



Reactive Power Compensation Capability and Active Power Transfer of PMSG Based Variable Speed WECS

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ABSTRACT: The renewable energy sources are very essential to replace conventional generation to control the global warming and atmospheric pollution. In order to increase the wind penetration the wind farm has to be connected to the best suitable bus and it should be controlled by suitable methods. This paper presents the dynamic model and control of PMSG based variable speed wind energy systems. The proposed system consists of a PMSG, wind turbine, two back to back converters, a dc link, battery system, a highly nonlinear load and power electronic regulators. The dynamic model of PMSG is represented in synchronous rotating reference frame and equations explained their behaviour. The wind turbine and generator are modelled and developed separate control strategy for both the converters. At the point of common coupling (PCC) the harmonics and reactive power compensation capability is analysed. The proposed model is implemented in MALAB/SIMULINK using *Simpower system library.Simulation* results shows the active power transfer and reactive power compensation capability of the model with minimal harmonics pollution.

KEYWORDS: Wind Energy Conversion System, PMSG, Grid side and Generator side converters, Hysteresis controller, PLL, Active and Reactive power Transfer.

I. INTRODUCTION

Conventional fossil fuelled power plants emitting greenhouse gases and moreover their prices are also rising. With the depletion of energy sources worldwide every effort is made to convert nonconventional energy sources into electrical energy. Wind power has been used for centuries with different purposes such as pumping water, propelling boats or grinding corn. The remarkable contribution to the electric grid started in the mid 1980s with the incentives from government sector. At that time the government only provided required financial support for installing wind turbines. Since the interest in wind power has increased with the new demand for clean and sustainable energy sources. The installed wind energy capacity has increased significantly around the world during the last years.

An overview of wind energy system is presented in [6], which helps to understand the basic concept related to the topic. The harmonics and reactive power compensation capability of PMSG is analysed in [1] after synchronizing with the grid. This paper described the power electronic interface of wind energy conversion system clearly. But they didn't mention, how to minimize the power fluctuation in the dc link. The power quality and improvement of voltage profile in distribution system is explained in [2-3]. In order to interconnect the distributed resources in power system, it needs to follow some IEEE standards. It is clearly described in [4]. The fixed speed wind turbines produce maximum power output only for a particular wind speed and gearbox reduces the efficiency of the system. Hence variable speed wind turbine based PMSG [7-8] is required.

This paper presents a novel control strategy for grid synchronization of wind energy conversion system for reactive power compensation, harmonic minimization and power fluctuation reduction. So at the point of common coupling, it helps to solve the power quality problems. The proposed system consists of PMSG based variable speed wind turbine, a highly nonlinear load, converters, a common dc link, battery system and controllers. The grid side converter is called inverter, which regulate the dc link voltage. And also injects the generated power into the grid in order to meet the power requirement of nonlinear load. The current harmonics generated by the nonlinear load is compensated by this grid side inverter along with reactive power compensation. The power fluctuation is reduced because of battery

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system. This will help to maintain unity power factor throughout the operation and the grid is able to supply only sinusoidal current without any harmonic distortion.

II. SYSTEM DESCRIPTION

The system under consideration includes a permanent magnet synchronous generator (PMSG) based variable speed wind turbine, a rectifier, an inverter, highly nonlinear load, a common dc link and controllers. The block diagram representation of the proposed wind energy conversion system is shown in the figure below.

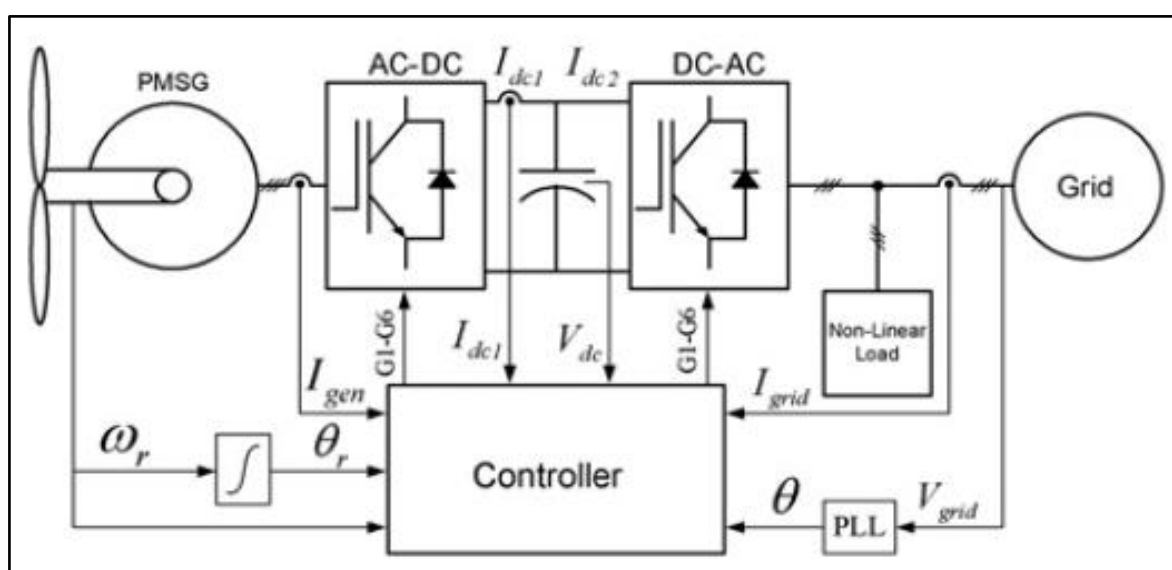


Figure 1 Block diagram of PMSG-based variable speed WECS

WIND TURBINE

The wind turbine converts kinetic energy of wind into mechanical energy. According to Albert Betz “less than 59% of the kinetic energy of the wind can be converted into mechanical energy using a wind turbine”. Operation of wind turbine can be disturbed if voltage, frequency, voltage unbalance and harmonics levels are not within specified limits. Generally, the wind turbines impact on the grid depends on wind turbines characteristics and the grid characteristics at the connection point (PCC). A healthy grid can accept more wind turbine without negative consequences on power quality of the system where as weak grids can accept limited number of wind turbines, or the grid has to be reinforced. The relationship between power co-efficient (C_p) and wind power captured by the wind turbine is given by the following equation,

$$C_p = \frac{P_{\text{turbine}}}{P_{\text{wind}}} \quad (1)$$

Therefore the expression for power captured by the wind turbine is given by,

$$P_{\text{turbine}} = 0.5 \rho \pi r^2 V_w^3 C_p \quad (2)$$

Where ρ is the air density, C_p is the power coefficient, V_w is the wind velocity in meter/sec, r is the radius of circular swept area of rotor blades and P is the power in watts. From the above equation it is clear that the power output from the wind turbine is directly proportional to cube of the wind speed. The power coefficient C_p is not constant for a given wind turbine and depends on the most common parameters like the tip speed ratio λ and the pitch angle β . In order to



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capture high power output, the C_p value should be high. Therefore the selection of optimal value of tip speed ratio and pitch angle is very important.

GENERATOR

Recently the permanent magnet synchronous generator has been gaining more attention compared to other wind energy conversion systems. The advantages of permanent magnet synchronous generators are, compact size, higher power density, reduced losses, high reliability and robustness.

Because of the regular maintenance due to tear and wear of brushes and gear box, the doubly fed induction generators and induction generators eliminated from such applications. Directly coupled low speed generators eliminates the use of brushes and the gear boxes. The nacelle of PMSG without gear box has less weight and there is a reduction of cost of the entire system. Also the efficiency of wind energy conversion system is increased by 10% by the elimination of this gear box. It is possible to represent the dynamic model of permanent magnet synchronous generator in rotating reference frame. In the two phase synchronous reference frame, with respect to the direction of rotation the q axis is 90° ahead of the d axis. With the help of a phase locked loop (PLL) the synchronization between the d-q rotating reference frame and a b c-three phase frame is maintained.

The mathematical model of PMSG in the rotating reference frame in the state equation form is given by,

$$V_q = R_s i_q + L_q \frac{di_q}{dt} + w_r L_d i_d + w_r \lambda_m \quad (3)$$

$$V_d = R_s i_d + L_d \frac{di_d}{dt} - w_r L_q i_q \quad (4)$$

Where the subscripts d and q refers to direct and quadrature axis quantities, R_s is the stator resistance in ohm, L is the inductance in henry, λ_m is the magnetic flux in weber, and w_r is the rotor speed of the generator.

III. DEVELOPMENT OF PROPOSED CONTROL STRATEGY

The proposed control strategy for generator side converter and grid side converter is described in this section.

Generator Side Converter Control

In order to capture maximum power from the wind, variable speed operation of the turbine is necessary. This is achieved with the help of proper control of the wind energy conversion system for the generator side converters. In a variable speed wind energy conversion system, the generator speed and maximum power for different wind velocities are cubically related. Therefore in order to maximise the power, the generator should follow power speed characteristics. Hence the generator speed should be controlled. The reference speed for the power speed characteristics is from the power at the dc link. The difference between actual speed and reference speed is given to the proportional integral (PI) controller. As the speed controlling variable of the rotor speed is ' i_q ', the PI controller output is reference for ' i_q '. The expression for the reference torque is given by,

$$T_e^* = (K_{pw} + \frac{K_{iw}}{s}) (w_r^* - w_r) \quad (5)$$

Where K_{pw} = proportional gain for generator speed control & K_{iw} = Integral gain for generator speed control
The expression for torque controlling or q-axis reference current component is given by,

$$i_q^* = \frac{4}{3} \left(\frac{T_e^*}{P \lambda_m} \right) \quad (6)$$

The reference currents are transformed back to abc frame to produce the gating signal for the converter. In the hysteresis controller, the actual current continuously tracks the reference current within a specified hysteresis band. The Simulink model of generator side controller is shown in below figure. In the below model it is observed that

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the d-axis reference current is set to zero. It helps to obtain maximum torque at minimum current. Hence it leads to reduction of resistive losses in the generator.

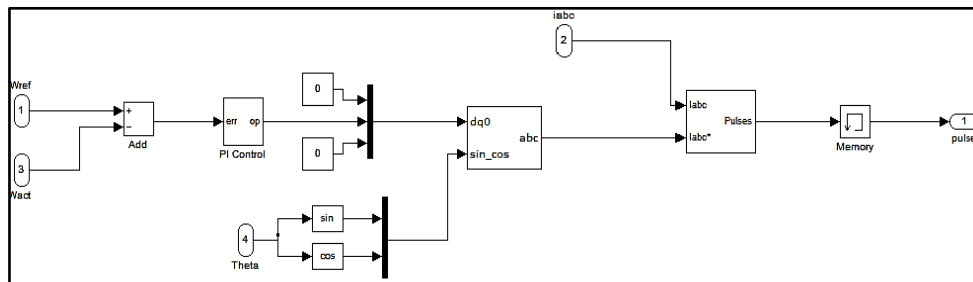


Fig (2) Simulink model for PMSG control

GRID SIDE CONVERTER CONTROL

The grid side converter is an inverter, which convert dc to ac and then it is transferred to grid. The main objective of grid side converter is to deliver captured power with required reactive power compensation and harmonic minimization. Simulink model developed for Grid side converter is shown in below figure. The active power control is done by the outer loop. The outer loop is called dc voltage control loop, which sets the reference current. This reference current is used for active power control. Similarly the inner loop is a current loop, which is required to meet the demand of nonlinear load for reactive power and harmonic compensation at the point of common coupling. The synchronous rotating reference frame is used to realize the proposed control strategy. In this synchronous rotating reference frame the filtering and controlling is very easy because the control variables are dc quantities. With the help of the voltage phase angle θ the above equations are transformed into a-b-c reference voltages. The phase lock loop (PLL) technique is used to extract the grid synchronizing phase angle.

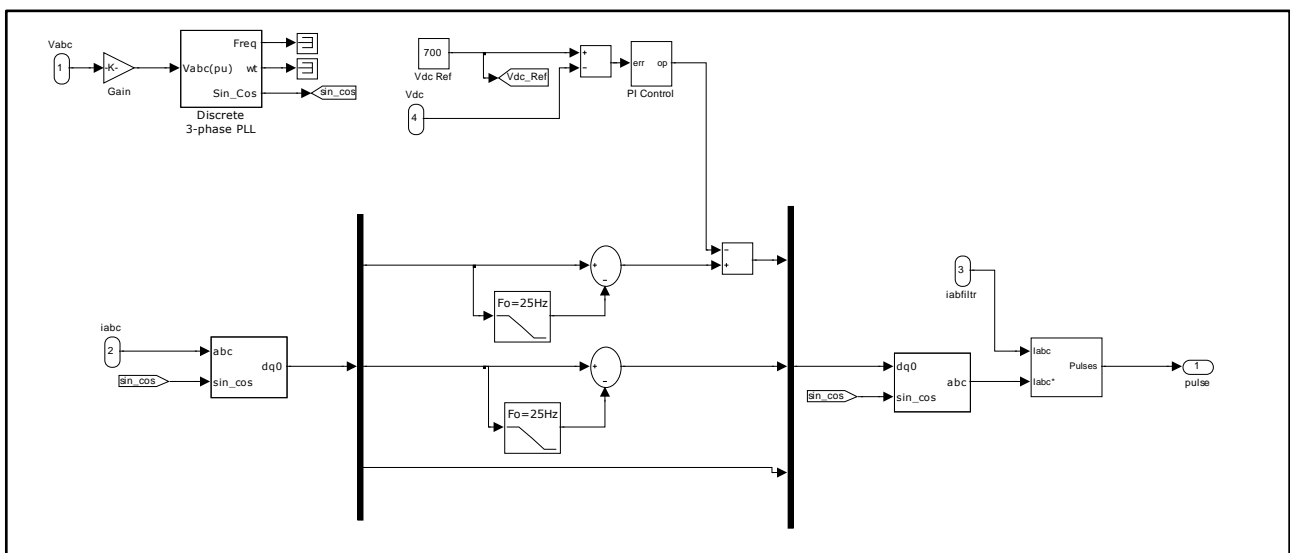


Fig (3) Simulink model for grid side converter control

IV.SYSTEM MODELLING IN MATLAB/SIMULINK

This section includes the complete modelling of wind energy conversion system. At this stage of modelling, a battery bank is employed in order to reduce power fluctuation in the inverter output. The battery bank is connected to the

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common dc link for compensating the power fluctuations. Also the proposed system is able to store the energy during off load conditions. This power can be used for electric vehicles. Hence atmospheric pollution due to transportation as well as generation can be reduced simultaneously.

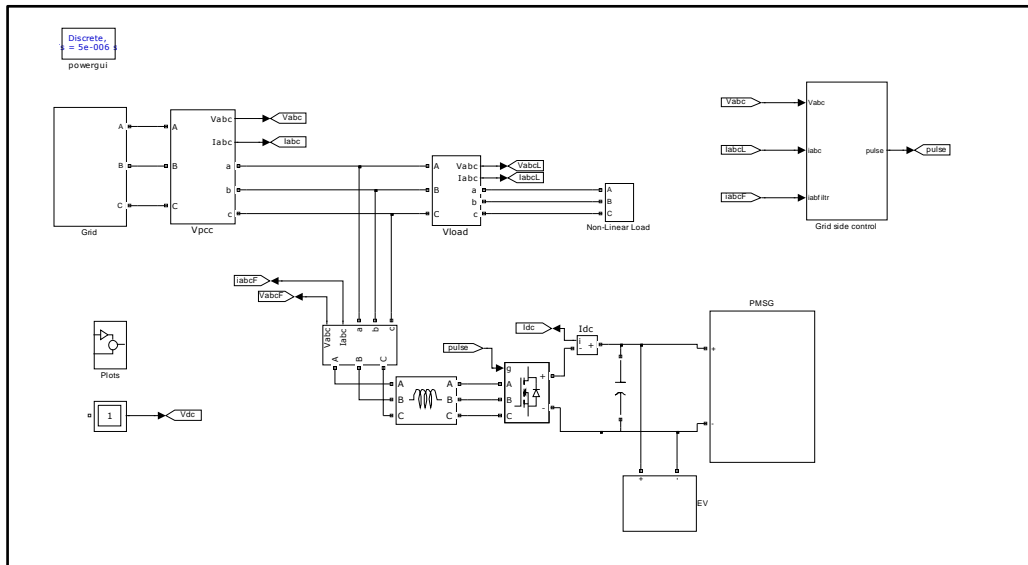


Fig (4) Simulink model of wind energy conversion system with a battery bank

V. SIMULATION RESULTS

The proposed control strategy for PMSG based variable speed WECS is simulated MATLAB/SIMULINK under different operation conditions are explained here. This section includes the traces of wind speed, tracking of wind speed by PMSG, simulation results of grid active and reactive power, load active and reactive power, inverter active and reactive power and current output of the proposed system.

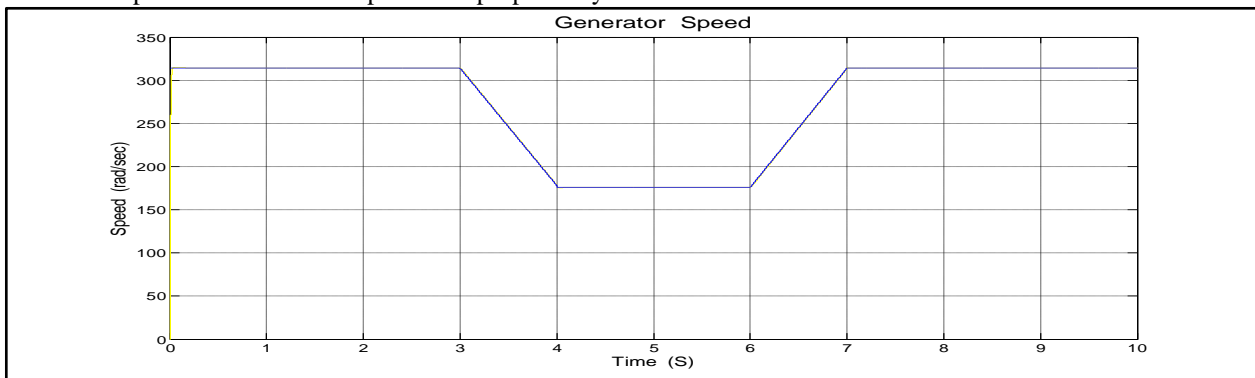


Fig (a) Tracking of reference speed by PMSG

The controlled rotor speed by regulators based on reference speed of PMSG is shown in the above graph. It is observed that the generator follows exactly the reference speed. This power output is maximum because it follows the power speed characteristics of the generator.

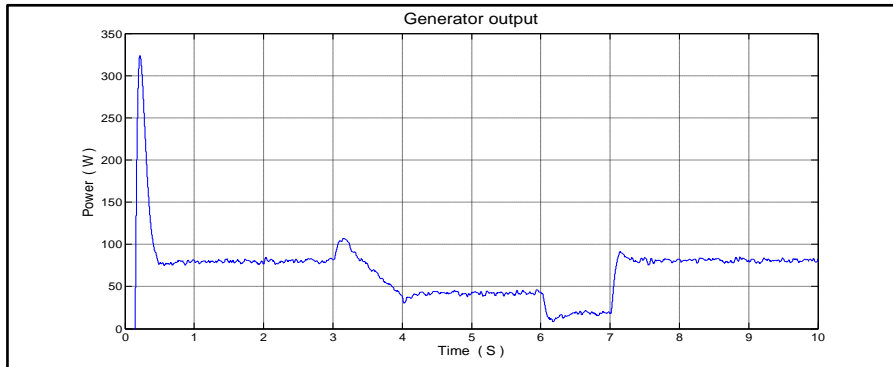


Fig (b) Power output of PMSG

The active power require for the nonlinear load is shown in below graph. This nonlinear load consists of fundamental component, reactive component and harmonic component. The inverter and grid together need to supply this 3 components of nonlinear load.

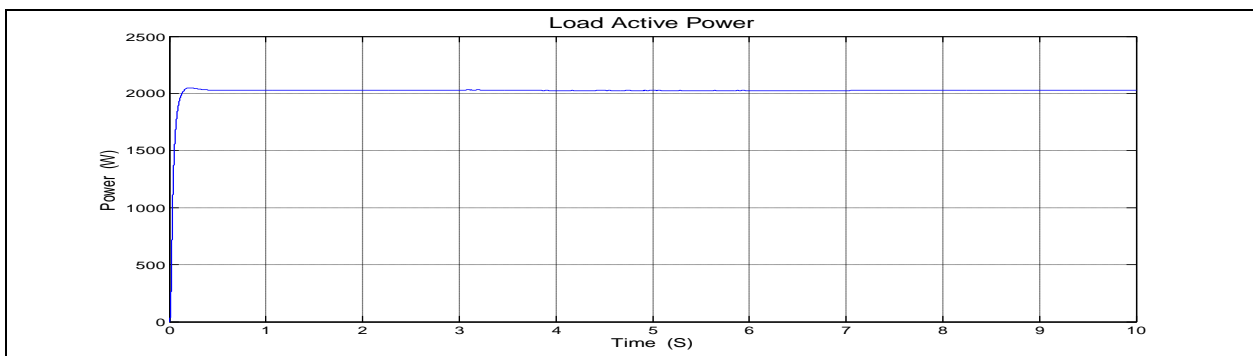


Fig (c) Required active power of load

Similarly the reactive power required for the nonlinear load is obtained in the below graph. Usually the reactive component is controlled by quadrature axis component i_q . Because the dc link voltage constant, then the reactive component varies according to i_q .

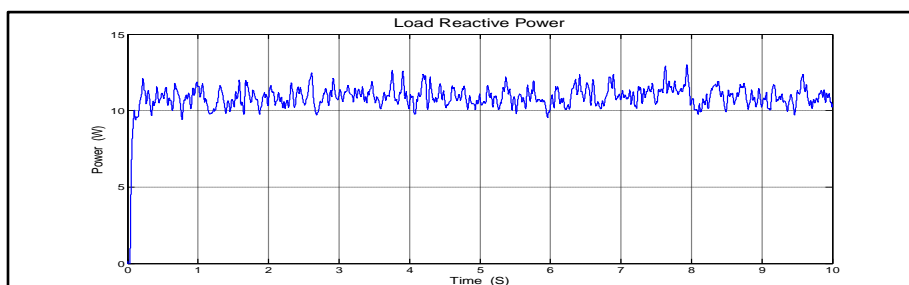


Fig (d) Reactive power required for the load

The active power supplied by the grid in order to meet the requirement of the nonlinear load is shown in below figure. From the below graph it is observed that the active power supplied by the grid is not sufficient meet the requirement of nonlinear load. The active power produced by the PMSG together with grid is also not sufficient to meet this demand.

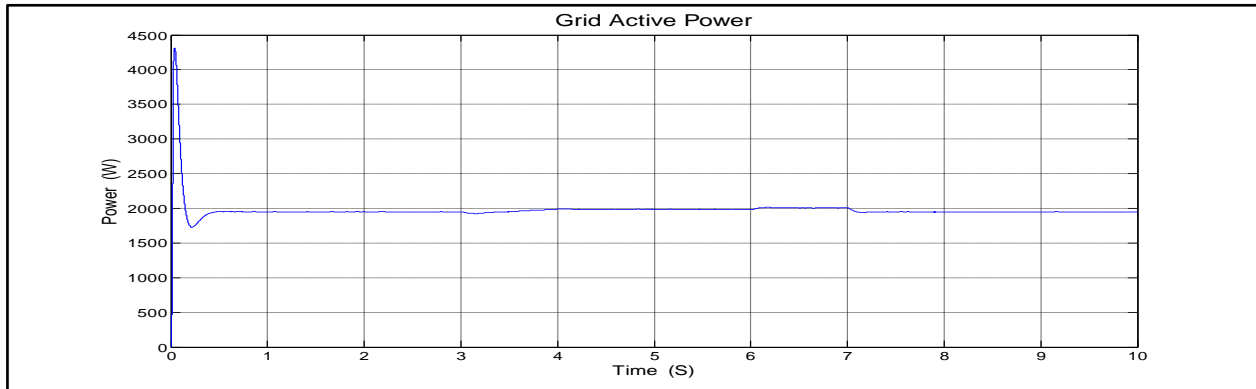


Fig (e) Active power supplied by the grid

The reactive power supplied by the grid is shown in the below graph. This is also less than the requirement of the nonlinear load. So the inverter output should be capable to meet the active and reactive component of power according to the requirement of load.

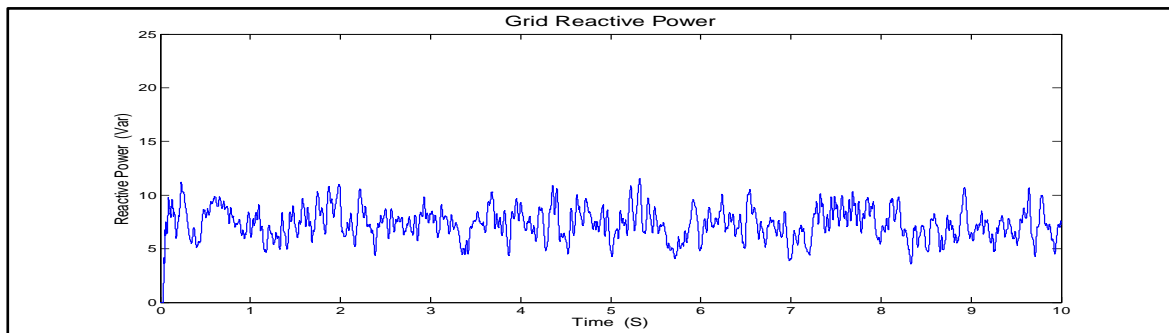


Fig (f) Reactive power supplied by grid

The generator is producing maximum power according to the reference speed. But that power is fluctuating because of the variable nature of the wind. So in order to remove that power fluctuation, we are using that battery bank in the proposed system. So inverter is capable of deliver power without power fluctuation.

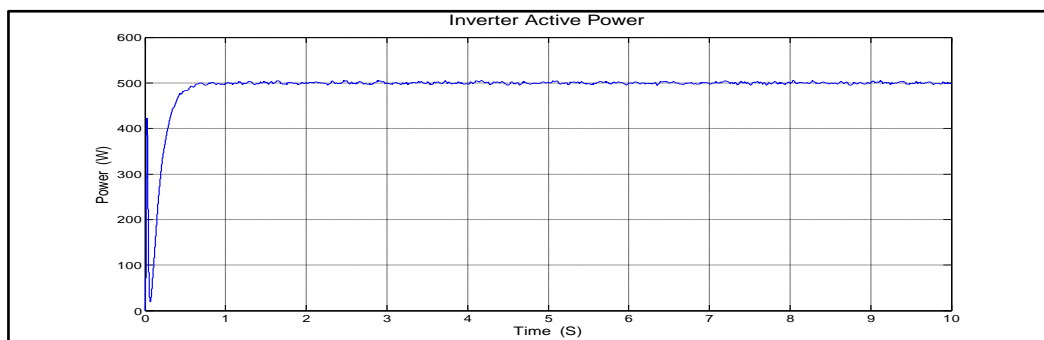


Fig (g) Inverter power output

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The reactive power supplied by the inverter is represented in below graph. In order to extract the harmonics a low pass shunt active filter is used. The reactive component varies according to quadrature axis component i_q and active component varies according to i_d .

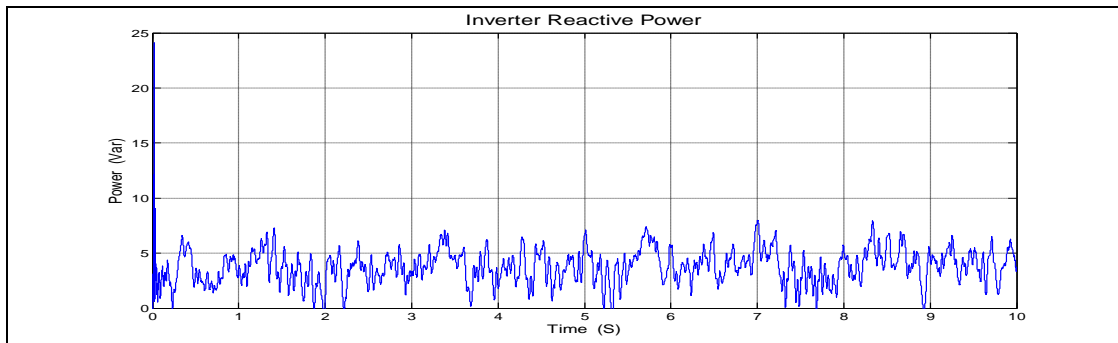


Fig (h) Reactive power supplied by the Inverter

From the above graphs it is observed the remaining power required for the load is provided the inverter with the help of battery system. The battery system is able to provide and absorb the power from the grid, and hence the power fluctuation in the grid is minimized. The dc link voltage is represented in the below figure.

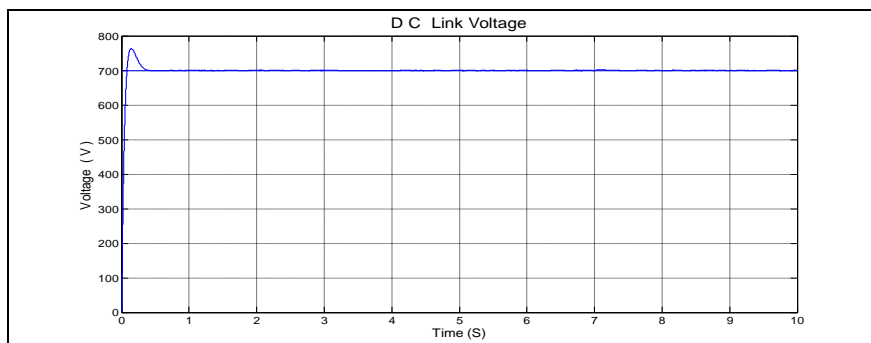


Fig (I) DC Link Voltage

After using the grid side converter control, the inverter current is shown in the below. This current satisfies the requirement of active, reactive and harmonic component of the load. It helps to maintain unity power factor operation with minimal harmonic pollution.

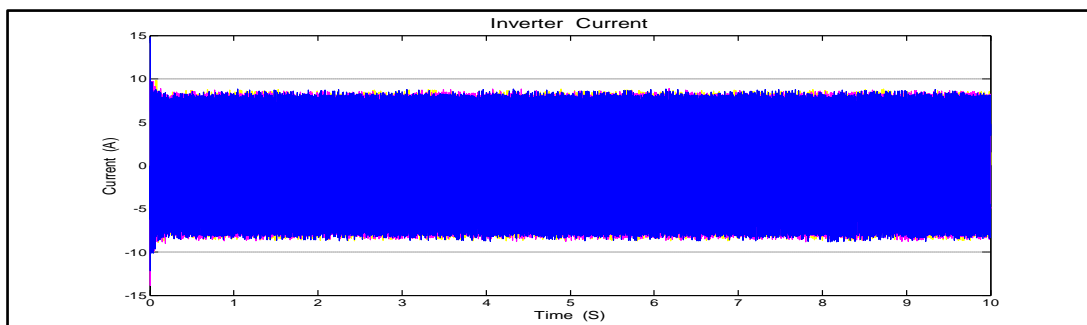


Fig (j) Inverter current



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VI.CONCLUSION

The PMSG based wind energy conversion system is modelled in MATLAB/SIMULINK and equations are used to explain its behaviour. Under varying wind conditions the performance of PMSG based wind energy conversion system is demonstrated. The proposed regulator incorporates grid synchronisation of wind energy system. The PMSG is able to track the wind speed exactly with the help of proposed controller. The grid side converter is able to transfer the capture power to nonlinear load at the PCC with minimal harmonics distortion and required reactive power compensation. The system works satisfactorily under normal as well as dynamic condition. The battery bank is connected to the common dc link for compensating the power fluctuations. The grid side inverter is able to inject sinusoidal current at unity power factor. Also the proposed system is able to store the energy during off load conditions and this power can be used for electric vehicles. Hence atmospheric pollution due to transportation as well as generation can be reduced simultaneously.

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BIOGRAPHY

Surya N. received her AMIE in Electrical Engineering from Institution of Engineers India (IEI), Kolkata in 2011 and she is currently doing M.Tech in Power System Engineering University BDT College of Engineering, Visvesvaraya Technological University, Belgaum, India. Her research is focused on the control of power converters, especially when employed for renewable energy systems. Her major interest includes Power quality, power system voltage stability, reactive power compensation and harmonic minimization problems.

H.R.Sudarshana Reddy received his B.E degree in electrical engineering from Karnataka University, Dharwad in 1989 and M.E in Electrical engineering from Bangalore University in 1992. He received PhD in 2007 from Kuvempu University, Karnataka, India. His research areas include pattern recognition, Recognition of unconstrained patterns, Genetic algorithm application to pattern recognition, computer application to power systems. He is currently professor in Department of Electrical and Electronics Engineering in University BDT College of Engineering, Visvesvaraya Technological University, Belgaum, India. To date he is authored and co-authored over 25 technical papers comprising of national and international conference proceedings and journals. Dr H.R Sudarshana Reddy actively involved in the professional activities and currently is a member of ISTE. He received an award as "Promising Engineering Teacher Award" for contribution to technical education from ISTE, Delhi in 2006.