Proposed Power Electronics Interface for PV System: Simulations & Results

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***Abstract*—When sunlight shines on a PV cell, the absorbed light produces electricity. Though PV technologies use both direct and dispersed sunlight to create electricity, harnessing efficiency is 68% eventually against the claim of 85% by the various manufacturers worldwide. Power Electronics Interface are incorporated with Photovoltaic (PV) System to intensify the efficiency of the PV system and undoubtedly we have reached to the goalmouth. There are two stages where power electronics converter is used. First DC-DC converter stage in which lower level PV voltage is boosted-up at the required higher level; and second DC-AC inverter stage in which increased DC link voltage is efficiently converted into AC. Purpose of this paper to elaborate the proposed power electronics interface. It is observed that the buck boost converter is able to track the maximum power of PV by variation of its duty cycle. Increasing the load resistance PV still deliver power near maximum point. It is also observed that; at the load side the output voltage is increases that depends on the load conditions. Simulation results are taken at various stages to visualize the effect of interface. For whole PV system simulation, PV module is connected to the converter system. The output of the Buck Boost converter is connected to the single-phase inverter and the inverter output is fed to the AC grid.**

I. Introduction

FOR developing countries, providing energy to its stakeholders in an efficient and cost effective manner is a highly challenging task. In spite of significant harnessing of the fossil fuel reserves, the gap between supply and demand of energy is ever growing. One of the possible options to fill this gap is by making extensive use of solar power [4], [19], [20], [21].

The need for a clean surroundings and the incessant increase in energy demand makes decentralized renewable energy production more substantial [4], [18]. Photovoltaic generate electric power when illuminated by sunlight or artificial light. It directly converts the sun's energy into electricity which can be easily transported and converted to other forms for the benefit of society [2], [3], [10].

Though PV technologies use both direct and dispersed sunlight to create electricity, harnessing efficiency is 68% eventually against the claim of 85% by the various manufacturers worldwide. Power Electronics Interface are incorporated with PV System to intensify the efficiency of the PV system and undoubtedly we have reached to the goalmouth.

$$v_L = V_g$$

$$i_c = -\frac{V_o}{R}$$

Power Electronics is the field of engineering which deals with the use of electronics for the conversion, control and conditioning of bulk electrical power. It also plays an important role in the solar system [1], [5], [7], [8]. There are two stage where power electronics converter is used. First DC-DC converter stage in which lower level PV voltage is stepped-up at the required higher level [9]; and second DC-AC inverter stage in which boosted DC link voltage is converted into AC [12], [13], [18]. If Maximum Power Point Tracking (MPPT) is accountable for optimizing the efficiency of the photovoltaic system, power electronics interface is the solver. Power loses incurred at the converter stage is reimbursed at inverter stage. This proposed PV module gives maximum power, voltage and current independent of the load.

II. Switched Inductor Buck Boost Converter

Here inductor is replaced by switched inductor as compared to Traditional Buck-Boost converter. It comprises of two inductors and three diodes as shown in fig. 1. Introducing this switched inductor, we get the advantage of high voltage gain with keeping the efficiency almost no change. The proposed converter operates in discontinuous conduction mode. It has three modes of operations.

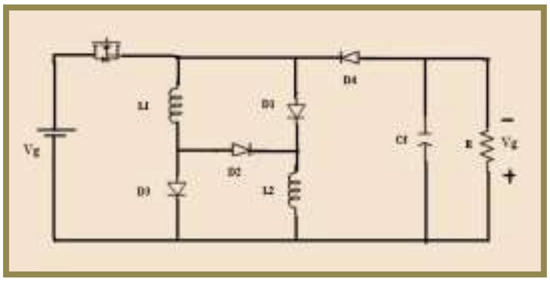

Fig. 1 Switched Inductor Buck Boost Converter

A. *Mode-1*

From Fig. 1 (a), mode-1 takes place when SW_1, diodes D_1 and D_3 are on. When switch Sw1 is on and D_2 and D_4 are off, the circuit is split into two different parts: the source chargers the two inductors on the left while the right has the capacitor, which is responsible for sustaining outgoing voltage via energy, stored previously. The current of inductor L is increased gradually. In this case, the steady state equation of the converter is given by.

(1)

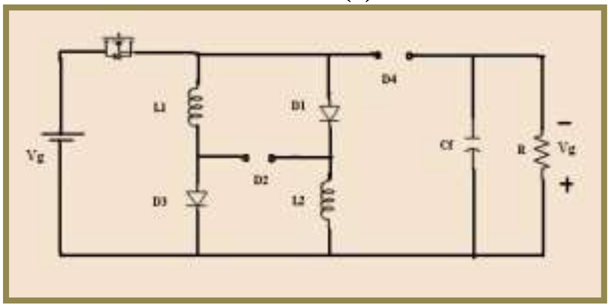

Fig. 1 (a) Mode 1

B. *Mode-2*

From Fig. 1 (b), mode -2 takes place when diodes D2 and D4 are on. $SW_1$and diodes D_1, D_3 are off. When the switch SW1 is off and D2 and D4 are on, the energy that is stored within the two inductors will help supplement power for the circuit that is on the right; there by resulting in a boost for the output voltage. Then, the inductor current discharges and reduces gradually. The output voltage could be sustained at a particular wanted level if the switching sequence is controlled. The steady state equation of the converter in this mode is given by,

$$v_L = -\frac{V_O}{2}$$

$$i_c = I_L - \frac{V_O}{R}$$

(2)

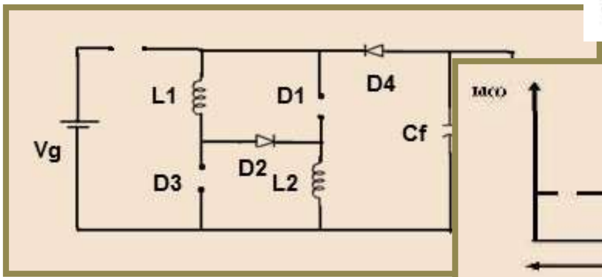

Fig. 1 (b) Mode 2

C. *Mode-3*

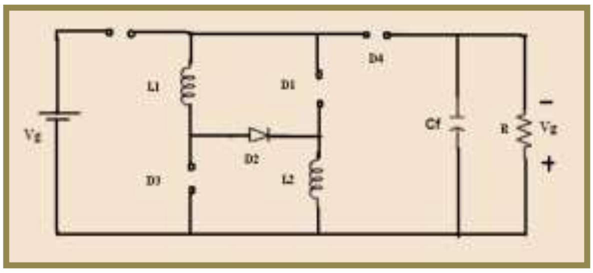

Fig. 1 (c) Mode 3

Mode-3 takes place when SW_1 and all diodes are off fig. 1 (c). Then the inductor current becomes zero.

(3)

Fig. 2 shows discontinuous inductor current waveform. From the steady state analysis and balance theory the average value of inductor voltage is zero.

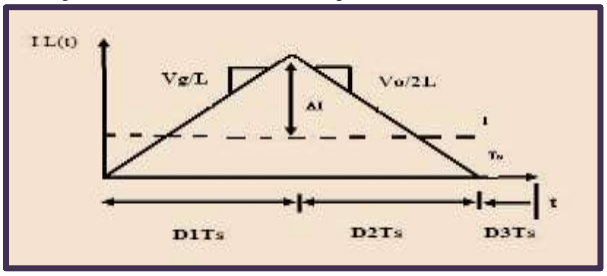

Fig. 2 Inductor current

$$< v_L > = 0$$

$$D_1 v_g + D_2\left(-\frac{V_O}{2}\right) + D_3(0) = 0$$

Solve for V_O

$$V_O = 2\frac{D_1}{D_2} v_g$$

(4)

Peak Inductor current is

$$i_{pk} = \frac{v_g}{L} D_1 T_S$$

(5)

$$i_d(t) = i_c(t) + \frac{V_O}{R}$$

From the capacitor charge

Balance theory $< i_c > = 0$

Therefore, $< i_d > = \frac{V_O}{R}$

(6)

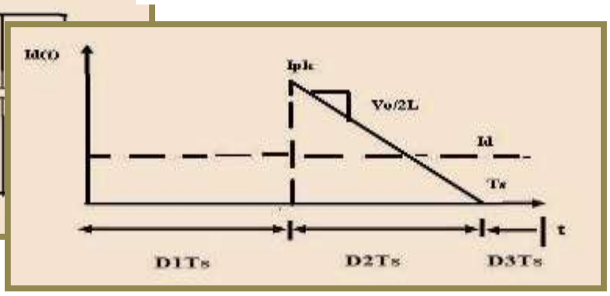

Fig. 3 Diode D_4 Current

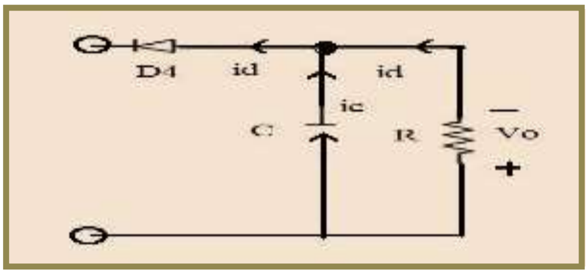

Fig. 4 Current flows through Diode D_4

Taking node equation in Fig. 4. Average diode current

$$v_L = 0$$

$$i_c = -\frac{V_O}{R}$$

$$< i_d > = \frac{1}{T_s}\int_0^{T_s} i_d(t)\, dt$$

From the triangle area formulae

$$\int_0^{T_s} i_d(t)\, dt = \frac{1}{2} i_{pk} D_2 T_s$$

Therefore average diode current is

$$< i_d > = \frac{1}{T_s}\left(\frac{1}{2} i_{pk} D_2 T_s\right)$$

$$= \frac{1}{2}\left(i_{pk} D_2\right)$$

$$\frac{V_O}{R} = \frac{V_g D_1 D_2 T_S}{2L} \quad (7)$$

From the above equation (7),

$$\frac{V_O}{v_g} = \frac{R\, D_1\, D_2\, T_S}{2L} \quad (8)$$

From the Volt second balance (4),

$$D_2 = \frac{2 D_1 v_g}{V_O} \quad (9)$$

Substitute this equation 9 in charge balance equation 8,

$$\frac{V_o}{vg} = RD_1\left(\frac{2\, D_1 v_g}{V_o}\right)\frac{T_s}{2L} \quad (10)$$

Hence

$$\frac{V_O}{v_g} = \sqrt{2K} \quad (11)$$

Where

$$K = D_1^{\,2}\frac{R}{2L}T_s \quad (12)$$

From the equation 16 gain of switched inductor buck boost converter is higher by √2 than the traditional buck boost converter.

III. Simulation of Buck Boost Converter Connected with Photovoltaic Module

Two simulations are performed to test the performance of the photovoltaic module. The PV is set at irradiance equal to 1000 at temp.25°C. First simulation is run with constant resistive load and at different duty cycles table shows the results. Second simulation is run with fix duty cycle and at different resistive loads.

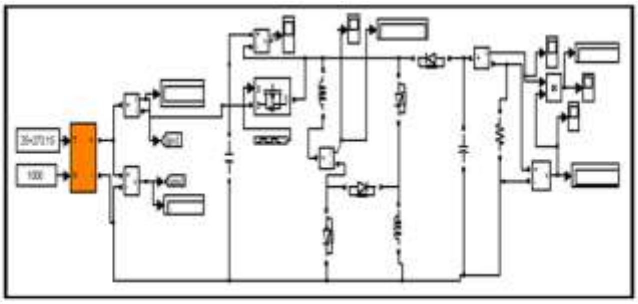

Fig. 5. Simulink block diagram of buck boost converter connected with PV module

From the Table 1 we can see that the buck boost converter is able to track the maximum power of PV by variation of its duty cycle. From the table 2 increasing the load resistance PV should still deliver power near maximum point (170W). At the load side the output voltage is increased depend on load conditions. The PV module gives the maximum power, voltage and current independent of the load [1], [5].

From the Table 1 we can see that at duty cycle 37% PV output power is 172.3W, therefore maximum power point is obtain near to the 37% duty cycle. At 37.2% duty cycle we get maximum power 170W from the photovoltaic module.

TABLE 1
SIMULATION RESULT AT DIFFERENT DUTY CYCLE AT CONSTANT LOAD

Duty Cycle (%)	Vpv (V)	Ipv (A)	Ppv (W)	Vdc out (V)
35	37.1	4.96	184	-126.1
36	35.34	5.088	180	-124.3
37	33.53	5.13	172.3	-121.2
38	31.99	5.15	165	-118.5

Simulation results at different duty cycles at constant load Converter with PV module at Duty cycle = 37%, R = 100 ohm, Cout = 1000 uf, f = 10 kHz

TABLE 2
SIMULATION RESULT AT DIFFERENT RESISTIVE LOAD WITH CONSTANT DUTY CYCLE

Rload(Ω)	Vpv	Ipv	Ppv	Vdcout
50	32.92	5.13	168.9	-85.49
100	33.13	5.127	169.9	-120.3

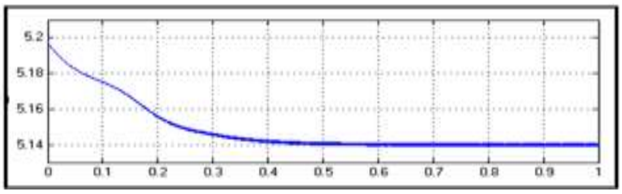

Fig. 6. PV output current

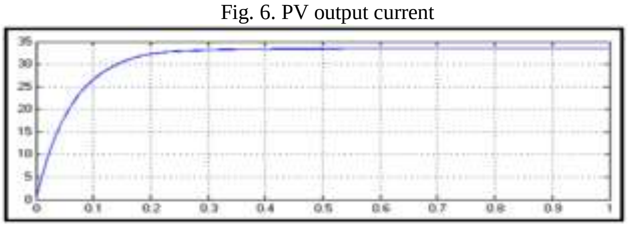

Fig. 7. PV output voltage

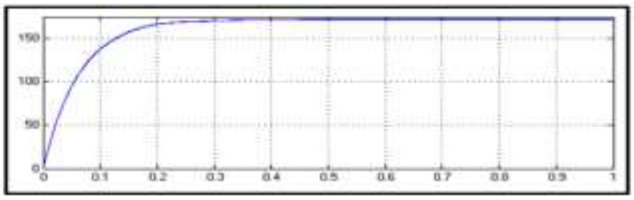

Fig. 8. PV output power

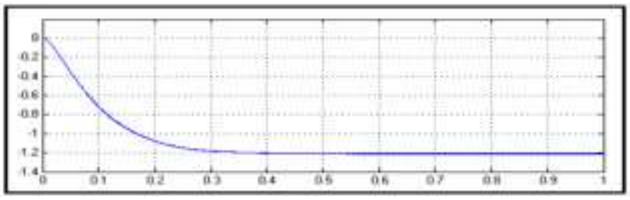
Fig. 9. Converter output current

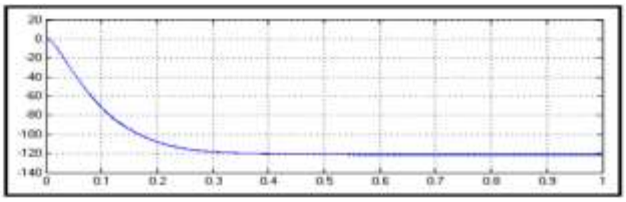
Fig. 10. Converter output voltage

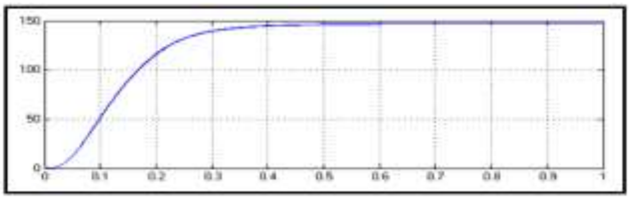
Fig. 11. Converter output power

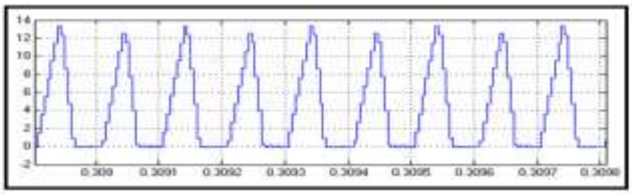
Fig. 12. Buck boost converter inductor current

IV. Full Bridge Inverter

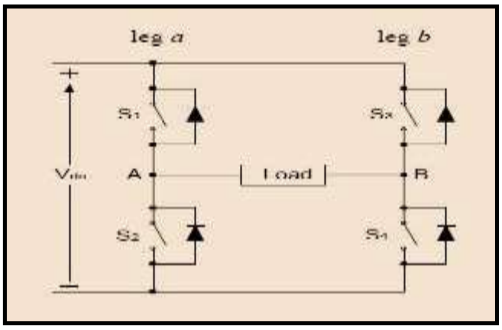

Fig. 13. Full - Bridge Inverter

Fig 13 the Full bridge inverter consists of two parallel strings contributing two switching power devices in series with anti-paralleled diodes. Variation of duty cycle of the PWM signal offers a voltage across the load in a specific pattern which appear to the load as AC signal. A pure sin wave is attained after passing the signal through a low pass filter [17]. The pattern at which the duty cycle of a PWM signal varies can be realized using simple analogue components or a digital microcontroller [15]. Either of the two basic topologies generate sinusoidal PWM that controls the output of the inverter [11]. The full bridge converter can be used to generate two different PWM pulse trains depending on the switching scheme implemented [6], [14], [15], [1], [16].

V. Simulation of PV Connected to the Single Phase Full Bridge Inverter

The output of the Buck Boost converter is connected to the single-phase inverter and the inverter output is fed to the AC grid. The simulation of the single phase photovoltaic system is realized by adding a single phase full bridge inverter from the Simulink block toolbox.

The Simulink block diagram of the current control loop is shown in Fig 14. First of all, an external voltage signal corresponding to the grid voltage is fed into a discrete single- phase phase-locked-loop (PLL). The gain at the input of PLL is recycled to normalize the actual voltage signal. The output of the PLL block produces a reference sin wave. This Sine wave together with the gain block is used to create the reference current.

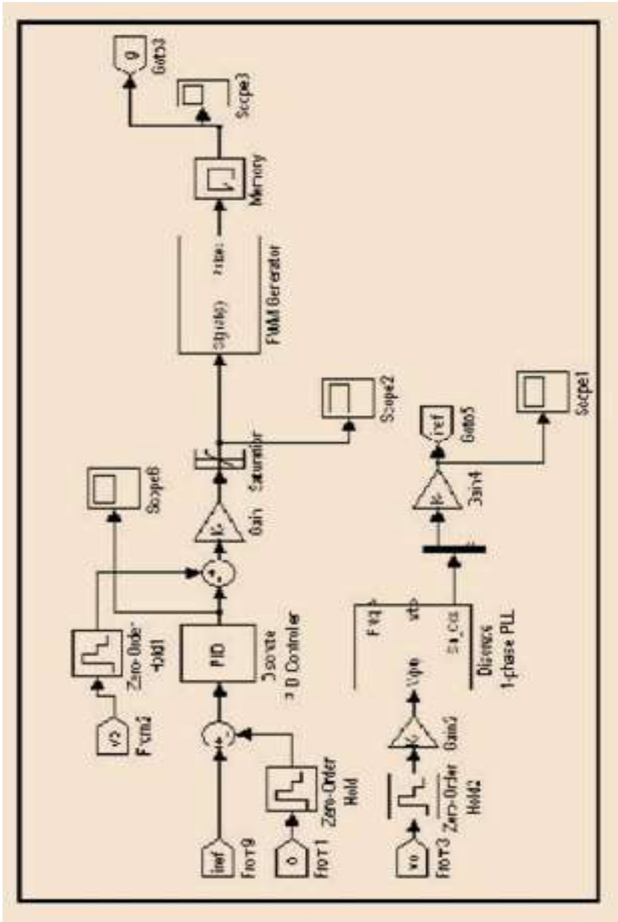
Fig. 14. Simulink model of the grid current control scheme

Current measured from the inverter output and created reference current is compared and the error from the output of comparator is given to the discrete PID controller. Here proportional gain taken is K_p = 100, Integral K_i = 200, and derivative gain K_d = 0. Controller output is added with ac voltage feed forward from the inverter. This output is the reference grid voltage, which separated by the DC source voltage with the use of gain block, it also provides the duty cycle for the inverter.

TABLE 3
SIMULATION PARAMETERS FOR CONVERTER

Description	Rating
Inductor	85µH
Capacitor	300µF
Resistive Load	100Ω
Switching Frequency	10KHz

for PV module BP 3170 and switched inductor buck-boost converter parameters mentioned in Table 3.

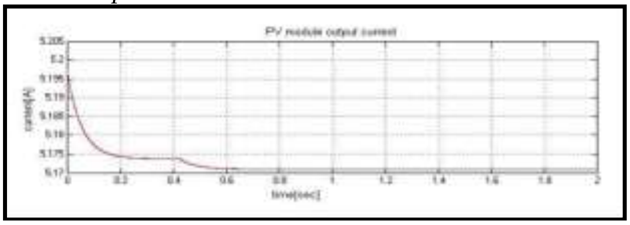

Fig. 15. PV module output current

Fig 15 shows the output current from the photovoltaic module. From this result we can see that photovoltaic current is gradually decreases from short circuit current 5.2A to the 5.17A and after this it remain constant.

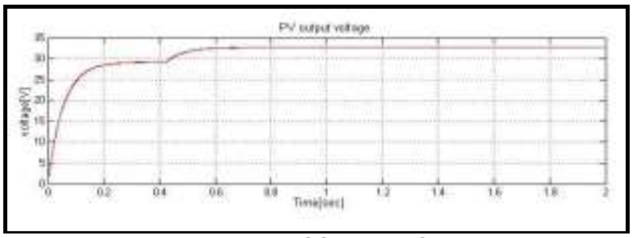

Fig. 16. PV module output voltage

Fig 16 shows the output voltage from the photovoltaic module. From this result we can see that photovoltaic voltage increases from zero to 32.8 volt. After this it remains constant.

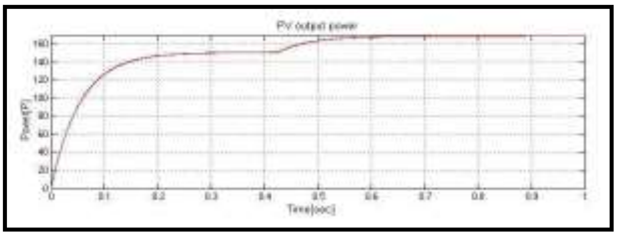

Fig. 17. PV module output power

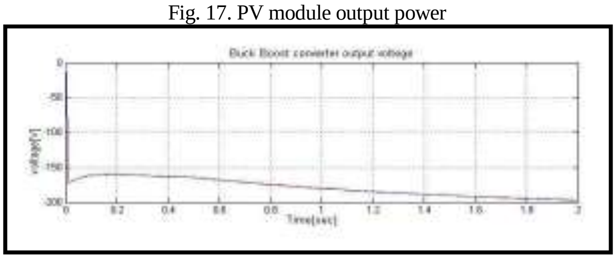

Fig. 18. Buck boost converter output voltage

Fig 17 shows the output power from the photovoltaic module. Maximum power output from the photovoltaic module is 169.5W which is almost equal to P_{mpp} given into the data sheet of the photovoltaic module.

Fig 18 shows the buck boost converter output voltage. Input voltage from the photovoltaic module 32.8 is boosted up to 200 volts.

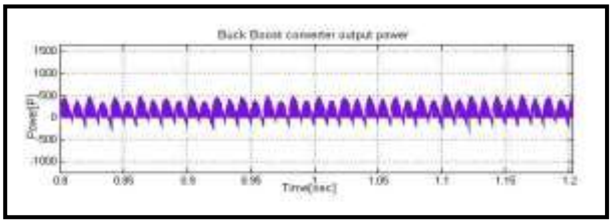

Fig. 19. Buck boost converter output power

Saturation block is used to

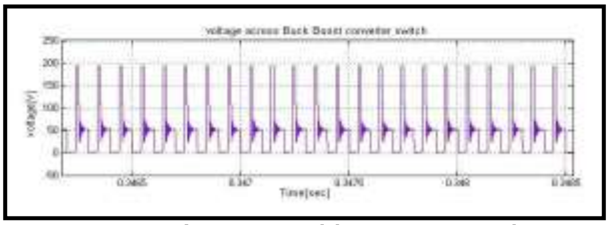

Fig. 20. Voltage across Buck boost converter switch

Fig 19 and Fig 20 are the buck boost converter output power and voltage across the converter switch.

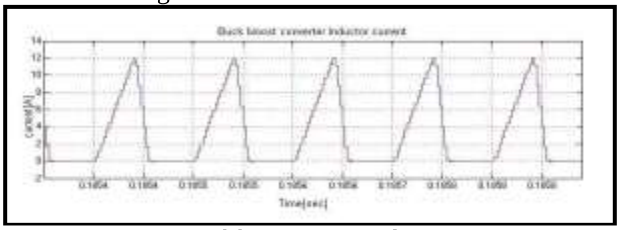

Fig. 21. Buck boost converter inductor current

Fig 21 shows the buck boost converter inductor current which is discontinuous.

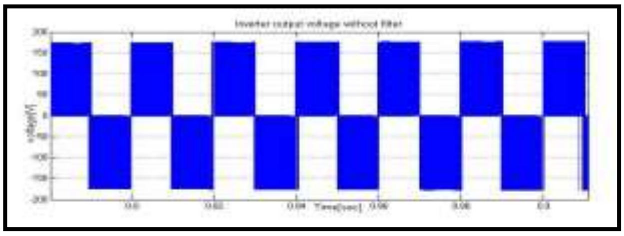

Fig. 22. Inverter output voltage without filter

Buck boost converter output voltage is converted into AC by using Full bridge inverter. Fig 22 is the output voltage of inverter without filter. Fig 23 and Fig 24 shows the filtered output current and voltage of the inverter.

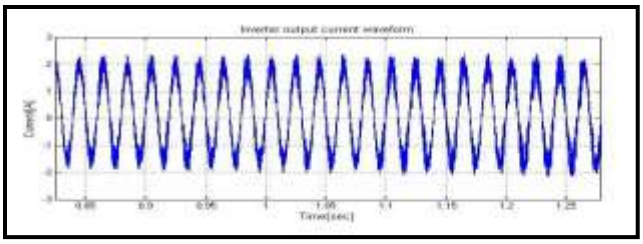

Fig. 23. Inverter output current with filter

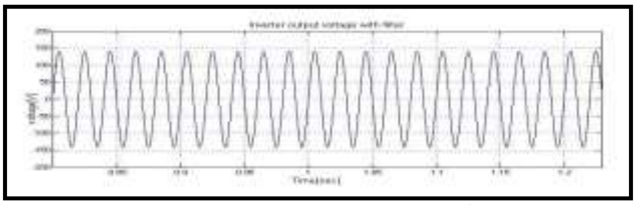
Fig. 24. Inverter output voltage with filter

VI. Conclusion

- Buck Boost converter is simulated with photovoltaic module and results we have seen that by varying the duty cycle of the converter switch, maximum power from the PV module is extracted.
- Increasing the load resistance, PV still deliver power near maximum point.
- At the load side, the output voltage is increased; depends on the load conditions.
- The PV module gives the maximum power, voltage and current independent of the load.
- Photovoltaic current is gradually decreases from short circuit current 5.2A to the 5.17A and after this it remain constant Fig. 15.
- Photovoltaic voltage increases from zero to 32.8 volt & after this value it remains constant Fig. 16.
- Maximum power output from the photovoltaic module is 169.5W which is almost equal to P_{mpp} given into the data-sheet Fig. 17.
- Buck-boost converter output voltage is boosted up from 32.8 volt to 200 volts Fig.18.
- Switching losses are significantly reduced due to the allied voltage drop of switching from one state to another in unipolar switching scheme.
- The power loses incurred at the converter stage is reimbursed at inverter stage.
- Thus the overall efficiency and reliability of the photovoltaic system is improved.

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