IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Analysis and Design of Quasi Single Stage Buck Boost Inverter

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Abstract—In this paper, a new quasi single stage highly efficient buck boost inverter is presented. The structure of the inverter leads to the reduction of inductor shoot through current and dead time elimination. This is also capable of bidirectional power conversion and due to this, the body diodes of the switches can be avoided and the losses and reverse recovery issues is avoided. Due to the high frequency pwm switching phenomenon, the size of the inductors and capacitors are greatly reduced. The fuzzy logic control is replacing the existing PI controller so that the system can be adapted to transient changes in input voltage variations. The simulation is performed in MATLAB/Simulink software.

Key words—**dc-dc converters;Bidirectional converters;fuzzy logic control;single stage converters.**

I. INTRODUCTION

The current source inverters and voltage source inverters are the conventional type of inverters which only capable of only boost and only buck respectively. In voltage source inverters, due to EMI interference, shoot through problems arises. In current source inverter, open circuit issues are there due to EMI. To avoid those issues, we need dead time for VSIs and overlap time for CSIs in gating pulses. This causes power quality issues in output waveforms.

The load regulation is an important aspect in variable dc voltage sources especially with renewable energy sources such as PV, wind, etc., To maintain the constant load voltage with varying input voltage, two stage inverters are used. A dc-dc converter is cascaded with voltage source inverters can provide the necessary voltage regulation. But in boost converters, huge dc link capacitance is needed and in buck converter, the inductor will be bulky which leads to reduction in efficiency and also cause voltage and current stress which leads to increase in switching loss which further reduce the efficiency. This leads to the design of quasi z source inverters which can operate in both buck and boost modes. It can be done by the impedence network placed between source and the inverter. In this, the issues related to the EMI interference can be avoided. The drawback of these inverters are the limit in voltage conversion and switching losses due to higher voltage and current stress. It cannot be used in case of wide range of input voltage variation.

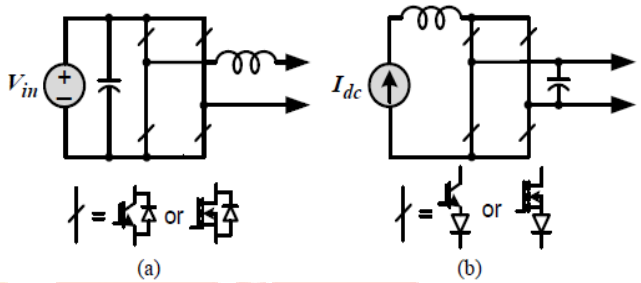

Fig 1 (a) Voltage source inverter, (b) Current source inverter

An active BBI was developed in which both buck and boost operations can be done but it needs snubber circuit in ac side to avoid commutation issues. This was rectified by introducing soft commutation technique but it increases complexity of control circuit as it needs to sense the polarity of the ac voltage and this reduce the reliability of the inverter.

The IGBTs are replaced with MOSFETs due to high frequency switching and reduced switching losses. But it risk failure due to reverse recovery of body diodes. The body diode issue was solved by introducing anti parallel diodes to the switches of dual buck inverter. This also eliminates the shoot through problems caused in VSIs. A boost converter is introduced with the above mentioned dual buck inverter which causes in increase of stages and also losses. The position of the buck and boost converter are interchanged results in reducing the number of passive elements used and also reduce the losses caused by them.

In this paper, a new quasi single stage buck boost inverter is introduced with bidirectional capability. It can provide regulated load voltage and also operates under wide range of input voltage variation. The operation of the proposed inverter is analyzed briefly along with the design of the parameters. The proposed inverter is operated under both boost and buck modes with PI and fuzzy controllers provide the much needed voltage regulation.

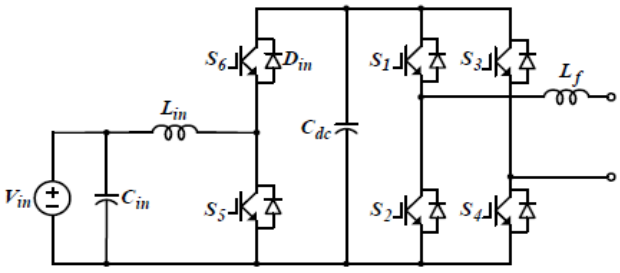

Fig 2 Two stage Conventional Boost Inverter

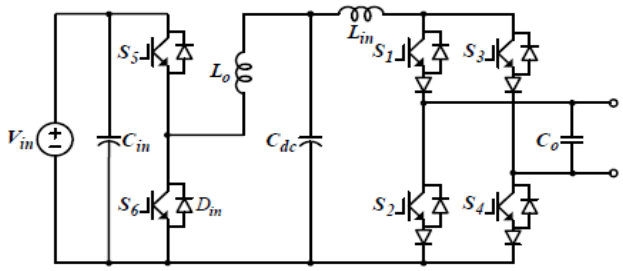

Fig 3 Two stage Conventional Buck Inverter

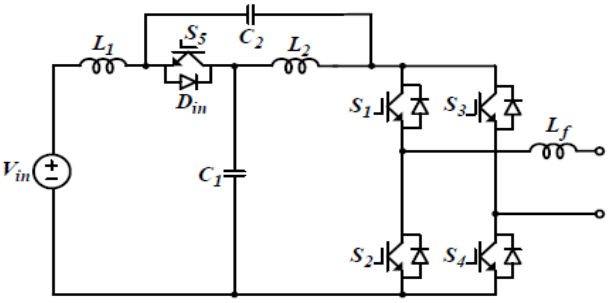

Fig 4Quasi Z-source Inverter

II.PROPOSED SINGLE STAGE BUCK BOOST INVERTER

The proposed inverter consists of MOSFETs coupled with external diodes in series, so that no shoot through current flow occurs.

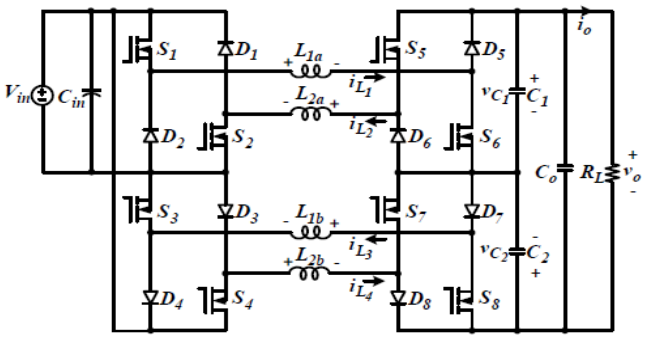

Fig 5 Proposed Buck Boost Inverter

The inductors in the proposed inverter will act as buck and boost inductors and also limits the current flow. When dead time occurs in gating pulses, the inductor currents will flow through the output capacitors. They will also reduce the inductor current ripples and act as filters.

The pulse generation circuit for the proposed inverter is provided below:

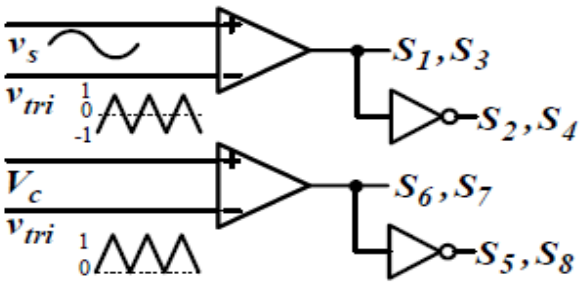

Fig 6 PWM pulse generation circuit for proposed inverter

The switches S1, S2, S3 and S4 will be turned ON and OFF by comparing the sine wave (M) with high frequency carrier wave and switches S5, S6, S7 and S8 will be turned ON and OFF by comparing a dc signal (D) with high frequency carrier wave.

The operation of the proposed inverter is provided below:

Buck mode of operation:

In this the input voltage (Vin) is higher than the load voltage (Vo). In this mode, S5 and S8 are ON and S6 and S7 will be OFF throughout the time.In this L1a and L1b operate in positive half cycle and L2a and L2b will operate in negative half cycle. The gating pulse waveforms of the proposed inverter in buck mode is provided below:

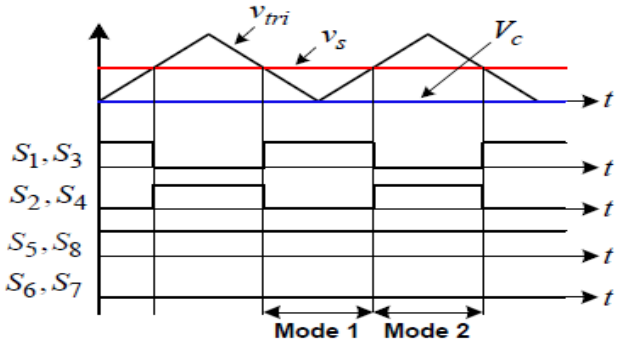

Fig 7 PWM pulses for proposed inverter in buck mode

The buck operation is divided into two modes which is explained below:

Mode 1:

In this, S1 and S3 are ON and S2 and S4 is turned OFF. The diodes D2 and D4 will not conduct in this mode. The inductor current in this mode is provided as

$$\Delta I_{L1} = \frac{V_{in} - V_o}{L}$$

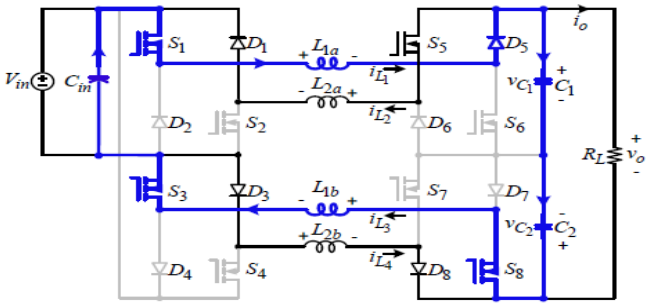

Fig 8.a Mode 1 of Buck operation and Mode 1 and 5 of Boost operation

Mode 2:

In this, S1 and S3 are OFF and S2 and S4 is turned ON.

The diodes D2 and D4 will starts conducting in this mode. It will freewheel the inductor currents which is provided as

$$\Delta I_{L1} = \frac{-V_{in} - V_o}{L}$$

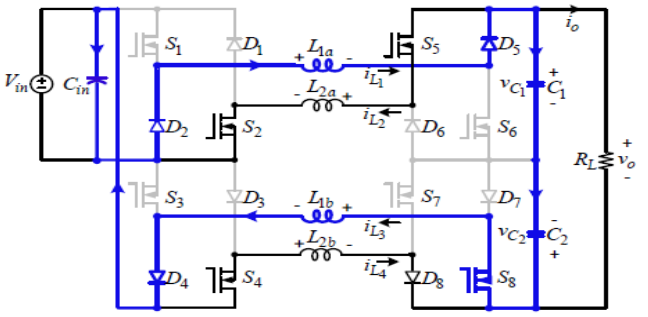

Fig 8.b Mode 2 of Buck operation and Mode 2 and 4 of Boost operation

Boost mode of operation:

In this the input voltage (Vin) is lower than the load voltage (Vo). In this L1a and L1b operate in series with the inductors L2a and L2b. The gating pulse waveforms of the proposed inverter in buck mode are provided below:

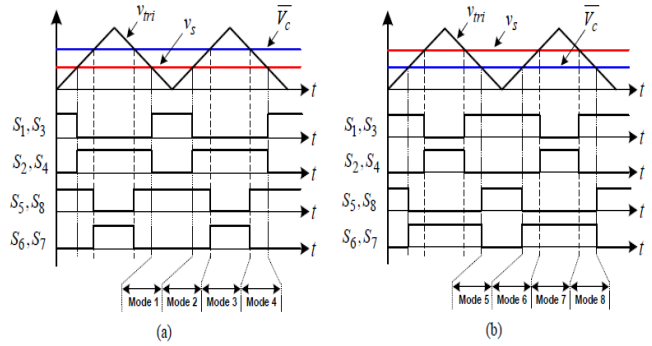

Fig 9 PWM pulses for proposed inverter in boost mode (a) Vin>Vo (b) Vin<Vo

The boost operational modes are explained below:

Mode 1 and 5:

The operation of proposed inverter under this mode is same as that of the operation of proposed inverter under Mode 1 of buck operation.

Mode 2 and 4:

The operation of proposed inverter under this mode is same as that of the operation of proposed inverter under Mode 2 of buck operation.

Mode 3 and 7:

In this, S1 S3 S5 and S8 are OFF and S2 S6 S7 and S4 is turned ON. The inductor current in this mode is provided as

$$\Delta I_{L1} = \frac{-V_{in}}{L}$$

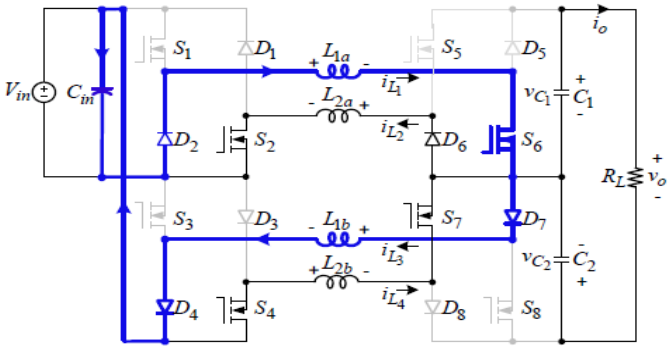

Fig 10.a Mode 3 and 7 of Boost operation

Mode 6 and 8:

In this, S2,S4, S5 and S8 are OFF and S1, S6, S7 and S3is turned ON. The inductor current in this mode is provided as

$$\Delta I_{L1} = \frac{V_{in}}{L}$$

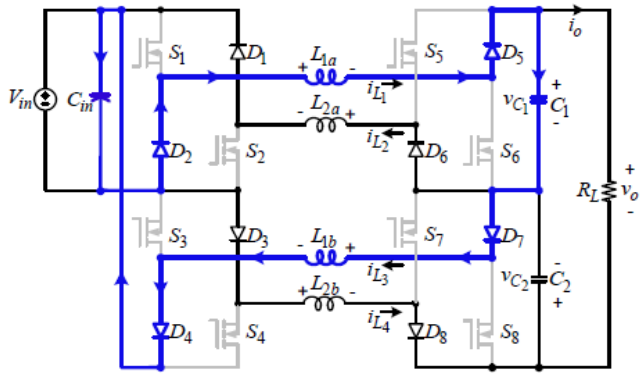

Fig 10.bMode 6 and 8 of Boost operation

Along with this modes, there are two other modes, named as overlap mode and dead time mode. In overlap mode, all the eight switches will be ON and the diodes are all reverse biased. The inductors will act as limiting inductors and hence shoot through current is avoided. In dead time mode, all the switches will be turned OFF and the capacitors will provide the path for the inductor current flow.

III. CLOSED LOOP CONROL

The proposed controller block diagram is shown below:

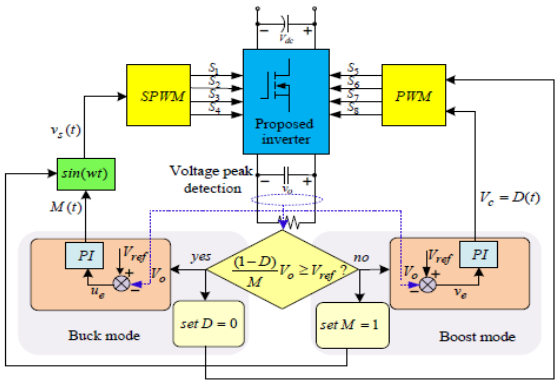

Fig 11Control circuit for proposed inverter

The reference voltage is compared with the measured load voltage and using that the mode of operation (buck or boost) is determined. The inverter function as boost inverter when Vo>Vin and the inverter function as buck inverter when Vo<Vin.

In buck function, Vo is compared with the Vref and the error signal generated is provided to the PI controller which generates the modulation index, M as provided below:

$$M(t) = k_p(V_{ref} - V_o) + k_i \int (V_{ref} - V_o)dt$$

In this mode, D = 0.

In boost function, Vo is compared with the Vref and the error signal generated is provided to the PI controller which generates the duty ratio, D as provided below:

$$V_c(t) = k_p(V_{ref} - V_o) + k_i \int (V_{ref} - V_o)dt$$

In this mode, M = 1.

The PI controller is replaced with the fuzzy control which provides smooth transition between buck and boost mode. The settling time of PI controller is higher than that of the fuzzy control and also the transient response of fuzzy control is much better than that of the conventional PI controller.

The process of fuzzy logic control is provided in the following block diagram,

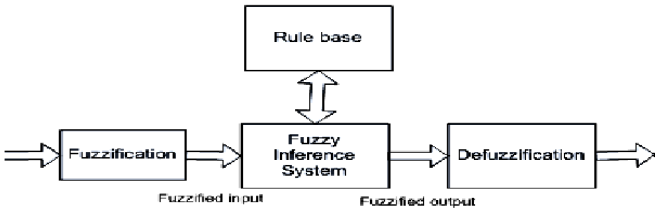

Fig 12 Internal process of Fuzzy Control circuit

IV.SIMULATION PARAMETER DESIGN AND SPECIFICATIONS

The proposed inverter specifications are tabulated below:

Table I Proposed Inverter Specifications

Input Voltage nominal (Vin)	180-400 V
Output Voltage nominal (Vo)	220 V
Load Power	1.1KW
Load resistance	45Ω
Switching frequency (Fsw)	30 Khz
Inductors(La1,La2,Lb1,Lb2)	0.46mH
Capacitors(C1,C2)	14μF

The inductor value can be calculated by the following equation:

$$L/2 = \frac{Vin*D}{\Delta Io*Fsw} = 0.46290548\text{mH}.$$

The inductor ripple current can be calculated using the following equation:

$$\Delta I_L = 0.2 * \frac{Vo}{V_{in}} * I_o = 0.55365349\text{A}$$

The output capacitance is given by the following equation:

$$Co = \frac{\Delta Ioc}{8 * Fsw * \Delta Vo} = 14.2963507uF$$

The capacitor ripple voltage can be calculated from the following equation:

$$\Delta Voc = \frac{\Delta Ioc}{8*Fsw*Cso} = 2.2199627222\text{ V}$$

The simulation circuit for the proposed buck boost inverter is provided below:

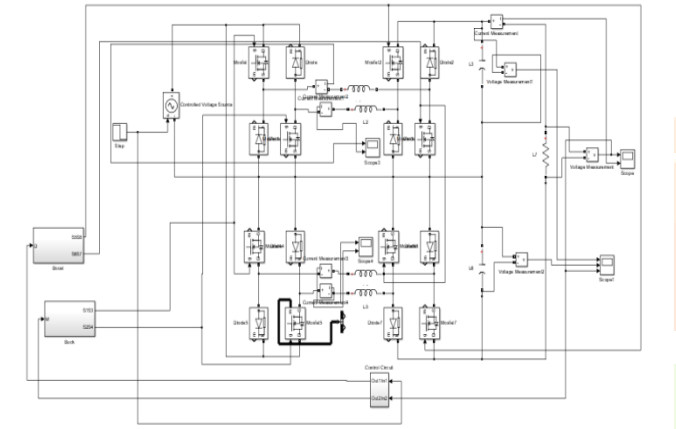

Fig 13 Simulation circuit of the proposed buck boost inverter

In this, the input voltage is varied from 180V to 400V at t=0.25s. The controller will sense any variation in the load voltage and regulate it by varying the modulation index and duty ratio in order to maintain constant load voltage.

The inductor current waveforms are shown in the following graph:

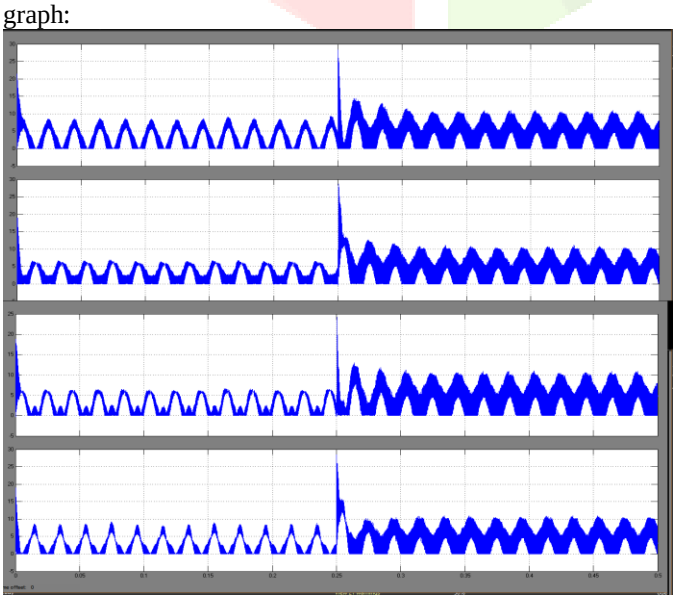

Fig 14 Inductor current of the proposed BBI

The capacitor voltage waveforms is provided in the following graph:

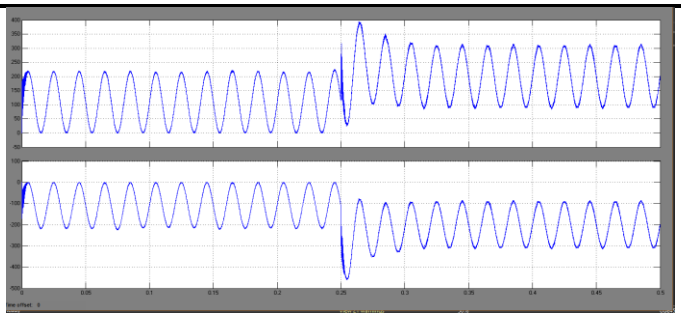

Fig 15 Capacitor voltages of the proposed BBI

The load voltage is obtained by adding the capacitor voltages. The load voltage and current with varying input voltage is provided in the following graph:

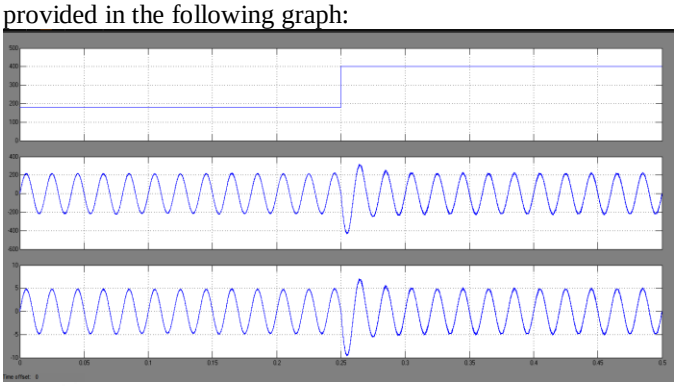

Fig 16 Load voltage and current of the proposed inverter with input voltage variation with PI controller

In this the input voltage varied from 180V to 400V and the load voltage, when the transient change occurs the peak overshot of 400V is occurred. This is due to the slow response of the PI controller. The PI controller is replaced with fuzzy controller. The load voltage and current waveforms with fuzzy controller in transient conditions is shown in the following graph:

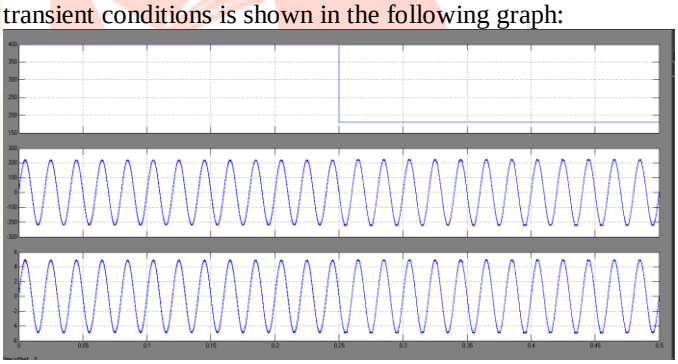

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Fig 17 Load voltage and current of the proposed inverter with input voltage variation with FUZZY controller

In this the load voltage experienced no disturbance unlike with PI controller when the input voltage suddenly changed.

The %THD of the load current with PI controller is provided below:

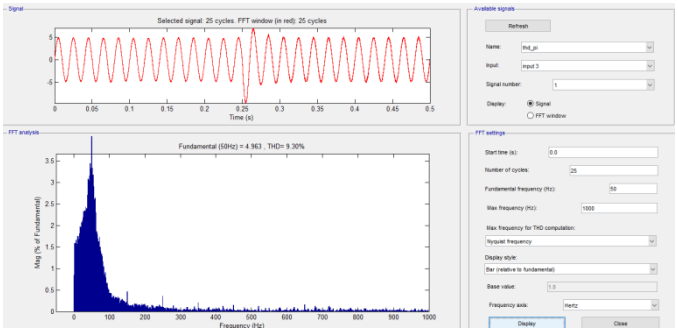

Fig 18 %THD of the load current with PI controller

The %THD for the load current of proposed buck-boost inverter with PI controller is 9.3%.

The %THD of load current with fuzzy logic controller is provided below:

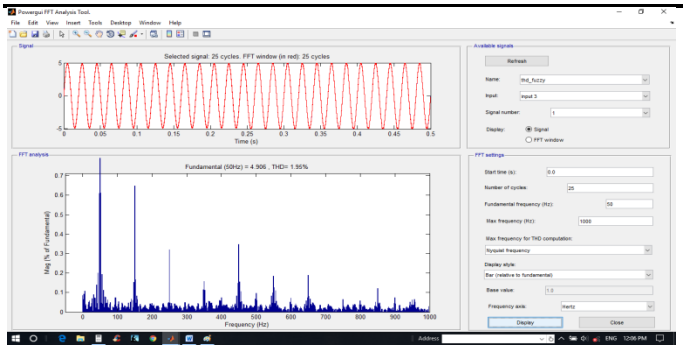

Fig 19 %THD of the load current with FUZZY controller

The %THD for the load current of proposed buck-boost inverter with fuzzy controller is 1.95%.

V.CONCLUSION

In this paper, the analysis and design of single stage buck boost inverter was done. The load voltage regulation is done and checked with input voltage variation. The proposed inverter is operated under both boost and buck modes with PI and fuzzy controllers provided the voltage regulation. The transient performance of both the controllers is noted and THD of load current is measured and compared for both controllers.

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