Implementation and Comparison of Smart Controllers on dc-dc Buck-Boost Converter for DC Motor Drives Applications

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Abstract— **As a result of increasing power electronic applications in abundant fields, the use of these kinds of devices have been intensively arising in comparison with past decades. On the other hand, the use of intelligent controllers have permanently felt, especially in significant requests. This essay zeroed in on this controversial matter respecting the neural network and fuzzy logic controller schemes of a dc-dc Buck-Boost converter for DC motor drives application alike on variable DC voltages, and they are independently applied. The neural network learning algorithm is back propagation. By planning smart controller, the output voltage of dc-dc Buck-Boost converter and its performance during the process improved. In addition, for investigation the usefulness and effectiveness of the proposed controllers, some operations such as starting and reference voltage variations are verified. Simulation results show that the neural network controller has superior performance than fuzzy logic controller. In general, design of the system is executed by using MATLAB/Simulink.**

Keywords-component; Back Propagation, DC-DC Buck-Boost Converter, Fuzzy Logic Controller (FLC), Neural Network (NN).

I. INTRODUCTION

Indisputably, in the advanced world, in comparison with past decades, utilization of DC power supplies have been extensively growing in numerous applications such as portable computers, photovoltaic [1], wind generator [2], fuel cell systems [3] and even, more advanced applications resembling electrical vehicles [4], Nowadays, dc-dc converters are commonly exploiting by their conversion to DC voltage. The DC voltage levels requires for providing power to the load can remove. Fundamentally, a dc-dc converter includes high-power semiconductor devices which are operated as electronic switches and classified as Switched-Mode DC-DC converters or normally refers as Switched-Mode Power Supply (SMPS). The operation of the switching devices causes the naturally nonlinear characteristic of the Buck-Boost Converters. By reason of this unwanted non-linear characteristics, the converters require a controller with a high degree of dynamic response. In recent times, researchers on the switching control techniques have been highlighted in order to achieve a high-quality power system. The Pulse Width Modulation (PWM) is the most frequency considers technique among a variety of choices switching control approaches [5-6]. In the past decades, the controller for the PWM switching control was reserved to Proportional-Integral-Differential (PID) controller. This controller often have applied to converters because of their straightforwardness. Nonetheless, using of this method for controlling the non-linear systems such as power converters will undergo from dynamic response of converter output voltage regulation. In general, when the overshoot in output voltage decreases, PID controller produces long rise time [6-7]. To improve the problem of the dynamic response of the DC-DC converters, several intelligent controllers have exploited such as Fuzzy Logic Control in [8], neural network control in [9] and neuro-fuzzy control methods for DC-DC converter has used in [10]. In [11], the purpose and utilization of the fuzzy controller for DC-DC converter have implemented. In [12], with using nonlinear function controller such as fuzzy logic controller, a simple alternative fuzzy logic controller for a power electronic converter have been reported. Reference [13], the laboratory implementation of a microprocessor-based fuzzy logic tracking controller for motion controls and drives have been done. For all intents and purposes, the relatively simple fuzzy controller has an adequate performance for those systems where linear control technique fail and can apply to any DC-DC converter topologies. Due to lack of formal analysis and synthesis technique [14], it has not viewed as a rigorous science, even though many practical successes has achieved by the fuzzy logic controller, therefore, more researchers has been carrying out to improve the control system. As previously mentioned, the fuzzy-neural sliding-mode (FNSM) control system is one of the ways to control power electronic converters for a PWM-based power electronic systems [10]. The fuzzy-neural sliding-mode includes of a compensation controller and a neural controller where the compensation robust controller is designed to recover the residual of the approximate error while the neural network controller is designed to sufficient an ideal controller. The fuzzy logic controller and neural network controller are as another types of intelligent controllers have ability to progress the parameters of systems such as controlling of dc-dc Buck-Boost converter for DC motor drives on variable DC voltage. The Neural Networks controls for the DC-DC converter has been tested in both situation laboratory [9] and computer simulation model [15], both turned out to be successful. This paper compared the performance of neural network control (NNC) and fuzzy logic control (FLC) for controlling of DC-DC Buck-Boost converter for DC motor drives on variable DC voltages. This paper is organized as follows: at the first part, an overview of

Buck-Boost Converter according to its functions is presented. Then, description of Fuzzy Logic Controller explained briefly. In the next section, explanation of Neural Network architecture is described. Also, simulation results and their reports that obtained by using Matlab/Simulink software are presented. Eventually, in last section, conclusion and suggestion for further work are given in VI.

II. DESCRIPTION OF BUCK-BOOST CONVERTER

The buck-boost converter is a kind of step-down and step-up DC-DC converter. The output of buck-boost converter is regulated according to the duty cycle of the PWM with input at fixed frequency. When the duty cycle ($\boldsymbol{d}$) is less than $\mathbf{0.5}$, the converter output voltage is fewer than the input voltage. When the duty cycle is more than $\mathbf{0.5}$, the converter output voltage is more than the input voltage. The Buck-Boost converter circuit is shown in Figure 1. Then, the input voltage source is $\boldsymbol{V_s}$, output voltage is $\boldsymbol{V_o}$, switching component is $\boldsymbol{S_w}$, $\boldsymbol{d}$ is diode, $\boldsymbol{C}$ is the capacitance, $\boldsymbol{L}$ is the inductance and $\boldsymbol{R}$ is the load resistance.

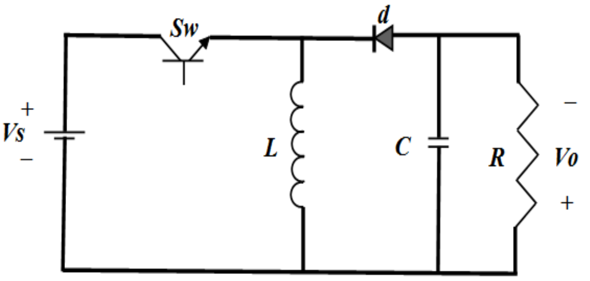

Fig. 1. Circuit diagram of a Buck-Boost converter

The equivalent equations for Buck-Boost converter during switching can be derived as following situation:

A. When switched is connected, the diode is $\boldsymbol{On}$. Then, we have:

$$v_L = v_S \tag{1}$$

$$v_L = L\frac{di_L}{dt} \tag{2}$$

From equation (1) and (2), we have:

$$v_S = L\frac{di_L}{dt} \tag{3}$$

$$\Delta i_{L(close)} = \frac{v_S DT}{L} \tag{4}$$

B. When switch is $\boldsymbol{Off}$, the diode is closed and we have:

$$v_L = -v_0 \tag{5}$$

$$v_L = L\frac{di_L}{dt} \tag{6}$$

From equation (5) and (6), we have:

$$-L\frac{di_L}{dt} = v_0 \tag{7}$$

$$\Delta i_{L(open)} = -\frac{v_0(1-D)T}{L} \tag{8}$$

Also, sign D is the duty cycle. In steady-state, by solving the linear equation during turn-on and turn-off, the average output voltage is calculated as follow:

$$\Delta i_{L(open)} + \Delta i_{L(close)} = 0 \tag{9}$$

$$\frac{v_S DT}{L} - \frac{v_0(1-D)T}{L} = 0 \tag{10}$$

$$\frac{v_0(1-D)T}{L} = \frac{v_S DT}{L} \tag{11}$$

$$v_0 = v_S\frac{D}{1-D} \tag{12}$$

For developing a dynamic model of a Buck-Boost converter, we used state-space models and $\boldsymbol{D' = 1 - D}$, where $\boldsymbol{D}$ is the duty cycle, then, we have:

$$\dot{X} = AX + BU \tag{13}$$

$$Y = CX \tag{14}$$

So that:

$$X = \begin{bmatrix} i_L \\ v_C \end{bmatrix}, \quad Y = v_0$$

$$A = \begin{bmatrix} 0 & -\frac{D'}{L} \\ \frac{D'}{C} & -\frac{1}{RC} \end{bmatrix}, \; B = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}, C = [\,0\ 1\,]$$

As a result, the transfer function of Buck-Boost converter in continues system is found as:

$$G(s) = \frac{D'R}{LRCs^2 + Ls + D'^2R} \tag{15}$$

III. DESCRIPTION OF FUZZY LOGIC CONTROLLER

During the past decades, fuzzy logic control has appeared as one of the most active and profitable research areas in the applications of fuzzy set theory, fuzzy logic and fuzzy reasoning [16]. A lot of industrials and consumer products, by utilization fuzzy logic technology, have been built and successfully sold worldwide. The basic idea behind fuzzy logic control is to incorporate the “expert experience” of a human operator in the design of a controller in controlling a process whose input-output relationship is described by a collection of fuzzy control rules (e.g. IF-THEN rules) involving linguistic variables. This utilization of linguistic variables, fuzzy control rules and approximate reasoning provides a meaning to integrate human expert experiences for designing the controller. In Fig 2, we can observe the Buck-Boost converter system with the fuzzy logic controller (FLC). The actual output voltage ($\boldsymbol{v_o}$) is compared to the reference voltage ($\boldsymbol{V_{ref}}$) to produce an error signal that is used to estimate the switching signal duty cycle. The switching signal is applied on the $\boldsymbol{S_w}$ used to decrease and enlarge output voltage on the circuit. The advantages of fuzzy logic control consists: able to design along linguistic lines – usage of rules based on experience, better performance than Conventional PID Controllers, and also, it is simple to design. The operation principle of a fuzzy logic controller is similar to human operator. It performs the same actions as a human operator by adjusting the input signal looking at only the system output. A fuzzy logic controller contains of three sections namely: fuzzifier, rule base and defuzzifier as shown in Fig 3. Two input signals, the main signal and its change for each sampling to the FLC are converted to fuzzy numbers first in fuzzifier. Then, they are used in the rule table to determine the fuzzy number of the compensated output signal. Finally, the resultant united fuzzy subsets representing the controller output are converted to the crisp values.

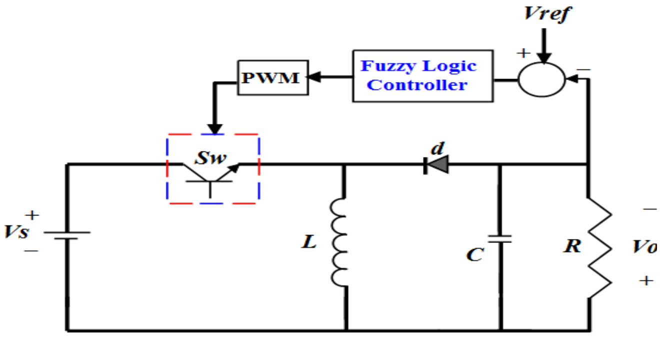

Fig. 2. Buck-Boost converter system with the FLC

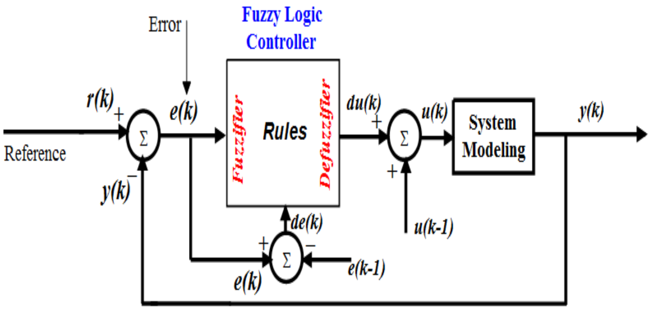

Fig. 3. The basic structure of FLC

The system variables and rules which depend on the variables are described for the control algorithm. The Buck-Boost converter output voltage is controlled by changing the switching duty cycle. The system error is defined as a different between the reference voltage and measured output value [17]. For the system, $\boldsymbol{r}(\boldsymbol{k})$ is the reference voltage and $\boldsymbol{y}(\boldsymbol{k})$ is the measured output voltage values, then the error voltage is calculated by using the following equation:

$$e(k) = r(k) - y(k) \tag{16}$$

Also, the change in the error voltage is calculated as:

$$de(k) = e(k) - e(k-1) \tag{17}$$

The membership function of the fuzzy logic controller as shown in figures 4 and 5.

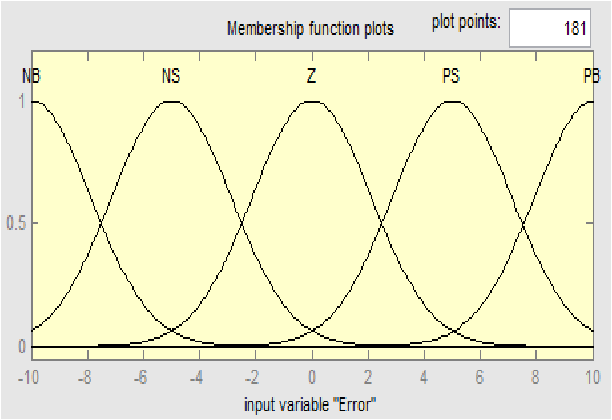

Fig. 4. Gaussian membership function for "Error"

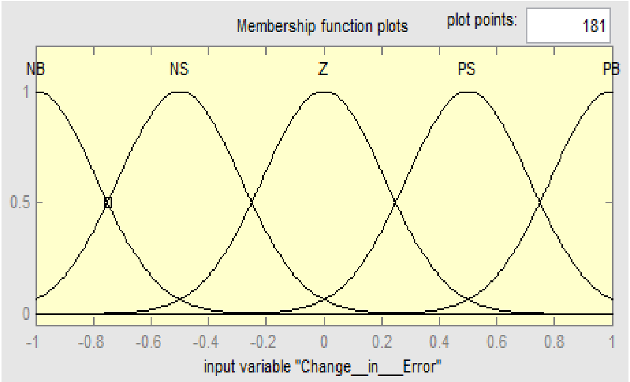

Fig. 5. Gaussian membership function for "Change in Error"

The Gaussian membership function is defined in following equation:

$$f(x) = e^{-\frac{1}{2}\left(\frac{x-c}{w}\right)^2} \tag{18}$$

The Table 1 shows the parameters of Buck-Boost converter. The Table 2 also presented the rules for fuzzy logic. This rule table can be used in the FLC rule-based controller with Simulink design.

TABLE 1. PARAMETERS OF BUCK-BOOST CONVERTER

Symbol	Parameter	Value
L	Inductance	0.6mH
C	Capacitance	100µF
V	Input Voltage	12V

TABLE 2. FUZZY RULES FOR BUCK-BOOST CONVERTER

		Δe				
		NB	NS	ZZ	PS	PB
e	NB	NB	NB	NS	NS	ZZ
	NS	NB	NS	NS	ZZ	PS
	ZZ	NS	NS	ZZ	PS	PS
	PS	NS	ZZ	PS	PS	PB
	PB	ZZ	PS	PS	PB	PB

IV. EXPLANATION OF NEURAL NETWORK

A. The Structure of Neural Network

For designing Neural Network Controller (NNC), some information about the project are required. Fundamentally, the quantity of input and output neuron at each layer are equal to the quantity of input and output signals of the system respectively. The structure of the proposed neural network control of a Buck-Boost converter is shown in Fig 6.

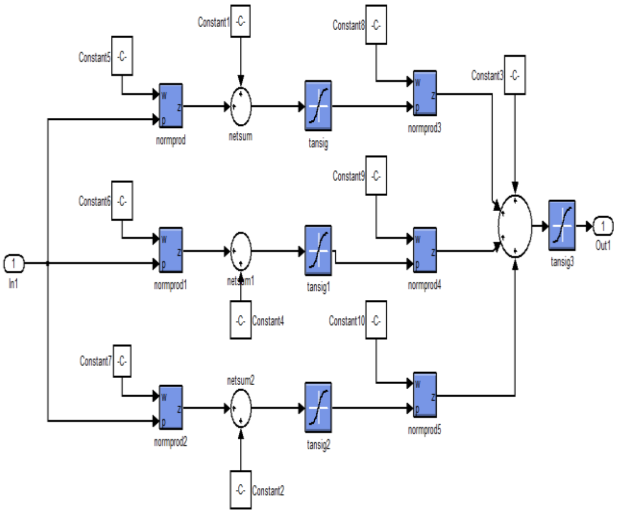

Fig. 6. Implemented architecture of the proposed NNC

For this configuration, the network has a 1-3-1 neurons structure. The input layer consists of an input neurons structure. The first input neuron is error signal between desired signal and actual signal. The connection weight parameter between j_{th} and i_{th} neuron at m_{th} layer is given by w_{th} , while bias parameter of this layer at i_{th}neuron is given by b_i^m. Transfer function of the network at t_{th} neuron in m_{th} layer is defined as:

$$n_i^m = \sum_{j=1}^{S^{m-1}} w_{ij}^m a_j^{m-1} + b_i^m \qquad (18)$$

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

$$a_i^m = f^m(n_i^m) \qquad (19)$$

So that, f is activation function of the neuron. In this design, the activation function for the output layer and the hidden layer are unity and a tangent hyperbolic function correspondingly. The activation function for hidden layer is given as:

$$f^m(n_i^m) = \frac{2}{1-e^{-2n_i^m}} - 1 \qquad (20)$$

And updating of the connection weight and bias parameters are given by:

$$w_{ij}^m(k+1) = w_{ij}^m(k) - \alpha \frac{\partial F(k)}{\partial w_{ij}^m} \qquad (21)$$

$$b_i^m(k+1) = b_i^m(k) - \alpha \frac{\partial F(k)}{\partial b_i^m} \qquad (22)$$

So that, $\boldsymbol{k}$ is sampling time, $\boldsymbol{\alpha}$ is learning rate and $\boldsymbol{F}$ is performance index function of the network.

B. The Back-Propagation Learning Algorithm

In this stage, we defined the learning model for updating the network parameters. By this capability, it makes the neural network suitable to be implemented for the system with motor parameters which are difficult to define and very against with environment. The training process minimizes the error output of the network through an optimization method. The parameters of induction motor drive vary with temperature and magnetic saturation, and also, the online learning Back-Propagation (BP) algorithm is developed. Based on the first order optimization scheme, updating of the network parameter is covered. The performance index sum of square error is given by:

$$F(k) = \frac{1}{2}\sum_i e_i^2\,(k) \qquad (23)$$

$$e_i(k) = t_i(k) - a_i(k) \qquad (24)$$

So that, t_i is target signal and a_i is output signal on last layer. The gradient descent of the performance index against to the connection weight is given by:

$$\frac{\partial F}{\partial w_{ij}^m} = \frac{\partial F}{\partial n_i^m}\frac{\partial n_i^m}{\partial w_{ij}^m} \qquad (25)$$

The sensitivity parameter of the neural network is defined as:

$$S_i^m = \frac{\partial F}{\partial n_i^m} \qquad (26)$$

$$S_i^m = \frac{\partial F}{\partial a_i^m}\frac{\partial a_i^m}{\partial n_i^m} \qquad (27)$$

The gradient the transfer function again to the connection weight parameter is given by the following equation:

$$\frac{\partial n_i^m}{\partial w_{ij}^m} = a_i^{m-1} \qquad (28)$$

From substitution equation (26) and (28) into (21) the updating connection parameter is given by the following equation:

$$w_{ij}^{m-1}(k+1) = w_i^{m-i}(k) - \alpha S_i^m(k)\alpha_i^{m-1}(k) \qquad (29)$$

With the same technique to update the bias parameter is given by:

$$b_i^{m-1}(k+1) = b_i^{m-i}(k) - \alpha S_i^m(k) \qquad (30)$$

Block diagram of the proposed neural networks controller (NNC) for Buck-Boost converter is shown in Fig 7.

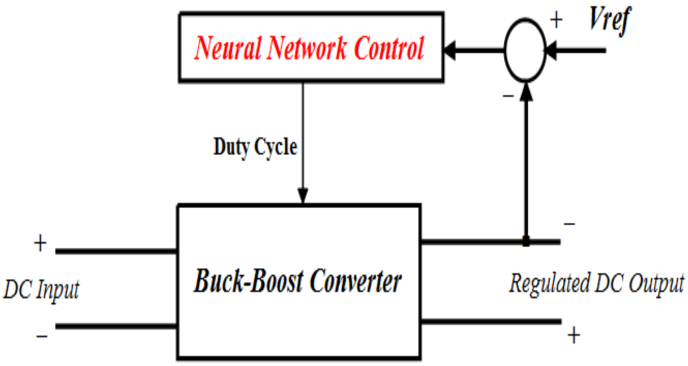

Fig. 7. Block diagram of the proposed NNC for Buck-Boost converter

V. SIMULATION RESULTS

Comparison between fuzzy logic, neural network and PI controller is done in Matlab/Simulink. We acquainted that the output voltage start-up transient response of the Buck-Boost converter with reference voltage is higher than the input voltage source as in the case of the boost converter and lower than the input voltage source as in the case of the buck converter as shown in Fig.8 and Fig.9 correspondingly. For description simulation results, we commenced from Fig 8.

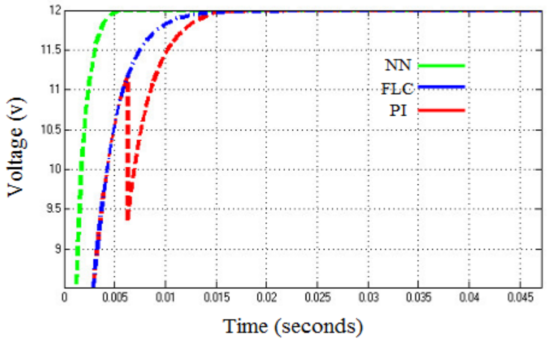

Fig. 8: Output voltage transient response of the converter during start-up at 12V

In Fig 8, it is noticeable that neural network has better performance than fuzzy logic and PI controllers. If you concentrate on picture precisely, you will realize that waveforms of FLC and PI, they are in the same situation, and also, mixed together roughly. But there is remarkable condition. For the reason that, after 0.05sec, the waveform of PI controller dropped spontaneously, and it has instability. Hence, we can understand that PI controller is not proper controller for this work, and it has significant lack unfortunately. In contrast, for assessment the situation of waveforms in time-rising, NN controller has high accuracy in comparison with FLC and PI controller indisputably. On the other hand, if you focused on Fig. 9, you could recognize that in steady-state, neural network waveform reached to less than 12 volts, but the related waveforms for FLC and PI were under the NN. By thoughtfulness this matter, it is conspicuous that in the steady state, for converter start-up, there are three output voltages for all controller, and output voltage for NN controller has better performance in association with FLC and PI controllers. Because it is so sensitive relatively about any kinds of changings. In Fig 10, we estimated the output voltage response for voltage changing from 12V to 24V. Alike Fig 8, there are some differences between three outputs. If you observed on Fig 10, you could comprehend that until one second, NN, FLC and PI controller are in the same condition. But, by spending time, this situation disordered suddenly. For more explanation, the disorder after one second, as you have seen, the waveform of NN controller established particular difference between own, FLC and PI controller, and at the same time, waveforms of FLC and PI controller blended together approximately. But between 1.005 seconds and 1.01 seconds other phenomenon happened. In the very diminutive time, the PI controller dropped unexpectedly. In the meantime, the NN controller and FLC controller again combined together. Also, it looks like that in the steady-state, they are in the same condition. Undeniably, in steady-state, the waveforms of controllers are similar Fig 9. By the way, we investigated the other circumstances for inverse condition. Fig 11 shows the condition about output voltage transient response from 24V to 12V.

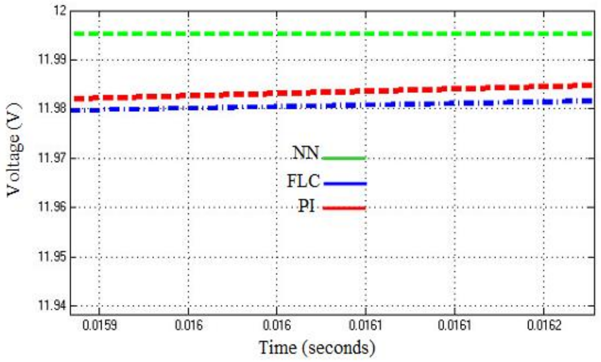

Fig. 9. Zooming on Fig 8, in the steady-state

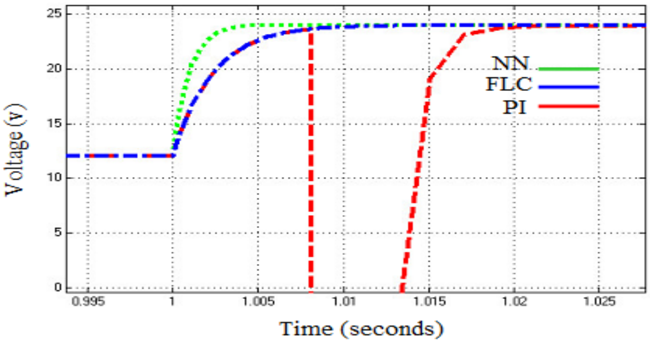

Fig. 10. Output voltage transient response to reference change from 12V to 24V

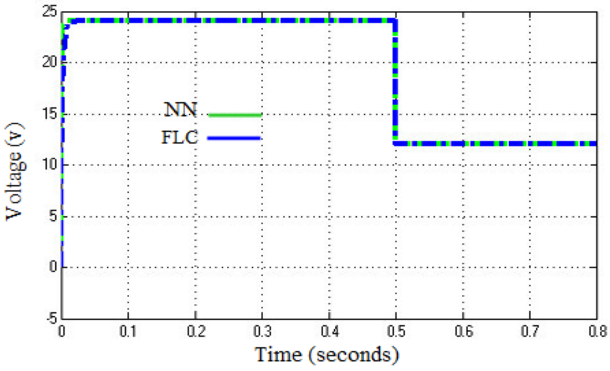

Fig. 11. Output voltage transient response to reference change from 24V to 12V

For Fig 11, we evaluated only NN and FL controllers. Firstly, it looks that, the NN and FLC are in the same way, and there is no differences. This matter is about the condition of simulation and Buck-Boost converter. Definitely, if you perceived on picture, you might find out that in start-up, waveforms for NN and FLC stuck together. But, by zooming on waveforms, we realized that they are separated, and there is undeniable space between them. In above figure, in the beginning, two outputs reached to 24V until 0.5 seconds, and the waveforms are in common situation approximately. After spending more time, the appearance of waveforms have changed and similar the situation before 0.5 seconds, they are in same condition roughly. Finally, after dropping, the reached to 12V. Alternatively, by zooming on Fig 11, we always understood that NN controller waveform has better response in comparison with FLC's waveforms. This phenomenon is observable in the following figure.

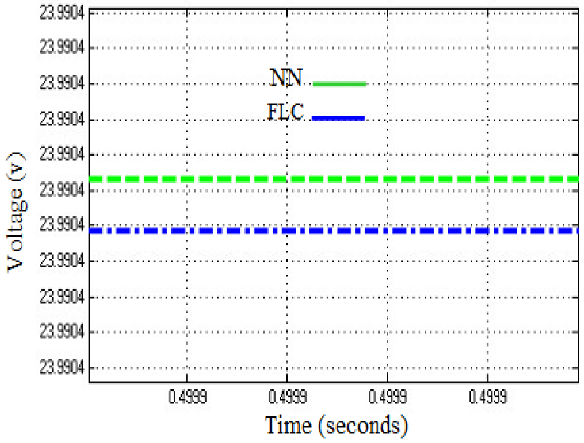

Fig. 12. Zooming on Fig 11, in the steady-state

VI. CONCLUSION

This paper has shown two different approaches that could use in DC motors drives applications: neural network control and fuzzy logic control in dc-dc Buck-Boost converter. In fuzzy logic control, Gaussian membership function used. In neural network control, back-propagation algorithm used. The dc-dc Buck-Boost converter circuit planned with Matlab/Simulink and then simulation consequences have been accomplished. It is lucid from results that neural network outputs are satisfactory in comparison with other outputs resembling fuzzy logic and PI controllers. The neural network has impressive effect on reducing overshoot as well as fluctuation, settling time and also has a rapid response to track desired output voltage. For further study, expanding knowledge about neural networks and fuzzy logic control, we can use these kinds of controllers to control the system of hydropower plants, especially for controlling governors, static frequency convertors (SFC), and also, in electrical propulsion applications in marine technology. In a nutshell, we would like to suggest for implementation of neural network and fuzzy logic in SFC in the future. Because SFC has significant role in pumped-storage hydropower plant. Designing new controller according to situations and parameters of power plants, for decreasing the any kind of lacks, execution new controllers by using different kind of neural networks controller for SFC will be valuable.

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