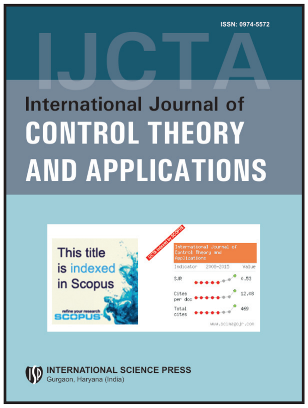

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Power Maximization and Control of PMSG Wind Energy System without Wind Speed Sensors

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Abstract: In this paper power maximization and control of back-to back converters connected PMSG wind energy system without Wind speed sensors is studied**.** The grid side converter is controlled by Voltage oriented control (VOC) and the generator is controlled by using zero d-axis current control (ZDC) scheme along with optimal torque control (OTC). Linear association between stator current and generator torque is obtained by using ZDC control and VOC is used to control the grid connected inverter. With this technique transformation is carried out between *abc* stationary frame of reference and *d-q* synchronous frame. Simulation results are presented for 2MW/ 690V Non-Salient Pole PMSG using MATLAB/SIMULINK.

Keywords: Permanent Magnet Synchronous Generator (PMSG); Zero d- axis Current (ZDC); Voltage Oriented Control (VOC); Sinusoidal Pulse Width Modulation (SPWM); Wind Energy Conversion System (WECS).

1. INTRODUCTION

Owing to exhausting fossil fuels, raise in cost and global warming, renewable energy sources have turned up as a new criterion to fulfill the society energy requirements[1]. The electricity generation from the wind, hydro, geothermal, solar, tidal, biomass and wave energy sources are drawing more attention these days[2, 3].

In the meantime, few renewable energy sources are made economical in market because of the advancement in the technology, reduction in the cost, and governmental encouragements. Among them, wind energy is one of the fastest budding sources of energy[4].

The two main electrical components of the WECS are power converter and generator. Different designs of the two components show the way to a broad range of configurations of WECS, are classified as: fixed-speed without power converter interface, using reduced-capacity converters, and with full-capacity converter[5]. Among the prevailing WECS, its generators are of four types[6, 7]: doubly fed induction generator (DFIG), squirrel cage induction generator (SCIG), PMSG and the wound rotor synchronous generator. These days, the WECS with PMSG is used for direct grid- connection because it has no slip ring maintenance and gives higher efficiency. Thus, the low maintenance and lightweight characters can be acquired in this kind of WECS[8,9].

The control scheme used to control the generator is ZDC control to attain linear association between stator current and generator torque[10, 11]. ZDC control can provide a simple solution and outstanding generator incorporation performance like easy control algorithm, maximum efficiency generation, and system losses minimization. On the other hand, ZDC control is not appropriate for synchronous generators with salient-pole[11].

VOC is used to control the grid connected inverter. With this technique transformation is carried out between *abc* stationary frame of reference and *d*-*q* synchronous frame.

The major objectives of the paper are to implement VOC with a decoupling controller for grid-connected converter; to design sinusoidal pulse width modulation scheme for grid- and generator-connected converters; and finally to implement ZDC control scheme for full-scale power converter based variable-speed, direct-drive non-salient PMSG WECS.

2. SYSTEM DESCRIPTION

The arrangement of back-to-back converters connected PMSG WECS is shown in Figure 1. By means of a supplementary inverter, with PMSG can supply ac power with constant frequency and voltage to grid[12]. The control schemes of generator side and grid side converters are presented in later sections.

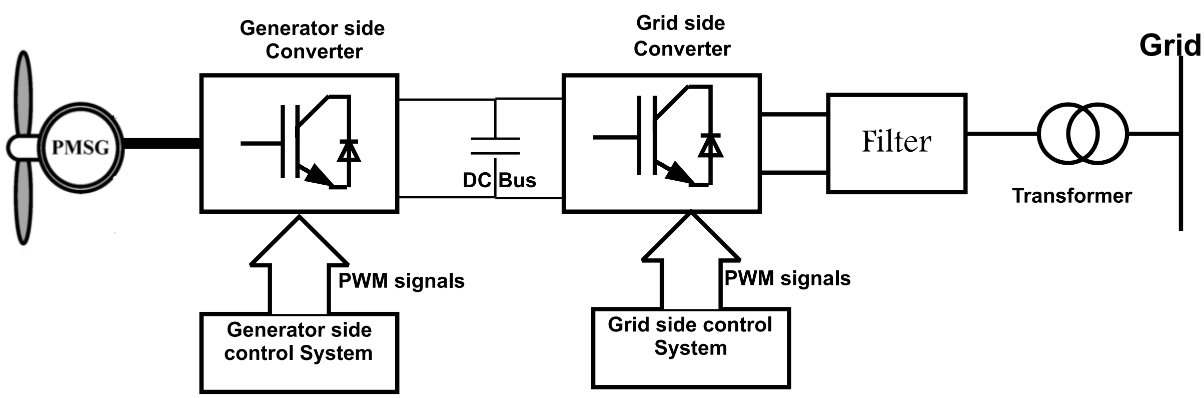

Figure 1: PMSG wind energy conversion system with back to back converters

2.1. PMSG Modelling

Generator is modeled in rotor field synchronous frame of reference. The voltage equations are

$$v_{ds} = -R_s i_{ds} - \omega_r \lambda_{qs} + p\lambda_{ds} \tag{1}$$

$$v_{qs} = -R_s i_{qs} - \omega_r \lambda_{ds} + p\lambda_{qs} \tag{2}$$

where, λ_{ds} and λ_{qs} are stator flux linkages along *d*-axis and *q*-axis, given by

$$\lambda_{ds} = -L_d i_{ds} + \lambda_r \tag{3}$$

$$\lambda_{qs} = -L_q i_{qs} \tag{4}$$

where, λ_r is rotor flux, L_d and L_q are stator *dq*-axis self-inductances. Substituting (3), (4) in (1), (2) and for constant field current I_f, We have

$$v_{ds} = -R_s i_{ds} + \omega_r L_q i_{qs} - L_d p i_{ds} \tag{5}$$

$$v_{qs} = -R_s i_{qs} - \omega_r L_d i_{ds} + \omega_r \lambda_r - L_q p i_{qs} \tag{6}$$

based on the above equations, PMSG simplified model is represented in Figure 2. The torque can be calculated by

$$T_e = \frac{3P}{2}\left[i_{qs}\lambda_r - \left(L_d - L_q\right)i_{qs}i_{ds}\right] \tag{6}$$

P is pole pairs.

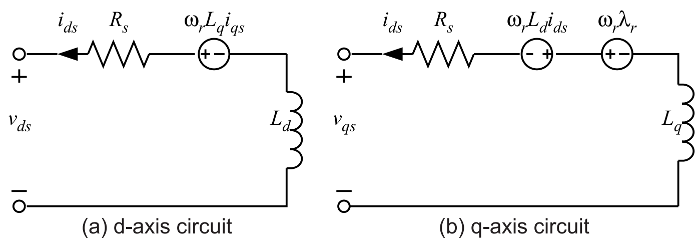

Figure 2: Simplified PMSG model

3. OPTIMAL TORQUE CONTROL

The generator is controlled under the rated speed of wind by controlling the variable speed wind turbine. Maximizing the power capture at different speeds is the main objective which is achieved by turbine speed adjustment. The power curve is represented by the trajectory of maximum power points, which is described by

$$P_M \propto \omega_M^3 \tag{7}$$

In terms of torque power captured by the turbine is

$$P_M = T_M \omega_M \tag{8}$$

where, T_M is the turbine mechanical torque. From (8) & (9)

$$T_M \propto \omega_M^2 \tag{9}$$

MPPT scheme, with OTC is realized by computing the desired torque reference T_e^*[13].The optimal torque coefficient (K_{opt}) can be estimated from the generated rated parameters. Wind speed sensors are not required in this scheme. With the reduction in the wind speed, the turbine torque decrease and based on this active power output from wind system and the inverter current declines[14].

4. GENERATOR SIDE CONVERTER CONTROL

The generator side control scheme is presented in Figure 3. Using MPPT method the generator torque reference T_e^* is generated in accord with the measured generator speed ω_m. The *d*-axis current component i_{ds} is made zero [6]. With zero *d*-axis current, stator current is equal to *q*-axis current.

$$i_s = i_{qs} \tag{10}$$

where, i_s, is the space vector of stator current. With zero *d*-axis current the torque equation (7) becomes

$$T_e = \frac{3P}{2}\left[i_s \lambda_r\right] \tag{11}$$

The above equation shows that, the generated torque is directly proportional to stator current i_s.The reference torque T_e^* is obtained from MPPT controller and torque producing component i_{qs}^* is calculated from (12).

$$i_{qs}^{*} = \frac{2T_{e}^{*}}{3P\lambda_{r}} \tag{12}$$

The position angle of rotor flux θ_r is to be found for rotor flux field orientation. Three phase currents are measured and are then transformed into i_{ds} and i_{qs} using abc/dq transformation. These currents are compared with i_{ds}^* and i_{qs}^* the corresponding errors are processed by the controllers to generate v_{ds}^* and v_{qs}^* for rectifier. By controlling the rectifier using PWM technique active power is controlled.

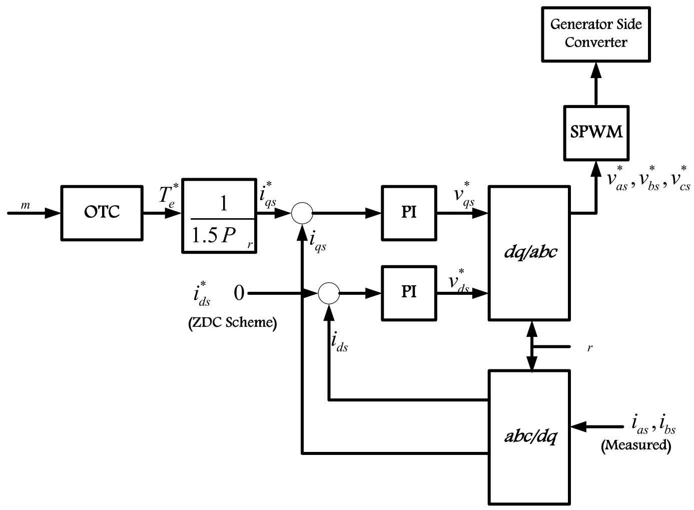

Figure 3: Generator side converter control scheme

5. CONTROL OF THE CONVERTER ON GRID SIDE

Grid side converter controls the reactive power and the DC link voltage v_{dc}. Phase locked loop tracks grid voltage vector and generates the angle θ_g. The grid side converter control scheme block diagram is shown in Figure 4.

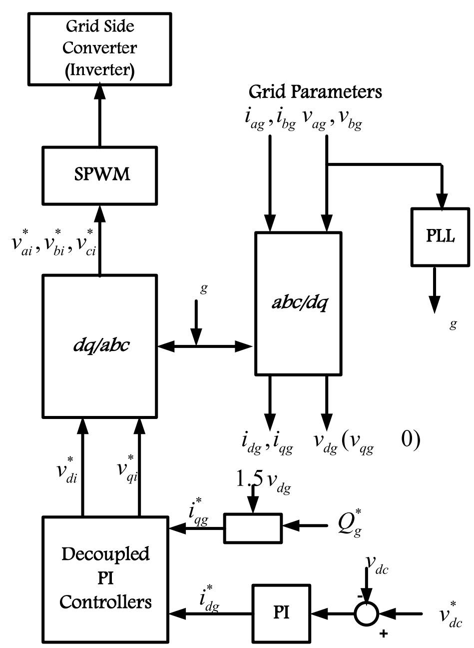

Figure 4: Grid side converter control scheme

The *d*-axis of the synchronous frame is aligned with the grid voltage vector to obtain the VOC scheme, therefore ($v_{dq} = v_g$), and *q*-axis voltage v_g is then zero, from which the reactive and active power obtained using:

$$P_g = \frac{3}{2} v_{dg} i_{dg} \tag{3}$$

$$Q_g = -\frac{3}{2} v_{dg} i_{qg} \tag{4}$$

The *q*-axis reference current will be obtained from

$$i_{qg}^* = -\frac{2}{3} \frac{Q_g^*}{v_{dg}} \tag{15}$$

Considering inverter losses negligible, inverter AC side real power is

$$P_g = \frac{3}{2} v_{dg} i_{dg} = v_{dc} i_{dc} \tag{16}$$

The DC reference voltage can be obtained from

$$V_{dc}^* = \frac{\sqrt{6}\, V_{ail}}{m_a} \tag{17}$$

where, V_{ail} is inverter line voltage and m_a is modulation index.

6. SIMULATION RESULTS

The performance of non-salient PMSG WECS with ZDC control of the converter on the generator-side and VOC of the converter on grid side with SPWM for both converters was simulated in the Matlab/Simulink software. PMSG parameters used for the simulation are given in table I. Generator side wave forms during start up are shown in Figure 5. At 0.4 seconds generator torque T_e starts to increase. T_e follows T_e^* and rises to rated value (1 pu) at 1.4 sec.

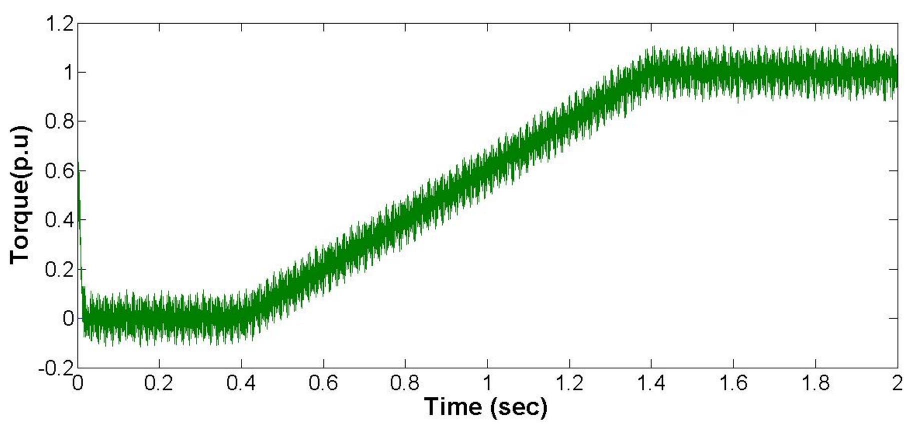

Figure 5: (a) Generator torque waveform during start up

The *d*-axis stator current i_{ds} and *q*-axis stator current i_{qs} are DC values in steady state as they are in the rotor flux synchronous frame are shown in Figure 5(b).

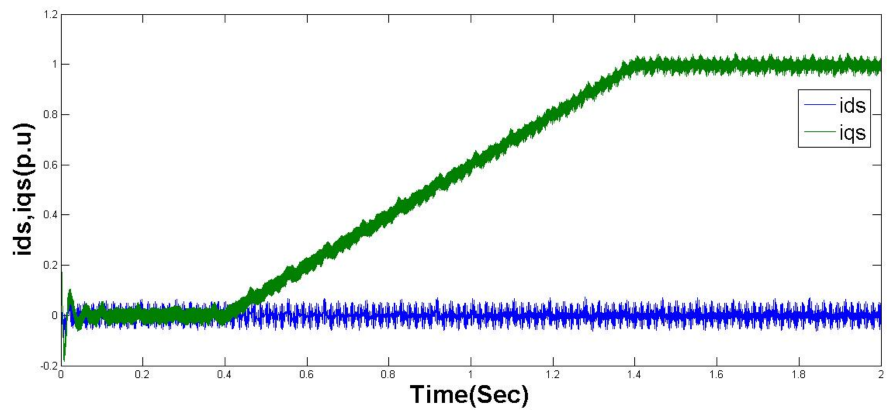

Figure 5: (b) Generator *d*- and *q*-axis currents

Phase *a* current of generator i_{as}, is shown in the Figure 5 (c). Its amplitude is proportional to i_{qs}.

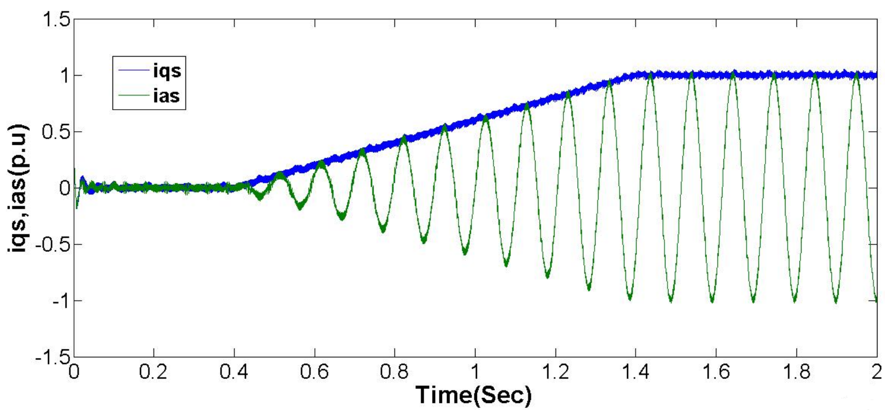

Figure 5: (c) Generator a phase current

Figure 6. shows DC voltage v_{dc} which is retained at its reference value of 2.15 pu during transient and also steady state by inverter.

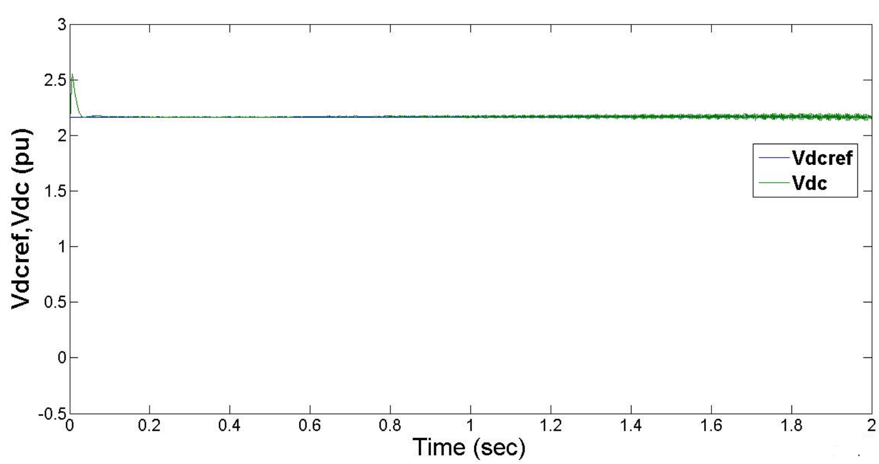

Figure 6: DC link voltage in p.u.

For unity power factor operation, Q_g is maintained at zero on grid side. The Grid active power P_g is shown as negative value in Figure 7, pointing out the power flow is from inverter to the grid.

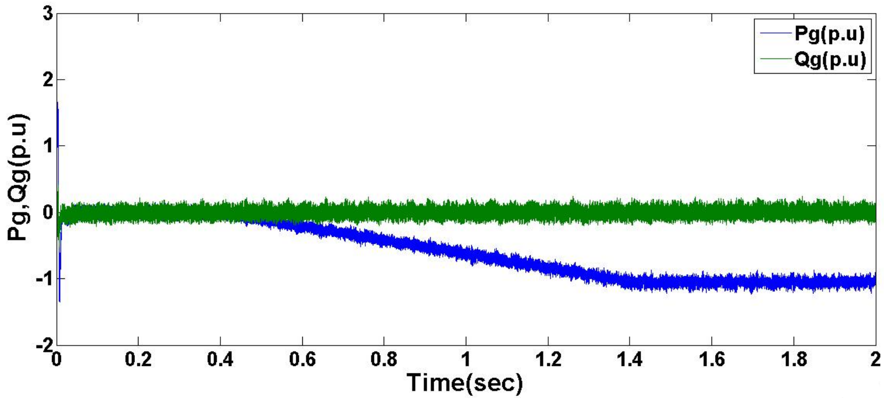

Figure 7: Active power and reactive power on the grid side

Amplitude of phase–a grid current is depicted in Figure 8. It is found that, it is proportional to the active power.

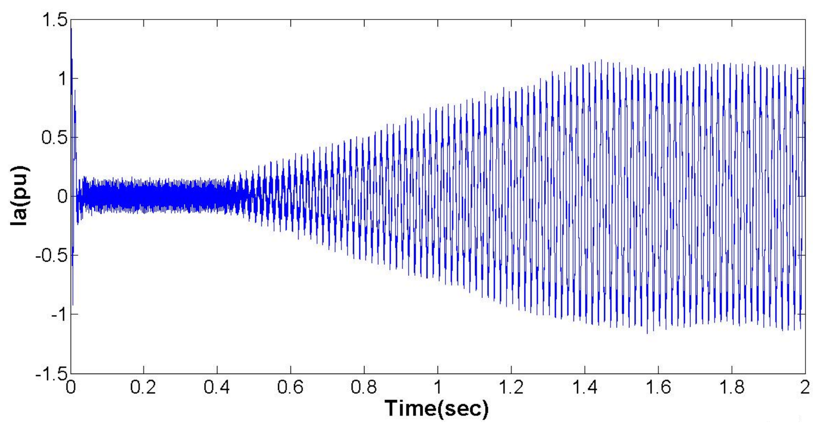

Figure 8: Amplitude of Phase a grid current in pu

7. CONCLUSIONS

In this paper, performance of back-to back PWM converters connected PMSG based WECS was analysed. VOC is used for grid-connected converter along with SPWM scheme. The generator was controlled by ZDC control scheme along with OTC. For the improved operation of generator, the control strategy was developed while deriving the maximum power. With vector control of the converter on the generator, the *q*- axis and *d*-axis stator current are decoupled. The analysis was presented with simulation results.

Table 1
PMSG Parameters

PMSG, 2.0MW/690V/9.75Hz, Non-Salient Pole		
Rated Mechanical Power	2.0 MW	1.0 pu
Rated Apparent Power	2.2419 MVA	1.0 pu
Rated Line-to-line Voltage	690V rms	
Rated Stator Current	1867.76 A (rms)	1.0 pu
Rated Stator Frequency	9.75 Hz	1.0 pu
Rated Power Factor	0.8921	

PMSG, 2.0MW/690V/9.75Hz, Non-Salient Pole		
Rated Rotor Speed	22.5 rpm	1.0pu
Number of Pole Pairs	26	
Rated Rotor Flux Linkage	5.8264 Wb (rms)	0.896 pu
Stator Winding Resistance Rs	0.821 mΩ	0.00387 pu
d-axis Synchronous Inductance Ld	1.5731 mH	0.4538 pu
q-axis Synchronous Inductance Lq	1.5731 mH	

REFERENCES

[1] V. Yaramasu, B. Wu, P. C. Sen, S. Kouro, and M. Narimani, High-Power Wind Energy Conversion Systems : State-of-the-Art and Emerging Technologies. Proc. IEEE, Vol. 103, No. 5, pp. 740–788, 2015.

[2] S. R. Bull. Renewable energy today and tomorrow. *Proc. IEEE*, Vol. 89, No. 8, pp. 1216–1226, 2001.

[3] I. Dincer.Renewable energy and sustainable development: a crucial review. *Renew. Sustain. Energy Rev.*, Vol. 4, No. 2, pp. 157–175, 2000.

[4] F. Blaabjerg and Z. Chen, *Power Electronics for Modern Wind Turbines (Synthesis Lectures on Power Electronics)*. 2006.

[5] Z. Chen, J. M. Guerrero, F. Blaabjerg, and S. Member. A Review of the State of the Art of Power Electronics for Wind Turbines. IEEE Trans. Power Electron., Vol. 24, No. 8, pp. 1859–1875, 2009.

[6] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, S. S. Member, E. Galván, R. C. P. R. C. P. Guisado, M. Ángeles, M. M. Prats, J. I. León, N. Moreno-alfonso, E. Galvan, M. Angeles, and J. I. Leon,Power-Electronic Systems for the Grid Integration of Renewable Energy Sources : A Survey. *IEEE Trans. Ind. Electron.*, Vol. 53, No. 4, pp. 1002–1016, 2006.

[7] A. Grauers. Efficiency of three wind energy generator systems. *IEEE Trans. Energy Convers.*, Vol. 11, No. 3, pp. 650–655, 1996.

[8] Z. Chen and E. Spooner. Wind Turbine Power Converters: a Comparative Study. Proc. 1998 IEE Power Electron. Variable Speed Drives Seventh Int. Conf., 1998, No. 456, pp. 21–23.

[9] M. Chinchilla, S. Arnaltes, and J. C. Burgos.Control of Permanent-Magnet Generators Applied to Variable-Speed Wind-Energy Systems Connected to the Grid. *IEEE Trans. Energy Convers.*, Vol. 21, No. 1, pp. 130–135, 2006.

[10] K.H.K. Huang, S.H.S. Huang, F.S.F. She, B.L.B. Luo, and L.C.L. Cai.A control strategy for direct-drive permanent-magnet wind-power generator using back-to-back PWM converter.*2008 International Conference on Electrical Machines and Systems*, 2008, pp. 2283–2288.

[11] Bin Wu, Yongqiang Lang, Navid Zargari, Samir Kouro.Power Conversion and Control of Wind Energy Systems,willey IEEE Press book, 2011.

[12] S. Sh and J. Srikakolapu, “PMSG Based Grid Integrated Wind Energy Conversion System with Controlled Power Injection,” in *Power India International Conference (PIICON), 2014 6th IEEE*.

[13] R. M. Linus.Maximum Power Point Tracking of PMSG based Grid Connected WECS using Quadrature Axis Current. International Conference onRenewable Energy Research and Applications (ICRERA), 2015, 2015, Vol. 5, No. 1, pp. 671–676.

[14] Maziar Izadbakhsh, Alireza Rezvani , Majid Gandomkar and Sohrab Mirsaeidi. Dynamic Analysis of PMSG Wind Turbine under Variable Wind Speeds and Load Conditions in the Grid Connected Mode. Indian Journal of Science and Technology, Vol. 8(14), July 2015.