Voltage Tracking of a DC-DC Flyback Converter Using Neural Network Control

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Article Info	ABSTRACT
	This paper proposes a neural network control voltage tracking scheme of a DC-DC Flyback converter. In this technique, a back propagation learning algorithm is employed. The controller is designed to improve performance of the Flyback converter during transient and steady state operations. Furthermore, to investigate the effectiveness of the proposed controller, some operations such as starting-up and reference voltage variations are verified. The numerical simulation results show that the proposed controller has a better performance compare to the conventional PI-Controller method.

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1.   INTRODUCTION

In recent pass, DC power supplies are extensively utilized in many areas compromising of simple electronic devices such as notebook computers, till even more advance application such as electric vehicle and also the aerospace applications. Hence, the DC- DC converter is widely used by convert a DC voltage to a different DC voltage level in order to provide the DC voltage source level requirements of the load to the DC power supply, In addition, the DC-DC converter is also an important application for the power conditioning of the alternative electrical energy such as photovoltaic, wind generator and fuel cell system. Due to these reasons, the DC-DC converter application will head to a more potential market in the future.

Basically, the DC-DC converter consists of the 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]. Operation of the switching devices causes the inherently nonlinear characteristic of the Flyback converters. Due to this unwanted nonlinear characteristics, the converters requires a controller with a high degree of dynamic response. Recently, the research on the switching control techniques has been highlighted in order to achieve a high-quality power system. Pulsewidth modulation (PWM) is the most frequently consider method among the various switching control method [1].

In the past decade, the controller for the PWM switching control is restraining to Proportional-Integral-Differential (PID) controller. This controller often applied to the converters because of their simplicity. However, implementations of this control method to the nonlinear plants such as the power converters will undergo from dynamic response of the converter output voltage regulation. In general, PID controller produces long rise time when the overshoot in output voltage decreases [2].

In order to tackle this problem and improve the dynamic response of DC-DC converters, several intelligence controllers such as fuzzy logic control, neural network control and hybrid neuro-fuzzy control methods for DC-DC converter have been reported in [3]-[10]. The purpose and utilization of the fuzzy controller for dc-dc converter has been developed in [5]. Implementations of the fuzzy logic control to dc-dc converter using micro controller have been verified in [6]. Inherently, the relatively simple fuzzy controller has a good 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 [4] it has not been viewed as a rigorous science, even though many practical successes has been achieved by the fuzzy logic controllers, hence, a lot of research has been carried out to improve the control system. A fuzzy-neural sliding-mode (FNSM) control system is one of the approaches that develop to control power electronic converters [3] for a PWM-based power electronic system. The FNSM control system consists of a compensation controller and a neural controller where the compensation robust controller is designed to recover the residual of the approximation error, while the neural controller is designed to approximate an ideal controller. An Adapt recurrent fuzzy neural network (ARFNN) control system is proposed in [4] in order to achieve good regulation performances. With the on-line learning algorithm is applied, the ARFNN control scheme is suitable to control the dc-dc converter.

Neural network controls [NNC] for the DC-DC converter has been tested in both laboratory [7] and computer simulation model [8]-[10] both turned out to be successful. NNCs illustrate the result in minimizing the difference between the output voltage and the reference voltage [9]. In addition, the dynamic characteristics of dc-dc converter are improved and can realize excellent dynamic characteristics with the used of neural network [8],[10] as compare with the conventional PID method.   In order to improve performance of the NNC some researchers have been done to develop online learning scheme of the NNC.

The organization of this paper is as follows: Section II discusses basis concept of a Flyback converter as a step-up and step-down of a DC-DC converter. In section III, the design of neural network control is described. Simulation results are carried out in section IV. Finally, conclusions are summarized in Section V.

2.   FLYBACK CONVERTER

The Flyback Converter is the basic fundamental of the DC-DC converter. More precisely, the Flyback converter is a buck-boost converter with the inductor split to form a transformer, so that the voltage ratios are multiplied with an additional advantage of isolation. In this project, the Flyback Converter was proposed due to the advantages in electrical isolation rather than the other converter. Flyback converter is a type of step-down and step-up DC-DC converter. Output of the Flyback converter is regulated according to the duty cycle of the PWM input at fixed frequency. When the duty cycle (d) is less than 0.5, the output voltage of converter is lower than the input voltage. On other condition, when the duty cycle is more than 0.5 the output voltage of converter is higher than the input voltage. The basic circuit of a Flyback converter is illustrated in Figure 1 where V_s is input voltage source, V_o is output voltage, S_w is switching component, D_1 is diode, C is capacitance and R is load resistance.
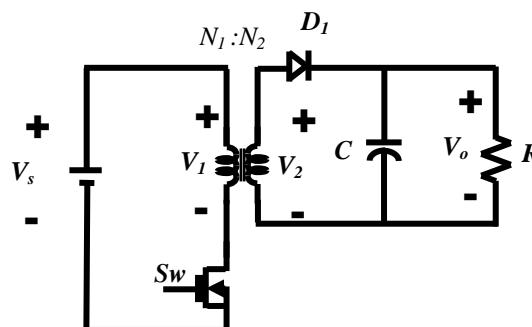

Figure 1. Circuit diagram of a Flyback converter

The equivalent equations for Flyback converter during switching-on and switching-off the power semiconductor device can be derived as follow:

When the switch device is closed

$$V_1 = V_S \tag{1}$$

$$V_1 = L_m \left(\frac{di_m}{dt} \right) \tag{2}$$

$$\Delta i_{m(\ close\ )} = \frac{V_s DT}{L_m} \tag{3}$$

Where L_M is isolated inductor windings, D is duty cycle and T is switching period.

When the switch device is opened

$$V_2 = -V_o \tag{4}$$

$$V_1 = V_2 \left(\frac{N_1}{N_2} \right) \tag{5}$$

$$\Delta i_{m(\ open\ )} = \frac{-V_o(1-D)T}{L_m} \left(\frac{N_1}{N_2} \right) \tag{6}$$

In steady state operation

$$V_o = V_s \frac{D}{1-D} \left(\frac{N_2}{N_1} \right) \tag{7}$$

$$i_m = \frac{V_s D}{(1-D)^2 R} \left(\frac{N_2}{N_1} \right)^2 \tag{8}$$

$$\Delta i_m = \frac{V_s DT}{2L_m} \tag{9}$$

L_m at continuous current mode is

$$L_{m(\min)} = \frac{(1-D)^2 RT}{2} \left(\frac{N_1}{N_2} \right)^2 \tag{10}$$

3. NEURAL NETWORK CONTROL STRUCTURES AND LEARNING ALGORITHM

To design the neural network control, some information about the plant is required. Basically, the numbers of input and output neuron at each layer are equal to the number of input and output signals of the system respectively.

3.1. Structure of Neural Network Controller

The structure of the proposed neural network control of a flyback converter is as shown in Figure 2. Based on the number of neurons in each layer of the proposed NNC architecture, the network has a 1-3-1

neurons structure. In the input layer consists of an input neurons. The first input neuron is error signal between desired signal and actual signal.
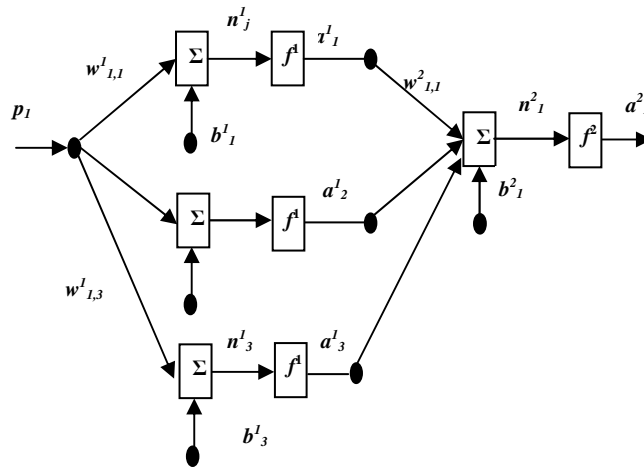

Figure 2. Architecture oɪ ᴛne proposed neural network controller

The connections weight parameter between jth and ith neuron at mth layer is given by wij, while bias parameter of this layer at ith neuron is given by bmi. Transfer function of the network at tth neuron in mth layer is defined as

$$n_i^m = \sum_{j=1}^{S^{m-1}} w_{ij}^m a_j^{m-1} + b_i^m \tag{11}$$

The output function of neuron at mth layer is given by

$$a_i^m = f^m(n_i^m) \tag{12}$$

Where 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 respectively. The activation function of the hidden layer is given as

$$f^m(n_i^m) = \frac{2}{1 + e^{-2n_i^m}} - 1 \tag{13}$$

Updating of the connection weight and bias parameters are given by

$$w_{ij}^m(k+1) = w_{ij}^m(k) - \alpha \frac{\partial F(k)}{\partial w_{ij}^m} \tag{14}$$

$$b_i^m(k+1) = b_i^m(k) - \alpha \frac{\partial F(k)}{\partial b_i^m} \tag{15}$$

where k is sampling time, α is learning rate, and F performance index function of the network.

3.2. Learning Algorithm of Back Propagation

After the neural network architecture is modelled, the next stage defines the learning model to update network parameters. By this learning capability, it makes the ANN suitable to be implemented for the system with motor parameters which are difficult to define and vary against with environment. The training process minimizes the error output of the network through an optimization method. Generally, in learning mode of the neural network controller a sufficient training data input-output mapping data of a plant is

required. Since the motor parameters of the induction motor drive vary with temperature and magnetic saturation, the online learning Back propagation algorithm is developed.

Based on the first order optimization scheme, updating of the network parameters are covered. The performance index sum of square error is given by

$$F(k) = \frac{1}{2} \sum_i e_i^2(k) \tag{16}$$

where ti is target signal and ai output signal on last layer.

$$e_i(k) = t_i(k) - a_i(k) \tag{17}$$

The gradient descent of the performance index against to the connection weight is given by:

$$\frac{\partial F}{\partial w_{ij}^m} = \frac{\partial F}{\partial n_i^m} \frac{\partial n_i^m}{\partial w_{ij}^m} \tag{18}$$

The sensitivity parameter of the network is defined as

$$s_i^m = \frac{\partial F}{\partial n_i^m} \tag{19}$$

$$s_i^m = \frac{\partial F}{\partial a_i^m} \frac{\partial a_i^m}{\partial n_i^m} \tag{20}$$

Gradient the transfer function again to the connection weight parameter is given by

$$\frac{\partial n_i^m}{\partial w_{ij}^m} = a_i^{m-1} \tag{21}$$

From substitution equations above the updating connection parameter is given by:

$$w_{ij}^{m-1}(k+1) = w_i^{m-i}(k) - \alpha s_i^m(k) a_i^{m-1}(k) \tag{22}$$

With the same technique the updating bias parameter is given by:

$$b_i^{m-1}(k+1) = b_i^{m-i}(k) - \alpha s_i^m(k) \tag{23}$$

4. RESULTS

A computer simulation using Simulink - MATLAB has been conducted to verify the effectiveness of the proposed controller. Block diagram of the proposed NNC for the Flyback converter is show in Figure 3. The Flyback converter parameters are shown in table 1.
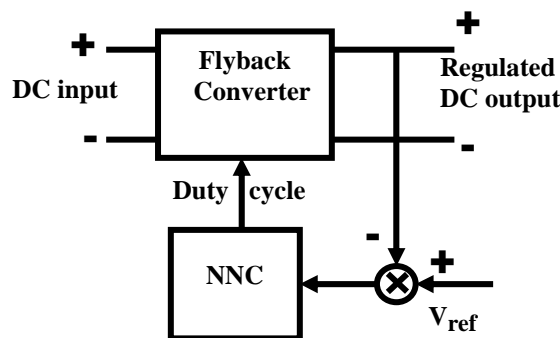

Figure 3. Block diagram of the proposed NNC control of Flyback converter

Table 1. Parameters of the flyback converter

Variable	Parameter	Value
L1	Primary inductance	0.6 (mH)
n	Turn Ratio	1/4
C	Capacitance	100 (μF)
V1	Input voltage	12 (volt)

The comparison between conventional PI controller and the proposed NNC is done in this simulation. It is found that the output voltage startup transient response of the Flyback converter with reference voltage is higher than the input voltage source as in the case of the boost converter (the output voltage at 24 volt) and lower than the input voltage source as in the case of the buck converter (the output voltage 12 volt)as shown in Figure 4 and Figure 5 respectively.

The proposed NNC produce a better performance than PI-Controller such as removing overshoot and oscillation to achieve desired output voltage as shown in Figure 4 and 5. Furthermore, the settling time of the NNC also faster than PI-Controller.

Figure 6 and 7 shows the output voltage transient responses of the Flyback converter to the change of reference voltage. In Figure 6, the reference voltage stepping-up from 12 to 24 volt. In Figure 7, the references voltage stepping-down from 24 to 12 volt. It is obvious from Figure 6 and 7, the proposed NNC has a better transient response rather than the PI-Controller under the reference voltage-step variations.
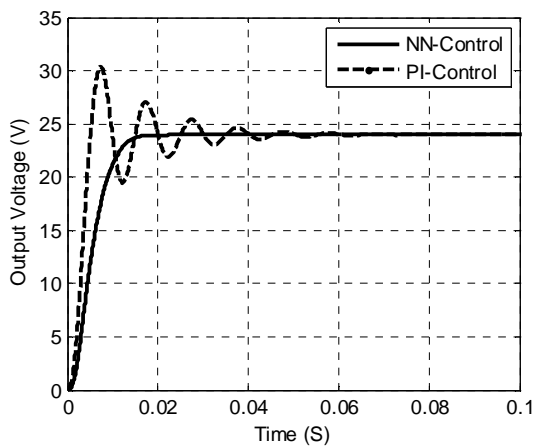

Figure 4. The output voltage transient response of the converter during starting-up at 24 volt
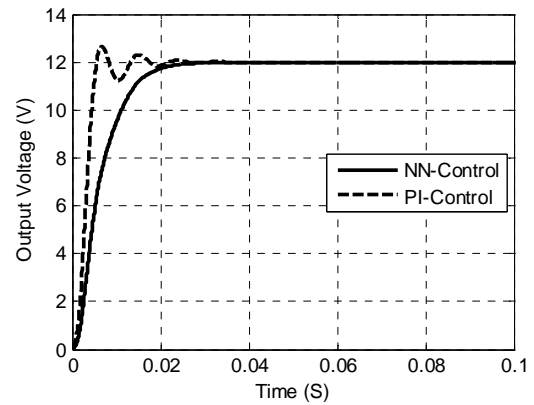

Figure 5. The output voltage transient response of the converter during starting-up at 12 volt
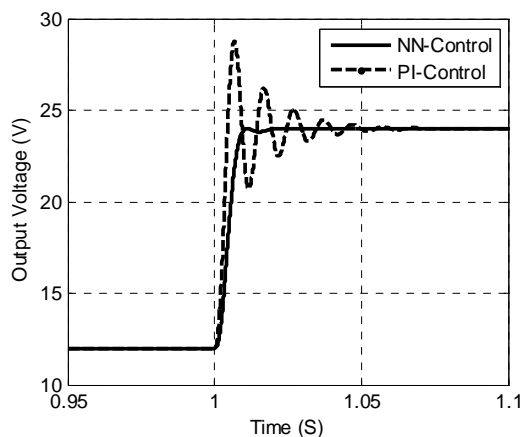

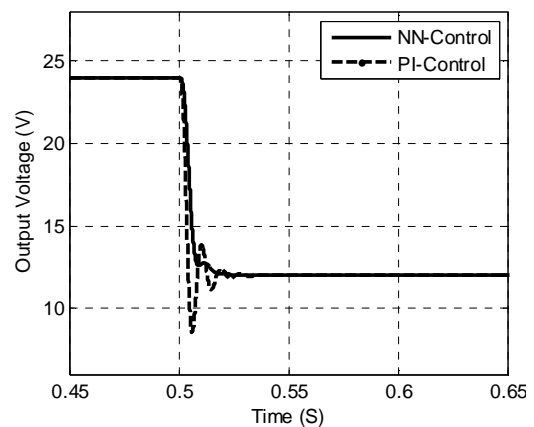Figure 6. output voltage transient response to reference change from 12 to 24 volt

Figure 7. output voltage transient response to reference change from 24 to 12 volt

5.   CONCLUSION

In this paper a neural network control for Flyback DC-DC converter is discussed. To enhance performance of the voltage tracking of a Flyback converter, a back propagation learning algorithm is developed. The implementation of the back propagation learning technique is feasible for the Flyback converter based on the results in the simulation. It is observable that the NNC is effective in decreasing overshoot, reducing settling time and also has a fast response to track desired output voltage.

ACKNOWLEDGEMENTS

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