DESIGN AND ANALYSIS OF MULTIDEVICE INTERLEAVED DC-DC BIDIRECTIONAL CONVERTER

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Abstract - This paper deals with thedesign and analysis of Multidevice Interleaved DC-DC Bidirectional Converter (MDIBC)for Electric Vehicles (EVs)with respect to output power, device count, switchingfrequency, losses, efficiency, consistency. This is the one of the most suitable converter topology forhigh-power EVs (>10 kW), due to its low current ripple at the input, low voltage ripple at the output, reduced electromagnetic interference, bidirectionality, high efficiency and high reliability. For low-power EVs (<10kW), it is hard to propose a single type that suits in all probableaspects. We compare different converter topologies to recommend the optimum converter design for the EV on the basis of switching frequency, efficiency and ripple factor with MATLAB simulation.
Keywords - MDIBC, Converter topology, Efficiency, Ripple factor, MATLAB.

I. INTRODUCTION

The electric and hybrid vehicle market has been increasing over the years and is continuing to raiseeveryday. Influenced by both government regulations and customer demand, automobile manufacturers have continued to pursue technologies to increase efficiency and fuel economy. EVs have low maintenance cost and low running cost, they do not emit much sound, they are convenient to charge, easy to drive and more over they are environment friendly as they do not require any type of fuel to run. Therefore, to meet the current demand and to provide a highly efficient and reliable EV this type of topology is proposed. In order to meet the increasing demand, EVs are designed using MDIBC type of topology to attain higher efficiency and reliability and also to make it cost efficient.

II. MDIBC

MDIBC is a multi-port multi-phase interleaved converter which employs two high frequency switching devices per phase connectedacross two more switches, and phase interleaving technique is used.Multi-device Interleaved DC-DC Bidirectional Converter (MDIBC) provides high efficiencyand reliability, low current stress on switches, low input ripple current and low output ripple voltage [1,6]. In hybrid EVs converteris present between the fuel cell and the powertrain [2]. Design of bidirectional isolated DC-DC converter can be used with phase-shift and duty cycle controlin fuel cell hybrid EVs. It mainly focuses on minimizing the number of switches [3]. A multi-device converter with interleaved control to reduce the input ripple current, output ripple voltage, and reduced size of passive elements with high efficiency is proposed [4,7]. One of the ways to reduce passive components size is by increasing the switching frequency.To achieve this phase-shift interleaved control is proposed. This will double the ripple frequency of the inductor current and the switching frequency. This delivers a higher bandwidth and results in faster dynamic response [5].

III. COMPARISION OF DIFFERENT CONVERTER TOPOLOGIES

A. Boost Converter

A boost converter is a DC-DC power converter which gives higher output voltageand at the same time stepping down the input current. It is a type of Switched Mode Power Supply (SMPS).

DESIGN OF L AND C FOR BOOST CONVERTER:

Design Specifications:

Input Voltage (V_{in}) = 200 V.
Output Voltage (V_{out}) = 400 V.
Switching Frequency (f_{sw}) = 20kHz.
Inductor Current (I_L) = 250 A.
Inductor Current ripple (ΔI_L) = 5% of Inductor Current (I_L).
= 5% of 250 A.
= 12.5 A.
Output Voltage ripple = 1% of V_{out}
= 1% of 400 = 4V.
Output Power = 30kW.

Duty cycle of converter is

$$D = 1 - \frac{V_{in}}{V_{out}}$$

$$= 1 - \frac{200}{400}$$

= 1-0.5

D = **0.5**

Inductor value can be calculated as

$$L > \frac{V_s \times D}{f_{sw} \times \Delta I_L}$$

$$= \frac{200 * 0.5}{20 * 10^3 * 12.5}$$

L **= 400µH.**

We know that,Power = $Vo*I_o$
$30 * 10^3 = 400*I_o$

I_o = **75A**.

Capacitorvalue canbe calculatedas:

$$C = \frac{I_{o(max)} \times D}{f_{sw} \times \Delta V_c}$$

$$= \frac{75*0.5}{20*10^3*4}$$

= 468.75µF

ConsideringStandardvalueofCapacitor
C**=680µF**

TakingRload
R**= 39Ω.**

Note: *We take the values of R, L an C components as per the market standards and it varies for every topology design values*

L=400µH, C=680µF, Input Voltage= 200V, R=5Ω

$$Efficiency = \frac{29.66kW}{30.9kW} * 100 = 95.98\%$$

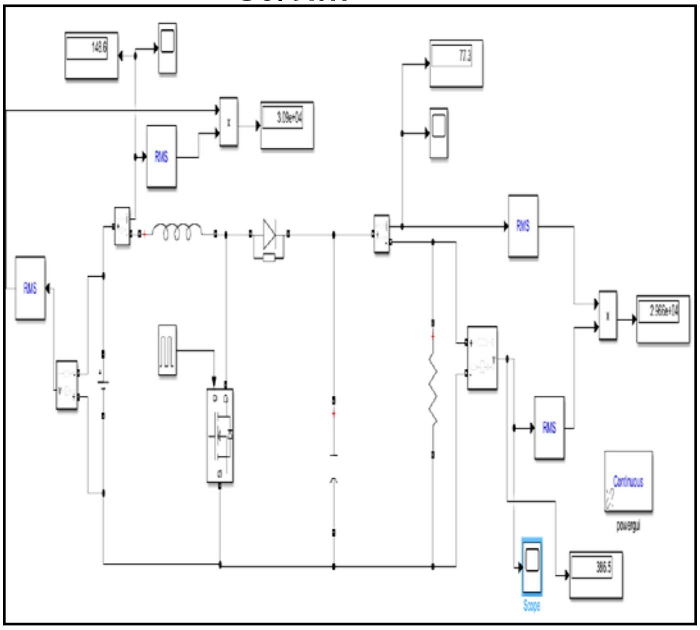

Figure 1: Boost Converter connected to Inverter with R load

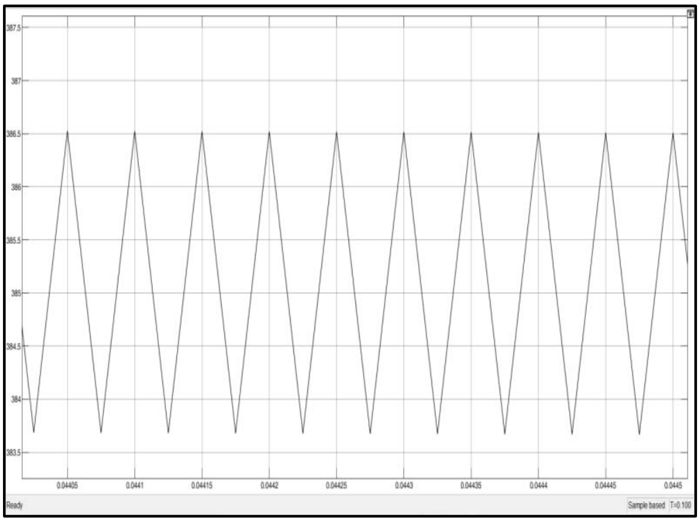

Figure 2: Voltage Ripple waveform (Voltage vs Time)

$$\boldsymbol{Voltage\ Ripple} = \frac{\mathbf{386.5 - 383.6}}{\mathbf{386.5}} \times \mathbf{100} = \mathbf{0.750\%}$$

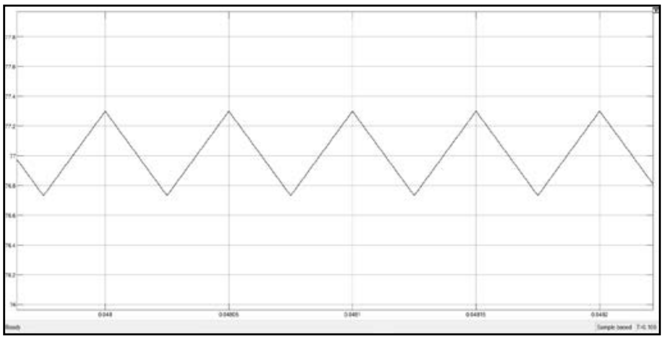

Figure 3: Current Ripple waveform (Current vs Time)

$$\boldsymbol{Current\ Ripple} = \frac{\mathbf{77.3 - 76.73}}{\mathbf{77.3}} \times \mathbf{100} = \mathbf{0.737\%}$$

L=180μH C=150μF Input Voltage= 200V R=5Ω

$$\boldsymbol{Efficiency} = \frac{\mathbf{29.66}\boldsymbol{kW}}{\mathbf{30.9}\boldsymbol{kW}} * \mathbf{100} = \mathbf{95.98\%}$$

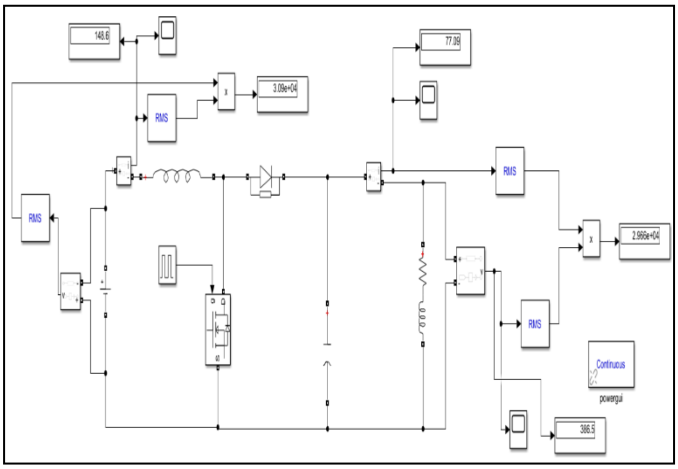

Figure 4: Boost Converter connected to Inverter with RL load

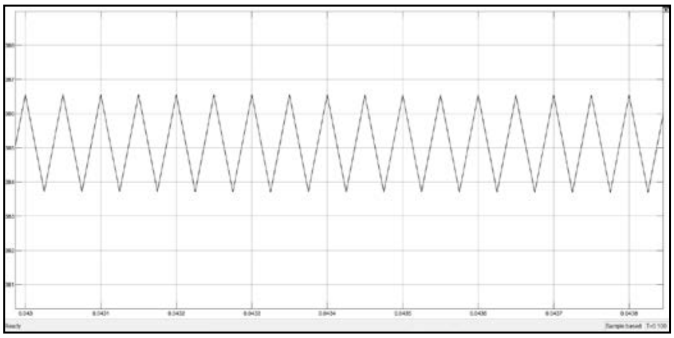

Figure 5: Voltage Ripple waveform (Voltage vs Time)

$$\boldsymbol{Voltage\ Ripple} = \frac{\mathbf{386.55 - 383.7}}{\mathbf{386.5}} \times \mathbf{100} = \mathbf{0.737\%}$$

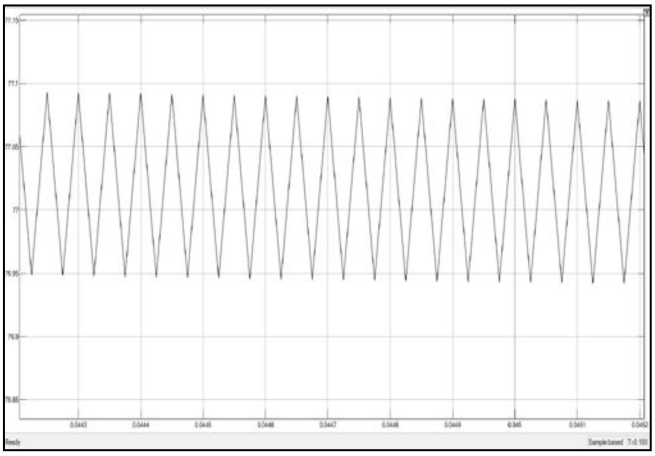

Figure 6: Current Ripple waveform (Current vs Time)

$$\boldsymbol{Current\ Ripple} = \frac{\mathbf{77.09 - 76.95}}{\mathbf{77.09}} \times \mathbf{100} = \mathbf{0.1816\%}$$

B. Interleaved Boost Converter

Interleaved Boost DC-DC Converter has improved performance in comparison with the conventional boost converter due to its improved efficiency, reduction in size and better reliability. In this converter four identical inductances are used (L1, L2, L3, L4), having separate magnetic core. The interleaving technique permits the size reduction of input inductor and output capacitor. Each level of the step-up converter share the samequantity of current which is supplied by the source. As the control signals are interleaved and the phase angles is 360^0/N, the total current frequency is N times higher than the switching frequency.

Note: *In Interleaved Boost Converter the values of L and C are reduced by 4 times as that of the calculated values of Boost Converter due to the design of 4 stageconverter.*

L=100μH C=180μF Input Voltage= 200V R=5Ω

$$\boldsymbol{Efficiency} = \frac{\mathbf{31.34}\boldsymbol{kW}}{\mathbf{32.31}\boldsymbol{kW}} * \mathbf{100} = \mathbf{96.99\%}$$

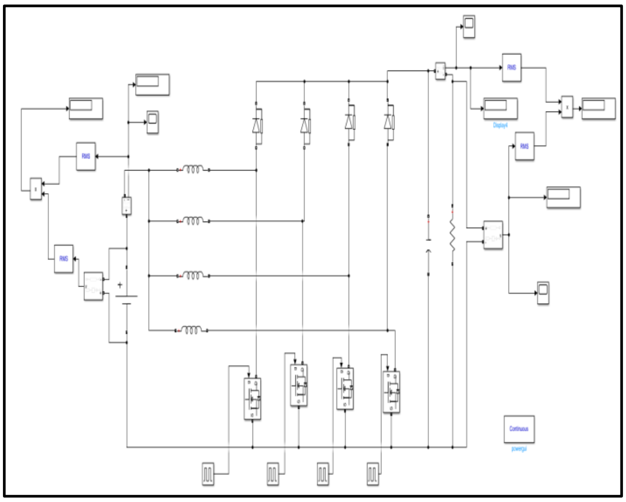

Figure 7: Interleaved Boost Converter connected to Inverter with R load

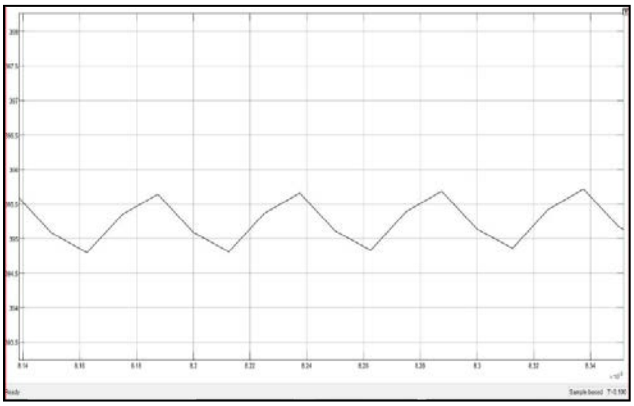

Figure 8: Voltage Ripple waveform (Voltage vs Time)

$$\boldsymbol{Voltage\ Ripple} = \frac{395.65-394.32}{395.2} 100 = 0.336\%$$

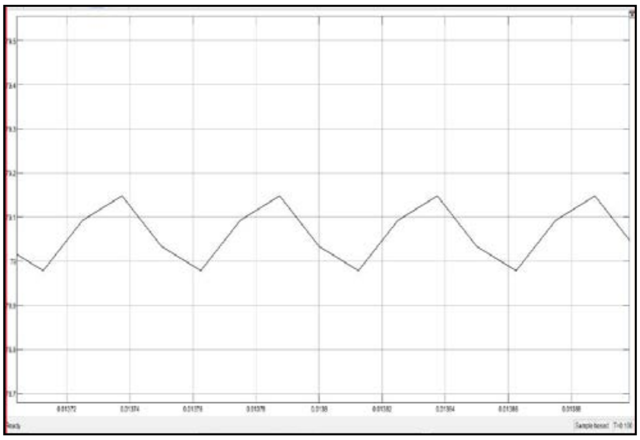

Figure 9: Current Ripple waveform (Current vs Time)

$$\boldsymbol{Current\ Ripple} = \frac{79.16 - 78.98}{79.03} \times 100 = 0.227\%$$

L=100µH C=180µF Input Voltage= 200V R=5Ω L=40µH

$$\boldsymbol{Efficiency} = \frac{31.34kW}{32.31kW} * 100 = 96.99\%$$

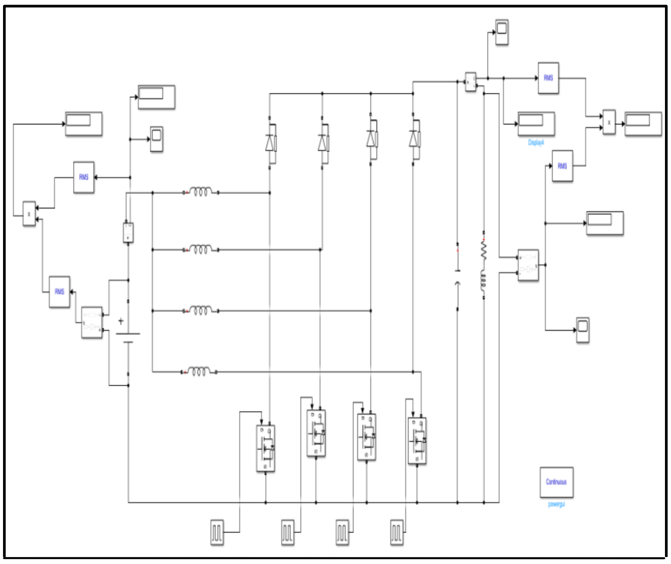

Figure 10: Interleaved Boost Converter connected to Inverter with RL load

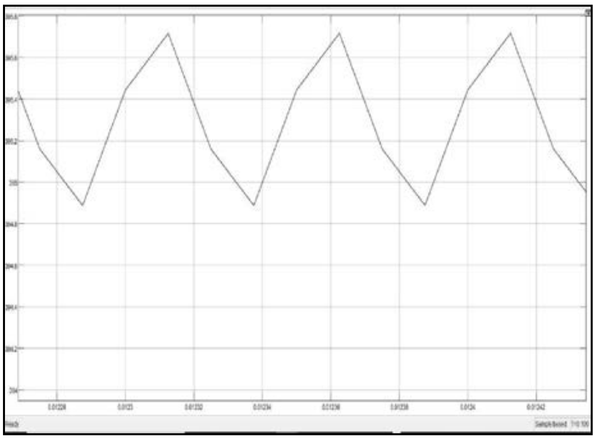

Figure 11: Voltage Ripple waveform (Voltage vs Time)

$$\boldsymbol{Voltage\ Ripple} = \frac{395.74 - 394.9}{395.4} \times 100 = 0.212\%$$

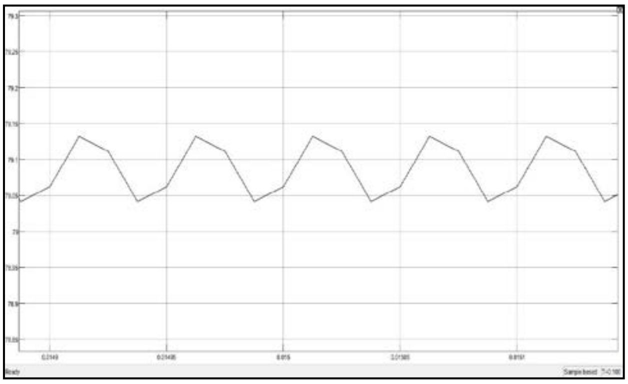

Figure 12: Current Ripple waveform (Current vs Time)

$$\boldsymbol{Current\ Ripple} = \frac{\mathbf{79.13 - 79.042}}{\mathbf{77.06}} \times \mathbf{100}$$
$$= \mathbf{0.114}\%$$

C. Multi Device Interleaved Boost Converter (MDIBC)

In high power auto applications, converter requires transformer but it increases itsheaviness, hence MDIBC is proposed for EVs. It consists of two high frequency switching devices in each phase which is connected across two more switches and utilizes phase interleaved technique. By adding more number of parallel phases, the size of the devices per phase can be decreased. The component size can also be reduced by using higher switching frequency and interleaving technique. Its main feature is division of current among multiple phases. The gate signals are used to reduce the input current ripples. It adds the power of multiple sources at the input to give a constant voltage output, maintaining therequired level of input ripple current and output ripple voltage without increasing the value of the components. MDIBC is used in high power and high voltage single port application. In MDIBC, the device count is high, converter has sensibility and stability issue due to changes in load current profile, and it is challenging to assess the features at transient and steady state condition, but to meet the existing demand and to provide a highly efficient and reliable EV this type of topology is proposed. Hence in our work we have proposed this type of topology which will prove that it is better than other converter topologies.

DESIGN OF L AND C FOR BOOST MDIBC:

$$D_{max} = \frac{1}{m}\left(1 - \frac{V_{in}}{V_{out}}\right)$$

Where, m=number of parallel switches per phase = 2

$$D_{max} = \frac{1}{2}\left(1 - \frac{200}{400}\right)$$

$$D\boldsymbol{max} = \mathbf{0.25}$$

$$L = \frac{V_{out} \times (1 - mD) \times D}{N \times f_{sw} \times \Delta IL_{max}}$$

$L = 166.667\mu H$

Selecting standard value,
L= $\mathbf{180}\mu\boldsymbol{H}$

$$C = \frac{V_o \times D}{N \times f_{sw} \times R \times \Delta V_o}$$

$C = 104.16\mu F$

Selecting standard value,
C = $\mathbf{150}\mu\boldsymbol{F}$

L=180µH C=150µF R= 5Ω Input Voltage= 200V

$$\boldsymbol{Efficiency} = \frac{\mathbf{31.28}\boldsymbol{kW}}{\mathbf{31.99}\boldsymbol{kW}} * \mathbf{100} = \mathbf{97.78}\%$$

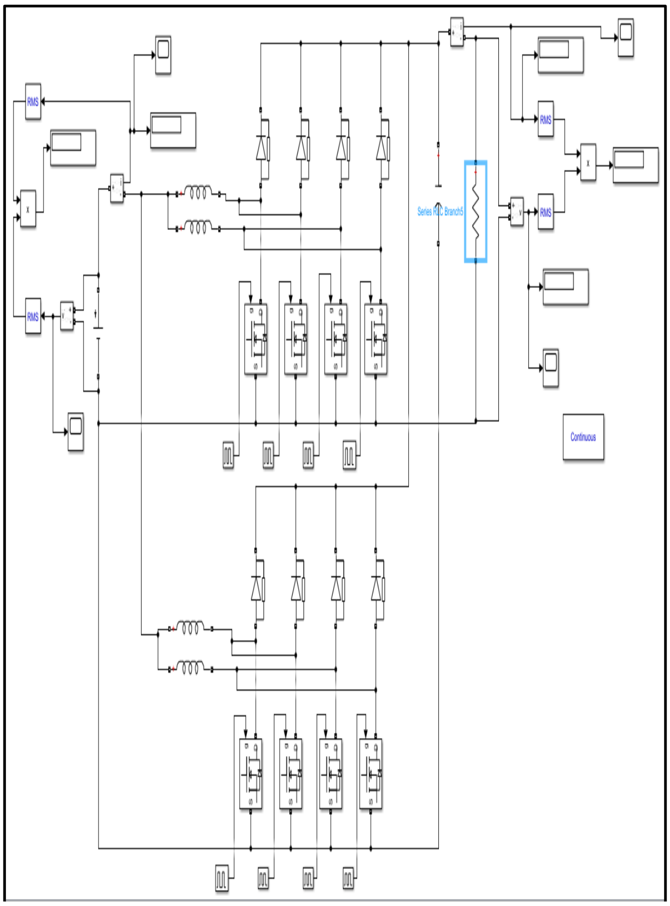

Figure 13: Multi Device Interleaved Boost Converter connected to Inverter with R load

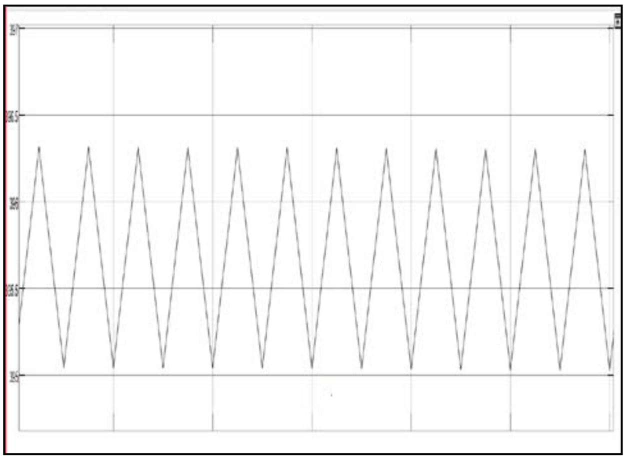

Figure 14: Voltage Ripple waveform (Voltage vs Time)

$$\boldsymbol{Voltage\ Ripple} = \frac{\mathbf{396.4 - 395.1}}{\mathbf{395}} \times \mathbf{100} = \mathbf{0.329\%}$$

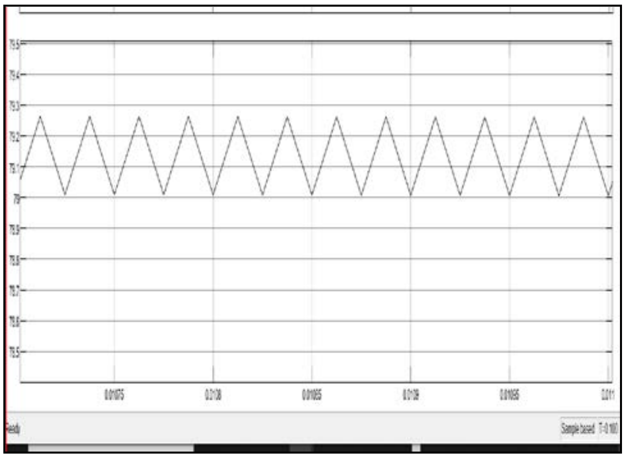

Figure 15: Current Ripple waveform (Current vs Time)

$$\boldsymbol{Current\ Ripple} = \frac{\mathbf{79.28 - 79}}{\mathbf{79}} \times \mathbf{100} = \mathbf{0.354\%}$$

L=180μH C=150μF R= 5ΩInput Voltage= 200V L(load)= 40μH

$$\boldsymbol{Efficiency} = \frac{\mathbf{31.28}\boldsymbol{kW}}{\mathbf{31.99}\boldsymbol{kW}} * \mathbf{100} = \mathbf{97.78\%}$$

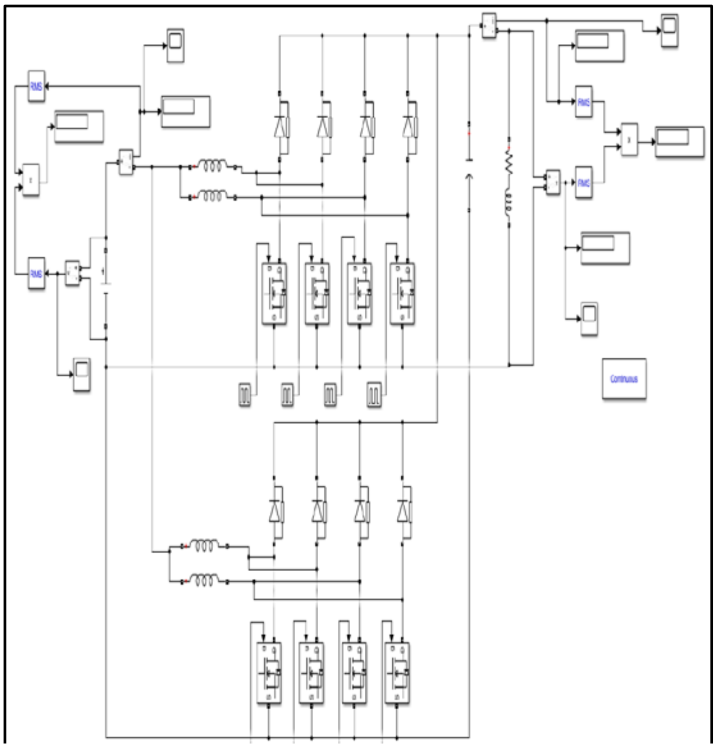

Figure 16: Multi Device Interleaved Boost Converter connected to Inverter with RL load

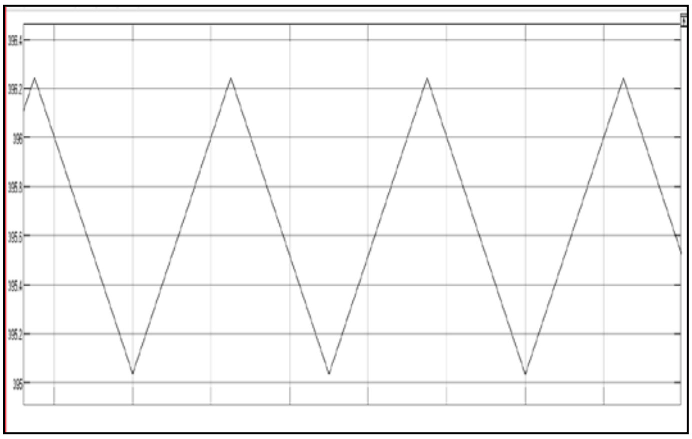

Figure 17: Voltage Ripple waveform (Voltage vs Time)

$$\boldsymbol{Voltage\ Ripple} = \frac{\mathbf{396.25 - 395.02}}{\mathbf{395}} \times \mathbf{100} = \mathbf{0.311\%}$$

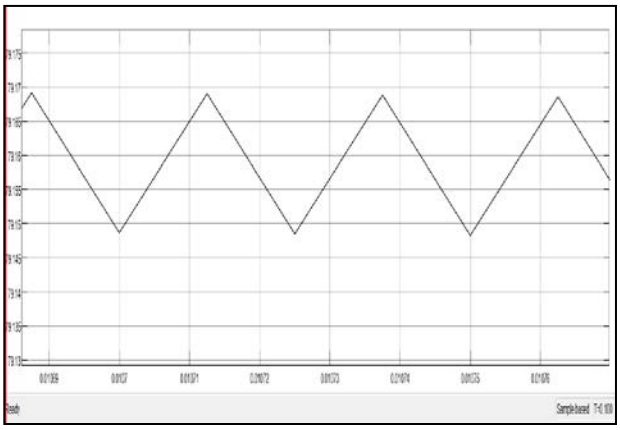

Figure 18: Current Ripple waveform (Current vs Time)

$$\boldsymbol{Current\ Ripple} = \frac{\mathbf{79.17 - 79.1487}}{\mathbf{79.15}}\mathbf{100} = \mathbf{0.0269\%}$$

E. Future Scope

The proposed converters can be extended to different motor loads such as induction motor, switched reluctance motor, inverter to be implemented in EVs.

These converters can be coupled with fuel cells or supercapacitor or any other storage devices in order to provide bidirectionality and to allow integration of storage devices to increase the performance of the electric vehicles.

F. Summary

To improve EVs performance and make it economical, one of the solutions proposed by all counts is MDIBC as it is one the most reliable, cost-effective converter used to increase the efficiency and performance of the electric and hybrid vehicles. It also improves the switching frequency, effectiveness, efficiency and reliability. These days MDIBC isgaining popularity in automobile industries as it allows flexible control, compressed size, and due to its multifunctional capabilities. By this we conclude MDIBCs can be considered as one the converter to improve the performance of EVs as well as fast charging stations.

VI. CONCLUSIONS

By comparing the output waveforms of boost converter, interleaved boost converter and multidevice interleaved boost converter, with R and RL loads we infer, as the number of stages increases the size of the L and C will decrease. Higher converter efficiency is achieved by connecting boost converters in parallel. Input voltage, output current ripples switching period are reduced.

Table 1: Comparison Table

CONVERTER	INPUT POWER	OUTPUT POWER	EFFICIENCY	VOLTAGE RIPPLE(in %)	CURRENT RIPPLE(in %)	OUTPUT CURRENT	OUTPUT VOLTAGE	PASSIVE COMPONENT SIZE L AND C
BOOST R LOAD	30.9kW	29.66kW	**95.98**	0.750	0.737	77.3	386.5	L=400µH C= 680µF
BOOST RL LOAD	30.9kW	29.66kW	**95.98**	0.737	0.1816	77.09	386.5	L=400µH C= 680µF
INTERLEAVED R LOAD	32.31kW	31.34kW	**96.99**	0.336	0.227	79.03	395.2	L=100µH C= 180µF
INTERLEAVED RL LOAD	32.31kW	31.34kW	**96.99**	0.212	0.114	79.06	395.4	L=100µH C= 180µF
MULTI DEVICE INTERLEAVED R LOAD	31.99kW	31.28kW	**97.78**	0.329	0.354	79	395	L=180µH C= 150µF
MULTI DEVICE INTERLEAVED RL LOAD	31.99kW	31.28kW	**97.78**	0.311	0.0269	79.15	395	L=180µH C= 150µF

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