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SINGLE INPUT AND MULTIPLE OUTPUT DC-DC CONVERTER FOR ELECTRIC VEHICLE APPLICATIONS

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ABSTRACT

In this paper a DC-DC single input multi output (SIMO) converter is developed for electrical vehicle applications. In the proposed converter the output port terminals can be incremented. Such multi-port converters are increasingly playing a key role in electric vehicle applications. Designing SIMO converters still faces difficulties due to the cross-regulation issue. In order to get beyond the earlier described restrictions, a SIMO topology is suggested in this work. With regard to duty cycle and inductor currents, it is capable of producing three different output voltages. Different single-input multi-output (SIMO) converter configurations are described in the literature. The majority of SIMO converters generate outputs with operating restrictions on duty ratio and inductors' charging. The proposed topology does not have cross regulation issues, hence changes in output current have no effect on the load voltage. During control, the loads are kept separate.

Keywords: *DC*-DC *Converters, Multiports, Duty Ratio, SIMO Converter*

1. INTRODUCTION

The automobile business is severely impacted by the depletion of fossil fuels, which is influenced by environmental problems such as global warming and an increase in carbon emissions. Power converter integration with green energy technologies like photovoltaic (PV) and fuel cells easily resolves these problems. However, their penetration is made more difficult by the diversity of renewable energy sources and power converters. In Electric Vehicles (EVs) and grid-tied converters, the DC-DC converters are typically application-specific and appropriate for low to high-power applications [1], [2]. The development of EVs and hybrid electric vehicles (HEVs) has recently received significant support from the automotive industry and funding from numerous national governments in an effort to reduce reliance on fossil fuels while offering consumers ecologically friendly, energy-efficient transportation. The increase in EV and HEV purchases.

The use of numerous combined power electronics subcomponents in an energy-efficient electric powertrain while achieving component expenditure, power density, and volume goals is a significant design challenge.

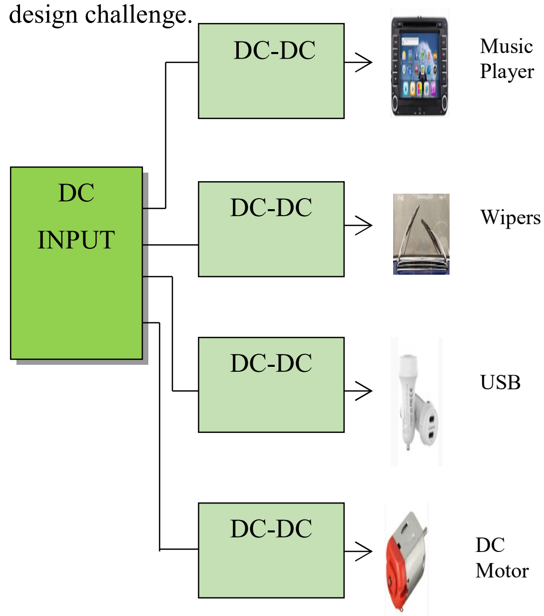

Figure 1: Auxiliary Power Module

Figure 1 illustrates the various power electronic converter components that make up a conventional powertrain, each with a distinct power rating. A DC-DC converter, also referred to as an auxiliary power module, is an essential component of the powertrain because it powers various car accessories, including the power steering, wiper blade motors, music systems, headlamps, and other modules. Additionally, it keeps working while the car is in motion.

Over the past few decades, the demand and use of renewable energy sources has increased dramatically in electric vehicles, grid connected applications and auxiliary power [3] – [6]. As opposed to numerous separate single-input DC-DC converters, multiport DC-DC converters (MPCs) lower the system's component count, complexity, and cost by enabling the hybridization of power sources in these applications [7] – [9].

MPC converters have been made available over the previous ten years. In [10], a brand-new SIMO converter is suggested. This structure simultaneously generates distinct boost, buck, and inverted outputs. However, 'n' voltage levels must be produced using n plus 2 switches, increasing the converter's overall size and expense. Unexpected errors in the computation of the output voltages and state-space formulae for a SIMO converter are addressed and corrected in [11]. In comparison to single inductor SIMO converters, the single linked inductor-based SIMO buck is shown in [12] to have less output inductor current ripple. Nayak and Nath [13] provided in-depth evaluations of the cross-coupling performance of SIDO converters based on coupled inductor and single inductor (SI). The coupled inductor offers superior performance in both steady-state and transient circumstances. A SI SIMO configuration, on the other hand, alternates the inductor between the loads, leading to high ripples and cross-regulation problems.

To solve the cross-regulation problem in a SI SIMO converter, various control strategies are put forth in the literature; the current predictor controller is given in [14] as an alternative to the traditional charge-balance strategy. However, it has been somewhat challenging to generate the duty rates for active switches. Similar to this, [15] presents the deadbeat-based control method. Since it is built on an output current observer, noise and significant parametric variations can affect it. To reduce voltage ripples, eliminate cross-regulation issues, and manage output voltages, a multivariable digital controller-based SIMO converter is suggested in [16]. However, complexity may rise as a result of controller architecture.

[17] presents a non-isolated, single-switch SIMO converter design. It lowers the system's expense and has fewer components. Nevertheless, it might be difficult to separately control the outputs.

A non-isolated SIMO converter is suggested in [18]–[20] to address the issues with a single inductor SIMO converter. This converter has self-reliantly regulated output voltages and does not need any promote control circuit. For generating the step-up and step-down output voltages for electrical vehicle applications, a novel SIDO converter topology is suggested in [13] that integrates buck and super lift converter. It has a restriction on-duty ratio, D2<D1, which raises D2 to limit D1's operational range. Less semiconductor switches are used in the designs suggested in [14] and [15]. But the converter's function depends on how quickly inductors charge (i.e., iL1 > iL2). This maintains the restriction on the on-duty percentage.

For PV uses, [19] put forward combining high gain step-up and SEPIC converter-based SIMO. The capacitors and diodes surge the output voltage in this configuration so that both outputs are greater than the supply voltage. Nevertheless, expense and conduction losses are influenced by the quantity of capacitors and diodes.

In [21], a brand-new SIDO buck-boost topology is created to produce both progressive and adverse outputs. [22] makes the suggestion of a multi-output converter with a smaller component count. But because there are more diodes, there are more transmission losses.

The benefits of a SIMO configuration structure are that it reduces the size of the passive filter and stress at low voltage. A high-density multi-output converter with improved power density and reduced switching losses is proposed for portable electronic applications in [23-26] based on the front-end switched-capacitor method.

In the traditional method, Figure 2 depicts the auxiliary power supply system for EVs to manage the load requirements. Although it appears straightforward, this method has a cross-regulation issue, and the loads are not separated from one another while they are operating. Additionally, there is a possibility of grounding problems when the battery is being charged and multiple charges are turned on at the same time.

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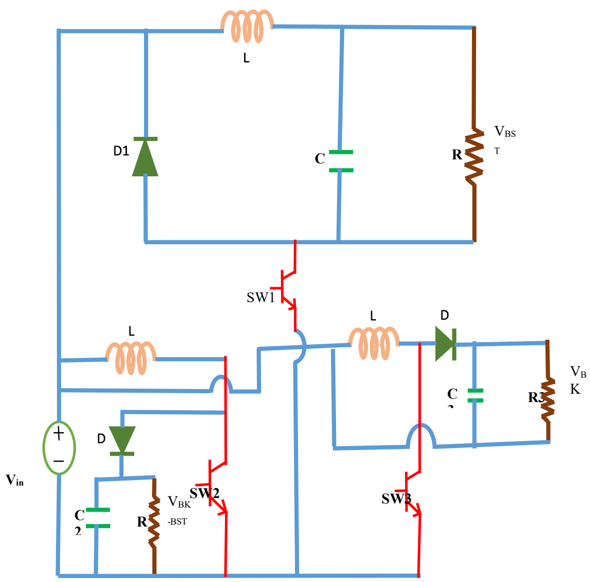

Figure 2: DC – DC Non-Isolated SIMO Structure

The circuit in Figure 3 is set up so that energy in the inductor is restricted to just one output and is not shared with the other outputs during control, allowing the output voltages to be regulated with separate duty cycles. More significantly, the loads are kept apart during control, which effectively solves the cross-regulation issue. Additionally, even if battery charging and grounding are involved, there are no issues with grounding because there is an internal power converter.

Following is the breakdown of the remaining parts of the article: In Section 2, the developed SIMO configuration and modes of operation are described. Results from the trial and simulation are displayed in Section 3. Section 4 gives conclusions.

2. PROPOSED SIMO CONFIGURATION AND OPERATING MODES

In Figure 3, the suggested single input, three output DC-DC arrangement is shown. The components used in this structure are DC input voltage source (V_D), three power semiconductor switches (SW_1-SW_3), three diodes (D_1-D_3), three inductors (L_1-L_3) and three capacitors (C_1 – C_3). This structure can provide three different output voltages at three different stages of DC-DC conversion. The three different voltages are Boost (V_{BST}), Buck (V_{BK}), Buck – Boost (V_{BK-BST}) with positive polarity. With the duty cycles D1, D2, and D3, the suggested converter can independently control the output voltages. Figure 4 shows the current and voltage waveforms of circuit components for Boost operation.

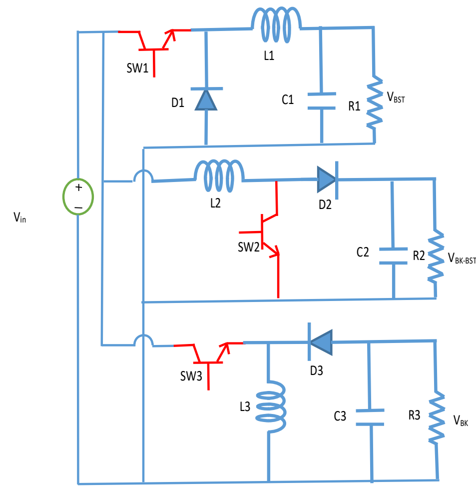

Figure 3: DC – DC Isolated SIMO Structure

2.1 Operating Modes

Operating Modes of DC – DC Isolated SIMO converter is divided into two states depending on the ON and OFF states of the switches.

When the switches SW1, SW2 and SW3 are in ON state current establishes in the three converters i.e., Boost, Buck-Boost and Buck converters and the respective inductors L1, L2 and L3 get energized. The Capacitors C2 and C3 discharges through R2 and R3. Capacitor C1 charges in the Boost operation.

When the switches SW1, SW2 and SW3 are in OFF state, inductors L1, L2 and L3 de-energizes. During this period energy stored in the inductor de-energizes through diodes D1, D2 and D3 and supply energy to load.

Output voltages of three isolated converters and are

$$V_{BST} = \frac{V_D}{(1 - K_1)} \qquad (1)$$

$$V_{BK-BST} = \frac{V_D K_2}{1 - K_2} \qquad (2)$$

$$V_{BK} = K_3 V_D \qquad (3)$$

Where

V_D - Input DC source
V_{BST} - Voltage at the output of Boost converter
$V_{BK\text{-}BST}$ - Voltage at the output of Buck-Boost
V_{BK} - Voltage at the output of Buck
K_1 - Duty cycle of Boost converter
K_2 - Duty cycle of Buck-Boost converter
K_3 - Duty cycle of Buck converter

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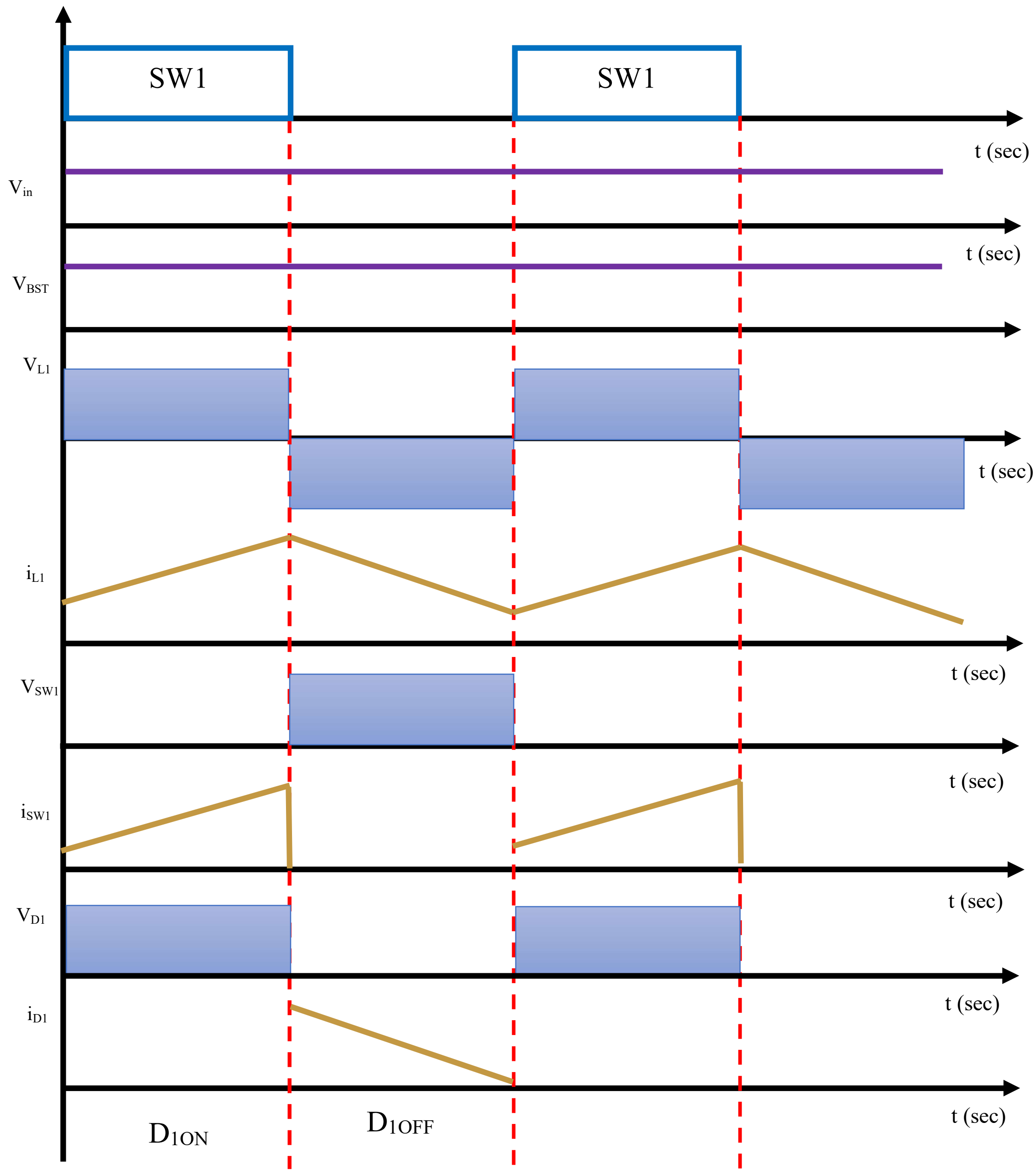

Figure 4: Voltage and Current waveforms across different elements for Boost operation

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2.2 Controller

PI controller is used to control the operation of DC-DC SIMO converter. By using the PI controller underdamped nature of system, steady state error can be reduced and low frequency performance can be increased. By using small-signal modeling, control transfer function is calculated for output of each converter.

2.3 Parameter Selection

Converter parameters L1-L3 and C1-C3 are formulated using equations from (4)-(8).

$$L_{1\min} = L_{2\min} = \frac{2}{27}\frac{R_{L\max}}{f_s} \tag{4}$$

$$L_{3\min} = \frac{R_{L\max}(1 - K_{\min})}{2 f_s} \tag{5}$$

Where

$$C_{1\min} = \frac{K_{\max} V_{BST}}{V_{P-P} R_{1\max} f_s} \tag{6}$$

$$C_{2\min} = \frac{K_{\max} V_{BK-BST}}{V_{P-P} R_{2\max} f_s} \tag{7}$$

$$C_{3\min} = \frac{K_{\max}}{2 r_C f_s} \tag{8}$$

Where K_{max} – Maximum duty cycle
K_{min} – Minimum duty cycle
f_s – Switching frequency
V_{P-P} – Peak – Peak voltage of the capacitor
r_C – Maximum ESR of filter capacitor

Inductor and capacitor values are chosen depending on the switching frequency, peak-peak voltage of the capacitor, minimum and maximum duty cycles.

Selection of duty cycle, various parameters and the gain values are done by using the Newton-Raphson method and is programmed in MATLAB version R2022a.

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3. SIMULATION AND RESULTS

Table 1: DC Motor Ratings

The proposed work is implemented in MATLAB SIMULINK. Model is simulated with an input voltage of 24V and 48V with different duty cycles. Simulink model of DC-DC SIMO converter is shown in figure 5. DC motor is connected at the load terminals of buck converter. Parameters and ratings of the DC motor are given in Table. 1

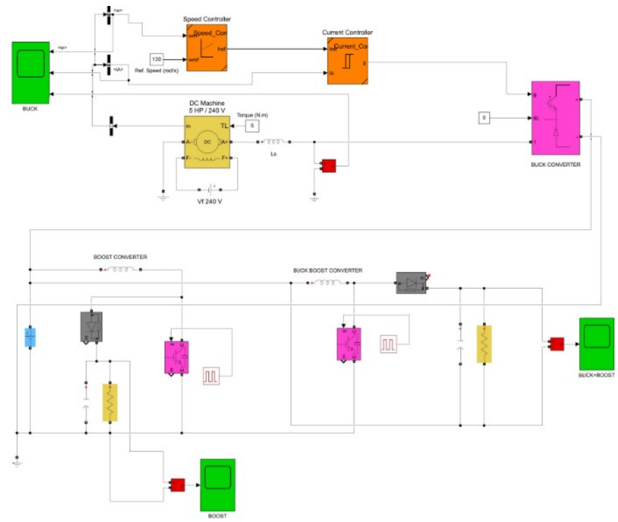


Figure 5: Simulink model of DC – DC Isolated SIMO Converter

Speed of the DC motor is regulated using current controller and speed controller by choosing appropriate reference values. Figure 6 depicts the speed curve of DC machine.

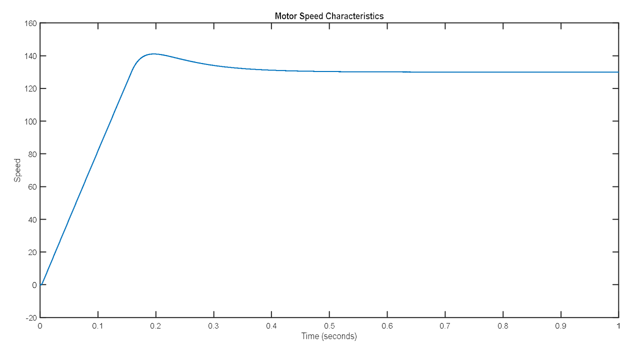


Figure 6: Speed of DC Motor at the load terminals of Buck converter

Table 1: DC Motor Ratings

Parameters	Ratings
Power	5HP
Voltage	240V
Speed	1750RPM
Field Voltage	300V

Table 2 and 3 represents simulation and theoretical results of Boost converter with an input voltage of 24V and 48V respectively. As it is observed that the simulation results are nearer to the theoretical values.

Table 2: Simulation and Theoretical Results of Boost Converter Input Voltage: 24V

DUTY CYCLE (%)	SIMULATION OUTPUT (V)	THEORITICAL OUTPUT (V)
50%	46.92	48
60%	58.85	60v
70%	79.42	80v
80%	119.47	120v
90%	239.1	240v

Table 3: Simulation and Theoretical Results of Boost Converter Input Voltage: 48V

DUTY CYCLE (%)	SIMULATION OUTPUT	THEORITICAL OUTPUT
50%	95.1v	96v
60%	118.97v	120v
70%	159.26v	160v
80%	238.981v	240v
90%	479.3v	480v

Table 4 and 5 represents simulation and theoretical results of Boost converter with an input voltage of 24V and 48V respectively. As it is observed that the simulation results are nearer to the theoretical values.

Table 4: Simulation and Theoretical Results of Buck-Boost Converter Input Voltage: 24V

DUTY CYCLE (%)	SIMULATION OUTPUT	THEORITICAL OUTPUT
50%	23.26v	24v
60%	35.15v	36v
70%	55.46v	56v
80%	95.76v	96v
90%	216.89v	216v

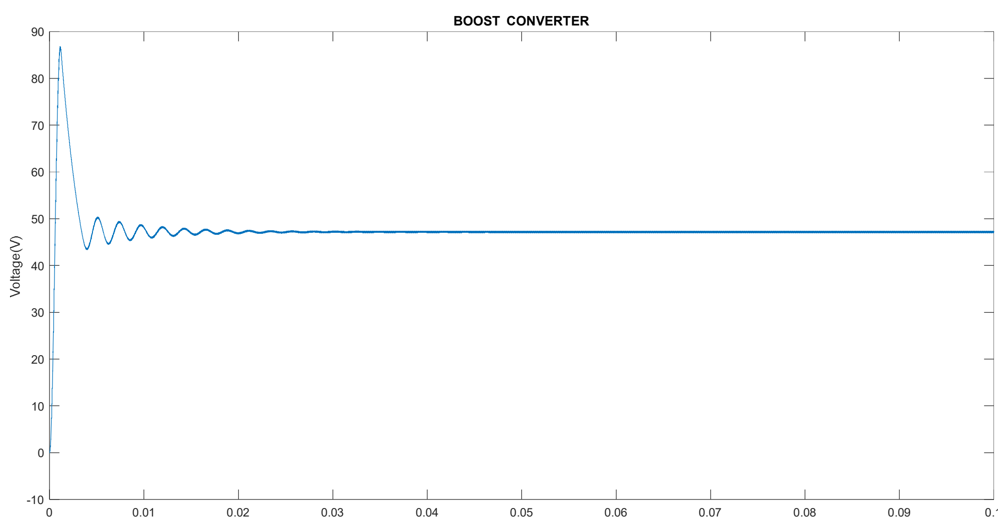
Table 5: Simulation and Theoretical Results of Buck-Boost Converter Input Voltage: 48 V

DUTY CYCLE (%)	SIMULATION OUTPUT	THEORITICAL OUTPUT
50%	46.97v	48v
60%	71.45v	72v
70%	111.49v	112v
80%	192.32v	192v
90%	431.67v	432v

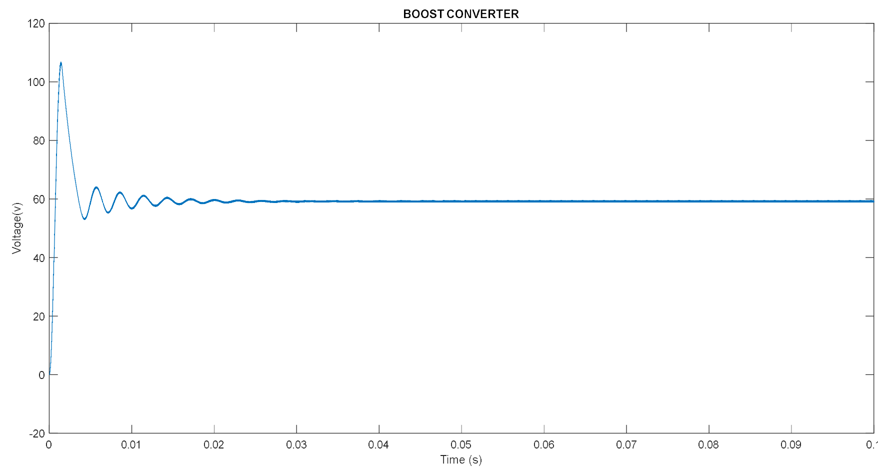
Figure 7 shows the output voltage waveforms of Boost Converter for an input voltage of 24V with different duty cycles from 50% to 90%. As the duty cycle increases output voltage increases with reduction in ripples in voltage.

Figure 8 shows the output voltage waveforms of Buck-Boost Converter for an input voltage of 24V with different duty cycles from 50% to 90%. Depending upon the duty cycle output of Buck-Boost converter is either be decreased or can be increased.

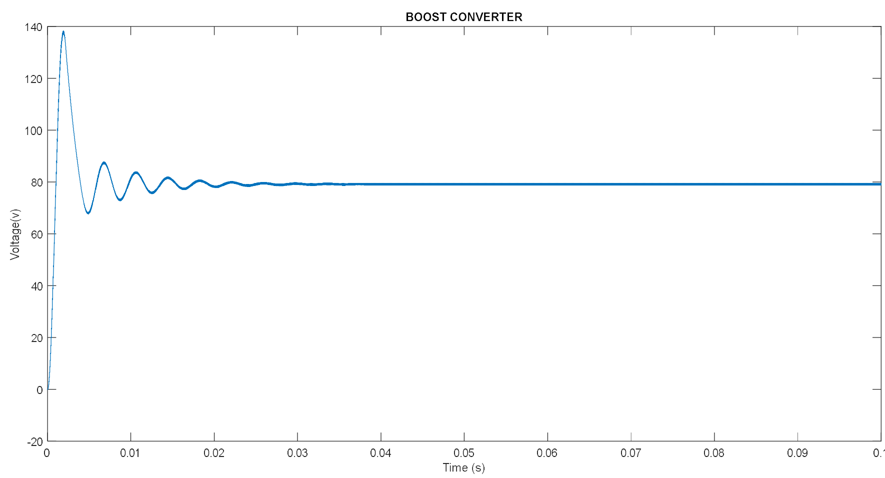
Based on the theoretical and simulation results, it is observed that the results obtained from the simulation output is very nearer to the theoretical output. On-state drop is very less in all the three converters. It is also observed that the speed of the DC motor is nearer to the reference speed.



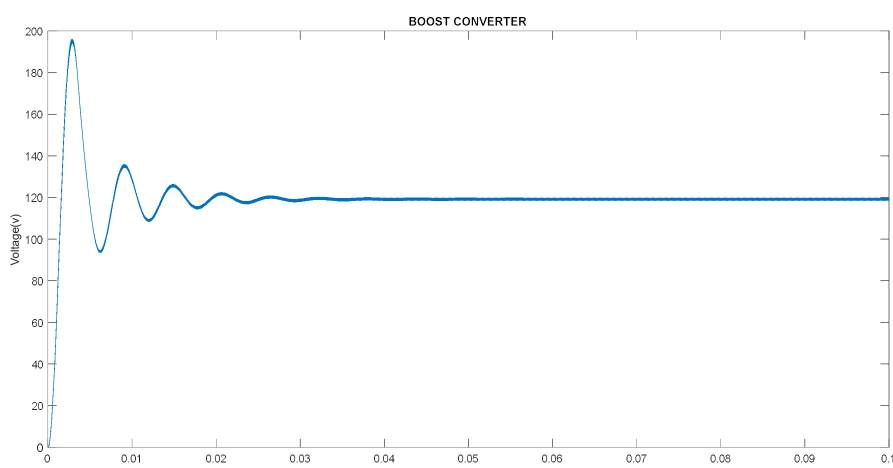
(a)


BOOST CONVERTER
Voltage(v)
Time (s)
120
100
80
60
40
20
0
-20
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

(b)


BOOST CONVERTER
Voltage(v)
Time (s)
140
120
100
80
60
40
20
0
-20
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

(c)


BOOST CONVERTER
Voltage(v)
Time (s)
200
180
160
140
120
100
80
60
40
20
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

(d)

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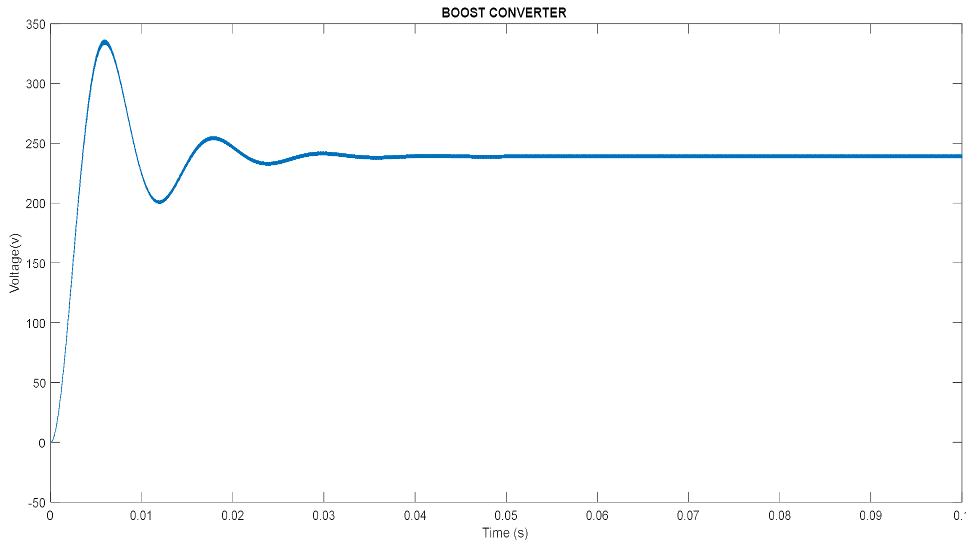
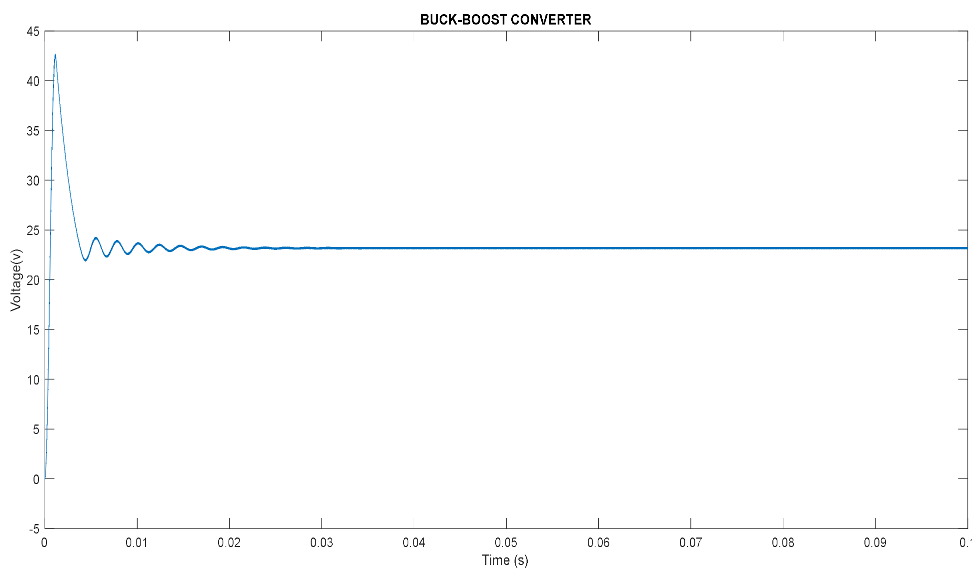
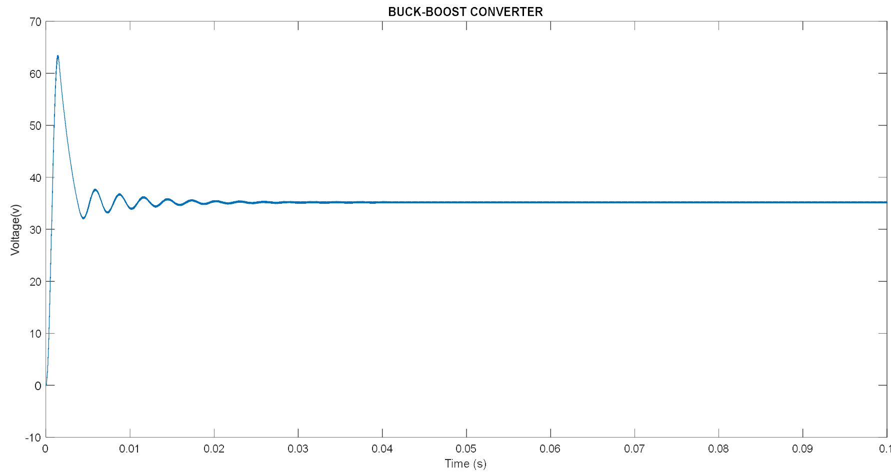


(e)

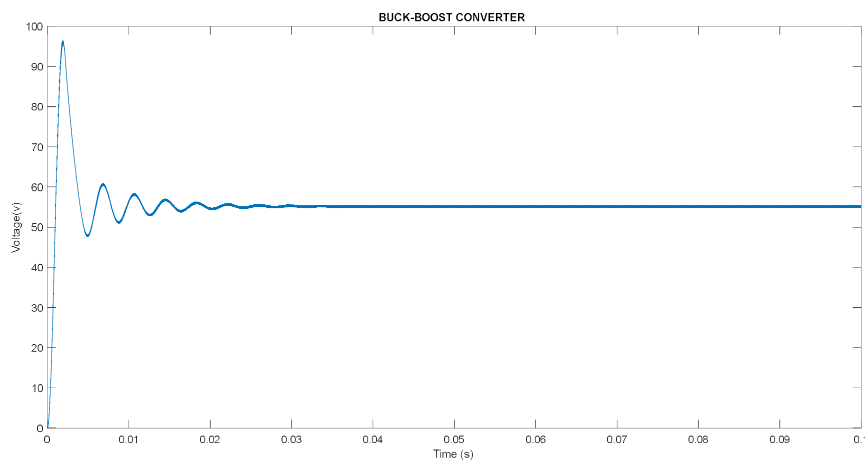
Figure 7: Simulation results at the output terminals of Boost Converter for different duty cycles with input voltage of 24V (a) 50% (b) 60% (c) 70% (d) 80% (e) 90%



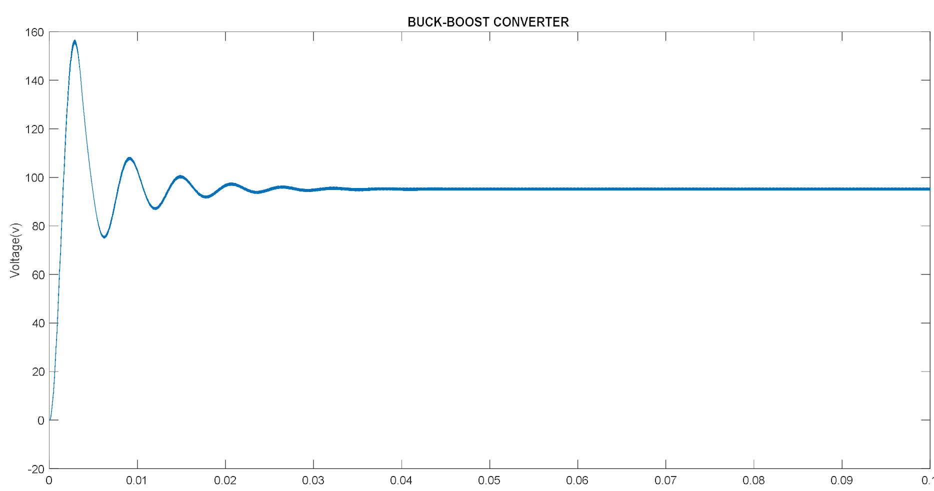
(a)


BUCK-BOOST CONVERTER
Voltage(v)
Time (s)

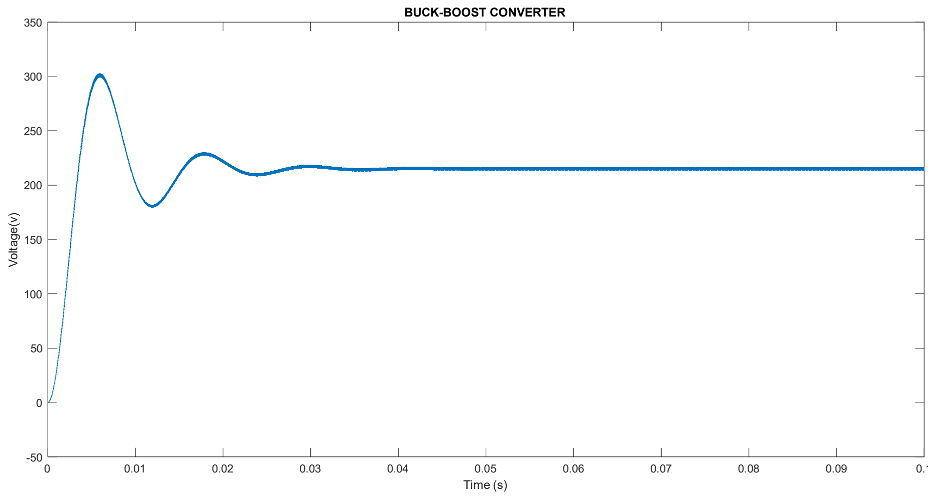
(b)


BUCK-BOOST CONVERTER
Voltage(v)
Time (s)

(c)


BUCK-BOOST CONVERTER
Voltage(v)
Time (s)

(d)



(e)

Figure 8: Simulation results at the output terminals of Buck-Boost Converter for different duty cycles with input voltage of 24V (a) 50% (b) 60% (c) 70% (d) 80% (e) 90%

3. CONCLUSIONS

In this paper an isolated DC-DC SIMO Converter is presented. The operational theory and modes of operation have been thoroughly explained. The suggested arrangement is straightforward and makes no assumptions on the inductors' charging or operating duty cycle. With independent regulated voltages, it can produce the output voltages for buck, boost, and buck-boost. The proposed topology does not have cross regulation issues, hence the quick change in inductor and load currents has no impact on the output voltages. Simulation results are presented and compared with theoretical results.

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