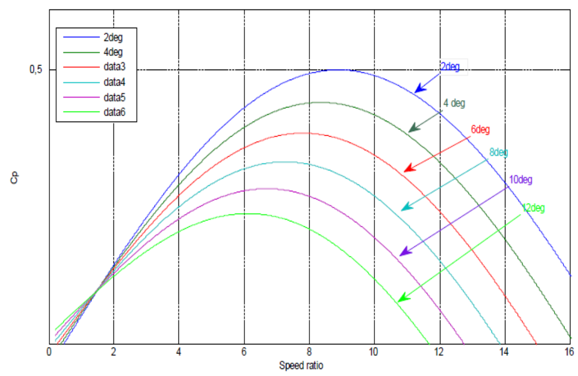


Figure 3. PMSG wind turbine's C_p- λ characteristics

When you shift the pitch angle, Figure 3 shows the improvement in the C_p-λ curve. The pitch angle is controlled at minimum and average wind speeds to run the wind turbine optimally. The angle of pitch is increased at high wind speeds to retain a controllable rotor speed and develop some aerodynamic power. The wind turbine is running at a lower efficiency as the pitch angle increases.

3. Modelling of the PMSG

In PMSG, it consists of a PM rotor which is not supplied to magnetic field by an independent source. Therefore, the rotor voltage equation does not need to be established because the rotor flux wrt time does not change. The stator voltage equation is as follows [19]

$$V_{sd}=R_S I_{sd} + (d\phi_{sd})/dt - \omega\phi_{sq} \quad (5)$$
$$V_{sq}=R_S I_{sq} + (d\phi_{sq})/dt - \omega\phi_{s} \quad (6)$$

The flux in stator are given by

$$\phi_{sd} = L I_{sd} + \phi_m \quad (7)$$
$$\phi_{sq} = L I_{sd} \quad (8)$$

Organizing the Equations (5)(6)(7) and (8):

$$V_{sd}= R_S I_{sd} + L\, dI_{sd}/dt - \omega L I_{sq} \quad (9)$$
$$V_{sd}= R_S I_{sq} + L\, dI_{sq}/dt - \omega L I_{sd} + \omega\phi_m \quad (10)$$

The electromagnetic torque is given by

$$C_{em} = p\phi_m I_{sq} \quad (11)$$

Where L represents stator inductance (H), Vsd and Vsq represents the d – q components of the stator voltages, ω is the electrical rotor velocity (rad s-1), Rs represents stator winding phase resistance, ϕsq represents permanent magnetic flux (Wb), and p represents pairs of poles, Isd and Isq represents the d – q components of the stator currents.

4. Control Variable Pitch System

Much research has been done on this topic. Reactive power control, wind turbine protection, active power, pitch control or voltage control as well as frequency, are significant topics [20].

Depending on the wind speed stage, the control VPS can be classified into two modes. The control mechanism is needed if wind speed is below the rating value to collect the most wind energy in the wind turbine. On the other hand, the control unit must adjust the torque input pitch angle to the generator to maintain a suitable value, despite wind speed varying, is between the ratings and the cut-offs [21].

5. Artificial Neural Network

ANNs are computer models that can thoroughly analyze the behavioral patterns of the immense number of data for each device component, as they consist of human brain influenced (artificial neurons) processing units. As shown in Figure 4, neurons are linked in layers.

Every layer has different neurons operating at the same time, the neurons are linked to other layers' neurons, and each connection has a weight associated with them (artificial synapses) that modulates the effect of the signs [13]. Each neuron j with n input X has a value called the state of activation θ and an output activation state Function F, which gives an output signal Y. The output signal is sent to an additional neuron, but its value can be altered according to related weights w [12]. Neurons can be seen in Figure 5.

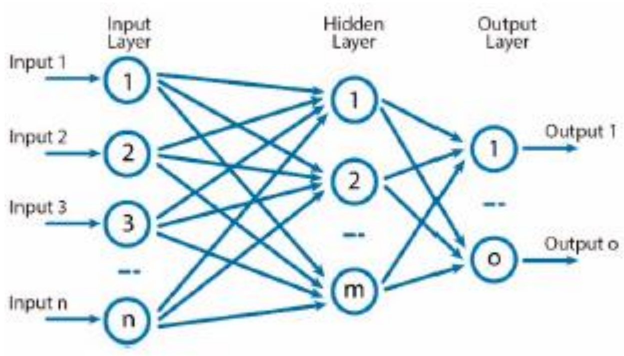


Figure 4. Multi-layer Neural Network Architecture

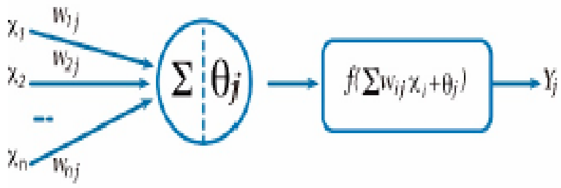


Figure 5. Artificial Neuron Model

ANN analysis is based on the optimization algorithm to change weight to ensure the best solution for a control system is given across the network [14]. Various ANN types can be differentiated by their method of training, information presentation, topology and type of input-output data [15].

6. Design of Predictive Control Neural Network

The descriptive controller 'neural network' being introduced to predict output in wind turbine consists of PMSG uses a nonlinear plant. Then the controller measures feedback to maximize plant output over a predetermined potential time horizon. Firstly, the predictive control model evaluates the type of neural network (NN) plant using system recognition. Secondly, the controller using the plant model to forecast potential production [22].

The neural network model acts as device recognition for wind turbines consists of PMSG using a learning algorithm by updating errors. As shown in Fig. 6 the NN model acts as device recognition for wind turbines consists of PMSG using a learning algorithm by updating errors. The plant configuration for the neural network is done through a controller and the framework for optimization. U' value is defined through optimization block which then inserts the optimum u into the field. Neural network architecture leads to Wind turbine PMSG plant device recognition. Any alteration at the input (u) of the PMSG wind turbine is often addressed by the configuration of the NN and hence the output (yp) changes (see figure 7).

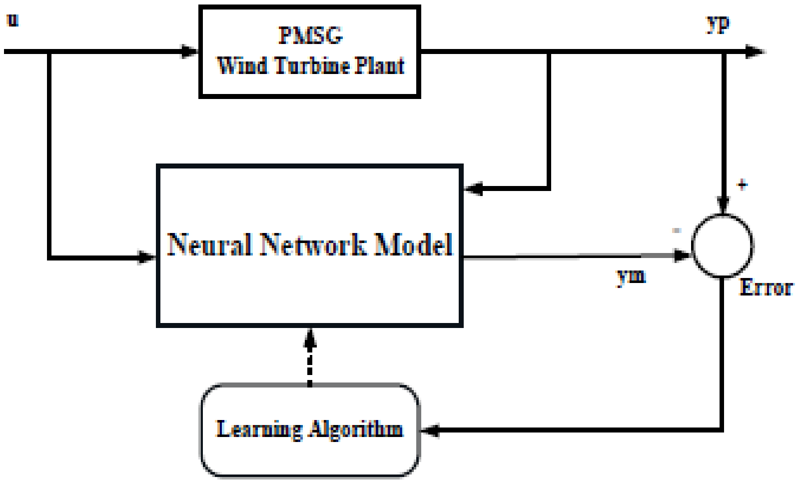


Figure 6. PMSG Wind turbine plant recognition method [23]

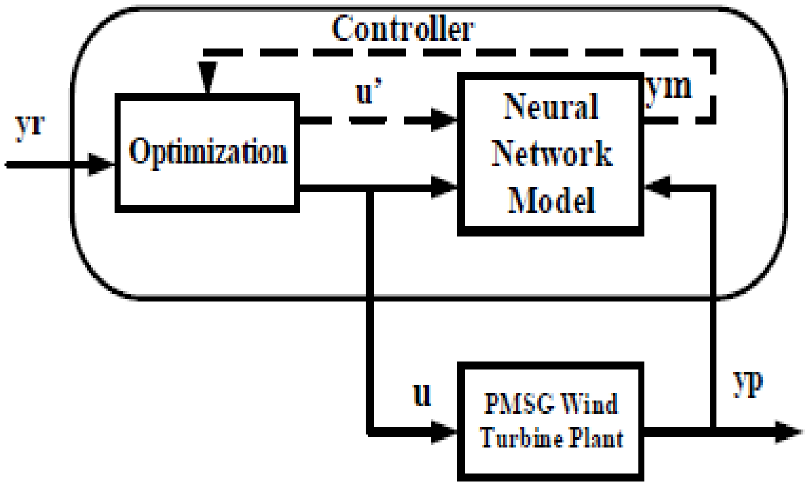


Figure 7. Predictive control development block diagram

7. NNPC PMSG Design and Simulation

In the Simulink-MATLAB simulator, accurate models are also developed and built to test a complete PMSG based wind turbine configuration design and simultaneous use of NNPC (see Figure 8). The efficiency of the wind turbine variable PMSG has also been demonstrated by simulations. The pitch angle was conditionally regulated by NNPC.

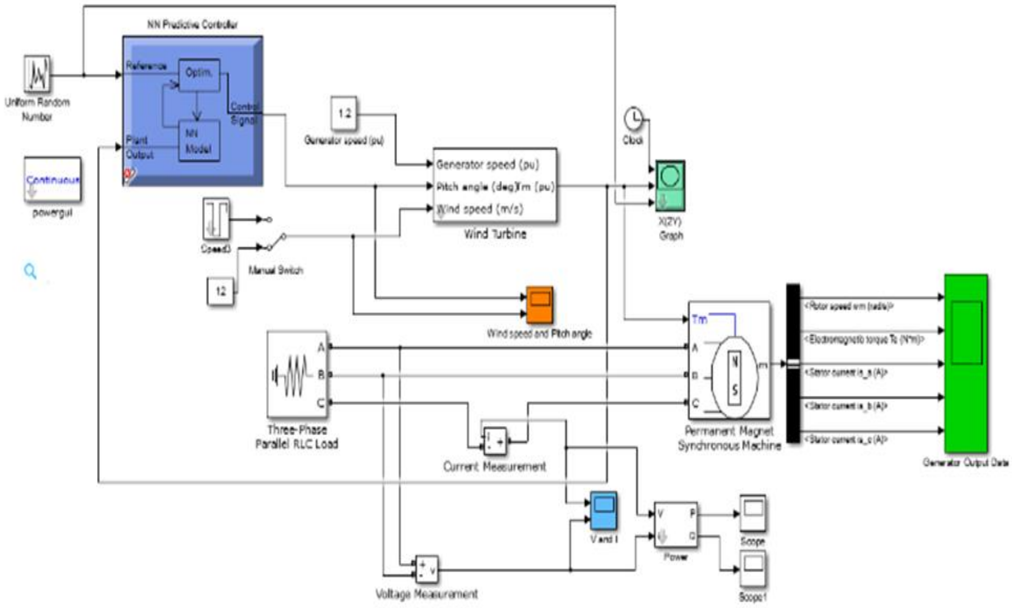


Figure 8. PMSG variable wind turbine based NNPC

The pitch angle of PMSG based wind turbine does plant recognition and forecast plant power. The NN is the forward dynamics of PMSG wind turbines in the system identification, as presented in Figure 9. The installation inlet is the wind turbine pitch (degree) and the outlet is the deviation angle of the pitch from the wind turbine orientation angle.

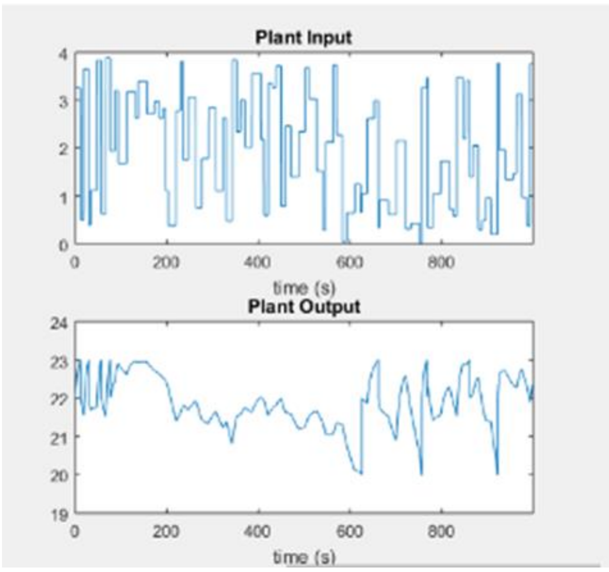
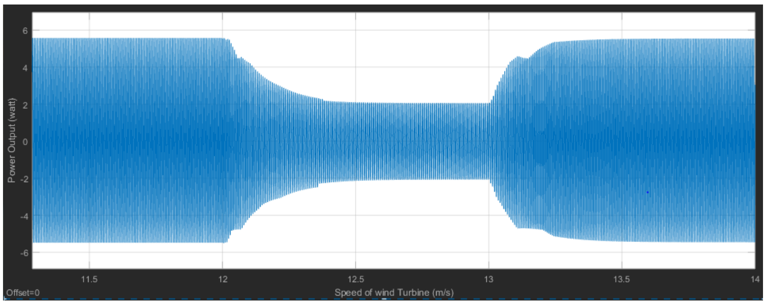


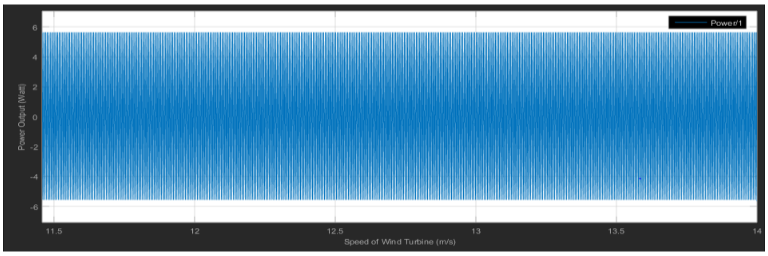
Figure 9. Dynamics of movement in the system with variable pitch wind generator PMSG

Prediction is used to evaluate the pitch angle control signal which minimizes disturbances and stabilizes the wind turbine VPS power output of PMSG.

Results from the simulation showed that two results could be obtained from NNPC. Firstly, the wind turbine without power generation in constant output power, the NNPC-pitch angle did not provide good performance as shown in Fig. (10) (a). Attenuation of a signal on one of the wind turbine speed ranges has occurred. When used for grids, the low signal reliability of the distribution network would be affected.



(a) Wind turbine with power without NNPC pitch angle



(b) NNPC pitch angle output power

Figure 10. Implementation of NNPC pitch angles in a system with variable pitch from PMSG wind turbines

Finally, wind turbines with output power at an NNPC pitch angle provide good efficiency with constant output power from the PMSG VPS wind turbine shown in Fig. 10 (b). Its result is the effect of wind power in the distribution network structure of the power system and on its stability.

8. Conclusion

In the paper, the Pitch angle wind turbine based on PMSG was designed to harness wind energy and regulate a large amount of wind speed. All this has been accomplished with the help of intelligent NNPC that reduce the wind energy conversion system cost and complexity. Design-based methods and simulations have been analyzed for minor pitch angles shifts to affect constant wind speed output range of 11.5-14 m / s. The results achieved high efficiency in the operation of wind turbines in the distribution network. The predictive controller for the neural network was employed in wind turbine based PMSG of a non-linear neural network.

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