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Seamless Power Supply of Grid Connected PV System

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Abstract:

This paper is mainly to supply seamless power to load utility by grid connected photovoltaic array. The maximum power from the PV array is delivered by DC-DC boost converter with incremental conductance maximum power point tracking (MPPT) technique. The system is followed by DC-AC inverter control system along with grid synchronization condition, which is connected to grid. The results are output voltage and current of PV array, output AC voltage, current and real power to the system by using MATLAB.

Keywords:

PV array, MPPT algorithm, DC-DC boost converter, Grid –Tie inverter.

I. INTRODUCTION:

As a solution for the depletion of conventional fossil fuel energy sources and serious environmental problems, focus on the photovoltaic (PV) system has been increasing round the world. Since it is clean, pollution-free, and inexhaustible, researches on the PV power generation system have received much attention. Furthermore, for the continuing decrease in PV arrays cost and the increase in their efficiency, PV power generation system could be one of comparable candidates as energy sources for mankind in near future [1]. A photovoltaic system converts sunlight into electricity. The basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form panels or modules. Panels can be grouped to form large photovoltaic arrays. [2]. PV module represents the fundamental power conversion unit of a PV generator system. The output characteristics of PV module depends on the solar insolation, the cell temperature and output voltage of PV module.

Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system applications. The mathematical PV models used in computer simulation have been built for over the past four decades [3]-[4]. To make best use of the solar PV systems the output is maximized either by mechanically tracking the sun and orienting the panel in such a direction so as to receive the maximum solar irradiance or by electrically tracking the maximum power point under changing condition of insolation and temperature. The overall performance of solar cell varies with varying Irradiance and Temperature [5]-[6]. The PV application ranges from small installations of a few kW located in individual premises to large power plants generating several MW of power [7]-[8].

A maximum power point tracking (MPPT) algorithm has been proposed i.e. incremental conductance (INC) [9]–[10]. In addition, the photovoltaic grid-connected system greatly eases the problem that the existing electricity supply system is often unable to meet peak demand, and then it has become an important supplement of the electricity supply in many countries. Regarding the endless aspect of solar energy, it is worth saying that solar energy is a unique prospective solution for energy crisis. However, despite all the above mentioned advantages of solar power systems, they do not present desirable efficiency [11]. The control approach in designing the grid connected PV system employs two control loops: an outer control loop that is used to regulate the output power from the PV array to the grid, and an inner control loop that is used to regulate the injected current to the grid and keep it in phase with voltage to achieve unity power factor operation [12]-[13] with a Neutral-Point Balancing in the Three-Level NPC Inverter [14].

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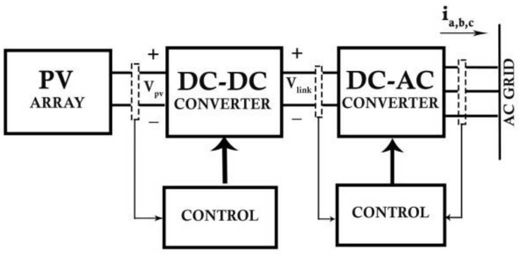

Fig.1. Block diagram of proposed system

Fig.1. shows the proposed system where the PV array is connected to the grid through the DC-DC converter and DC-AC converter with control techniques. The main aim of this paper is to provide the information regarding the integration of PV array with grid and the results may be used for the further research over this area. The principle and operation of the PV cell and the fundamental characteristics of PV cell are discussed in section II. The incremental conductance MPPT algorithm is discussed in the section III. The obtained output from the PV array is boosted with a DC-DC converter where its operation is discussed in section IV. A Three level inverter along with control technique is discussed in the section V. The simulation model developed using MATLAB/SIMULINK and the results obtained are presented and discussed in section VI and finally the conclusions and the future scope are discussed in section VII.

II. PV ARRAY:

During darkness, the solar cell is not an active device; it works as a diode, i.e a p-n junction. It produces neither a current nor a voltage. However, if it is connected to an external supply (large voltage), it generates a current I_d, called diode current or dark current [27]. The model contain a current source Iph , one diode, a parallel resistance Rsh & a series resistance Rs , which represents the resistance inside each cell and in the connection between the cells. The net current is the difference between the photocurrent is the connection between the cells. The net current is given by the following equation:

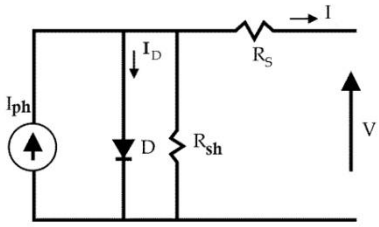

Fig.2. Circuit diagram of PV Cell

$$I = Iph - I_{rs}\left(e^{q(V+IRs)/kTcA} - 1\right) - (V+IRs)/R$$

Where A is idealizing factor, k is Boltzmann's gas constant, Tc the absolute temperature of the cell, q electronic charge & V is the voltage imposed across the cell. I_{rs} is dark saturation current and it is strongly dependent on the temperature. PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature as shown in Fig.3.

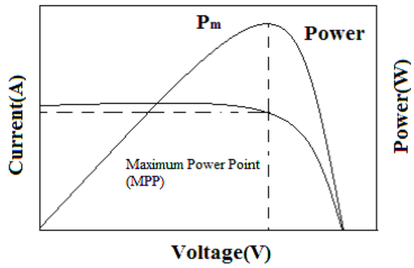

Fig.2 Characteristic curve of PV system.

III. MPPT ALGORITHM:

There are a large number of algorithms that are able to track MPPs. An improved method for INC on the basis of variable step is presented [15].Some of them are simple, such as those based on voltage and current feedback, and some are more complicated, such as perturbation and observation (P&O) or the incremental conductance(IncCond) method. They also vary in complexity, sensor requirement, speed of convergence, cost, range of operation, popularity, ability to detect multiple local maxima, and their applications [16]–[17]. Having a curious look at the recommended methods, hill climbing and P&O [18]–[21] are the algorithms that were in the center of consideration because of their simplicity and ease of implementation.

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Hill climbing [19], [22] is perturbation in the duty ratio of the power converter, and the P&O method [20], [23] is perturbation in the operating voltage of the PV array. However, the P&O algorithm cannot compare the array terminal voltage with the actual MPP voltage, since the change in power is only considered to be a result of the array terminal voltage perturbation. As a result, they are not accurate enough because they perform steady-state oscillations, which consequently waste the energy [16]. By minimizing the perturbation step size, oscillation can be reduced, but a smaller perturbation size slows down the speed of tracking MPPs. Thus, there are some disadvantages with these methods, where they fail under rapidly changing atmospheric conditions [24]. On the other hand, some MPPTs are more rapid and accurate and, thus, more impressive, which need special design and familiarity with specific subjects such as fuzzy logic [25] or neural network [26] methods. MPPT fuzzy logic controllers have good performance under varying atmospheric conditions and exhibit better performance than the P&O control method [16]; however, the main disadvantage of this method is that its effectiveness is highly dependent on the technical knowledge of the engineer in computing the error and coming up with the rule-based table. It is greatly dependent on how a designer arranges the system that requires skill and experience.

Table.1. Comparison of various MPPT techniques

MPPT technique	Speed	Complexity	Reliability	Implementation
Fractional I_{sc}	Medium	Medium	Low	Digital/Analog
Fractional V_{oc}	Medium	Low	Low	Digital/Analog
IncCond	Varies	Medium	Medium	Digital
Hill climbing	Varies	Low	Medium	Digital/Analog
Fuzzy logic	Fast	High	Medium	Digital
Neural network	Fast	High	Medium	Digital

Incremental conductance (INC) method utilizes the incremental conductance (dI/dV) of the photovoltaic array to compute the sign of the change in power with respect to voltage (dP/dV). INC method provides rapid MPP tracking even in rapidly changing irradiation conditions with higher accuracy than the Perturb and observe method.

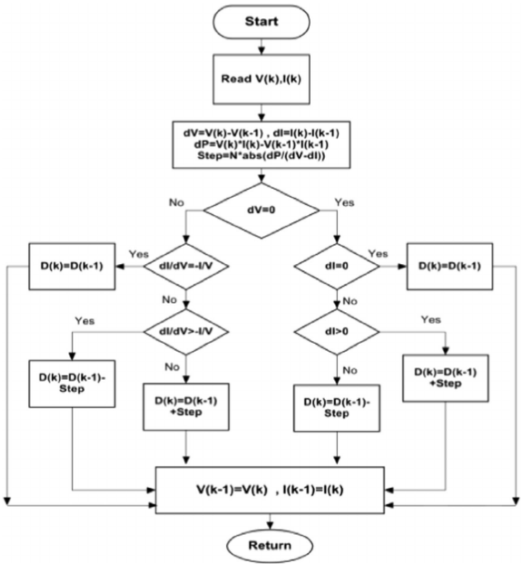

Fig.4. Flowchart of Incremental Conductance

IV. DC-DC CONVERTER:

Switched mode DC-DC converter converts unregulated DC input voltage into regulated DC output voltage at a specified voltage level. Switching power supplies offer much more efficiency and power density compare to linear power supplies. Basic converters that step up or step down voltage input contains elements like transistors, diodes, capacitor and inductors. Three basic converter topologies exist; they are buck (step-down), boost (step-up) and buck-boost (step-up or step-down). In our proposed design boost topology is used because its freewheeling diode can be used for blocking reverse current and it efficiently amplify PV arrays output voltage into higher level. Converters are controlled by pulse width modulation (PWM) duty cycle since the output of converter being determined by state of transistor switch. Thus optimum load impedance of PV module is achieved by varying duty cycle.

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The boost DC converter is used to step up the input voltage by storing energy in an inductor for a certain time period, and then uses this energy to boost the input voltage to a higher value. The circuit diagram for a boost converter is shown in figure 5. When switch Q is closed, the input source charges up the inductor while diode D is reverse biased to provide isolation between the input and the output of the converter. When the switch is opened, energy stored in the inductor and the power supply is transferred to the load. The relationship between the input and output voltages is given by:

$$Vin\,ton + (Vin - Vout)\,toff = 0$$

$$\frac{Vout}{Vin} = \frac{toff + ton}{toff} = \frac{1}{1-d}$$

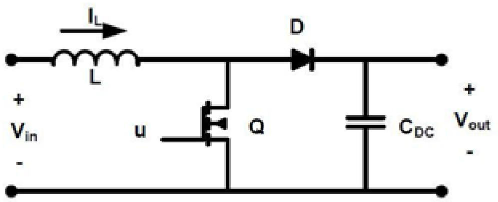

Figure 5: Schematic diagram of a DC boost converter

V. THREE LEVEL INVERTER AND CONTROL TECHNIQUE

A. Three Level Inverter

Voltage source inverters (VSI) are mainly used to convert a constant DC voltage into 3-phase AC voltages with variable magnitude and frequency. The converter used in this project is a Neutral-Point-Clamped three-level converter with three bridge legs. “Three-level” means that each bridge leg, A, B and C can have three different voltage states. The converter topology can be seen in Figure 6. Switch 1 and 3 on each leg are complementary, which means that when switch 1 is on, switch 3 is off and vice versa. Switch 2 and 4 is the other complementary switching pair.

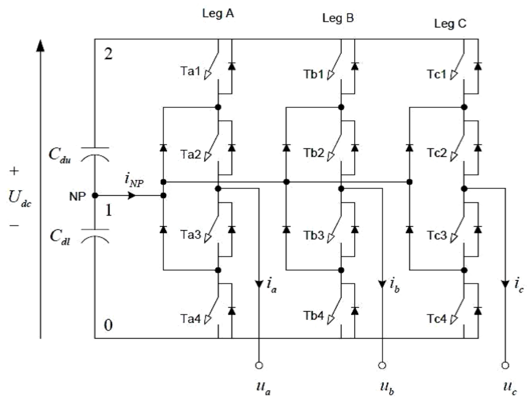

Fig.6. Three Level inverter topology

If each of the capacitors has a constant voltage of 0.5 Udc, then having the two upper switches on will give an output voltage of Udc compared to level 0, switch 2 and 3 on will give 0.5 Udc and by having the two lower switches on, an output voltage of 0 will occur. In addition to these three states there is a forbidden state where the first switch is on while the second is off.

Table.2. Bridge leg voltages at different combinations of switch states

Leg state	U_{a0}	T_{a1}	T_{a2}	T_{a3}	T_{a4}
2	U_{dc}	ON	ON	OFF	OFF
1	$0.5U_{dc}$	OFF	ON	ON	OFF
0	0	OFF	OFF	ON	ON

B. System Structure

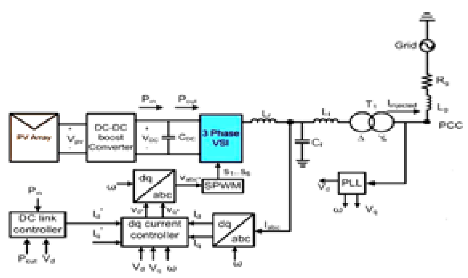

Fig.7. Grid connected PV system structure

The voltage source inverter is controlled in the rotating dq frame to inject a controllable three phase AC current into the grid.

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To achieve unity power factor operation, current is injected in phase with the grid voltage. A phase locked loop (PLL) is used to lock on the grid frequency and provide a stable reference synchronization signal for the inverter control system, which works to minimize the error between the actual injected current and the reference current obtained from the DC link controller. An LC low pass filter is connected at the output of the inverter to attenuate high frequency harmonics and prevent them from propagating into the power system grid. A second order LCL filter is obtained if the leakage inductance of the interfacing transformer is referred to the low voltage side. This provides a smooth output current which is low in harmonic content.

C. The abc/dq Transformation

The dq transformation is used to transform three phase system quantities like voltages and currents from the synchronous reference frame (abc) to a synchronously rotating reference frame with three constant components when the system is balanced. The relationship that govern the transformation from the abc to dq frame is

$$\begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = \mathrm{T} \times \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}$$

$$T = \sqrt{\frac{2}{3}} \times \begin{bmatrix} \cos(\omega t) & \cos(\omega t - 2\pi/3) & \cos(\omega t + 2\pi/3) \\ -\sin(\omega t) & -\sin(\omega t - 2\pi/3) & -\sin(\omega t + 2\pi/3) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}$$

Where, x can be either a set of three phase voltages or currents to be transformed, T is the transformation matrix or ω is the angular rotation frequency of the frame. The angle between the direct axis (d-axis) and phase a-axis is defined as θ as shown in figure 8.

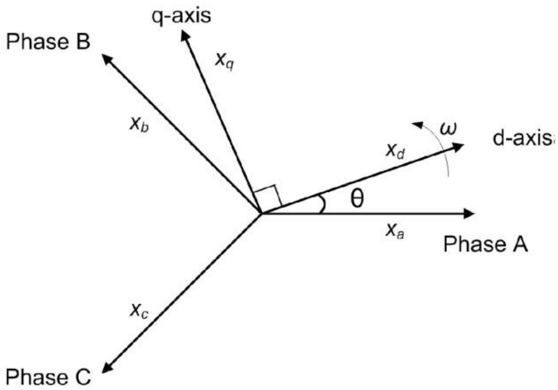

Fig.8. Relationship between the abc and dq reference frames

D. Phase Locked Loop (PLL)

The role of the phase locked loop is to provide the rotation frequency, direct and quadrature voltage components at the point of common coupling (PCC) by resolving the grid voltage abc components. Multiple control blocks of the PV system rely on this information to regulate their output command signals. As stated earlier, the PLL computes the rotation frequency of the grid voltage vector by first transforming it to the dq frame, and then force the quadrature component of the voltage to zero to eliminate cross coupling in the active and reactive power terms. A proportional integral controller is used to perform this task as shown in figure 9. The proportional (Kp) and integral (Ki) gains of the controller were set through an iterative process to achieve a fast settling time.

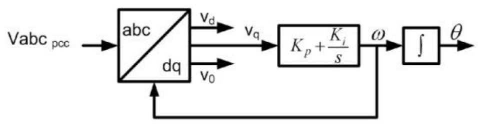

Fig.9. Schematic diagram of the phase locked loop (PLL)

The output from the PI controller is the rotation frequency ω in rad/s. Integrating this term results in the rotation angle θ in radians. The operation of the PLL is governed by

$$\omega = K_p V_q + K_I \int V_q dt$$
$$\theta = \int \omega dt$$

VI. SIMULATION AND RESULTS:

This section presents the simulation model and results for the grid connected PV system shown in figure 10 using Matlab software.

The detailed model contains:

- PV array delivering a maximum power of 100 kW at 1000 W/m2 sun irradiance.
- Boost converter increases voltage from PV natural voltage to 500 V DC. Switching duty cycle of the boost converter is optimized by the MPPT controller that uses the "Incremental Conductance" technique.
- 1980 Hz (33*60) 3-level 3-phase VSC. The VSC converts the 500 V DC to 260 V AC and keeps unity power factor.
- 10-kvar capacitor bank filtering harmonics produced by VSC.
- 100-kVA 260V/25kV three-phase coupling transformer.
- Utility grid model (25kV distributor feeder + 120 kV equivalent transmission system).

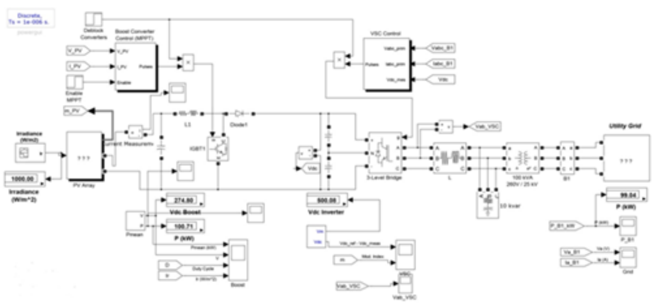

Fig.10. Simulink model of 3 phase grid connected photovoltaic system

Table 3: System Parameters

Grid frequency	60 Hz
PWM carrier frequency	1980 Hz
Nominal power	100 kW
Line Grid voltage	230 V
DC link voltage	500 V

Table 4: SOLAR PANEL specifications

Peak Power (+/- 5%)	Pmax	305 W
Rated Voltage	Vmp	54.7 V
Rated Current	Imp	5.58 A
Open Circuit Voltage	Voc	64.2 V
Short Circuit Current	Isc	5.96 A
Maximum System Voltage	IEC, UL	1000 V, 600 V
Temperature Coefficients	Power	–0.38% / °C
	Voltage (Voc)	–176.6 mV/°C
	Current (Isc)	3.5 mA/°C

The Table.3 shows the system parameters where the grid frequency and voltages at grid and dc link are mentioned and the PWM carrier frequency is also mentioned. The PV array module is used in the simulation of Sun Power SPR 305 WT and the corresponding specifications of that module are specified in the table 4. This module has 5 series and 66 parallel connected arrays. The power and voltage (P-V) and current and voltage (I-V) characteristic curves of the above mentioned model are shown in the fig.11 and fig.12. The fig.13, fig.14, and fig. 15 show the results of the output voltage and current as the output from the PV array and current through the diode of PV array. By the output we find that the value of voltage and current are varying with the change in value of irradiance

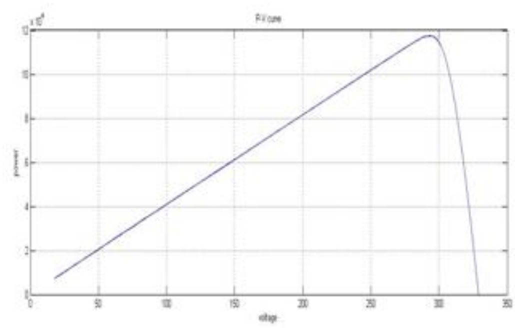

Fig.11. Power and Voltage characteristic curve

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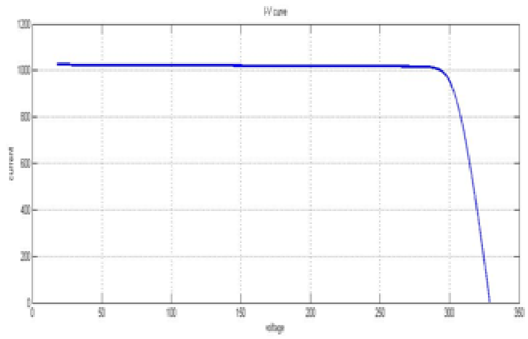

Fig.12. Current and Voltage characteristic curve

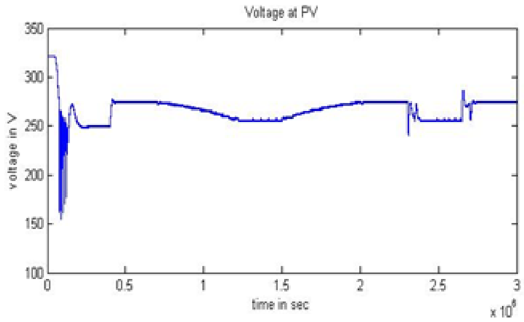

Fig.13. Output Voltage at PV array

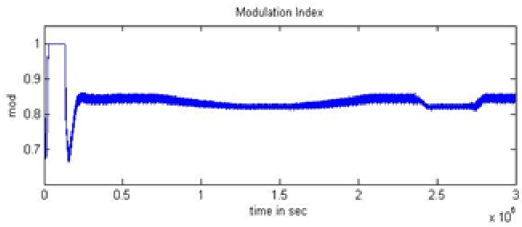

Fig.16. Modulation index

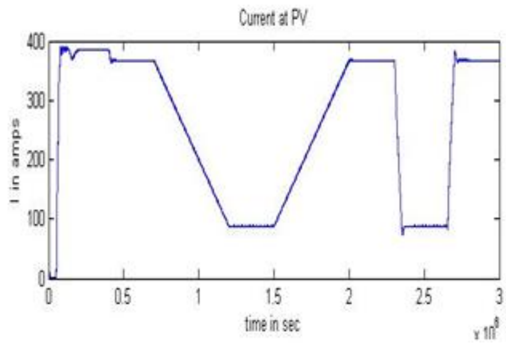

Fig.14. Output Current at PV array

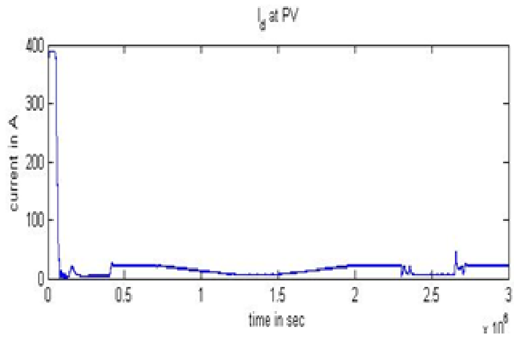

Fig.15. Current through Diode at PV

The Fig.16 shows the modulation index and Fig.17 shows the reference DC voltage and measured DC voltage and results show that the reference voltage and the measured voltage are almost balanced and it is achieved by the implementation of incremental conductance MPPT technique.

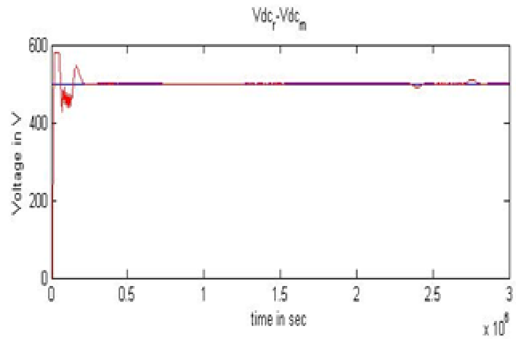

Fig.17. Reference DC voltage and Measured DC voltage

Figure 18 shows the output line voltage of the 3-level inverter before filtering. It is clear that the output voltages need to be filtered to obtain clean sinusoidal voltages. The harmonic content in the output voltages of the inverter depends on the choice of the frequency of the carrier signal.

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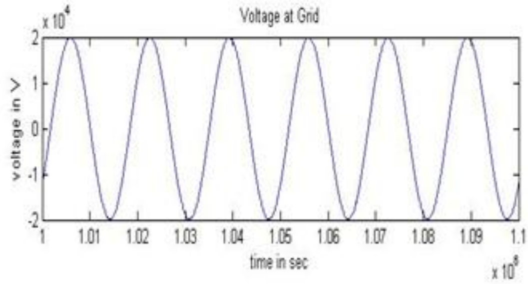

Fig.19.Volatge at Grid

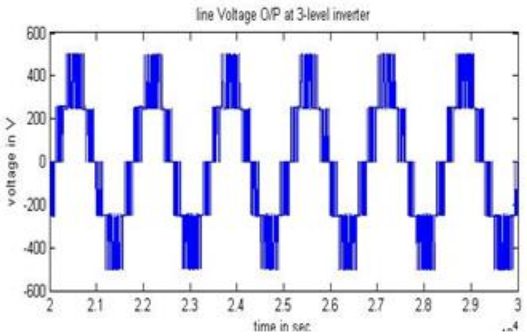

Fig.18.Line voltage at 3-level inverter before filtration

The control system uses two control loops: an external control loop which regulates DC link voltage to +/- 250 V and an internal control loop which regulates Id and Iq grid currents. The output waveform in Fig.19 and Fig.20 shows us that with such a control loop we get perfectly sinusoidal waveform. Also with this with MPPT enabling after some instance we find that the system power keep on tracking maximum power so as to supply the grid. The Fig.21 shows the real power at the grid.

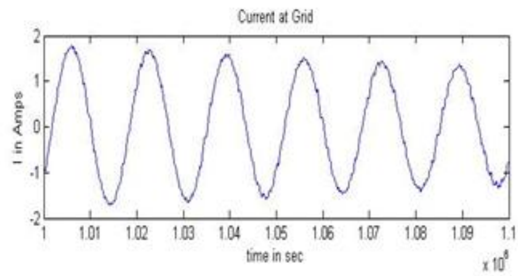

Fig.20. Current at Grid

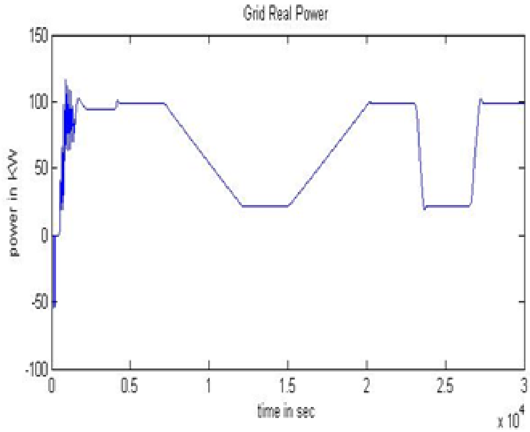

Fig.21. Real power at Grid

VII. CONCLUSION:

In this paper modeling and simulation of PV system with Incremental Conductance MPPT Algorithm on Grid Connected Photovoltaic System is performed on MATLAB/SIMULINK. We discuss in brief about various MPPT Algorithm and we perform simulation with incremental conductance algorithm. By this algorithm we keep on tracking the maximum power from the PV System that can be supplied to the grid and proper grid synchronization with the grid is made with the help of control technique by using the PLL. The various waveforms that obtain in simulation are presented which proves the result of getting MPPT. The future scope of this project is to extend with multiple PV arrays with good improvement of MPPT technique.

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