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Neural Network Controller for Triple-Lift Luo Converter

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ABSTRACT: Positive output Luo converters are a series of new DC-DC step-up (boost) converters, which perform positive to positive DC-DC voltage conversion with high power density, high efficiency and cheap topology in simple structure. They are different from other existing DC-DC step-up converters with a high output voltage and small ripples. Triple-Lift Luo circuit is derived from positive output elementary Luo converter by adding the lift circuit three times. Due to the time varying and switching nature of the Luo converters, their dynamic behavior becomes highly non-linear. Various conventional control techniques have been investigated and analyzed in order to minimize oscillations during the operation of the converters. The classical control methods employed to design the controllers for Luo converters depend on the operating point so that it is very difficult to select control parameters because of the presence of parasitic elements, time varying loads and variable supply voltages. Conventional controllers require a good knowledge of the system and accurate tuning in order to obtain the desired performances. Neural Network Controller (NNC) are gaining popularity in modeling, identification and control of power electronic converters. These controllers have fast dynamic behavior and robustness. A back propagation neural network is used. This research work deals with a neural network control scheme for a Triple – Lift Luo converter to produce regulated DC output voltage. The controller is designed to track the reference voltage and to improve performance of the Luo converter during transient operations. Furthermore, to investigate the effectiveness of the proposed controller, supply voltage and load variations are verified. The numerical simulation results show that the proposed controller has a better performance than conventional controllers.

KEYWORDS: Triple-Lift Luo converter, NNC, Back Propagation algorithm.

I.INTRODUCTION

DC-DC Power electronic converters are periodic time-variant systems because of their switching operation. The performance of the DC-DC converter is influenced by uncertainties, which are usually circuit parameters variations, line and load disturbances and nonlinear dynamics of the system. Nonlinear control, variable structure system control, adaptive control, optimal control and the robust control have been developed for the DC-DC converter. In the application of such techniques, development of mathematical model is necessary. Since the effect of parasitic elements limits the output voltage and power transfer efficiency of DC-DC converters, the voltage lift technique can lead to improve circuit characteristics.Triple-Lift Luo converter is developed from elementary Luo converter using the voltage lift technique. Luo converter is a highly nonlinear system used for DC-DC voltage regulation, reducing harmonic distortion and power factor correction in switch mode power supplies. The nonlinear characteristic of the converter is duo to the continuous opening and closing of a switch. The control of these converters has become a challenging issue. Traditional design techniques are based on the mathematical model of the converter. Therefore, in recent years soft computing techniques are used as a tool to control the DC-DC converter when there are changes in the input voltage and the load, resulting minimum overshoot and settling time. Hence the purpose of this research work is to develop a neuro controller for Triple-Lift Luo converter . The back propagation algorithm has been used to realize the learning mechanism. . Analysis, design and simulation of the proposed controller for Luo converters have been discussed.

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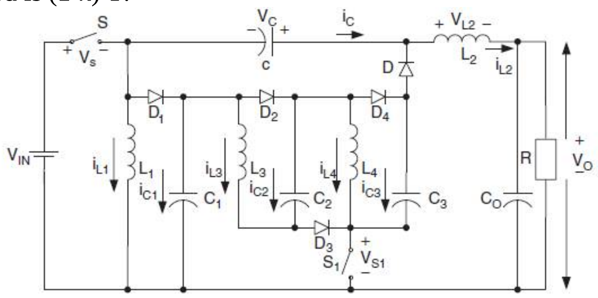
II.ANALYSIS OF TRIPLE-LIFT LUO CONVERTER

The triple- Lift Luo circuit is shown in Fig.1 .Switch S is a p-channel power MOSFET device (PMOS), and S_1 is an n-channel power MOSFET device (NPMOS). They are driven by a pulse-width-modulated (PWM) switching signal with repeating frequency *f* and conduction duty *k*. In this work, the switch repeating period is $T = 1/f$, so that the switch-on period is *kT* and switch-off period is (1-*k*) T.



(a)

Fig.1 circuit diagram of positive output Triple- Lift Luo converter

The load is usually resistive, i.e. $R = V_0/I_0$; the combined inductor $L = L_1 L_2/ (L_1 + L_2)$; the normalized load is Z_N = R/fL. Converter consists of a pump circuit S–L_1–C–D and a low-pass filter L_2-C_o, and lift circuit the pump inductor L_1 transfers the energy from the source to capacitor C during switch-off and then the stored energy on capacitor C is delivered to load R during switch-on. Therefore, if the voltage V_0 should be correspondingly higher. When the switch S turned off the current i_n flows through the free-wheeling diode D. This current descends in whole switching-off period (1 –k) T. If current i_D does not become zero before switch S turned on again, this working state is said to be continuous mode. If current i_D becomes zero before switch S turned on again, this working state is said to be discontinuous mode. The triple-lift LUO circuit consists of two static switches S and S_1 four inductors L_1, L_2, L_3 and L_4, five capacitors C, C1, C2, C_3 and C_0, and five diodes. Capacitors C1, C2, and C_3 perform characteristic functions to lift the capacitor voltage V_C by three times of source voltage V_1, L_3 and L_4 perform the function as ladder joints to link the three capacitors C1, C2, and C_3 and lift the capacitor voltage V_C up. Current $i_{C1}(t)$, $i_{C2}(t)$, $i_{C3}(t)$ are exponential functions. They have large values at the moment of power on, but they are small because $V_{C1} = V_{C2} = V_{C3} = V_1$ are in steady state. The circuit parameters of the chosen Luo converter is listed in Table.1

The output voltage and current are

$$V_0 = \frac{3}{1-k} V_I \quad (1)$$

$$I_0 = \frac{1-k}{3} I_I \quad (2)$$

Other average voltages:

$V_C = V_0$; $V_{C1} = V_{C2} = V_{C3} = V_I$

Other average currents:

$$I_{L2} = I_0 \,; \quad I_{L1} = \frac{k}{1-k} I_0 \quad (3)$$

$$I_{L3} = I_{L4} = I_{L1} + I_{L2} = \frac{1}{1-k} I_0 \quad (4)$$

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Table 1. Circuit parameters of Triple –Lift Luo converter

Parameters	Symbol	Values
Input voltage	V_{in}	10 V
Output voltage	V_o	60V
Inductors	L_1-L_2-L_3-L_4	330µH
Capacitors	C_0-C1-C2-C3-C	22µf/60V
Load resistance	R	10Ω
Switching frequency	f_s	50KHZ
Duty ratio	d	0.5

III. ARTIFICIAL NEURAL NETWORK (ANN)

The artificial neural network is an information-processing system that has certain performance characteristics in common with biological neural networks. Artificial neural networks have been developed as generalizations of mathematical models of human cognition or neural biology, based on the assumptions that Information processing occurs at many simple elements called neurons. Signals are passed between neurons over connection links. Each connection link has an associated weight, which multiplies the signal transmitted to obtained net input. Each neuron applies an activation function (usually nonlinear) to its net input (sum of weighted input signals) to determine its output signal.

A neural network is characterized by (1) its pattern of connections between the neurons (called its architecture), (2) its method of determining the weights on the connections (called its training, or learning, algorithm), and (3) its activation function. A neural net consists of a large number of simple processing elements called neurons, units, cells, or nodes. Each neuron is connected to other neurons by means of directed communication links, each with an associated weight. The weights represent information being used by the net to solve a problem.

Consider a neuron Y, illustrated in Fig. 2 , that receives inputs from neurons X_I, X_2 , and X_3 . The weights on the connections from X_I, X_2, and X_3 to neuron Y are W_1 , W_2, and W_3, respectively. The net input,Y_{in}, to neuron Y is the sum of the weighted signals

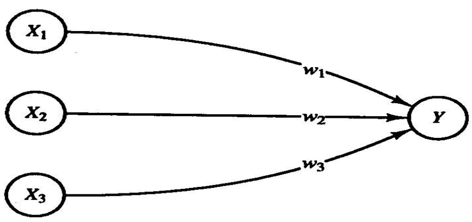

Fig. 2 Single Layer Neural Network

As shown in Fig.3 the activation y of neuron Y is given by some function of its net input, $y = f(y_{in})$, e.g., the logistic sigmoid function (an S-shaped curve) which is given by

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$$f(y_{in}) = \frac{1}{1+e^{-y_{in}}} \quad (5)$$

or any other activation functions. For a single layer net, the weights for one output unit do not influence the weights for other output units. A multilayer net is a net with one or more layers (or levels) of nodes (the so called hidden units) between the input units and the output units. Typically, there is a layer of weights between two adjacent levels of units (input, hidden, or output). Multilayer nets can solve more complicated problems than can single-layer nets

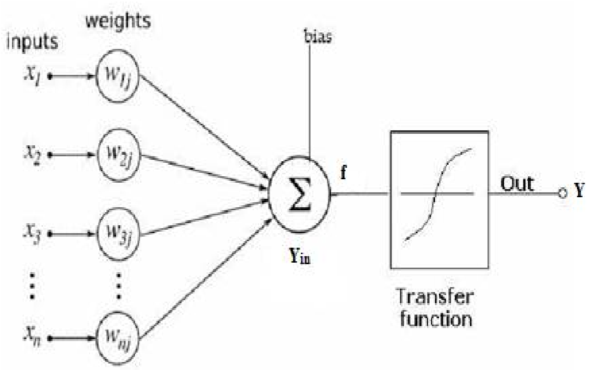

Fig. 3 Structure of an elementary neuron

IV. ANN CONTROLLER BASED TRIPLE-LIFT LUO CONVERTER

Considering the inherent nonlinearity of the Luo converter, the output dependence of the circuit parameters that can change continuously and the demands on regulation and response time normally required for a power supply, it is clear that the design based on linear models does not meet the requirements. Artificial neural networks have many characteristics similar to the human brain are capable of learning from experience, generalization, abstracting essential characteristics from inputs high tolerance to faults, real time operation, etc. Therefore, neural networks offer many advantages for the control of Luo converter. The actual output voltage is fed back and is compared with reference voltage. After comparison, error and the change in error are calculated and are given as input to the controller. The ANNC attempts to reduce the error to zero by changing the duty cycle of switching signal.

MATLAB/Simulink model of the Triple-Lift Luo converter was developed and simulated with Fuzzy Logic Controller using Fuzzy Tool Box. From the simulation, error, change in error and duty cycle was acquired. These data were used to train the ANN controller. Then the closed loop operation was simulated with Neuro controller using MATLAB NN Tool Box to achieve the desired performance. In this work Quasi-Newton back-propagation algorithm is employed to update weights Mean Square Error (MSE) is the performance criterion that evaluates the network according to the mean of square of error between the target and computed output. The minimum MSE that can be achieved in this work is 1e-7. LEARNGDM learning function which has the gradient descent with momentum weight / bias learning function has been used in this work. Learning occurs according to the learning parameters: learning rate α=0.01 and momentum factor t=0.9.

For back-propagation training algorithm, the derivative of the activation function is needed. Therefore the activation function selected must be differentiable. The logistic or 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 linear activation function in the output layer does not 'squash' (compress) the range of output. Hence bipolar sigmoid type activation function and linear activation function are used for hidden and output layers respectively. There is no general procedure to determine the exact size of the neural network. However, the size of the

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network developed in this work showed itself satisfactory as far as the output voltage regulation is concerned. Trials have been carried out to obtain maximum accuracy with minimum number of neurons per layer. The feed forward neural network controller developed consists of three layers with two neuron in the input layer, 15 neurons in the hidden layer and one neuron in the output layer (Figs. 4-7) and Fig. 8 shows the block diagram of NNC for Luo converter

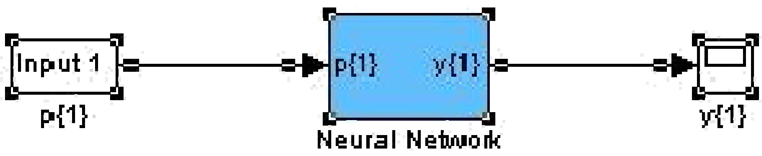

Fig. 4 SIMULINK block for neuro controller

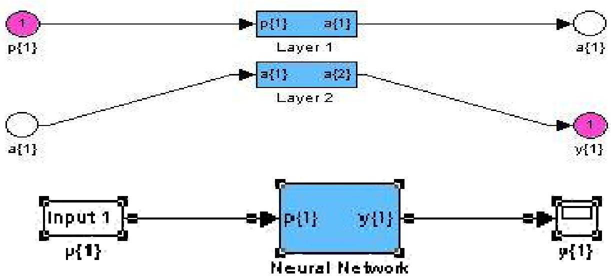

Fig. 5 SIMULINK model of neural network chosen for Luo converters

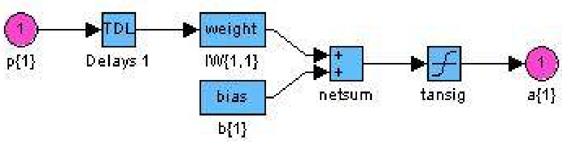

Fig. 6 SIMULINK model of hidden layer

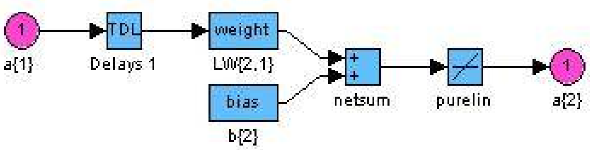

Fig. 7 SIMULINK model of output layer

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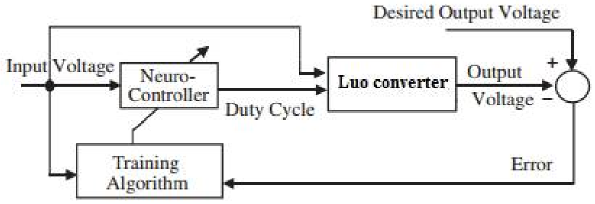

Fig. 8 Block Diagram of NNC for Luo converter

V.SIMULATION RESULTS

In Fig.9, the input supply voltage stepping-up from 10v to 12.5v (25% of rated supply voltage) at 0.035 sec. The %peak overshoot and settling time are 8.5 and 4msec and stepping down from 10v to 7.5v (25% decrease of rated supply voltage) at 0.07sec. The %peak overshoot and settling time are 4.16 and 4.5 msec.

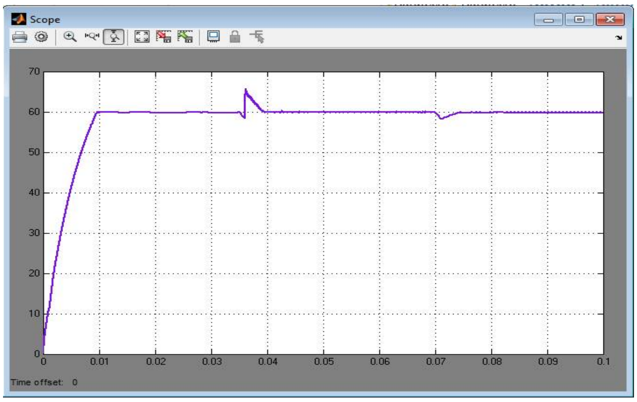

Fig.9. Transient response of Triple-Lift Luo converter with NNC (step change of ±25% Input source voltage)

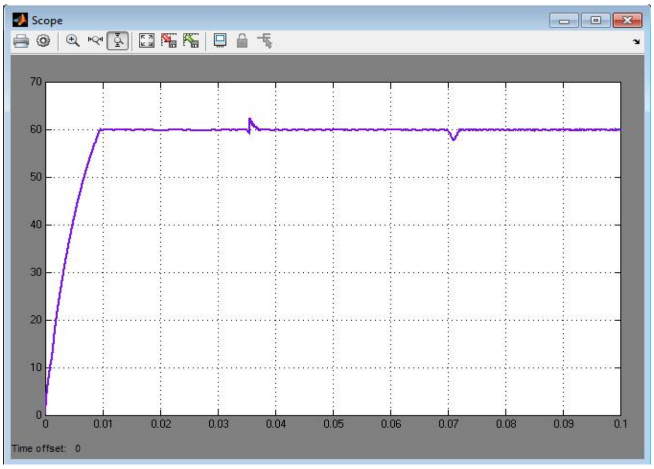

Fig. 10 Transient response of Triple-Lift Luo converter with NNC (±20% Load variation)

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Fig. 10 shows the output voltage of the Luo converter with a step change of ±20% of rated load at 0.035 sec and at 0.07 sec. It can be seen that the %peak overshoot is 5 and the settling time is 2msec for a step change of 10 -12 Ω. The %peak overshoot is 3.5 and settling time is 2 msec for a step change of 10 – 8 Ω . As a result, it is revealed that the transient response of the Luo converter is improved by adding the neural network based control as the feed forward control since the Luo converter has less peak overshoot and settling time.

VI. CONCLUSION

The dynamic response of Triple-Lift Luo converter with NNC was analysed for line and load variations are controlled effectively. The NNC gives the proper output regulation minimum value for steady state error, settling time and peak overshoot.

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