Modeling and Simulation PMSG based on Wind Energy Conversion System in MATLAB/SIMULINK

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Abstract—**This paper presents the dynamic model of Permanent Magnet Synchronous Generator (PMSG) based on Wind Energy Conversion System (WECS). The models of WECS consist of a wind turbine, pitch angle control, drive train, PMSG and power converter. Wind turbine model with controller for generator protection in high wind speed is also presented in this paper. The PMSG and converter model are established in the *d-q* model. The presented model, dynamic simulation and simulation results are tested in MATLAB/SIMULINK.**

Keywords—**permanent magnet synchronous generator (PMSG), wind energy conversion system (WECS), wind turbine, MATLAB/SIMULINK.**

I. Introduction

The issue of global warming has been raised due to the consumption of oil, coal and natural resources for the electricity producing process. Apart from that, the amounts of these fuels on earth are now decreasing day by day. Thus, the focus has been shifted to the green alternative energy which is not polluted and has no impact on the environment. The power of wind is now being explored which the researcher believes that it has all the qualifications to replace traditional fuel since it has less effect to global warming [1-3].

During the past decade, the amounts of wind capacity have been installed every three years. Around 83% of wind capacities are located in these five countries, German, United states or America, Denmark, India and Spain [4-5].

Wind energy conversion system (WECS) consist of wind turbine, pitch angle control, drive train, generator and power converter. There are various kinds of generators used in WECS such as induction generator (IG), doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG) [6]. The PMSG based on WECS can connect to the turbine without using gearbox. The gearbox causes in the cost of maintenance, and then it will decrease the weight of nacelle [7].

MATLAB/SIMULINK is a graphical software package for modeling, simulating and analyzing dynamic systems. It supports linear and nonlinear systems both in continuous time and sample time. There are various researches presented the PMSG based on WECS in MATLAB/SIMULINK [8-9]. In order to understand the principle of producing electricity from

wind with WECS and analyze before it will be implemented in practical case. Thus, it is needed to further study and investigate the PMSG based on WECS.

This paper presents the mathematical model and simulation of PMSG based on WECS in *d-q* model. The model of system will be presented in section II. Section III shows PMSG in MATLAB/SIMULINK. Section IV shows simulation results.

II. Mathematical Model

This section will present mathematical model of PMSG base on WECS. It consists of wind energy conversion, wind turbine, drive train, PMSG and converter as show in Fig. 1.
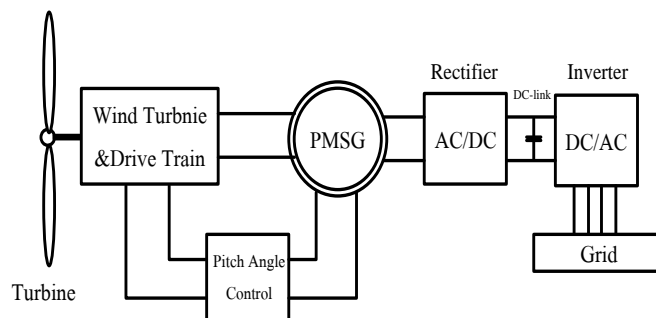

Figure 1. PMSG based on WECS.

A. Wind energy conversion

The kinetic energy of wind is given by [10]

$$E_c = \frac{1}{2}mv^2 \tag{1}$$

$$m = \rho v S \tag{2}$$

where

m = air mass

v = wind speed

ρ = air density

S = covered surface of the turbine.

The wind power is given by

$$P_w = E_c = \frac{1}{2}mv^2 = \frac{1}{2}\rho S v^3 \qquad (3)$$

B. *Wind turbine*

Wind turbine is applied to convert the wind Energy to mechanical torque. The mechanical torque of turbine can be calculated from mechanical power at the turbine extracted from wind power. This fact of the wind speed after the turbine isn't zero. Then, the power coefficient of the turbine (C_p) is used. The power coefficient is function of pitch angle (β) and tip speed (λ), pitch angle is angle of turbine blade whereas tip speed is the ratio of rotational speed and wind speed. The power coefficient maximum of (C_p) is known as the limit of Betz.

The power coefficient is given by [11]

$$c_p(\lambda,\beta) = c_1(c_2/\lambda_i - c_3\beta - c_4)e^{-c_5/\lambda_i} + c_6\lambda \qquad (4)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \qquad (5)$$

The c_{p_λ} characteristics, for different value of the pitch angle β, are illustrated in Fig. 2.

The power coefficient is given by

$$C_p = \frac{P_m}{P_w}; C_p < 1 \qquad (6)$$

$$P_m = C_p(\lambda,\beta)\frac{\rho S}{2}v_{wind}^3 \qquad (7)$$

where

P_m = the mechanical output power of the turbine

C_p = the performance coefficient of the turbine

ρ = the air density

S = the turbine swept area

v_{wind} = the wind speed

k_p = gain power

λ = the tip speed ratio

β = the blade pitch angle

The mechanical torque is given by

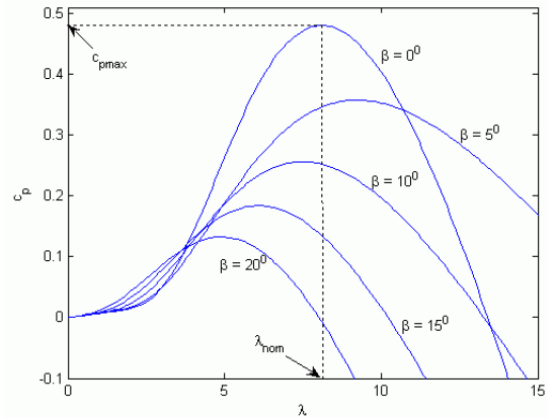$$T_m = \frac{P_m}{\omega} \qquad (8)$$

Figure 2. $c_p(\lambda,\beta)$ characteristic for different value of the pitch angle.

C. *Drive train*

In this paper, the WECS is presented with two-mass drive train model. The mathematical model are given by [12]

$$2H_t\frac{d\omega_t}{dt} = T_m - T_s \qquad (9)$$

$$\frac{1}{\omega_{ebs}}\frac{d\theta_{sta}}{dt} = \omega_t - \omega_r \qquad (10)$$

$$T_s = K_{ss}\theta_{sta} + D_t\frac{d\theta_{sta}}{dt} \qquad (11)$$

where

H_t = the inertia constant of the turbine

θ_{sta} = the shaft twist angle

ω_t = the angular speed of the wind turbine

ω_r = the rotor speed of generator

ω_{ebs} = the electrical base speed

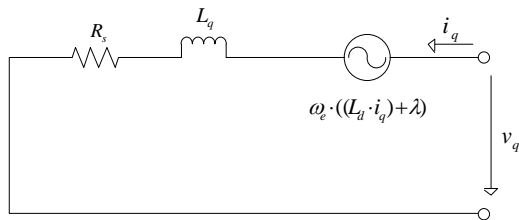T_s = Shaft torque

K_{ss} = the shaft stiffness

D_t = the damping coefficient

D. **PMSG**

Consider the equivalent circuit of PMSG based on WECS in Fig. 3. The model of PMSG is established in the *d-q* synchronous reference frame as shown in Fig. 3A and Fig. 3B, respectively [10].
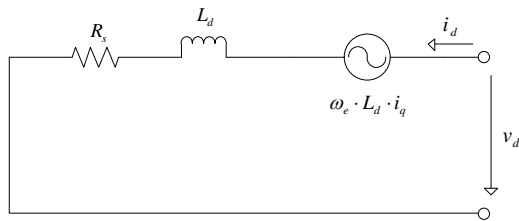
A. *d-axis* equivalent circuit

B. *q-axis* equivalent circuit

Figure 3. Equivalent circuit of PMSG in *d-q* reference frame.

The voltage equations of PMSG as shown in Fig. 3 are given by [13]

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}p\omega_r i_q \qquad (12)$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}p\omega_r i_d - \frac{\lambda p\omega_r}{L_q} \qquad (13)$$

The electromagnetic torque equation is given by

$$T_e = 1.5p[\lambda i_q + (L_d - L_q)i_d i_q] \qquad (14)$$

where

L_q = q axis inductance

L_d = d axis inductance

R = resistance of the stator windings

i_q = q axis current

i_d = d axis current

v_q = q axis voltage

v_d = d axis voltage

ω_r = angular velocity of the rotor

λ = amplitude of flux induced

p = the number of pole pairs

The dynamic equations are given by

$$\frac{d}{dt}\omega_r = \frac{1}{J}(T_e - F\omega_r - T_m) \qquad (15)$$

$$\frac{d}{dt}\theta = \omega_r \qquad (16)$$

where

J = inertia of rotor

F = friction of rotor

θ = rotor angular

E. **Power converter**

Power converter consists of rectifier, DC-link and inverter. Rectifier will convert AC voltage output from PMSG based on WECS to DC voltage. Inverter will convert DC voltage from DC-link capacitor to AC voltage at fundamental frequency. The relation of AC voltage at fundamental frequency and DC voltage is given by [14]

$$V_B = \frac{1}{2\sqrt{2}}m_B v_{dc}\angle\delta_B \qquad (17)$$

where

m_B = the modulation index

δ_B = the phase angle of control wave

III. PMSG in MATLAB/SIMULINK

This section will present a model of PMSG based on WECS in MATLAB/SIMULINK at show in Fig. 4. It consists of wind speed, wind turbine, drive train, PMSG, Pitch angle control, rectifier, DC-link capacitor and inverter module.

In Fig. 4 wind turbine, drive train, PMSG and inverter module are based on (1)-(8), (9)-(11), (12)-(16) and (17), respectively.
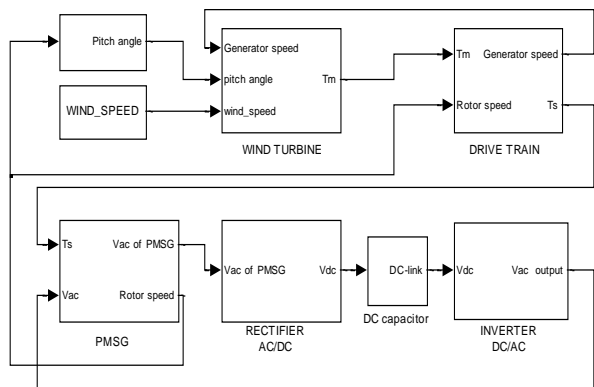

Figure 4. Implement model of WECS in MATLAB/SIMULINK.

IV. Simulation Results

The presented method and simulation results are conducted in MATLAB/SIMULINK. PMSG model, wind turbine model and two-mass drive train data is shown in Table I, II and III, respectively. In this paper, the base wind speed is considered as 12m/s. Fig. 5 shows mechanical torque of PMSG, Fig. 6 shows Electromagnetic torque of PMSG and Fig. 7 shows power of PMSG based on WECS. Blade pitch angle are controlled by pitch angle control model to adjust (c_p), it only active in high wind speed. This paper uses variable wind speed as 12 m/s and change to 16m/s at t = 3 second. Simulation results of pitch angle controlled shows in Fig. 8. It can be seen from Fig. 8 that at time = 8 second, pitch angle is increased because the rotor speed in system is over limit.
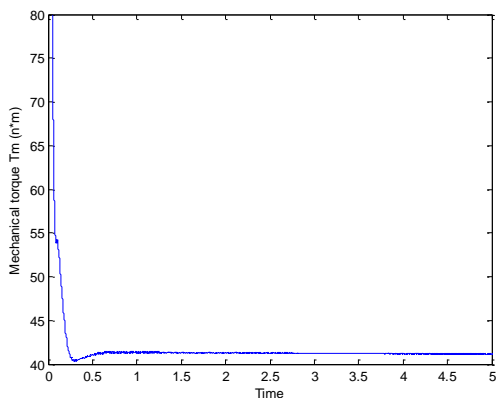

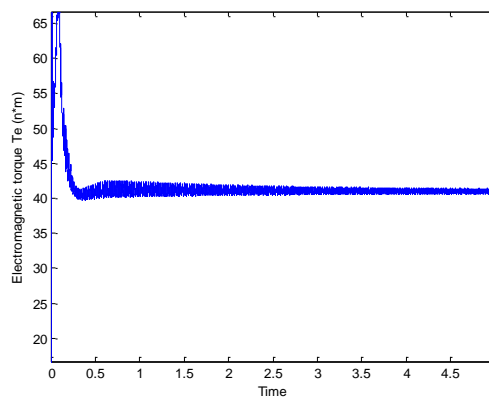Figure 5. Mechanical torque at wind speed 12m/s.

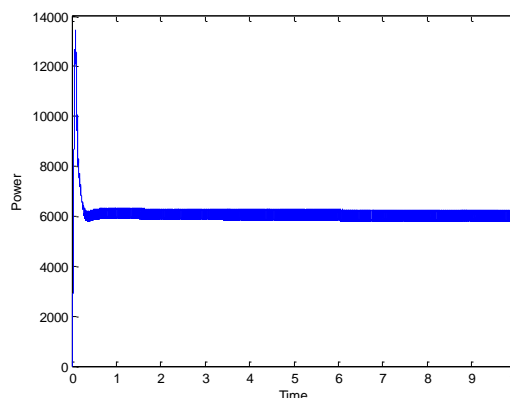Figure 6. Electromagnetic torque at wind speed 12m/s.
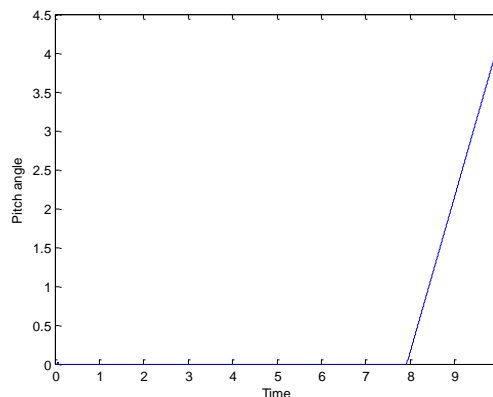

Figure 7. Powers at wind speed 12m/s.

Figure 8. Pitch angle at variable wind speed as 12m/s and change to 16m/s at t = 3 second.

V. Conclusion

This paper presented the modeling of PMSG based on WECS. It consists of wind turbine, drive train, PMSG, pitch angle control and ac/dc/ac converter model. PMSG and converter are established in *d-q* model. The simulation results is shown that the pitch angle control active at high wind speed from control rotor speed to adjust power coefficient (c_p) for protect generator.

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TABLE I. PARAMETER OF PMSG

Number of pole pairs	5
Rated speed	152
Stator phase resistance	0.425 Ω
Flux linkage	0.433 Wb
Inductance	0.0082 H

TABLE II. PARAMETER OF WIND TURBINE

Base power	8.5 Kw
Base wind speed	12 m/s
Max power at base wind speed	0.8
Base rotational speed pu	1

TABLE III. PARAMETER OF DRIVE TRAIN

Inertia at turbine	4
Shaft stiffness	0.3
Damping	1

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