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Performance Improvement of a DC/DC Converter Using Neural Network Controller in comparison with Different Controllers

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Abstract. Controlling a system is a complicated job, especially when we talk about the nonlinearity of the system introduced by the external changes. This paper presents the procedure of designing, analysis, and verification of nonlinear autoregressive moving average controller (NARMA L2) as an artificial intelligence technique to track the output voltage of a Buck dc/dc converter in comparison with PID controller, digitalized sliding mode controller so as to reduce the ripples in output voltage and to suppress the transient overshoots, or in other words, enhance the transient response diversity of the plant in the case of load and line changes. In this technique, a back- propagation learning algorithm is derived to increase the effectiveness of the proposed controller. Finally, the proposed method of control using a neural network controller is designed using MATLAB/SIMULINK and the results of the converter for the Neuro controller are compared with different techniques of control.

1   Introduction

Regulated power supplies are highly efficient devices that enable different systems to execute their functions, one important type that can secure a low stable output voltage is the step down dc/dc converter (Buck), this device has a non-linear properties resulted by parameters aging, fluctuation, and disturbances   which at the end affect the stability. Controlling these non-linear converters is a difficult process, especially when their characteristics change with time, many approaches are involved in this purpose such as PID controller, sliding mode controllers (SMC), also digital sliding mode controllers (DSMC), fuzzy controllers [1], [2], [3]. Another approach is widely considered in this field is the artificial neural networks (ANN) which is an aspect from the artificial intelligence that many modern applications are based on it such as robotics, aerospace, automotive, Telecommunications, medical and so on. This approach is similar to the biological nervous system of mankind with the ability of training to execute a fixed-function by tuning the weights between elements, resulting in a precise output that is formed by explicit input as is outlined in Fig.1. The supervised learning is based on a comparison between the output and target until the output of the network matches the target using several couples of input-target values.

In this paper a Neuro-controller type NARMA-L2 controller is considered, this neuro-controller can give a stable response and can overcome the control difficulties by identifying nonlinear converter and

linearize it by itself using input and output to train the network. In the present work the NARMA -L2 controller is considered and compared with the PID controller and the digital sliding mode controller to demonstrate the improvement of the dynamic response, rising time, settling time considered by these types to choose the adequate control strategy can be used for practical implementation. A digital simulation is obtained to represent the characteristics and responses of each controller.
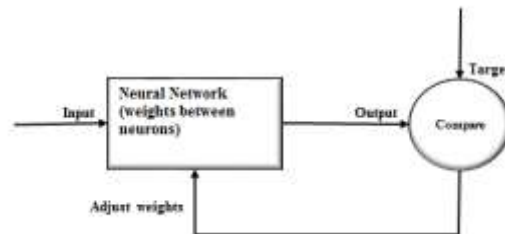

Figure 1. Training of a neural network.

1.1. The dc/dc converter

As it is known that dc/dc converters are devices by which the output voltages can be controlled in cases of boosting, depressing, or both cases, the case under study is the Buck dc/dc converter or sometimes is called step down converter which its basic circuit is shown in **Fig.2**. The converting process is established depending on switching procedure, or in other words we have two states, ON, and OFF state, from here we can define the continuous-time model of such converter given in canonical from as [4]:
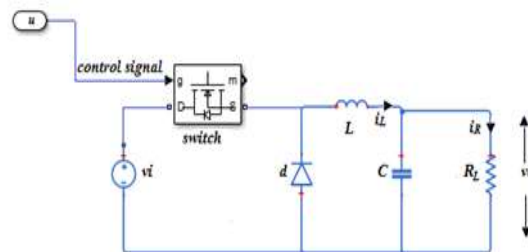

Figure 2. Buck topology.

$$A = \begin{bmatrix} 0 & 1 \\ -\dfrac{1}{LC} & -\dfrac{1}{R_L C} \end{bmatrix}; \ B = \begin{bmatrix} 0 \\ \dfrac{\beta v_i}{LC} \end{bmatrix}; \ C = \begin{bmatrix} 1 & 0 \end{bmatrix} \tag{1}$$

Also, we can define the transfer function as:

$$TF_{back}(s) = C \begin{bmatrix} SI - A \end{bmatrix}^{-1} B$$

$$TF_{buck} = \frac{\beta V_i}{R_L L C s^2 + L s + R_L} \tag{2}$$

Where: vi, vo, u: is the input, output, control voltage respectively, L-inductor, C-capacitor, d- diode, RL- output resistance, $\beta-$ is the sensor gain.

In **Fig.3**, is proposed the conventional   Buck dc/dc converter .
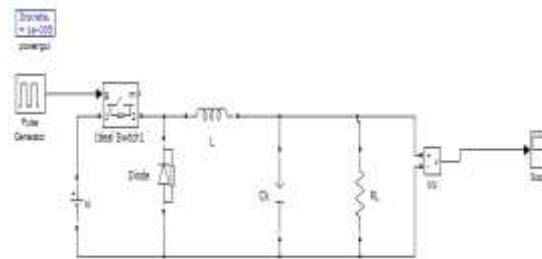

Figure 3. Conventional   Buck dc/dc converter   .

1.2. PID Controller

This controller combines different types of control with the aim to reduce the variance between the given variable and the required value (the error value), resulting in a corrective action that regulates the process accordingly. Each of these parameters can be tuned separately,   so in case we need to tune the reaction to the current error, we change the proportional value, also, the integral controller is responsible for adjusting the total errors, finally in case of adjusting the reaction to the rate at which the error has been changed we change the derivative one [5],the control action can be reached by tuning these three parameters to reach the specified process requirements depending on trial and error approach and the engineer experience. This controller produces a long rise time by decreasing the overshoot of the converter [6]. **Fig.4** illustrates the implementation of PID controller.
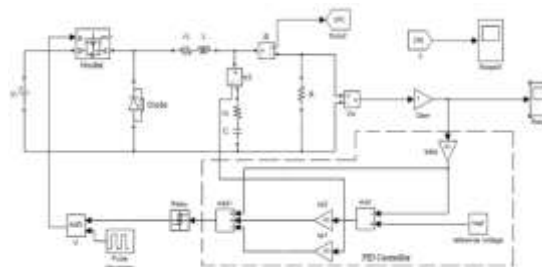

Figure 4. The implementation of a PID controller.

1.3. Digital Sliding Mode Controller (DSMC)

This controller has advantages compared to analogue controller which is sensitive to component variation, and that's why we have difficulties in realization of the control law, also the DSMC has fast response, good transient performance, insensitiveness to matching parameter uncertainties and external disturbances, also, there is no need for critical sensors in signal estimation. The simulation circuit for the Buck Dc/dc converter with DSMC is considered in **Fig.5** [4].
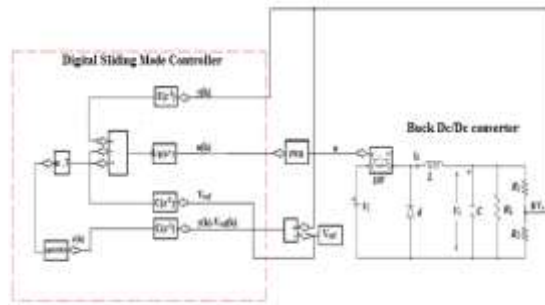
Figure 5. The implementation of DSMC.

2. Artificial Neural Network (ANN)

Artificial neural network is a useful technique that can change its structure through learning stage to establish data patterns by modelling the dependence between inputs and outputs of the system, or briefly it can be trained with the help of known examples to achieve information about a problem, the whole process is built upon the control process of the duty cycle regulation. The basic circuit of ANN consists of three layers: input layer, pattern layer, and output layer as it can be seen from **Fig.6**, so the ANN are systems which can acquire, store, and implement experiential knowledge resulted by studying and designing the required neuro controller for the specified task.

2.1. Nonlinear Autoregressive Moving Average NARMA- L2

The NARMA L2 or sometimes is called Feedback linearization principle is considered to estimate plant model given in companion form, the basic concept of such control principle is to cancel the nonlinearity of the system by transforming nonlinear system dynamics into linear ones [7], [8], [9].
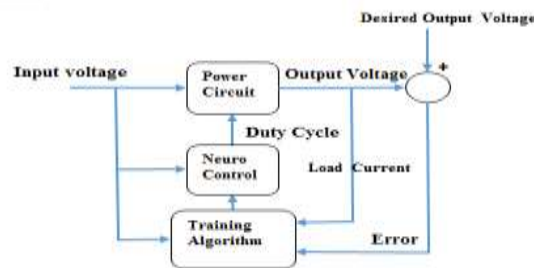

Figure 6. The proposed NNC of Buck converter.

The procedure is accomplished by identifying the system model at the beginning, followed by a training process of the NN to attend the proposed specifications (dynamic) using the so-called non-linear autoregressive moving average as a standard model to signify general discrete-time non-linear system with input u(t), output y(t), and non-linear function N as following:

$$y(k+d) = N\big[y(k), y(k-1),..., y(k-n+1), u(k), u(k-1),..., u(k-n+1)\big] \tag{3}$$

The NN will be trained to approximate this function, in case the output of the system needs to follow a reference trajectory:

$$y(k+d) = y_r(k+d) \tag{4}$$

Followed by non-linear controller design:

$$u(k) = G\big[y(k), y(k-1),..., y(k-n+1), y_r(k+d), u(k-1),..., u(k-m+1)\big] \tag{5}$$

Training such NN while using this controller to create such function G that minimizes mean square error is coupled with using dynamic backpropagation, which is quit slow [10], so the solution is obtained by [11]:

$$\hat{y}(k+d) = f\left[y(k), y(k-1), ..., y(k-n+1), u(k-1), ..., u(k-m+1)\right] + g\left[y(k), y(k-1), ..., y(k-n+1), u(k-1), ..., u(k-m+1)\right]u(k) \quad (6)$$

This is the companion form of the system, we notice that the next controller input *u(k)* is not participating in the nonlinearity, this advantage is achieved by forcing system output to pursuit the reference $y_{ref}(k+d)$, so the control law now is:

$$u(k) = \frac{y_r(k+d) - f\left[y(k), y(k-1), ..., y(k-n+1), u(k-1), ..., u(k-n+1)\right]}{g\left[y(k), y(k-1), ..., y(k-n+1), u(k-1), ..., u(k-n+1)\right]} \quad (7)$$

Or we can represent the input of the system *u(k)* as a function of output *y(t)*:

$$y(k+d) = f\left[y(k), y(k-1), ..., y(k-n+1), u(k-1), ..., u(k-n+1)\right] + $$
$$g\left[y(k), y(k-1), ..., y(k-n+1), u(k), ..., u(k-n+1)\right]u(k+1) \qquad d \geq 2 \quad (8)$$

The control law of NARMA L2 is:

$$u(k+1) = \frac{y_r(k+d) - f\left[y(k), ..., y(k-n+1), u(k), ..., u(k-n+1)\right]}{g\left[y(k), ..., y(k-n+1), u(k), ..., u(k-n+1)\right]} \qquad d \geq 2 \quad (9)$$

The simulation circuit of such model is demonstrated in **Fig.7**.
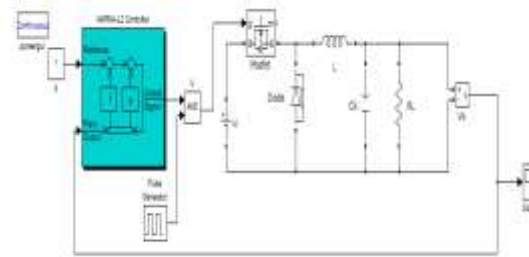

Figure 7. Simulation circuit of NARMA-L2 Controller.

3. Simulation Consideration

The simulation process is evaluated with the use of the MATLAB/Simulink environment and component values declared in **Table.2**, the sample rate is 0.001 s. For the NARMA L2 controller, the hidden layers are considered as 20, delayed inputs are considered as 3, and the number of delay outputs is taken as 2, the number of data input and output trained by the neural network is 60000.
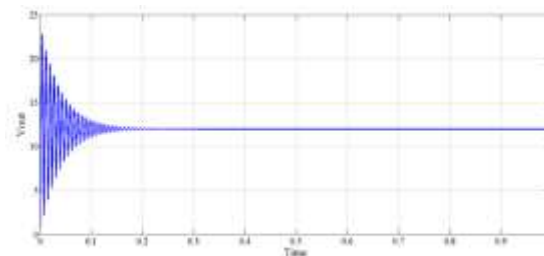
Figure 8. Open loop Buck dc/dc converter.

Table 1. Components value.

No.	Element	value	No.	Element	Value
1	Vi	12V	7	Duty Cycle	1
2	L	1µH	8	K_p	8
3	C	376µF	9	K_i	280
4	rc	5mΩ	10	K_d	0.001
5	rL	80mΩ	11		
6	R_L	30Ω	12		

The result of the simulation for the conventional buck converter is shown in **Fig.8**, while **Fig.9** illustrate the output voltage of the converter with PID controller:
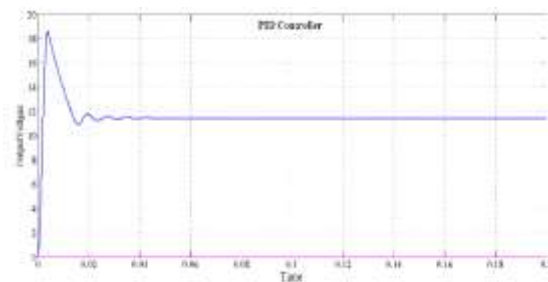

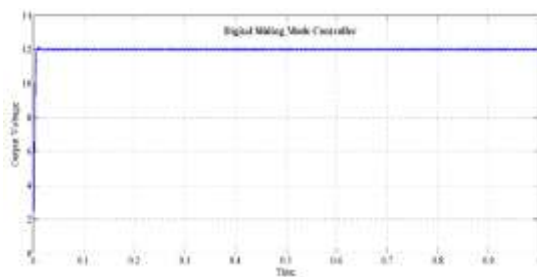
Figure 9. Converter with a PID controller.

Fig.10 illustrate Buck dc/dc converter with digital sliding mode controller.

Figure 10. Converter with DSM controller.

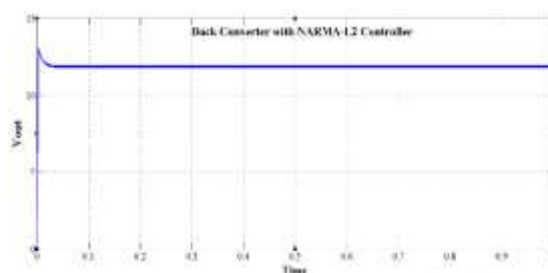In **Fig.11** the converter with NARMA-L2 controller is considered.

Figure 11. Converter with NARAMA -L2 controller.

Specification of each circuit is declared in **Table. 1** with different algorithms.

Table 2. Components value.

Type	Overshoot	Rise time	Settling time
Conventional	91.346%	651.758μs	0.1
PID	18%	1.2*10^-5	0.06
DSMC	0.95%	1.5*10^-6	0.03
NARMA-L2	1.56%	1.2*10^-6	0.02

4. Conclusion

In this paper, different approaches are considered in comparison with the NARMA-L2 controller with the aim of reaching adaptable regulation with a higher dynamic response and to defeat the control problems. The PID controller is found unstable in case of element alteration and disturbances, while the DSMC and NARMA L2 controllers are found so close in dynamic response and stability, but the DSMC which needs detailed calculations of the model, while NARMA-L2 needs less computation either for training the neural network and designing controller. In the end, we conclude that the adjustment of the NN is more obvious and easily more than PID and DSM controllers.

The important result obtained from this work is the fast dynamic response of the proposed approach and less cost and computation in comparison with PID and DSMC controllers.

Acknowledgments

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