© December 2018 | IJIRT | Volume 5 Issue 7 | ISSN: 2349-6002

MPPT with Current Control for a PMSG Small Wind Turbine in a Grid-Connected DC Micro grid

Kota Kantha Rao[1], K.Ratna Raju[2]
[1]Pursuing M.Tech (PE&D), dept. of EEE, Nova College of Engineering &Technology, Jangareddygudem
[2]Assoct Professor Dept. of EEE,Nova College of Engineering &Technology, Jangareddygudem

Abstract- **A simple sensor-less maximum power point extraction scheme for a Permanent Magnet Synchronous Generator (PMSG) connected wind turbine supplying power to a DC micro-grid has been proposed in this paper. The wind extraction topology has a small-scale wind turbine directly coupled with a PMSG. The three phase output voltage of the generator has been rectified using a 3φ uncontrolled rectifier and a DC–DC buck converter whose output voltage is controlled as per the modified Maximum Power Point Tracking (MPPT) algorithm. The algorithm changes the resistance value as viewed from the source and in turn affects the rotor speed to change such that Power Coefficient (Cp) of the wind turbine reaches its maximum value. This algorithm detects quick wind speed and reaches its maximum power point (MPP) by adjusting the slope of the power with respect to duty ratio of converter. The proposed system has been developed and simulated using MATLAB/SIMULINK under varying wind conditions and the maximum power is obtained.**

Index Terms- Maximum Power Point Tracking; Incremental Conductance; Wind Energy Extraction; Buck convertor; DC micro-grid; PMSG.

1. INTRODUCTION

In the advent of serious concerns surrounding the sustainability and the ecological footprint of non-renewable energy sources, renewable energy sources such as wind energy systems have been fast gaining momentum. In developing countries like India with a high wind potential, the development of distributed generation and advancements in power electronics devices has led to a higher penetration of wind technology. DC micro-grids are localized stand-alone systems involving hybrid renewable energy sources like solar power, wind power technologies. In view of reduced current ratings and compactness of devices for a small scale wind turbine system and considering the bus voltage standards, the voltage of DC micro grid has been chosen to be 48V.

The various MPPT techniques used in small scale wind turbines which include Optimal Torque control, PSF control, TSR control, and Perturb and Observe (P&O) method. The performance of different techniques is also presented in the paper. Though optimal torque control has a faster convergence and is relatively simple and can exhibit very good performance under varying wind speed conditions, it requires prior training [1], whereas HCS algorithms require no such training which is one of the main advantages of sensor-less HCS algorithms. Márton Örs has proposed a Perturb and Observe control for a gear driven SCIG based wind turbine system. However, the advantage of PMSG over SCIG is that the need of the gear box is completely eliminated in PMSG.

Gary Moor [3] has proposed sensor-less as well as sensor based and pre-trained MPPT control methodologies. Constant and variable step based control are simple albeit lack a faster time response. Anemometer based and calculation equation control was used lookup tables to estimate the operating point and used the appropriate controls to shift the operating point to MPP. The lookup table approach has a significantly faster response but the inherent disadvantage in lookup system based approach being the requirement of higher number of data points to make the response as accurate as possible. The requirement of data points makes installation of MPP control by time-consuming procedure.

Koutroulis et al. [4] has proposed a more compact system to feed a battery load and has demonstrated an increase in output power up to 50% with the inclusion of MPPT. The paper also has suggested an alternative approach using a wind speed sensor used to calculate the optimum TSR. However, the advantage of sensor- less systems is that they are as fast as optimum torque control without the requirement of any prior training.

Sandeep Anand and B.G. Fernandes [5,6] have described various convertor topologies used to interface DC micro-grids[10] and also have discussed the validity of different DC bus voltage levels in the micro- grid. The architecture used here is RSC (Renewable Side Convertor), where in a power electronics interface (Buck convertor) is used between the turbine rectified output and the DC micro-grid. The 48V grid interface is usually used in telecom industries and hence, this project has scope of powering remote data centers which are usually installed in remote areas. The e efficiency observed is also significantly higher in case of adoption of 48V bus as compared to 120V bus.

2. PROPOSED SYSTEM

A controllable current source injecting power to the load and the excess to the DC grid through a buck converter is shown in Fig.1.The reason of Buck DC-DC converter used in the proposed system is that the voltage generated by the PMSG is larger than the grid voltage for all wind speeds over 5 m/s which is the desired zone of operation and it operates in CCM (Continuous current mode), ensuring continuous power injection to grid. The ON time of the MOSFET switch is affected by an algorithm (modified P&O) by taking in converter output voltage and current as inputs.

$$C_p(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{\frac{-21}{\lambda_i}} + 0.0068\lambda$$

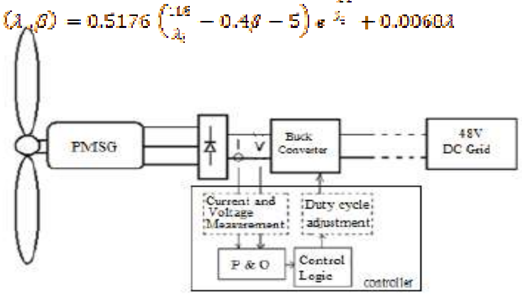

Figure 1. Schematic diagram of proposed system

This algorithm operates on the fact that the change in power due to an increase in duty cycle of converter must be higher, i.e. the ON time of the MOSFET is continuously increased till the change in power becomes negative after which it is reduced by the same amount it was incremented in the previous iteration.

3. MODELING OF SYSTEM COMPONENTS

A. Modeling of Wind turbine

The ideal available power in a wind stream tube(PW) passing through the wind turbine according to Bernoulli's equation is given by[1],

$$P_W = \frac{1}{2}\rho A v^3 \quad (1)$$

where, ρ is the air density, v is the wind velocity, and A is the area swept by the rotor. However, the power extracted (PT) by the wind turbine-generator system is only a fraction of Pw, this fraction varies with the rotor speed of the generator for the given particular wind speed and pitch angle and it is described by the equation (2). The fraction is called power coefficient Cp.

$$P_T = C_p \frac{1}{2}\rho A v^3 \quad (2)$$

The maximum value of Cp is theoretically limited to 16/27 or around 0.593,which is called as Betz Limit. Commercial turbines however can have a Cp between the range of 0.25 -0.45. Cp depends on two parameters of the wind turbine namely the Tip Speed Ratio(TSR) and the pitch angle(□) of the blades. The Tip Speed Ratio(λ) is defined as the ratio of wind velocity to angular rotor speed of the generator and λ, is usually expressed using (3) ,

$$\lambda = \frac{\omega R}{v} \quad (3)$$

where, ω = Speed of the rotor in rad/sec, R = Radius of tip of rotor in metres, v = Wind speed in m/s. The power coefficient (Cp) is defined as the function of TSR (λ) and the pitch angle (β) and the interrelation of Cp(□,□) is given in (4,5).[9] (4)

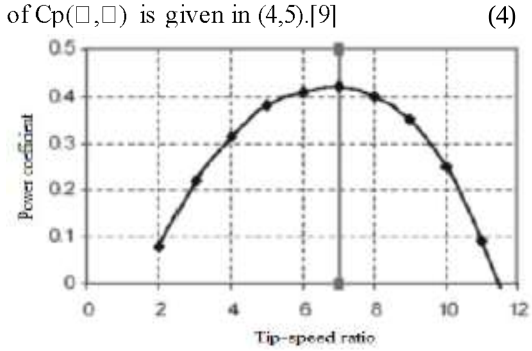

Figure 2. CP - λ Characteristics

(5)

As it is evident that the relation between Cp, λ and β is highly non-linear. The following Fig.2 gives the CP- λ characteristics of the turbine used in the proposed system.

B. Modeling of PMSG and diode rectifier

The differential equations describing the PMSG with a rotor reference are as follows: [8, 9]

$$v_q = -(R i_q + L_q \dot{i}_q) - \omega_r L_d i_d + \omega_r \lambda_m \quad (6)$$

$$v_d = -(R i_d + L_d \dot{i}_d) + \omega_r L_q i_q \quad (7)$$

$$\omega_r = \left(\frac{P}{J}\right)(T_m - T_e) \quad (8)$$

where R is the PMSG stator resistance per phase, Ld and Lq are the d-axis and q-axis PMSG stator inductance per phase, id and iq are the d-axis and q-axis stator currents; vd and vq are the d-axis and q-axis stator voltages, and λm is the amplitude of the flux linkage from the permanent magnet. J is the moment of inertia of the turbine generator set. Tm is the mechanical torque from the wind turbine. The electromagnetic torque Te is expressed as follows [9].

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\{(L_d - L_q) i_q i_d - \lambda_m i_q\} \quad (9)$$

Where P is the PMSG pole pairs. The average voltage of 3 uncontrolled rectifier is as follows

$$V_{dc} = \frac{3\sqrt{3}}{\pi} V_m \quad (10)$$

where Vm is the stator voltage.

C. Modeling of Buck Converter

The proposed scheme is used buck converter or step down converter which converts the unregulated DC voltage to a stabilized DC voltage of a lower magnitude. The advantage of buck converter is that it always operates in continuous conduction mode. The Fig.3.represents the block diagram of a buck converter [7].

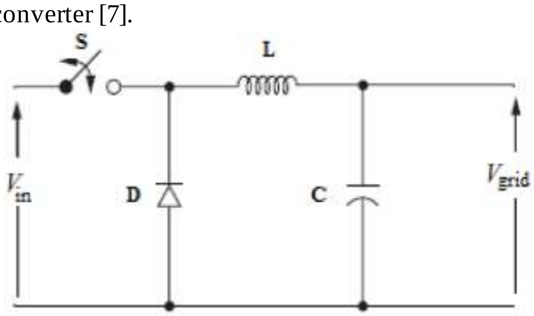

Figure 3. Buck-converter

The major design aspect of designing the buck converter is selection of the value of the inductance required for the desired operation, which is computed using the equation

where Vo is the grid supply voltage i.e., 48V, D is operating duty ratio, ΔiL is required current ripple, f is switching frequency of converter. The designed value of inductance is 0.73mH at 30 kHz switching frequency with a ripple requirement of 30% of average inductor current,. The capacitance however is found to be unnecessary in this case as the converter output voltage is connected to the grid which has significantly a very high internal capacitance.

4. CONTROL ALGORITHM

Fig.4 represents the control algorithm used in the proposed system for MPPT. The logic of algorithm is based on the fact that the power varies with respect to the duty ratio increases till the MPP and then consequently decreases. The sign of the slope of power versus duty ratio gives a precise picture of whether the MPP is on the right or the left of the current operating duty ratio and uses the same to change the duty ratio in an appropriate manner as to which the duty ratio reaches the optimal value where the power output is maximum.

The algorithm initializes the duty ratio, the change in duty ratio and the power output of converter at present & previous samples. It calculates the power of present sample and the change in power. This algorithm adjusts the duty ratio based on the magnitude of the change in power. This procedure is repeated for small step size of the power change which makes it suitable for its implementation in varying wind speed conditions where other MPP techniques may face considerable lag in time of operation.

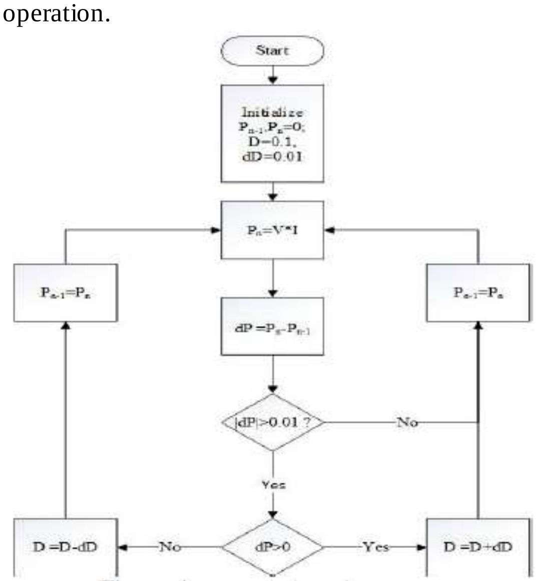

Figure 4. Control algorithm

5. RESULTS AND DISCUSSION

The proposed Wind Energy Conversion System (WECS) is simulated in MATLAB/SIMULINK environment for both fixed and variable wind speed conditions and the system is allowed to operate at the MPP extraction by tuning the duty ratio of converter. Fig.5. shows the SIMULINK model of the PMSG based wind turbine system. The specifications of the wind turbine and PMSG employed in the system are listed in Table I and Table II.

Table 1. Specifications of Wind Turbine

Rated mechanical output power (W)	500W
Rated Wind speed (m/s)	12 m/s
Generator rotor speed at maximum power (Pu)	1
Maximum output power at rated wind speed (Pu)	1

Table 1. Specifications of Wind Turbine

Table 2. PMSG Specification

Rated Voltage	200 V, 50 Hz
Rated Current	1.5 A
Rated power	500W
Rated Speed	500 rpm
Resistance per phase	9 mΩ
Inductance per phase	47 mF
Voltage Constant	564.10 V/k-rpm

Table 2. PMSG Specification

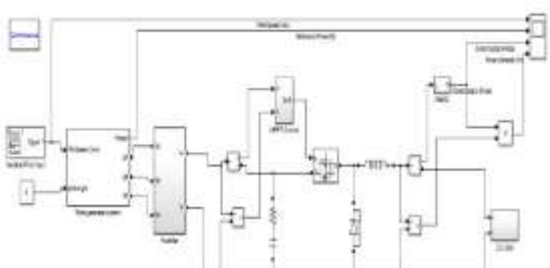

Figure 5. MATLAB model of PMSG based wind turbine system

Open loop response

The power output of the converter for the different duty ratio of switching pulse at a wind speed of 12m/s is obtained. Similarly, the open loop responses for various wind speeds have been plotted and the maximum power obtained for different wind speeds are obtained as shown in Table III. The variation of maximum powers for different wind velocities is plotted in Fig.6

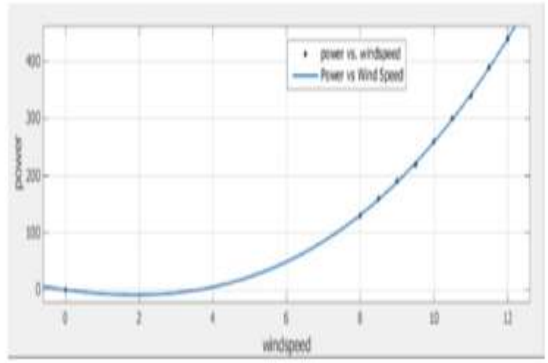

Figure 6. Maximum power output vs Wind speed

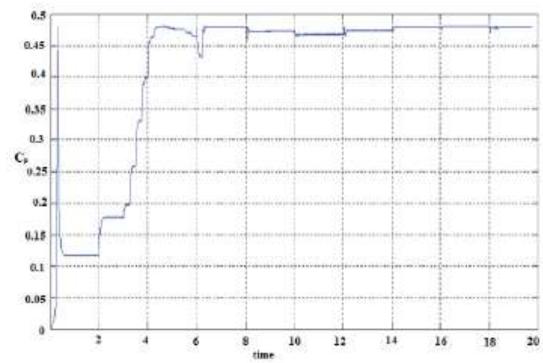

Figure 7. Cp Variations without MPPT Controller

A. Closed loop response

As shown in Fig. 7, power coefficient is maintained at 0.47 for the wind speed variations without MPPT. It is observed that the WECS operates at maximum power point. The disadvantage of the algorithm is that the next perturbation direction can be misled owing to the fact that the P&O algorithm is blind to the wind speed change. The proposed method uses the slope of DC power information to scale the step size during sudden change of wind speed conditions with MPPT shown in Fig. 8

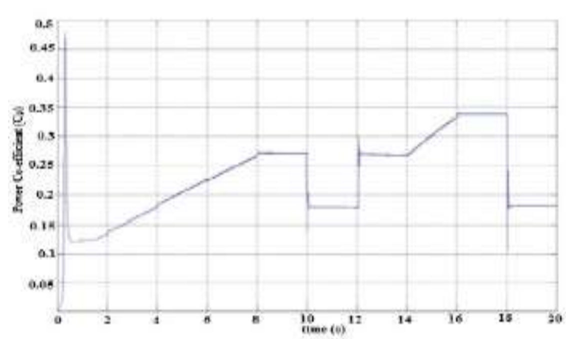

Figure 8. Cp Variations with MPPT Controller

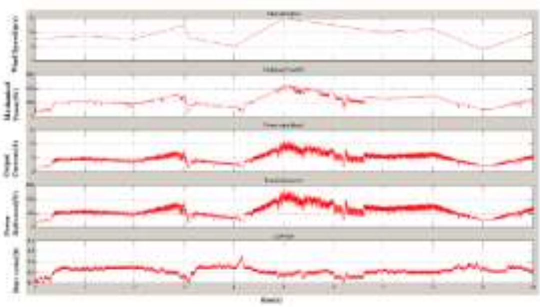

Figure 9. Response for continuously varying wind speed conditions; plots from top to bottom, wind speed (m/s), mechanical Power delivered , current injected into the grid, electrical power injected to grid and duty ratio variation due to MPP control

It can be observed that there is a slight degree of oscillations in the output, which can be attributed to the constant monitoring and tracking of the MPPT system to ensure that the system is always in operated in MPP. These oscillations can be relatively mitigated with a high switching frequency and lower step size.

Fig.9. shows the results of closed loop system, when the system is operated in constant and variable wind speed conditions with proposed P&O algorithm. The system is applied to different sets of wind speed conditions to observe the speed of response and the maximum power obtained from the open loop response is verified.

6. CONCLUSION

The simulation of the MPPT controlled small scale wind turbines connected to DC micro grid is performed and the results are obtained. It is observed that the output ripple of current as well as power is significantly higher with grid connected at the output as compared to a resistive load. It is also observed that the time required for reaching MPP is approximately higher for lower wind speeds due to the varying generator response times.

REFERENCES

[1] Abdullah M.A., Yatim A.H.M., Tan C.W.and Saidur R., “A review of maximum power point tracking algorithms for wind energy systems”, Renewable and Sustainable Energy reviews, Vol. 16, 2012.

[2] Márton Örs, “Maximum Power Point Tracking for Small Scale Wind Turbine With Self-Excited Induction Generator”, Control Engineering and Applied Informatics Vol.11, No.2, pp. 30-34, 2009.

[3] Gary Moor, and Johan Beukes, "Maximum power point tracking methods for small scale wind turbines." Proceedings of Southern African Telecommunication Networks and Applications Conference, 2003.

[4] N Nandhini, C Nandini,R Ramya,R Swetha,A Suyampulingam, " Variable speed wind turbine emulator” International Conference on Emerging Trends in Electrical Engineering (ICETREE 2014), Elsevier, T.K.M College of Engineering, Kollam ,August 2014, pp. 48-52.

[5] Sandeep Anand, and B. G. Fernandes. "Optimal voltage level for DC micro grids." 36th Annual. IEEE Ind. Electron. Society Conference, IECON, 2010.

[6] Rezkallah,Ambrish Chandra,D. R. Rousse,H. Ibrahim and A. Ilinca, “Control Design of New Eco- friendly Microgrid based on Wind/Diesel/Battery Driven Variable Speed Generators" IEEE International Conference on Power Electronics, Drives and Energy Systems(PEDES),pp. 1-6, 2016.

[7] S. Masri, N. Mohamad M. H.M. Hariri, “Design and development of DC-DC buck converter for photovoltaic application”, International Conference on Power Engineering and Renewable Energy (ICPERE),3-5 July, Bali, Indonesia,2012.

[8] Chinchilla, M, Arnaltes, S & Burgos, “Control of permanent-magnet generators applied to variable- speed wind-energy systems connected to the grid”, IEEE Transactions on Energy Conversion, vol. 21, pp. 130-135,2006.

[9] A. Suyampulingam, V. Subbiah, R. Neelaveni, “Closed Loop Control

[10] of Permanent Magnet Synchronous Generator Wind Turbine for Standalone System along with MPPT Control” , International Journal of Control theory and Applications, 10(02), 2017, pp. 275-284.

[11] Surya Prakash, Sukumar Mishra, Narayana Prasad Padhy, “Coordinated control of a grid connected DC micro-grid with multiple renewable sources”,IEEE PES Asia-Pacific

Power and Energy Engineering Conference (APPEEC), Xi'an -China ,pp. 520- 525,2016.
[12] Priyanka.D, Thilaka.M,” Electromagnetic analysis of rounded shape core and eight-sided polygon core for distribution transformer”, International Innovative Research Journal of Engineering and Technology, Vol, 02, No 04, pp.22-25, 2017.
[13] T. Padmapriya and V.Saminadan, “Improving Performance of Downlink LTE-Advanced Networks Using Advanced Networks Using Advanced feedback Mechanisms and SINR Model”, International Conference on Emerging Technology (ICET), vol.7, no.1, pp: 93, March 2014.
[14] S.V.Manikanthan and K.srividhya "An Android based secure access control using ARM and cloud computing", Published in: Electronics and Communication Systems (ICECS), 2015 2nd International Conference on 26-27 Feb. 2015,Publisher:IEEE,DOI:10.1109/ECS.2015.71 24833.
[15] Rajesh, M., and J. M. Gnanasekar. "GCCover Heterogeneous Wireless Ad hoc Networks."Journal of Chemical and Pharmaceutical Sciences (2015): 195-200.