International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 9
September 2017

Control of Grid Connected PMSG Based WECS Linked With DSTATCOM

Princy Deepak
Research Scholar, Oriental Institute of Science and Technology, Bhopal, India
Narayan Prasad Gupta
Faculty, Oriental Institute of Science and Technology, Bhopal, India

ABSTRACT

It is essential to find an alternate form of energy before the world's fossil fuels will be depleted in the next few decades. The renewable energy sources are in great demand because of their abundant availability and eco-friendly nature. Electrical energy generated by the wind power plants is the fastest developing, the most cost effective, technologically improvable and promising renewable energy source than the other resources such as solar, hydal, biomass, geothermal etc. The wind is a clean, free and inexhaustible energy source. This paper describes about the wind energy conversion system (WECS); a permanent magnet synchronous generator (PMSG) is coupled to the wind turbine to generate the electrical power. A variable speed wind turbine provides more energy than the fixed speed wind turbine as it reduces power fluctuations and improve reactive power supply. The PMSG is used as a variable speed wind turbine generator due to its property of self excitation which eliminates the excitation losses. The power arising out of the wind turbine when connected to a grid or isolated system concern about the issues of power quality and harmonic distortion which can be overcome by the use of DSTATCOM at PCC. It is used for power factor correction, harmonic mitigation and load balancing. A battery energy storage system (BESS) is also connected in the WECS for the purpose of storing excess energy and supplying energy required during deficiency in power supply of the system. The model of the DSTATCOM has been developed for wind turbine coupled with PMSG in MATLAB / Sim Power System tool box.

Keywords- Renewable energy system (RES), Wind energy, PMSG, Harmonic Distortion and DSTATCOM.

I. INTRODUCTION

The power system today is integrated in the fields of generation, transmission and distribution in the variety of AC and DC systems. There are two types of energy sources in the world i.e. renewable energy sources and non-renewable energy sources [1,2]. Renewable energy sources are the type of energy sources which are plenty in quantity and can never be depleted such as wind, solar, biomass, geothermal etc. The renewable energy sources potentially increases overall efficiency of utilizing primary energy sources and consequently provides substantial environmental gain regarding carbon emission. Globally there is a rapid increase in the utilization of renewable energy source in the power system especially for solar photovoltaic (PV) and wind energy system. Wind power installed capacity is growing exponentially and integration of wind power is proceeding at a rapid pace. The Global Wind Energy Council (GWEC) released its annual global report describing that more than 54GW of clean renewable wind power was installed across the global market in 2016, which now comprises in more than 90 countries including 9 with more than 10,000MW installed and 29 which have now passed the 1,000MW mark. The total installed capacity of electrical power in India is about 330.15GW of which 67.1% is of fossil fuels and 30.8% is of renewable energy sources. Of about total installed renewable power across the country, over 55% is wind power. Wind power generation is the process of conversion of wind energy into electrical energy and can be highly variable at several different time scales: hourly, daily or seasonally [5]. A wind turbine converts mechanical energy into electrical energy and it produces ac output voltage, this ac output voltage is converted to dc by the help of converter [7, 9].

Wind power is abundant, widely distributed and produces no green house gas emission during operation; also it consumes no water and uses little land. There are different components of a WECS, of which the most important is the type of generator used. There are several types of generator which are used in WECS such as self-excited induction generator (SEIG), doubly-fed induction generator (DFIG) and permanent magnet induction generator (PMSG) [11,14]. Among these generators, PMSG has several advantages which make it very suitable for WECS. PMSG is simple and maintenance free as it doesn't use slip rings. The power arising out of the wind turbine when it is connected to the grid or an isolated system concern about the power quality issues such as voltage sag, voltage swell, flicker, transients, harmonic distortions etc [15]. These power quality problems can be mitigated by using the FACTS compensating devices Static Synchronous Compensator (STATCOM), Thyristor Controlled Reactor (TCR), Thyristor Switched Reactor (TSR), Thyristor Switched Capacitor (TSC), Static VAR Compensator (SVC), Static Synchronous Series Compensator (SSSC), Thyristor Controlled Series Capacitor (TCSC) etc. Distribution static synchronous compensator (DSTATCOM) is used for the reduction of undesired harmonics in the system, voltage regulation, load balancing and for the compensation of reactive power. The DC bus voltage of voltage source converter (VSC) is regulated under all conditions of varying load, verifying the self-supporting operation of the DSTATCOM [17,18]. The VSC is connected at the point of common coupling (PCC) [16]. A battery energy storage system is also connected in the WECS for the purpose of storing excess energy and supplying energy required during deficiency in power supply of the system.

II. WIND ENERGY CONVERSION SYSTEM

A. General Description

Wind energy is the kinetic energy associated with movement of large masses of air. Wind farms consist of many individual wind turbines which are connected to the electric power transmission network. Wind power hardly ever suffers major technical failures, since failures of individual wind turbines have hardly any effect on overall power [12]. So that the distributed wind power is reliable and predictable. Modern wind farms use generators for the production of electricity. They include wind turbines connected to the prime mover through a gear box arrangement [13].

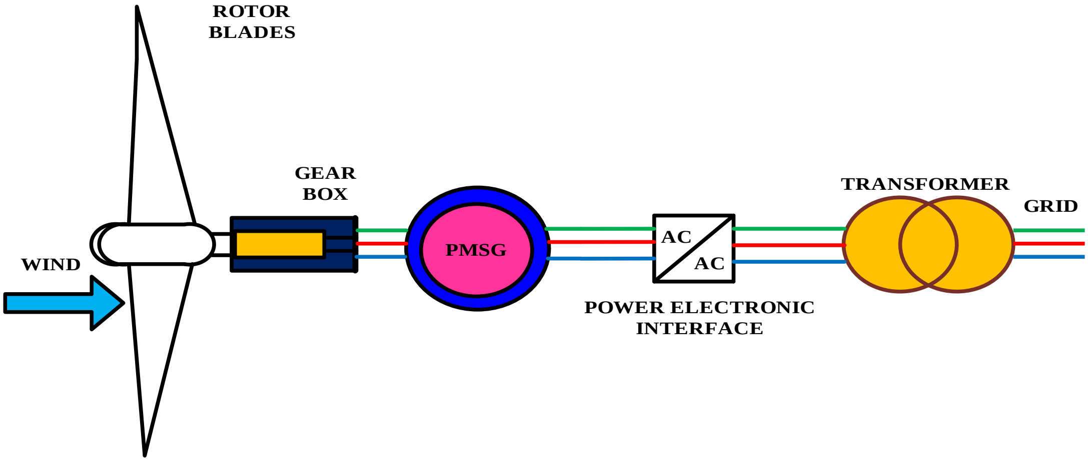

Figure.1 Block Diagram Of PMSG.

The prime mover is connected to the shaft of the generator's rotor, while the stator is connected either to the standalone loads or the electrical grid. This arrangement converts energy from mechanical form to the electrical at the grid. Wind turbines produce electricity by using the power of the wind to drive an electrical generator. Passing over the blades, wind generates lift and exerts a turning force. The rotating blades turn a shaft inside a nacelle which goes into the gear box. The gear box adjusts the rotational speed to that which is appropriate for the generator. The generator converts the rotational energy to electrical energy. This electrical energy is passed to the grid through the power transformer [14,15].

B. Modeling of Wind Power System

Wind energy systems harness the kinetic energy of wind and convert it into electrical energy or use it to do other work, such as pump water, grinds grains etc. The kinetic energy of air of mass m moving at speed ν can be

$$E_b = \frac{1}{2} m\nu^2 \quad (1)$$

During time period t, the mass (m) of air through a given area A at speed v is:

$$m = \rho A \nu t \quad (2)$$

Where, ρ is the density of air (kg/m³).

Based on the above two equations, the wind power

$$P = \frac{1}{2} \rho A \nu^3 \quad (3)$$

We have;

$$P = \frac{1}{2} \rho A \nu^3 C_p \quad (4)$$

Where, Cp is called the performance coefficient [11].

C. Pitch angle control

Pitch control is a practical technique for power regulation above the rated wind speed it is considered as the most efficient and popular power control method. Ideally, the wind turbine should be operated at maximum C_P most of the time.

In the lower wind speed, when the aerodynamic power produced by the wind turbine is below the maximum power rating of the power converter, the wind turbine is operated in the C_{Pmax}. The pitch angle of the wind turbine is controlled to have the maximum possible C_{Pmax} .

As the wind speed increases, the power generated by the wind turbine also increases. Once the maximum rating of the power converter is reached, the pitch angle is increased (directed to feather) to shed the aerodynamic power. As the pitch angle is increased, the wind turbine operates at lower efficiency [7].

III. SYSTEM CONFIGURATION

The proposed isolated generating system consists of a wind turbine, a permanent magnet synchronous generator (8.5KW), DSTATCOM and linear and non-linear loads. The controller consists of three-leg voltage source converter (VSC) with a battery and a filter capacitor at its DC link as shown in figure. 2.

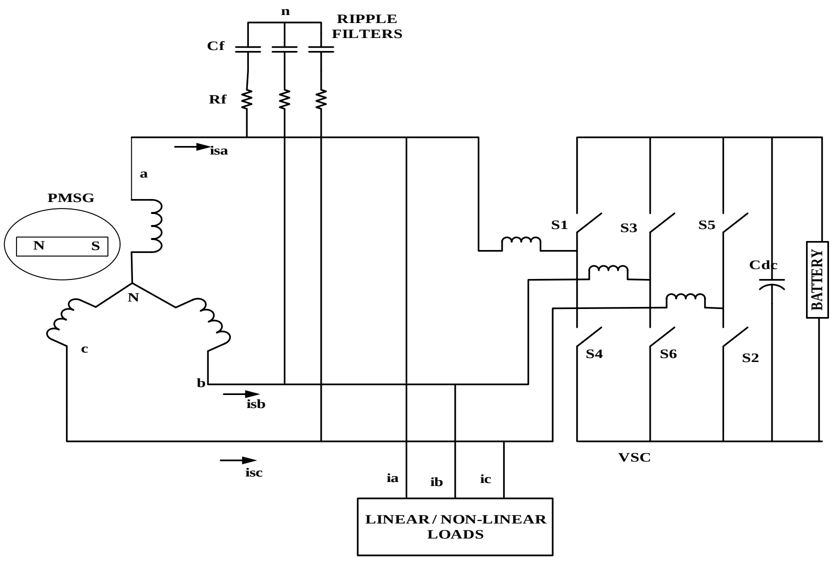

Figure.2 Schematic Diagram of VSC for a PMSG

The basic principle of operation for controlling the voltage and frequency in isolated wind energy conversion system (IWECS) is that the controller is having the capability of regulating the reactive power to control the voltage as well as active power to control the frequency. Under the condition of high wind speeds the output power of the generator is increased and if this generated power is not fully utilized it is stored in the revolving component of the generator and increases the speed which in turn increases the system frequency. Therefore, the battery system which is connected at the DC link of the VSC is used to store the additional generated power not consumed by the consumer loads. Under the condition of low wind speed, when the generated power is insufficient to full fill the demands of the consumer loads, the battery provides the active power through its discharging process. In all such conditions the controller also maintains the voltage at constant value through reactive power compensation.

IV. CONTROL ALGORITHM

Basic equations of the control scheme of the proposed controller are given as follows:

Figure.2 shows the control scheme of the controller to regulate the terminal voltage and frequency of the generator which is based on the generation of reference source currents. It has two components in-phase and quadrature with the AC voltage. The voltages V_a, V_b and V_c are considered sinusoidal and hence their amplitude is computed as

$$V_t = \{(2/3)\,(V_a^2+V_b^2+V_c^2)\}^{1/2} \qquad (5)$$

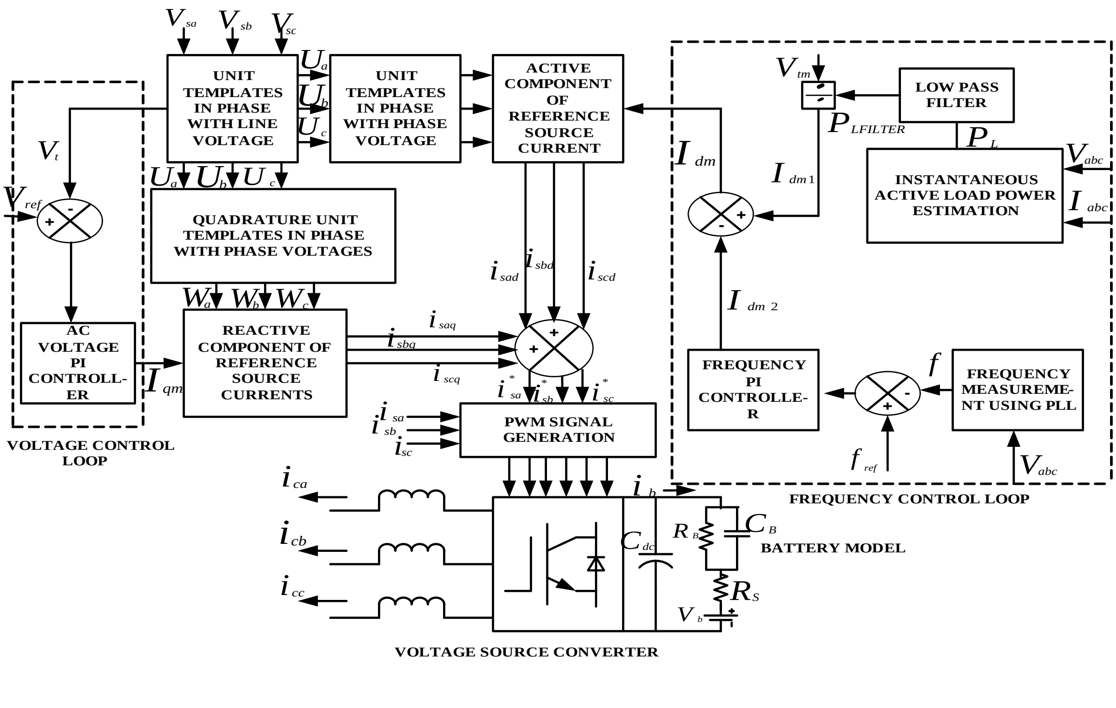

Figure.3 Schematic Diagram of the Control Scheme.

The in-phase unit templates (u_a, u_b and u_c) are three phase sinusoidal functions, computed by dividing the AC voltages V_a, V_b and V_c by their amplitude V_t. The unit template in phase with V_a, V_b and V_c are derived as

$$u_a = V_a / V_t \qquad (6)$$

$$u_b = V_b / V_t \qquad (7)$$

$$u_c = V_c / V_t \qquad (8)$$

The unit template in quadrature with V_a, V_b and V_c are derived using a quadrature transformation of the in-phase unit template u_a, u_b and u_c as

$$W_a = -u_a/\sqrt{3} + u_c/\sqrt{3} \quad (9)$$

$$W_b = \sqrt{3}u_a/2 + (u_b - u_c)/2\sqrt{3} \quad (10)$$

$$W_c = -\sqrt{3}\,u_a/2 + (u_b - u_c)/2\sqrt{3} \quad (11)$$

A. Quadrature component of reference source currents.

The AC voltage error $V_{er(n)}$ at the n[th] sampling instant is

$$V_{er(n)} = V_{ref(n)} - V_{t(n)} \quad (12)$$

Where, $V_{ref(n)}$ is the amplitude of reference AC terminal voltage and $V_{t(n)}$ is the amplitude of the sensed three-phase AC voltage at the generator terminals at n[th] instant. The output of the PI controller ($I_{qm(n)}$) for maintaining the AC terminal voltage constant at the n[th] sampling instant is expressed as:

$$I_{qm(n)} = I_{qm(n-1)} + K_{pa}\{V_{er(n)} - V_{er(n-1)}\} + K_{ia} V_{er(n-1)} \quad (13)$$

Where, K_{pa} and K_{ia} are the proportional and integral gain constants of the proportional integral PI controller. $V_{er(n)}$ and $V_{er(n-1)}$ are the voltage errors in n[th] and (n-1)[th] instants and $I_{qm(n-1)}$ is the amplitude of the quadrature component of the reference source current (n-1)[th] instant. On multiplication of the quadrature unit templates (W_a, W_b and W_c) with the output of the PI based AC voltage controller (I_{qm}) yields the reactive or quadrature components of the reference source currents (i^*_{saq}, i^*_{sbq} and i^*_{scq}) to control the voltage. The quadrature components of the reference source currents are computed as:

$$i_{saq} = I_{qm} W_a \quad (14)$$

$$i_{sbq} = I_{qm} W_b \quad (15)$$

$$i_{scq} = I_{qm} W_c \quad (16)$$

B. In-phase component of reference source currents

In-phase component of reference source current is estimated by taking the difference of rated generator current (I_{dm1}) and the output of frequency PI controller (I_{dm2}). The frequency error is defined as:

$$f_{er(n)} = f_{ref(n)} - f_{(n)} \quad (17)$$

where, f_{ref} is the reference frequency (50Hz in present system) and f is the frequency of the voltage of the synchronous generator. The instantaneous value of 'f' is estimated using phase locked loop (PLL). The rated current of the generator is calculated as:

$$I_g = \sqrt{2}(P_{r}) / \sqrt{3}(V_{r}) \quad (18)$$

The difference of the rated generator current (I_{dm1}) and the output of the frequency PI controller (I_{dm2}) decides the amplitude of the active or in-phase component of reference source current (I_{dm}). Multiplication of the in-phase unit templates (u_a, u_b and u_c) with in-phase component (I_{dm}) yields the in-phase component of reference source current (i_{sad}, i_{sbd} and i_{scd}). The instantaneous values of in-phase components of reference source currents are estimated as:

$$i_{sad} = I_{dm} u_a \quad (19)$$

$$i_{sbd} = I_{dm} u_b \quad (20)$$

$$i_{scd} = I_{dm} u_c \quad (21)$$

C. Reference source currents

Reference source currents are the sum of in-phase and quadrature components of the reference source currents as:

$$i^*_{sa} = i_{saq} + i_{sad} \quad (22)$$

$$i^*_{sb} = i_{sbq} + i_{sbd} \quad (23)$$

$$i^*_{sc} = i_{scq} + i_{scd} \quad (24)$$

D. PWM current controller

The reference source currents (i^*_{sa}, i^*_{sb} and i^*_{sc}) are compared with sensed source currents (i_{sa}, i_{sb} and i_{sc}). The ON/OFF switching patterns of the gate drive signals to the IGBTs are generated from the PWM current controller. The current errors are computed as:

$$i_{saerr} = i_{sa} - i^*_{sa} \quad (25)$$

$$i_{sberr} = i_{sb} - i^*_{sb} \quad (26)$$

$$i_{scerr} = i_{sc} - i^*_{sc} \quad (27)$$

These current error signals are amplified and then used in the PWM hysteresis current controller to generate the gating signals for IGBTs of VSC.

V. SIMULATION RESULTS AND DISCUSSION

The MATLAB model for variable wind speed driven permanent magnet synchronous generator system feeding balanced and unbalanced three-phase three-wire loads is shown in figure.4.

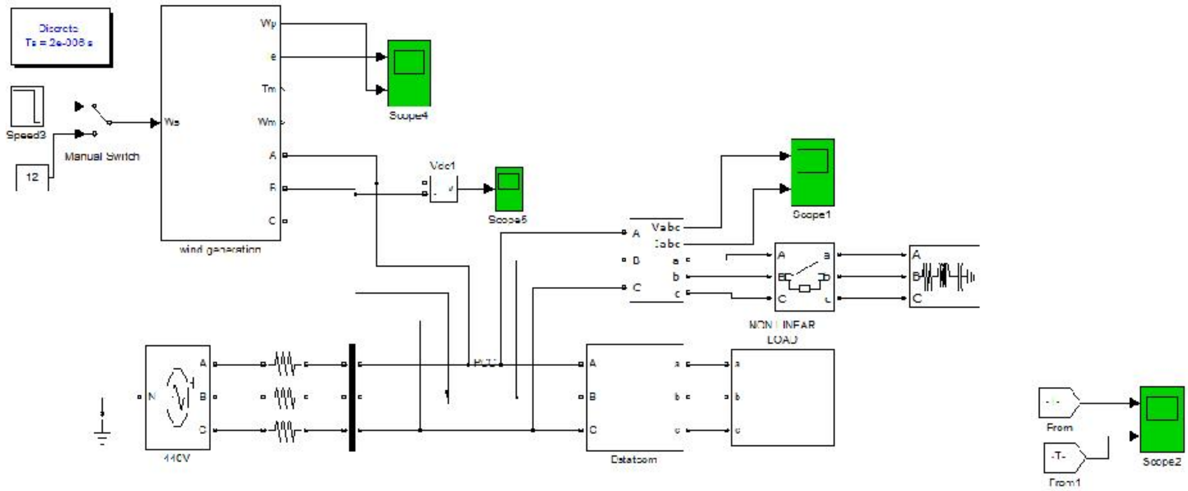

Figure.4. MATLAB model

The performance of the proposed controller under varying wind speeds for unbalanced load is shown below. In figure.5 variation in the wind speed (m/s) has been shown.

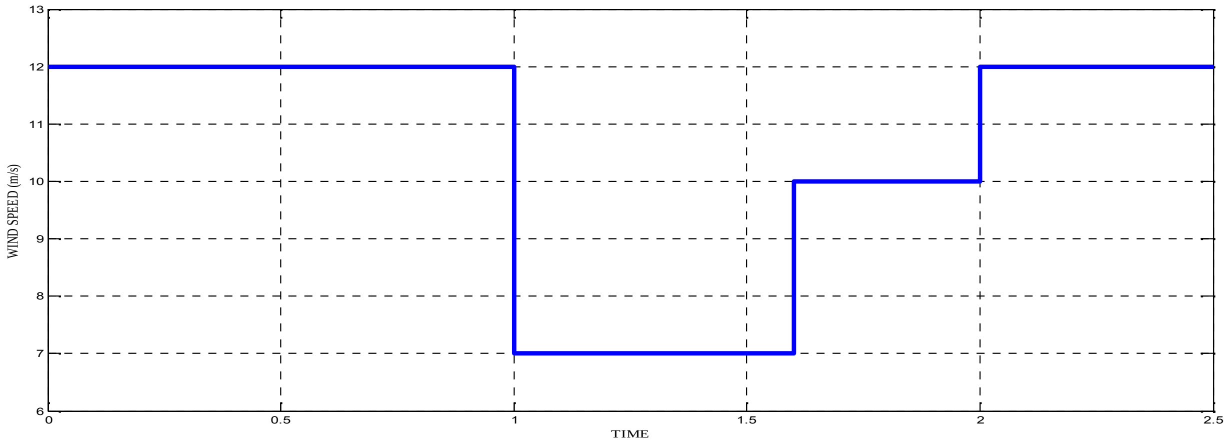

Figure.5. Variation in Wind Speed (m/s).

Figure. 6 Shows the waveform of the voltage (V_{ab}) of permanent magnet synchronous generator based wind energy conversion system feeding non-linear loads. With respect to the change in wind speed the output voltage of PMSG is maintained constant.

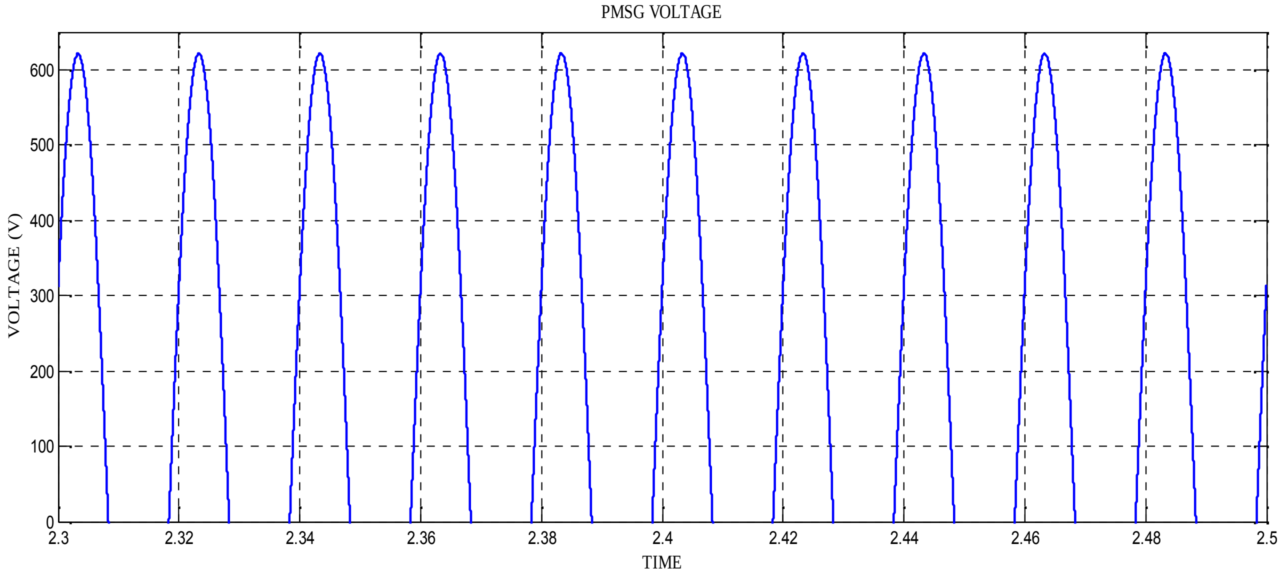

Figure.6 Voltage waveform of the PMSG based WECS.

Three-phase waveform of load current is shown in figure.7. At 0.9sec phase a of load is disconnected which is again connected at 1.3sec. At 1sec phase b of load is disconnected which is again connected at 1.4sec. At 1.1sec phase c of load is disconnected which is again connected at 1.5sec. Between 1.1sec and 1.3sec there is no load connection.

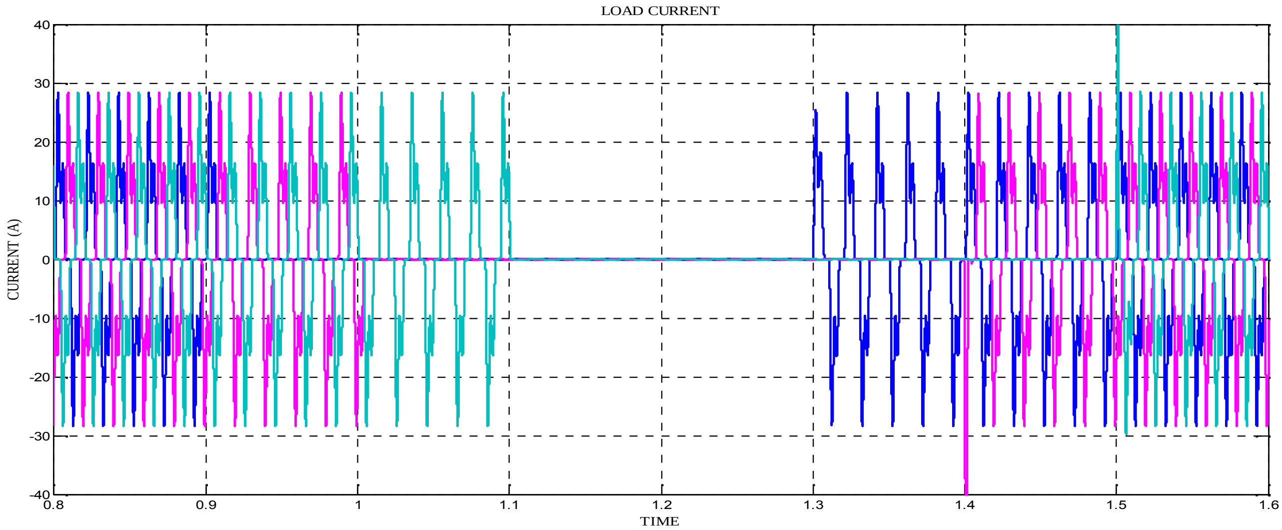

Figure.7 Waveform of the load current.

Figure.8 Shows the three-phase waveform of the DSTATCOM voltage which is connected to the permanent magnet synchronous generator based wind energy conversion system. The voltage is maintained constant with variable wind speed and non-linear loads.

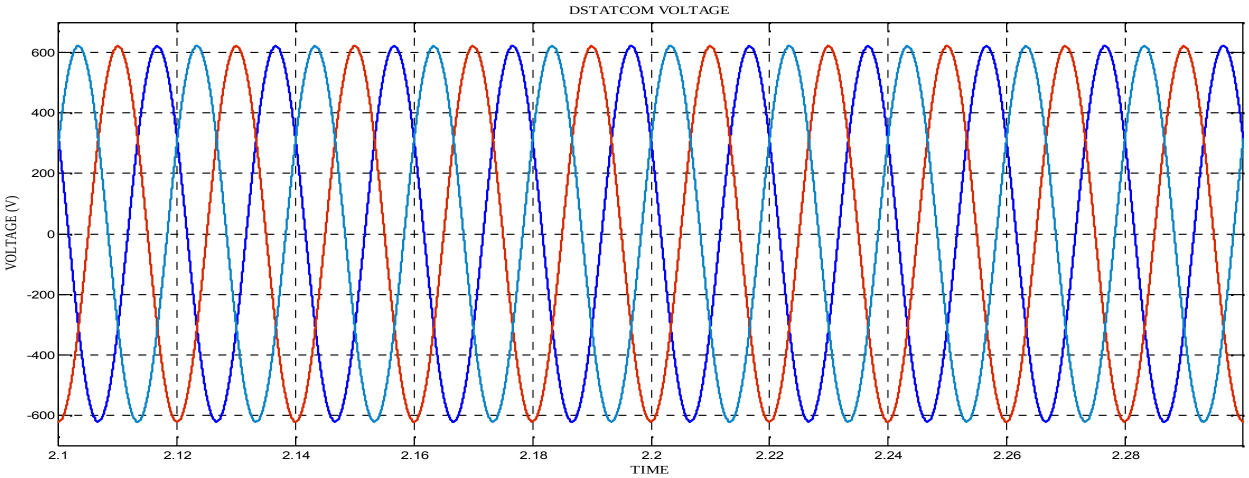

Figure.8 Waveform of the DSTATCOM Voltage.

Figure.9 shows the waveform of the DSTATCOM current. In the PMSG based WECS the controller starts at 0.6sec. Before the DSTATCOM gets ON the non-sinusoidal waveforms are observed and as the DSTATCOM gets on three-phase sinusoidal waveforms are observed.

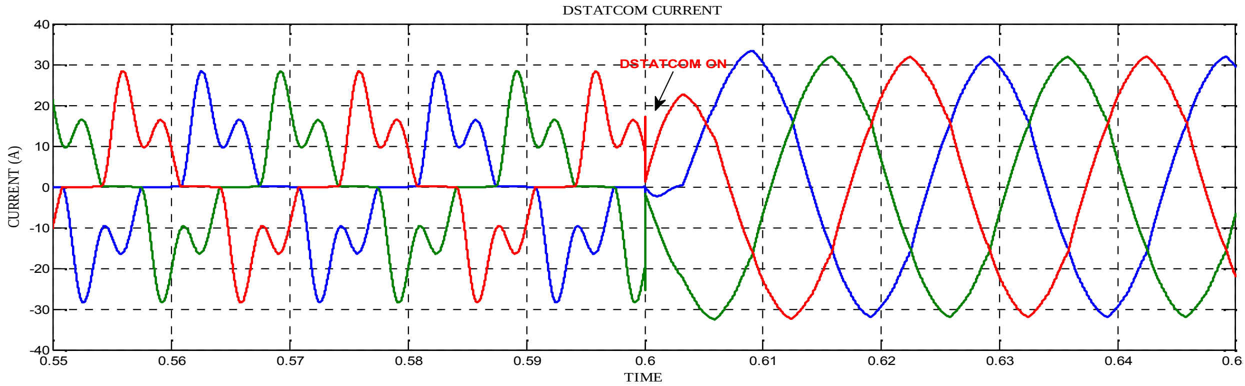

Figure.9 Waveform of the DSTATCOM Current.

Figure.10 Shows the waveform of terminal voltage (V_t), it is fairly maintained constant at 620V.

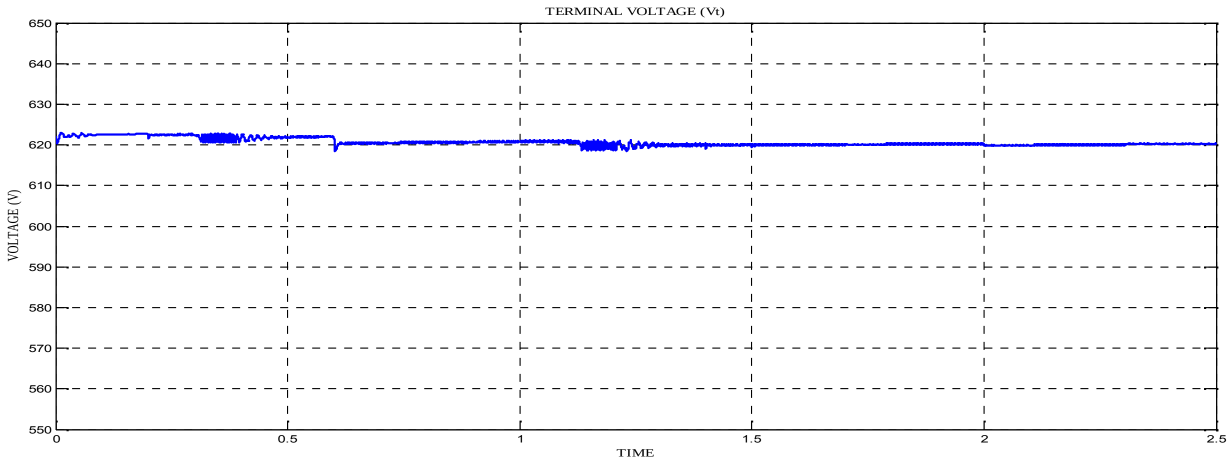

Figure.10 Waveform of the Terminal Voltage.

Figure.11 shows the waveform of the frequency of the PMSG based WECS. A slight disturbance is observed in the frequency waveform when the DSTATCOM is ON at 0.6sec. but after that the frequency of the system remains constant at 50Hz.

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 9
September 2017

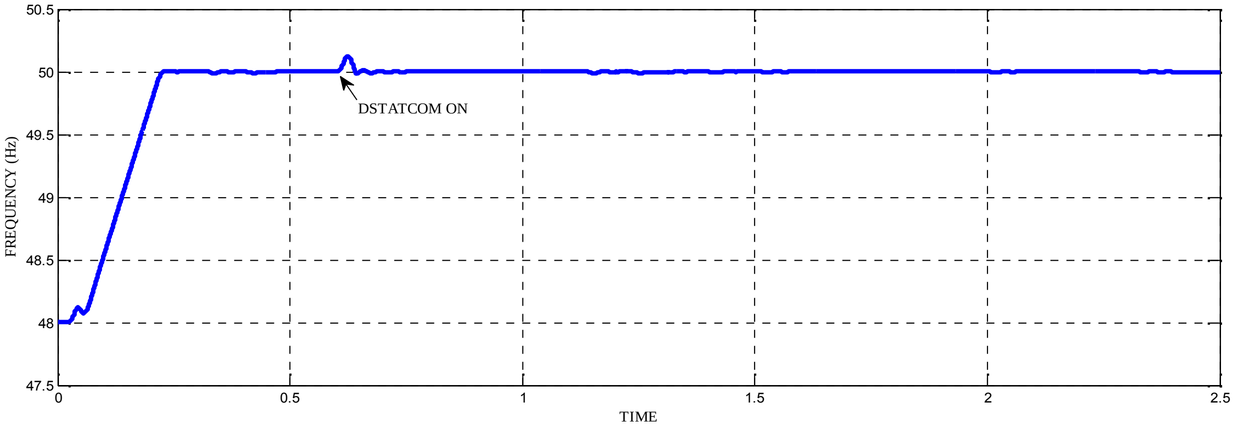

Figure.11 Waveform of the frequency of PMSG based WECS.

Figure.12 Shows the waveform of the three-phase voltage (V_{abc}) which remains constant at 620V with variable wind speed at the point of common coupling (PCC).

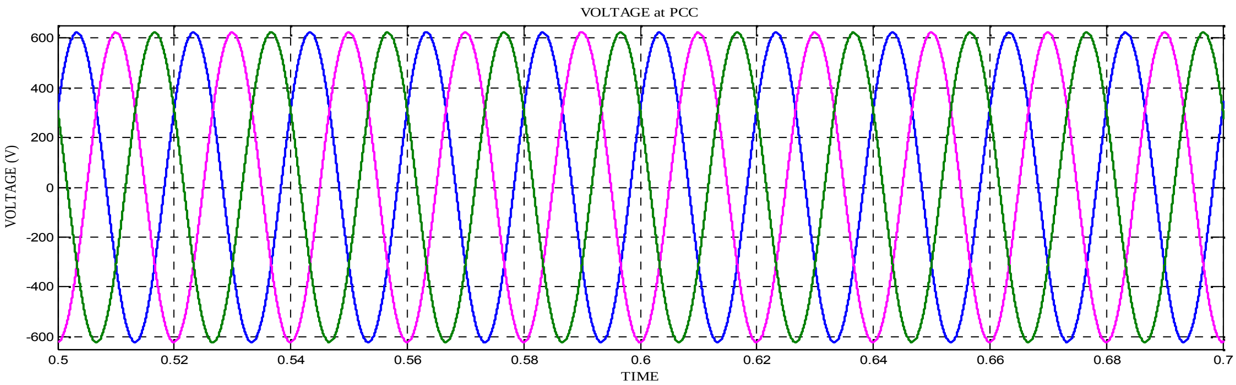

Figure.12 Waveform of the voltage at PCC.

The total harmonic distortion (THD) of the DSTATCOM voltage and current is obtained as 0.02% and 2.26% respectively and the THD of load current of 51.04% under the balanced and unbalanced non-linear load condition, which are well within the limit of 5% imposed by IEEE-519 standard.

VI. CONCLUSION

The performance of the proposed system has been demonstrated for a permanent magnet synchronous generator driven by variable speed wind turbine. The proposed controller has been found suitable with simple control strategy to regulate the voltage and frequency with variation of the load. The performance of the DSTATCOM has also been investigated with balanced and unbalanced non-linear loads and it has been found that the total harmonic distortion of the terminal voltage and the generator current in such type of the load conditions is well within the limit of IEEE-519 standard. Therefore, it is concluded that the DSTATCOM coupled with PMSG for fixed wind also functions as a load balancer, harmonic eliminator and load leveler.

VII. APPENDIX

A. The parameters of 8.5KW, 440V, 50Hz permanent magnet synchronous generator are given below.

J = 0.01197 kg-m^2 , R_s = 0.425Ω

B. Battery Specification

R_b = 10KΩ, C_b = 9760F, R_s = 0.01Ω, V_{oc} = 900V

C. Controller Parameters

$L_f = 7mH$, $R_f = 0.1\Omega$, $C_{dc} = 14000\mu F$

D. Wind Turbine Specifications

Rating 8.5KW, $C_{pmax} = 0.48$, $\lambda_{max} = 8.1$

$C_1 = 0.5176$, $C_2 = 116$, $C_3 = 0.4$, $C_4 = 5$, $C_5 = 21$, $C_6 = 0.0068$

VII. REFERENCES

[1] Sarkut Ibrahim, Surya Prakash, AK Bhardwaj. Power quality Improvement Performance using Hybrid (solar wind) energy for Distributed Power Generation. IJARCCE 2013, vol.2, Issue 10.

[2] Aruna Garipelly. Improvement of power quality of a distributed generation power system. IJAET 2012, Vol.5, Issue 2 P. 276-287.

[3] Ibrahim Dincer. Renewable Energy and Sustainable Development: A Review. ELSEVIER June 2000, Volume 4, Issue 2, Pages 157–175.

[4] M.K. Deshmukh, S.S. Deshmukh. Modeling of hybrid renewable energy systems. January 2008, Volume 12, Issue 1, P 235–249.

[5]L Dodson, K Busawan & M Jovanovic. Estimation Of The power Coefficient in a Wind Conversion System. Proceeding of the 44th IEEE conference on design & control and the European control conference Dec. 2005, P 12-15.

[6] Rajveer Mittal, K.S. Sandhu and D.K. Jain. An Overview of Some Important Issues Related to Wind Energy Conversion System (WECS). International Journal of Environmental Science and Development, October 2010, Vol. 1, No. 4.

[7]E. Muljadi and C.P. Butterfield. Pitch-Controlled Variable speed wind turbine generation. IEEE Industry applications society annual meeting Phoenix, Arizona. Oct,1999, P 3-7.

[8]Ami Joseph and Mohammad Shahidehpour. Battery Storage System in Electric Power Systems. IEEE 2006.

[9]Bhavna Jain, Sameer Singh, Shailendra Jain & R.K. Nema. Flexible mode control of grid connected wind energy conversion system using wavelet. Hindawi publishing corporation, journal of energy. Vol. 2015.

[10]Neha Verma, Arun Pachori. Theoretical Approach for Comparison of Various Types of Wind Generator Systems. IJRREEE June 2015, Vol. 2, Issue 2, P 29-35.

[11] Puneet K Goel, Bhim Singh, Navin Kishore. Modelling and control of autonomous wind energy conversion system with doubly fed induction generator. IEEE int. conf. of power electronics (2010), drives and energy systems, p 1-8.

[12] Vishal Verma, Peeyush Pant, B. Suresh, Bhim Singh. Decoupled indirect current contol of DFIG for wind energy applications. IEEE int. conf. on power electronics (2011), P 1-6.

[13] Youssef Errami, Abdellatif Obbadi, Smail Sahnoun, Mohammed Ouassaid, and Mohamed Maaroufi. Performance Evaluation of Variable Structure and Linear Control Strategies for Grid Connected PMSG Wind Energy System under Different Operating Conditions. IJEEI June 2016,Volume 8, Number 2.

[14]Deepika Masand, Shailendra Jain and Gayatri Agnihotri. Control Strategies For distribution Static Compensator for power quality improvement.IETE journal of research sept, 2009, vol.54, issue 6.

[15] Pragnya Jita Satpathy , Asima Sabat. Harmonic Analysis of Grid Connected Wind Farm under Different Fault Condition. International Journal of Computer Applications. International Conference on Emergent Trends in Computing and Communication (ETCC-2014). pp 29-32.

[16] N P Gupta, Preeti Gupta, Deepika Masand. Power quality improvement using hybrid active power filter for a DFIG based wind energy conversion system. IEEE NUICONE, (2012), P 1-6.

[17]Maitree Patel. Power Quality Improvement Using DSTATCOM. IJIERE 2016. Vol. 3, Issue 5.

[18]T. Sukanth, D. Srinivas, K. Pritam Satsangi. Comparative study of different control strategies for DSTATCOM. IJAREEIE November 2012, Vol.1, Issue 5.

[19]S. P. Gawande and S. Khan. Design Consideration for Configuration, Topology & Control Schemes of DSTATCOM Implemented on Distribution Systems. Lecture Notes on Information Theory Sept. 2013, Vol. 1, No. 3.

[20] Narayan Prasad Gupta, Sushma Gupta, Anil Kumar. Performance analysis of wind fuel cell hybrid system linked with BESS-VF controller. IVth International conference on advances in energy and research (2012), IIT Bombay, P 1-8.