A New Single-Phase Single-Stage Buck-Boost Inverter For Grid Connected PV Applications

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***Abstract*-This paper develops a grid linked single stage single phase inverter for PV applications. The developed inverter has the ability to generate voltage with an amplitude less or greater than the DC source voltage, buck-boost capability, and extracting the ultimate PV power in one juncture. The developed inverter has the advantage of using a single inductor to output the positive and negative halves of the grid voltage which eliminates parameters mismatching problem. Lower switching losses is a distinct feature for the developed inverter, during positive part of the grid wave only one switch is run at switching-frequency and to create the negative part of the grid wave only two-switches are run at the switching frequency. Another feature for the proposed inverter is the reduced voltage stresses across its switching components, which leads to compact size and reduced cost. To ensure transmitting current to the grid in phase with the grid voltage, the system is designed to operate in discontinuous conduction mode (DCM). The system is simulated using PSIM platform to validation the developed inverter and its MPPT control.**

Keywords—MPPT, PV, Buck-boost, Single stage inverter

I. INTRODUCTION

PV earned a great attention nowadays, as it is an important, efficient and repeatable power origin. It also has emission-free working principle, less required maintenance and the big advantage which is the availability [1]-[3].

When a photovoltaic system is established, one of the main components that will be used is the inverter to mutate the dc output of PV into AC. The common inverter is the H-bridge inverter which can only produce an output voltage with a peak amplitude less than the input dc voltage [4]-[9]. If power conditioning feature is required a dc/dc converter stage should be used in front of the H-bridge and in this case, it is called a two-stage inverter. As in [10] a buck-boost converter is in series with an H-bridge. other configurations are mentioned in [11] where a boost dc/dc converter is cascaded by an H-bridge. But the two stage inverters have the disadvantages of less efficiency, large size, large weight, reduced reliability and increased cost.so several configurations of one stage inverters developed in the literature to mend the efficiency and compactness. As in [12] a half-bridge buck-boost inverter is proposed but the main disadvantages of this topology is that each one of the PV sources operates half the cycle time only which weakens the benefit from the PV power to half. In [13] a single stage topology was proposed with a usage of mutually coupled coils but it suffers from high switching losses, asymmetrical operation in positive and negative halves of the sinewave and it is convenient only for depressed power enforcement [14]. In [15] a single stage Buck-Boost and Full-Bridge Integration was presented but all topology switches have a high voltage stress and the buck-boost main switch operates at a high frequency at both halves of grid voltage leading to a concentrated losses at that switch which reduces its life time.

In this work, a new one phase single stage inverter for grid tied PV systems is suggested in this paper with the advantages of:

- Production of an ac output voltage with a peak value less or more than the input voltage.
- Snatching the PV ultimate power.
- Improvement of the efficiency by lowering the number of switches which operates at the switching frequency.
- Reduction in the number of objects used in the circuit which helps in reducing size, weight and price of the inverter.
- Reduction in the voltage stress on two of the switching components to the input voltage.
- Usage of a single inductor in the two halves of the ac cycle which guarantee symmetry.
- Low value of Total Harmonic Distortion (THD) is obtained.

The paper structure is as below: Section II offers the operation principle of the proposed single stage buck boost inverter. Section III offers the analysis and design of the proposed inverter. Section IV presents the maximum power point tracking technique used for extracting the maximum power from PV. Section V introduces the simulation results.

II. OPERATION PRINCIPLE

The suggested inverter is shown in fig.1. It consists of one buck-boost inductor, five switches, three diodes, input capacitor, filtering capacitor and filtering inductor. Circuit parameters are selected to ensure the discontinuous conduction mode operation.

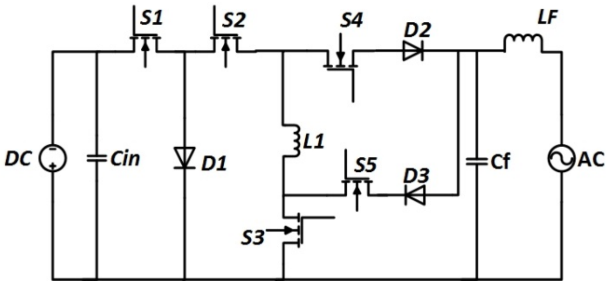

Fig.1.proposed single stage buck-boost inverter

A. production of the sinewave positive voltage

At the charging mode switches S_1 , S_2 , S_3 , S_4 are on as presented in fig.2(a). At the discharging subinterval S_2 is altered to off state as offered in fig.2(b) and the energy stored inside the inductor is received by the output. And hence, only one switch operates at the switching frequency during the sinewave positive voltage production which limits the losses and improves the efficiency. Circuit behavior in the third subinterval is offered in fig.2(c). which offers that diode D_2 state is altered to be off and the energy stops to be stored in the inductor or received by the grid.

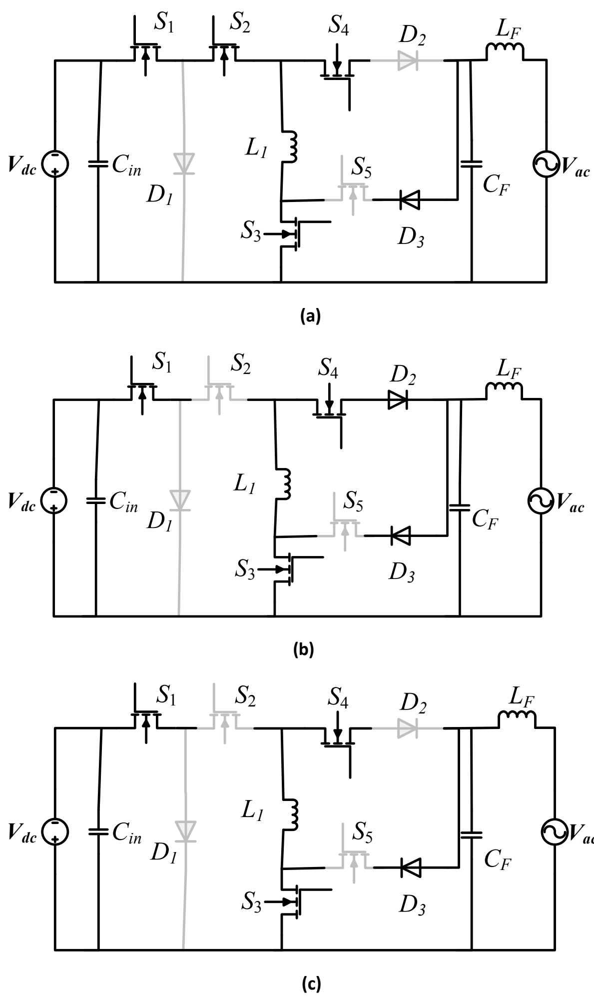

Fig.2. Positive half cycle circuit diagrams (a) modes 1, (b) mode 2 and (c) mode 3.

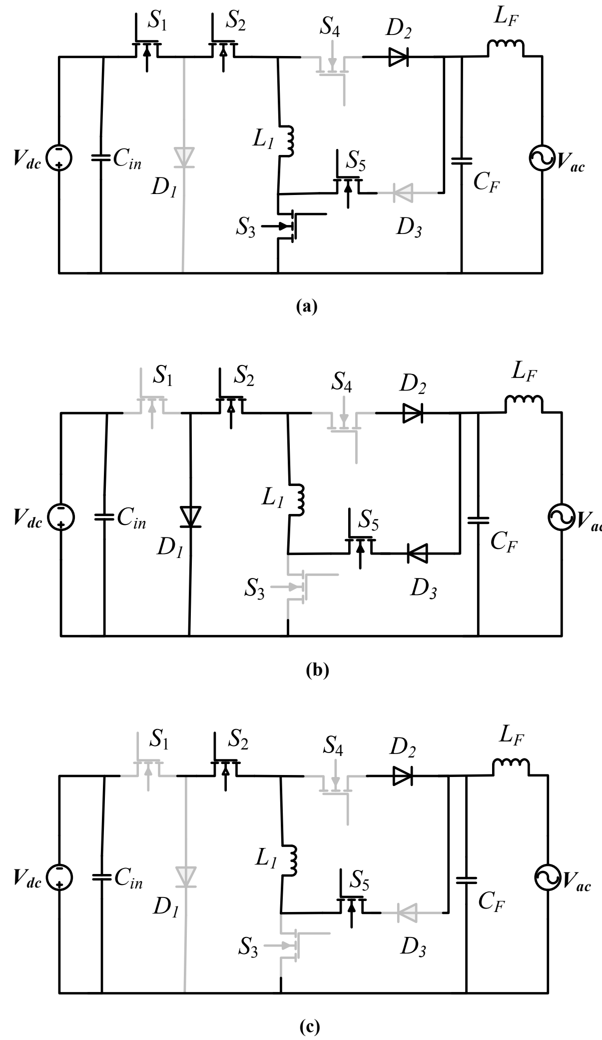

Fig.3.negative half cycle circuit diagrams (a) modes 1, (b) mode 2 and (c) mode 3.

B. production of the sinewave negative voltage

At the charging mode switches S_1 , S_2 , S_3 , S_5 are on as offered in fig.3(a). And hence, the inductor is connected to the PV source to receive and store energy for the next subinterval. At the discharging subinterval switches S_1 , S_3 are altered to off state as given in fig.3(b). And hence, the stored energy of the inductor is received by the output. circuit behavior in the third subinterval is given in fig.3(c) which presents that diode D_3 state is altered to be off and the energy stops to be stored in the inductor or received by the grid.

III. ANALYSIS AND PARAMETERS DESIGN

To ensure the circuit operation at the Discontinuous Conduction Mode (DCM) and obtain a unity power factor injected power with a low THD circuit parameters must be carefully designed as following:

A. Buck-Boost inductor design

The maximum photovoltaic modules power could be obtained as

$$P_{pv\_m} = I_{pv\_m} * V_{pv\_m} \quad (1)$$

Where I_{pv_m}, V_{pv_m} are maximum voltage and current of the PV module respectively. For a power factor equal to one, the peak injected power to the grid is

$$P_{inj\_m} = V_{g\_m} * I_{inj\_m} \quad (2)$$

Where V_{g_m}, I_{inj_m} are peak grid voltage and peak injected current to the grid respectively. For an ideal inverter topology

$$P_{pv\_m} = 0.5 P_{inj\_m} \quad (3)$$

And hence,

$$I_{pv\_m} * V_{pv\_m} = \frac{1}{2}(V_{g\_m} * I_{inj\_m}) \quad (4)$$

The critical conduction mode is shown in fig.4 at which

$$V_L = L\frac{dI}{dt} \quad (5)$$

$$slope = \frac{dI}{dt} = \frac{V_L}{L} \quad (6)$$

$$T_{on} = \frac{I_p * L_{crit}}{V_{pv\_m}} \quad (7)$$

$$T_{off} = \frac{I_p * L_{crit}}{V_{g\_m}} \quad (8)$$

$$T_s = T_{on} + T_{off} \quad (9)$$

$$I_p = \frac{T_s}{L_{crit} * [\frac{1}{V_{g\_m}} + \frac{1}{V_{pv\_m}}]} \quad (10)$$

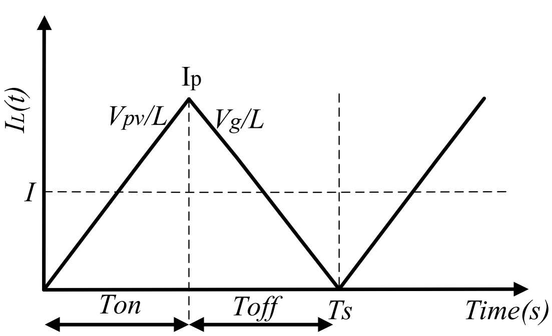

Fig.4 Current of inductor in the Critical Conduction Mode

$$\textit{The inductor stored energy} = 0.5LI^2 \quad (11)$$

And hence,

$$\textit{The maximum inductor stored energy} = 0.5L_{crit}I_p^{\,2}$$

$$I_p = \frac{1}{2}\frac{(T_s)^2}{L_{crit} * [\frac{1}{V_{g\_m}} + \frac{1}{V_{pv\_m}}]^2} \quad (12)$$

The maximum energy received by the grid for a switching period is

$$E_{inj\_m} = V_{g\_m} * I_{inj\_m} * T_s \quad (13)$$

From (12) and (13)

$$L_{crit} = \frac{1}{2V_{g\_m} * I_{inj\_m}}\frac{T_s}{[\frac{1}{V_{g\_m}} + \frac{1}{V_{pv\_m}}]^2} \quad (14)$$

From (4)

$$L_{crit} = \frac{1}{4I_{pv\_m} * V_{pv\_m}}\frac{T_s}{[\frac{1}{V_{g\_m}} + \frac{1}{V_{pv\_m}}]^2} \quad (15)$$

B. Filtering capacitor design

The energy received by the filtering capacitor is from the buck-boost inductor so that leads to

$$0.5L_{crit}I_p^{\,2} = 0.5C_f V^2 \quad (16)$$

$$= 0.5C_f (V_{g\_m} + \Delta v)^2 - 0.50.5C_f (V_{g\_m} - \Delta v)^2 \quad (17)$$

$$C_f = \frac{L_{crit} * I_p^{\,2}}{4\Delta v V_{g\_m}} \quad (18)$$

From (18) and (10)

$$C_f = \frac{L_{crit}}{4\Delta v V_{g\_m}}\left(\frac{T_s}{L_{crit} * [\frac{1}{Vg\_m} + \frac{1}{Vg\_m}]}\right)^2 \quad (19)$$

C. Filtering inductor design

$$F_c = \frac{1}{2\pi\sqrt{L_f C_f}} \quad (20)$$

where F_c is the cut off frequency

$$L_f = \frac{1}{4\pi^2 F_c^{\,2} C_f} \quad (21)$$

Table.2.is a comparison between the developed topology and other topologies exist in the literature in count of component. Table.3. represents a comparison in voltage stress on switches. From tables.2 it is seen that the developed topology has a reduced number of components which ensures the compactness and reduces the cost and weight of the topology. The developed topology also achieved a reduced voltage stress on its component compared to the available topologies in literature as can be seen in table.3. which reduces the cost and improves the topology compactness.

Table.2. component count comparison

Component	Proposed	[16]	[17]	[9]	[14]
Dc source	1	1	2	1	1
Inductor	1	1	2	2	1
Capacitor	2	2	3	3	2
Switch	5	5	4	4	5

Table.3. switches voltage stress

comp.	proposed	[16]	[17]	[9]	[14]
S1	Vin	Vin+Vo	Vin+Vo	Vin+ Vo	Vin+ Vo
S2	Vin+Vo	Vo	Vin+Vo	Vin+ Vo	Vo
S3	Vo	Vo	Vin+Vo	Vin+ Vo	Vo
S4	Vo	Vo	Vin+Vo	Vin+ Vo	Vo
S5	Vo	Vo	------	------	Vo

IV. MAXIMUM POWER POINT TRACKING CONTROL

Because of The great initial price of PV modules and the variation in the environmental conditions like temperature, radiation and others a MPPT control is necessary for snatching the ultimate available PV power [16]-[18].

The MPPT algorithm used in this paper is shown in fig.5. Where V_n and I_n are the measured amounts of the PV modules. V_p and I_p are the prestored values for voltage and current of the PV modules. The algorithm could be explained as following V_n and I_n are sensed and with the help of V_p and I_p the difference between the measured and prestored values in PV voltage and current could be obtained which are dI and dV respectively. If $dV = 0$ and $dI = 0$ then no increase or decrease in the duty cycle will happen. If $dV = 0$ and $dI > 0$ then the duty cycle should be decreased. If $dV = 0$ and $dI < 0$ then the duty cycle should be increased. If dV does not equal to zero and $I + dI / dV * V = 0$ then no increase or decrease in the duty cycle should be happened and if dV does not equal to zero and $I + dI / dV * V > 0$ then a decrease in the duty cycle should be happened but if d_V does not equal to zero and $I + dI / dV * V < 0$ then an increase in the duty cycle should be done.

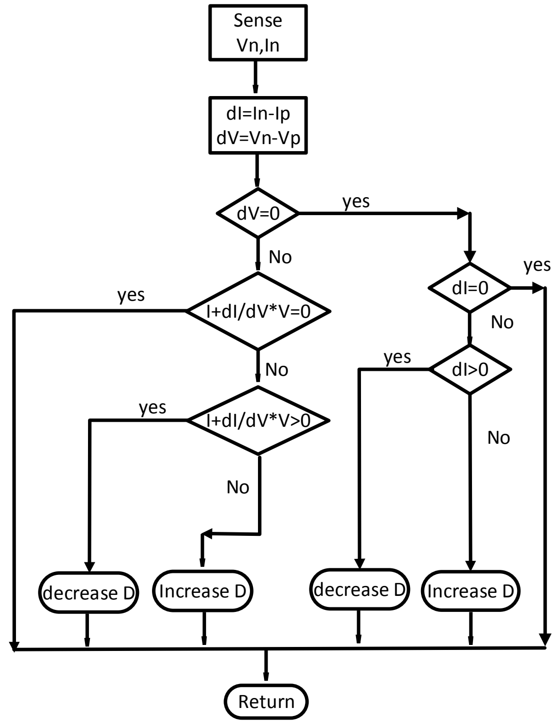

Fig.5.MPPT control flowchart

V. SIMULATION RESULTS

The simulation tool used in this paper is PSIM software. Four BP485 85W PV panels were used with a characteristic as shown in Table .1. simulation parameters of the circuit are: *buck-boost inductor=120uH*, $f_s = 15KHZ$, $C_{in} = 10mF$, $C_f = 1uF$, $L_f = 3.5mH$,*peak grid voltage =311v* and *grid frequency =50HZ*. Fig.6. is for grid voltage and current which shows a unity power factor power injection.

Table .3. BP485 85W PV panel properties

Ultimate power	85W
V_{MPP}	17.8 V
I_{MPP}	4.9 A
Isc	5.4 A
Voc	22 V

Fig.7. presents the voltage stress of S_1 and D_1 which is limited to the input voltage so that improved efficiency and reduced cost could be achieved.

Fig.8.presents PV output current, output voltage, output power and radiation when a step change from *700 W/m²* to *1000 W/m²* happened in the radiation which ensures the validation of the MPPT control and its ability of tracking the ultimate PV power.

Fig.9. shows the switching pulses for the five switches which shows that at the positive half cycle only one switch is run at the switching rate and in the second part of sinewave a different two switches are run at the switching rate. So that losses are limited, efficiency is improved, the working stress on the switches is minimized and distributed among switches which improves the switches life time and decreases its cost and cooling requirements.

Fig.10. represents the efficiency curve of the suggested inverter topology. In the efficiency calculation the switching losses of switches, the conduction losses of switches, the switching losses of diodes and the conduction losses of diodes were considered.

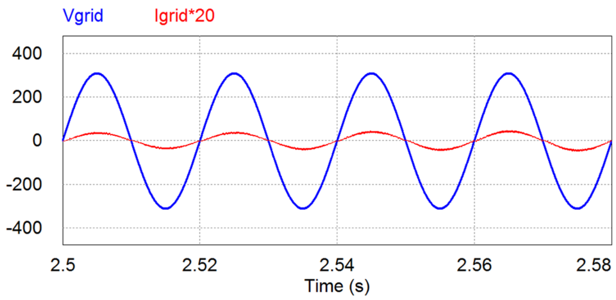

Fig.6.grid voltage and current.

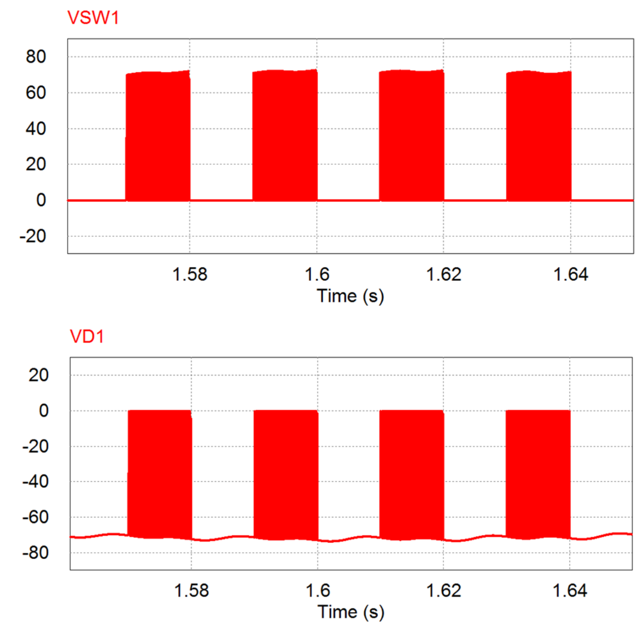

Fig.7.Voltage stress on S_1 and D_1 respectively

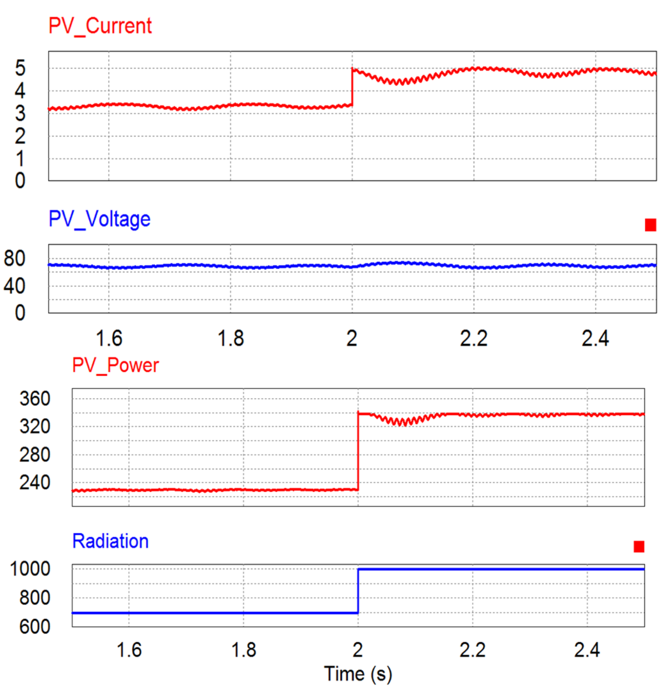

Fig.9. PV output and radiation

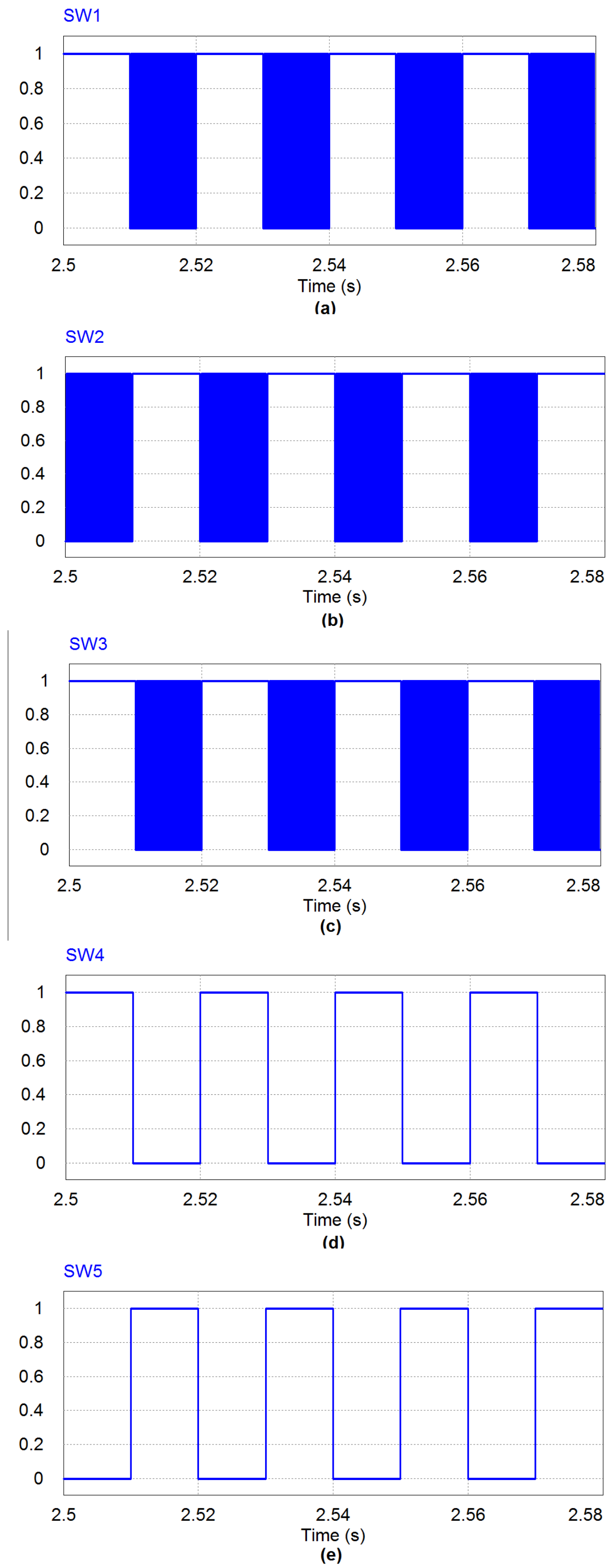

Fig.7.Switching pulses for switches (a) S_1, (b) S_2, (c) S3, (d) S_4 and (e) S_5

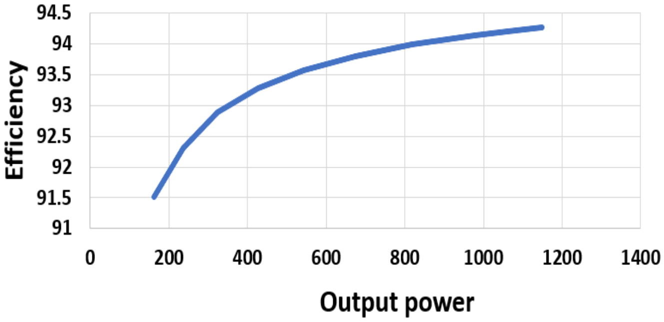

Fig.10.The developed inverter efficiency curve

VI. CONCLUSION

A novel inverter was suggested which is able to output a voltage with a level less or greater than the input PV voltage, convert the input PV voltage into ac one, inject a current to the grid in phase with the grid voltage and track the MPP of PV modules. The suggested topology uses a single buck boost inductor in positive and negative halves of the sinewave. Improved efficiency is obtained due to limitation of the switching losses of switches. A reduced voltage stress on some switching components is also achieved. PSIM software is used to ensure the validation of the suggested topology.

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