Modeling of Permanent Magnet Synchronous Generator for Wind Energy Conversion System

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***Abstract*-During recent years the wind turbine technology had undergone a vast development in the field of renewable energy system. High power machine has become a large market for wind energy conversion, since the size of these machines become much larger than conventional one, optimal modeling has become a very important. This project work deals with modeling of permanent magnet synchronous generator for the wind energy conversion system. Permanent magnet synchronous generator is mostly preferred for variable speed offshore wind farms because it doesn't require any excitation in rotor and gears also not required. Models and equations that describe the different components of the system and their implementation in the software using MATLAB were focused.**

***Keywords*-Wind energy conversion, permanent magnet synchronous generator, optimal modeling.**

I. INTRODUCTION

Throughout the history the use of wind energy has been a constant for human kind. This kind of energy comes by the natural and continuous atmospheric process of the earth, which is given as renewable energy. Still now some of the people are not connected to the utility grid they are living in the villages without current. The reason for this problem is to connect the villages with the utility grid need more transmission line and the cost will increase due to this. The only solution to overcome this problem is to give independent supply with them with the help of the stand alone system which work on the renewable energy system. Among them wind based renewable energy system is playing a major role with them.

Among the stand alone system the Variable Speed Wind Turbine (VSWTS) attracts considerable interest around the world, which is one of the solutions with the highest potential to reduce wind energy cost. The very basic problem which we are facing with the variable speed system is the gear box which we are having with the wind turbine coupling system to improve the output in them which is connected to the generator. The reason for this problem is they require a constant maintenance and even sometimes want to replace the system even before their life ends, because this system will be located over at the top of the tower which is connected to the nacelle. And even the materials, lubrication and seals are also very costly. To overcome this problem we are going with the direct drive variable speed wind turbine based on multipole Permanent Magnet Synchronous Generator (PMSG) which began to gain acceptance among wind turbine. The reason for going with variable speed permanent magnet synchronous generator are better reliability, longer life, and improved performance, elimination of gearbox, high power density, and low losses. Since these types of machine are characterized by the large dimension and weight which are larger than the conventional industrial one optimum machine modeling is needed. This system is modeled and they are simulated using SIMULINK with the help of the MATLAB software.

This project work is organized as follows. First the system configuration and modeling of the variable speed PMSG wind turbine is presented in section two. The simulation of the system with their modeling equations are explained in section three. And their results were analyzed in the next section.

II. MODELING OF THE PMSG

A. Wind speed

Wind which is a form of renewable energy is caused by difference in atmospheric pressure. This wind is produced in the atmosphere due to the pressure which exists in the atmospheric, when a difference in atmospheric pressure exists, air moves from the higher to the lower pressure area, and winds of various speeds are produced. The direction of the wind is usually expressed in terms of the direction from which it orginates.Wind energy is the kinetic energy of the air in motion. The kinetic energy of a packet of air of mass 'm' with velocity 'v' is given by '½mv^{2}'. To find the mass of the packet passing through an area 'A' perpendicular its velocity, we multiply its volume after time this passed with the air density 'ρ', which gives us 'm = A v t ρ'. So, we find that the total wind energy is:

$$E = \frac{1}{2}\rho A v^3 t \qquad (1)$$

To find over the total wind power we want to differentiate the above equation with respect to time to find the rate of increase of energy, thus the total wind power is:

$$P = \frac{dE}{dt} = \frac{1}{2}\rho A v^3 \qquad (2)$$

From the above equation the wind power is thus proportional to the third power of the wind velocity.

B. Wind turbine

The kinetic energy of the wind is converted into mechanical energy with the help of the wind turbine which we are having in the system. Wind turbines produce electricity by using the power of the wind to drive an electrical generator. This wind passes over the blades, generating lift and exerting a turning force. The rotor aerodynamics are presented by the well-known static relations

$$P_w = c_p 1/2\ pAv_w^3 \qquad (3)$$

where 'p' is the power extracted from the wind, 'p' is the air density, which is equal to 1.225 kg/m at sea level at temperature T = 288 K, 'Cp' is the power coefficient, 'Vw' is the wind speed upstream of the rotor and 'A' is the area swept by the rotor. The amount of aerodynamic torque 'τw' in Nrn is given by the ratio between the power extracted from the wind 'Pw' in W, and the turbine rotor speed 'ω_w' in rad/s, as follows

$$\tau_w = \frac{P_w}{\omega_w} \qquad (4)$$

C. Drive train

Based on the Newton second law for the torsional version of the motion the equations for the drive train model are derived. The derived drive train equation has the state equation for the rotor angular speed at the wind turbine and for the rotor angular speed at the generator The modeled drive train of a wind turbine generator system consists of the following elements: a blade-pitching mechanism with a spinner, a hub with blades, a rotor shaft and a gearbox with breaker and generator. It must be noted that gearbox is not considered because the analyzed system consists of a wind turbine equipped with a multi-pole PMSG. The acceptable way to model the drive train is to treat the system as a number of discrete masses connected together by springs defined by damping and stiffness coefficients. Therefore, the equation of i_{th} mass motion can be described as follows

$$\frac{d^2\theta_i}{dt^2} = \frac{v_i c_i}{J_i}\frac{d\theta_{i-1}}{dt} - \frac{v_{i+1}^2 c_{i+1} + c_i}{J_i}\frac{d\theta_i}{dt} + \frac{v_{i+1}c_{i+1}}{J_i}\frac{d\theta_i}{dt} + \frac{v_i k_i}{J_i}\theta_{i-1} - \frac{v_{i+1}^2 k_{i+1} + k_i}{J_i}\theta_i + \frac{v_{i+1}k_{i+1}}{J_i}\theta_{i+1} + \frac{\tau_i}{J_i} - D_i\frac{d\theta_i}{dt} \qquad (5)$$

Where 'v' is the transmission rate 'c' is the shaft viscosity [kg/ (m's)], 'k' is the shaft elastic constant [N/m], 'J' is the moment of inertia of the mass [kg-rrr], 't' is the external torque [Nrn] applied to the mass and 'D' is the damping coefficient [Nm/s], which represents various damping effects .

D.Generator model

The permanent magnet synchronous generator given in this paper is modeled based on the equations which are given below

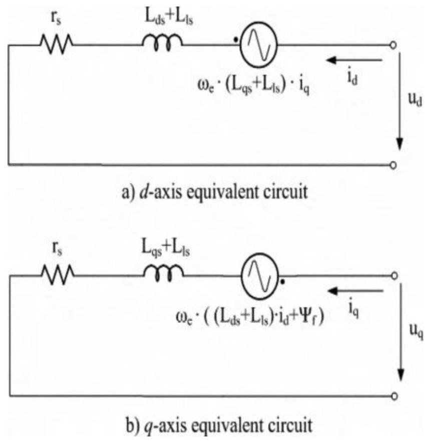

Fig. 1. d & q axis equivalent circuit

The d-axis and q-axis equivalent circuit which guide over the generator is given above and their corresponding equation were explained,

$$\frac{di_d}{dt} = \frac{1}{l_{ds}+l_{ls}}\left(-R_s i_d + \omega_e\left(l_{qs} + l_{ls}\right)i_q + u_d\right) \qquad (6)$$

$$\frac{di_q}{dt} = \frac{1}{l_{qs}+l_{ls}}\left(-R_s i_q - \omega_e\left[\left(l_{qs} + l_{ls}\right)i_d + \psi_f\right] + u_q\right) \qquad (7)$$

where subscripts *d* and *q* refer to the physical quantities that have been transformed into the *d*-*q* synchronous rotating reference frame, 'R' is the stator resistance, 'L_d' and 'L_q' are the inductances of the generator on the *d* and *q* axis, 'L_{ld}' and 'Llq' are the leakage inductances of the generator on the *d* and *q* axis respectively, 'Ψ_f' is the permanent magnetic flux and 'We' is the electrical rotating speed [rad/s] of the generator, defined by

$$\omega_e = P\omega_g \qquad (8)$$

Where 'p' is the number of pole pairs of the generator. In order to complete the mathematical model of the PMSG the mechanical equation is needed, and it is described by the following electromagnetic torque equation

$$\tau_e = 1.5P((l_{ds} + l_{ls})i_d i_q + i_q \psi_f) \qquad (9)$$

E. Three Phase Diode Bridge Rectifier

The rectifier is the circuit that which is used over for conversion of AC wave into DC wave. The diode rectifier is the most commonly used topology in power electronic applications. We are using over the three phase bridge rectifier which is commonly used in high power applications. For a three phase system it consists of six diodes. It can be operated over with or without transformer with them. This modeling is done over on the basis of the following equation with them,

$$\text{Max}\ (v_{ab}, v_{bc}, v_{ca}) \qquad (10)$$

F. Buck-Boost converter

The output voltage which is being generated from the wind energy with the help of the permanent magnet synchronous generator should want to be getting stabilized to meet over the load which we are connecting with them. This can be achieved over with the help of the buck-boost converter which we are having in them. As the name implies, the output voltage can be stepped up or stepped down as per the load voltage which we are having.

$$v_o = -\frac{v_s k}{1-k} \qquad (11)$$

III. SIMULATION

Simulation models for the wind energy conversion system is done with the help of the modeling equation which are given above are developed in the software package with the help of the MATLAB. Major elements such as PMSG, diode bridge rectifier, buck-boost converter, wind speed, wind turbine model and drive train are represented by blocks in the below model. In the Fig. 2 given below all the components of the system are given in whole for the simulation, in the later diagram each and every subsystem were given in detail.

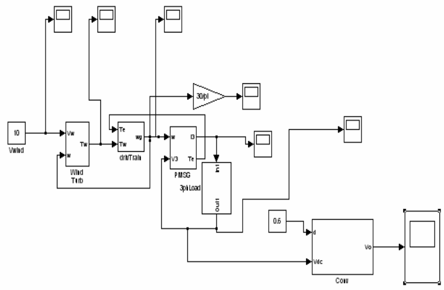

Fig. 2. Simulation diagram for the wind energy conversion system

In the Fig. 3 the simulation diagram of wind turbine which is used to convert the wind energy into mechanical energy is shown below. The wind turbine will convert this wind energy into mechanical with the help of the turbine blade structure with them. The wind speed at a particular velocity will be converted into angular velocity at a particular angle with them and the energy will be converted with them.

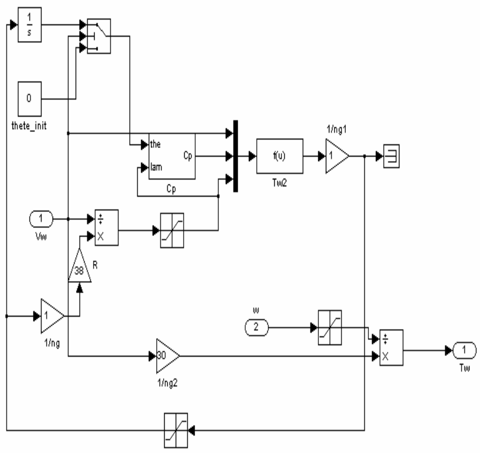

Fig. 3. Simulation of wind turbine system

The input which we are giving in this one is the wind speed. The wind speed will be sensed by the system and it will be processed by the wind turbine which we are having the wind turbine will be processed with the power coefficient which we are having and the output will be generated which will be the wind turbine torque.

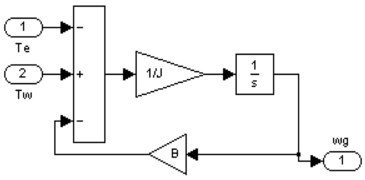

Fig. 4. Simulation of drive train

The next simulation circuit Fig. 4. which is given here will be the drive train which carries over the two mass models with them. The two mass models carry over the wind blade structure and the hub with them. The wind speed will be processed and the output will be generated based on the wind turbine torque which we are having the output with them will be the drive train torque.

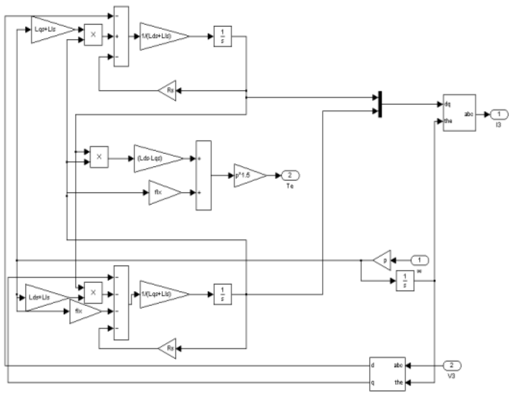

Fig. 5. Simulation of permanent magnet synchronous generator

The output of the wind turbine and the drive train torque will be given as the input to the permanent magnet synchronous generator which will be useful to convert the mechanical energy with them into the electrical energy The permanent magnet synchronous generator is modeled with the d axis and the q axis system separately with the and inductance parameter will be given as a separate input with them At final the wind speed is converted into the electrical energy with them and this will be used as an input to the rectifier and the converter circuit.

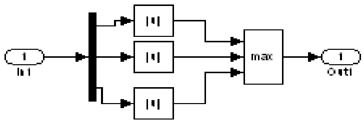

Fig. 6. Simulation of rectifier

The output of the permanent magnet synchronous generator will be the alternating waveform it wants to be converted into the direct waveform to feed the converter this can be done with the above circuit in which the maximum values of the waveform will be chosen and it will be given as the input to the converter.

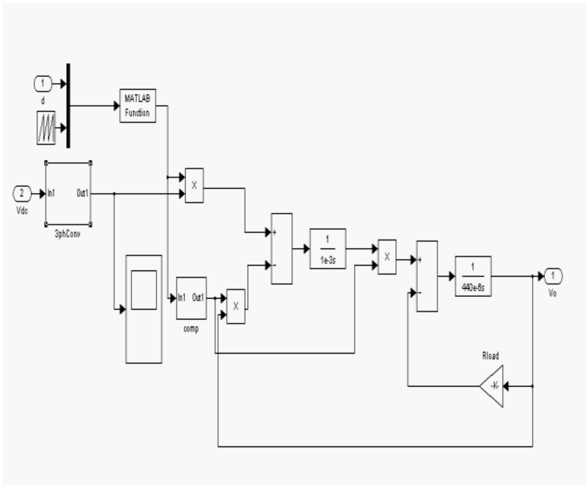

Fig. 7. Simulation of converter

The converter circuit which is used here is the buck boost converter circuit in which it is modeled with the final output of the converter. And the output of the rectifier will be given as the input and we can get over a stabilized output with the system which we are having this can be feed to the need which we are having.

IV. RESULT

The complete simulation for the system has been done using the above equations and the simulation circuits which were given above. The output for the simulation circuit is given over with the different output that which is being obtained over for the each and every system. The first output which is being given in the Fig. 8. is the constant wind speed which is being taken as the input for the system.

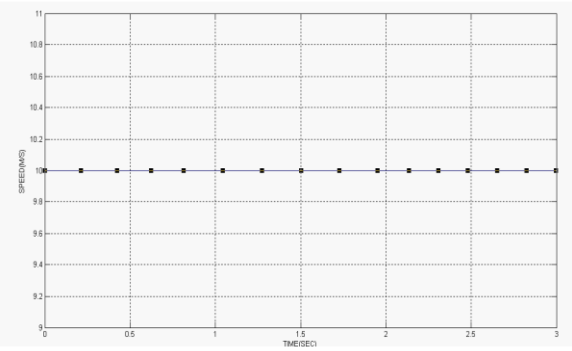

Fig. 8. Simulation output of wind speed

The second graph Fig. 9. deals over with the wind turbine torque as the wind speed the output for the turbine torque will change. The output for the system will be in the range of 80 (N/m) with them. The torque will decide over the output for the system which we are having.

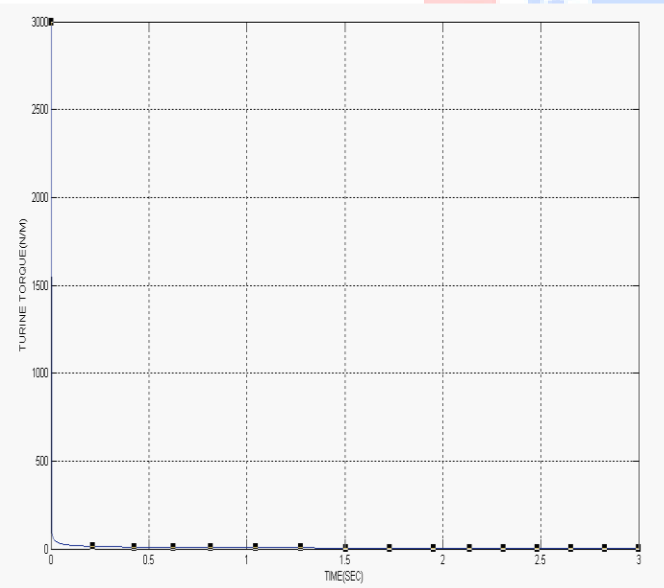

Fig. 9. Simulation output of wind turbine

In the Fig. 10. deals over with the drive train torque which we are having with them. The graph is obtained over for the two mass system which we are having the output will be obtained as per the input which we are having there will be a gradual increase with the input which we are having.

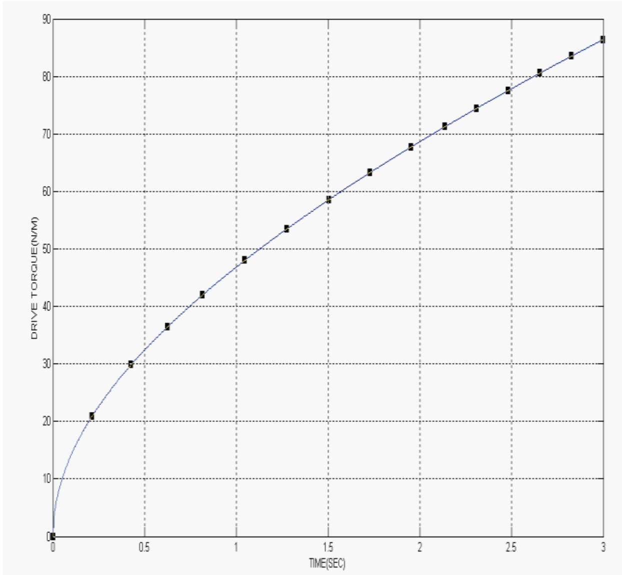

Fig. 10. Simulation output of drive train system

The speed of the permanent magnet synchronous generator is given below in the Fig. 11. the torque of the drive train and the turbine will decide over the speed of the generator. The speed which is obtained for this system is 3024 RPM.

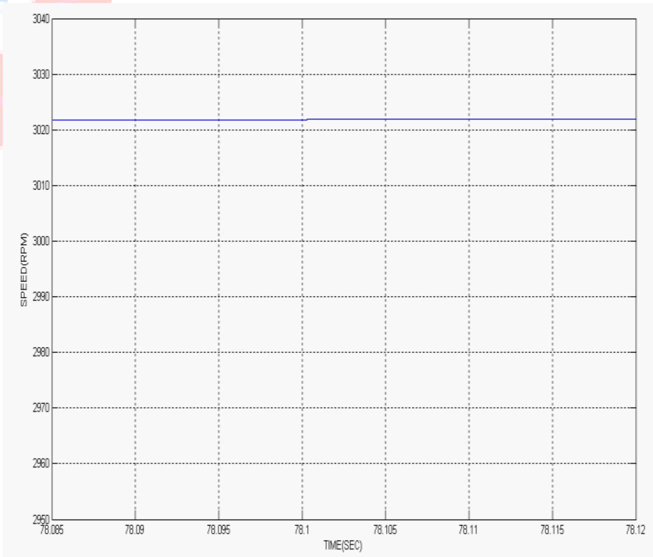

Fig. 11. Simulation output of generator speed

In the next graph Fig. 12. which is being obtained over here is for the current of the permanent magnet synchronous generator. The value which is obtained in the generator will be 1.25A. Since we are having over a very high configured voltage for the system the current value will be low.

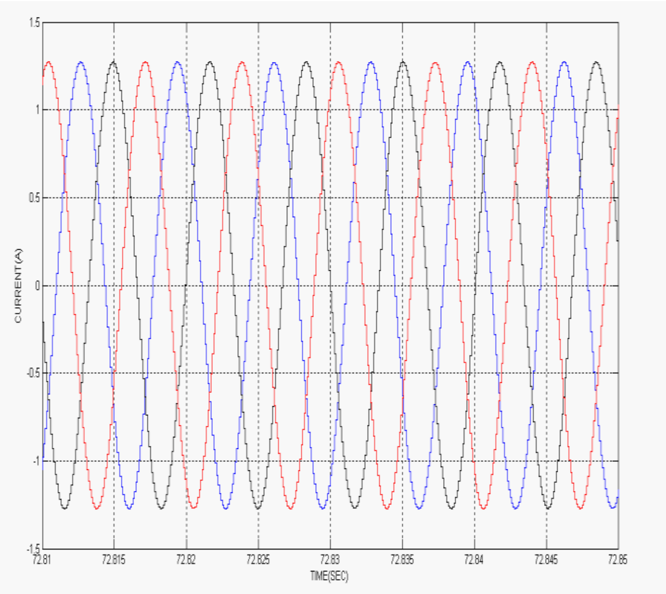

Fig. 11. Simulation output of generator current

The voltage range which is obtained in the generator system is 125v. This voltage can be given to the converter to get over the stabilized output with them.

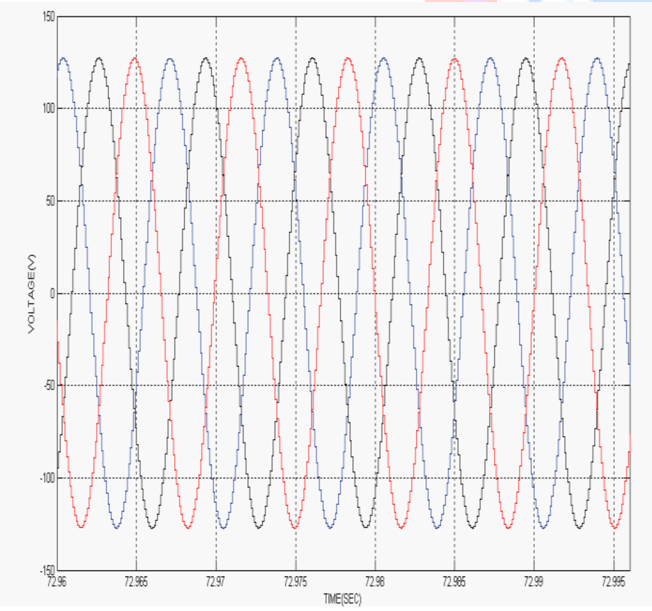

Fig. 12. Simulation output of generator voltage

The final graph shown in Fig. 13. deals with the output of the converter circuit in this one we are getting over a stabilized output for the system. The voltage range obtained here is 132 Kv. This voltage can be feed over as a input to the direct current appliances or it can be converted into alternating current and given to the other appliances.

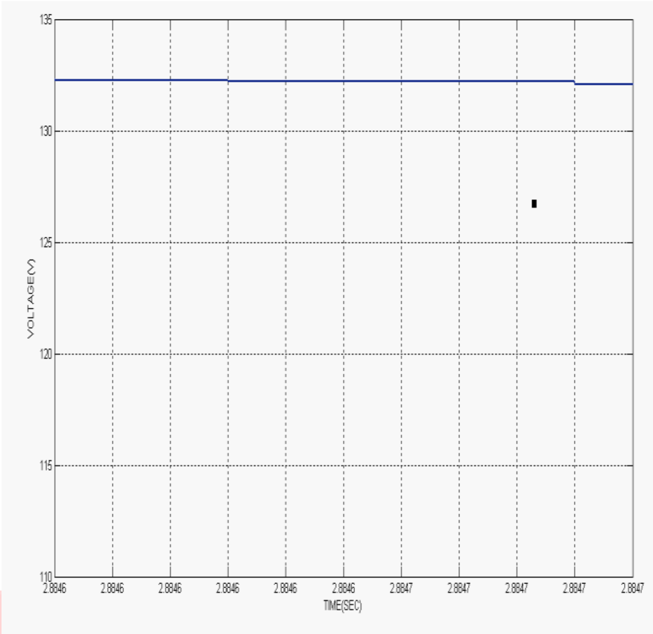

Fig. 13. Simulation output of converter

References:

[1] Ali M. Eltamaly 'modeling of wind turbine driving permanent magnet generator with maximum power point tracking system'.

[2] Guannan Duan Haifeng Wang, Hui Guo, and Guobiao Gu (2010), 'Direct Drive Permanent Magnet Wind Generator Design and Electromagnetic Field Finite Element Analysis' IEEE Transaction on applied superconductivity, Vol 20, no-3, June.

[3] Yuanye Xia, Khaled H. Ahmed, and Barry W. Williams (2011)' A New Maximum Power Point Tracking Technique For Permanent Magnet Synchronous Generator Based Wind Energy Conversion System, IEEE transactions on power electronics, vol. 26, no. 12, December.

[4] Ahmed M. Hemedia, Wael A. Farag, Osma A.Mahgoub (2011) 'Modeling and control of direct driven pmsg for ultra large wind turbines' World academy of science, engineering and technology 59.

[5] Benchabane.F, Titaouine.A, Bennis.O, Guettaf.K, Yahia.K, and Taibi.D (2012) 'An Improved Efficiency of Fuzzy Sliding Mode Control of Permanent Magnet Synchronous Motor for Wind Turbine Generator Pumping System' ISSN 0003_701X, Applied Solar Energy, 2012, Vol. 48, No. 2, pp. 112–117. © Allerton Press, Inc., 2012.

[6] López-Ortiz.E.N, Campos-Gaona.D, Moreno-Goytia.E.L (2012) 'Modeling of a Wind Turbine with Permanent Magnet Synchronous Generator' 978-1-4673-2308-6/12/2012.

[7] Marei.M.I and El-Goharey.H.S.K (2012) 'Modeling and Dynamic Analysis of Gearless Variable-Speed Permanent

Magnet Synchronous Generator Based Wind Energy Conversion System' International Conference on Renewable Energies and Power Quality (ICREPQ'12) Santiago de Compostela (Spain), 28th to 30th March, 2012.

[8] Ratheen Kumar Reddy.B, Padma Lalitha.M, Chennaiah.P.B (2012) 'Modeling and Control of a Variable Speed Wind Turbine Equipped with Permanent Magnet Synchronous Generator' International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol.2, Issue.4, July-Aug 2012 pp-2702-2706.

[9] Juan A. Tapia , Juha Pyrhönen , Jussi Puranen , Pia Lindh , and Sören Nyman(2013) 'Optimal Design of Large Permanent Magnet Synchronous Generators' IEEE transactions on magnetics, vol. 49, no. 1, January 2013.

[10] Kulkarni, Thosar (2013) 'Mathematical Modeling and Simulation of Permanent Magnet Synchronous Machine 'International Journal of Electronics and Electrical Engineering Vol. 1, No. 2, June.