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Modelling and Control of Permanent Magnet Synchronous Generator for Variable Speed Wind Energy Conversion System Using PID Controller

Veena Vijayan[1], Priya P.S[2]

PG Student, Department of EEE, Lourdes matha College of Science and Technology, Trivandrum, Kerala, India[1]

Asst Professor, Department of EEE, Lourdes matha College of Science and Technology, Trivandrum, Kerala, India[2]

Abstract: This paper deals with the dynamic model and analysis of a Wind energy conversion system equipped with permanent magnet synchronous generator (PMSG).There are different types of synchronous generators, but the PMSG is chosen in order to obtain its dynamic model. It offers better performance due to higher efficiency and less maintenance since it does not have rotor current and can be used without gearbox. The PMSG, wind speed, wind turbine and drive train have been model led and the mathematical equations that explain their behaviour have been introduced .Simulation results prove the validity of the model. Using pi the speed is tracked and the PMSG output is obtained.

Keywords: Wind speed, drive train, wind turbine, PMSG

I. INTRODUCTION

Now a day the consumption of fossil fuel is increasing day by day. The main reason behind the use of fossil fuel is to generate more and more energy. Due to consumption of more fossil fuel all living and non living beings including the environment is badly affected .Wind energy is one of the best technologies available today to provide a sustainable supply to the world development, due to abundant ,inexhaustible potential. In terms of the generators for wind power applications, there are different concepts today. The major distinction among them is made between fixed and variable speed wind turbine generator concepts. The generators used for the wind energy conversion systems mostly of either doubly fed induction generator (DFIG) or per Manet magnet synchronous generator (PMSG).However the variable speed directly driven multi pole permanent magnet synchronous generator. DFIG have windings on both stationary and rotating parts both windings transfer significant power between shaft and grid. In DFIG the converters have to process only percent of total generated power and the rest being fed to grid directly from stator.

The converter used in PMSG has to process 100 percent power generated. Majority of wind turbine manufacturers utilize DFIG for their WECS due to the advantage in terms of cost, weight and size. But the reliability associated with gearbox, the slip rings and brushes in DFIG is unsuitable for certain applications. PMSG does not need a gear box and hence, it has high efficiency with less maintenance. The PMSG drives achieve very high torque at low speeds with less noise and require no external excitation. In the present trend WECS with multi bird concept is interesting and offers the same advantage for large systems in future.

Multi brad is a technology where generator, gearbox, main shaft and shaft bearing are all integrated within a common housing. This concept allows reduce in weight and size of generators combined with the gear box technology. To achieve the high efficient energy conversion on these drives different control strategies can be implemented like direct torque control, field oriented control (FOC) . The wind turbine electrical as well as mechanical parts are mostly linear. The blade aerodynamics of the wind turbine is a nonlinear one and hence the overall system model will become nonlinear.

II.SYSTEM DESCRIPTION

The figure 1 shows the PMSG based wind energy conversion systems. It consists of wind turbine, drive train, PMSG and converter. Wind turbine is connected to PMSG through drive train and connected to back to back.

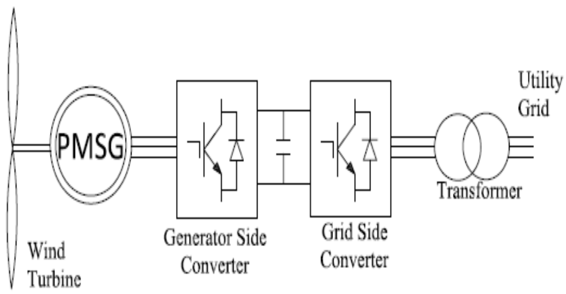

Fig.1.A PMSG based WECS

Wind turbine is one of the most important elements in wind energy conversion systems. Wind turbine produce

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electricity by using the power of wind to work an electrical generator. Wind moves over the blades, generating lift. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotational speed to which is suit for the generator, uses magnetic fields to convert the rotational energy to electrical energy. The power output goes to a transformer, which convert the electricity from the generator by regulating the voltage. Wind turbine is applied to convert the wind energy into mechanical torque. The mechanical torque of turbine can be calculated from mechanical power, the turbine extracted from wind power .The power coefficient is function of pitch angle and tip speed, pitch angle is angle of turbine blade whereas tip speed is the ratio of rotational speed and wind speed. There were significant differences between wind power and conventional power generation systems. Wind turbines employ, often converter based generating systems. Wind is the prime mover of the wind turbines. The typical size of the wind turbines is much smaller compared to the conventional utility generators. Due to these differences, the power generation from wind interacts with the network. The configuration is developed with PMSG based wind energy conversion system and two controlled two-level voltage source converters. The major concern of wind energy conversion system is to control the speed of a wind turbine.

III.SYSTEM MODELLING

(A).Wind Energy Conversion

The wind consists of a source that generates wind speed signal to be applied to the wind turbine. The kinetic energy is given by

$$E_c = \frac{1}{2} m v^2 \qquad (1)$$

The wind power is given by

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

Where m is the air mass, ρ is the air density, S is the covered surface of the turbine, v is the wind speed.

(B). Wind Turbine

Wind turbine is able to convert the wind energy to mechanical torque. The mechanical torque of turbine can be calculated from mechanical power, the turbine extracted from wind power. The wind speed after the turbine is not zero. The power coefficient of the turbine is used. The pitch angle and tip speed is function of the power coefficient. Wind turbine is applied to convert the wind energy to mechanical torque

$$T_m = \frac{\rho S C_p(\lambda, \beta) v^3}{2\omega} \qquad (3)$$

The power coefficient is given by

$$C_p(\lambda, \beta) = c_1 \left(\frac{c_2}{\lambda_i} - c_3 \beta - c_4\right) e^{-\frac{c_5}{\lambda_i}} + c_6 \lambda \qquad (4)$$

Where c1=0.516,c2=116,c3=0.4,c4=5,c5=21,c6=0.0068

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

Where λ is the tip speed ratio, β is the blade pitch angle.

(C).Drive Train Model

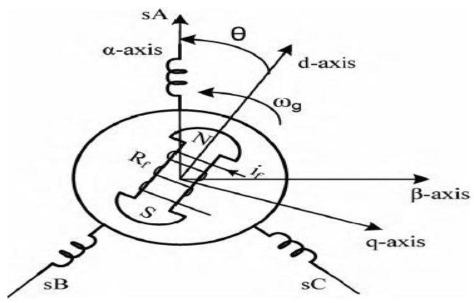
Drive train of a wind turbine generator system consists a blade-pitching mechanism with a spinner, a hub with blades, a rotor shaft and gear box with breaker and generator. The gearbox is not considered because the analyzed system consists of wind turbine equipped with a multi pole PMSG. The drive train can be treated as lumped mass model for the sake of the time and acceptable efficiency. The rotational speed can be of the following equation

$$\frac{dw_r}{dt} = \frac{T_m - T_e}{J} - \frac{Bw_r}{J} \qquad (6)$$

Tm is the torque has been transferred to generator side, Te is the electromechanical torque, B is the damping coefficient, J is the moment of inertia, wr is the rotational speed.

(D). PMSG Model

Dynamic model of the PMSG is obtained from the two phase synchronous reference frame, which the q axis is 90 degree ahead of the d axis with respect to the direction of rotation. The synchronization between the d-q rotating frame is maintained by a phase locked loop.Figure2 shows the dq reference frame used in a salient -pole synchronous machine.



where θ is the mechanical angle ,the angle between the rotor d axis and the stator axis .The stator windings are positioned sinusoidal along the air-gap as far as the mutual effect with the rotor. The stator winding is symmetrical, damping windings are not considered, the

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capacitance of all the windings can be neglected and the resistances are constant. The mathematical model of the PMSG in the synchronous reference frame is

$$u_d = R_s i_d + \frac{d\varphi_d}{dt} - \omega_e \varphi_q \quad (7)$$

$$u_q = R_s i_q + \frac{d\varphi_q}{dt} + \omega_e \varphi_d \quad (8)$$

ud is the d axis voltage, uq is the q axis voltage ,id is the d axis current, iq is the q axis current,, Rs is the stator resistance, φ_d, φ_q are the d axis and q axis flux linkage respectively, ω_e is the electrical speed.

$$\varphi_d = L_d i_d + \varphi_m \quad (9)$$

$$\varphi_q = L_q i_q \quad (10)$$

Ld is the d axis inductance, Lq is the q axis inductance, φ_m is the permanent magnet flux linkage.
substitute(9)and (10) in(7) and (8)

$$u_d = R_s i_d + \frac{d}{dt}(L_q i_d + \varphi_m) - \omega_e L_q i_q \quad (11)$$

$$u_q = R_S i_q + L_q \frac{di_q}{dt} + \omega_e (L_d i_d + \varphi_m) \quad (12)$$

The surface mounted PMSG is considered ,the inductance are equal for d axis and q axis ,the equation becomes

$$u_d = R_S i_d + \frac{di_d}{dt} L - \omega_e L i_q \quad (13)$$

$$u_q = R_s i_d + L \frac{di_q}{dt} + \omega_e L i_d + \varphi_m \omega_e \quad (14)$$

The general mechanical equation of the machine is

$$\frac{dw_r}{dt} = \frac{T_m - T_e}{J} - \frac{Bw_r}{J} \quad (15)$$

Where

$$K_t = \frac{3}{4} P \varphi_m \quad (16)$$

$$T_e = K_t i_q \quad (17)$$

The mathematical model of PMSG is

$$\frac{di_d}{dt} = -\frac{R_s}{L} i_d + \frac{P}{2} i_q \omega_r - \frac{1}{L} u_d \quad (18)$$

$$\frac{di_q}{dt} = -\frac{R_s}{L} i_q - \frac{P}{2}\left(i_d - \frac{\varphi_m}{L}\right)\omega_r - \frac{1}{L} u_q \quad (19)$$

$$\frac{d\omega_r}{dt} = \frac{T_m}{J} - \frac{k_t i_q}{J} - \frac{B\omega_r}{J} \quad (20)$$

IV. PI CONTROLLER

To adjust PMSG rotational speeds according to an optimal references speed .The rotational speed is controlled by changing the dq axis currents'-axis reference current is set as zero in order to avoid demagnetisation of rotor permanent magnets and to decrease the copper losses in a stator winding. The q-axis reference current is proportional to the speed reference varies under wind speed variations. Two separate first order models in the d-q axis

$$\frac{i_d}{v_q} = \frac{1}{sL_d + R_a} \quad (21)$$

$$\frac{i_q}{v_q} = \frac{1}{sL_q + R_a} \quad (22)$$

We obtain two similar PI regulators used in two independent current loops that one of them controls q-axis component and the second controls d-component and the second controls d-component.

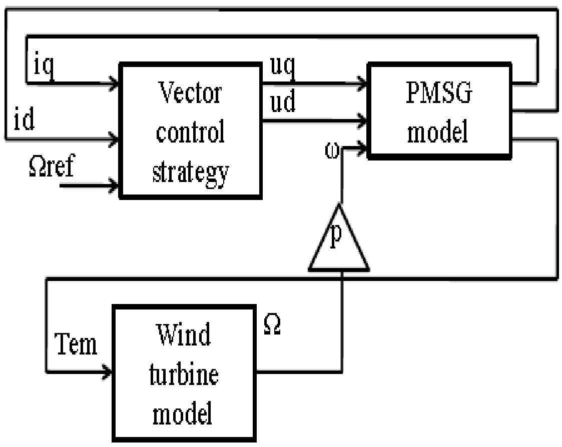

Fig.3.Model of WECS using control strategy

TABLE 1controller values

Tuning Parameter	Values
kp	For d axis 0.0982 For q axis 12.4265*10^-4
ki	For d axis 0.051677 For q axis 2.1801*10^-6

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Tuning of q axis and d axis is done using pi tuning technique. The speed of rotor is tracked and orrespondingly the output of PMSG is improved.

V. SIMULATION RESULTS

The mathematical model of PMSG based wind energy conversion system is studied and to evaluate the system and its corresponding output the detailed modelling of each component d in MATLAB/Simulink is done. The parameters used in the study are given in the Table1.

TABLE 2 Parameters

Description	Symbol	Units	Values
Air density	ρ	Kg/m3	1.025
Rotor radius	R	M	38
Stator resistance	Rs	Ω	0.08
d-axis inductance	Ld	H	0.334
q-axis inductance	Lq	H	0.217
Permanent magnet flux	φ_m	Wb	0.4832
Pole pairs	P	-	3

The variable wind conditions are considered,the results are shown below.

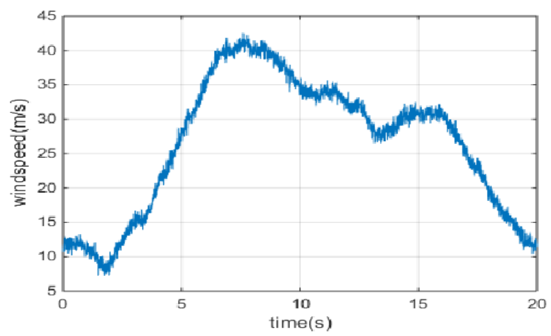

Fig.4.Simulation of wind speed

The wind source output is shown ,when variable speed approaches the variation of speed according to time is shown in Figure3.The rotational speed of the shaft according to wind speed is shown in Figure4.

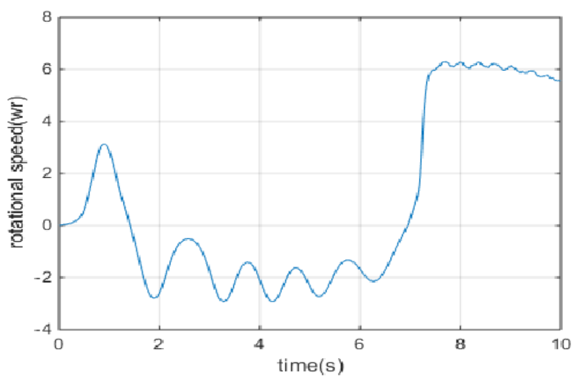

Fig.5.Simulation of rotational speed

The corresponding wave form of d-axis current, q-axis current, torque are shown in Figure 5, Figure 6, Figure 7.

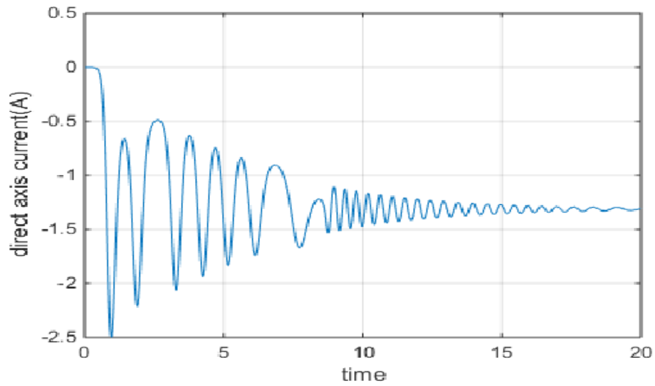

Fig.6.Simulation of direct axis current

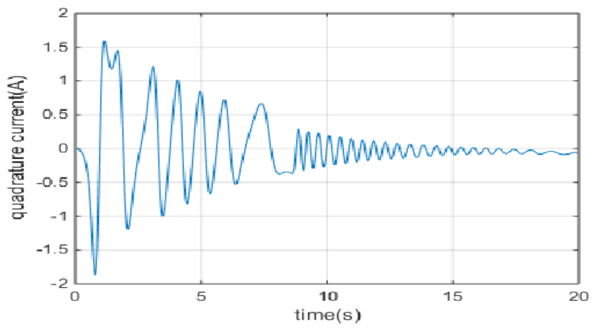

Fig.7.Simulation of quadrature axis current

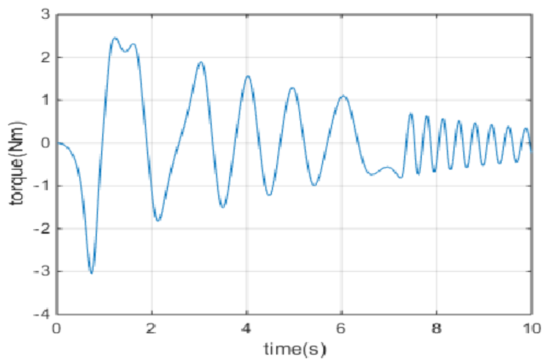

Fig.8.Simulation of torque

Variation of system behaviour using PI controller is shown below. The reference speed is tracked.

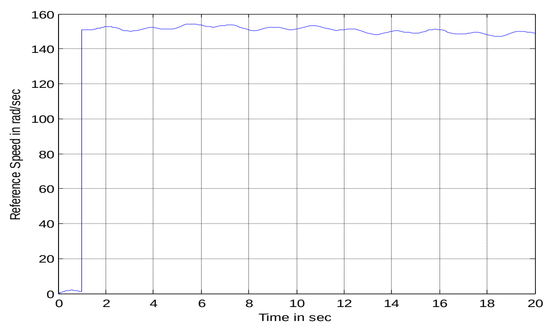

Fig.9. Simulation of reference speed using pi controller

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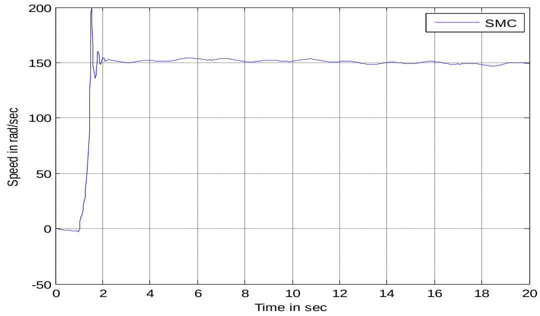

Fig.10.Simulation of rotational speed using pi controller

Fig.11.Simulation of d axis current using pi controller

Fig.12.Simulation of q axis current using pi controller

Fig.13.Simulation of torque using pi controller

VI.CONCLUSIONS

The complete model of the variable speed wind turbine with PMSG is implemented. The model consists of a PMSG model, wind speed, wind turbine and a drive train model. MATLAB/Simulink is implemented to build the dynamic model of the wind turbine with PMSG and simulations have been conducted. The generator has been modelled in the dq synchronous rotating reference frame, taking into account different simplifications. For the pi controllers have to be tuned properly. The optimal criterion for adjusting the gains is the magnitude optimum while for the speed controller is symmetry optimum.

REFERENCES

[1] F.Luo,K. Meng,et al. Coordinated operational planning for wind farm with battery energy storage system.IEEE Transactions On Sustainable Energy,2015,6(1):253-262.
[2] Akhmatov V.,"Variable -Speed Wind Turbines with Doubly-Fed Induction Generators Part III:Model with the back-to-back Converters",Wind Engineering, Volume 27,No.2,pp 79-91,2003.
[3] Boyl G., Renewable Energy,OXFORD university press,2004.
[4] Mukund R.Patel,Design,Analysis, and Operation,Wind and Solar Power System,Taylor and Francis Group,2nd Edition,2006.
[5] Khan B.H ,Non-Conventional Energy Resorces, Tata Mcgraw- Hil Publishers,2nd Edition,2009.
[6] Global wind energy council(GWEC)global wind 2012 report', available online at http://www.awea .org/publication/reports.
[7]T.Ackermann,Windpowerinpowersystems,JohnWiley&Sons,Ltd,UK,2005.
[8] You ssef. Errami "Maximum power point tracking of a wind power system basd on the PMSG using sliding mode diret torque control,"IEEE Transactions on Energy conversion, 4673-6374.
[9] F.Luo,K.Meng,et al.Coordinated operational planning for wind farm with battery energy storage system.IEEE Transactions On Sustainable Energy,2015,6(1):253-262.

BIOGRAPHIES

Veena Vijayan received her B.Tech degree in Electrical and Electronics from Kerala University in 2013.She is currently pursing second year M.Tech in Control Systems at Lourdes Matha College of Science and Technology.

Priya P S received her B.Tech degree in Electrical and Electronics from Bharathidasan University followed M. Tech in Control systems and Instrumentation from Sastra University. She is currently working as Assistant Professor in Electrical and Electronics department at Lourdes Matha College of Science and Technology