Studies On Switching Losses In Electric Vehicle Drive Train System

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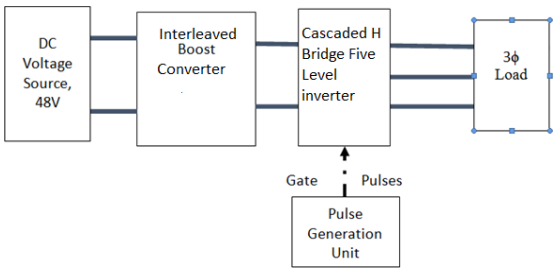
Abstract— The losses in a converter is an important aspect for the development of converters with performant features such as high reliability and efficiency, cost-effectiveness and high-power density. Power losses are generally controlled by modification of electric parameters in interleaved boost converter and cascaded H-bridge multilevel inverter. Battery-powered electric vehicle technology is gaining importance. In internal combustion engine vehicles power loss is more. EVs (Electric vehicle) use electric motor instead of an internal combustion engine. In order to reduce losses in EVs powertrain system is used. powertrain system comprises of interleaved boost converter and cascaded H bridge inverters. Interleaved boost converter is used to reduce the current stress and cascaded H-bridge multilevel inverter (MLI) is used to reduce the voltage stress. The analysis of power loss in each switch of interleaved boost converter and cascaded H-bridge multilevel inverter is investigated. The interleaved boost converter and cascaded H-bridge multilevel inverter model are developed, and simulated in MATLAB by using Simulink software. Simulation result indicate that a significant reduction loss is achieved by using interleaved boost converter and cascaded H-bridge multilevel inverter. A prototype model of hardware is implemented and the results are validated with simulation.

Keywords—Interleaved boost converter, cascaded H-Bridge MLI, power loss model.

1.INTRODUCTION

Battery-powered electric vehicle technology is becoming more significant in the modern era. Power electronic converters contain a significant amount of semiconductor components. Researchers are working to develop an effective and dependable powertrain system because the powertrain is responsible for transferring stored energy from the vehicle's battery system to the motors [1]. Power electronics inverters must operate distortion-free, electromagnetically compatible, have high-power factor and be extremely reliable while converting AC/DC. Compared to conventional silicon (Si) technology, wide band gap (WBG) semiconductor presently have higher-level material properties and have better performance in high power EV applications [2]. Policymakers & stakeholders are currently working on advance market share for electric cars. Power electronics experts are working to improve EV power electronic systems through increased power density and reducing cost to the system, size, and volume. The DC/AC inverter is the essential section in EV, controls the battery power as well as drives the electric motor. The development of converters with excellent reliability and efficiency, low cost, and high-power density depend on the losses of a converter. The modelling approach using software like LT spice or Saber is lengthy simulation period. By incorporating the small subintervals in the waveform duration of the inverter half bridge and also determining the transitional period for power dissipation, switching energies are estimated to use switch on, switch off, as well as rise and fall timings for both Ids (MOSFET (drain-source) current) and Vds (MOSFET (drain-source) voltage) [5]. Datasheet charts can be used to determine the electro thermal properties of MOSFETs. In this paper, an inverter model is proposed which represents the operational behavior of a real inverter. The proposed system involving interleaved boost converter and h-bridge inverter, which is subsequently translated to a multi level inverter enables pre and post-analysis of the system by modifying the operational switching frequency, circuit characteristics, and control architecture. Furthermore, the losses are measured and compared with conventional system. A prototype hardware model is implemented and verified with the results.

2.SYSTEM DESCRIPTION



The block diagram for the proposed system is provided in Fig 1:

Fig 1 : Proposed system configuration

In this, the dc voltage source is provided for interleaved boost converter in which the source voltage is getting boosted and provided to H-Bridges individually in the five level Cascaded H-Bridge Multi Level Inverter (CHBMLI) connected to R load. The losses are less in the above mentioned system compared to conventional system as the current stress in dc-dc converter switch is reduced due to interleaving of the converters and voltage stress across the inverter switches are reduced as it deals with only half the system voltage. Total power losses of the inverter, based on conduction loss and switching loss, are provided below:

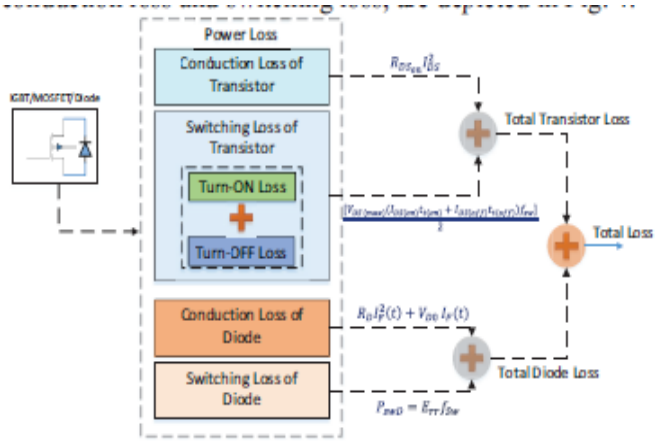


Fig 2: Power loss model of inverter

The conduction loss of the half-two bridge's switches is determined by internal on-state resistance and transient current, as shown in equation below:

$$P_{s1_{cond}} = \theta_{s1} R_{dson} I_x^2 \quad (30), \quad P_{s2_{cond}} = \theta_{s2} R_{dson} I_x^2$$

The conduction loss of the half-two bridge's diodes is determined by the internal resistance of the diode, the voltage drop across the diode, and the transient current, as shown in equation below

If, $I_x > 0$

$$P_{D1_{cond}} = (1 - \theta_{s1} - \theta_{s2}) I_x (V_{f0} + R_d I_x)$$
$$P_{D2_{cond}} = 0$$

Else, $I_x < 0$

$$P_{D1_{cond}} = 0$$
$$P_{D2_{cond}} = -(1 - \theta_{s1} - \theta_{s2}) I_x (V_{f0} - R_d I_x)$$

If the MOSFET is not conducting:

$$P_{s1_{cond}} = 0 \qquad P_{s2_{cond}} = 0$$

If, $I_x > 0$,
$P_{D1_{cond}} = I_x (V_{f0} + R_d I_x)$, $P_{D2_{cond}} = 0$
Else, $I_x < 0$
$P_{D1_{cond}} = 0$, $P_{D2_{cond}} = -I_x (V_{f0} - R_d I_x)$

The total power losses of conduction are described as:

$$P_{sw,cond_{total}} = P_{s1_{cond}} + P_{s2_{cond}}$$
$$P_{di,cond_{total}} = P_{D1_{cond}} + P_{D2_{cond}}$$
$$P_{total} = P_{sw,cond_{total}} + P_{di,cond_{total}}$$

The power loss equations during switching of the half-bridge are given as:

If, $I_x > 0$

$$P_{s1_{swon}} = 0 \quad , \quad P_{s1_{swoff}} = 0$$
$$P_{s2_{swon}} = f_s (E_{on_{1-2}} + E_{on_{2-3}})$$
$$P_{s2_{swoff}} = f_s (max(E_{off_{1-2}} + E_{off_{2-3}}))$$

Else, $I_x < 0$

$$P_{s1_{swon}} = f_s (E_{on_{1-2}} + E_{on_{2-3}})$$
$$P_{s1_{swoff}} = f_s (max(E_{off_{1-2}} + E_{off_{2-3}}))$$
$$P_{s2_{swon}} = 0 \quad , \quad P_{s2_{swoff}} = 0$$

Fs is the switching frequency. From all of the above equations of the switching loss, the total power losses of switching are described in equation:

$$P_{sw_{total}} = P_{s1_{swon}} + P_{s1_{swoff}} + P_{s2_{swon}} + P_{s2_{swoff}}$$

3.INTERLEAVED BOOST CONVERTER

The circuit of interleaved boost converter is provided in Fig 3.

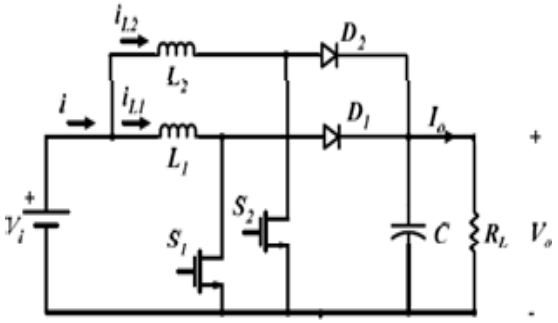


Fig 3: Circuit configuration of interleaved boost converter

When the device S1 is switched on, the current flowing through the inductor iL1 grows linearly. During this time, power is stored within the inductor L1. When S1 is switched off, diode D1 conducts and the energy stored in inductor slopes down with such a slope determined by the difference in input and output voltage. The inductor starts to discharge and the current is transferred to load via diodes. S2 is turned on after half a switching period of S1, completing a same cycle of operations. Because the output capacitor combines both power channels, the effective ripple frequency is double that of a single-phase boost converter. The input current ripple has a small amplitude.

The following equations are used to design the boost converter circuit parameters. The boost converter switch gate signal duty ratio is :

$$D = \frac{Vo - Vin}{Vo}$$

The following equation provides the inductor of a boost converter:

$$L = \frac{Vin - D}{\Delta Io * Fsw}$$

The inductor ripple current is:

$$\Delta L = 0.2 * \frac{Vin}{\text{Vin}} * Io$$

The output capacitance of the boost converter is:

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

The output capacitor ripple voltage is determined by using

$$\Delta \text{Voc} = 2\% \text{ of Vo}$$

4. FIVE LEVEL CHBMLI INVERTER

Multilevel Inverters (MLI) are popular and available in hundreds of thousand inverters are available worldwide. Multilevel inverter have several benefits as well as capabilities. Cascaded H Bridge inverter is one of them (CHB). Overall, the CHB multilevel inverter's advantage is on improving output signal performance and elimination of higher possibility of power device failure. The specified single phase 5-level CHBMLI is shown in Fig 4.

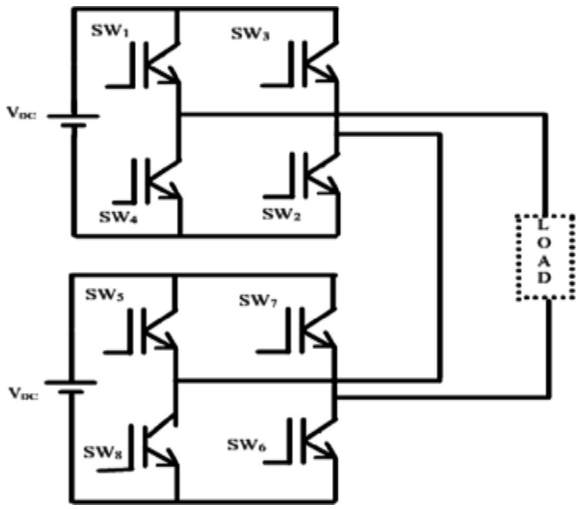


Fig 4: Five level CHBMLI

Multilevel inverters have been created as a means of overcoming drawbacks of conventional inverters. They have some impressive features, including the ability to generate output voltage and current with least amount of distortion and ability to operate at low switching frequencies.

As a result of multiplying its input voltage source (Vdc), the single phase 5-level CHBMLI produce five steps of output, including 2Vdc, Vdc, 0, -Vdc, and -2Vdc. The resulting AC output voltage swing across zero level from +2Vdc to -2Vdc. The function of Multilevel inverters are determined by the switch-close and switch-open states of each semiconductor device. The inverter's output value is determined by the switching state configurations. There are five possible configurations for the switching state in the five-level CHBMLI. Each configuration output voltage can be explained as:

a) Mode 1:

In this operation the S1, S2, S5, S6, are closed, hence the output voltage is 2 time of Vdc

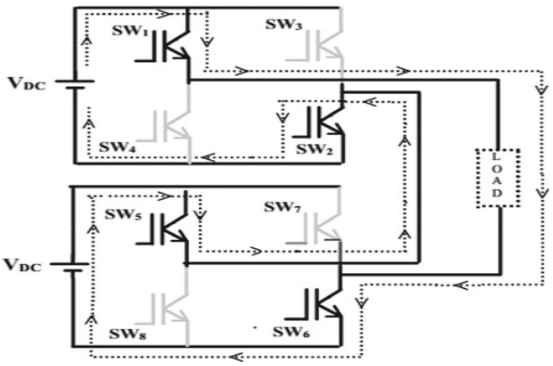


Fig 5: Mode 1 equivalent circuit of 5 level CHBMLI

b) Mode 2:

In this operation the S1, S2, S6, S8, are closed, hence the output voltage is Vdc.

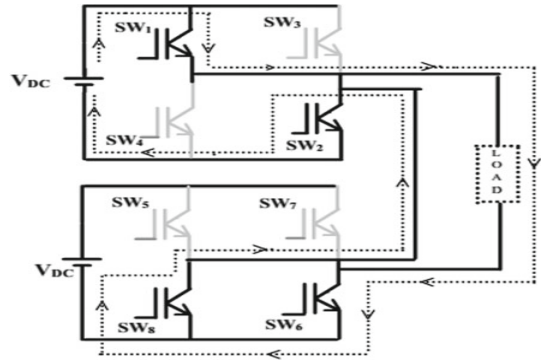


Fig 6: Mode 2 equivalent circuit of 5 level CHBMLI

c) Mode 3:

In this operation the S2 S4, S6 S8 are closed, hence the output voltage is 0 volt.

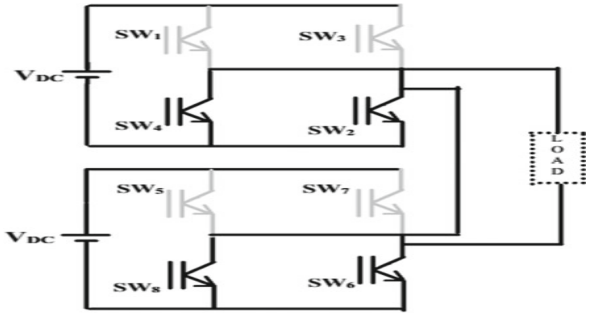


Fig 7: Mode 3 equivalent circuit of 5 level CHBMLI

d) Mode 4:

In this operation when S3 S4, S6 S8, are closed, hence the output voltage is –Vdc (negative polarity)

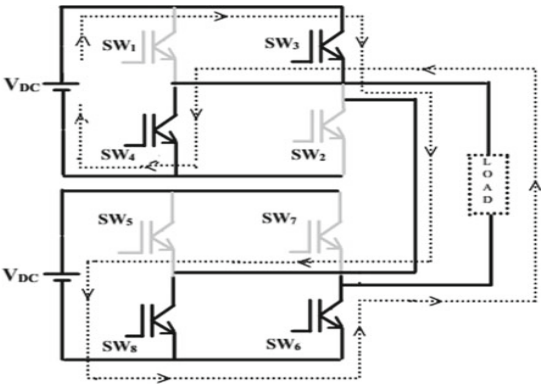


Fig 8: Mode 4 equivalent circuit of 5 level CHBMLI

e) Mode 5:

In this operation when S3 S4, S7 S8, are closed, hence the output voltage is 2 time of –Vdc (negative polarity).

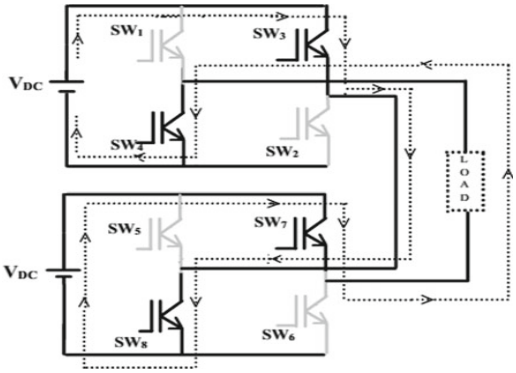


Fig 9: Mode 5 equivalent circuit of 5 level CHBMLI

5. SIMULATION & HARDWARE RESULTS

The simulation circuit for the conventional single phase inverter is provided in Fig 10:

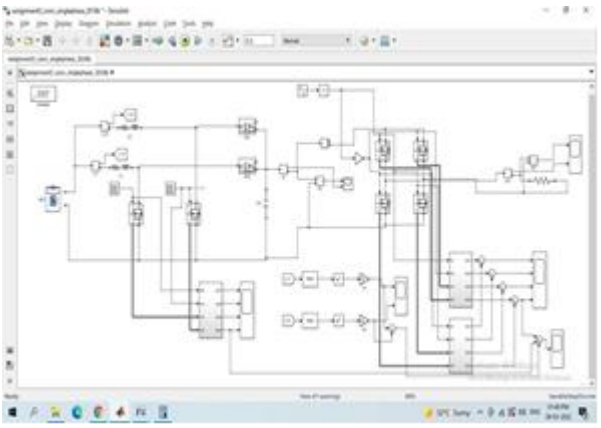


Fig 10: Simulation circuit of conventional system

The single phase H-Bridge inverter in this system uses a battery with 12V DC voltage source that is increased to 48V by an interleaved boost converter. At each stage, the losses are calculated and total losses are computed. Fig 11 represent interleaved boost converter output voltage and current.:

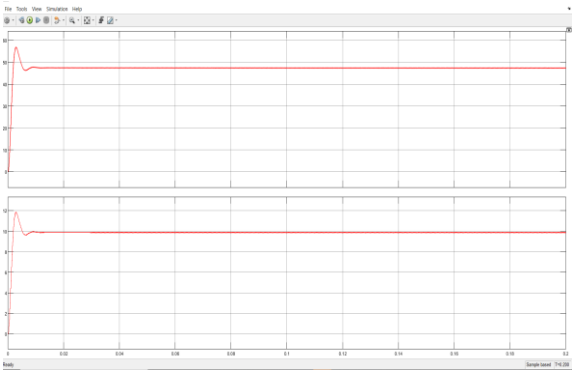


Fig 11: Interleaved boost converter voltage and current

The output voltage is 48V and current is 11A. The Interleaved boost converter switch losses are provided in Fig 12:

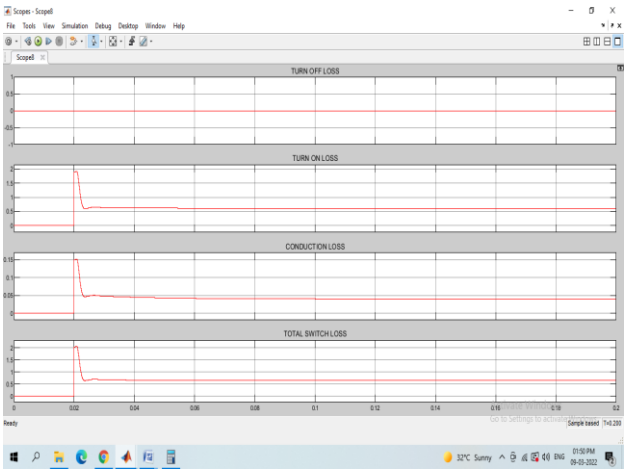


Fig 12: Switching losses of Interleaved boost converter

The boost converter total switching loss is 0.65W. The inverter voltage and current is shown in Fig 13.

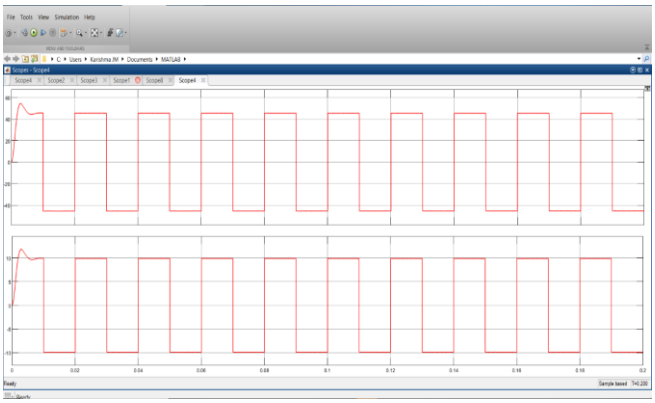


Fig 13: Inverter voltage and current

The output voltage is around 48V and current is around 10A. The inverter switch losses are provided below:

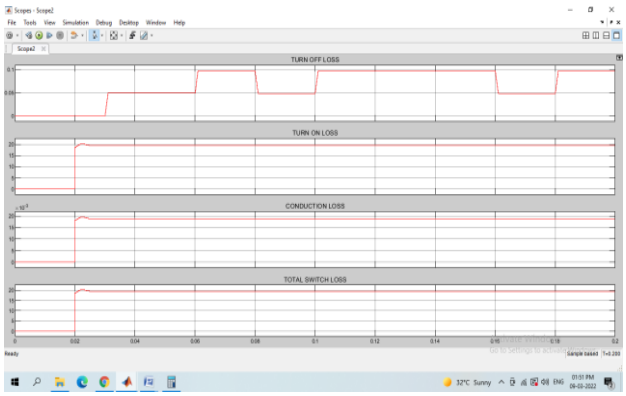


Fig 14: The inverter switch losses

The total switch loss for inverter is around 19.5W. The overall switching losses including inductor core loss are provided in Fig 15:

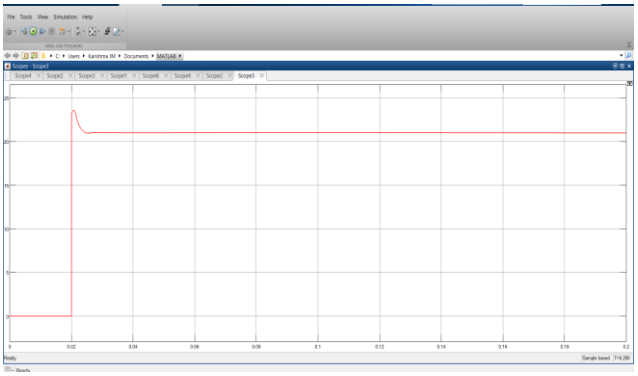


Fig 15: Switching losses of conventional system

The total losses are around 21W. The simulation circuit for the conventional three phase inverter is provided in Fig 16:

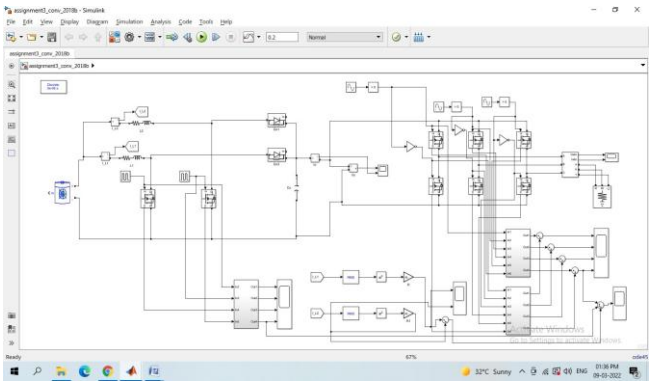


Fig 16: Simulation circuit of conventional three phase system

12V DC is boosted to 48V by the interleaved boost converter and provided to the three phase inverter. The losses are calculated at each stage and sum of the losses are computed.

Fig 17 show the output voltage and current of the interleaved boost converter:

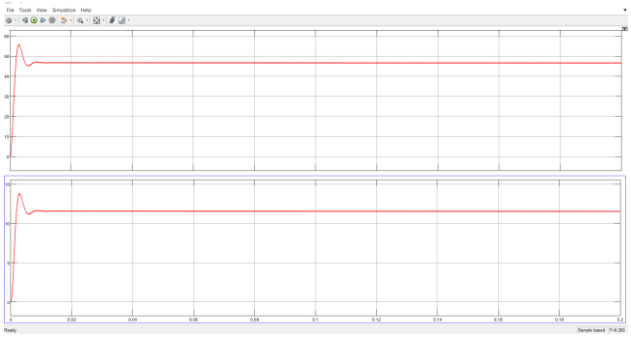


Fig 17: Interleaved boost converter output voltage and current

Output voltage is around 48V and current is around 11A. The boost converter switch losses are provided in Fig 18.

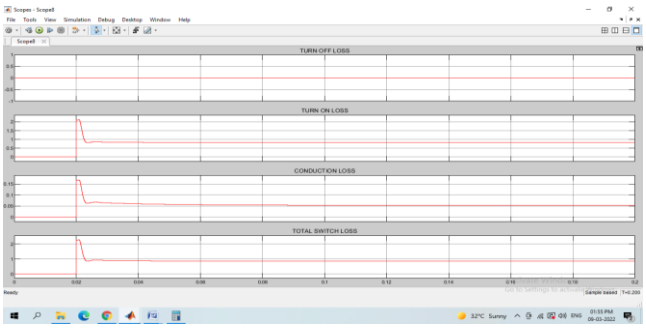


Fig 18: Switching losses of Interleaved boost converter

The boost converter total switch loss is 0.875W.

Fig 19 provide the inverter voltage and current:

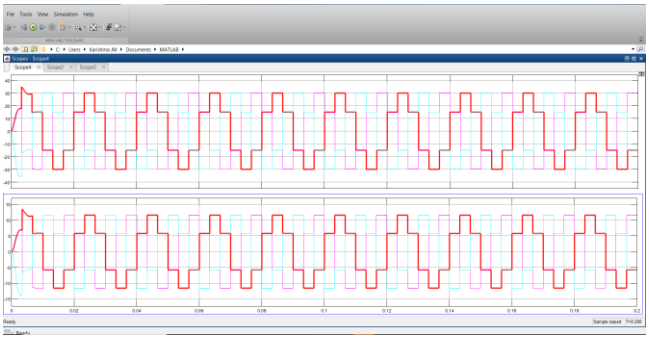


Fig 19: Inverter load voltage and current of three phase system

The output voltage is around 30V and current is around 11A. The inverter switch losses are provided in Fig 20:

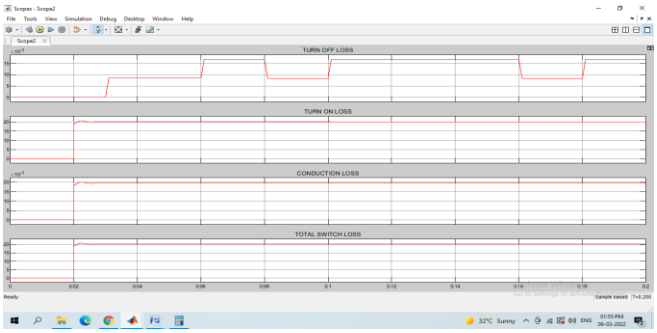


Fig 20: Inverter Switching losses

The total switch loss for inverter is around 20.1W. The overall switching losses including inductor core loss in Fig 21:

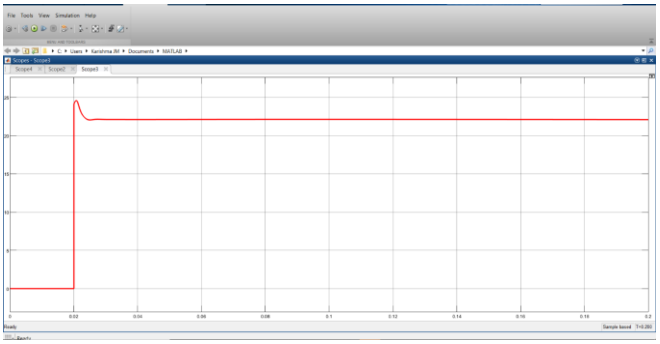


Fig 21: Overall switching losses including inductor core loss

The total losses are 22.1W. The simulation circuit for the proposed single phase 5 level CHBMLI is provided in Fig 22:

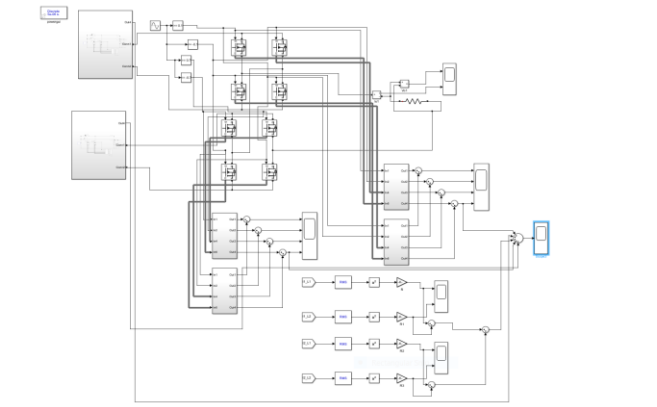


Fig 22: Simulation circuit of proposed system

The battery of 12V is provided as source and it is boosted to 24V by the interleaved boost converter and provided to H-Bridge and output voltage of cascaded H-Bridge inverter is 48V. The losses are calculated at each stage and the sum of the losses are computed. Fig 23 show the output voltage and current of interleaved boost converter.

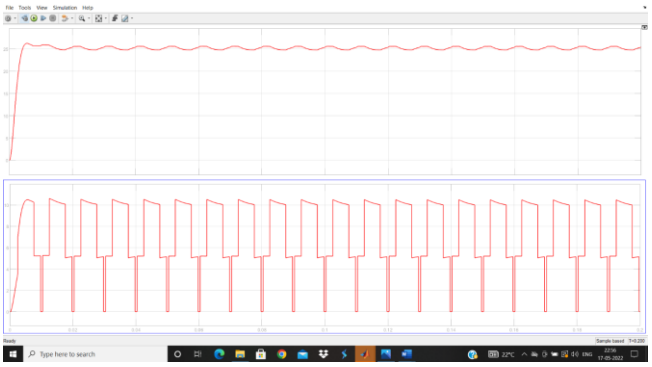


Fig 23: Interleaved boost converter voltage and current

The output voltage is around 25V and current is around 11A. The interleaved boost converter switching losses are provided Fig 24:

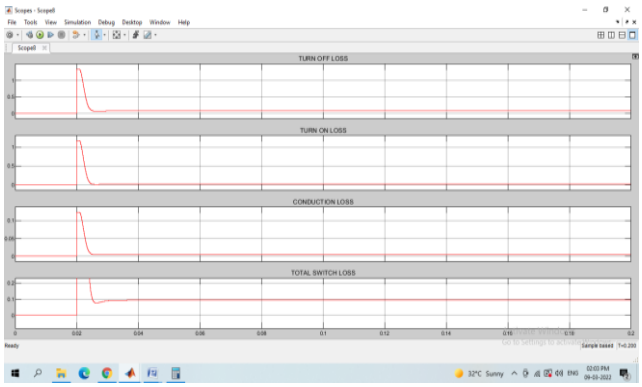


Fig 24: Switching losses of Interleaved boost converter

The boost converter switching loss is 0.1W.

The inverter voltage and current is shown in Fig 25.

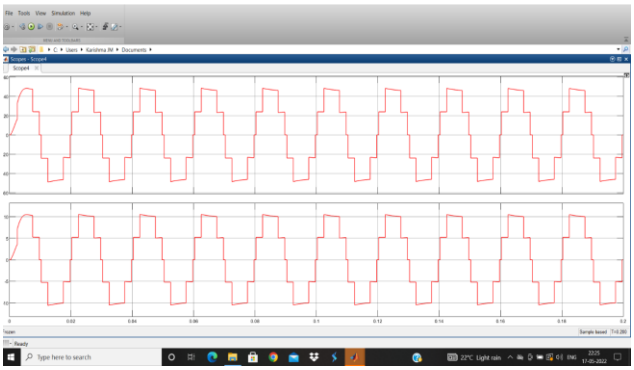


Fig 25: Inverter load voltage and current

The inverter output voltage is 48V and current is 10A. The H-Bridge switching losses are shown in Fig 26.

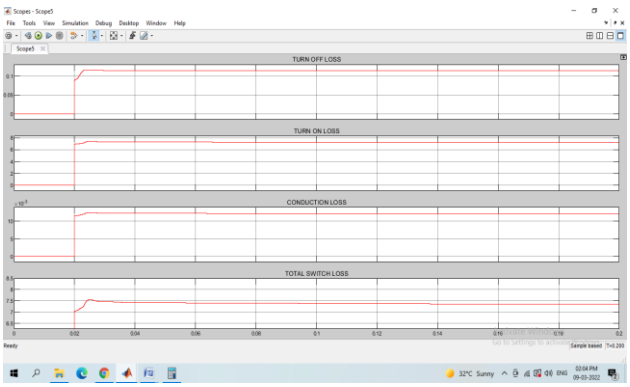


Fig 26 : Switching losses of 5 level inverter

The total switch loss for inverter is 7.5W. Fig 27 represent the overall switching losses including inductor core loss.

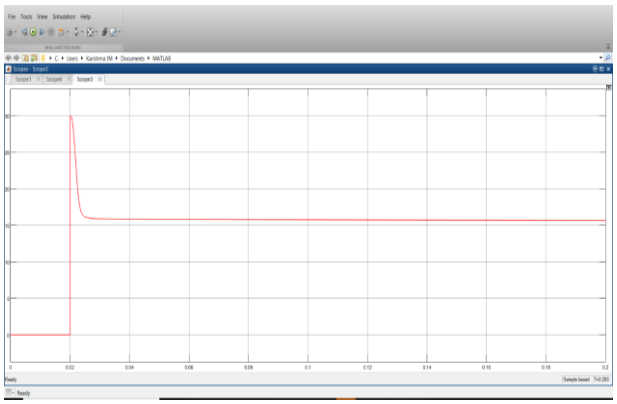


Fig 27: overall switching losses of proposed system

The total losses are 15.75W.

6. Hardware Implementation

A single phase AC supply of 230V, 50Hz is stepped down to 12 V and converted to 12 V DC using a diode rectifier. The rectified dc voltage is provided to 5V and 12V Voltage regulator. 5 V supply Arduino micro controller which generates the pulses according to the control strategy. 12 V to driver circuit to drive Power Electronic switches of the proposed inverter. It can be designed by connecting two single phase bridge converters in cascade on load side. The interleaved boost converter boost DC voltage from 12 V to 24 V to s supply two H-Bridge converters. The load voltage is around 48 V. Fig 28 show the hardware implementation.

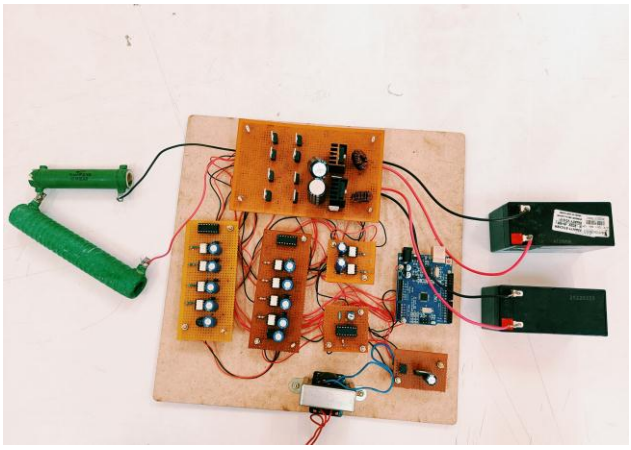


Fig 28 : Hardware circuit of proposed system

A 230 V / 12 V, 0.75A stepdown transformer supply the switching circuit, controller, Pulse width modulation (PWM), signal generator and driver circuits. Rectified voltage is supplied to Arduino and driver IC TLP 250 and 5V regulator from which the buffer IC.

Arduino Atmega328 generate 50 Hz square wave, control all the signals, and provide the gate signal to the MOSFET drivers that drive the switches. PWM IC TL494 is used for providing pulses to boost operation. The generated pulses are provided to buffer IC which isolates the driver circuit components and the controller. The output of buffer IC and the driver IC trigger the switches according to pulses.

The load voltage of the five level inverter is shown in Fig 29:

Fig 29 : 5 level Inverter voltage

The first level is around 24V and second level is around 24V which provides the peak ac load voltage as 48V. We get the five levels as +48V, +24V, 0, -24V and -48V.

7. CONCLUSION

A power conversion system with boost converter and inverter is designed for providing power to single phase and three phase loads of 500 W from battery source. In order to reduce the current stress across the boost converter switch, the interleaving concept is used and the power losses were measured. Further by use of cascaded structure inverter topology, the voltage stress across the inverter switches are reduced and corresponding power losses were measured. The total power loss for conventional single phase inverter system is 21W and conventional three phase inverter losses is 22.1W. The losses with cascaded structure of multilevel inverter is 15.75W. The percentage of reduction of losses is around 25.1%. The simulation for the proposed system is carried out for a power rating of 500W.

A power conversion system with boost converter and inverter is designed and implemented for providing power of 150 W to single phase . Due to cost considerations, a prototype hardware is implemented for the proposed system. In the implemented hardware system, the power loss is 14 W.

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