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Development of a Neuro Controller for a Negative Output Elementary Luo Converter

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ABSTRACT

The negative output elementary Luo converter is a newly developed DC-DC converter. Due to the time-varying and switching nature of the above converter, its dynamic behavior becomes highly non-linear. Conventional controllers are incapable of providing good dynamic performance for such a converter and, hence, a neural network is utilized as a controller in this work. The performance of the chosen Luo converter using PI versus neuro controls is compared under load and line disturbances using MATLAB and TMS320F2407 DSP. The results validate the superiority of the developed neuro controller.

Keywords: Neuro control, negative output elementary Luo converter

1. Introduction

The negative output elementary Luo converter [1] is a recently developed sub-set of DC-DC converters. A neuro controller is developed in this work to regulate the output voltage of this converter under line and load disturbances since such a controller works well for complex, non-linear and time-variant systems [2-5]. The performance of the converter using PI versus neuro controllers is evaluated using MATLAB as well as TMS320F2407 DSP. The results are presented and analyzed.

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2. Modeling of a Negative Output Elementary Luo Converter

A negative output elementary Luo converter (Fig.1) performs step-up/step-down conversions from positive input DC voltage to negative output DC voltage. The voltage transfer ratio of the above converter is *(k/(1-k))* where k is the duty ratio [1]. The circuit parameters of the chosen converter are listed in Table 1. The circuits (Figs.1(a) and 1(b)) for the switch-on and switch-off modes of the chosen converter are modeled using a state-space approach. At this point, these two models are averaged over a single switching period T using a state-space averaging technique. The state variables are:

$x_1 = i_L \quad x_2 = v_C \quad x_3 = i_{Lo} \quad x_4 = v_{CO}$

$U = V_I \quad Y = V_O$

Using the equivalent circuits (Figs.1(a) and 1(b)) for the switch-on period (mode 1) and switch-off period (mode 2) of the chosen circuit, the respective state matrices A_1, B_1, C_1 and A_2, B_2, C_2 are:

$$A_1 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & -1/C & 0 \\ 0 & 1/Lo & 0 & -1/Lo \\ 0 & 0 & 1/Co & -1/RCo \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 1/L & 0 & 0 & 0 \end{bmatrix}^T$$

$$C_1 = \begin{bmatrix} 0 & 0 & 0 & -1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 0 & -1/L & 0 & 0 \\ 1/C & 0 & -1/C & 0 \\ 0 & 1/Lo & 0 & -1/Lo \\ 0 & 0 & 1/Co & -1/RCo \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 0 & 0 & 0 & 0 \end{bmatrix}^T$$

$$C_2 = \begin{bmatrix} 0 & 0 & 0 & -1 \end{bmatrix}$$

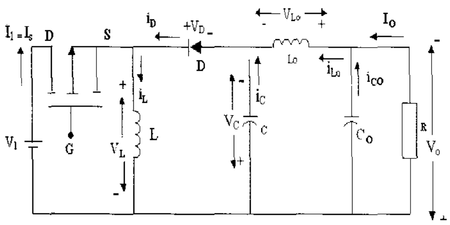


Fig. 1 Negative output elementary Luo converter

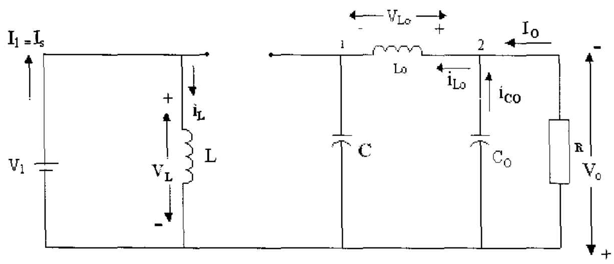


Fig. 1a Negative output elementary Luo converter - mode 1

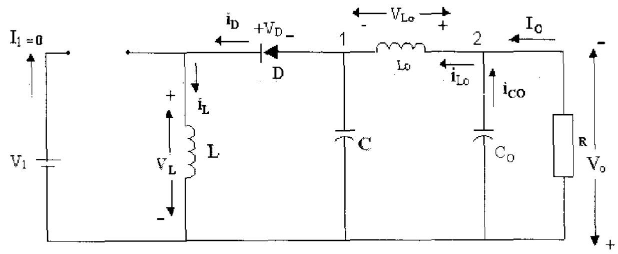


Fig. 1b Negative output elementary Luo converter - mode 2

3. Neuro Controller

The input-output data necessary for the off-line training of the neural network have been obtained in the present work using the voltage transfer ratio of the chosen Luo converter. The data set is made sufficiently rich to ensure stable operation since no additional learning will take place after training. A back-propagation algorithm [2-5] is used for training of the created network. The LEARNGDM function which has a gradient descent with momentum weight / bias learning is used in this work. Learning occurs according to the learning parameters: learning rate=0.01 and momentum constant t = 0.9. The neural network weights are:

After load disturbances:

w1=	-4.3396	*b1*=	4.5387
	1.0328		-0.6714
	-0.9796		-0.7780
	-4.1411		-4.1621

w2= 0.0259 -0.5370 1.0723 0.0682

b2 = 0.2595

After supply disturbances:

w1=	4.2698	*b1*=	-4.3006
	-1.0492		0.7756
	0.8594		0.6985
	4.1234		4.0341

w2= -0.0172 0.4589 -1.2668 -0.0568

b2 = 0.3386

MSE is the performance criteria used in this work that evaluates the network according to the mean of the square of the error between the target and computed output. The minimum MSE that can be achieved in this work is 1e-7.

For a back-propagation training algorithm, the derivative of the activation function is needed. Therefore, the activation function selected must be differentiable. The sigmoid function satisfies this requirement and it is the commonly used soft-limiting activation function. It is also quite common to use linear output nodes to make learning easier and using a linear activation function in the output layer does not 'squash' (compress) the range of output. Hence, a bipolar sigmoid activation function and a linear activation function are used for the hidden and output layers, respectively. Trials have been carried out to obtain maximum accuracy with a minimum number of neurons per layer. The feed forward neural network developed consists of one neuron in the input layer, four neurons in the hidden layer and one neuron in the output layer. The optimum number of neurons for the hidden layer is chosen as four (Table 2) since the number of epochs for training the neural network is reduced considerably. The tansig function is found to be better than the logsig activation function for the hidden layer since the logsig function takes (Table 3) approximately 200 more epochs than the tansig function. The input to the neuro controller (Fig.2) is voltage error*(e)*. The output of the controller is the corrected duty ratio(d_k).

4. Results and Conclusion

A PI controller with settings K_p=0.4205 and T_i=0.22ms obtained by the Ziegler-Nichols tuning technique has been used for comparison with the developed neuro controller. Fig. 3 shows the closed-loop responses using the above two controllers with k = 0.666 and for set point voltage 20V under sudden changes of 25% of the rated supply (10V) at t = 0.04sec and t = 0.06sec. Fig.4 shows the corresponding responses under sudden changes of 20% of the rated load. With 50 KHz switching frequency (i.e. 20μsec cycle time) of the converter, the neuro controller takes approximately 100 cycles to reject the supply disturbances (Fig.3) since the controller implemented regulates the output voltage within 2msec which is acceptable for power supply applications. Likewise, load disturbances are also effectively rejected (Fig.4). Performance indices listed in Table 4 establish the effectiveness of the simulated neuro controller except for the high overshoots under supply disturbances.

The above controllers are also implemented using TMS320F2407 DSP and Figs.5 and 6 show the corresponding responses. Fig.7 shows the DSP based closed loop control scheme for the chosen converter. The converter output voltage is initially scaled down (Fig. 7) suitably by a resistance divider network in the signal conditioning circuit. The output voltage of the divider circuit is fed to the on-chip ADC of the DSP through a high impedance differential amplifier to compute the digital equivalent of the output voltage. This is compared with the reference voltage to compute the error which is processed by the DSP based PI/neuro control algorithms to suitably adjust the duty cycle of the PWM signal. This PWM signal provided by the event manager module of DSP is applied to the MOSFET through the optocoupler and the MOSFET driver. Optocoupler HCPL-4506 provides isolation between the event manager module of the DSP and the gate of the MOSFET. In order to strengthen the pulses, an IR2110 driver is used. Table 4 also portrays the experimental performance evaluation of the controllers. These results also validate the superiority of the neuro controller developed.

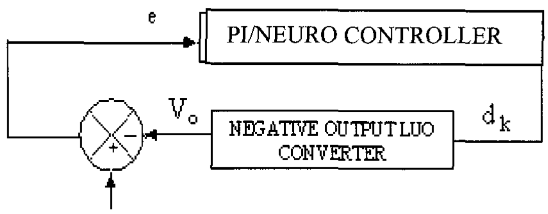


Fig. 2 Block diagram of PI/neuro controls for negative output elementary Luo converter

Table 1 Circuit parameters of the negative output elementary Luo converter

Parameters	Value
Inductors L, L_O	100μH
Capacitors C, C_O	5μF
Load resistance R	10Ω
Input voltage V_I	10V
Switching frequency f_s	50kHz
Duty ratio k	0.1 to 0.9
MOSFET	IRFP9240
Diode	UF5042

Table 2 Choice of hidden neurons

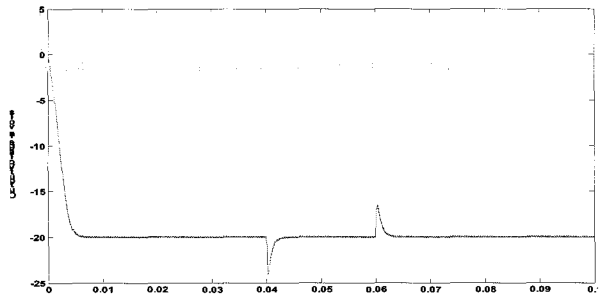
Number of hidden neurons	Number of epochs for training the network
1	Performance goal not met
2	Performance goal not met
3	≈ 400
4	**≈ 200**
5	≈ 300
6	≈ 400
7	≈ 450
8	≈ 480

Table 3 Choice of bipolar sigmoid transfer function as activation function for hidden layer

Number of hidden neurons	Number of epochs with tansig activation function	Number of epochs with logsig activation function
1	Performance goal not met	Performance goal not met
2	Performance goal not met	Performance goal not met
3	≈ 400	≈ 500
4	**≈ 200**	**≈ 400**
5	≈ 300	≈ 480
6	≈ 400	≈ 510
7	≈ 450	≈ 550
8	≈ 480	≈ 480

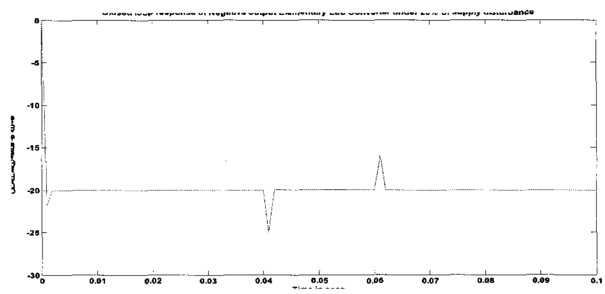
Table 4 Performance evaluation of controllers for negative output elementary Luo converter

RESULTS	CONTROLLERS	Supply disturbance: Supply increase (25%)		Supply disturbance: Supply decrease (25%)		Load disturbance: Load increase (20%)		Load disturbance: Load decrease (20%)	
		Peak over shoot (%)	Settling time (msecs)	Peak over shoot (%)	Settling time (msecs)	Peak over shoot (%)	Settling time (msecs)	Peak over shoot (%)	Settling time (msecs)
SIMULATION	PI	20	3.9	17.5	3.4	25	1	20	1
	NEURAL	24.75	2	19.8	2	1.5	0.5	1.16	0.5
EXPERIMENTAL	PI	20	10	15	10	20	11	15	15
	NEURAL	15	5	2.5	1	5	6	10	3



Time in secs

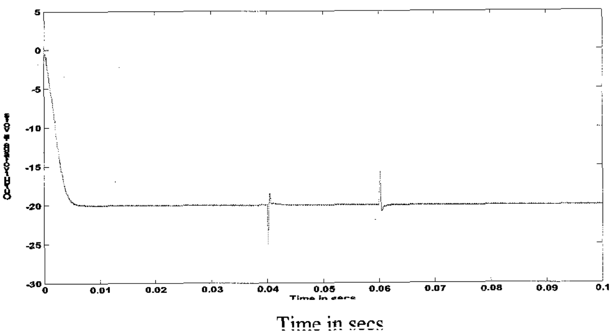
(a) PI controller



Time in secs

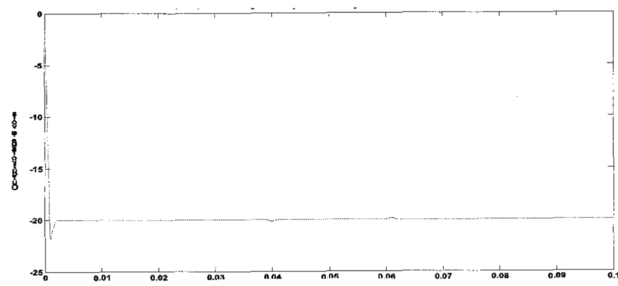
(b) Neuro controller

Fig. 3 Closed loop responses with sudden disturbances of 25% of rated supply using Matlab



Time in secs

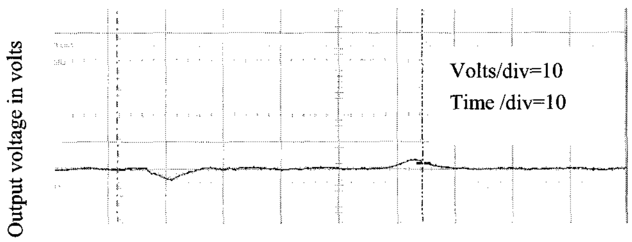
(a)PI controller



Time in secs

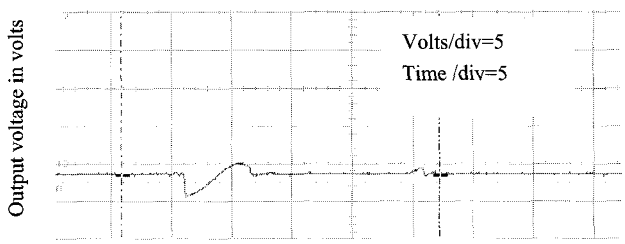
(b) Neuro controller

Fig. 4 Closed loop responses with sudden disturbances of 20% of rated load using Matlab



Time in msec

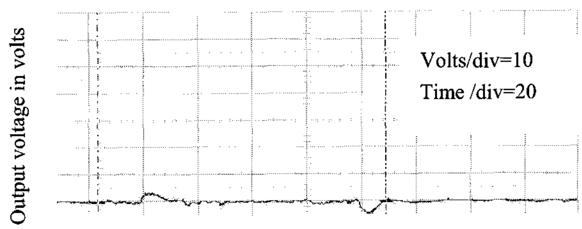
(a) PI controller



Time in msec

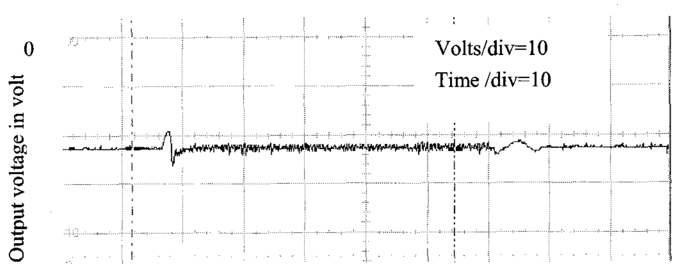
(b) Neuro controller

Fig. 5 Closed loop responses with sudden disturbances of 25% of rated supply using DSP



Time in msec

(a) PI controller



Time in msec

(b) Neuro controller

Fig. 6 Closed loop responses with sudden disturbances of 20% of rated load using DSP

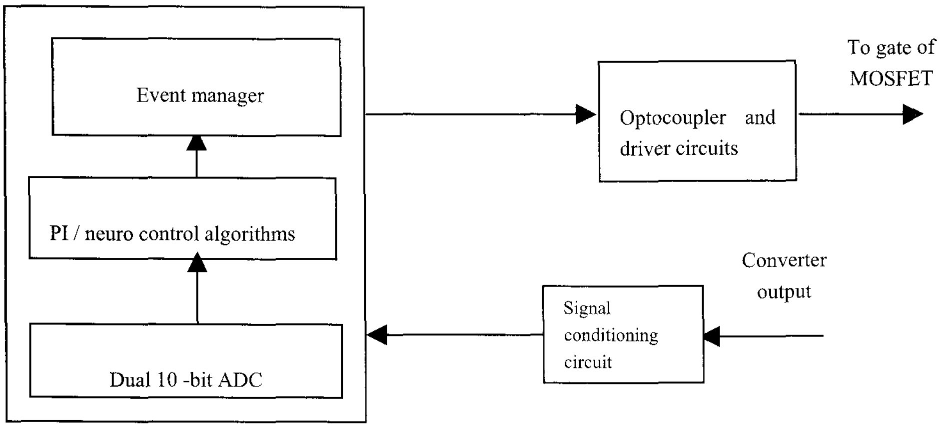


Fig. 7 Block diagram of PI / neuro controllers for negative output elementary Luo converter using DSP

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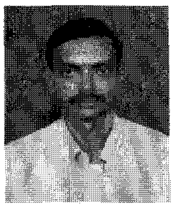

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