Control of Synchronous Generator in Wind Power Systems Using Neuro-Fuzzy Approach (B15)

by Ramadhoni Syahputra

Control of Synchronous Generator in Wind Power Systems Using Neuro-Fuzzy Approach

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Abstract **- This paper presents the control scheme of a synchronous generator in wind energy power system using adaptive neuro-fuzzy approach. A neuro-fuzzy-based controller is used for controlling a permanent magnet synchronous generator (PMSG) that is used in wind power systems. The variables have been controlled are the angular velocity, dc voltage, reactive power, active power, a phase current and voltage phase of generator output. The simulation results show that the adaptive neuro-fuzzy controller has successfully controlling all variables in a relatively short time to get back to a stable state. Several simulation results are given to show the effectiveness and the good performances of the proposed control structure.**

Index Terms – Wind power, synchronous generator, fuzzy logic controller, ANFIS, wind farm system.

I. Introduction

Production of electricity from renewable energy sources like wind energy increases due to environmental problems and the shortage of traditional energy sources in the near future [1]-[4]. Among renewable sources, wind energy is one of the fastest growing and lowest-priced renewable energy technologies available today. Wind power depends mainly on geographical conditions and weather conditions. Therefore, it is necessary to construct a system capable of generating maximum power under these constraints [5]-[6].

Nowadays, permanent magnet synchronous generators (PMSG) are used in wind turbine because of its advantages: better reliability, less maintenance and more effective [7]-[9]. In addition, exploiting the case of variable speed allows obtaining an optimal efficiency of the system [10]. For remote sites located far from the utility, a practical approach for power generation is to use a variable speed wind turbine to create an autonomous system. It often includes batteries, used when the wind cannot provide sufficient power. If wind conditions are favorable, these autonomous wind energy systems can provide electricity at low cost. If wind power exceeds the load demand, the surplus can be stored in batteries and if wind power cannot meet load demand, the batteries can compensate it [11]. On the other hand, the use of artificial intelligence-based method has a lot of help in the field of electrical power systems [12]. The use of artificial intelligence-based method is not only limited to the field of image processing [13]–[16].

In this research, we present the control scheme of a synchronous generator in wind energy power system using adaptive neuro-fuzzy approach. A neuro-fuzzy-based model reference adaptive system is continuously tuned with actual permanent magnet synchronous generator (PMSG) to neutralize the effect of parameter variations such as stator resistance, inductance, and torque constant. This neuro-fuzzy-tuned estimator is able to estimate the rotor position and speed accurately over a wide speed range with a great immunity against parameter variation. The simulation is done in Matlab-Simulink environment.

II. Synchronous Generator in Wind Power System

A. *Wind Power System*

There were several attempts to build large scale wind powered system to generate electrical energy. The first production of electrical energy with wind power was done in 1887 by Charles brush in Cleveland, Ohio. DC generator was used for power production and was designed to charge the batteries. The induction machine was used at the first time in 1951.

Wind turbines convert the kinetic energy present in the wind into mechanical energy by means of producing torque. Since the energy contained by the wind is in the form of kinetic energy, its magnitude depends on the air density and the wind velocity. The wind power developed by the turbine is given by the equation (1) [11]:

$$P = \frac{1}{2} C_P \rho A V^3 \qquad (1)$$

where C_p is the Power Co-efficient, ρ is the air density in kg/m^3, A is the area of the turbine blades in m^2 and V is the wind velocity in m/sec. The power coefficient C_p gives the fraction of the kinetic energy that is converted into mechanical energy by the wind turbine. It is a function of the tip speed ratio λ and depends on the blade pitch angle for pitch-controlled turbines. The tip speed ratio may be defined as the ratio of turbine blade linear speed and the wind speed

$$\lambda = \frac{R\omega}{V} \tag{2}$$

Substituting (2) in (1), we have:

$$P = \frac{1}{2} C_P(\lambda)\rho A \left(\frac{R}{\lambda}\right)^3 (\omega)^3 \tag{3}$$

The output torque of the wind turbine $T_{turbine}$ is calculated by the following equation (4):

$$P = \frac{1}{2}\rho A C_P \left(\frac{V}{\lambda}\right) \tag{4}$$

where R is the radius of the wind turbine rotor (m) There is a value of the tip speed ratio at which the power coefficient is maximum. Variable speed turbines can be made to capture this maximum energy in the wind by operating them at a blade speed that gives the optimum tip speed ratio. This may be done by changing the speed of the turbine in proportion to the change in wind speed. Fig.1 shows how variable speed operation will allow a wind turbine to capture more energy from the wind [11]. As one can see, the maximum power follows a cubic relationship.

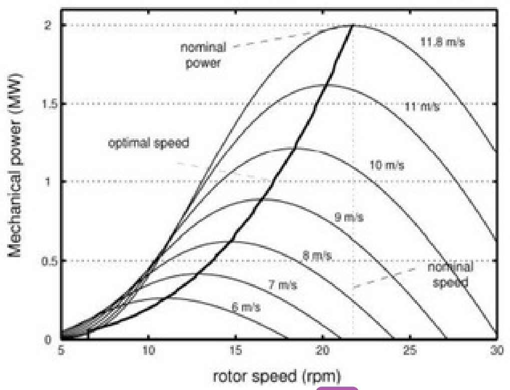

Fig 1. Variable speed operation of wind turbine

B. *Permanent Magnet Synchronous Generator*

In this work, we have used permanent magnet synchronous generator (PMSG) type for wind turbine system. Figure 2 shows the d–q equivalent circuits of the PMSG. The voltage equations of the PMSG are expressed in the synchronous d–q coordinates as:

$$v_s = R_s i_{ds} + L_s \frac{di_{ds}}{dt} - \omega_r L_d i_{qs} \tag{5}$$

$$v_{qs} = R_s i_{qs} + L_s \frac{di_{qs}}{dt} - \omega_r L_q i_{ds} + \omega_r \lambda_f \tag{6}$$

where v_{ds} and v_{qs} are the d- and q-axes stator voltages, i_{ds} and i_{qs} are the d- and q-axes stator currents, R_s and L_s are the stator resistance and inductance, L_d and L_q are the d- and q-axes inductance, λ_f is the magnetic flux, and ω_r is the electrical angular speed.

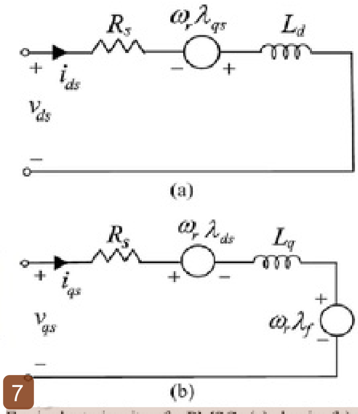

Fig 2. Equivalent circuits of a PMSG: (a) d-axis, (b) q-axis

For the generator with surface-mounted permanent magnets, d- and q-axes inductances are the same ($L_d = L_q$). Then, the electromagnetic torque T_e is expressed as:

$$T_e = \frac{3}{2}\frac{p}{2}\lambda_f i_{qs} \tag{7}$$

where p is the number of poles.

In this research, the system consists of a PMSG-based variable speed of wind energy power system consisting two back-to-back inverters with a common dc link. The generator-side inverter controls its speed to extract maximum power at different speeds, while the grid side inverter delivers the renewable power to grid with nonlinear-load compensation simultaneously. The block diagram of the system is shown in Figure 3.

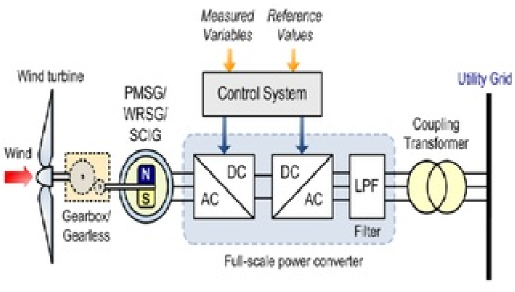

Fig 3. Block diagram of control of PMSG in wind power system

III. Neuro-Fuzzy Adaptive Method

The basic structure of the type of fuzzy inference system could be seen as a model that maps input characteristics to input membership functions. Then it maps input membership function to rules and rules to a set of output characteristics. Finally it maps output characteristics to output membership functions, and the output membership function to a single valued output or a decision associated with the output. It has been considered only fixed membership functions that were chosen arbitrarily.

Figure 4 shows Sugeno's fuzzy logic model while Figure 5 shows the architecture of the ANFIS, comprising by input, fuzzification, inference and defuzzification layers. The network can be visualized as consisting of inputs, with N neurons in the input layer and F input membership functions for each input, with F*N neurons in the fuzzification layer. There are F^N rules with F^N neurons in the inference and defuzzification layers and one neuron in the output layer. For simplicity, it is assumed that the fuzzy inference system under consideration has two inputs x and y and one output z as shown in Fig. 2. For a zero-order Sugeno fuzzy model, a common rule set with two fuzzy if-then rules is the following:

Rule 1: If x is A_1 and y is B_1, Then $f_1 = r_1$ (8)

Rule 2: If x is A_2 and y is B_2, Then $f_2 = r_2$ (9)

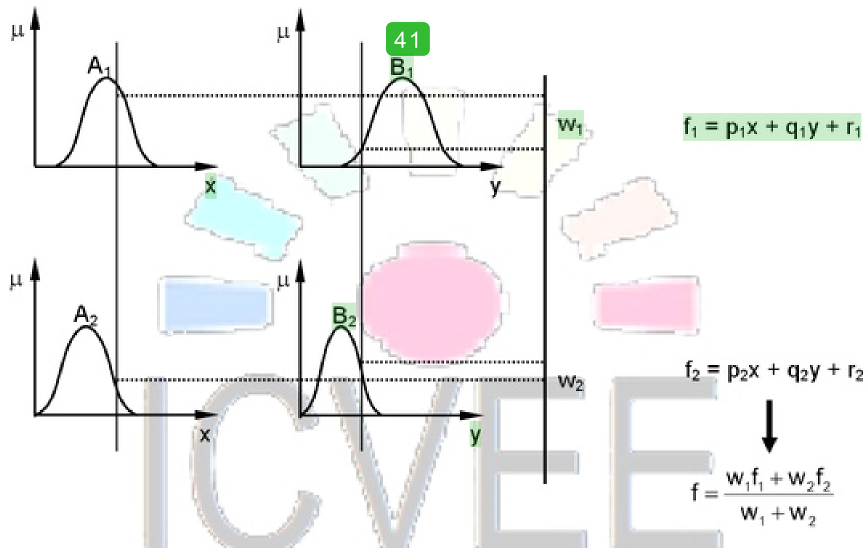

Fig 4. Sugeno's fuzzy logic model

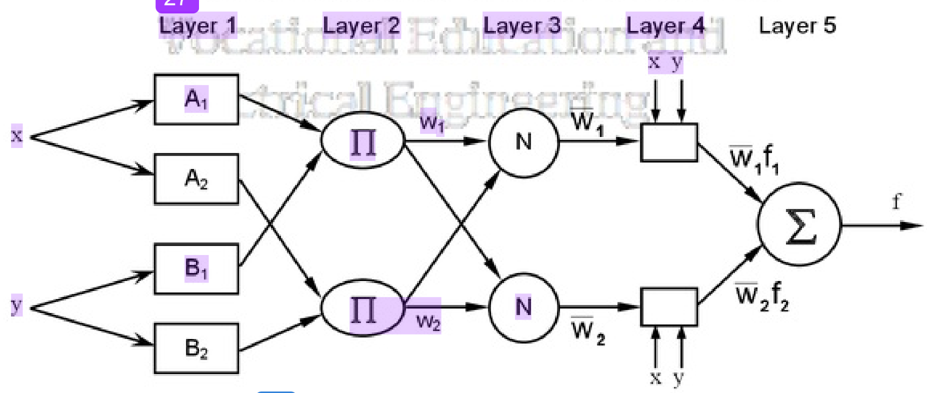

Fig 5. The architecture of the ANFIS with two inputs and one output

Here the output of the ith node in layer n is denoted as $O_{n,i}$:

Layer 1. Every node i in this layer is a square node with a node function:

$$O_i^1 = \mu A_i(x), \text{ for } i = 1, 2, \quad (10)$$

or,

$$O_i^1 = \mu B_{i-2}(y), \text{ for } i = 3, 4 \quad (11)$$

where x is the input to node-i, and A_i is the linguistic label (*small* , *large*, etc.) associated with this node function. In other words, O_i^1 is the membership function of A_i and it specifies the degree to which the given x satisfies the quantifier A_i. Usually $\mu Ai(x)$ is chosen to be bell-shaped with maximum equal to 1 and minimum equal to 0, such as the generalized bell function:

$$\mu_A(x) = \frac{1}{1+\left[\frac{x-c_i}{a_i}\right]^{2b_i}} \quad (12)$$

Parameters in this layer are referred to as *premise parameters*.

Layer 2. Every node in this layer is a circle node labeled Π which multiplies the incoming signals and sends the product out. For instance,

$$O_i^2 = wi = \mu Ai(x) \times \mu B(y), \quad i = 1, 2. \quad (13)$$

Each node output represents the firing strength of a rule. (In fact, other *T-norm* operators that performs generalized AND can be used as the node function in this layer.)

Layer 3. Every node in this layer is a circle node labeled N. The *i-th* node calculates the ratio of the i-th rule's firing strength to the sum of all rules firing strengths:

$$O_i^3 = \overline{w} = \frac{w_i}{w_1 + w_2}, \quad i = 1, 2. \quad (14)$$

For convenience, outputs of this layer will be called *normalized firing strengths*.

Layer 4. Every node i in this layer is a square node with a node function:

$$O_i^4 = \overline{w}_i f_i = \overline{w}_i (p_i x + q_i y + r_i) \quad (15)$$

where $\overline{w}_i$ is the output of layer 3, and $\{p_i, q_i, r_i\}$ is the parameter set. Parameters in this layer will be referred to as *consequent parameters*.

Layer 5. The single node in this layer is a circle node labeled Σ that computes the overall output as the summation of all incoming signals, i.e.

$$O_i^5 = \sum \overline{w}_i f_i \quad (16)$$

IV. Methodology

In this work, the control scheme of a synchronous generator in wind energy power system using adaptive neuro-fuzzy approach is presented. The control schemes and wind power system with permanent magnet synchronous generator have been developed in Matlab-Simulink software. The research steps are summarized in the flow chart as can be seen in Figure 4.

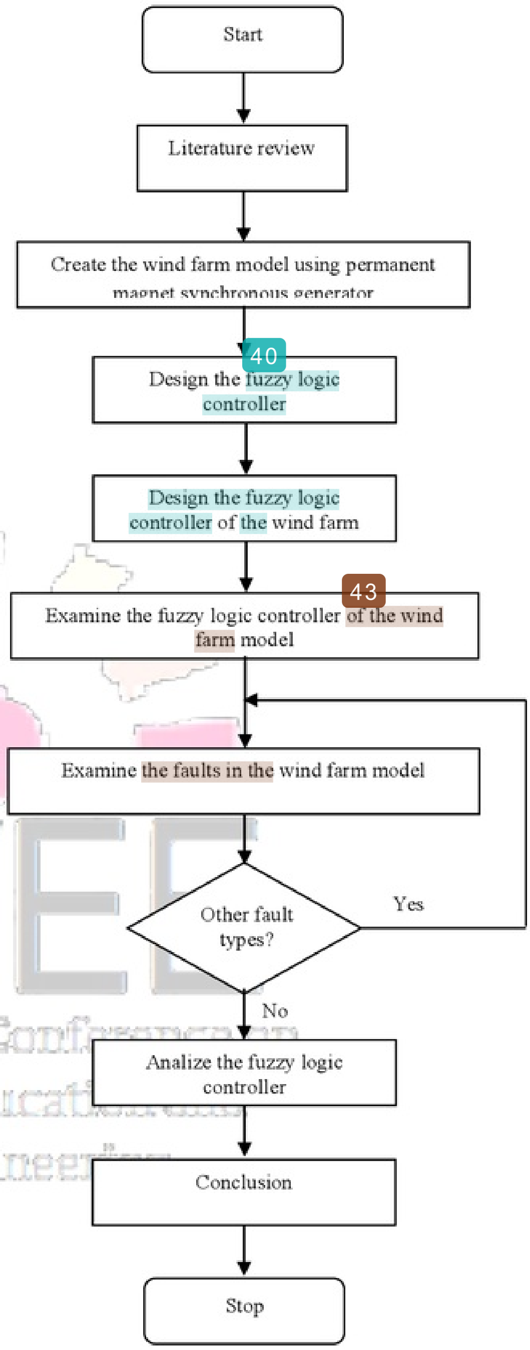

Fig 4. Research steps of this research

V. Results and Discussion

In order to analyse the advantage of adaptive neuro-fuzzy method to control the permanent magnet synchronous generator in wind power system, the overall system is simulated using Matlab-Simulink software. The system described in this section illustrates the steady-state and dynamic performance of a 10 MW wind farm connected to a distribution system. A 10 MW wind farm consisting of five 2 MW wind turbines connected to a 25 kV distribution system exports power to a 120 kV grid through a 30 km, 25 kV feeder. The system that created in Matlab-Simulink simulation software can be seen in Figure 5, while Figure 6 shows the control scheme of wind power system. In this research, type 4 wind turbine model is used. The Type 4 wind turbine presented in this work consists of a synchronous generator connected to a diode rectifier, a DC-DC IGBT-based PWM boost converter and a DC/AC IGBT-based PWM converter modeled by voltage sources. The Type 4 technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

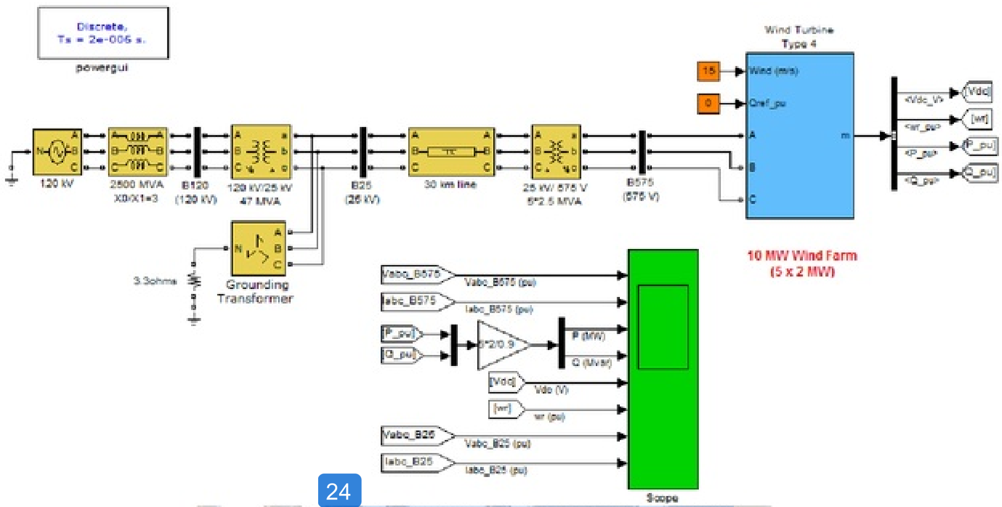

Fig 5. Wind power system connected to a distribution system

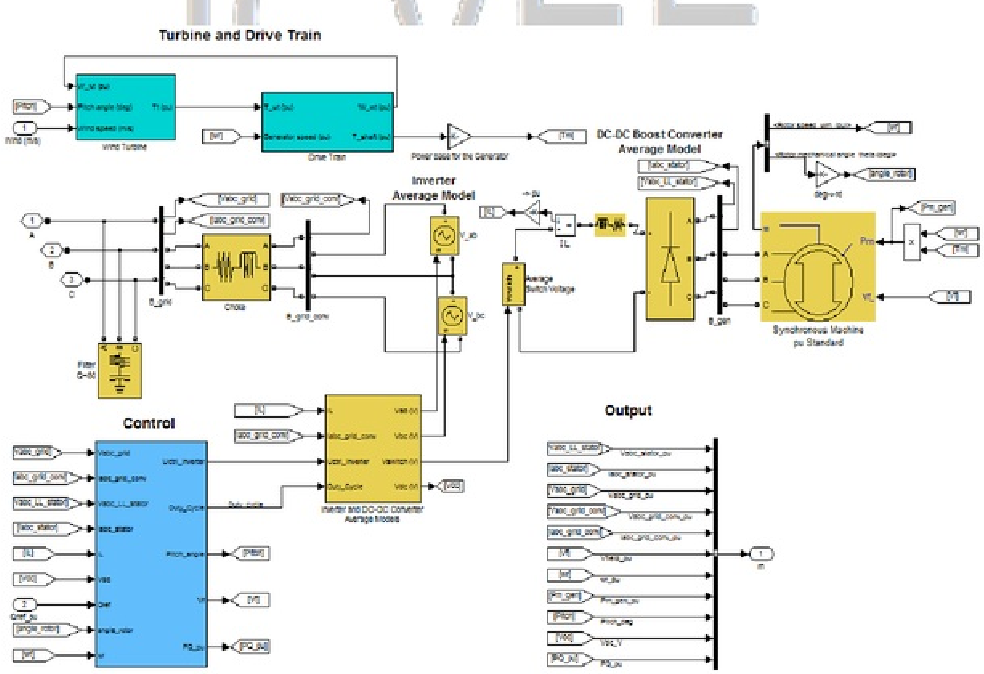

Fig 6. Control scheme of wind power system

In this study, the wind speed is maintained constant at 15 m/s. The control system of the DC-DC converter is used to maintain the speed at 1 pu. The reactive power produced by the wind turbine is regulated at 0 MVAr.

Figure 7 shows the performance characteristic of wind power system with PMSG using neuro-fuzzy controller. The variables shown in Figure 7 is the angular velocity, dc voltage, reactive power, active power, a phase current and voltage phase of a permanent magnet generator output.

Rotor angular velocity is relatively stable 1 pu up to t=0.03 seconds, but subsequently rose to 1.0005 pu which occurred up to time t = 0.15 seconds, and after that, there is experiencing stable again. Rotor angular velocity change is due to a short circuit on the network that causes a voltage drop at the current time of 0.03 seconds. This voltage drop is as a consequence of the increase in network flows due to short circuit. Voltage changes that occur at t = 0.03 s also affect the amount of active power and reactive power generator. As shown in Figure 7 that there has been a reduction in active power of 10 MW to 7 MW at t = 0.03 s to t = 0.08 s. Conversely, the generator reactive power increases at t = 0.03 s is from 0 MVAr to 0.4 MVAr happens to t = 1 s, after which the system becomes unstable because it is controlled by the neuro fuzzy controller. In general it appears that the whole system parameters can be controlled well by controllers based on adaptive neuro-fuzzy approach.

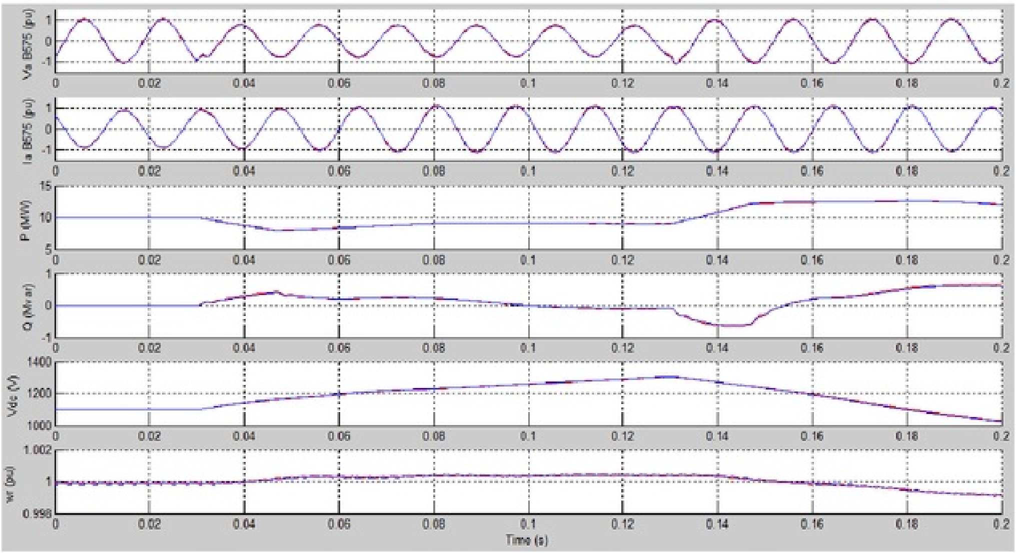

Fig 7. Performance characteristic of wind power system

VI. Conclusion

In this study has demonstrated performance of intelligent controller based on adaptive neuro-fuzzy. This controller is used for controlling a permanent magnet synchronous generator (PMSG) that is used in wind power systems. The variables have been controlled are the angular velocity, dc voltage, reactive power, active power, a phase current and voltage phase of a permanent magnet generator output. The simulation results show that the adaptive neuro-fuzzy controller has successfully controlling all variables in a relatively short time to get back to a stable state.

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