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Closed Loop Control Implementation of Switched Boost Inverter for PV Applications with AC/DC Loads

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***Abstract*- Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies. In the field of renewable energy after boosting operation, for converting DC to AC voltage for feeding load, inverters plays vital role Due to many limitations faced by Conventional voltage source inverter,Z-SourceInverter became popular by preventing the limitations due to its by providing LC impedance network connected between source and load Thereby this inverter can be used for Buck/Boost operation. But presence of LC impedance made the system bulky and not suitable for low power application. This causes the introduction of Switched Boost inverter, which exhibits similar advantages of ZSI with less number of passive elements. This paper proposes closed loop control of switched boost inverter for PV applications with less cost and reduced size. The closed loop control enhances the efficiency of SBI and it also shows fast response to the voltage given as reference. SBI has unique features of buck/boost operation along with AC/DC inversion. This feature is embedded in this topology due to the presence of impedance network in the input side of SBI.**

Keywords*- Switched Boost Inverter(SBI);Impedance source Inverter(Z-source Inverter);Electromagnetic Interference(EMI)

I. INTRODUCTION

The conventional inverter are mainly used for DC/AC conversion. Initially voltage source inverters were widely used .But later onwards Z-source inverters became popular, due to its unique capability of Buck/Boost operation along with dc/ac inversion. Z-source inverter consists of impedance network in the input side .The impedance network consist of inductors and capacitors ,compared to voltage source inverters ,ZSI has the ability to boost or buck the voltage .The buck/boost operation in z-source inverter is possible due to the presence of LC impedance. During power interval these elements gets charged and supplies to load during next power interval. The LC impedance charging takes place during zero interval .ie during shorting of source .Due to this feature, this is applicable in wide area. The Buck/Boost operation is incorporated due to its ability to utilize shoot through state through the impedance network connected[1].The ZSI also possesses robust electromagnetic interference (EMI) noise immunity, which is achieved by allowing the shoot-through of the inverter leg switches. As a result, the output voltage of the converter can be either higher or lower than the input voltage as per the requirement. In addition, the ZSI also possesses robust electromagnetic arises when gate signals are given to the switches placed in same leg of H-bridge. So utilization of zero interval for charging the LC impedance by short circuiting the load is named as shoot through state .This state can be achieved by giving gate signals to both switches in the same leg of inverter bridge. In addition z-source inverter posses interference (EMI) noise immunity.

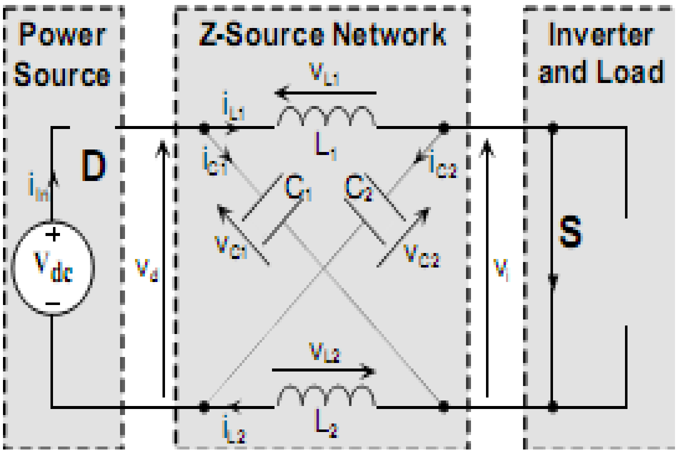

Fig1 Z-Source inverter

Though Z-Source Inverter having capability of Buck/Boost operation, the presence of impedance network say inductor and capacitor makes the system bulky and costly. Therefore this topology may not suitable for low power application .Therefore we need to find an alternative solution ,which overcome the limitation faced by Z-source Inverters .Due to above reasons switched boost inverters are being used in low power applications. The main difference of SBI from Z-source inverter is basically the number of passive elements used in SBI. This converter uses comparatively lower number of passive elements say inductor and capacitor and more active components .Even though this topology uses more active components, it retains operational advantages of ZSI .It can be used for both AC and DC loads. This paper proposes a novel power converter say SBI with closed loop approach is presented .This paper also explained about two pulse width modulation (PWM) control strategies .Section II presents the basic working of Switched Boost Inverter, which include all modes of operation related to SBI and section III presents the two pulse width modulation technique that can be used for SBI.The detailed description of closed loop control of Switched Boost inverter is analyzed and explained with required blocks in section V. The comparison of SBI and ZSI are analyzed and listed down in [7].The experimental results are given in Section VI to validate the theoretical analysis. The concluding remarks of this paper are given in Section VII.Note that, in this paper, G_S, G_{S1}, G_{S2}, G_{S3}, and G_{S4} represent the gate control signals of switches S, S_1, S_2, S_3, and S_4, respectively.

II. SBI TOPOLOGY

Fig. 2 shows the schematic of the SBI in which a switched boost network comprising of one active switch (S), two diodes(D_a,D_b), one inductor (L), and one capacitor (C) is connected between voltage source V_g and the inverter bridge. A low-pass LC filter is used at the output of the inverter bridge to filter the switching frequency components in the inverter output voltage.SBI has mainly two modes of operation namely mode I and mode II ,where mode I operation is tagged as DT_s interval and mode II is $(1\text{-}D)T_s$ .where DTs is referred as shoot through interval and $(1\text{-}D)T_s$ is non shoot through state of H-bridge inverter.

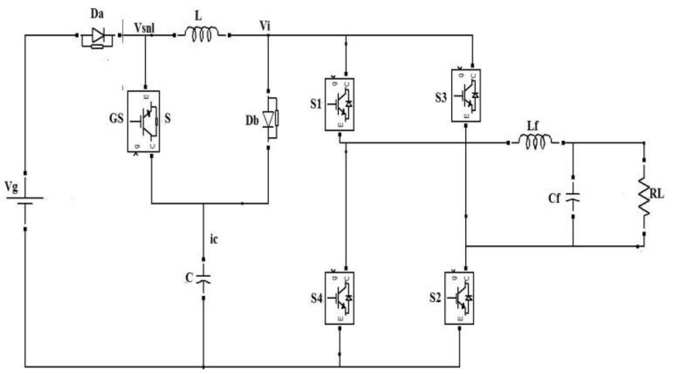

Fig.2. Switched Boost Inverter(SBI)

The operation during shoot through state of SBI is already explained in section I,which is similar to ZSI .The steady state operation of SBI can be explained by two modes of operation namely DT_s and $(1\text{-}D)T_s$ .The switch S is operated during shoot through period, inorder to charge the inductor by capacitor .The modes of operation is shown in the figure2 (a) and figure2 (b). As shown in the Fig. 2(a), the inverter bridge is represented by a short circuit during this interval. The diodes D_a and D_b are reverse biased (since $V_C>V_g$), and the capacitor C charges the inductor L through switch S and the inverter bridge. The inductor current in this interval equal to the capacitor discharging current. For the remaining duration in the switching cycle $(1-D).T_S$, the inverter is in non-shoot-through state, and the switch S is turned off. The inverter bridge is represented by a current source, which is shown in Fig. 2(b). Now, the voltage source V_g and inductor L together supply power to the inverter and the capacitor through diodes D_a and D_b. The inductor current in this interval equals the capacitor charging current added to the inverter input current. Here its under assumption that the inductor current is to be sufficient enough for the continuous conduction of diodes D_a and D_b for the entire interval is given by $(1-D).T_S$

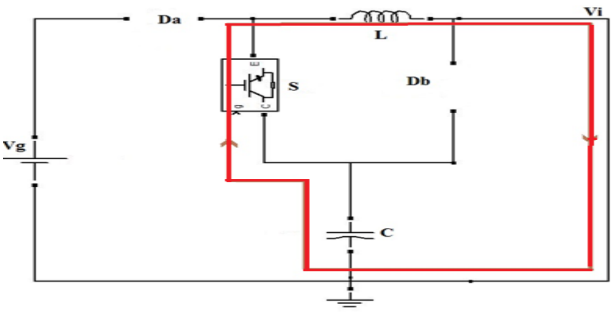

Fig 2.1 SBI during D.Ts interval

From the figure 2(a) and 2(b) it is able to frame the equations for inductor voltage ,DC link voltage and the capacitor current with small ripple approximation

$$V_L(t) = \begin{cases} Vc & , \text{ if } 0 < t < dT_s \\ & \text{or} \\ Vg - Vc & , \text{ if } D.T_s < t < T_s \end{cases} \tag{1}$$

$$I_C(t) = \begin{cases} -I_L & , \ if \quad 0 < t < DT_s \\ I_L - I_i & , \ if \quad DT_s < t < T_s \end{cases} \tag{2}$$

$$V_i(t) = \begin{cases} 0 & , if\ 0 < t < DT_s \\ V_c & , if\ DT_s < t < T_s \end{cases} \tag{3}$$

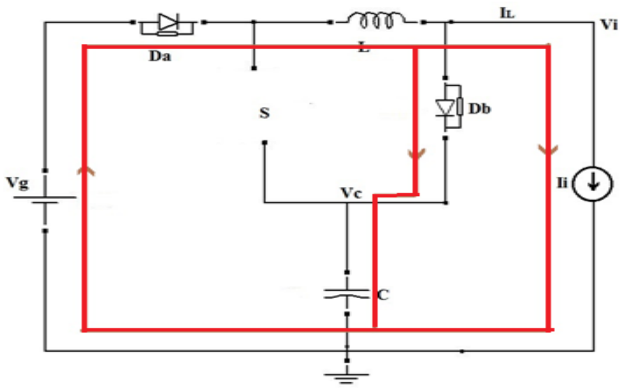

Fig 2.2 SBI during (1-D)T_s interval

Under steady state average voltage across the inductor and average current through the capacitor should be zero. Thereby using the voltage-second equation we have,

$V_C.D + (Vg-V_C)(1-D) = 0$

$$\frac{VC}{Vg} = \frac{(1-D)}{(1-2D)} \quad (4)$$

$-I_L.D + (I_L-I_i)(1-D)=0$

$$\frac{I_L}{I_i} = \frac{(1-D)}{(1-2D)} \quad (5)$$

Where I_i is current drawn by the inverter bridge during (1-D)Ts period .The average DC link voltage V_i can be framed by

$V_i = 0.D + V_C(1-D) = V_C(1-D)$ (6)

The limitation for conversion ratio (V_c/V_g) is mentioned so maximum range of D is limited to 0.5.From [5], it can be observed that the expressions for the conversion ratios (V_C/V_g) and (I_L/Ii) of SBI are the same as those for a ZSI, while the average dc link voltage of SBI is(1 $-D$) times that of ZSI [1]. Also, it will be shown in Section V that the switching states of SBI and ZSI are the same provided that the *LC* impedance network of ZSI is symmetrical.

III. PWM CONTROL OF SBI

Pulse width modulation technique is basically used for modulating the width of the pulses generated There are many pwm techniques available, in which unipolar switching scheme is used here. Unipolar switching scheme is basically the comparison of $V_m$sin(wt) and $-V_m$sin(wt) with triangular wave .The peak amplitude of sine wave is represented by V_m and peak amplitude of triangular wave is represented by V_p. In this case SBI has mainly five switches ,inorder to control all the five switches and tune to proper shoot through duty ratio two more signals are used namely V_{ST} and $-V_{ST}$. In this control strategy $V_m$sin(wt) and $-V_m$sin(wt) are the modulating (reference signal) of frequency f_o and Triangular wave is used here as carrier wave of frequency f_s..The introduction of these constants are for varying shoot through duty cycle without disturbing the power interval, thereby Boost/Buck operation is possible .The gate control signals G_{SX} (x = 1 to 4) are generated by comparing the reference signals with triangular carrier signal v_{tri}. The signal GSX becomes high whenever the value of the corresponding reference signal becomes either higher or lower than that of the carrier. The gate control signal (GS) for switch S is obtained by adding the two individual shoot-through periods S_{T1} and S_{T2} as shown in the Figure 3.1.Fig.3 shows the control signals generated [during the positive half cycle of V_m(t)] for one switching cycle T_S. The gate control signals for switches $S1$ and $S2$ are generated by comparing the sinusoidal modulation signals with a high frequency triangular carrier $V_{tri}(t)$ of amplitude V_p. The frequency of the carrier signal is chosen such that $f_S >> f_O$. Therefore, V_m is assumed to be nearly constant during a switching cycle since switching frequency is greater. Whenever V_m is greater than V_{tri} pulses generates. The signals S_{T1} and S_{T2} are generated by comparing V_{tri} with two constant voltages V_{ST} and $-V_{ST}$, respectively[7]The purpose of these two signals is to insert the required shoot-through interval DT_S in the gate control signals of the inverter bridge.

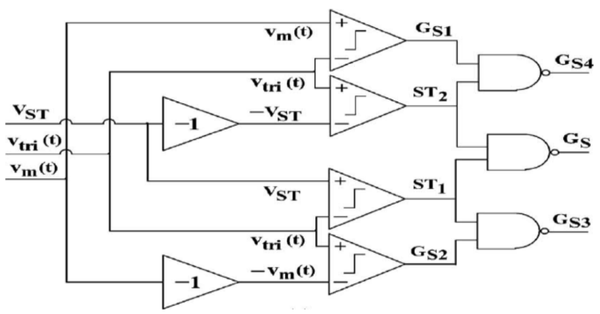

Fig 3 control circuit for gate signal generation

Now, the gate control signals for switches $S3$, $S4$, and S can be obtained using the logical expressions given as follows.

$G_{S3} = \overline{G_{S2} \wedge ST_1}$

$G_{S4} = \overline{.G_{S1} \wedge ST_2}$

$G_S = \overline{ST_1 \wedge ST_2}.$

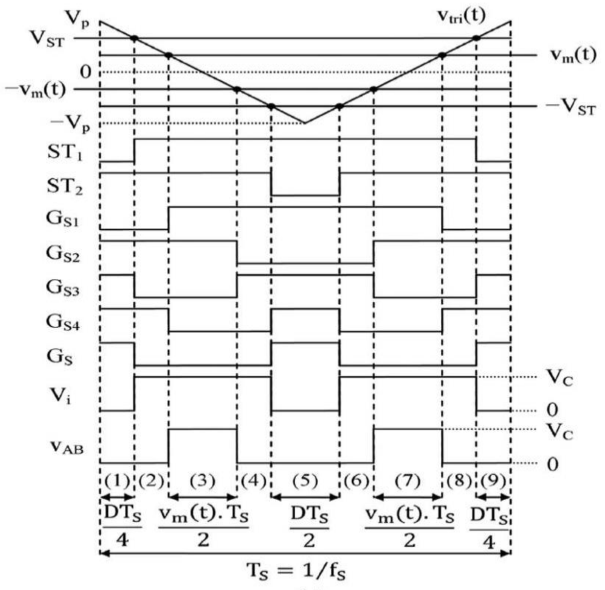

Fig 3.1 PWM control signals for SBI during positive half cycle

A. *Mathematical relation between V_{ST} and shoot-through duty ratio D*

$$V_{tri}(t) = \frac{-Vp}{Ts/4}\left(\frac{Ts}{4}\right) \text{ if } 0< t < (Ts/2)$$

$$= \frac{Vp}{Ts/4}(t-3T_s/4) \text{ if } \frac{Ts}{2} < t < (T_s) \tag{7}$$

$V_{tri}(t_1)=V_{tri}(t_2) = -V_{st}$ and $t_2-t_1=DT_s$

$$D=\left(1-\frac{Vst}{Vp}\right) \tag{8}$$

B. *Effect of Shoot-Through State on Output Voltage (V_{AB}) of SBI*

The voltage v_{AB} has three zero intervals (when $V_{AB}= 0$) and two power intervals (when $V_{AB}= V_C$) in each switching cycle T_S. In order to ensure that the shoot-through interval does not disturb the power intervals of V_{AB}, D should be chosen such that the total width of the shoot-through interval does not exceed the total available width of the zero interval in any switching cycle .Here D denotes the shoot through duty ratio. And Ts is the total time period .$V_m(t)$ denotes the amplitude of reference wave .

$$D.Ts < Ts\text{-max}\left(\frac{Vm(T)}{Ts}\right)$$

$$D< 1-M. \tag{9}$$

Where V_{ST} should be greater than $M.V_p$.The peak magnitude of the fundamental component of V_{AB}.That is peak value is given by an expression given by

$$V_{AB} = M.\frac{(1-D)}{(1-2D)} V_g \tag{10}$$

Where Vg is the input voltage and M is the modulation index. It can be observed that the voltage v_{AB} has three zero intervals and two power intervals While assigning the value of shoot through Duty ratio, it is advisable to control the D value before it disturbs power interval .

TABLE I. VOLTAGE AND CURRENT EQUATIONS OF SBI

Voltage/current	Formulae
V_C	$\hat{V_i}$
$\hat{V_i}$	$\hat{V_o}/M$
Vg	$\frac{(1-2D)}{(1-D)}.Vc$
I_i	$\frac{Vo/Vi}{2RL(1-D)}$
I_L	$\frac{(1-D).Ii}{(1-2D)}$
ΔI_L	$VC.DTs/_L$

TABLE II. PARAMETERS USED IN THE EXPERIMENT

Vg	107V
L	5mH
C	100µF
L_f	4.6mH
C_f	10 µF
R_L	25Ω

IV. DESCRIPTION OF CLOSED LOOP CONTROL SYTEM

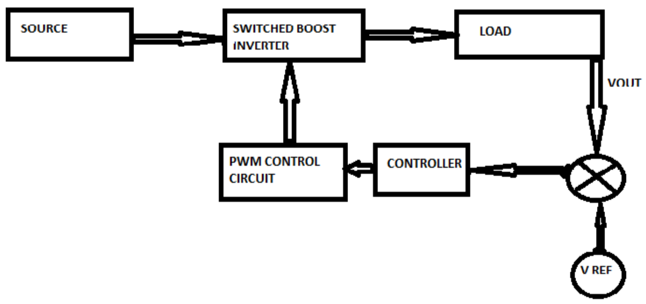

Fig 4 Block diagram of closed loop control

The block diagram representation of closed loop control of SBI for AC and DC load is shown in the figure 4.The control systems consists of source it can be a pv module or a DC supply ,Switched Boost Inverter and AC load is connected across the LC filter ,and DC load can be connect across capacitor(C) of SBI and PI controller is used for minimization of error signal .Initially a reference

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voltage is given to the summing point and the measured output across the load is compared with the reference ,inorder to track the reference voltage .The error produced over here is processed with the intervention of PI controller.It has good steady state response .Due to integral controller steady state error can be minimized .The output of PI controller can be considered to be modulation index(M).So here the controlling parameter chosen is modulation index.

V. SIMULATION RESULTS

The designing of SBI has done and both the open and closed loop control circuitry are simulated using Matlab/Simulink software .The results and output waveform are verified for various duty ratio. In the case of close loop control of SBI ,output voltage waveform, voltage across the capacitor ,Inductor current are obtained .Gating signals are observed before and after the inclusion of controller for better performance .The study is carried with the help of certain parameters ,input voltage is taken as 107V ,and V_{ref} is taken as 150V.The closed loop control enables tracking of reference voltage .This control strategy can control wide range of voltage variation. The proportional and integral controller gains are changed for different reference voltages and simulated further for better performance of the system. In this study ripple approximation is about 1.12 percentage .The waveforms corresponds to output voltage is given in figure 5.1 and gating signals for all the switches in SBI are listed down in figure 5.2.Where GS is the switch which controls the shoot through duty ratio ,hence proper utilization of zero interval can be achieved.

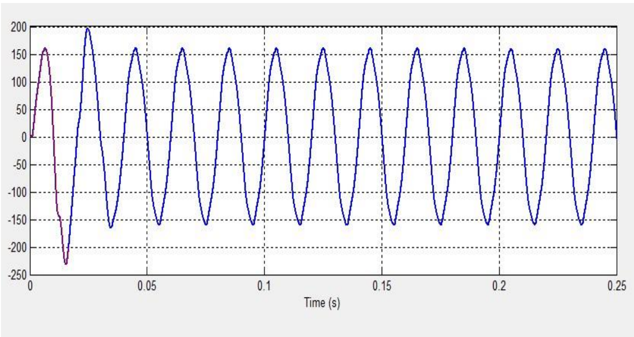

Figure5.1. voltage across the load

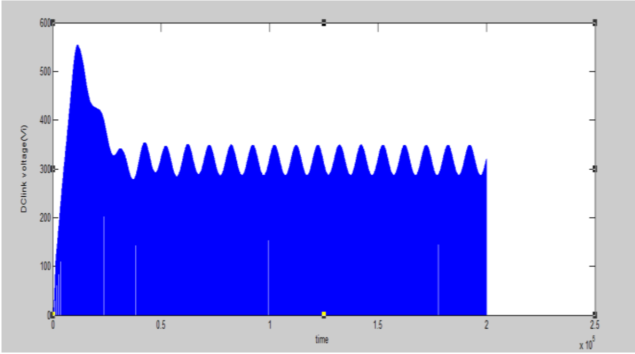

Fig 5.2 DC link voltage

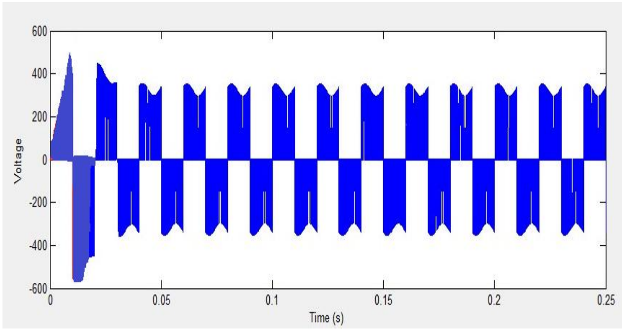

Fig 5.4 Output voltage (V_{AB})

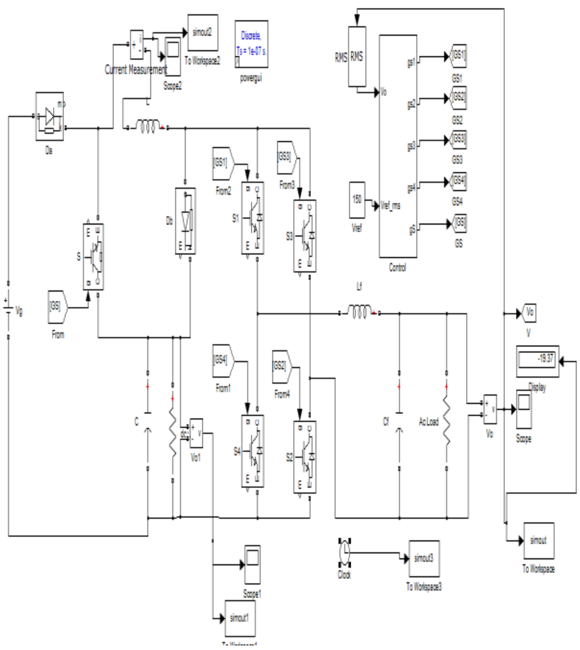

Fig 5.3 simulink block of closed loop control of SBI

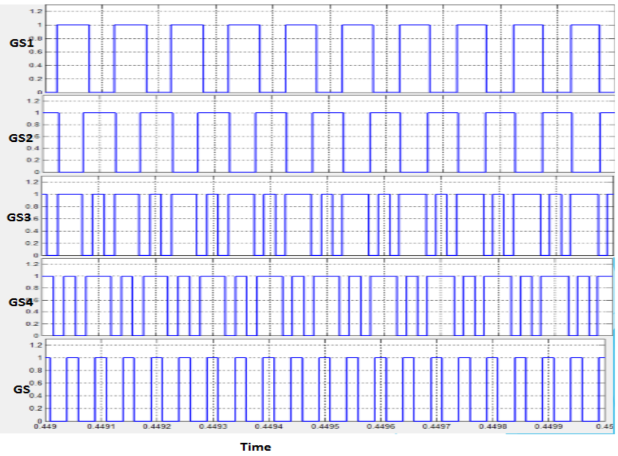

Fig 5.5 gating signals for switches of SBI

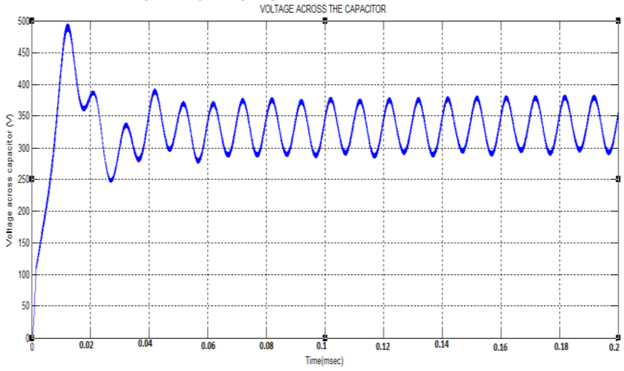

Fig 5.6. voltage across the capacitor

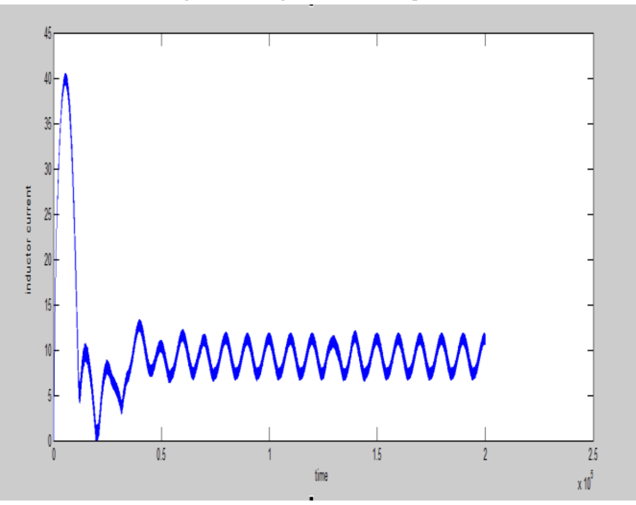

Fig 5.7 Inductor current

VI. CONCLUSION

The paper proposes the closed loop control of Switched Boost inverter for AC/DC load .It is found that this topology can be used for PV applications .Since it acts as Buck/Boost converter by controlling shoot through time period,along with its inverter operation having less number of passive components made this inverter suitable for low power applications .Modeling of closed loop control fed ac/dc load has done using MATLAB/Simulink software and compared to conventional inverters proposed topology has countable added advantages .Due to its comparatively small and cost effective design ,it can be use in wide applications. Thereby reduces cost and losses .

For different reference voltage and modulation indices simulation has done ad output voltage ,input current ,capacitor voltages are observed .It also proves that theoretical calculation and simulated values are almost equal .Unlike the conventional systems which use more number of passive components ,so becomes bulky and costly.So this proposed method improves SBI performances and gives better efficiency.

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