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Design and analysis of standalone photovoltaic for synchronous SEPIC Converter with grid connected system

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Abstract-This paper describes a grid connected photovoltaic system with SEPIC DC-DC converter.The DC-DC SEPIC converter using pulse width modulation has been designed grid PV module. The conversion efficiency of the proposed SEPIC converter system is increased when PWM is used as a control scheme. The single-ended primary-inductance converter (SEPIC) is a step-down/step-up DC/DC converter circuit that provides a constant positive output voltage from a positive input voltage which can be lower or higher than the output. This kind of DC/DC converters is very important when the output voltage has to be maintained constant, it can be used in open loop without any IP controller. Solar photovoltaic conversion is based on the photovoltaic effect to transform a part of energy of the sun to electricity. This technology requires little maintenance but it needs a good implementation of the DC-DC or/and DC-AC converters to obtain high efficiencies. To make the converter operates in its continuous conduction mode, it must be synchronized. The input quantities acting on the photovoltaic generator are the irradiance and the temperature; the controller parameters are the pulse width modulation (PWM) signals that control the converter's switches by introducing the right duty cycle.

Keywords: Stand-alone PV systems, Synchronous SEPIC converter,full-bridge DC/AC inverter and grid connected system

I.INTRODUCTION

The development in renewable energy sourcesreplaces the other traditional energy sources. Amongthe renewable energy sources, solar energy plays amajor role due to its pollution-free nature. Foreconomical reasons the solar energy is not directlyinterfaced with the utility grid. Hence a powerelectronic interface is developed to interface the solarsystems to the utility grid [1].A SEPIC converter is introduced between solarsystem and grid connected PV system SEPIC converterClosed Loop Controlled Buck [2] has output voltage can beinclude lesser transistor stresses, higher value oftransistor RMS current, limiting the inrush currentsand isolated topologies are possible.Further, recent researches have focused on how toget maximum power from solar energy. All theschemes invariably employ forced commutation foran inverter. In the present paper three phase linecommutated inverter is operating at fixed value offiring angle, SEPIC converter and its closed loopsimulation.

It consists of a SEPIC converter, an inductor andline commutated inverter. The SEPIC converter is anon-inverting DC-DC [3] converter and can generatevoltages either above or below the input. The inputcurrent is non-pulsating, but the output current ispulsating. The name SEPIC is an acronym for singleended primary inductance converter. The powercircuit of SEPIC DC-DC converterand the grid connected PV energy storage system [4-7].

A modular grid-connected PV generation system presents an actual behavioral model of a grid tied PV system suitable for system level investigations. Simplified means for modeling the PV array is very simple averaged model of the power converter was developedCuk converter in comparison to the conventional buck-boost [8]. A single-phase grid-connected inverter which is usually used for residential or low-power applications of power ranges that are less than 10 kW. Types of single-phase grid-connected inverters have been investigated [9-10]. The nominal duty cycle of the main switch of DC-DC SEPIC converter is adjusted so that the solar panel output impedance is equal to the input resistance of the DC-DC converter which results in better spectral performance in the tracked voltages when compared to conventional PWM control.

This paper is about the design and the simulation of the single-ended primary-inductance DC-DC converter using its synchronous model in continuous conduction [11] mode to insure a good compatibility with grid connected photovoltaic systems. This paper is organized as follows. In the next section; the basic of photovoltaic effect is presented. The third section suggests a synchronous SEPIC converter. In the fourth section; the simulation results of the stand alone photovoltaic system are shown.

II. THE STAND ALONE SYSTEM

The stand-alone photovoltaic system requires storage to meet the energy demand during period of low solar irradiance and night time. The DC-Dc converters allow the charge current to be reduced continuously in a way that the resulting batteries' voltage is maintained constant at a specific value. Fig. 1 shows the photovoltaic system's block diagram to be discussed in this paper. The system consists of a photovoltaic generator composed by two modules assembled in parallel, a synchronous DC/DC SEPIC converter controlled by PWM technique, and a bank of batteries.

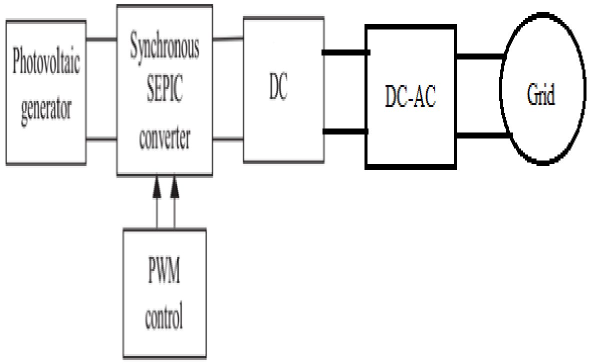

Fig.1. Block diagram of the studied stand-alone PV system with grid connected system.

The input quantities acting on the photovoltaic generator are the irradiance and the temperature; the controller parameters are the pulse width modulation (PWM) signals that control the converter's switches by introducing the right duty cycle.

A photovoltaic array is made with combined series/parallel combinations of PV solar modules, which are composed of combinations of PV cells usually assembled in series, the PV cell is a device that absorbs light and converts it into electrical energy in the form of direct current thanks to the photovoltaic effect. The operating of a PV cell can be represented by an equivalent circuit model such as the one given in Fig.2.

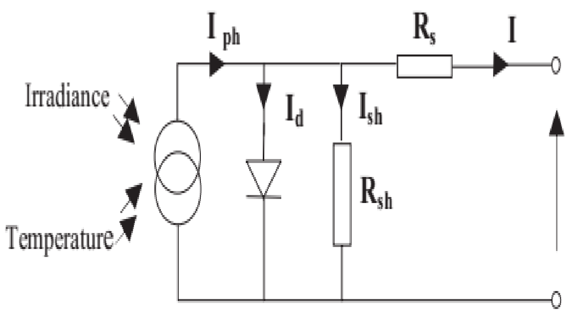

Fig. 2. Equivalent circuit of photovoltaic cell.

The basic equation that describes the I-V curve characteristic of the photovoltaic model is as follows:

$$I = I_{ph} - I_s \cdot \left[\exp\left(\frac{q(V + R_s I)}{nkT}\right) - 1\right] - \frac{V + R_s I}{R_{sh}} \quad (1)$$

Where:
I: cell current (A).
Iph: light generated current (A).
Is: diode saturation current (A).
q: charge of electron = l.6xl0-l9 (Coulomb).
V: cell output voltage (V).
Rs: series resistor (fi).
K: Boltzmann constant = l.380662 × l0-23 (j/K).
T: cell temperature (K).
Rsh: shunt resistor (fi).

For a given irradiance and temperature, the photovoltaic call based on silicon has a nonlinear I-V characteristic as it is shown in the next curve.

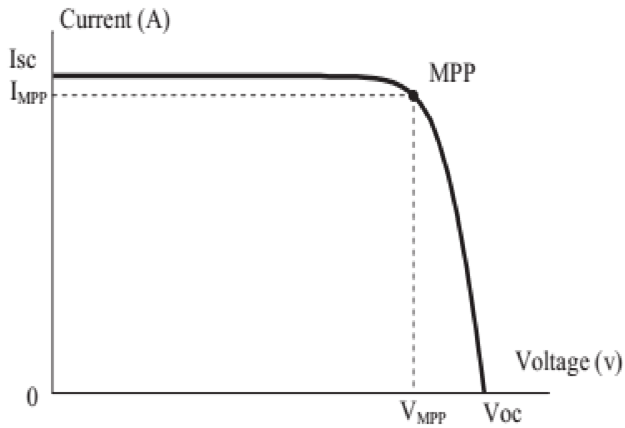

Fig. 3 Characteristic of I-V curve of photovoltaic cell for a given temperature and irradiance.

Where:
Isc: short circuit current (A).
IMPP: current when power is max (A).
Voc: open circuit voltage (V).
VMPP: voltage when power is max (V).

III. STUDY OF THE SYNCHRONOUS SEPIC CONVERTER

The single-ended primary-inductance converter (SEPIC) is a step-down/step-up DC/Dc converter circuit that provides a constant positive output voltage from a positive input voltage which can be lower or higher than the output. This kind of DC/DC converters is very important when the output voltage has to be maintained constant, it can be used in open loop without any IP controller.

Fig.4. shows the basic electrical scheme of the SEPIC converter, consisting of an input capacitor, $C_{in;}$ an output capacitor $C_{out;}$ an AC coupling capacitor, C_c; coupled inductors $L_1$and L_2; a diode D and a switch Q1.

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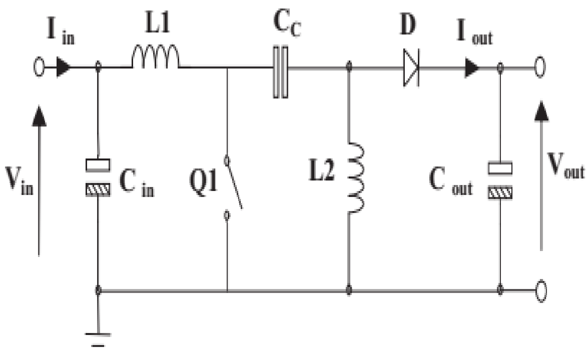

Fig.4. Asynchronous SEPIC converter electrical scheme

To make the converter operates in its continuous conduction mode, it must be synchronized. The proposed method is to replace the diode D by another switch $Q_2$and this is to avoid any shift and also to save the inverse diode voltage. The obtained electrical scheme is shown in Fig. 5.

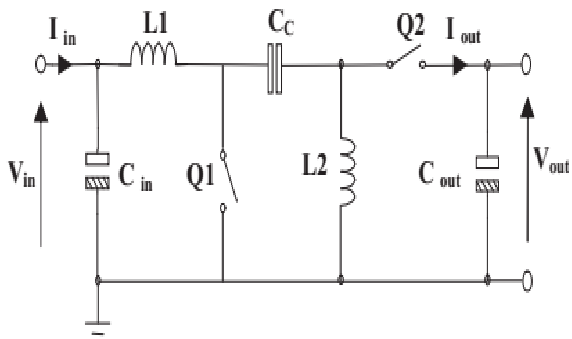

Fig. 5 Synchronous SEPIC converter electrical scheme

Those two switches, Q_1 and Q_2 are controlled by two complementary PWM signals produced in the driving circuit using a saw tooth generator. In continuous conduction mode, SEPIC converter has two operating modes “Q1 on, Q2 off” and “Q1 off, Q2 on “. Figure 6 and Figure 7 show respectively the equivalent circuits of these operating modes.

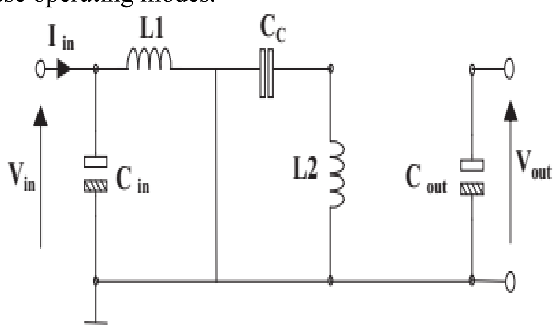

Fig .6 First operating mode “Q1 on, Q2 off” for DT seconds

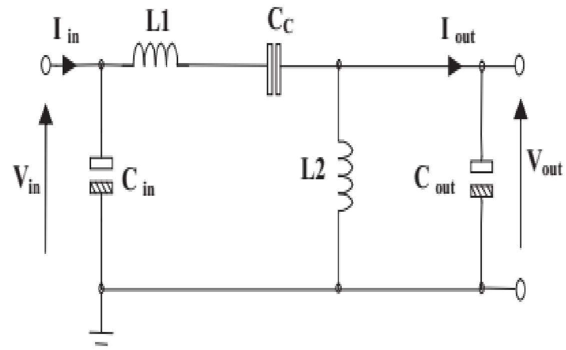

Fig.7. Second operating mode “Q1 off, Q2 on “ for (1-D)^{T}seconds nnn

Where:
T: period of the PWM signals (s).
D: duty cycle of the PWM signal of the first switch (%).

$$D = \frac{Time\ when\ Q1\ is\ on}{T} \quad (2)$$

From 0 to DT: the first switch Q1 is closed and the second Q2 is open, so the current across L1 increases at the rate of:

$$\frac{di_{L1}}{dt} = \frac{V_{in}}{L_1}, \quad 0 \leq t \leq Dt \quad (3)$$

So that L1 and L2 are charging: C_c and C_{out} are discharging.
From DT to T: the first switch is open and the second one is closed, and I_{L1}decreases at the rate of:

$$\frac{di_{L1}}{dt} = \frac{-V_{out}}{L_1}, \quad DT \leq t \leq T \quad (4)$$

So that L1 and L2 are discharging; Cc and C_{out} are charging.
V_{L1}has two levels, their average equals zero, so:

$$\frac{(V_{in})DT + (-V_{out})(1-D)T}{T} = 0 \quad (5)$$

So that

$$(V_{in})D + (-V_{out})(1-D) = 0 \quad (6)$$

Simplifying the above equation, the final input – output voltage expression:

$$V_{out} = V_{in} \times \frac{D}{1-D} \quad (7)$$

Thus, the converter performs buck function mode for D less than 0.5, and boost function mode for D larger than 0.5.

Assuming lossless circuit, the input power equals the output power, so:

$$V_{out}I_{out} = V_{in}I_{in} \tag{8}$$

So that:

$$I_{out} = I_{in} \times \frac{1-D}{D} \tag{9}$$

The ripple current across both inductors, L1 and L2 is given approximately by:

$$\Delta I_L = 30\,\% \times I_{in(\max)} \tag{10}$$

So that, the values of L1 and L2 are as next:

$$L1(\min) = L2(\min) = \frac{V_{in(min)} \times D}{2 \times \Delta I_L \times f} \tag{11}$$

The selection of the AC coupling capacitor is as follows:

$$C_C(\min) = \frac{I_{out} \times D}{\Delta V_{C\ ripple} \times f} \tag{12}$$

Also, the output capacitor is given by:

$$C_{out}(\min) = \frac{I_{out} \times D}{\Delta V_{ripple} \times f} \tag{13}$$

With:

$$\Delta V_{ripple} = 1\,\% \times V_{out} \tag{14}$$

IV.GIRD CONNECTED SYSTEM

These systems are directly coupled to the electric distribution network and do not require battery storage. Figure.8 describes the basic system configuration. Electric energy is either sold or bought from the local electric utility depending on the local energy load patterns and the solar resource variation during the day, this operation mode requires an inverter to convert DC currents to AC currents. There are many benefits that could be obtained from using grid-tied PV systems instead of the traditional stand-alone schemes. These benefits are:

- Smaller PV arrays can supply the same load reliably.
- Less balance of system components are needed.
- Comparable emission reduction potential taking advantage of existing infrastructure.
- Eliminates the need for energy storage and the costs associated to substituting and recycling batteries for individual clients. Storage can be included if desired to enhance reliability for the client.
- Takes advantage of the existing electrical infrastructure.
- Efficient use of available energy. Contributes to the required electrical grid generation while the client's demand is below PV output.

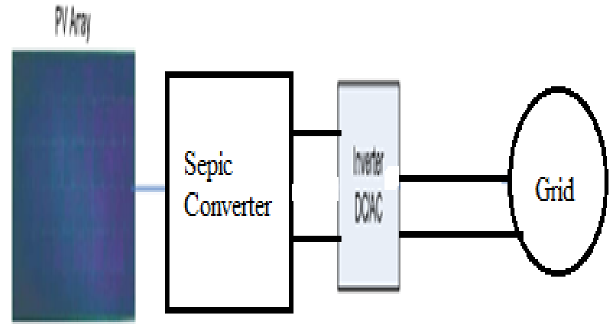

Fig.8.Grid-Tied Photovoltaic System.

Hybrid systems may be possible were battery storage or a generator (or both) can be combined with a grid connection for additional reliability and scheduling flexibility (at additional cost). Most of the installed residential, commercial and central scale systems use pre-fabricated flat plate solar modules, because they are widely available. Most 5-7 available reports on PV system costs are therefore related to this kind of technology and shall be our focus in this chapter. Other specialized technologies are available (e.g., concentrating PV systems), but not as commercially available as the traditional PV module.

V.MATLAB AND SIMULATION RESULTS

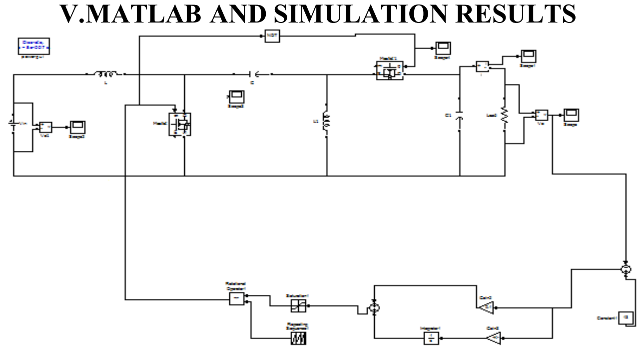

Fig.9. shows the Simulink model of SEPIC converter.

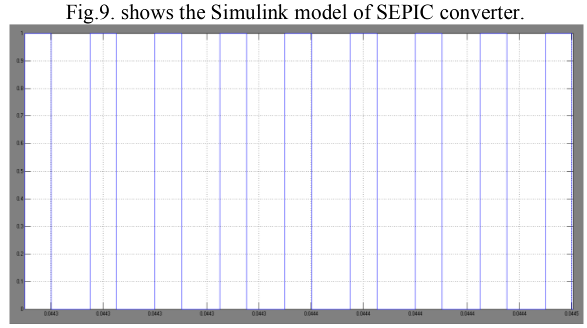

Fig.10. PWM 1 Curve.

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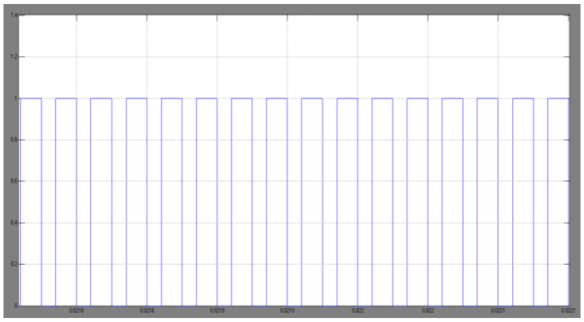

Fig.11. PWM 2 Curve

Fig.10 and Fig.11 shows that the Pulse Width Modulation Signals PWM1 and PWM2.

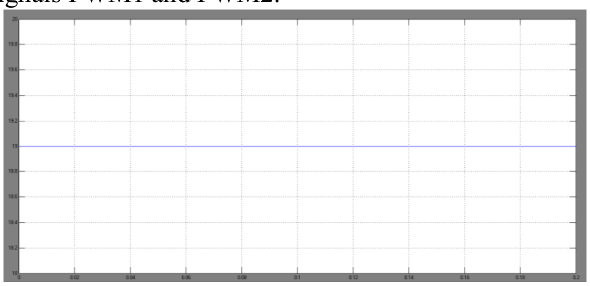

Fig.12.Input Voltage (V)

Fig.12. shows that the input Voltage of the System, the Supply Voltage is 19 volts

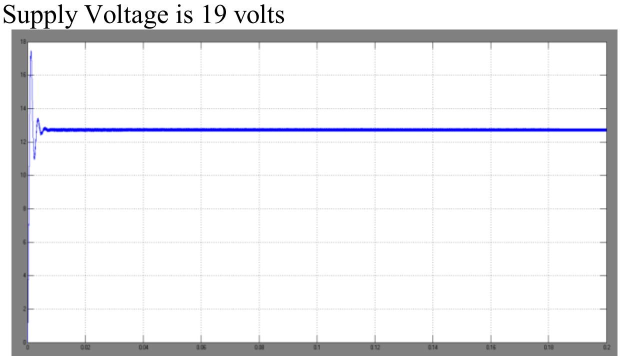

Fig.13.Output Voltage (V)

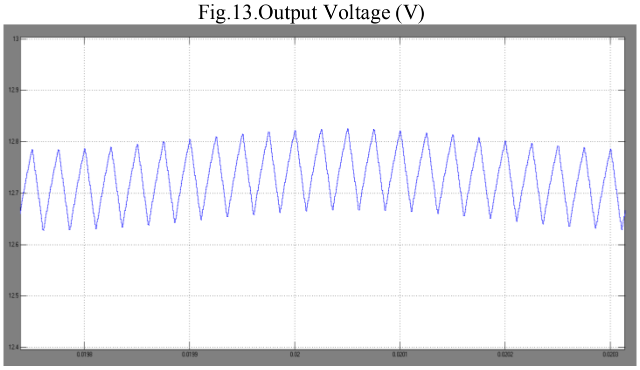

Fig.14.Zoom in of the Output Voltage (V)

Fig.13 and Fig.14Shows that the Output Voltage wave form when normal and zoom in conditions

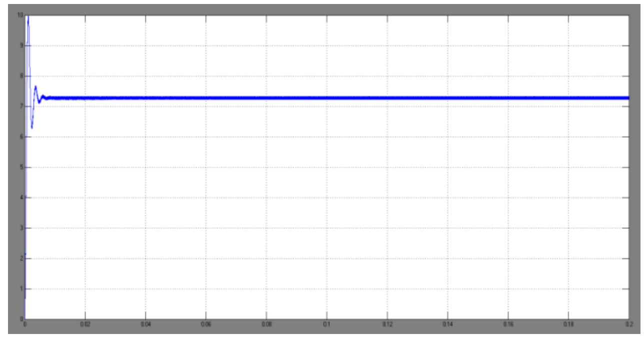

Fig.15.Output Current (Amp)

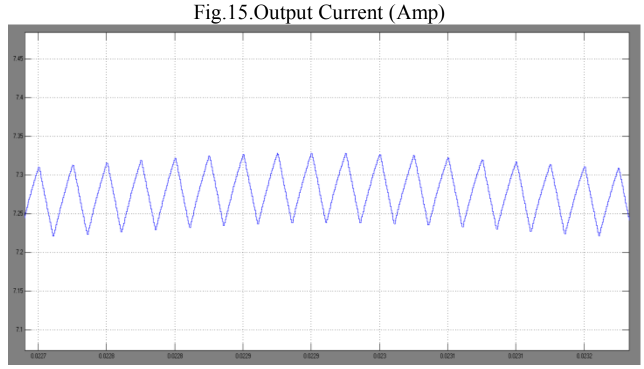

Fig.16.Zoom in of the Output Current (Amp)

Fig.15 and Fig.16 Shows that the Output Current wave form when normal and zoom in conditions

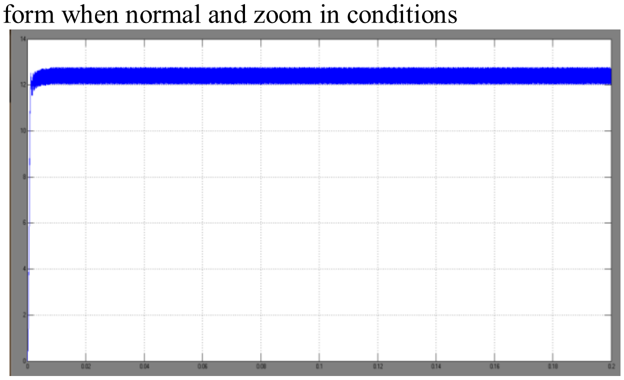

Fig.17. Output Voltage (V)

Fig.17 shows that Output Voltage wave form of the Closed Loop System

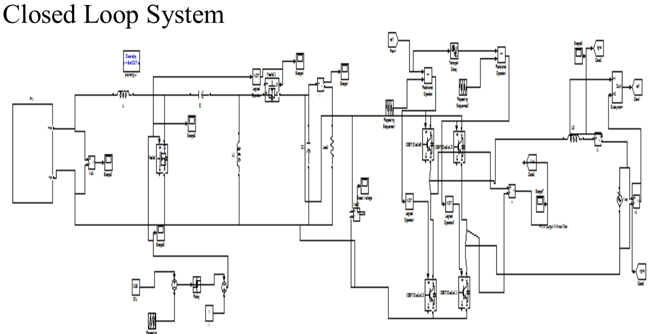

Fig.18. shows the Simulink model of Grid connected SEPIC converter.

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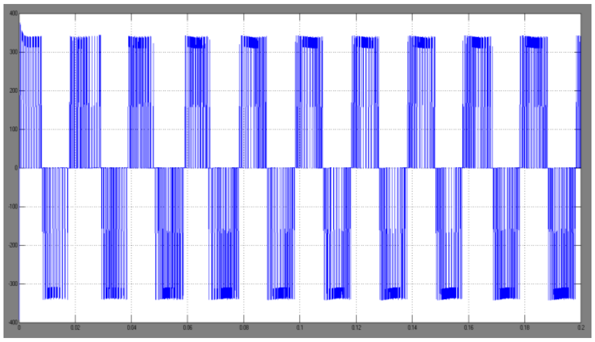

Fig.19. Inverter Output Voltage (V)

Fig.19 Shows that the Inverter Output Voltage of the Grid Connected System

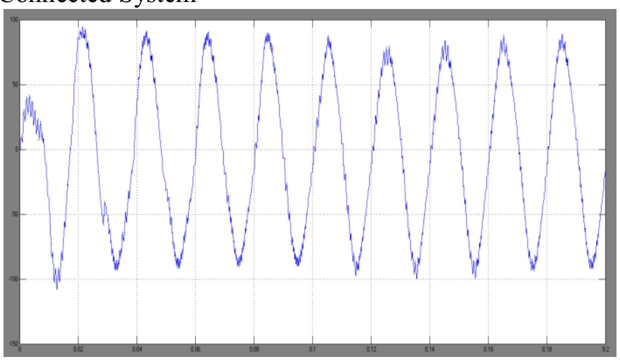

Fig.20.Grid Current.

Fig.20. Shows that the wave form represented by Grid Current

VI.CONCLUSION

This paper presented the simulationwork of a photovoltaic array to gridconnected system.A simple closed loop scheme employing a SEPICconverter and PWM inverterhas been developed for interfacing solar array withthe utility grid. Simulation studies have been carriedout to get the various parameters of the scheme suchas active power and reactive powers. As the inverteris being operated as line commutated, thesynchronization of output frequency with gridfrequency does not arise. However due to losses inthe inductor, the output power fed to the grid is fairlysmall.The results show that it has many advantages over conventional converters and it is a good choice to be taken in the case of autonomous systems because of its simple operation where it only has two states of operation, so, the discontinuous conduction mode has been avoided and the inverse voltage of the diode is eliminated by replacing it with another switch controlled by PWM. However, the function of this converter maintains its output voltage constant which can improve the efficiency of the photovoltaic system and ensure a good transfer of energy.

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