NEURAL NETWORK BASED MULTI-OUTPUT DC-DC CONVERTER FOR ELECTRIC VEHICLE APPLICATION

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ABSTRACT

Multiport converters are essential components in applications involving electric vehicles (EVs) and portable electronic devices. Existing Single Input Multiple Output (SIMO) converters face challenges related to cross-regulation, often constrained by duty ratios and inductor charging. Duty cycles and inductor currents are not restricted by the suggested SIMO converter, which produces three different output voltages. Unlike traditional SIMO converters, the new topology eliminates cross-regulation issues, ensuring that load voltages remain unaffected by output current variations. To enhance converter performance, a PI controller is initially employed to reduce steady-state error. Recognizing the limitations of PI controller in speed of response, this paper explores an innovative approach by replacing PI controllers with Neural Network (NN) controllers. This adaptation aims to enhance system speed of response, thereby reducing overshoot, settling time and improving overall converter performance. The results suggest that the integration of NN controllers holds promise for advancing the capabilities of SIMO converters in electronic devices and EV applications. The simulation results can be validated by MATLAB/Simulink Software.

Keywords: Multiport converters, single input multi output converters, Neural Network controller, Electric vehicle, Battery.

I. INTRODUCTION

Auxiliary power, grid-connected applications using renewable energy sources, and electric vehicles (EVs) has grown during the last ten years [1]–[5]. When compared to many independent DC-DC converters with one input and many ports are crucial in these applications in order to hybridize energy sources, which reduces the cost, complexity of the system, and number of components [6], [7]. The cross-regulation issue with a SIMO converter based on a single inductor is addressed by a variety of control strategies in the literature. In [8], The conventional charge balance method is replaced with the current predictor controller. However, It has proven a little The duty ratio generation for active switches is difficult. Similarly, [9] presents the deadbeat-based control technique. a multivariable digital controller-based Single Input Multi Output (SIMO) In order A converter is recommended in order to manage output voltages, suppress cross-regulation problems, and lessen voltage ripples. Conversely, controller design may lead to an increase in complexity.The circuit layout depicted in Figure 1 enables the regulation of the voltages at the outputs with separate duty cycles as a result of the inductor's energy being linked to only one output during control rather than being shared by several outputs. More crucially, the cross-regulation issue is successfully resolved and the loads are segregated from one another during control. To enhance converter performance, a PI controller is initially employed to reduce steady-state error. Recognizing the limitations of PI controller which is it’s slow speed of response.

A DC-DC converter's small size and high efficiency make it particularly popular. The most popular duty ratio control technique is modification of pulse width (PWM), in which the duty cycle d(N) fluctuates with changes in load resistance and the Nth sampling period. The duty cycle shift is dictated by the predetermined controller's output, d_N. then the duty cycle d(N-1) to the change in the duty cycl $\delta d(N)$,i.e. d(N) = d(N-1) + $\delta d(N)$.After that, a PWM output stage receives this duty cycle signal and produces the proper switching patterns for the switching power supplies.

Recently, DC-DC in dynamic systems, converters have been performing better thanks to the application of neural networks (NN), which provide performance with good regulation. Since neural networks (NNs) are a kind of intelligence control that can learn to approach any function, they are a good fit for nonlinear control systems. NN-based control is efficient in reducing overshoot, oscillations, and settling time while offering quick reaction in tracking target output voltages.

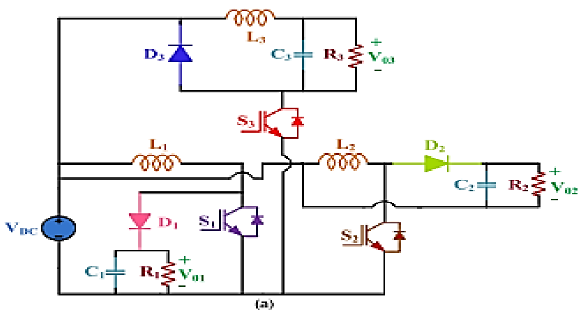


Figure 1:Proposed SIMO configuration

II. PROPOSED SIMO CONFIGURATION AND MODES OF OPERATION

Figure 1(a) shows the proposed DC-DC architecture with one input and three outputs. The following are the components of this arrangement: input voltage V_{DC}, switches (S_1-S_3), diodes (D_1-D_3), as well as inactive components (L_1-C_1, L_2-C_2 and L_3-C_3). It is capable of producing three distinct output voltages. It is capable of producing three distinct output voltages. i.e., boost (V_{01}), buck-boost (V_{02}) with positive voltage polarity, and buck (V_{03}). By using duty cycles D_1, D_2, and D_3, respectively, The output voltages may be individually controlled by the proposed converter. The suggested setup for the traditional parallel combination of boost, buck, and buck-boost configurations. In the proposed method, the loads are segregated during the simultaneous control circuit arrangement. As seen in the following pictures, load R_3 through S_3 is the only load linked to the input power supply during mode-1 operation; Every other load is segregated. according to Figure 2(a). Similarly, only loads R_1 through D_1 are connected to the input supply, as seen in Figure 2(b) during mode-2; all other loads are isolated. Every load in the suggested control strategy is kept apart from the others while it is being controlled in any mode of operation.

Modes of Operation

1)Switching State 1

Switches S_1, S_2, and S_3 are activated, establishing the path of current flow as seen in Figure 2(b). This setup results in the magnetization of inductors L_1, L_2, and L_3 by the energy port V_{DC}. As a result, capacitors C_1 and C_2 discharge to loads R_1 and R_2, respectively, while capacitor C3 undergoes charging to load R3. The currents flowing through the inductors and the voltages across the capacitors are described in equations (1)-(4) [1].

$$i_{L_1}(t) = \frac{v_{DC}}{L_1} + i_{L_1(0),} \quad vc_1(t) = v_{c_1}(0)e^{\frac{-1}{R_1c_1}t} \tag{1}$$

$$i_{L_2}(t) = \frac{v_{DC}}{L_2} + i_{L_2(0),} \quad vc_2(t) = v_{c_2}(0)e^{\frac{-1}{R_2c_2}t} \tag{2}$$

$$i_{L_3}(t) = \frac{v_{DC}}{R_3} + e^{-\alpha t}[c_1 \cos\omega_d t + c_2 \sin\omega_d t] \tag{3}$$

$$v_{C_3(t)} = v_{DC} - \frac{L_3}{2C_3}e^{-\alpha t}\begin{bmatrix} \cos\omega_d t\left(\frac{\alpha c_1}{R_3} + \omega_d c_2\right) \\ + \sin\omega_d t\left(-\alpha c_2 + \frac{\omega_d c_1}{R_3}\right)\end{bmatrix} \tag{4}$$

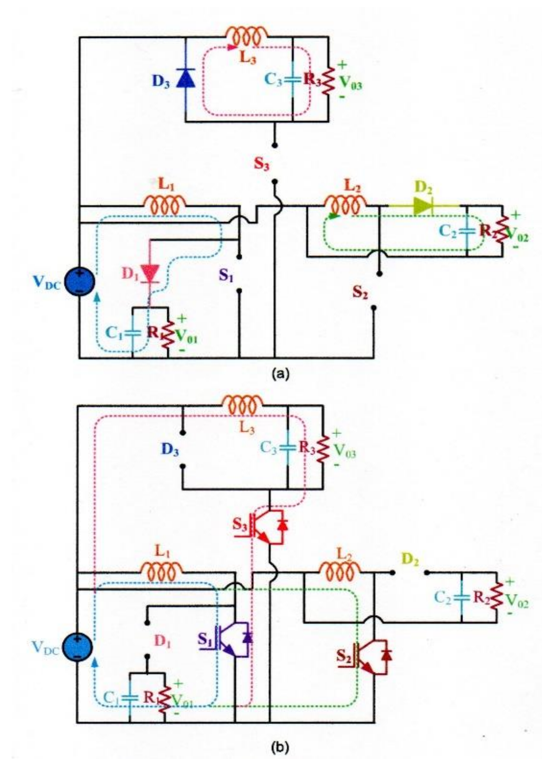


Figure 2. Operating states: (a) Switching state-2 and (b) Switching state-1 .

2)Switching State 2

In this state, L_1, L_2, and L_3 are de-magnetized and deliver their energy to the load through D_1, D_2, and D_3, correspondingly Figure 2(b) provides an illustration of it. The following are the capacitor voltages and inductor currents found in Eqs. (5)–(11)[1].

$$i_{L_1}(t) = \frac{v_{DC}}{R_1} + e^{-\alpha_1 t}[c_1 \cos\omega_{d1} t + c_2 \sin\omega_{d1} t] \tag{5}$$

$$v_{C_1(t)} = v_{DC} - \frac{L_1}{2C_1} e^{-\alpha_1 t} \begin{bmatrix} \cos \omega_{d1} t \left(\frac{\alpha c_1}{R_1} - \omega_{d1} c_2 \right) \\ + \sin \omega_{d1} t \left(\omega_{d1} c_1 + \frac{c_2}{R_1} \right) \end{bmatrix} \quad (6)$$

$$i_{L_2}(t) = e^{-\alpha_2 t} [c_3 \cos \omega_{d2} t + c_4 \sin \omega_{d2} t] \quad (7)$$

$$v_{C_2(t)} = -L_2 e^{-\alpha_2 t} \begin{bmatrix} (-\alpha_2 c_3 + \omega_{d2} c_4) \cos \omega_{d2} t \\ +(\omega_{d2} c_3 - \alpha_2 c_4) \sin \omega_{d2} t \end{bmatrix} \quad (8)$$

$$i_{L_3}(t) = e^{-\alpha t} [c_5 \cos \omega_d t + c_6 \sin \omega_d t] \quad (9)$$

$$v_{C_3(t)} = -L_3 e^{-\alpha t} \begin{bmatrix} (-\alpha c_5 + \omega_d c_6) \cos \omega_d t \\ +(\omega_d c_5 - \alpha c_6) \sin \omega_d t \end{bmatrix} \quad (10)$$

$$\alpha_1 = \frac{1}{2R_1C_1}, \quad \omega_{d1} = \frac{1}{2} \sqrt{\left(\frac{1}{R_2^2 C_2^2} - \frac{4}{L_2 C_2} \right)},$$

$$\alpha_2 = \frac{1}{2R_1C_1}, \quad and \omega_{d2} = \frac{1}{2} \sqrt{\left(\frac{1}{R_2^2 C_2^2} - \frac{4}{L_2 C_2} \right)}$$

$$\alpha = \frac{1}{2R_3C_3}, \quad \omega_d = \frac{1}{2} \sqrt{\left(\frac{1}{R_3^2 C_3^2} - \frac{4}{L_3 C_3} \right)}, \quad (11)$$

Where C_1, C_2 and C_3 are initial values.

In the suggested arrangement, the output voltages are as follows

$$V_{01} = \frac{V_{DC}}{(1-D_1)}, \quad V_{02} = \frac{V_{DC} D_2}{(1-D_2)}, \quad V_{03} = D_3 V_{DC} \quad (12)$$

D_1, D_2, and D_3 are duty ratios of the S_1, S_2, and S_3 respectively.

According to the suggested control scheme, if the supply flows from source to Load R_1 through S_1 switch then the system will be operated in Boost Mode. if the supply flows from Source to Load R_2 through S_2 switch then the System operated in Buck-Boost Mode. If the supply flows from source to Load R_3 through S_3 Switch then the System will be operated in Buck Mode. During the simultaneous control, each load is segregated from the others. Additionally, the circuit's design ensures that The energy that the inductor stores is exclusive to that one output that is kept separate from all other outputs. while control is in effect. This permits separate duty-cycle regulation of the output voltages. As a result, the load voltage V_{01} (V_{02}) (V_{03}) is unaffected by changes in the load current i_{03} (i_{02}) (i_{01}). Therefore, all of the concerns regarding cross-regulation problems are avoided in the suggested setup using this control strategy.

III. Proposed Method OF Neural Network Controller

Neural network: Neural Network (NN) NNs are widely recognized as a technology that provides an alternative approach to resolving challenging issues because these NNs are not in need of any in-depth system knowledge. Through an analysis of the previously recorded data, they discover the connection between the variables that are input and output. Another advantage of using NNs is their capacity to manage sizable, intricate systems with a wide range of constant characteristics. These trained NNs can be applied to approximate a system's unrestricted input-output mapping.

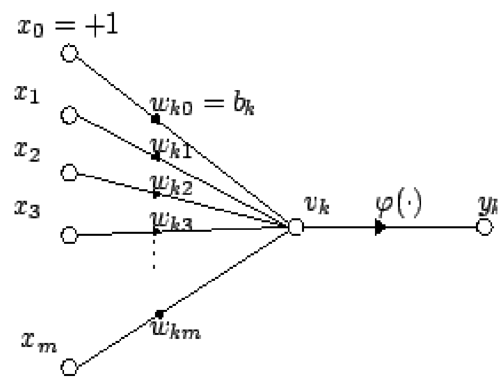


Figure 3: Artificial neuron

The synthetic neuron k, allow there to$m$ + 1 inputs with signals x_0 through $x_m$and,weights w_{k0} through w_{km}. x_0 -input is assigned the value +1, which makes it a bias input with $w_{k0} = b_k$. This leaves only m actual inputs to the neuron: from x_1 to x_m.

The output of the K^th^ neuron is: $Y_k = \varphi(\sum_{j=0}^{m} w_{kj} x_j)$.

Scaled data propagate from neurons in the input layer of the network to the output via intermediary layers. A weight is assigned to each link, and this weight modifies the signal strength. The neural network can be trained using a variety of techniques for maximizing criteria functions. Usually, iterative strategies are needed for neural network training. Of all the training algorithms available, the back-propagation approach is the most popular since it is simple, stable, resilient, and straightforward to use. It was trained using the gradient descent method.

TABLE 1:parameter specifications.

parameters	Simulation
Input voltage (V_{DC})	50 V
Output voltages (V_{01}, V_{02}, V_{03})	100/50/25 V
Output currents (I_{01}, I_{02}, I_{03})	100/50/25 V
Switching frequency(f)	50Hz
Inductor (L_1, L_2, L_3)	0.6/0.9/1 mH
Capacitor (C_1, C_2, C_3)	200/470/360 μf

IV.THE CONTROL METHOD OF PROPESED CONVERTER

Effective voltage regulation requires a well-designed method. Small-signal modeling has been used to generate a control transfer function for each output[1].The software is run for various load changes to gather the data needed for training the neural network (NN). The NN is then taught to respond more quickly and accurately to changes in either without changing the voltage regulation on the source or load side. Every training set has been standardized, and the output is controlled. of the neural network (NN) is de-normalized before being fed to a PWM modulator, which switches the pulses.Figure 4 displays the NN closed loop control system's fundamental block diagram.

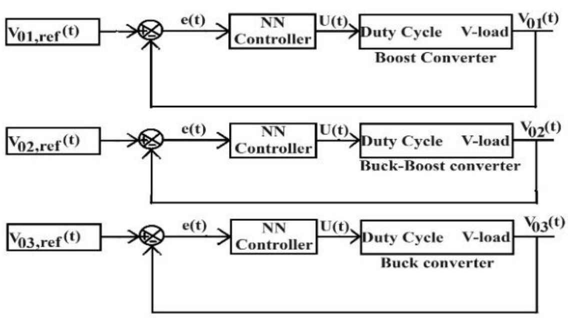


Figure 4: NN Closed loop control system.

Parameters of Neural Network:

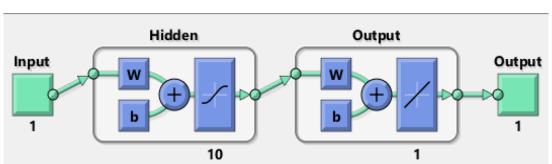


Figure 5: NN controller parameters

NN controller parameters for Buck, Boost and Buck-Boost Converter are:
For Boost Converter:

- number of data inputs:4(Error, output voltage(V_{01}), input voltage(V_{DC}) and reference voltage($V_{01,ref}$))
- The quantity of input neurons:1
- Quantity of output neurons: 1 (processed control output)
- quantity of training data:236 iterations
- Performance:0.00119

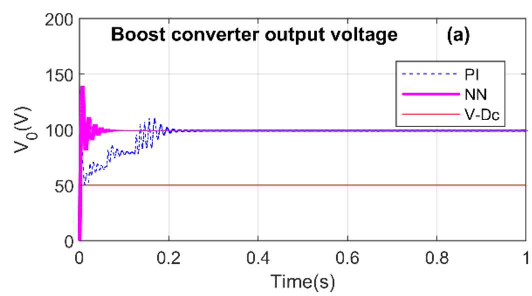
For Buck-Boost Converter:

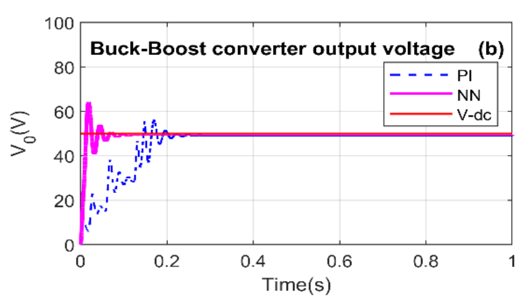
- number of input data:4(Error, output voltage(V_{02}), input voltage(V_{DC}) and reference voltage($V_{02,ref}$))
- The quantity of input neurons:1
- Quantity of output neurons: 1 (processed control output)
- quantity of training data:87 iterations
- Performance:0.000110

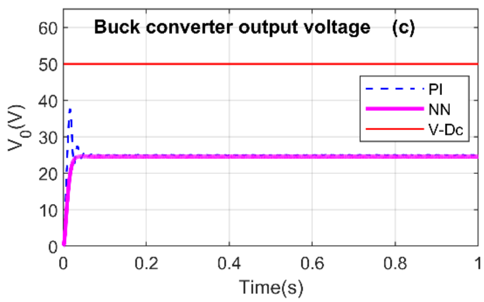
For Buck Converter:

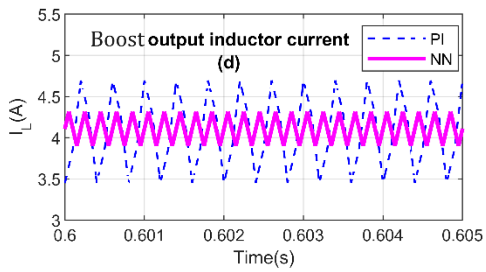
- number of input data:4(Error, output voltage(V_{03}), input voltage(V_{DC}) and reference voltage($V_{03,ref}$))
- The quantity of input neurons:1
- Quantity of output neurons: 1 (processed control output)
- quantity of training data:107 iterations
- Performance:0.000491

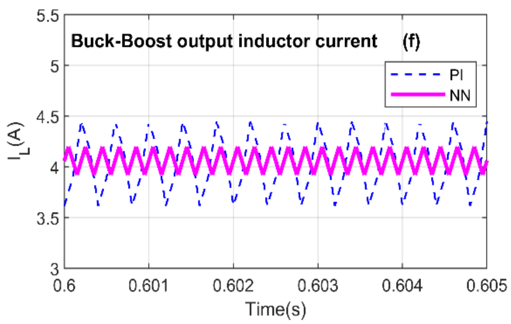
V. SIMULATION RESULTS











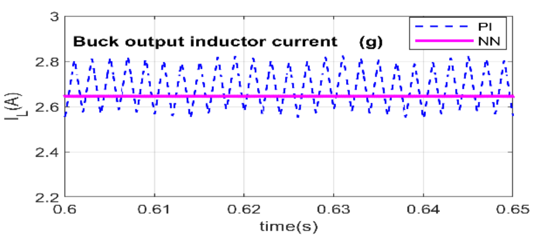
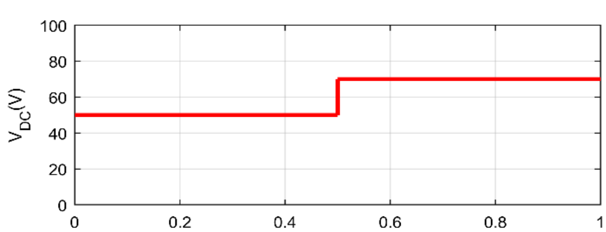
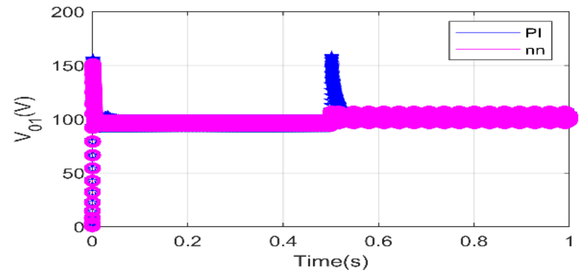
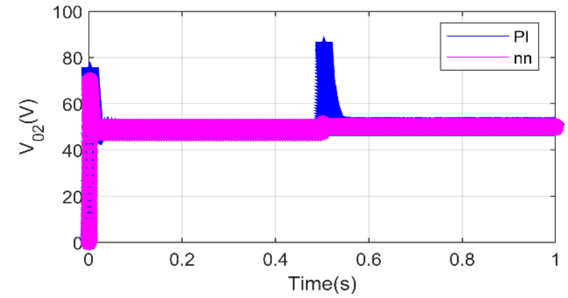


Figure 6: (a)v_{01},(b)v_{02},(c)v_{03},(d)i_{L1},(f)i_{L2},(g)i_{L3}.







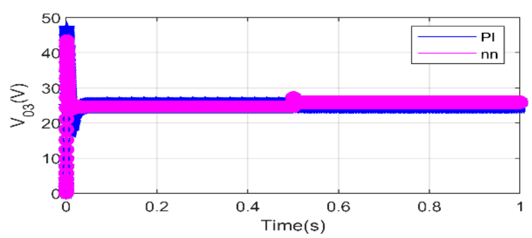


Figure 7:performance of closed loop control for a sudden variations in input voltage (V_{DC}) at 0.5 sec

To validate the proposed system, a model was created in the MATLAB environment. V_{DC} = 50V, frequency is 50 Hz.The parameter details are specified in Table. 1. The matching output voltages (V_{01}, V_{02}, and V_{03}) and inductor currents (i_{L1}, i_{L2}, and i_{L3}) are illustrated in Figure 6, respectively. The suggested configuration's closed-loop control is put into practice, and the system's overall dynamic performance is confirmed in the event of an abrupt input voltage shift. The simulation result for a quick shift in the input voltage (V_{DC}) from 50 V to 70 V at 0.5 sec is displayed in Figure 7. The NN controller is chosen for regulating the voltages for Boost, Buck-Boost, and Buck. The results show that the recommended configuration yields a quicker and more precise reaction to variations in the load and input voltage.

VI. CONCLUTION

One method that shows promise for increasing the efficiency of electric vehicles is the multi-output DC-DC converter founded on neural networks. The DC-DC converter's control system responds to changes in input voltage and load faster and more accurately thanks to the usage of a neural network. The proposed converter has been designed to provide multiple outputs with varying voltages for different applications. The recommended converter's output voltages can be efficiently controlled, as per the simulation findings. under different load conditions, and the performance is comparable to the traditional PI controller-based system. The use of a neural network-based control system in the converter is a significant contribution of this project, as it provides a better speed of response to the system's nonlinearity and eliminates the need for precise mathematical models. In conclusion, the neural network-based A multi-output DC-DC converter is a useful tool for electric vehicle applications. promising approach to improve the performance of electric vehicles.

FUTURE SCOPE:

The future potential of this neural network-based multi-output DC-DC converter for electric vehicle applications lies in reinforcement learning, which could further enhance its efficiency and performance.

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