Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Maximum Power and Power Quality Control of PMSG Based Wind Energy Conversion System

Lavkesh Kumar Prajapati [1] and Namrata sant [2]

lavkesh571997@gmail.com *and* santnamrata82@gmail.com

[1] *PG Scholar, Department of Electrical & Electronics Engineering", Bhopal Institute of Technology, Bangrasiya Bhopal, (M.P.)*

[2] *Prof. Department of Electrical & Electronics Engineering", Bhopal Institute of Technology, Bangrasiya Bhopal, (M.P.)*

***Abstract*—This research article presents maximum power and power quality control of wind energy conversion system (WECS) that is coupled with permanent magnet synchronous generator (PMSG). The WECS has developed for grid connected mode to supply power of PMSG to grid. The PMSG is obtained maximum power point (MPPT) in variable wind speed conditions. The MPPT is obtained by the control of PMSG side voltage source converter (PVSC) control. However generated PMSG power is injected to the grid by control of grid side VSC (GVSC) This GVSC provide power to the grid with international standard as well as their grid code in grid synchronization manner. It improves power quality on grid voltage and injected grid current i.e. total harmonics distortion (THDs) has been improve. The proposed system and its developed control algorithm is proves, using soft tools MATLAB 2015a software using sim power system toolbox and perforce validated through the simulations results**

***Index Terms*— permanent magnet synchronous generator (PMSG), maximum power point tracking (MPPT), Voltage Source Converter (VSC), machine side converter (MSC), grid side converter (GSC) and Wind energy conversion system (WECS)**

I. Introduction

The demand for electricity is growing drastically as well will continue to increase. It is predicted that from 2007 to 2035 Global electricity production will increase by 87%, in an average of 2.3% per annum [1]. Due to the limit of fossil fuel and the negative effect of hot fuel consumption sustainable energy (SERs) is increased by energy production. These days, the use of renewals is rapidly growing in the electricity production, in the reference case, grows by an average annual rate of 3.6% during the period 2018 to 2050 [2]. Years ago, among many SERs for example Wind Energy, Solar Energy, Biomass etc., wind power is growing rapidly. On general economic account and new power, it was the least expensive type of sustainable energy [3] - [4]. In wind energy conversion system (WECS) various type of machines are used for example induction machine (squirrel cage, doubly fed induction generator), permanent magnet synchronous generator (PMSG) etc. [5]

Recently MPSG are commonly used in WECS due to its power generation capability with following features such as,

- Power generate at low speed,
- Light weight.
- Les maintenance

However its cost is higher and less robust than other used generator [6]. Moreover PMSG control is simple than other generator to obtained MPPT from nature. Its control is possible under fixed speed or variable operation with direct connect with turbine. Therefore voltage control of PMSG is designed to convert electrical energy [7-8].

In the proposed research back-back VSC have been connected, first one is MPSG side VSC known as PVSC and another one is grid side voltage source converter (GVSC). The power quality issues may be eliminated by the control of these power converters [9]. The power quality issues like that Power Fluctuations, Voltage Fluctuations, Frequency Fluctuations, Harmonics, and Fault Ride through Capability etc. [10-11].

There are various control scheme have been reported for WECS control such as[12-14], Field oriented control (FOC) and direct power control (DPC) are many common control strategies now. In addition to the stable good performance and dynamic performance of FOC, is complex due to PI adjustment problems. On the other hand, DPC offers the best performance, simplification of control structure, and durability compared to control parameters variation. However, the harmonic spectrum of the current ad is large and varied change frequency is a complex filter formation. Here PI controller less with MPPT tracking capability of WECS control has been developed.

Same as various controls are reported for GVSC control such as Finite control Set model predictive control (FCS-MPC) [15]. However, quality work needs to be improved in order to improve current spectrum. Also, the model predicts direct torque control without use the weight gain of the PMSG wind energy system is studied in [16], which is a reduction computer time and overcomes the effect of parameter variations. Moreover, it is fixed changing the frequency of the FCS-MPC algorithm that compensates for system delays by a two-level conversion application.

II. WECS MODELLING

The PMSG based WECS system has consists of a two insulated-gate-bipolar transistor (IGBT) based three phase three leg back-back connected voltage source converter (VSC). One is connected with PMSG; moreover second one is connected with to utility-grid. The PVSC and GVSC are two-level converters consisting of six cells; each comprises an IGBT in parallel with a diode. Its subsections, provides complete modeling of the proposed WECS.

A. Wind turbine modeling

A full-blown turbine (FBT) using a PMSG is preferred for low maintenance and its low operating costs [5]. In a wind turbine conversion system (WECS), wind power is converted into electricity with the help of wind turbines and PMSG, in the proposed research work a PMSG is used to convert electricity into electricity. In WECS modeling follows key statistics used,

Energy containing uninterrupted air is in the form of kinetic energy then,

$$E = \frac{1}{2}mv^2 \qquad (1)$$

Where *m* and *v* are rate of flow of wind and speed of undisturbed wind respectively, and the rate of flow of wind is the function of air density, area through wind is passing and speed of wind then the power contains in undisturbed wind can be also written as[17],

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

Where ρ and A are the density of wind and swept area of wind turbine respectively

Power output from the wind turbine is given as[18],

$$P = \frac{1}{2} r A v^3 C_p \qquad (3)$$

$$P = \frac{1}{2} r \Pi R^2 \left(\frac{wR}{l}\right)^3 C_p \qquad (4)$$

Where λ is tip speed ratio it is depends on wind speed length of blade and generator angular speed in the case of direct driven wind turbine. And C_p is the betz limit its optimums value is 0.49. Characteristic of wind turbine is shown in Fig. 1

B. Modeling of Permanent Magnet Synchronous Generator (PMSG)

Analyzing the equivalent PMSG circuit commonly modeled in a compatible reference frame. The PMSG rotor circuit model has no field folds and can therefore be replaced with a current fixed source of a fixed size

The following mathematical manipulation can be made. The voltage equation of PMSG by the synchronized reference framework is provided by [19]

$$V_{ds} = -(I_{ds}R_s + w_r l_{qs} - \frac{dl_{ds}}{dt}) \qquad (5)$$

$$V_{qs} = -(I_{qs}R_s - w_r l_{ds} - \frac{dl_{qs}}{dt}) \qquad (6)$$

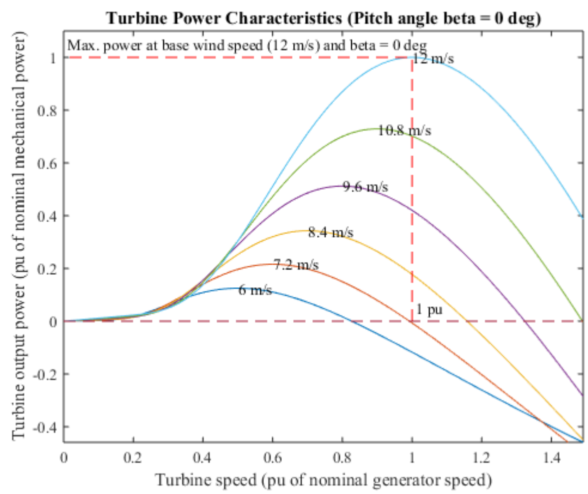


Fig. 1Wind turbine characteristic

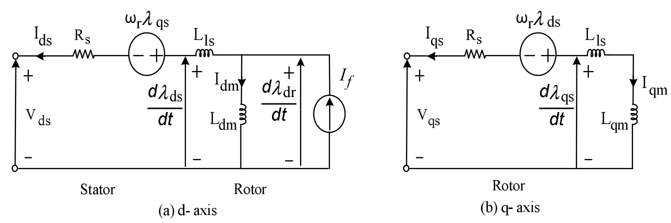


Fig.2 Equivalent circuit of PMSG in synchronous reference frame

III. CONTROL OF PROPOSED SYSTEM

Installing a control algorithm, hearing from others Signs are required. These signals are the third phase voltages of PMSG currents (v_a, v_b and v_c), and grid line currents (i_a, i_b and i_c). To performing high speed control to achieve maximum power from WECS speed generating. Also the proposed suspension of the scheme is shown in Figure 3

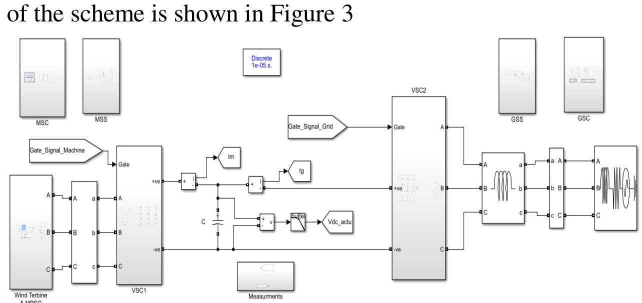


Fig. 3 Proposed System modeling

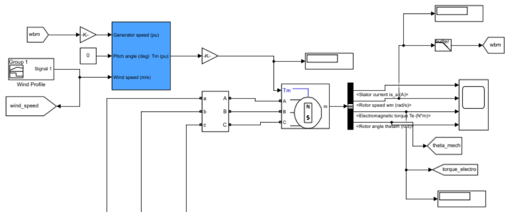
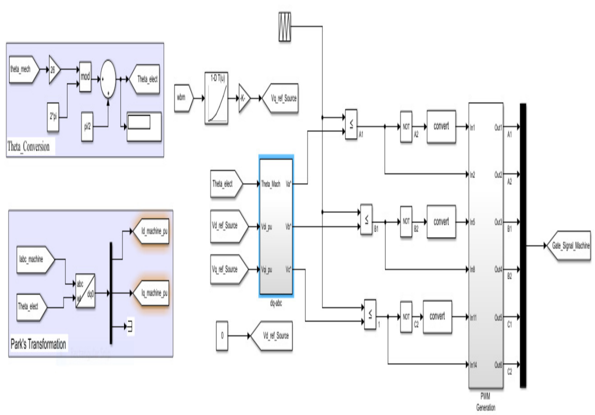


Figure 4 WT and MPSG

A. Machine side converter control

The MSC controller must conform, the MPPT operation with control of the speed of the wind turbine. Therefore, those electric torque generators should be controlled. Depending on the type of generator used inside the wind turbine, the structure of the controller will vary. Stop donating to that one wooden camera performs different exchange calculations for example, such as DTC, vector control et cetera for different purposes. Figure 5(a) shows the control frame representation of the variable on the generator side of the recommended frame. And Figure 5(b) shows the it's internal parts



(a)

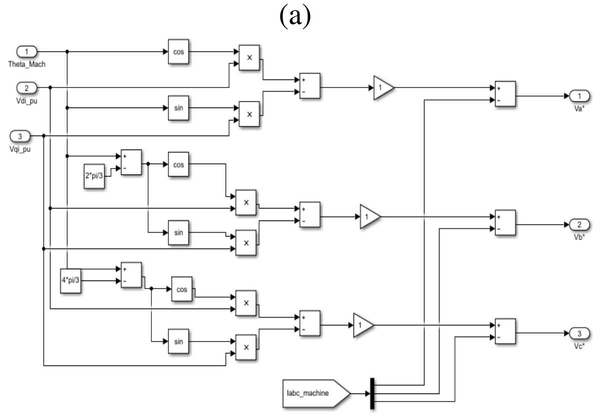
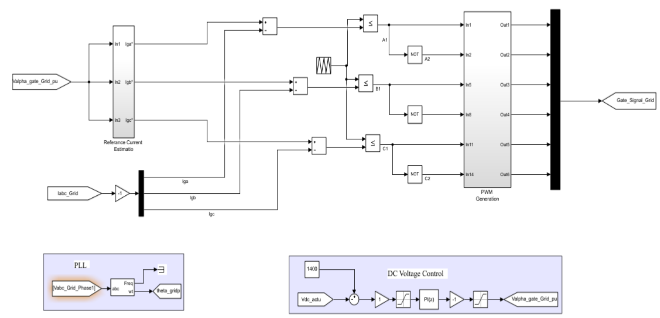


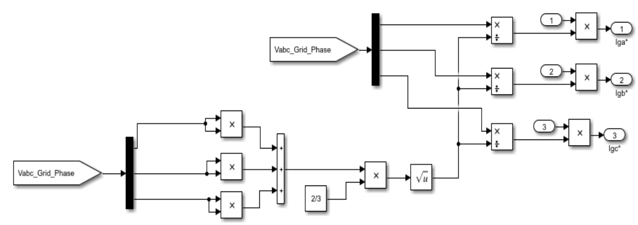
Fig. 5 MSC control

B. GSC control

Most GSC operate as current sources injecting a current to the utility grid in sinusoidal shape and just out of phase phase with the grid voltage, with a power factor equal or very close to unity. It is required that the GSC must synchronizes with the fundamental component of the grid voltage, even in the cases when the grid voltage is distorted or unbalanced or when the grid frequency varies. An example of synchronization in steady state for a three-phase system is shown in Fig. 6(a), in which three phase wind energy based system. And 6(b) shows the its internal part of reference current estimations.



(a)



(b)

Fig. 6 GSC control

IV. RESULTS AND DISCUSSIONS

The proposed WECS have been simulated with discrete time at 10µs in R2015a. The developed WECS is examined under different condition with different wind speed and power. The proposed system result is valued through the matlab at the developed model is tested under different conditions such as change in change in wind speed such as rated wind speed, variable wind speed like sudden fall or increases and linearly increasing, result are plotted in terms of toque speed, voltage, current and power DC voltage (Vdc), grid voltage (V_g) , grid current (I_g) grid power active (P_g) and reactive power (Q_g), generator current (I_w) active power from WECS (P_w), voltage and current controllers

A. WECS under Fixed wind speed and fixed power

The general execution of MSC, GSC and Pitch Angle Regulation is exhibited in Figure. 7 with constant wind speed. Demonstrating the performance of proposed system under normal conditions where wind speed is fixed at 12 m / s with disturbance. When PMSG operated near rated condition, machine side converter maintained DC link voltage at 1400V.

As shown in Fig. 7 (a) input power to DC link and power output from DC link is equal. The speed of the generator and the generator's electromagnetic torque is constant and each phase of the current generated form generator is fully sinusoidal and has been shifted from 120 degrees.

According to the grid code, the behavior of the grid side converter is sterling, as shown in Fig. 7 (b) the voltages and currents of the grid are exactly out of phase, which means the active power is injected to the grid and the system operated on unity power factor. The execution of control technology is excellent because the power generated from the generator is fully injected to the grid and the system only injected the active powers with only a few watt reactive powers, with the fact that some value of inductance is always exist in practical system.

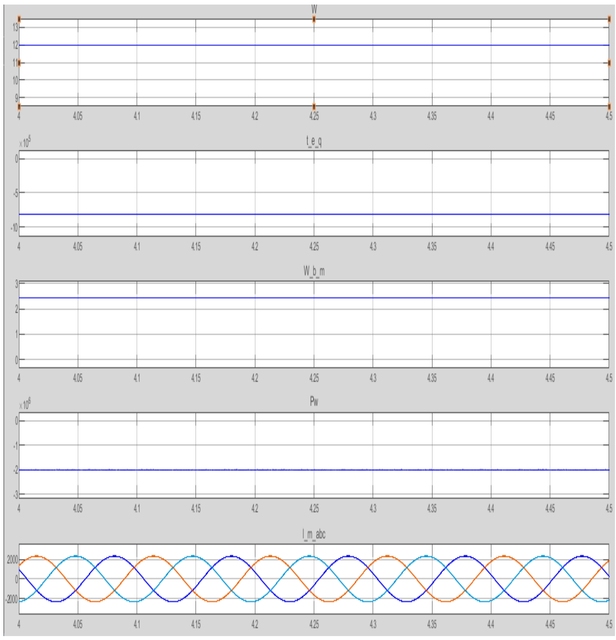


Fig. 7 (a)performance of MSC with fixed wind speed 12m/s

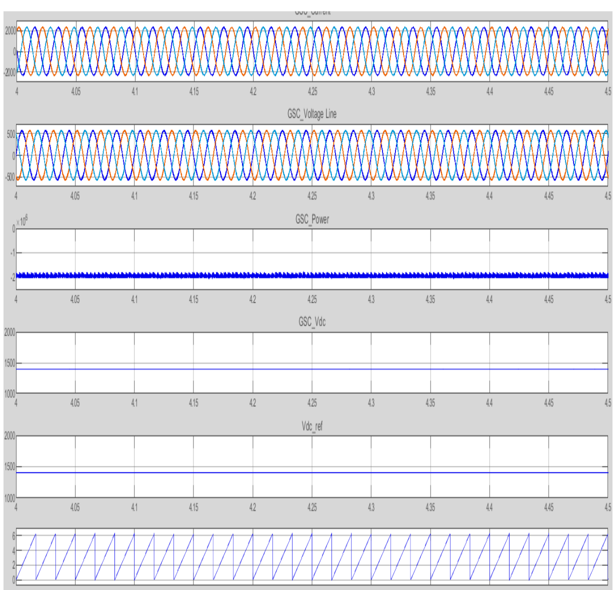


Fig. 7 (b) Performance of GSC with fixed wind speed 12m/s

B. WECS under Variable wind speed

In The general execution of MSC, GSC and Pitch Angle Regulation is exhibited in Fig. 7 with variable wind speed.

Demonstrating the performance of machine side converter under normal conditions is shown in figure 8 where wind speed is varied from 9m/s to 12 m / s with disturbance. When PMSG operated lower than rated condition, machine side converter maintained DC link voltage at 1400V.

Under this conditions following changes are observed

- Wind speed is increases from 9 to 12 m/sec.
- Power generate increases from 0.86Mw to 2MW
- At generator speed increases from 1.8rad/sec. to 2.7rad/sec.
- DC link voltage is increased and staled within 0.1second

($\pm 0.143\%$). The generated currents from generator are fully sinusoidal, equal in magnitude during variable wind speed and each phase of currents is shifted from 120 degrees.

As the wind speed of increases there is slight change in speed of generator's speed and electromagnetic torque. These outcomes are demonstrated that execution of machine side tactic is prominent.

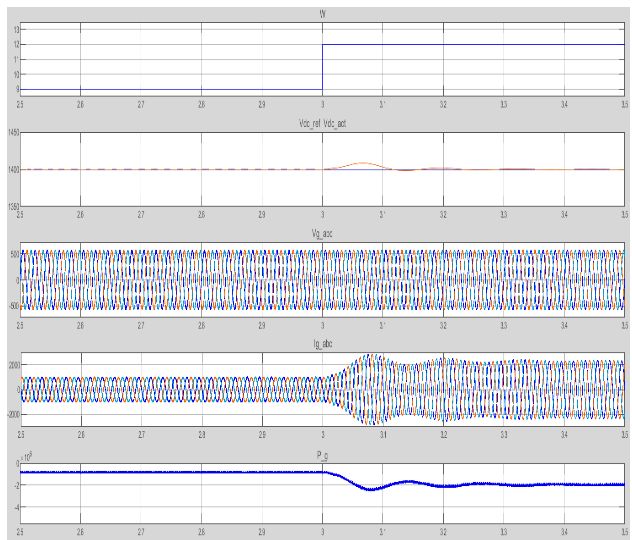


Fig.8 performance of WECS with variable wind speed from 9m/s to 12m/s

V. Conclusion

This paper has been discussed the control that of permanent magnet synchronous generator (PMSG) based wind energy conversion systems (WECS). it covers MPPT control as well grid side control to delivers power into the grid under synchronization manner. The control grid side voltage source converter (GSC) has been done by current control moreover PMSG side VSC i. e. MSC. The MSC is responsible for obtained the maximum wind power following the wind speed variations. However GSC control improves the power quality, less total harmonic distortions (THDs) and these are verified on MATLAB Simulink 2015a model.

Appendix

The parameters of PMSG based WECS are given in Table.

Table 1 Specifications of PMSG

Variable	Description	Value
P	Power	2MW
V_{LM}	Voltage	690 V
f	Frequency	9.75 Hz
R_s	Stator resistance	0.821 mΩ
L_d	d-axis armature inductance	1.5731 mH
L_q	q-axis armature inductance	5.839 mH
j	inertia	20000 $Kg.m^2$
Ns	rated synchronous speed	22.5 rpm
p	pair of pole	26

Table 2 Specifications of wind turbine

Variable	Description	Value
P	Active Power Output	2 MW
S	Apparent Power	2.2 MVAR
τ	Turbine Torque	848.8 kN.m
ω	Rated Turbine Speed	22.5 rpm
L_d	Blade radius	35.3 m

REFERENCES

[1] https://gwec.net/global-wind-report-2021/

[2] B. Prajapati and M. C. Chudasama, "Modeling of Grid Connected PMSG based WECS," 2020 IEEE International Power and Renewable Energy Conference, 2020, pp. 1-6,

[3] R. K. Tiwari, R. K. Rai and A. K. Pandey, "Assessment of grid connected PMSG based WECS," 2019 2nd International Conference on Power Energy, Environment and Intelligent Control (PEEIC), 2019, pp. 100-105

[4] J. Parmar and P. R. Gandhi, "PMSG Based Control Strategy for Interconnected Power System," 2018 3rd International Conference and Workshops on Recent Advances and Innovations in Engineering (ICRAIE), 2018, pp. 1-5,

[5] Ion Boldea, "Variable Speed Generators" CRC Press, September 29, 2015.

[6] N. S. Patil and Y. N. Bhosle, "A review on wind turbine generator topologies," 2013 International Conference on Power, Energy and Control (ICPEC), 2013, pp. 625-629,

[7] A. M. Eltamaly, H. M. Farh "Maximum power extraction from wind energy system based on fuzzy logic control", Electric Power Systems Research, vol. 97, p.p. 144–150, 2013.

[8] Y. Errami, M. Ouassaid, M. Maaroufi, "A performance comparison of a nonlinear and a linear control for grid connected PMSG wind energy conversion system", Electrical Power and Energy Systems, vol. 68, p.p.180–194, 2015.

[9] J. G. Ndirangu, J. N. Nderu, A. M. Muhia and C. M. Maina, "Power quality challenges and mitigation measures in grid integration of wind energy conversion systems," 2018 IEEE International Energy Conference (ENERGYCON), 2018, pp. 1-6,

[10] S. G. Varzaneh, G. B. Gharehpetian, and M. Abedi, "Output power smoothing of variable speed wind farms using rotor-inertia," Electr. Power Syst. Res., vol. 116, pp. 208–217, 2014.

[11] IEC, "Electrical Energy Storage White Paper," 2011.

[12] Ghany, Asmaa A.; Shehata, E. G.; Elsayed, Abo-Hashima M.; Mohamed, Yahia S.; Haes Alhelou, Hassan; Siano, Pierluigi; Diab, Ahmed A.Z. 2021. "Novel Switching Frequency FCS-MPC of PMSG for Grid-Connected Wind Energy Conversion System with Coordinated Low Voltage Ride Through" Electronics 10, no. 4: 492.

[13] B. Kedjar and K. Al-Haddad, "Optimal control of a grid connected variable speed wind energy conversion system based on squirrel cage induction generator," IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society, 2012, pp. 3560-3565.

[14] Zhang, Y.; Qu, C. Direct Power Control of a Pulse Width Modulation Rectifier Using Space Vector Modulation Under Unbalanced Grid Voltages. *IEEE Trans. Power Electron*. 2015, 30, 5892–5901.

[15] M. Debouza and A. Al-Durra, "Grid Ancillary Services From Doubly Fed Induction Generator-Based Wind Energy Conversion System: A Review," in IEEE Access, vol. 7, pp. 7067-7081, 2019

[16] Zhang, Y.; Qu, C. Table-based Direct Power Control for Three-Phase AC/DC Converters Under Unbalanced Grid Voltages. *IEEE Trans. Power Electron*. 2015, 30, 1.

[17] Calle-Prado, A.; Alepuz, S.; Bordonau, J.; Nicolas-Apruzzese, J.; Cortes, P.; Rodriguez, J. Model Predictive Current Control of Grid-Connected Neutral-Point-Clamped Converters to Meet Low-Voltage Ride-Through Requirements. IEEE Trans. Ind. Electron. 2015, 62, 1503–1514.

[18] A. Shafiei, B. M. Dehkordi, A. Kiyoumarsi and S. Farhangi, "A Control Approach for a Small-Scale PMSG-Based WECS in the Whole Wind Speed Range," in IEEE Transactions on Power Electronics, vol. 32, no. 12, pp. 9117-9130, Dec. 2017.

[19] Guo, L.; Zhang, X.; Yang, S.; Xie, Z.; Wang, L.; Cao, R. Simplified model predictive direct torque control method without weighting factors for permanent magnet synchronous generator-based wind power system. IET Electr. Power Appl. 2017, 11, 793–804

