Scientific Journal of Impact Factor(SJIF): 3.134
e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2,Issue 3, March -2015

Control of Grid connected Wind Energy Conversion System based PMSG

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Abstract- *This paper describes novel integration of wind energy conversion system to the grid through back to back PWM voltage source converters to make variable speed operation possible. The studied system here is a variable speed wind generation system based on Permanent Magnet Synchronous Generator (PMSG). Vector control of the machineside converter (MSC) provides active power control of the machine while vector control of the grid side converter (GSC) keeps the voltage of the DC link constant and provides reactive power control of the grid. This paper considers the Simulink/matlab simulation for DC link voltage control andreactive power control of grid connected PMSG and corresponding results and waveforms are displayed. The machine side converter control is also explained in this paper.*

Keywords-*PMSG, Back to back converter, Machine side converter, Grid side converter, DC link voltage, Active Power, Reactive power, Direct axis current, Quadrature axis current*

I. INTRODUCTION

Lately, there has been a developing interest in wind energy conversion system as it is a potential source for electrical power generation with minimal environment impact. Nowadays, renewable energy has received much attention due to the concerns about the environment, it is pollution free and exhaustless [1]. Doubly-fed induction generator has been widely used in the wind power generation area [2]. However, the presence of gearbox coupling the wind turbine to the generator suffers from considerable faults and increase regular maintenance [3]. Therefore, using direct drive PMSG can be eliminated the gearbox and increase the reliability of the variable speed wind turbine [4].

Moreover, PMSG has more advantages than other configuration of WECs which as a high power factor, lower losses and costs, high efficiency and low maintenance [3-5]. Direct drive operation can be achieved which makes the operation noiseless.

In this paper modeling of the wind turbine and Permanent Magnet Synchronous Generator has been done in Matlab/Simulink. For the direct drive operation, Back to back converter has been modeled and control of the back to back converter is also simulated in Matlab/Simulink. The control of machine side converter has been explain in this paper but not considered in simulation work so the machine side converter has worked as uncontrolled rectifier in simulation. The control of grid side converter is explained and modeled in Simulink software. The DC link voltage control and reactive power control has been done by PWM grid side converter.

II. MATHEMATICAL MODELING OF PMSG

A. Modeling of Wind turbine with PMSG

Wind turbines cannot fully capture wind energy. The components of wind turbine have been modelled by the following equations [6]. Output aerodynamic power of the wind-turbine is expressed as:

$$P_{Turbine} = \frac{1}{2}\rho A C_p(\lambda,\beta) v^3 \quad (1)$$

Where,$\rho$is the air density (typically 1.225 kg/m^3), A is the area swept by the rotor blades (in m^2), $C_p$is the coefficient of power conversion and v is the wind speed (in m/s).

The tip-speed ratio is defined as:

$$\lambda = \frac{\omega_m R}{v} \quad (2)$$

Where, ω_m and R are the rotor angular velocity (in rad/sec) and rotor radium (in m), respectively. The wind turbine mechanical torque output T_m given as:

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

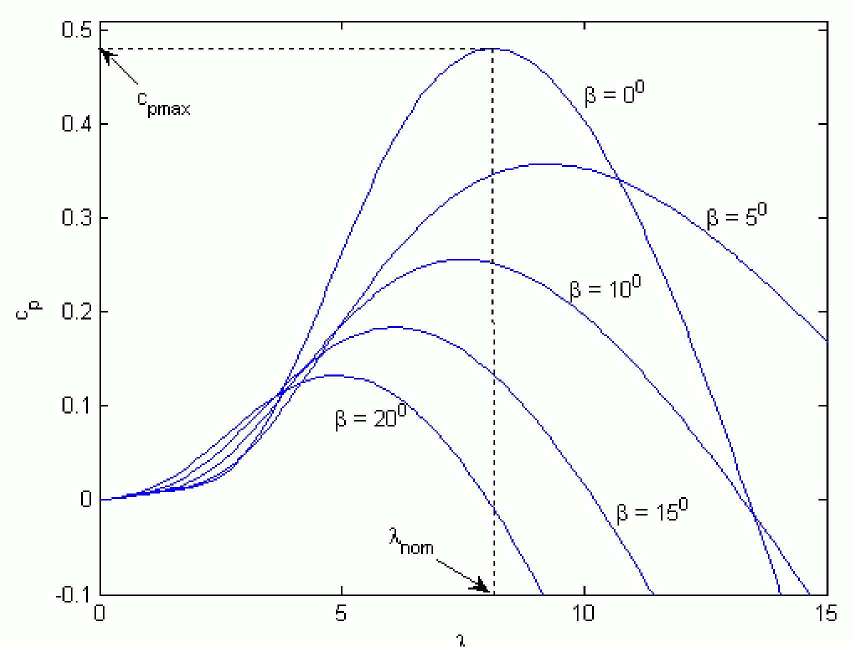


Fig. 1. Characteristics C_p vs ; for various values of pitch angle β

The power coefficient is a nonlinear function of the tip-speed ratio$\lambda$and the blade pitch angle β(in degrees). If the swept area of the blade and the air density are constant, the value of $C_p$is a function of $\lambda$and it is maximum at the particular λ_{opt}. Hence, to fully utilize the wind energy,λ should be maintained at λ_{opt}, which is determined from the blade design. Then:

$$P_{Turbine} = \frac{1}{2}\rho A C_{Pmax} v^3 \quad (4)$$

A generic equation is used to model the power coefficient $C_p(\lambda,\beta)$ based on the modeling turbine characteristics described in [6] as:

$$C_p(\lambda,\beta) = c_1\left({}^{c_2}/_{\lambda_i} - c_3\beta - c_4\right)e^{-c_5/\lambda_i} + c_6\lambda \quad (5)$$

With,

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1} \quad (6)$$

The characteristic function $C_p(\lambda,\beta)$ vs λ, for various values of the pitch angle β, is illustrated in Fig.1.The coefficients $c_1 to\ c_6$ are c_1=0.5176, c_2=116, c_3=0.4, c_4=5, c_5=21 and c_6=0.0068.The maximum value of $C_p(\lambda,\beta)$, that is C_{Pmax}=0.48, is achieved for $\beta = 0°$ and for $\lambda = 8.1$. This particular value λ_{opt}results in the point of optimal efficiency where the maximum power is captured from wind by the wind turbine. For each wind speed, there exists a specific point in the wind generator power characteristic, MPPT, where the output power is maximized. Thus, the control of the WECS load results in a variable-speed operation of the turbine rotor,so the maximum power is extracted continuously from the wind (MPPT control).That's illustrated in Fig.2.

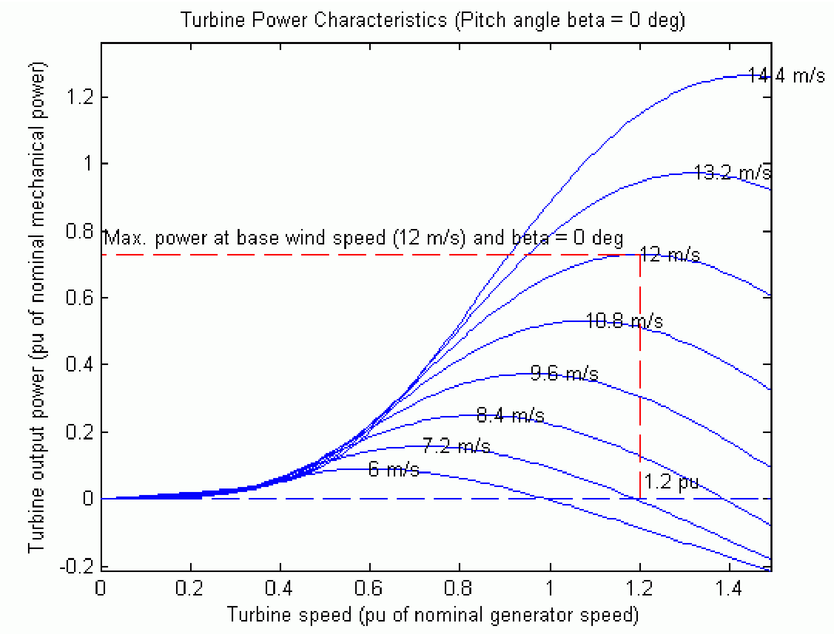


Fig. 2. Wind generator power curves at various wind speed

B. Generator Model

The PMSG has been considered as a system which makes possible to produce electricity from the mechanical energy obtained from the wind. The dynamic model of the PMSG is derived from the two phase synchronous reference frame, which the q-axis is 90° ahead of the d-axis with respect to the direction of rotation. The synchronization between the *d-q* rotating reference frame and the *abc*-threephase frame is maintained by utilizing a phase locked loop (PLL) [7]. Fig. 3 shows the *d-q* reference frame used in a salient-pole synchronous machine (which is the same reference as the one used in a PMSG), where $\theta$is the mechanical angle, which is the angle between the rotor d-axis and the stator axis.

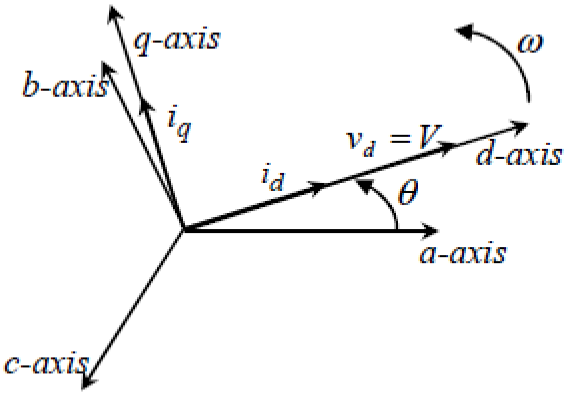


Fig. 3. *abc* and rotating reference frame

The mathematical model of the PMSG for power system and converter system analysis is usually based on the following assumptions [6], [7]: the stator windings are positioned sinusoidal along the air-gap as far as the mutual effect with the rotor is concerned; the stator slots cause no appreciable variations of the rotor inductances with rotor position; magnetic hysteresis and saturation effects are negligible; the stator winding is symmetrical; damping windings are not considered; the capacitance of all the windings can be neglected and the resistances are constant (this means that power losses are considered constant).

The mathematical model of the PMSG in the synchronous reference frame (in the state equation form) is given by [7], [8]

$$v_{gq} = -(R_g + pL_q)i_q - \omega_e L_d i_d + \omega_e \varphi_f \quad (7)$$

$$v_{gd} = -(R_g + pL_d)i_d + \omega_e L_q i_q \quad (8)$$

Where R_g is the stator resistance, L_q and L_d are the inductances of the generator on the d and q axis, φ_f is the permanent magnetic flux and ω_e is the electrical rotating speed of the generator, defined by

$$\omega_e = p\omega_m \tag{9}$$

Where, p is the number of pole pairs of the generator and ω_m is the mechanical angular speed. In order to complete the mathematical model of the PMSG, the expression for the electromagnetic torque can be described as [8]:

$$T_e = \frac{3}{2}p\left[\left(L_d - L_q\right)i_d i_q - \varphi_f i_q\right] \tag{10}$$

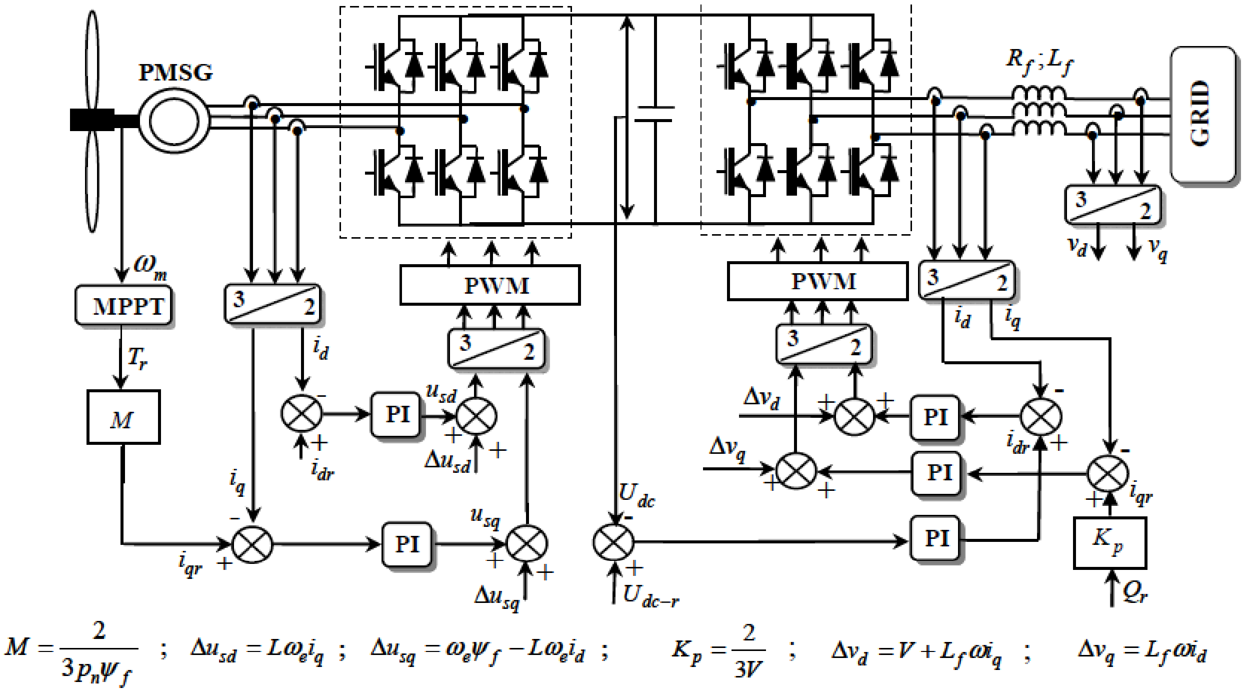
If $i_d = 0$ the electromagnetic torque is expressed as:

$$T_e = -\frac{3}{2}p\varphi_f i_q \tag{11}$$

III. CONTROL OF SYSTEM

A. Control of machine side converter

The generator side three-phase converter is used as a rectifier which uses a vector control strategy and controlling the generator operating at optimum rotor speed ω_{opt} to obtain maximum energy from wind [4]. u_{sq} is obtained by the error of i_{qr} and i_q that is delivered to a PI controller. The d-axis current component i_{dr} is set to zero so that we can get maximum active power from the generator as the magnetizing component of the current will be zero. Voltage feed-forward compensation, Δu_{sd} and Δu_{sd} are added into the control strategy to improve the dynamic response to eliminate the effect of inductance [4], [7]. Finally, PWM is used to produce the control signal to implement the vector control for the generator. The double closed-loop control diagram for generator-side converter is shown as Fig.4.



$$M = \frac{2}{3p_n\psi_f}\ ;\ \Delta u_{sd} = L\omega_e i_q\ ;\ \Delta u_{sq} = \omega_e\psi_f - L\omega_e i_d\ ;\ K_p = \frac{2}{3V}\ ;\ \Delta v_d = V + L_f\omega i_q\ ;\ \Delta v_q = L_f\omega i_d$$

Fig. 4. Schematic diagram of control strategy for generator side and grid side converter [9]

B. Control of grid side converter

The grid side three-phase converter feeds generated energy into the grid, keeps the DC-link voltage constant and adjusts the amount of the active and reactive powers delivered to the grid during load transients or wind variation [4-5]. The DC voltage PI controller stabilize the DC voltage to the reference value. PI controllers are used to regulate the output currents and voltage in the inner control loops and the DC voltage controller in the second loop. In order to compensate the cross-coupling effect due to the output filter in the rotating synchronously reference frame, the decoupling voltages are added to the current controller outputs (see in Fig.6). The vector control scheme used is based on a rotating synchronously reference frame as shown in Fig.5. The angular velocity of the rotating axis system ω is set in the controller and defines the electrical frequency at the load. The voltage balance across the inductor L_f is given by [1], [4]:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = R_f \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L_f \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (12)$$

Where L_f and R_f are the filter inductance and resistance respectively; e_a, e_b and e_c represent voltages at the inverter output; v_a, v_b and v_c represent the grid voltage components voltages; i_a, i_b and i_c are the line currents. A balanced three phase system and their equivalent vectors in a rotating dq reference frame are represented in Fig.5. Transformation in the rotating reference frame is calculated as follows [4-5]:

$$v_d = e_d - R_f i_d - L_f \frac{di_d}{dt} + \omega L_f i_q \quad (13)$$

$$v_q = e_q - R_f i_q - L_f \frac{di_q}{dt} - \omega L_f i_d \quad (14)$$

$$C \frac{dU_{dc}}{dt} = \frac{3}{2}\left(\frac{v_d}{U_{dc}} i_d + \frac{v_q}{U_{dc}} i_q\right) - i_{dc} \quad (15)$$

Where, e_d and e_q are the inverter d-axis q-axis voltage components respectively, v_d and v_q are the grid voltage components in the d-axis q-axis voltage components respectively, U_{dc} is the dc-bus voltage, i_{dc} is the DC-bus current. The instantaneous power in a three phase system is given by:

$$P(t) = v_a i_a + v_b i_b + v_c i_c = [v_a v_b v_c][i_a i_b i_c]^t \quad (16)$$

Using d-q transformation, the active and reactive power is given by:

$$P = \frac{3}{2}\left(v_d i_d + v_q i_q\right) \quad (17)$$

$$Q = \frac{3}{2}\left(v_d i_q - v_q i_d\right) \quad (18)$$

If the grid voltage space vector $\vec{u}$ is oriented on d-axis, then:

$$v_d = V (19)$$

$$v_q = 0 (20)$$

Therefore, equations (18-19) may be expressed below:

$$e_d = R_f i_d + L_f \frac{di_d}{dt} - \omega L_f i_q + V (21)$$

$$e_q = R_f i_q + L_f \frac{d i_q}{dt} + \omega L_f i_d (22)$$

Then the active power and reactive power can be expressed as:

$$P = \frac{3}{2} V i_d (23)$$

$$Q = \frac{3}{2} V i_q (24)$$

Therefore, active and reactive power can be controlled by direct and quadrature current components, respectively. The control strategy for grid-side converter is shown as Fig.6.

There are two closed-loop controls for the active and reactive power. The error signal between the dc-bus reference voltage U_{dc_r} and the detected voltage U_{dc} is used to form reference signal of the d-axis current i_{dr} by PI regulator, but the reference signal of the q-axis current i_{qr} is produced by the reactive power Q_r according to (24) with PI regulator. Finally, the decoupling terms, Δv_d and Δv_q are used. PWM is used to produce the controlsignal to control the grid-side converter.

IV. SIMULATION RESULTS

The system is built using Matlab/Simulink. This paragraph presents the simulated responses of the WECS under variable wind speeds shown as in fig. 5. The parameters of the turbine and PMSG used are given in Table I. The power electronics converter and the control algorithm are also implemented in the model. The direct axis and quadrature axis current component of gird current is show in the fig. 6 & 7. The Quadrature axis current is responsible for the reactive power so it is tends to zero. The dc link voltage is remains constant at 298 V. The inverter voltage, inverter current, grid voltage and grid current with zoom view is shown in fig. 9-15. The active power which is dependent on the direct axis current component is shown as in fig. 16. The reactive power of the grid is shown in the fig. 17.

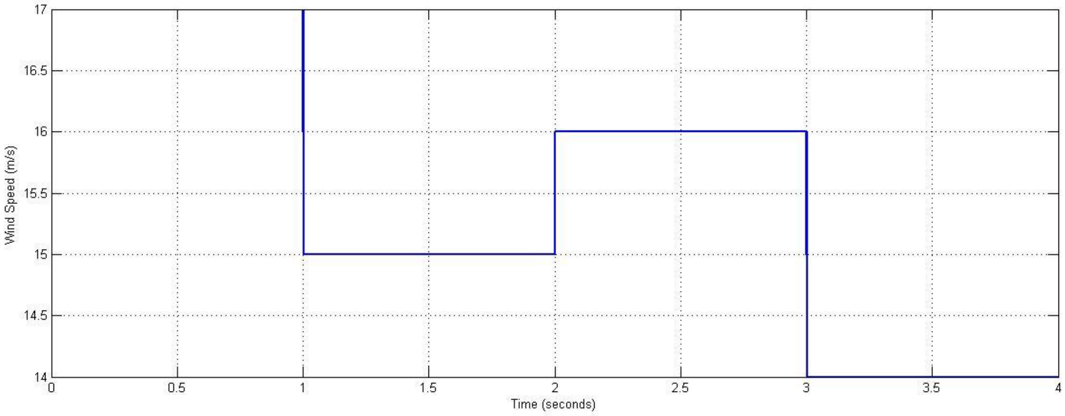


Fig. 5. Different Wind Speed varying with time

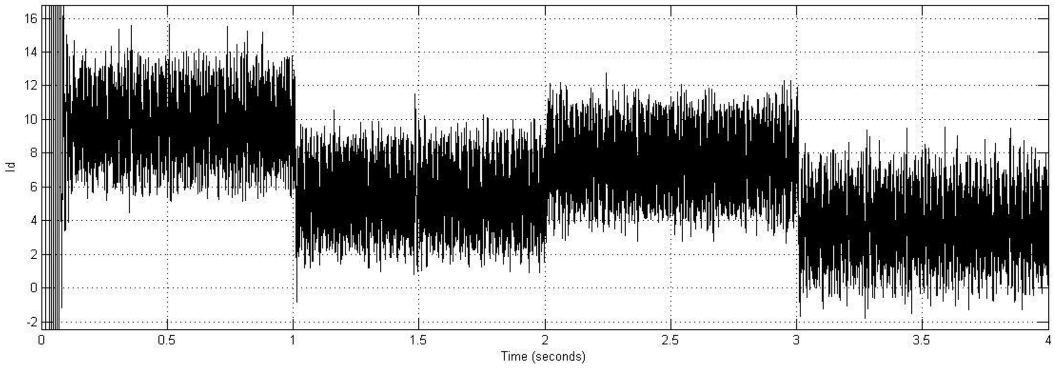


Fig. 6. Direct axis current component I_d of grid current

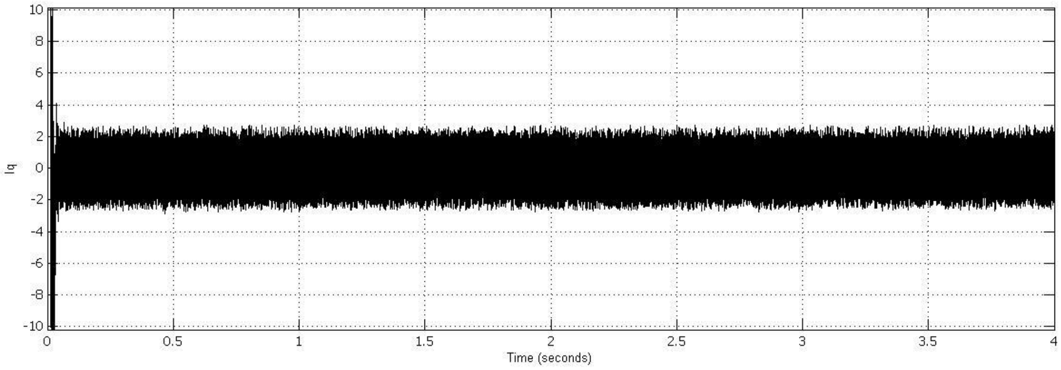


Fig. 7. Quadrature axis current component I_q of grid current

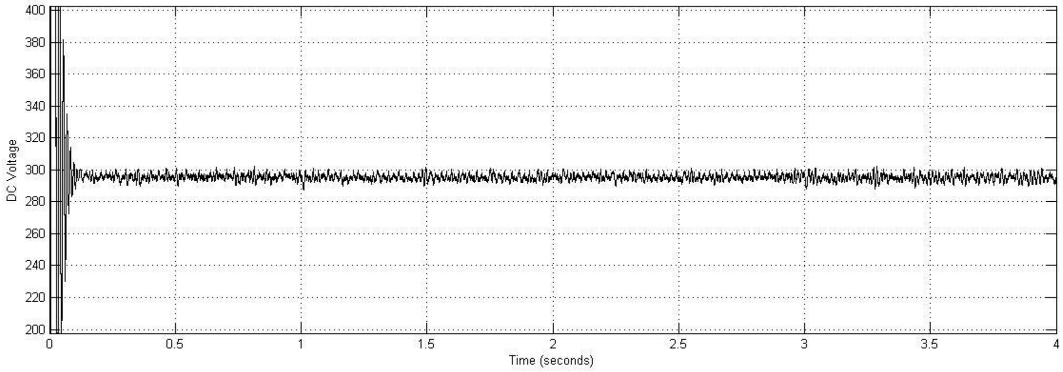


Fig. 8. DC link Voltage

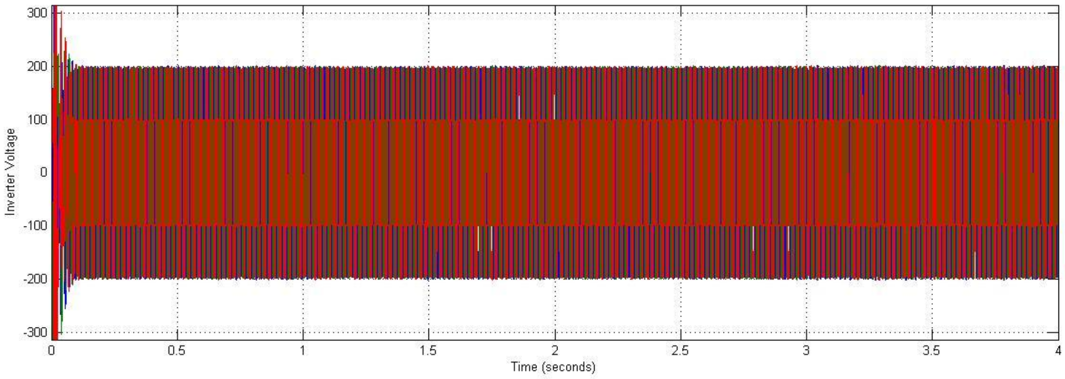


Fig. 9. Inverter Voltage

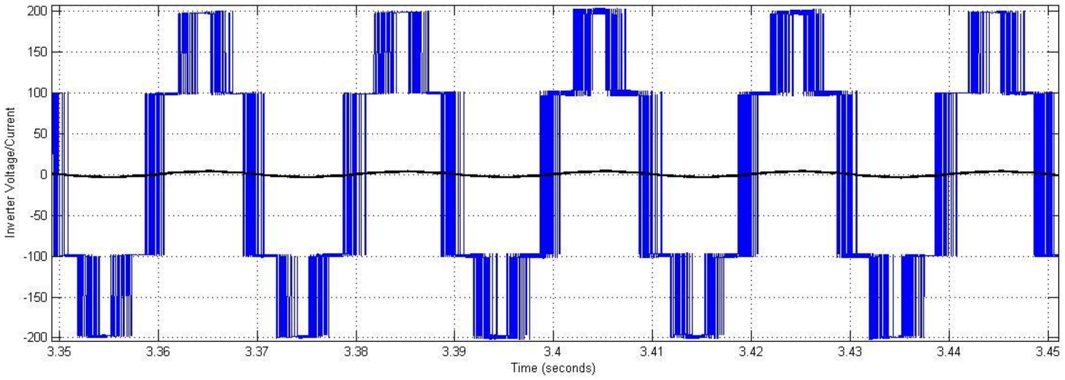


Fig. 10. Inverter Voltage/Current

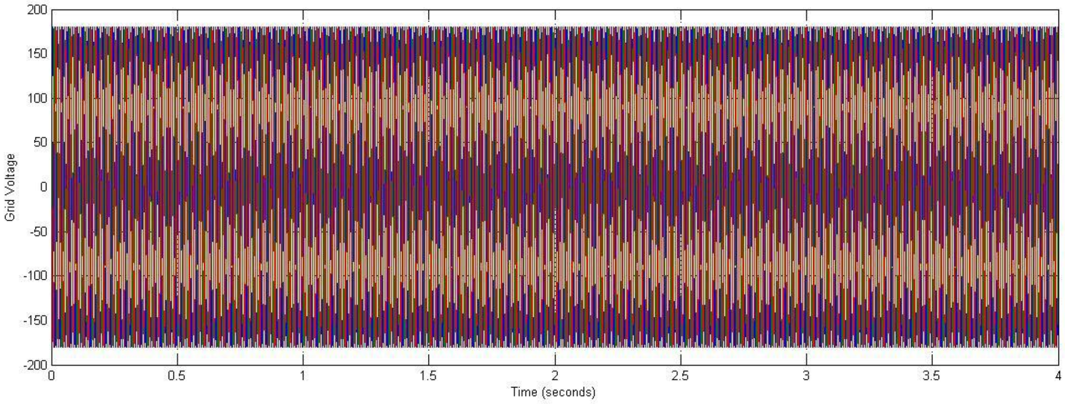


Fig. 11. Grid Voltage

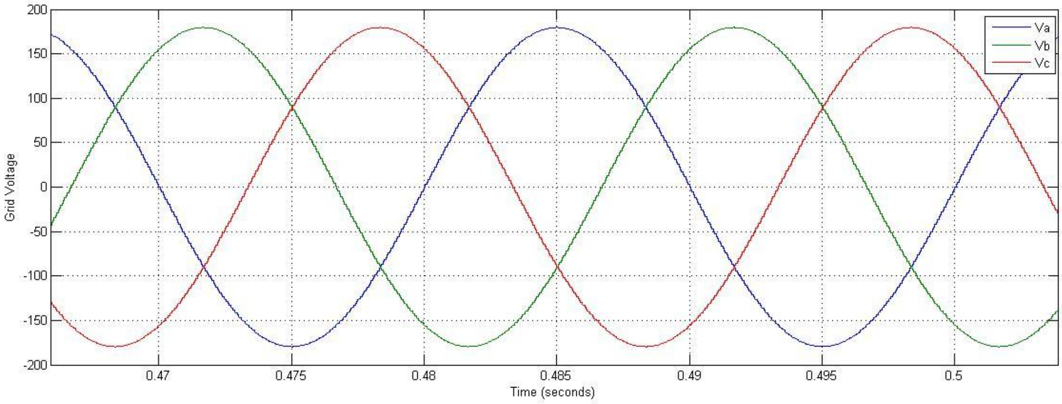


Fig. 12. Grid Voltage zoom view

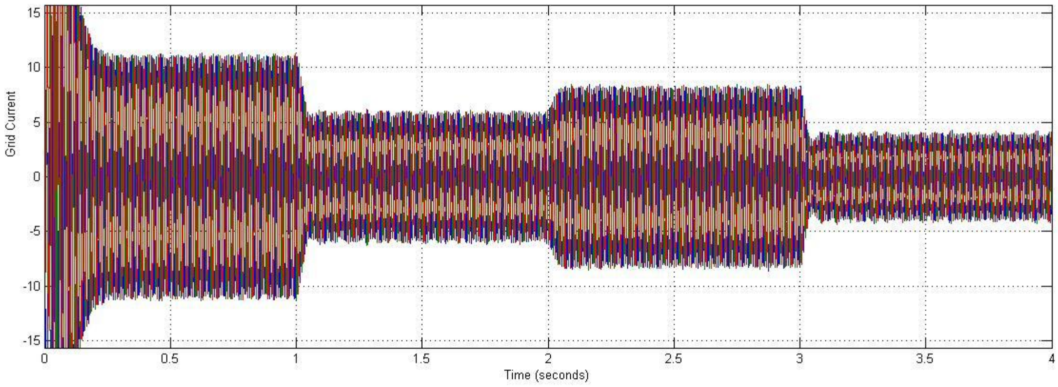


Fig. 13. Grid Current

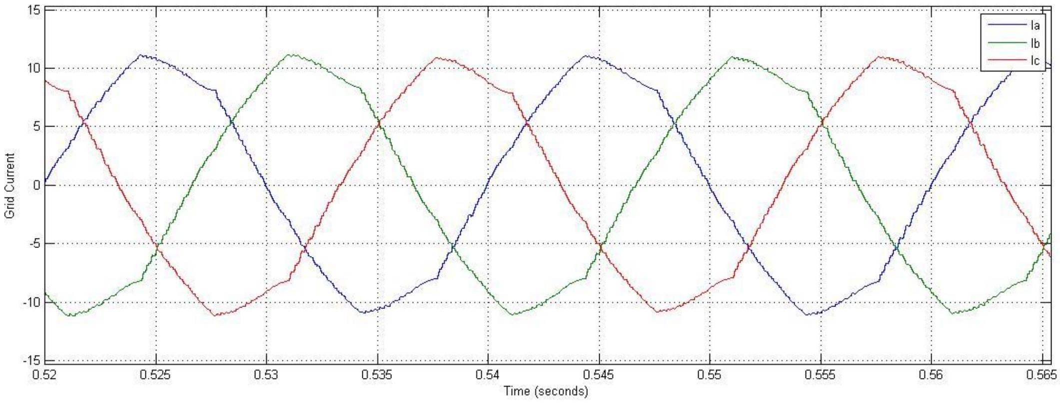


Fig. 14. Grid Current zoom view

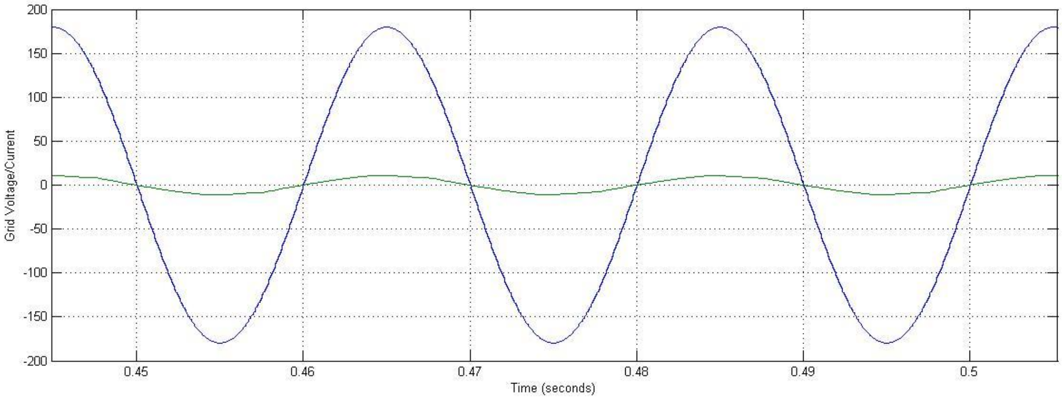


Fig. 15. Grid Voltage/Current

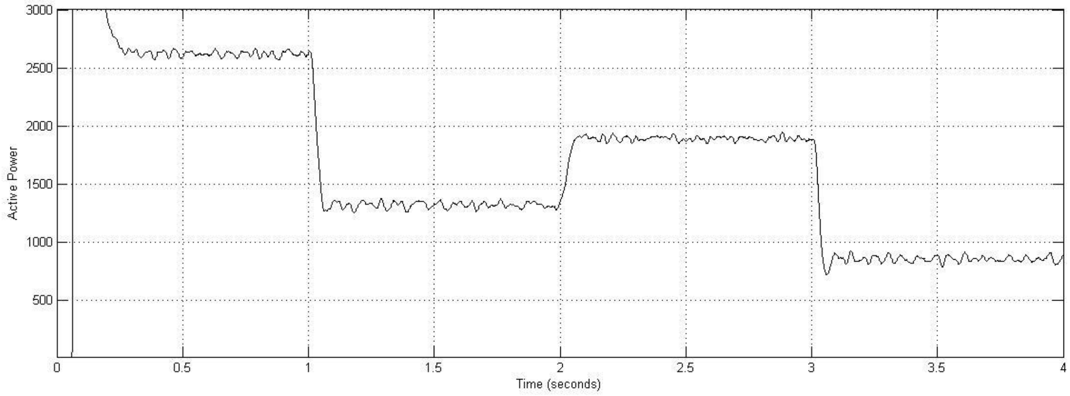


Fig. 16. Active Power of Grid

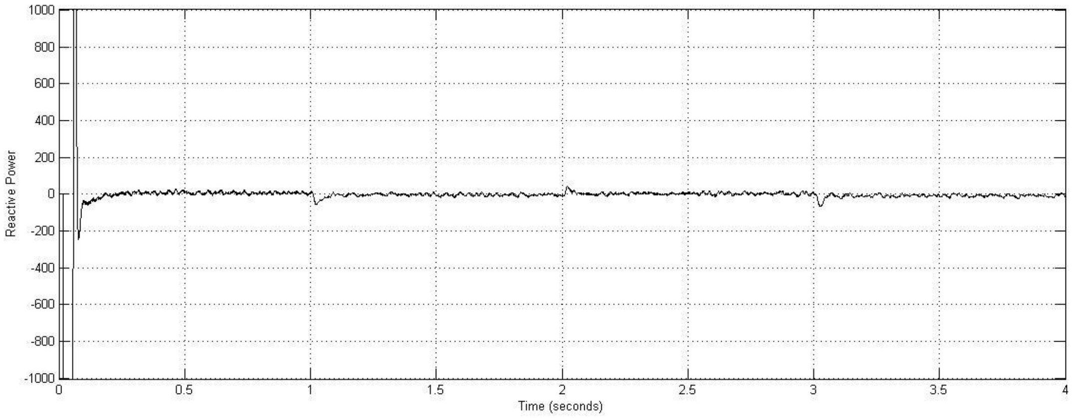


Fig. 17. Reactive Power of Grid

V. CONCLUSION

The modelling and optimum control method of PMSG for wind generation system has been proposed in this paper. A control strategy for the generator side converter is explained but not considered in simulation work. Moreover, the control of dc link voltage and reactive power is simulated in Matlab/Simulink. The results may fulfill the theory of the control strategy of Grid side converter. The grid side PWM inverter is controlled. At constant load and under varying load condition, the controller can maintain the load voltage and frequency quite well.

APPENDIX

No of poles	10
Rated Speed	153 rad/sec
Rated Current	12A
Armature resistance	0.425 Ω
Magnetic flux Linkage	0.433 Wb
Stator inductance Ld and Lq	8.4 mH
Rated Torque	40 Nm
Rated Power	6 kW
Rotor inertia	0.01197 Kg.m^2
Damping co efficient	0.001189 N.m/s

Table 1. Generator Data

REFERENCES

[1] G. Poddar, A. Joseph and A. K. Unnikrishnan, ”Sensorless Variable-Speed Wind Power Generator With Unity-Power-Factor Operation,” IEEE Trans.Ind. Electron., vol. 50, pp. 1007-1015, Oct. 2003.

[2] J. Carrasco, L. Franquelo, J. Bialasiewicz, E. Galvan, R. Guisado, M. Prats, J. Leon and N. Moreno-Alfonso, ”Power-electronic systems for the grid integration of renewable energy sources: A surey,” IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002-1016, Jun. 2006.

[3] H. Polinder, F. F. A. Van der pijl, G. J. de Vilder and P.J. Tavner, “Comparison of direct drive and geared concepts for wind turbines,” IEEE Trans. On energy conversion, vol. 21, no. 3, pp. 725-733, Sept. 2006.

[4] S. Morimoto, H. Nakayama, M. Sana and Y. Takeda, “Sensorless Output Maximization Control for Variable Speed Wind Generation System Using IPMSG,” IEEE Trans. On Industrial Application, vol. 41, no. 1, pp. 60-67, Jan. 2005.

[5] M. E. Haque, K. M. Muttaqi and M. Negnevitsky, “Control of a Stand Alone Variable Speed Wind Turbine With a Permanent Magnet Synchronous Generator,” IEEE Power and Energy Society General Meeting, pp. 20-24, July 2008.

[6] A. Rolan, A. Luna, G. Vazquez, D. Aguilar and G. Azevedo, “Modeling of a Variable Speed Wind Turbine with a Permanent Magnet Synchronous Generator,” IEEE Internation Symposium on Industrial Electronics, pp. 734-739, July 2009.

[7] M. Yin, G. Li, M. Zhou and C. Zhao, “Modelling of the Wind Turbine with a Permanent Magnet Synchronous Generator for Integrate,” IEEE Power Engineering Society General Meeting, pp. 1-6, June 2007.

[8] Y. Weizheng, K. Woo, Z. Ruijie, G. Wei, and Wang Yue, “Analyze of current control strategy based on vector Control for Permanent-Magnet Synchronous Generator in Wind Power System,” IEEE Power Electronics and Motion Control Conference, pp. 2209-2212, May 2009.

[9] Y, Errami, M. Ouassaid,“Modelling and Control Strategy of PMSG Based Variable Speed Wind Energy Conversion System,” IEEE Multimedia Computing and Systems (ICMCS), pp. 1-6, 2011.

[10] K. Patil, B. Mehta,”Modeling and control of variablespeedwindturbine with permanentmagnetsynchronousgenerator,”IEEE Advances in Green Energy (ICAGE), pp. 258-264, 2014.