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Performance Analysis of Power Flow Controller for Photovoltaic Generation System using MATLAB/SIMULINK

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***Abstract* -This Paper proposes the performance analysis of power flow controller for photovoltaic(PV) generation system and power quality improvement. Typical grid connected solar system includes Photovoltaic system, Dc to DC Converters, three phase inverter, battery units, related power electronics devices and loads. The detailed model of grid connected photovoltaic systems starts with PV source which is connected to boost dc-dc converter and then in turn connected to the three phase inverter which delivers the solar energy to the grid, as well as to the connected loads. This inverter operates as a shunt active power filter (APF)and adopted with non linear control scheme in order to compensate the voltage unbalances, harmonics ,reactive power, and load voltage and current fluctuation. Maximum Power Point Tracking (MPPT) technique is provided to control boost converter. The battery charging and discharging which is useful for grid back-up sources during peak demand of energy and hybrid electric vehicles. The overall system model is analyzed and simulated by using MATLAB/SIMULINK**.

***Keywords*-Photovoltaic, Active power filter ,Point of common coupling, MPPT, MATLAB /SIMULINK**

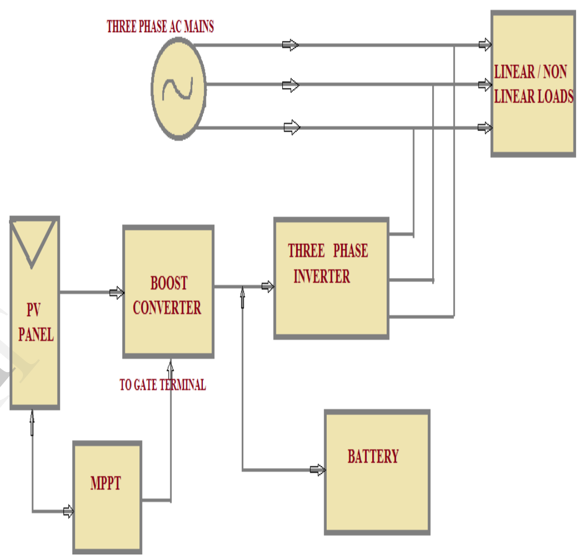


Fig1: Block Diagram of Grid connected photovoltaic system

I. INTRODUCTION

The Conventional sources of energy are rapidly depleting. Moreover the amount of consumption of energy is rising. So the contribution of renewable power sources in power generation is becoming important. Photovoltaic system is one of the promising alternative, but the main deterrent factor is cost and efficiency. Solar energy is a everlasting sustainable ,renewable energy source. This equitable availability can play a role in social development. Photovoltaic system is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material [1],[6]. Grid connected PV system yields different kind of challenges so it is necessary to develop power electronics devices with modern control strategy. Power quality improvement plays an important role in grid connected PV system. As per IEEE standard 519-1992 contributes the Power quality improvement at the point of Common Coupling (PCC).

In this paper current controlled three phase inverter operates as shunt active filter which avoids the use of passive filters that could affect the performance of compensation and dynamic response of the system [5]. Inverter operates as shunt active filter and works in multifunctional way as it delivers power from source to load, grid and helps in power quality improvement .Block diagram as shown in Figure 1 consists of solar panel which is connected to inverter through intermediate boost converter which is controlled by MPPT technique. MPPT algorithm depends on temperature and irradiation [4]. Power electronics interface devices are used for charging and discharging of battery. The associated theoretical and analytical formalism is used to validate the solution. The simulation results are presented.

II. GRID CONNECTED PHOTOVOLTAIC SYSTEM

Figure 2 shows a schematic diagram of PV system interfaced with the grid. The system is composed of a solar PV array, a rechargeable battery, a uni-directional DC/DC boost converter and DC/AC converter. The PV array and is connected to the DC-side of the Voltage Source Inverter (VSI) through the boost converter.

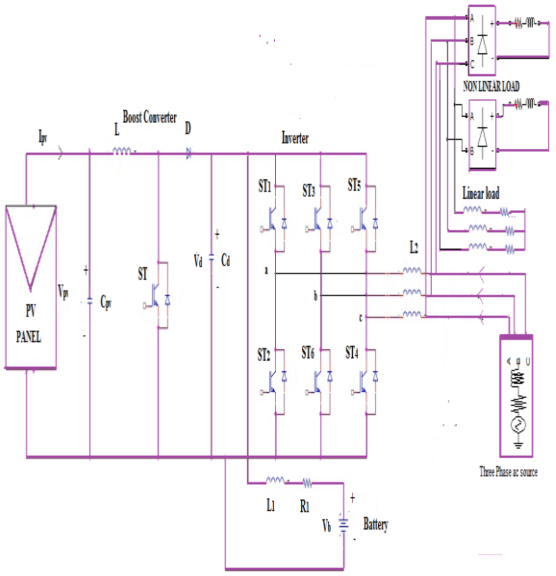


Fig 2: Schematic diagram of PV system interfaced with the grid

The PV array is regulated by a DC/DC boost converter to a fixed dc output, and is used to provide the power required for the load. inverter operates as a shunt active power filter (APF) [3] and adopted with non linear control scheme in order to compensate voltage unbalances, harmonics, reactive power and supply voltage fluctuation .The battery is connected in parallel to the DC bus, which allows the flow of power in both directions during charging and discharging. The PV/Battery system is required to supply all the power required by the load and grid . At light load conditions, the PV array can provide more power than the load demand, i.e. (Ppv > Pload), the excess energy from the PV array can be use to charge the battery.

A. *Solar cell Modeling*

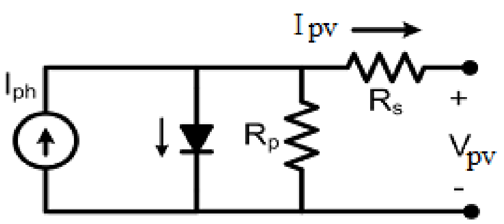


Fig 3: Solar Cell Equivalent Circuit

Basically solar cell is a current source.i.e voltage controlled current source .Output voltage of solar cell controls the current in a solar cell.Solar cell is made up of P &N materials with two layers hence diode is placed parallel with current source. we use solar cell above the ground potential because we can find charging current between the ground potential and solar cell potential .So in order to minimize that we have to use shunt resistance of high value .Series resistance of solar cell is mainly due to the leads of solar cell. Practically we find some metallic leads are connected to solar layer the resistance of that plates is nothing but series resistance as shown in equivalent circuit, this entire circuit is called electrical equivalent circuit.

Figure 3 shows the equivalent circuit of a general PV model which consists of a photocurrent, a diode, a parallel resistor which expresses a leakage current, and a series resistor which describes an internal resistance to the current flow [1],[6].

There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, the photon generated current will follow out of the cell as a short-circuit current (I_{SC}). Thus, $I_{PH} = I_{SC}$. When there is no connection to the PV cell (open-circuit), the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage (V_{OC}).

$$I = I_{SC} - I_d \quad (1)$$

Where,

I_{SC} is the short-circuit current that is equal to the photon generated current, and I_d is the current shunted through the intrinsic diode. [1]The diode current I_d is given by the Shockley's diode.

$$I_d = I_0 (e^{qV/kT} - 1) \quad (2)$$

$$I_{SC} = I_0 (e^{qV/kT} - 1) \quad (3)$$

Where,

I_0 is the reverse saturation current of diode (A)
q is the electron charge (1.602×10-19 C)
V_d is the voltage across the diode (V)
k is the Boltzmann's constant (1.381×10-2J/K)
T is the junction temperature in Kelvin (K)

Current- voltage relationship of the PV cell.

$$I = I_{SC} - I_0 (e^{qV/kT} - 1) \quad (4)$$

The reverse saturation current of diode in (I_0) is constant under the constant temperature and found by setting the open circuit condition. The mathematical equation of the model can be described by considering series and parallel resistance.

$$I_{PV}=N_P I_{PH}-N_P I_0[\exp(q(V_{PV}/N_S+I_{RS}/N_P)/kT_C A)-1] \quad (5)$$

Maximum power can be stated as

$$P_{max} = V_{max} I_{max} = \gamma V_{OC} I_{SC} \quad (6)$$

B. Boost dc to dc Converter

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage.

The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. A Boost converter (step-up converter) is a DC-to-DC power converter with an output voltage greater than its input voltage.

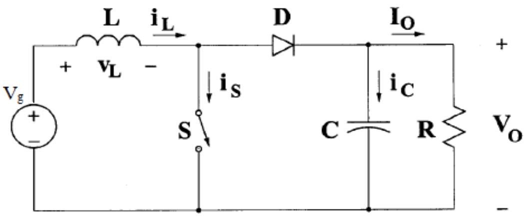


Fig.4: Boost converter Circuit

The Figure 4 shows a step up or PWM boost converter.It consists of a dc input voltage source Vg, boost inductor L, controlled switch S, diode D, filter capacitor C, and the load resistance R. When the switch S is in the on state, the current in the boost inductor increases linearly and the diode "D" is off at that time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit.

When the switch is off, the sum total of inductor voltage and input voltage appear as the load voltage is duty cycle.

When the switch is ON, the inductor is charged from the input voltage source Vg and the capacitor discharges across the load.
Design

The duty cycle,

$$d=T_{ON}/T \quad (7)$$

Where

$$T=1/f \quad (8)$$

$$L=d\,(1-d)^2 R/2f \quad (9)$$

$$C=d/2Rf \quad (10)$$

C. Battery

Figure 5 shows the battery which is modeled as a nonlinear voltage source whose output voltage depends not only on the current but also on the battery state of charge (SOC), which is a nonlinear function of the current and time represents a basic model of battery.

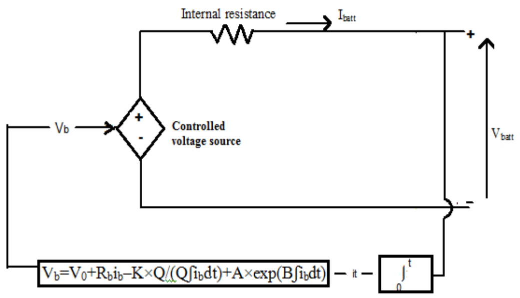


Fig 5: Internal circuit of Battery model

Two parameters to represent state of a battery i.e. terminal voltage and state of charge can be written as follows.

$$V_b=V_0+R_b i_b-K\times Q/\,(Q\int i_b dt)+A\times \exp(B\int i_b dt) \quad (11)$$

$$SOC = 100(1+\int i_b\, dt/Q) \quad (12)$$

D. Maximum Power point Tracking (MPPT)

PV panel is power source having nonlinear internal resistance. As the intensity of light falling on the panel varies, voltage as well as its internal resistance varies [4]. So to extract maximum power from the solar panel, the load resistance should be equal to the internal resistance of the panel. For this purpose maximum power point trackers (MPPT) are used.

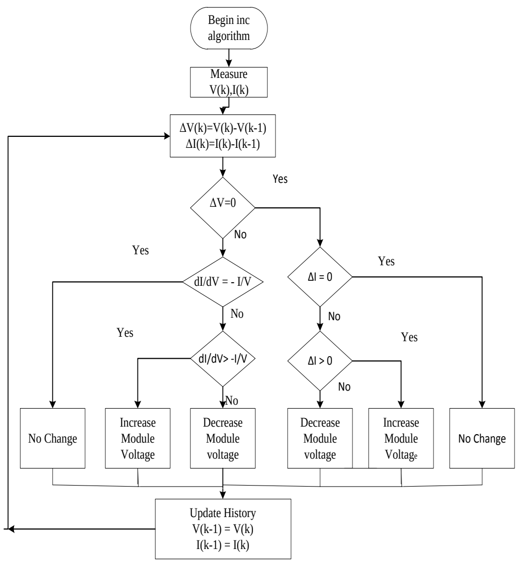


Fig 6: Algorithm of Incremental conductance MPPT

The incremental conductance decides that the MPPT has reached the MPP, it stops perturbing the operating point. If this condition is not achieved, MPPT operating point direction can be computed using dI /dV and −I/V relation. This relationship is derived from the fact that when the MPPT is to the right of the MPP dP /dV is negative and positive when it is to the left of the MPP. Figure 6 shows the algorithm which has benefits over perturb and observe in that it can determine when the MPPT has reached the MPP, where perturb and observe oscillates around the MPP. Here we are sensing both the voltage and current simultaneously. Hence the error due to change in irradiance is eliminated. Also, this algorithm can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe

E. Modeling of Three Phase Inverter

Figure 7 shows the the proposed three phase inverter acts shunt active filter which avoids the use of Passive filter .The three-phase inverter injects the PV energy to the load ,grid and helps in power quality improvement in order to compensates harmonics, reactive power and unbalance distortion at the point of common coupling [2],[3]. The inverter generates currents that are opposite to the undesirable components in the load currents and, improve the power factor at the PCC. An indirect non linear control technique of the three-phase inverter is proposed. It is based on the calculation of the positive sequence component of the unbalanced load current. Inverter current expressed in (d,q,0) synchronous frame.

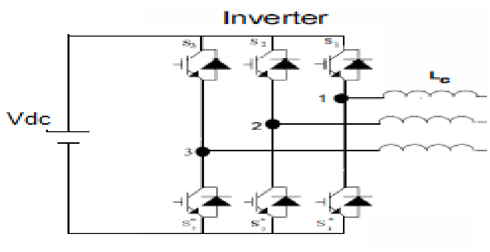


Fig 7: Three Phase Inverter

Grid connected photovoltaic generation systems need harmonic compensation, control of unbalanced current, an improved power factor, and anti-islanding methods. In particular, nonlinear loads at the point of common coupling lead to imbalance and low-order harmonics such as the third, fifth, and seventh harmonics in the grid voltage. These cause the grid voltage to be unbalanced and distorted into a non sinusoidal wave. To solve these problems, the rotating synchronous-frame proportional-integral (PI) controller is used in three-phase inverters to obtain a zero steady-state error.

To maintain DC bus voltage at desired value. Which is acting on active current i_{do} component helps in compensating the losses in inverter.

$$I_{do}=U_{dc}/d_{nd}=U_{dc}.V_{dc}/d_{nd}V_{dc}=\sqrt{(\tfrac{2}{3})}(V_{dc}/V) \qquad (13)$$

The main objective of current controller is to compensate reactive power harmonics and unbalances The control law equations

$$d_{nd}= (-U_d+L_c wi_{sq}-LcwiL_q+V_d)/V_{dc} \qquad (14)$$

$$dn_q= (-U_q-Lcwi_{sd}+LcwiL_d+V_q)/V_{dc} \qquad (15)$$

Vd,Vq are the d-q components of source voltages. dnd, dnq are the d-q components of switching state function .Vdc is bus voltage of inveter.

III. MATLAB SIMULINK CIRCUITS

Simulink Model of Grid connected Photovoltaic system

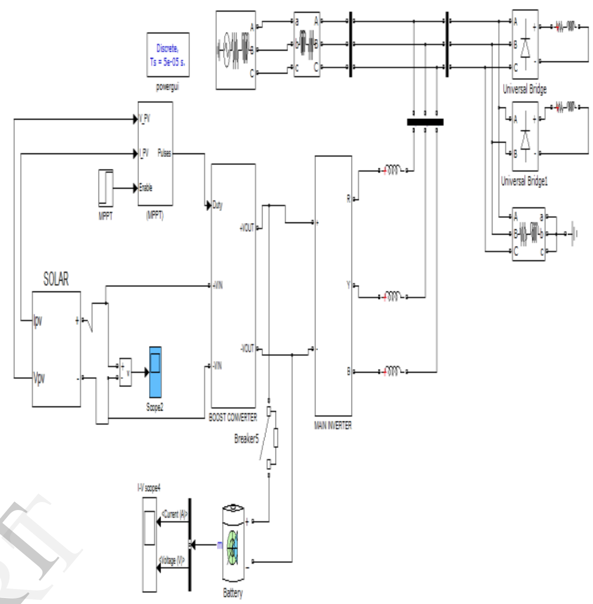


Fig 8: Simulink model of grid connected photovoltaic system

Figure 8 shows the entire system is modeled on MATLAB^{TM} R2012a and Simulink^{TM}. Simulation model of grid connected photovoltaic system consists of PV Panel, Boost converter , battery, three phase inverter .In this simulation PV is delivering power of 20KW to grid and load. PV source output Voltage 250V and current 80A.

Solar Array Simulink model

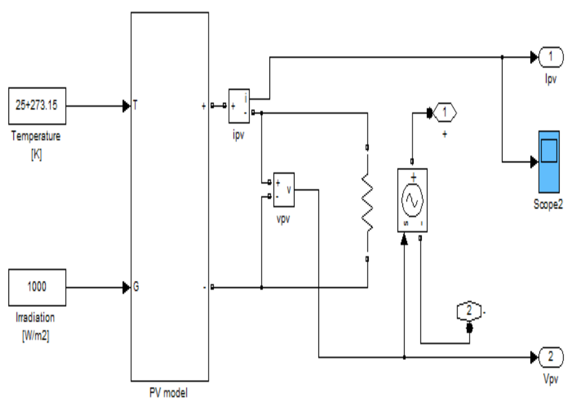


Fig 9.Simulink model of solar array

Simulink Model of Internal diagram of Control Scheme of inverter.

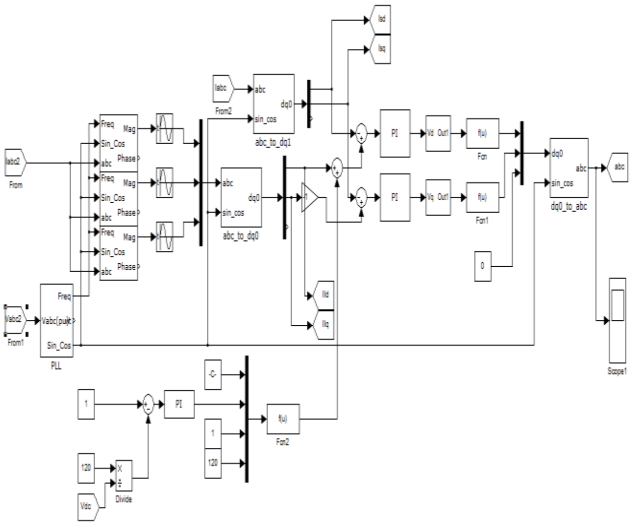


Fig 10: Simulink Model of Internal diagram of Control Scheme of inverter.

Figure 10 shows control scheme of the inverter which generate currents that are opposite to the undesirable components in the load currents and, improve the power factor at the PCC. An indirect non linear control technique of the three-phase inverter is proposed. It is based on the calculation of the positive sequence component of the unbalanced load current.inverter current expressed in (d,q,0) synchronous frame Vd,Vq are the d-q components of source voltages.dnd,dnq are the d-q components of switching state function Vdc is bus voltage of inveter. Designed using equation (13),(14),(15).

Simulink model of Generating PWM Signals to gate terminal of inverter

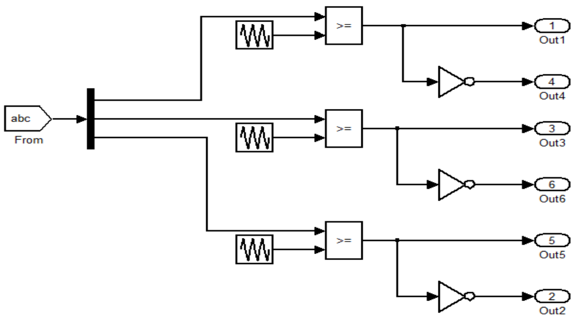


Fig 11: Simulink model of Generating PWM Signals to gate terminal of inverter

IV. MATLAB SIMULINK WAVEFORMS

The Matlab/ Simulink software tool is used to test the results.

During the photovoltaic model simulation, the temperature parameter was set at constant value 25°C and the irradiance parameter was set at 1000 W/m^2 respectively.PV array Output Voltage 245V and Current 80A as shown in Figure 12.

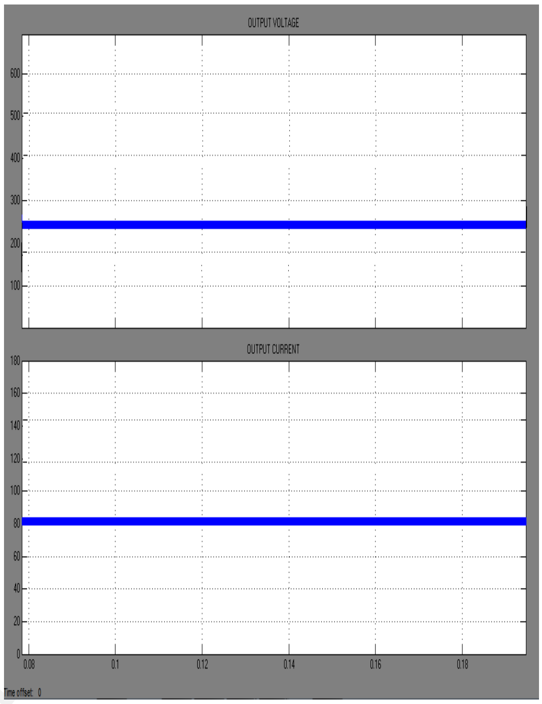


Fig 12: Output Voltage and current Waveforms of PV array

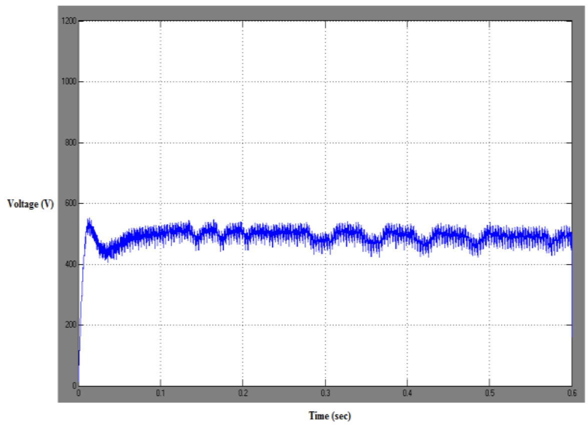


Fig 13: Output Voltage of Boost Converter

The output voltage of the boost converter is 430 V as shown in Figure 13.

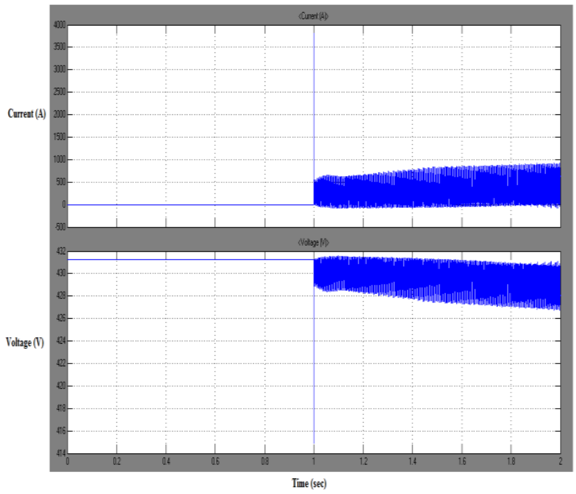


Fig 14: Output current and voltage waveforms of Battery

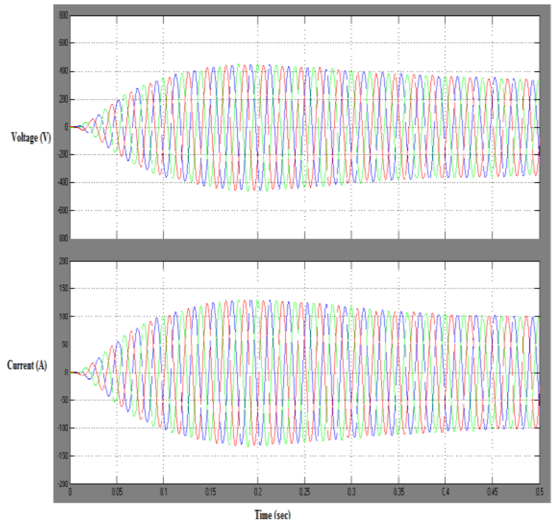
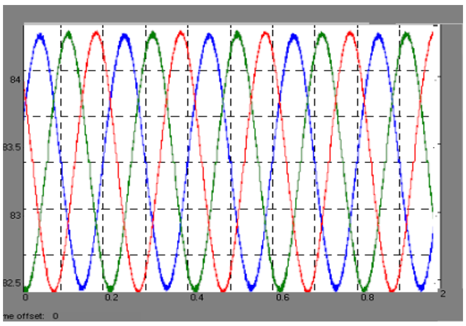


Fig 15 .Output voltage and current waveform of inverter.

Figure 14 shows the Nominal voltage of the battery is 430V DC, Capacity of the battery is 1000Ah, DOD is 60% , the battery is in open circuit condition so the battery current is zero, voltage is around 430V.Figure 15 shows The inverter output voltage is around 415V AC, current is 110A .



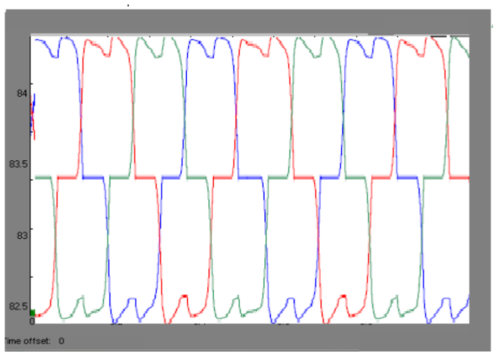


Fig 16 Compensated Waveform of load voltage and current.

V. CONCLUSION AND FUTURE SCOPE

In this present paper, better performance analysis of photovoltaic generation system is achieved by a three-phase two-level shunt active filter. Use of the filter is aimed at achieving the elimination of harmonics introduced by nonlinear loads. The results show the superiority and effectiveness of Controller. Extending this concept for better Power quality improvement, Modeling of Multilevel inverters with different control strategy in order to reduce THD significantly.

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