Voltage Tracking of a Multi-Input Interleaved Buck-Boost DC-DC Converter Using Artificial Neural Network Control

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***Abstract*—This paper proposes an artificial neural network (ANN) voltage tracking of multi-input interleaved buck-boost DC-DC converter. A back-propagation algorithm topology is implemented in this paper. The control unit is implemented to ameliorate the performance of the proposed multi-input converter during transient dynamic response and steady-state operation mode. The neural network controller unit design, which is adaptive against output voltage command tracking and reference voltage variations is proposed. The proposed design has been verified through the MATLAB software. The simulation outcomes emphasized the validity and reliability of the proposed neural network technique, which would be a promising an efficient control method that ensures multi-input converter suitable for electric vehicle and renewable energy application systems**

***Index Terms*—Multi-Input Converter; Algorithm Back-Propagation; Artificial Neural Network Control; Tracking Voltage Variations.**

I. INTRODUCTION

These days, multi-input DC control supplies are broadly utilized as a part of many advanced applications in comparison to the single port electronic system, for example, electric vehicle and furthermore the sustainable power source applications [1].

Thus, DC-DC multi-input converter is broadly utilized by change over a DC voltage created from various input voltage supplies to an alternate direct voltage amount to supply the direct voltage source amount demand of the electrical load.

Furthermore, the multi-input converter is likewise an imperative application for the power control of the renewable energy system, for example, solar panel and wind turbine. Because of these reasons, multi-input converter applications will go to a more potential market in sustainable power source applications [2].

Fundamentally, the multi-input converter comprises of the power semiconductor system which worked as an electrical converter with a specific end goal to transform the electrical energy from various power supplies. The operation processes of the switching system cause the innately nonlinear normal for the multi-input converters. Because of this undesirable nonlinear characteristic, the multi-input converters require a controller system with an excellent level of dynamic reaction [3].

With a specific end goal to handle this issue and enhance the dynamic reaction of multi-input DC-DC converters, a few knowledge controller procedures, for example, fuzzy logic controller and neural network control techniques for DC converter have been described for in [4]-[11].

II. MULTI-INPUT INTERLEAVED BUCK-BOOST CONVERTER

The circuit outline of the proposed multi-input interleaved buck-boost converter as described in Figure 1. It had been intentionally supposed that Switch$_{(1)}$, Switch$_{(2)}$, Switch$_{(3)}$ and Switch$_{(4)}$ signified as S$_{(1)}$, S$_{(2)}$, S$_{(3)}$ and S$_{(4)}$ separately while Diode $_{(1)}$, Diode $_{(2)}$, Diode $_{(3)}$ and Diode $_{(4)}$ indicated as D$_{(1)}$, D$_{(2)}$, D$_{(3)}$ and D$_{(4)}$ individually. The gate pulses of the switches for the proposed converter have been purposely assumed that the duty cycle of S$_{(1)}$, S$_{(2)}$, S$_{(3)}$ and S$_{(4)}$ described as d$_{(1)}$, d$_{(2)}$, d$_{(3)}$, and d$_{(4)}$ respectively. A circuit diagram of the proposed multi-input interleaved buck-boost DC-DC converter designed is shown in Figure 1. Switching pulses pattern of switches S$_1$, S$_2$, S$_3$ and S$_4$ are described in Figure 2.

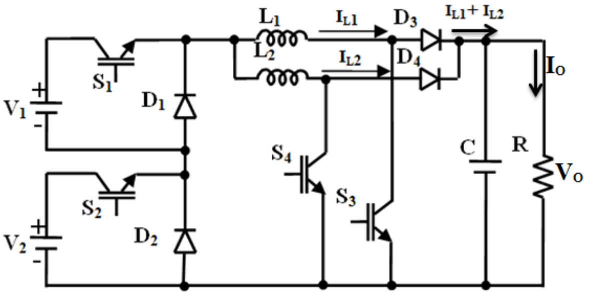

Figure 1: Circuit diagram of the Multi-Input Interleaved buck-boost DC-DC Converter

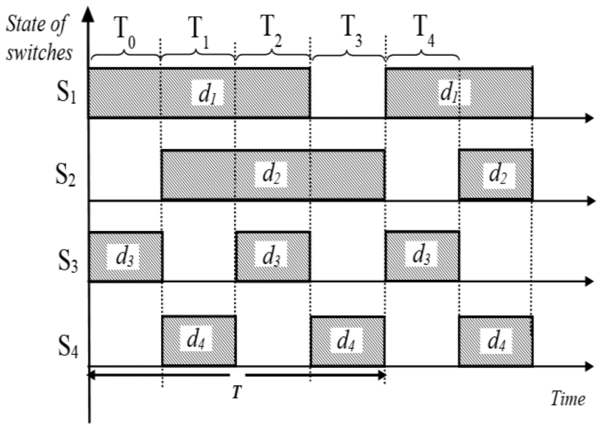

Figure 2: Switching pattern and duty cycles of switches S$_{(1)}$, S$_{(2)}$, S$_{(3)}$ and S$_{(4)}$

$$T_{(0)} = (d_1(t) - d_1(t))T \qquad (1)$$

$$T_{(1)} = d_{12}(t)\, T \qquad (2)$$

$$T_{(2)} = (d_2(t) - d_{12}(t))T \qquad (3)$$

$$T_{(3)} = d_3(t)T = (1-(d_1(t)+d_2(t)-d_{12}(t)))T \qquad (4)$$

Therefore, can write the following equations for a multi-input interleaved buck-boost converter based upon Figure 2 and volt-second balance equation of the inductors.

$$T_0 + T_1 + T_2 + T_3 = T \qquad (5)$$

Suppose that the current had reached a steady state. Thus, by analyzed can be obtained:

$$V_1(d_1 - d_{3,4})T + (V_1 + V_2)d_{3,4}T - V_o(1-d_1)T + V_2(d_2 - d_{3,4})T - V_0(1-d_2)T = 0 \qquad (6)$$

Equation (6) in principle can be solved to find voltage output transfer ratio V_o. After several algebraic manipulations and solving, the expression for the output voltage shown as the following Equation (7).

$$V_o = \frac{V_1 d_1}{(1-d_1)+(1-d_2)} + \frac{V_2 d_2}{(1-d_1)+(1-d_2)} \qquad (7)$$

III. THE PROPOSED STRUCTURE OF ARTIFICIAL NEURAL NETWORK CONTROLLER

The structure of proposed neural network controller of a multi-input converter is as described in Figure 3. The network of the suggested ANN controller has a 1-5-1 neurons network structure [3].

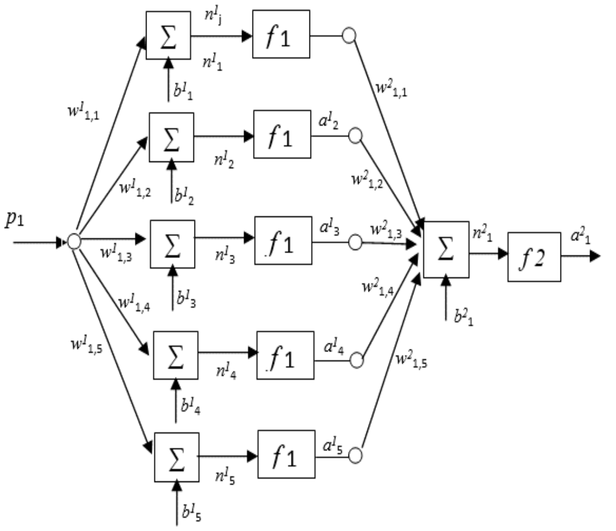

Figure 3: The proposed structure of the neural network controller system

The main weight connections value parameters between j_{th} and i_{th} neuron at m_{th} layer is presented by w_{ij}, while the bias value parameters of this layer at i_{th} neuron are presented by b_{mi}. The main transfer function model of the network of the neuron in m_{th} layer is defined as

$$n_i^m = \sum_{j=1}^{S^{m-1}} w_{ij}^m a_j^{m-1} + b_i^m \qquad (8)$$

The total output function of this neuron at m_{th} layer is given by

$$a_i^m = f^m(n_i^m) \qquad (9)$$

In Equation (9), f is defined as activation function model of the current neuron. This structure, the main activation function for the output layer and the hidden layer are unity and a tangent hyperbolic function respectively. The activation function of the hidden layer is presented as

$$f^m(n_i^m) = \frac{2}{1+e^{-2n_i^m}} - 1 \qquad (10)$$

Updating of the connection weight value and bias value parameters are presented by

$$w_{ij}^m(k+1) = w_{ij}^m(k) - \alpha \frac{\partial F(k)}{\partial w_{ij}^m} \qquad (11)$$

$$b_i^m(k+1) = b_i^m(k) - \alpha \frac{\partial F(k)}{\partial b_i^m} \qquad (12)$$

In Equations (11) and (12), k is defined as sample time, α is defended as learning rate, and F defined as performance index function of the network.

The training operation reduces and minimizes the error output percentage of the network through an optimization process [12]. Mostly, in learning mode technique of the ANN controller an appropriate training data input-output mapping data of a plant system is desired. The online learning back-propagation algorithm is designed and developed [3]. Therefore, the performance index is the sum of square error as a function of sampling time and is presented by

$$F(k) = \frac{1}{2}\sum_i e_i^2(k) \qquad (13)$$

$$e_i(k) = t_i(k) - a_i(k) \qquad (14)$$

In Equation (14), $\boldsymbol{t_i}$ defined as target signal and $\boldsymbol{a_i}$ defined as output signal on the last layer.

The gradient descent method of the performance index against to the connection weight values is presented by:

$$\frac{\partial F}{\partial w_{ij}^m} = \frac{\partial F}{\partial n_i^m}\frac{\partial n_i^m}{\partial w_{ij}^m} \qquad (15)$$

The sensitivity case of parameter for the network is defined as

$$s_i^m = \frac{\partial F}{\partial n_i^m} \qquad (16)$$

$$s_i^m = \frac{\partial F}{\partial a_i^m}\frac{\partial a_i^m}{\partial n_i^m} \qquad (17)$$

In gradient processes the transfer function again to the connection weight value parameter is given by

$$\frac{\partial n_i^m}{\partial w_{ij}^m} = a_i^{m-1} \tag{18}$$

By substituting Equations (16) and (18) through Equation (11). Consequently, the updating connection parameter is given by

$$w_{ij}^{m-1}(k+1) = w_i^{m-1}(k) - \alpha\, s_j^m(k)\;\; a_i^{m-1}(k) \tag{19}$$

The same processes will be implemented in order to update the bias parameter as given in Equation (20)

$$b_i^{m-1}(k+1) = b_i^{m-1}(k) - \alpha\, s_j^m(k) \tag{20}$$

IV. SIMULATION RESULTS

A Simulink-MATLAB software has been used to verify the efficiency of the proposed ANN control system. Schematic diagram of the proposed ANN controller system for the multi-input interleaved buck-boost DC-DC converter is described in Figure 4. The parameters of the multi-input DC-DC converter are shown in Table 1.

Table 1
Parameters for Proposed Multi-Input Converter

Symbol	Parameter	Values
L_1 & L_2	Inductance	0.5 mH
C	Capacitance	100 µF
R	Resistor	10 Ω
V_1	First input voltage	12 V
V_2	Second input voltage	24 V
$S_{(1)}$ & $S_{(2)}$	Switching frequency	10 kHz
$S_{(3)}$ & $S_{(4)}$	Switching frequency	20 kHz
$d_{(1)}$ & $d_{(2)}$	Duty cycle for main switches	75%
$d_{(3)}$ & $d_{(4)}$	Duty cycle for interleaved switches	50%
Vo	Output voltage	20 V- 60 V

The pulse width modulation switching technique with a fixed switching frequency for the gate pulse has been selected for verification simulation results study. All the results have been analyzed with continues current mode (CCM) under steady-state, transient conditions, and power flow management control. The simulation circuit of proposed multi-input interleaved buck-boost converter with using MATLAB Simulink is shown in Figure 5.

With a specific end goal to confirm the viability and effectiveness of proposed controller, the comparison between ordinary PID controller and the proposed ANN controller has been done in this investigation of simulation results.

The simulation outcomes showed that the proposed ANN controller has the capability of tracking the voltage reference variations in case of stepping-up and stepping-down, and displays a very low rise time and negligible overshoot.

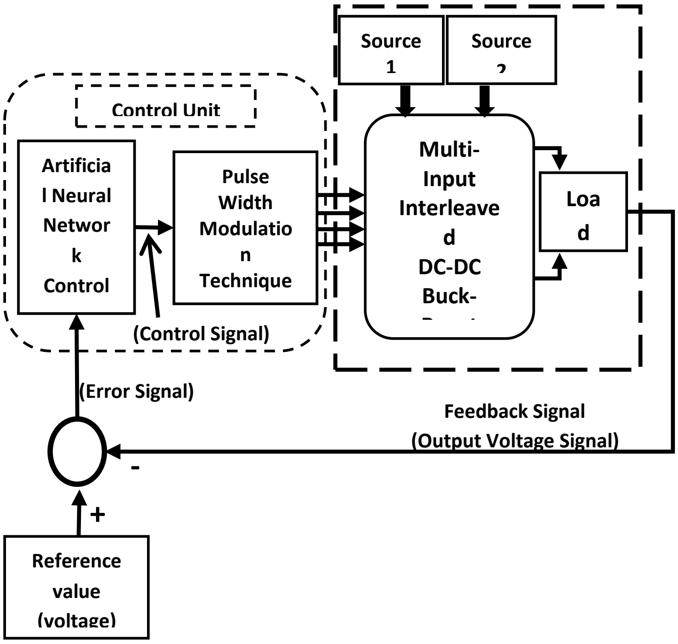

Figure 4: Schematic diagram of the proposed ANN controller system

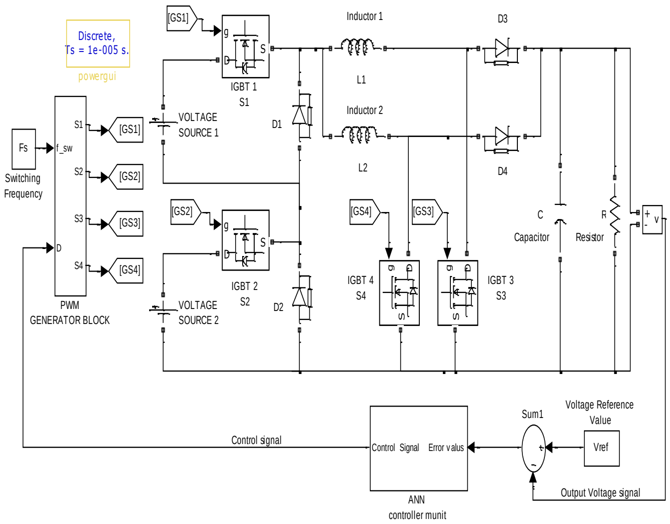

Figure 5: Simulation design of the proposed multi-input interleaved buck-boost converter

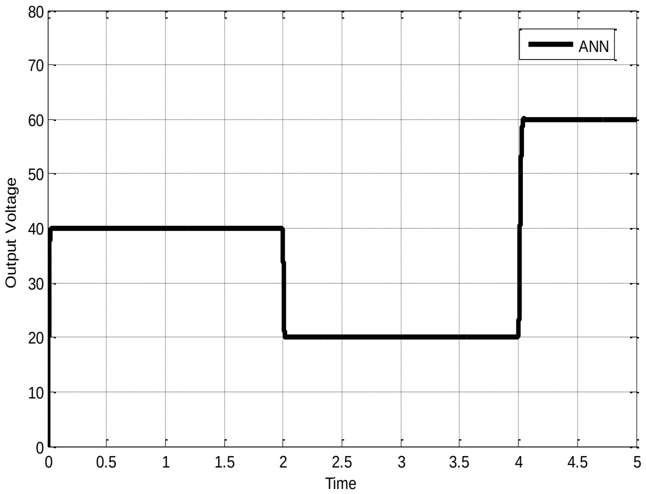

Figure 6: The dynamic response of the proposed converter when the output voltage is ordered to tracking voltage reference values 40V, 20V, and 60V.

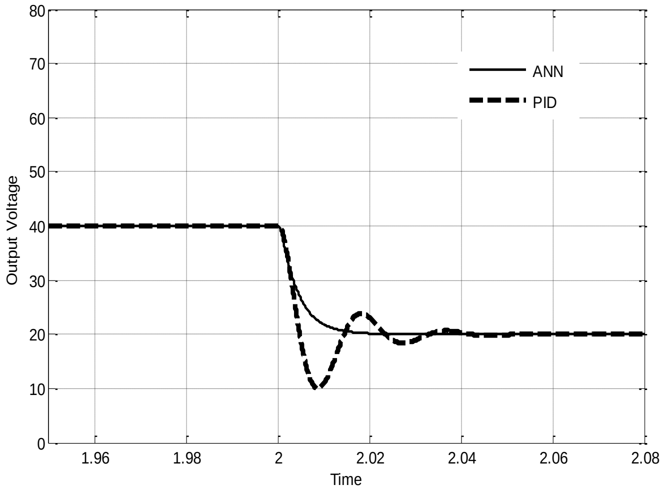

Figure 7: The dynamic response of the proposed converter when the output voltage is ordered to step-down from 40V to 20V

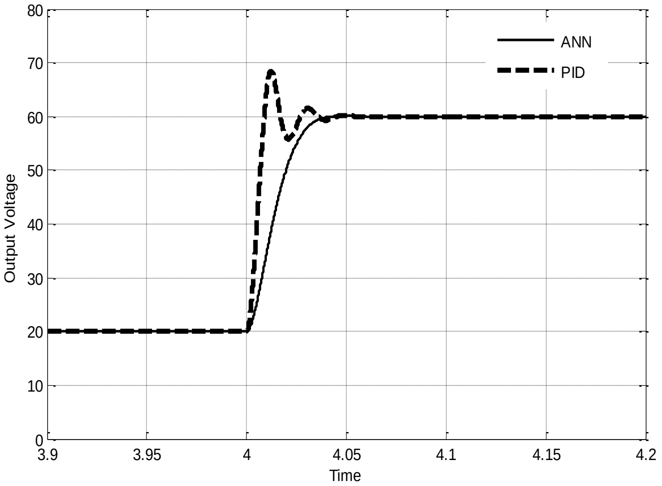

Figure 8: The dynamic response of the proposed converter when the output voltage is ordered to step-up from 20V to 50V

As observed that the output voltage dynamic transient response of the multi-input converter with reference voltage lower than the two input voltage sources (V1 and V2) as in the case of the buck converter (the output voltage 20 V) and higher than the two input voltage sources (V1 and V2) as in the case of the boost converter (the output voltage at 60V) and as described in Figure 7 and Figure 8 respectively.

The ANN proposed controller provides a preferable performance than PID-Controller such as eliminating overshoot and achieve required output voltage as described in Figure 7 and Figure 8. Moreover, the settle time of the proposed ANN controller also faster than PID-Controller.

Figure 7 and Figure 8 show the change of reference voltage of output voltage transient response for the multi-input converter. In Figure 7, the output voltage stepping-down from 40 to 20 V. In Figure 8, the output voltage stepping-up from 20 V to 60 V. It is obvious from Figure 6 and Figure 7, and Figure 8 the proposed ANN controller has a preferable transient dynamic response than the PID-Control under variations of the reference voltage-step.

V. CONCLUSION

ANN control technique for multi-input interleaved buck-boost converter has been discussed in this paper. To promote and develop performance of the voltage tracking of a multi-input interleaved buck-boost converter, a back-propagation algorithm has been developed. It is noticeable that ANN controller is efficient in decreasing the overshoot, reducing the settle time and also has a fast dynamic response to track the desired output voltage of the system. Additionally, based on the simulation outcomes, the implementation of the back-propagation technique is an appropriate solution for the output power regulation for multi-input converter supplied with different input voltage sources such as solar panel and wind turbine in renewable energy system applications.

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