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Variable speed Wind Turbine Driven PMSG Fed Wind Energy Conversion System using Vector Control

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***Abstract*—** A Wind energy conversion system (WECS) using Permanent Magnet Synchronous Generator (PMSG) is proposed in this paper. The effective wind energy utilization is now a day's getting very much importance. The energy collects from wind systems can provide a grid support or they can be used as standalone systems. WECS uses pitch angle control to maximize the power extraction. Controlled rectifier and inverter provided will maintain a constant DC link voltage and provide grid support. The advantages of PMSG allow an efficient mechanical to electrical energy conversion. The topology for the system with a wind turbine system, PMSG, and a controlled rectifier, Two level inverter has been implemented using MatLab/Simulink based models.

Keywords- *Wind energy conversion system, Permanent Magnet Synchronous Generator, Pitch angle control, Controlled rectifier, Two level inverter*

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I. INTRODUCTION

Availability of continuous power is still a dream for isolated communities in certain countries. To meet the energy demand of such places, alternative energy sources can be used. The renewable sources like solar, wind and hybrid systems are a solution for dat. The most promising application of such systems is the economically feasible power for remote communities. Such systems can either be grid connected or stand alone systems. Since wind systems are now seeking good attention over the world, WECS can be used as a solution to meet the energy demand. The application of power electronic devices together with good control methods makes a WECS efficient to meet the demand.

Wind turbines operates with either fixed speed or variable speed. The generator (induction generator) is directly connected to the grid for fixed-speed wind turbines (FSWT) systems. Since the speed is fixed to match with grid frequency, and is not controllable, so it is not possible to store the pulsating energy due to the variation of the wind in form of vibrations. Therefore, for a fixed-speed system the variation of the wind will result in power variations, and thus affect the power quality of the grid [1]. For a variable-speed wind turbine (VSWT) system, the generator is controlled by power electronic interface, which makes it possible to control the rotor speed. In this way the power fluctuations caused by wind variations can be reduced. And thus power variations originating due to wind variation can be reduced. The drive train used can also eliminated using efficient control of power electronic devices. Hence, the power quality issues caused by the wind turbine can be eliminated.

There are mainly two conversion stages in wind generation systems. The first one is the transformation of the wind speed kinetic energy to mechanical energy as the turbine speed and torque. In the second one, the turbine mechanical energy to electrical energy by means of a electrical generator, which can be synchronous or asynchronous machine. The performance of these two power conversions will define the effective performance of the wind power system. Generally, the grid connection is made by an electronic power converter or a frequency converter with high efficiency. So, it is very important to maximize the performance of the first and second conversion that can be done by using a wind turbine system with MPPT and a variable speed generators. Although the VSWT systems are usually based on doubly fed induction generators (DFIGs), the use of permanent magnet synchronous generators (PMSGs) has increased in recent years [3-10]. The advantages like small size and presence of permanent magnet rotor makes it effective.

The paper presents a WECS using PMSG. Pitch angle control and a two mass drive train is also used to maximize the power and for getting optimum torque. The system uses a voltage controller for grid support. That will maintain a constant grid voltage and frequency. The main requirement of a grid connected system is the maintenance of voltage magnitude, frequency and phase difference of power. To maintain this grid requirement a vector control algorithm is presented.

The paper is organized as follows. Section II provides the description about over all system. Section III presents wind turbine system driven PMSG. Section IV details basic features about two level inverters and voltage control algorithm. Section V explains the simulation results obtained.

II. PROPOSED SYSTEM

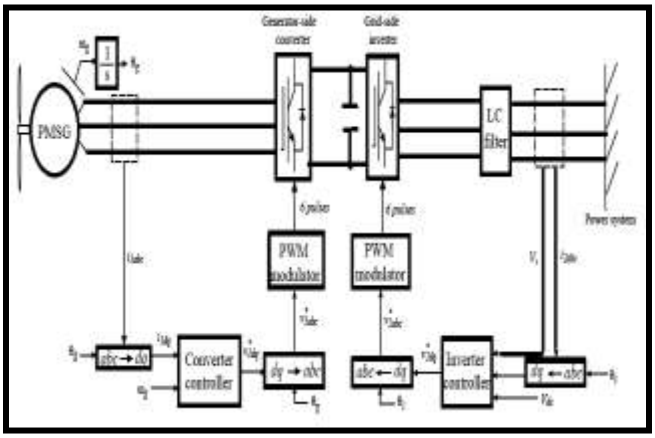

Fig.1 Block diagram of proposed system

The proposed system is shown in fig 1. Which is having a wind turbine system, PMSG, controlled rectifier and controlled inverter. The rectifier side control will maintain a constant DC link voltage and the inverter side control for grid interaction. The kinetic energy present in the wind is converted to electrical energy using wind turbine system with PMSG. Frequency converter will convert the variable frequency electrical energy to fixed frequency system.

III. WIND TURBINE DRIVEN PMSG SYSTEM

The modeling of wind turbine driven PMSG system includes modeling of wind turbine, PMSG, Pitch angle control and two mass drive train.

A. Modeling of wind turbine system

The expression of the mechanical torque developed by a wind turbine *Tm* is given by the following [10, 11]:

$$T_m = \frac{1}{2}\rho\pi R_t{}^2 C_p(\lambda,\beta)\frac{v^3}{\Omega_r} \quad (1)$$

Such that:

$$\lambda = \frac{R_t\Omega_r}{v} \quad (2)$$

In order to simulate the wind generation system, expression of *Cp (λ , β)* has been considered , such that; [4]

$$C_P = [0.5 - 0.00167(\beta-2)]\sin\left(\frac{\pi(\lambda+0.1)}{12-0.3(\beta-2)}\right) - 0.00184\,(\beta-2)(\lambda-3) \quad (3)$$

In this study, the pitch angle β is set to zero using pitch angle control. Along with this a two mass drive train is also connected. In order to maintain a constant input torque to avoid vibrations of the system. The equation of the torque for drive train is given by

$$H_g\frac{d\omega_g}{dt} = T_e + \frac{T_m}{n} \quad (4)$$

Since the wind turbine shaft and generator are coupled together via a gearbox, the wind turbine shaft system should not be considered stiff. To explain the interaction between the windmill and the rotor, an equation describing the motion of the windmill shaft is adopted.

$$H_m.\frac{d\omega_m}{dt} = T_\omega - T_m \quad (5)$$

The mechanical torque *Tm* can be modeled with the following equation.

$$T_m = K\frac{\theta}{n} + D\frac{\omega_g - \omega_m}{n} \quad (6)$$

$$\frac{d\theta}{dt} = \omega_g - \omega_m \quad (7)$$

where *n* is the gear ratio, θ is the angle between the turbine rotor and the generator rotor, ω_m , ω_g , H_m and H_g are the turbine and generator rotor speed and inertia constant, respectively .K and D are the drive train stiffness and damping constants, T_ω is the torque provided by the wind and T_e is the electromagnetic torque.

B. Modeling of PMSG

AC machine modeling, the electrical equations of the PMSG in a (d, q) reference frame, linked to the rotor flux vector, are [10, 11]:

$$\begin{bmatrix}V_d\\V_q\end{bmatrix} = \begin{bmatrix}r_s & 0\\0 & r_s\end{bmatrix}\begin{bmatrix}i_d\\i_q\end{bmatrix} + \frac{d}{dt}\begin{bmatrix}\varphi_d\\\varphi_q\end{bmatrix} + \omega_r\begin{bmatrix}0 & -1\\1 & 0\end{bmatrix}\begin{bmatrix}\varphi_d\\\varphi_q\end{bmatrix} \quad (8)$$

For a sinusoidal distribution of the back e.m.f, the flux and current phases are linked by the following expressions:

$$\varphi_d = L_d i_d + \varphi_r \quad (9)$$
$$\varphi_q = L_q i_q$$

where φ_r is the rotor flux.

Substituting equation (5) on equation (4), we obtain the following system via *Laplace* transformation

$$\left\{\begin{aligned} v_d &= (r_s + L_d\rho)i_d - e_d \\ v_q &= (e_s + L_q\rho)i_q + e_q \end{aligned}\right. \quad (10)$$

Such that the direct and the quadrature back e.m.f components are expressed as:

$$\begin{cases} e_d = \omega_r L_q i_q \\ e_q = \omega_r L_d i_d + \omega_r\varphi_r \end{cases} \quad (11)$$

The stator active and reactive powers of the PMSG Machine are given by the equations (8):

$$\begin{cases} P_s = \frac{3}{2}(v_d i_d + v_q i_q) \\ Q_s = \frac{3}{2}(v_q i_d - v_d i_q) \end{cases} \tag{12}$$

Under generator operation, the mechanical equation is expressed as follows:

$$T_m - T_{em} = J\frac{d\Omega_r}{dt} + K_f\Omega_r \tag{13}$$

The electromagnetic torque can be expressed ,in (d,q frame)as follows:

$$T_{em} = \frac{3}{2}n_p\left(\varphi_r - \left(L_q - L_d\right)i_d\right)i_q \tag{14}$$

IV. TWO LEVEL INVERTER WITH VECTOR CONTROL

The inversion stage is used to turn the output of the DC link back into AC. This is done through three phases of switching circuits, typically MOSFETs or IGBTs. There are many types of inverter available. The most basic system is a two level inverter. Control signals must be sent to the switches, typically done via PWM, and a control system can be implemented through them as well. The PWM scheme is most commonly used because of the possibility of voltage regulation, but it will also cancel out multiples of the third harmonic to help improve output power quality. The two level inverter is shown in fig. 2

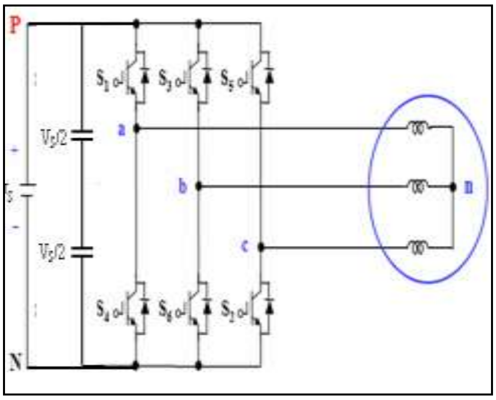

Fig. 2 . Two level inverter

Switching scheme of Two level inverter is given in table I.

Table I switching scheme of Two level inverter

Interval	S1	S2	S3	S4	S5	S6
0 to 60^0	On	Off	Off	Off	Off	On
60 to 120^0	On	On	Off	Off	Off	Off
120 to 180^0	Off	On	On	Off	Off	Off
180 to 240^0	Off	Off	On	On	Off	Off
240 to 300^0	Off	Off	Off	On	On	Off
300 to 360^0	Off	Off	Off	Off	On	On

The voltage regulator control used here is mainly used for grid interfacing. To interface the system with grid the voltage, frequency and phase of system generated power has to be match with grid power. For that purpose a vector control algorithm is used. Which will always maintain a constant voltage with fixed frequency that is required for the grid connection. The vector control algorithm will indirectly control the torque and power by controlling the d-q axis vectors [12].

V. RESULTS AND DISCUSSIONS

Simulation results of wind energy conversion system with 4 pole PMSG and controlled inverter and rectifier has been carried in this section. The parameters for the modeling PMSG and wind turbine are given in table 1

Table II parameters for wind turbine system

Parameters of turbine		Parameters of machine	
parameter	value	parameter	value
Air density	1.08 kg/m^3	Pr, rated power	2.00 KW
A, area swept by blades	31.98 m^2	L_d L_q	0.01 H
V, base wind speed	12 m/s	R_r , rotor resistance R_s, stator resistance	0.425 ohm
C_{pmax}	0.48	Pole pairs	4
Lambda	8.1	Voltage constant	300 Vpp/krpm
Pitch angle , β	0	Torque constant Inertia constant viscous	2.48 Nm/A 0.01197 kgm^2 0.001189 N.m.s

The overall wind energy conversion system using PMSG and vector controlled two level inverter is shown in fig.3

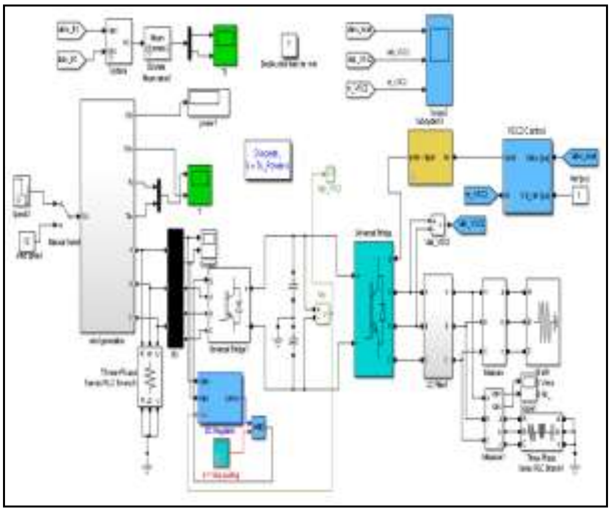

Fig. 3 wind energy conversion system model

The matlab model of wind turbine system and PMSG is shown in fig.4 and fig.5

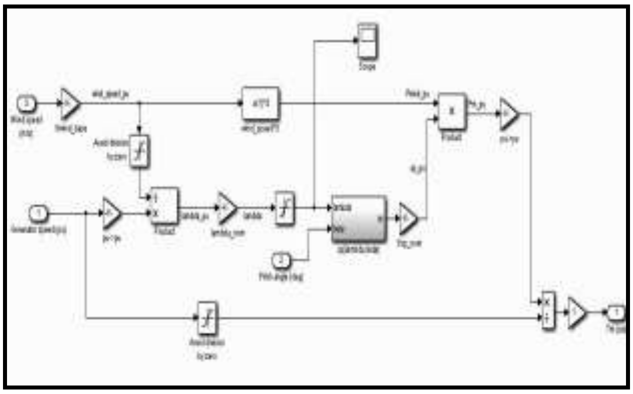

Fig. 4 wind turbine system model

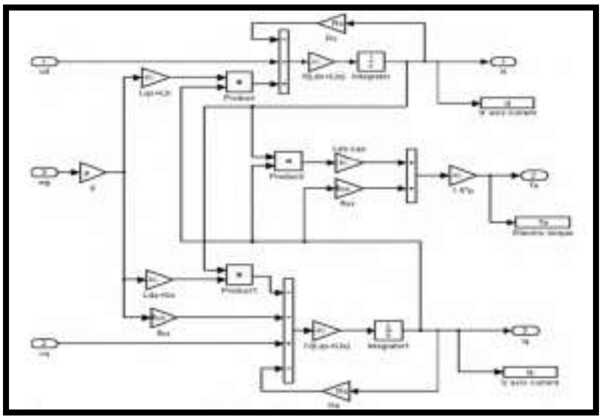

Fig. 5 PMSG model using Matlab

The simulation waveforms for wind velocity, torque produced from wind turbine system (Tm) and torque given to PMSG after two mass drive train (Tsh) are shown in below Fig. 6

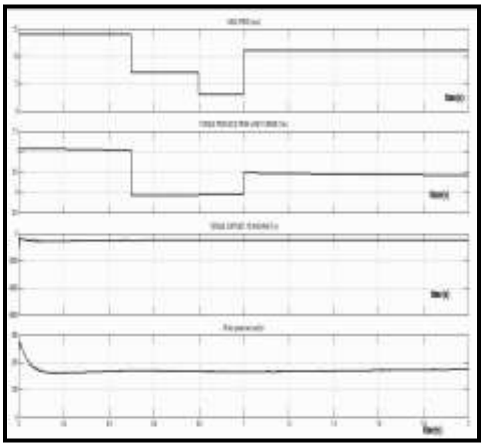

Fig. 6 Wind speed, Shaft torque, machine torque and rotor speed

The rectifier control model is given in fig. 7 which contain both current and voltage control. That will maintain a constant dc link voltage by maintaining torque and speed of PMSG, and there by keeping the generated voltage constant

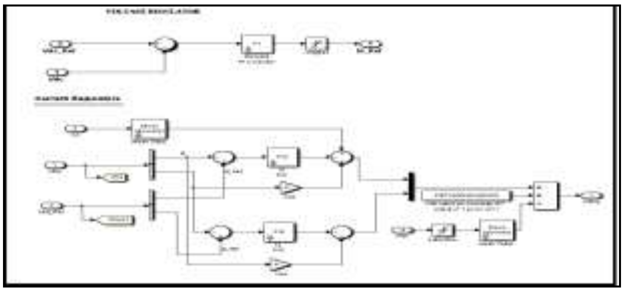

Fig. 7 controller model for rectifier

The generated voltage and current wave forms from PMSG of a WECS using controlled rectifier is shown in Fig. 8.

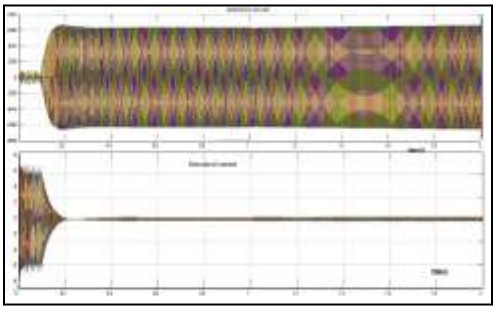

Fig. 8 PMSG generated voltage

The dc link voltage obtained using the controlled rectifier is shown in fig.9

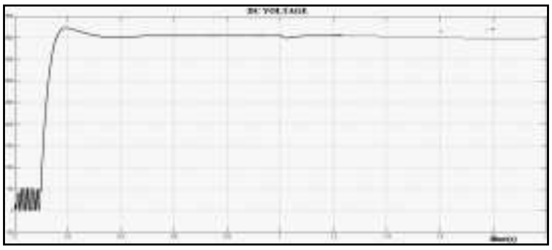

Fig. 9 dc link voltage

The voltage regulator algorithm used for two level inverter is shown in fig.10

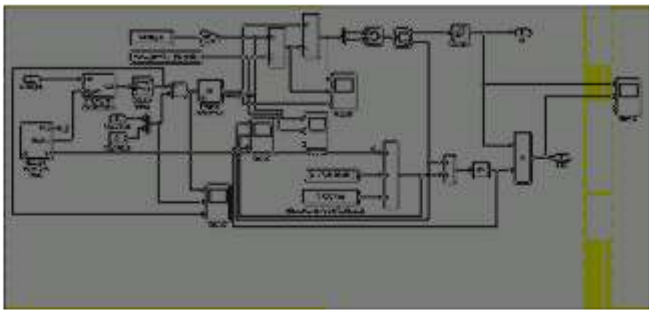

Fig. 10 voltage regulator model for Two level inverter using MatLab

The grid voltage and current obtained using the voltage controlled two level inverter is having a constant frequency 50 Hz and 415 V magnitude. So it can be used to interface with the grid easily. The voltage and current produced is shown in fig .11

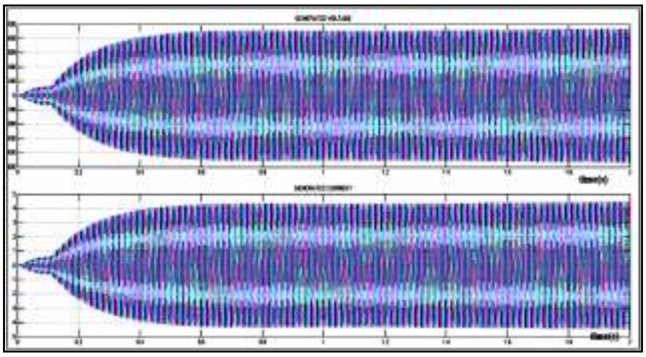

Fig. 11 Grid voltage and grid current

The THD analysis of the voltage and current obtained is shown in fig .12

Fig. 12 THD analysis

VI. CONCLUSIONS

In this paper a wind energy conversion system with five level inverter using controlled rectifier systems has been introduced. Model has been implemented using MatLab/ simulink software. The pitch angle control and two mass drive train will overcome the torque vibration along with controlled rectifier. The controlled inverter provides a grid integrated voltage and current with THD less than the IEEE standard value.

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