Modeling And Simulation Of Grid Connected Wind And PV Based Hybrid Power System

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***Abstract*-The renewable energy systems (RESs) are an attractive option to electrify the community as they are environment friendly, free of cost, and easily available all around us. The efficiency of these energy systems is very low and can be improved by integrating them in parallel. Solar and wind energy are present in abundant amount. In this paper a hybrid energy system is presented which consist of wind turbine generator set and photovoltaic (PV) array system. This paper also proposes a control strategy for the hybrid power system during grid connected mode without necessity of any dummy load on the DC bus. Under grid connected mode, the aim is to maintain a constant DC bus voltage irrespective of DC source or load variation. The proposed coordinated strategy for the renewable energy sources and load management ensures the operation and reliability of system under grid connected mode. Simulations have been done in MATLAB and the results are presented to demonstrate the proposed control system during grid connected mode.**

***Key words*: Grid connected mode, Renewable Energy, Hybrid Power System (HPS), PWM, MPPT, Boost Converter, Wind Turbine Generator (WTG), PV, MATLAB/SIMULINK.**

I. INTRODUCTION

The development of renewable energy has significantly increased in last few years. The recent developments have made possible to extract the energy more efficiently than ever before. Renewable Energy (RE) technologies offer important benefits as compared to those of conventional energy sources. They are sustainable and offer the promise of clean energy with minimal impact on the environment with economic benefits and longer life. From the past few years many authors have proposed control strategies for the stable operation of the hybrid grid. To make a hybrid power system, combination of two or more renewable energy sources is needed for better performance and to meet the power demand is presented in [1].

It has been observed that hybrid power system consists of wind turbine generator (WTG) and photo voltaic (PV) is better than a single PV or a single WTG configuration [2]. In [3] explained the importance and control of permanent magnet synchronous generator (PMSG), as it is a having higher efficiency and less maintenance because it doesn't have rotor current and can be used without a gear box, implying reduction in maintenance and cost. In [4] PV array is used to convert solar energy into electrical energy. The MPPT (Maximum Power Point Tracking) control is explained, in MPPT control is a technique which is used to maximize power output. There are different types of MPPT methods, among them Perturbation and Observation technique has been studied. A boost converter [5] is a DC-to-DC power converter which steps up the voltage while step down the current. It is a class of switched-mode power supply (SMPS) having at least two semiconductors (a diode and a transistor). In [6] a six arm converter topology is used with three arms for the uninterruptible power supply (UPS) rectifier-inverter and three arms for the PV, WTG combine online UPS to the grid. Pulse width modulation (PWM) in [7] is the most popular control technique in voltage-source inverters. Compared to the PWM converters, the current-controlled PWM has advantages of lesser distortion and lower harmonic noise. Filters [8] is a combination of inductors and capacitor is explained to reduce harmonics. Multi source hybrid renewable energy sources to some extent overcome the uncertainty, intermittency and less availability of single source renewable energy systems, which has made the power supply more reliable and economical [9]. Thus the importance of hybrid systems has grown as they emerge to be the near perfect solution for a clean and distributed energy production in near future.

The rest of this paper is organized as follows. Section II describes the mathematical modeling. Section III illustrates the control methodology. Section IV shows the result and discussion. Finally, Section V shows the conclusion.

II. Mathematical modeling

A. Modeling of Wind Turbine System: The wind turbine mechanical power is given by

$$P = \frac{1}{2}\rho A v^3 C_p(\lambda, \beta) \qquad (1)$$

Where,

A = rotor swept area, P_m = Power in watts, V= speed of wind in m/sec, ρ = air density, C_p is performance coefficient. The performance coefficient C_p is depends on two factors blade tip speed ratio (λ) and blade pitch angle (β). To formulate a relation for power coefficient in terms of the above variables several numerical approximations have been proposed, from the following relation is used.

$$C_p(\lambda, \beta) = \frac{1}{2}\left\{\frac{98}{\lambda_i} - 0.4\beta - 5\right\} \exp\left\{\frac{-16.5}{\lambda_i}\right\} + 0.0068\lambda \qquad (2)$$

$$\lambda_i = \left[\frac{1}{(\lambda + 0.089)} - \frac{0.035}{(\beta^3 + 1)}\right]^{-1} \qquad (3)$$

B. Modeling of PV system

The building block of PV arrays is the solar cell, which is basically a p-n junction that converts light energy into electrical energy. Its equivalent circuit is shown below in Figure 2.1.

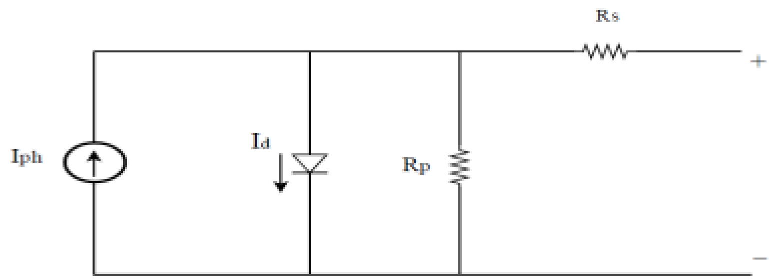

Fig. 2.1 Equivalent circuit of PV cell.

The equivalent circuit of PV cell can be modeled as a current source which is connected in parallel with diode. Since the PV modules produce DC power, it should be converted to AC with the help of an inverter to increase its utility.

The PV array can be mathematically modeled as

$$P_{pv} = I_{pv} V_{pv} = N_p P I_{ph} \left[\{(q/kAT) * (V_{pv}/N_s)\} - 1\right] \qquad (4)$$

where ,

P_{pv} =generated DC power of the PV array (kW)

V_{pv} =DC voltage of the PV array (V)

I_{pv}= current of the PV array (A)

I_{ph} = photocurrent of the PV cell (A)

q= charge of an electron,

A =ideality factor,

T =cell temperature (K),

N_S=number of series connected PV modules.

N_P=number of parallel connected PV modules.

C. Boost Converter

A boost converter is a DC-to-DC power converter which steps up the voltage. The output voltage of PV system is very low, to increase its output voltage boost converter is used. The circuit diagram of boost converter is shown in fig.2.2

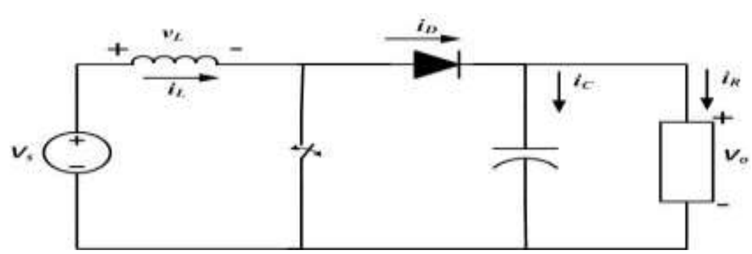

Fig. 2.2 Circuit of a Boost converter

The expression of a duty cycle (D) of a Boost Converter is given by:

$$\frac{V_o}{V_s} = \frac{1}{1-D} \tag{5}$$

Where, the value of D between 0 to 1
V_o= output of boost converter
V_s= input of boost converter

D. Hybrid Power System (HPS)

The block diagram of HPS have been shown in Fig. 2.3 which basically consists of the elements presented below connected together to form HPS.
The advantages of the HPS are outlines as below:
- Increases the efficiency and the reliability of renewable energy systems,
- Lower atmospheric contamination,
- Less dependency on fuel hence more economical
- HPS allow longer variations in the average wind speed.

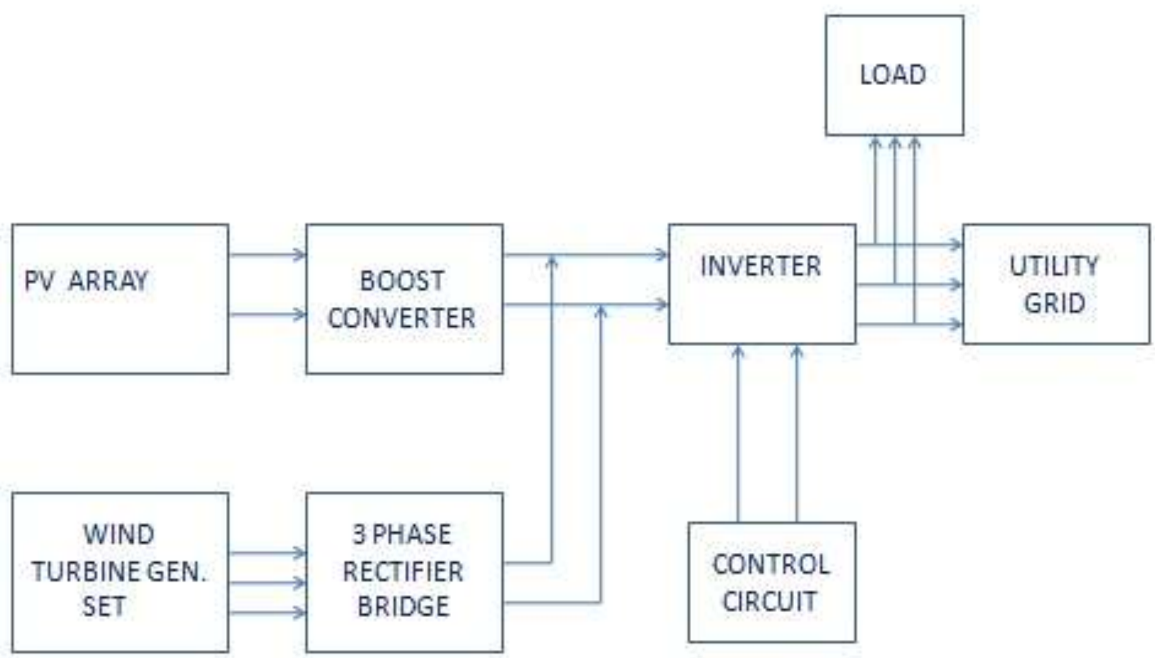

Fig. 2.3 Block Diagram of Proposed System

The PV cell is connected to Boost Converter, as PV generates dc power the boost converter raises the voltage to the required level so as to utilize the generated power. The power obtained from the wind generator is ac in nature so a rectifier is used with the WTG to convert ac into dc. The output of both PV cell and wind generator is collected at the common bus and this common output is fed to the inverter. HPS is connected to the utility grid by an inverter. This system can be considered as a complete green power generation system because the main energy sources of the system are all environmentally friendly, and it can be stand-alone or grid-connected.

III. METHDOLOGY

A. MPPT (Maximum Power Point Tracking) Control

It is a control technique used with photovoltaic solar systems to maximize power output. There are different types of MPPT methods, among them Perturbation and Observation technique has been used in this model. In this method the controller adjusts the voltage by a small amount and measures power; if the power rises, further adjustments in that direction are tried until power no longer rises. This is called the perturb and observe method and is most common. The flow chart of the MPPT control technique is shown in fig.3.1

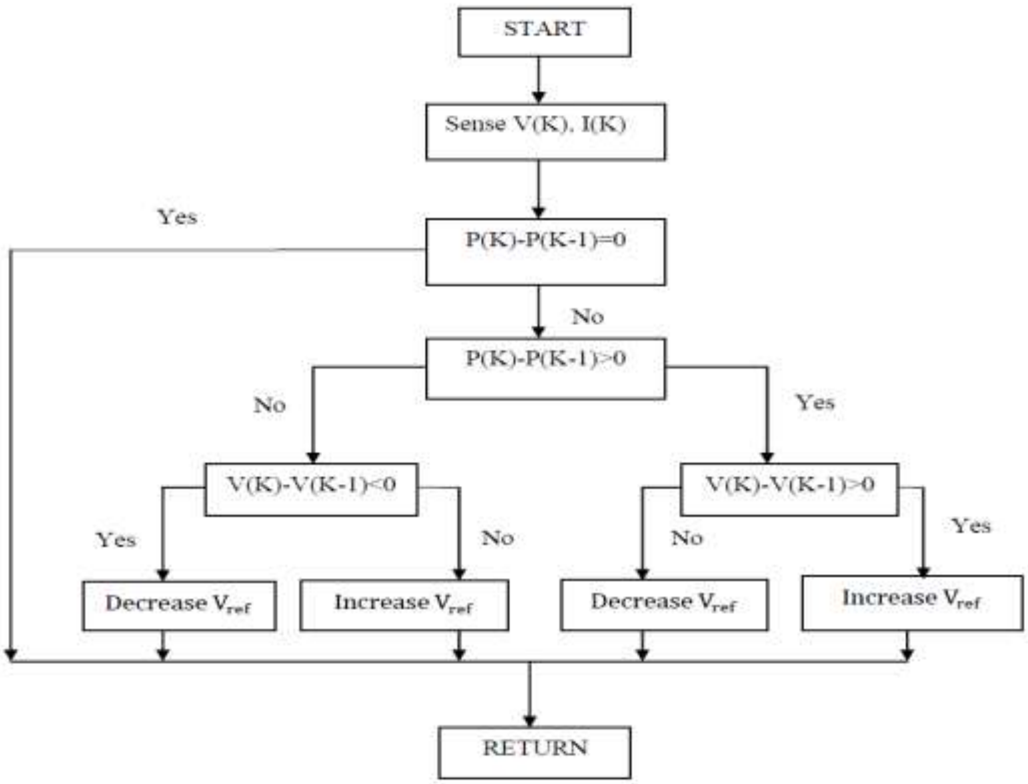

Fig. 3.1 Flow chart of MPPT control

B. Grid Connected Mode

To interface the dc bus to grid the inverter should be able to control the injected/absorbed reactive power and should have a fast active power response with fundamental frequency along with voltage amplitude. At low frequency the voltages and currents of the inverter are as given below

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = R_s \begin{bmatrix} i_{ga} \\ i_{gb} \\ i_{gc} \end{bmatrix} + L_s \frac{d}{dt} \begin{bmatrix} i_{ga} \\ i_{gb} \\ i_{gc} \end{bmatrix} + \begin{bmatrix} v_{ga} \\ v_{gb} \\ v_{gc} \end{bmatrix} + \begin{bmatrix} v_N \\ v_N \\ v_N \end{bmatrix} \tag{6}$$

Above is based on ABC to DQ coordinate transformation which allows independent control of d-axis and q-axis. After abc-dq transformation, the equation becomes as:

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = R_s \begin{bmatrix} i_{gd} \\ i_{gq} \end{bmatrix} + L_s \frac{d}{dt} \begin{bmatrix} i_{gd} \\ i_{gq} \end{bmatrix} + L_s \omega \begin{bmatrix} i_{gq} \\ i_{gd} \end{bmatrix} + \begin{bmatrix} v_{gd} \\ v_{gq} \end{bmatrix} \tag{7}$$

By this transformation the active and reactive powers can be controlled directly by controlling the d – axis and q – axis currents, here v_{gq} is taken as zero.

$$P = \frac{3}{2}\left(v_{gd} i_d + v_{gq} i_q\right) = \frac{3}{2} v_{gd} i_d \tag{8}$$

$$Q = \frac{3}{2}\left(v_{gd} i_q + v_{gq} i_d\right) = \frac{3}{2} v_{gd} i_q \tag{9}$$

Fig.3.2 shows the control structure with decoupling method which consists of two control loops, the inner loop represents the current loop whereas the outer loop represents the DC voltage loop. The current igd is used to control the active power flow between the grid and dc bus.

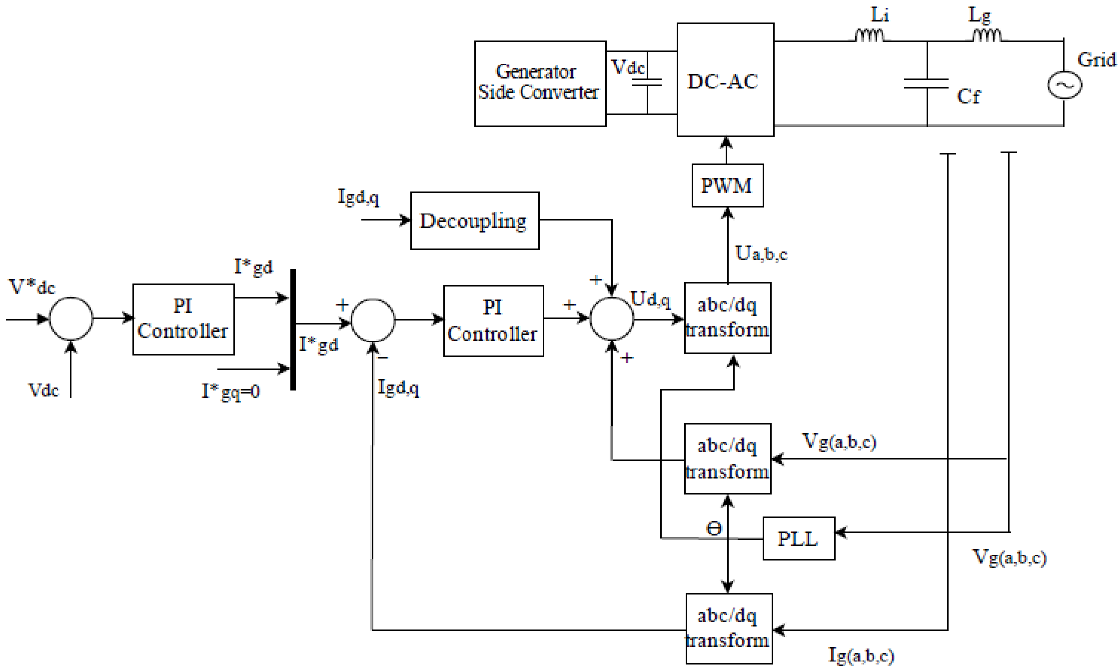

Fig 3.2 Control structure of voltage and current loop with decoupling method

IV. Results and Discussion

A. Parameters

Table 1 Wind turbine specification

Parameter	Rating
Rated Power	1 MW
Wind Speed	10 m/s - 12 m/s (0 to 0.5 s) (0.5 to 1s)
Blade Pitch Angle	0

Table 2 PMSG specification

Parameter	Rating
Stator connection winding	Star
Number of pole pairs	4
Frequency	50 Hz
Stator Phase Resistance	2.8750 Ω
Stator phase Inductance	0.835 mh
Torque constant	16.8 Nm
Friction factor	0.001 N.m.s.
Inertia constant	0.0008 kgm^2

Table 3 PV array specification

Parameter	Rating
Rated power	100 kW
Maximum Irradiance level	1000 W/m^2
Standard Operating Temperature	25 ^{0}C
Number of cells per module	96
Number of series connected module per string	5
Number of parallel strings	66

B. Simulation Model

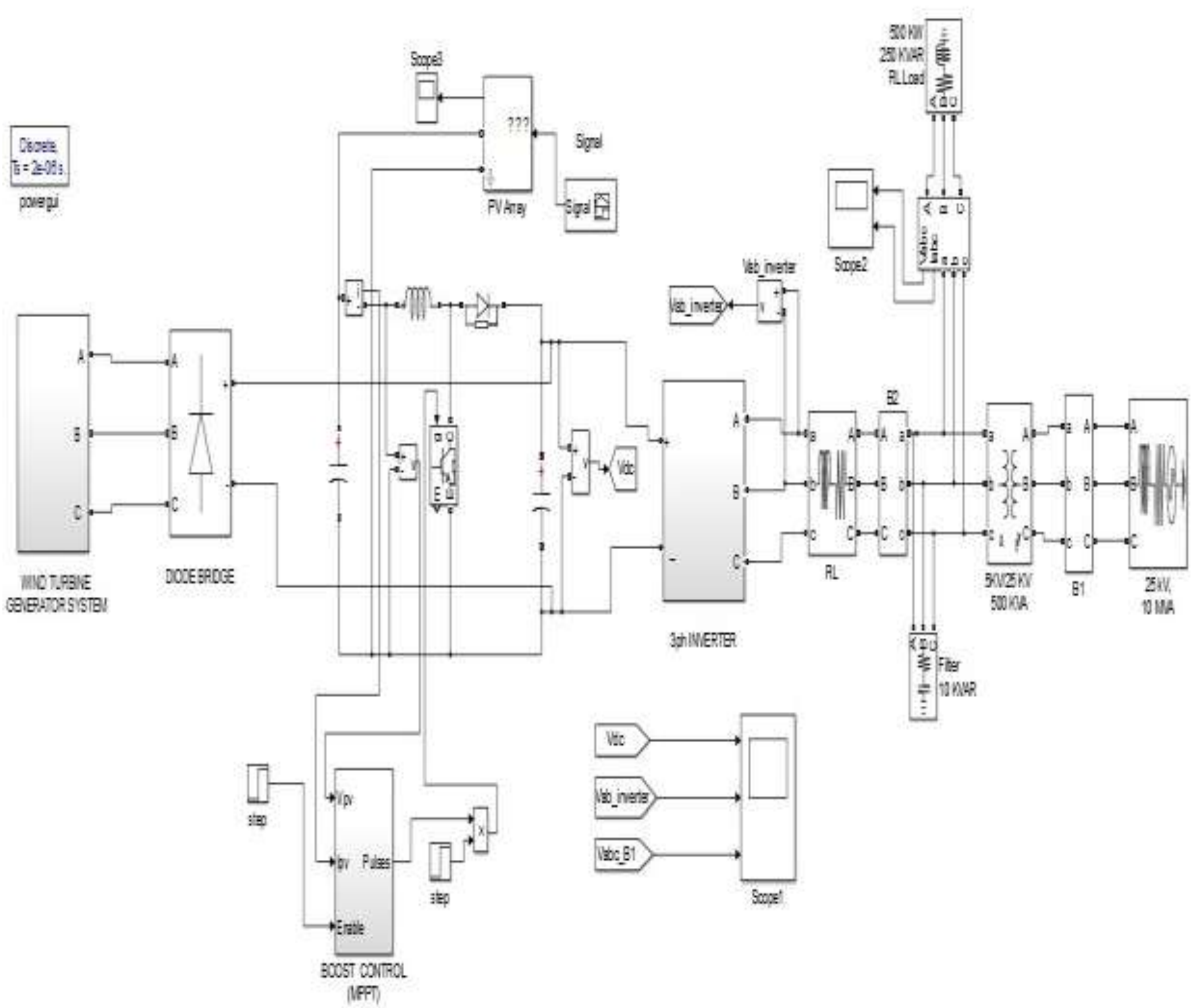

Fig. 4.1 Simulation model of proposed system

Fig 4.1 shows the simulation model of the proposed system. It consist of PV array and WTGs which is used to generate electricity. PV system generates dc power whereas WTGs system generates ac power, a rectifier is used in conjunction with WTGs to convert ac into dc. The output of the PV system is very low hence to increase its value boost converter is used in conjunction with the PV system. The output of both the system is taken across a common link. Filtering circuit is a combination of inductor and capacitor which is used to eliminate harmonic and smoothing common dc link voltage. The common dc link voltage is fed to PWM inverter to convert dc into ac. The output of the inverter is in form of pulse, hence to convert pulse into sinusoidal waveform a choke is used which consist of resistance and inductance. The obtained sinusoidal output is able to feed ac load and it may also transfer to the grid by using step up transformer.

C. Simulation Results

Figure 4.2 shows the output waveform of the common dc link voltage. The common dc link voltage is the sum of the voltage of the PV system and the wind system. The dc link voltage is increased after 0.5 sec due to the increase in wind speed from 10 m/s to 12 m/s. Figure 4.3 shows the output waveform of an inverter. The output of PWM inverter follows the same variation as the common dc link voltage.

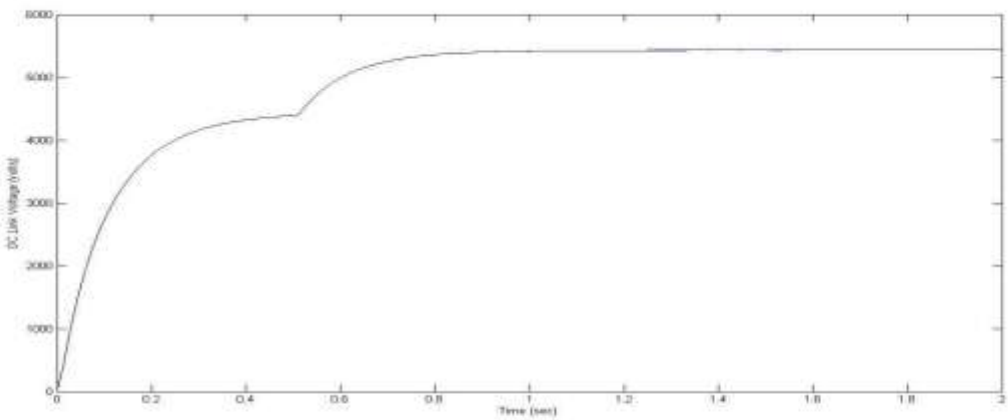

Fig. 4.2 waveform of common DC link voltage

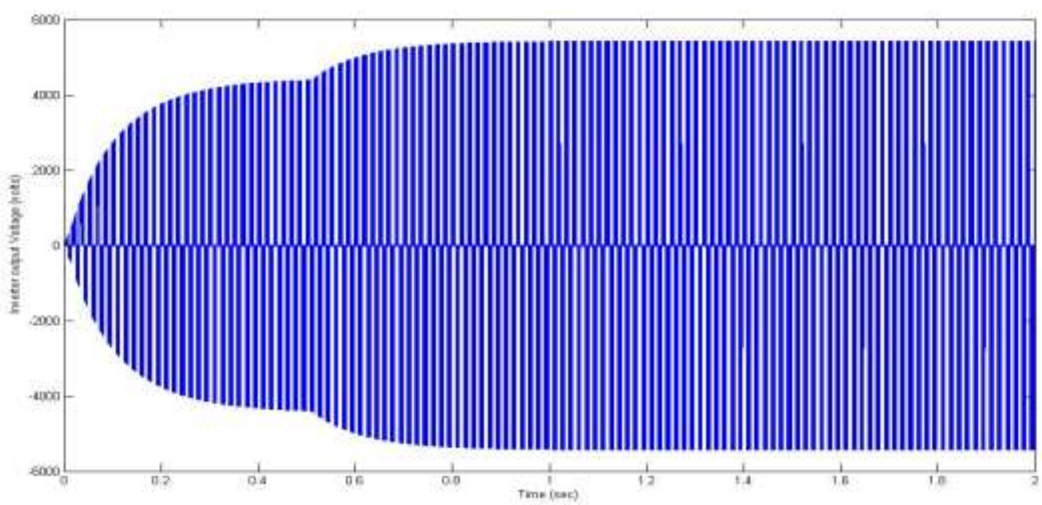

Fig. 4.3 waveform of inverter output voltage

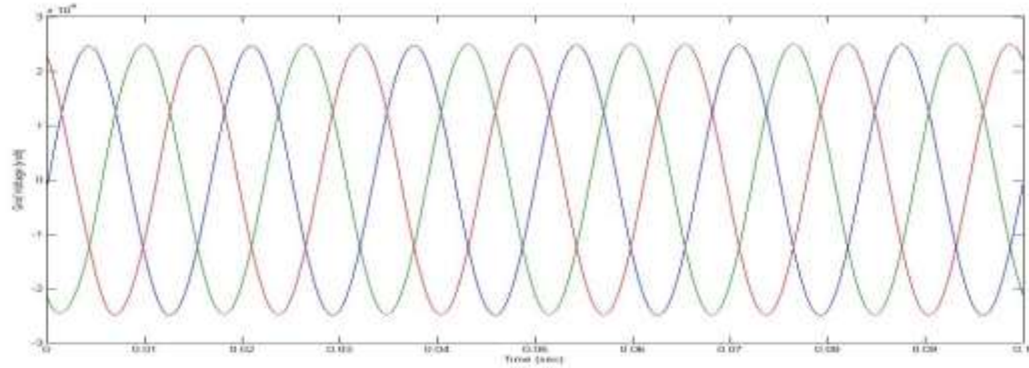

Fig. 4.4 waveform of grid voltage

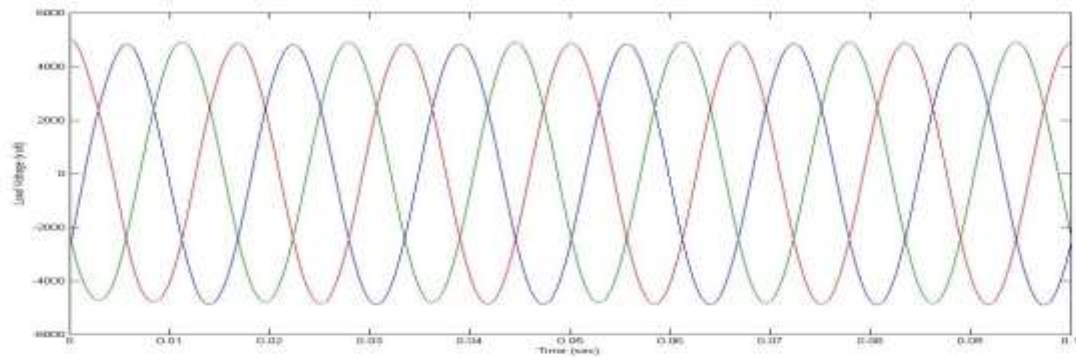

Fig. 4.5 waveform of load voltage

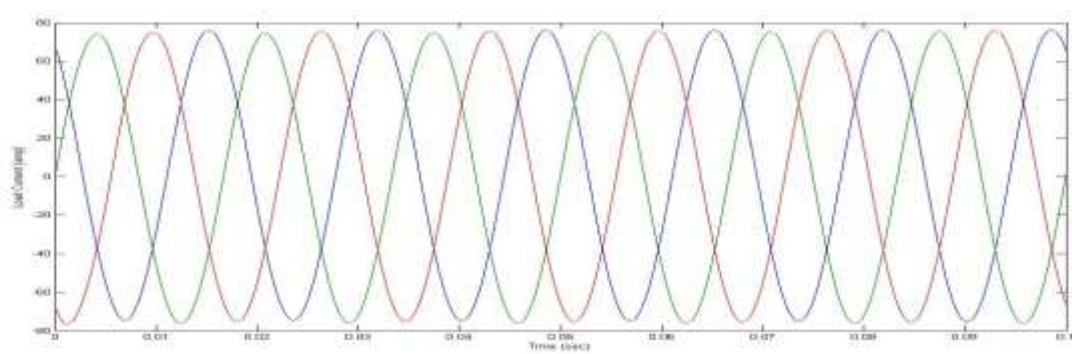

Fig 4.6 waveform of load current

Figure 4.4 shows the waveform of three phase grid voltage under grid connected mode. The three phase grid voltage also indicates a minimum variation in phase sequence. Figure 4.5 and figure 4.6 shows the output voltage and current across the three phase RL load respectively. The output results shows that the proposed system is able to feed ac as well as dc load.

V. Conclusion

In this article, analysis of the integration of renewable sources has been done. The proposed system is installed to those areas where the solar and wind energy are available at moderate nature such as Indian environmental condition. The nature of the wind and solar energy is intermittent or variable. Thus, using the individual system the continuous generation of power is not possible, and it may also increase burden to the grid. The proposed system reduces the complexity of the electrical system, having more cost effective as compared to other RESs and reliable operation. The operation of inverter is controlled through the constant current controller. The advantage of using constant current controller are reduced cross-coupling between the real and the reactive power control loop, greater immunity to phase measurement errors, improved transient response, less current harmonics, and inherent over current protection. The obtained result shows that the proposed system has the ability to supply local community. All the work is done on the MATLAB simulation.

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