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Original Article

Design and Implementation of Single-Input-Multi-Output DC-DC Converter Topology for Electric Vehicle

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Abstract: *This paper presents the design and implementation of an innovative Single-Input-Multi-Output (SIMO) DC-DC converter topology for electric vehicles (EVs). The growing demand for efficient and compact power conversion systems in the EV domain necessitates the exploration of advanced converter designs to enhance overall performance and address specific requirements. The proposed SIMO DC-DC converter aims to efficiently manage the diverse power needs within an electric vehicle, catering to multiple voltage levels and diverse loads. The converter is designed to handle the conversion of a single input voltage to multiple output voltages, adapting to the various electrical subsystems within an electric vehicle, including battery management, motor drives, and auxiliary systems. The design process involves detailed analysis, simulation, and optimization using advanced software tools to ensure optimal performance under various operating conditions. Critical parameters such as efficiency, voltage regulation, and transient response are evaluated and optimized to meet the stringent requirements of electric vehicle applications. To validate the proposed SIMO DC-DC converter topology, a prototype is implemented and tested on a real electric vehicle platform. Experimental results are presented, demonstrating the chaotic converter effectiveness in efficiently managing power distribution among different components within the EV system. The performance metrics, including efficiency, response time, and overall reliability, are evaluated and compared with existing converter topologies. This research contributes to the advancement of power electronics in electric vehicles by introducing a novel SIMO DC-DC converter topology that addresses the specific challenges of power distribution and management within the vehicle. The proposed design offers potential benefits in terms of improved efficiency, reduced component count, and increased power density, contributing to the ongoing efforts to enhance the sustainability and performance of electric vehicles.*

Keywords: *DC-DC Converter, SIMO, High Efficiency, Chaotic PWM.*

I. INTRODUCTION

The growing demand for efficient and compact power conversion systems in the EV domain necessitates the exploration of advanced converter designs to enhance overall performance and address specific requirements. The renewable energy sources, photovoltaic (PV) systems and fuel cells have gained prominence due to their ability to harness clean energy from sunlight and chemical reactions, respectively. However, the integration of these diverse renewable sources with existing power systems poses considerable complexity, particularly concerning the management of power conversion processes. In the real of power electronics, DC-DC converters play a pivotal role in facilitating efficient energy conversion, especially in applications such as Electric Vehicles (EVs) and grid-tied converters. Conventional DC-DC converters often exhibit limitations in terms of their adaptability to different power levels and diverse energy sources. In summary, the multi-port DC-DC converter with SIMO architecture presented in this project represents a significant advancement in power electronics technology. By circumventing traditional limitations and offering improved performance and flexibility, this innovative converter holds great promise for advancing the integration of renewable energy sources and addressing the challenges of sustainable energy conversion.

II. LITERATURE SURVEY

H. R. E. Larico - proposed a step-up/step-down isolated dc–dc converter referred to as a three-phase flyback push–pull dc–dc converter. The power circuit is constituted by a pair of coupled inductors, a three-phase transformer, a capacitor, three switching transistors and three power diodes. The proposed converter offers the advantages of compact passive devices, low conduction power losses, full duty cycle range (0–100%), and inherent protection against transformer saturation.

Ali -A novel DC-DC converter topology, viz., single switched impedance network (SSIN)-based converter with n-stage is proposed in this paper. The operation of the SSIN based converter in continuous and discontinuous conduction modes are discussed.

K. Sun, et al - proposed a distributed control strategy based on improved dc bus signaling is proposed for a modular photovoltaic (PV) generation system with battery energy storage elements. In this paper, the modular PV generation system is composed of three modular dc/dc converters for PV arrays, two grid-connected dc/ac converters, and one dc/dc converter for battery charging/discharging and local loads, which is available of either grid-connected operation or islanding operation.

III. PROBLEM STATEMENT

Critical aspect of EVs is the efficiency of their power management systems, particularly the DC to DC converters responsible for regulating and distributing power within the vehicle. The existing DC to DC converters in EVs typically have a single input and output, limiting their adaptability to the diverse power requirements of various components such as traction drives, auxiliary systems, and energy storage units. To enhance the overall efficiency and flexibility of power distribution in EVs, there is a need for the design and implementation of a Single Input Multi-Output (SIMO) DC to DC converter.

IV. BLOCK DIAGRAM

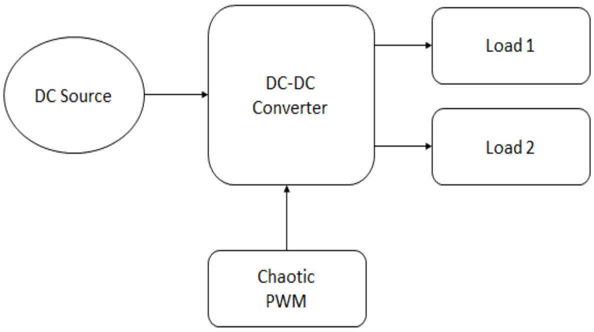
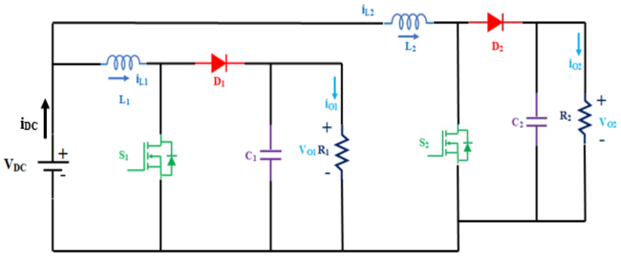


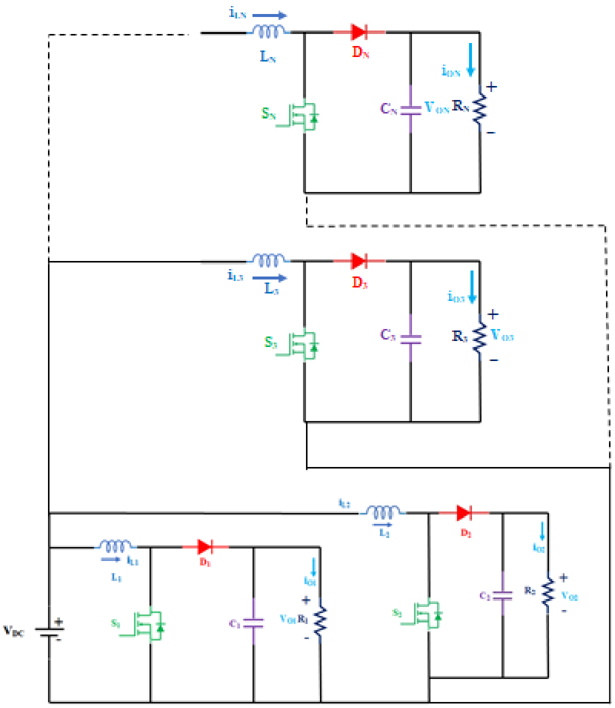
Figure 1: Block Diagram of Proposed method

V. PROPOSED SINGLE-INPUT-MULTI-OUTPUT DC-DC CONVERTER TOPOLOGY

The proposed converter operation for Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM) is elaborated here. The proposed SIMO converter structure is portrayed in Figure 2 (a). It has two switches (S1, S2), two diodes (D1D, D2D), two inductors (L1, L2), two capacitors (C1, C2), and load (R1, R2). In this topology, output voltages are independently regulated at different voltage levels by the duty cycle D1 – D2. The extended version of the proposed SIMO converter with multiple outputs is illustrated in Figure 2(b). It requires N switches, N-inductors, and N-capacitors for N-outputs. The proposed N-output version configuration can generate the independent outputs and avoid the ground problems between the outputs during their control. The advantages of the proposed converter are: • It is a simple structure, without using any operational constraint on duty ratio (D1> D2 or D2 < D1 or D1 = D2) • It can generate independent output voltages. • No assumptions are made on inductor currents like iL1 < iL2 or iL1 > iL2 during control. • Loads are isolated during real-time control of the loads, which avoids the issue of cross-regulation • The circuit configuration can also be extended to N-outputs It is observed that a buck mode of operation is required for EVs' auxiliary power system application. In the proposed configuration, as shown in Figure 2(b), the outputs Vo1–VoN are less than VDC, and they can be regulated simultaneously and individually. The converter presented in this paper is suitable to handle the loads on present and future load requirements of an EV.



(a)



(b)

Figure 2: Proposed configuration: (a) Dual output version, (b) N-output version

VI. MODES OF OPERATION

1) SWITCHING STATE 1

Power semiconductor switches S1 and S2 are kept ON in this state. The current flow path is depicted in Figure 3(a). In state 1, L1 and L2 are magnetized by the energy port VDC and supply energy to the loads (R1 and R2). The current through inductors and voltage across capacitors are given in equations (1)-(4).

$$i_{L1}(t) = \frac{V_{DC}}{R_1} + e^{-\alpha_1 t}\left[c_1 \cos\omega_1 t + c_2 \sin\omega_1 t\right] \tag{1}$$

$$v_{C1}(t) = V_{DC} - \frac{L_1}{2C_1} e^{-\alpha_1 t} \begin{bmatrix} \cos\omega_1 t\left(\frac{\alpha_1 c_1}{R_1} + \omega_1 c_2\right) \\ + \sin\omega_1 t\left(-\alpha_1 c_2 + \frac{\omega_1 c_1}{R_1}\right) \end{bmatrix} \tag{2}$$

$$i_{L2}(t) = \frac{V_{DC}}{R_2} + e^{-\alpha_2 t}\left[c_3 \cos\omega_2 t + c_4 \sin\omega_2 t\right] \tag{3}$$

$$v_{C2}(t) = V_{DC} - \frac{L_2}{2C_2} e^{-\alpha_2 t} \begin{bmatrix} \cos\omega_2 t\left(\frac{\alpha_2 c_3}{R_2} + \omega_2 c_4\right) \\ + \sin\omega_2 t\left(-\alpha_2 c_4 + \frac{\omega_2 c_3}{R_2}\right) \end{bmatrix} \tag{4}$$

2) SWITCHING STATE 2

In this state, the L1 and L2 are de-magnetized and deliver their stored energy to load R1 and R2 through D1D and D2D, as shown in Figure 3(b). The current through inductors and voltage across capacitors are given in equations (5)-(9) during this mode.

$$i_{L1}(t) = e^{-\alpha_1 t}\left[c_5 \cos\omega_1 t + c_6 \sin\omega_1 t\right] \tag{5}$$

$$v_{C1}(t) = -L_1 e^{-\alpha_1 t} \begin{bmatrix} (-\alpha_1 c_5 + \omega_1 c_6)\cos\omega_1 t \\ + (\omega_1 c_5 - \alpha_1 c_6)\sin\omega_1 t \end{bmatrix} \tag{6}$$

$$i_{L2}(t) = e^{-\alpha_2 t}\left[c_7 \cos\omega_2 t + c_8 \sin\omega_2 t\right] \tag{7}$$

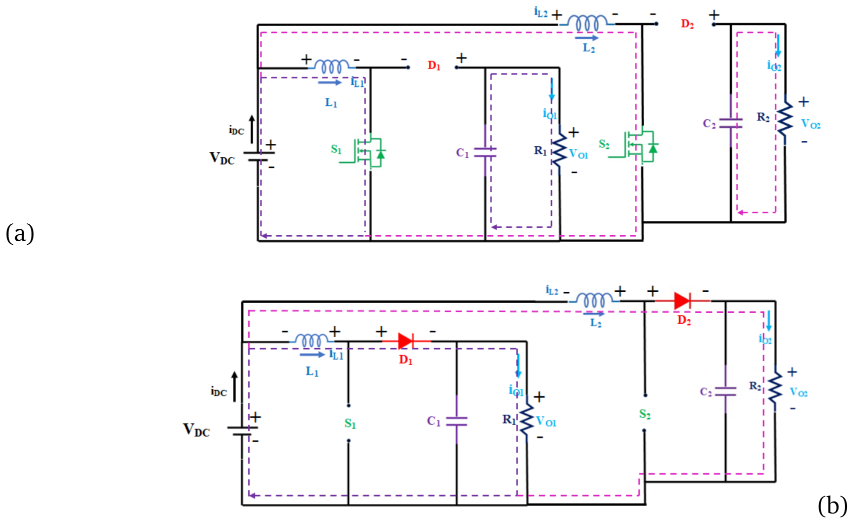


Figure 3: Modes of operation: (a) Switching state 1, (b) Switching state 2

$$v_{C2}(t) = -L_2 e^{-\alpha_2 t}\begin{bmatrix}(-\alpha_2 c_7 + \omega_2 c_8)\cos\omega_2 t\\ +(\omega_2 c_7 - \alpha_2 c_8)\sin\omega_2 t\end{bmatrix} \tag{8}$$

where

$$\alpha_1 = \frac{1}{2R_1C_1},\quad \omega_1 = \frac{1}{2}\sqrt{\left(\frac{1}{R_1^2C_1^2} - \frac{4}{L_1C_1}\right)},$$
$$\alpha_2 = \frac{1}{2R_1C_1} \text{ and } \omega_2 = \frac{1}{2}\sqrt{\left(\frac{1}{R_2^2C_2^2} - \frac{4}{L_2C_2}\right)} \tag{9}$$

In mode-1, when S1 and S2 are turned on, the voltage across inductor L1(VL1) is subjected to VDC − Vo1. The current is raised with the positive slope of (VDC − Vo1)/L1. Consequently, the voltage across inductor L2(VL2) is subjected to VDC − Vo2, and the current is raised with the positive slope of (VDC − Vo2)/L2. In mode-2, when S1 and S2 are turned off, the voltage across inductor L1(VL1) is subjected to −Vo1. Now the current is decreased with the negative slope of −Vo1/L1. At the same time, the voltage across inductor L2(VL2) is subjected to −Vo2. Consequently, the current decreases with a negative −Vo2/L2 slope. It is observed that during mode-2, the source current is zero as the source is open-circuited when S1 and S2 switches are turned off. This process is repeated for every cycle of control. From the CCM, the output voltage equations for the duty ratios are given (10) for the proposed converter.

$$V_{01} = D_1 V_{DC},$$
$$V_{02} = D_2 V_{DC} \tag{10}$$

From the above discussions, it is observed that change in one load would not influence the other. Hence, the issue of cross-regulation is eliminated, and the circuit configuration facilitates that the inductor stored energy is limited to one particular load only. So, the converter allows independent control and operation of loads. More importantly, the control of this converter is simple and has no control and operational constraints on duty ratio and inductor currents.

VII. SIMULATION MODEL OF PROPOSED METHOD

The simulation was conducted using MATLAB Simulink to model a converter system comprising a 12v dc source, and a resistive load of 10kΩ. The objective was to regulate the output voltage to 24V & 60V using a chaotic controller.

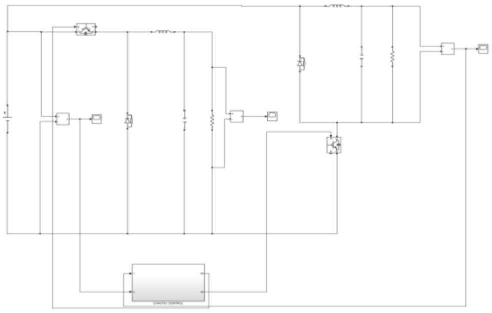


Figure 4: Simulation Circuit Diagram for SIMO Converter

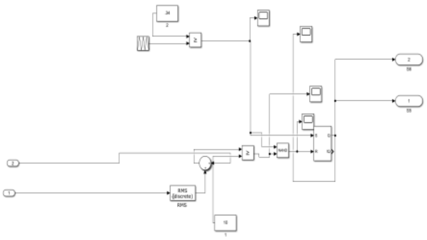


Figure 5: Chaotic Controller

Figure 5 shows the PWM generation using chaotic controller. In PWM, chaotic control might involve using chaotic signals to modulate the width of pulses in the waveform. These signals could be generated from chaotic systems like the Lorenz or Rössler attractors. By utilizing the chaotic behavior of these systems, one can create PWM signals that possess certain desirable properties for power electronic applications.

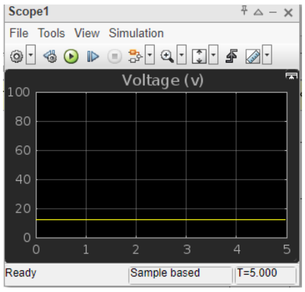


Figure 6: Input Voltage

Figure 5 shows input voltage for converter. The figure in the Simulink model for this DC-DC converter with a 12V input might showcase the connections between these blocks, potentially illustrating signal flow, control loops, or voltage/current waveforms at different points in the circuit. The visual representation helps in understanding the behavior of the system and verifying its functionality.

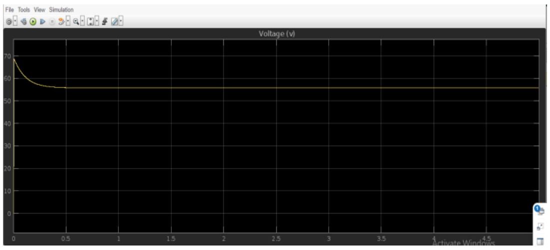


Figure 7: Output Voltage 1

Figure shows the output voltage of proposed converter. The output voltage of 60v obtained from the input voltage of 12v.

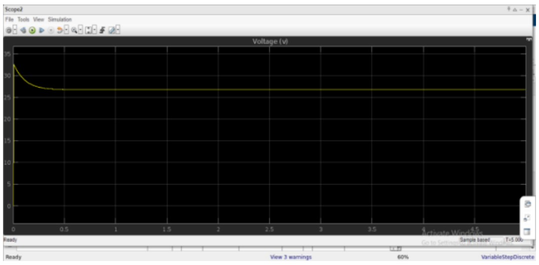


Figure 8: Output Voltage 2

Figure shows the output voltage of proposed converter. The output voltage of 24v obtained from the input voltage of 12v.

In this system, the input voltage of 12V undergoes a transformation through a specialized chaotic controller. This controller, employing chaotic dynamics derived from complex mathematical systems, generates control signals that influence the operation of the DC-DC converter. The chaotic nature of these signals introduces a non-linear, intricate modulation into the converter's parameters, perhaps altering duty cycles or frequencies in an unconventional manner compared to traditional control methods.

The core of this setup lies within the interplay of the chaotic controller with the converter circuitry—comprising switches, inductors, and capacitors—where the chaotic control signals guide the conversion process. This unique approach may offer advantages in terms of adaptability and robustness against certain disturbances due to the complex, seemingly random nature of chaotic systems.

The figure representing the output voltage of 24V likely showcases the result of this unconventional control strategy. It might display the voltage waveform, illustrating how the chaotic controller's influence leads to the desired output voltage. Understanding and harnessing the chaotic behavior for control purposes in such systems often involve intricate parameter tuning and rigorous analysis, paving the way for potential advancements in voltage regulation methodologies within power electronics.

VIII. CONCLUSION

In this project, a new schematic of the SIMO DC-DC converter topology is proposed, analyzed, and implemented for EVs' auxiliary power module. In addition, the extended version of the proposed converter topology is also proposed to get N-output voltages. The proposed converter in CCM and DCM are comprehensively explained. The proposed converter's small-signal modeling for estimating the transfer function, which is essential in the feedback control loop implementation, and the performance of the closed-control loop response of the proposed converter was verified with the bode plot analysis. The proposed SIMO converter topology is simple without any assumptions on the operational duty cycle and inductor currents during the control. It can produce the two independent output voltages at different duty ratios by avoiding the issues of cross-regulation. The controller was designed for good voltage regulation at load variations, and the converter has been validated with the simulation and experimental results. The simulation and experimental analysis of the proposed extended N-output converter will be carried out in the future. In addition, the proposed converter can also be tested for bi-polar DC microgrid applications.

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