Performance Evaluation of Positive Output Triple-Lift Luo Converter with different Controllers

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ABSTRACT

The voltage lifting technique is used in power electronic circuit. Since the effect of parasitic elements reduces the output voltage and power transfer efficiency of DC-DC converters, this lift technique has been successfully applied for DC-DC converters resulting Luo converters. Positive Output Triple-Lift Luo converters (POTLLC) are series of new DC-DC step-up (boost) converters, which were developed from elementary Luo converter using the voltage, lift technique. POTLLC circuit is derived from positive output elementary Luo converter by adding the lift circuit three times. These converters perform DC-DC voltage-increasing conversion with high power density, high efficiency and cheap topology in simple structure. The performance evaluation of the PI , Fuzzy Logic Controller (FLC) and Neural controller for Triple-Lift Luo Converter is compared under supply voltage disturbance load disturbances ISE and IAE. The simulations are done using Matlab- Simulink.

Keywords— Fuzzy logic controller; Positive output Triple-Lift Luo converter; PI controller; Neural controller; ISE; IAE

INTRODUCTION

For DC-DC converters with constant output voltage, it is always desirable that the output voltage remains unchanged in both steady state and transient operations whenever the supply voltage and/or load current are disturbed. This condition is known as zero-voltage regulation and it means that the output voltage is independent of the supply voltage and the load current. DC-DC converters are generally divided into two groups: hard switching converters and soft-switching converters. In hard-switching converters, the power switches cut off the load current within the turn-on and turn off times under the hard switching conditions. The output voltage is controlled by adjusting the on time of the power switch, which in turn adjusts the width of a voltage pulse at the output. This is known as PWM control. Because of the effect of parasitic elements, the output voltage and power transfer efficiency of all DC-DC converters is limited. The elementary Luo circuit which can perform step-down and step-up DC-DC conversion. Other Positive output Luo converters are derived from this elementary circuit; they are the self-lift circuit, re-lift circuit and multiple-lift circuits (e.g. triple-lift and quadruple-lift circuits).The commonly used control methods for DC-DC converters are pulse width modulated (PWM) voltage mode control, PWM current mode control and PID controller. These conventional controllers are unable to perform satisfactorily under large parameter or load variation. Fuzzy logic control and neuro control are work very well for nonlinear, time variant and complex systems, this research work presents the control of positive output Triple- Lift Luo Converter using FLC ,Neural controllers and compared with PI controller. Simulations are made in MATLAB. Test for load regulation and line regulation are carried out to evaluate the performances of the controller.

ANALYSIS OF NEGATIVE OUTPUT TRIPLE –LIFT LUO CONVERTER

The POTLLC 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 (NMOS). They are driven by a pulse-width-modulated (PWM) switching signal with repeating frequency *f* and conduction duty *k*. *T*he switch repeating period is $T = 1/f$, so that the switch-on period is *kT* and switch-off period is (1-*k*) T.

The load is resistive, i.e. $R = V_0/I_0$; the combined inductor $L = L_1 L_2/ (L_1 + L_2)$; the normalized load is $Z_N = R/fL$. The converter consists of a pump circuit S–L_1–C–D and a low-pass filter L_2-C_0, 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 the 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_D 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 defined as continuous mode. If current i_D becomes zero before switch S turned on again, this working state is defined as discontinuous mode.The triple-lift LUO circuit consist 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 $V_{C1} = V_{C2} = V_{C3} = V_1$ in steady state. The circuit parameters of the chosen Luo converter is listed in Table.1

The output voltage and current are

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

and $I_0 = \frac{1-k}{3} I_I$

The Voltage transfer gain in continuous mode is

$$M_T = \frac{V_0}{V_I} = \frac{3}{1-K}$$

Other average voltages:

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

Other average currents:

$I_{L2} = I_0$; $I_{L1} = \frac{k}{1-k} I_0$

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

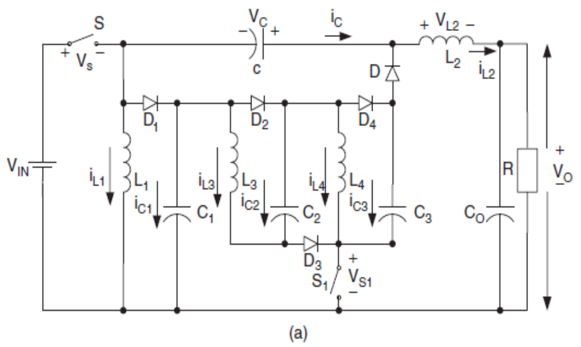

Fig.1 Positive output Triple –Lift Luo Converter

TABLE I CIRCUIT PARAMETER 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	fs	50KHZ
Duty ratio	D	0.5

DESIGN OF PI CONTROLLER

The function of a PI controller is to receive the actual output voltage from the converter is measured and compares it with the reference voltage and to produce the error signal so as to drive the converter to the desired value. The main function of PI controller is to reduce the peak overshoot and make steady state error zero. PI controller settings K_p and T_i are designed using Ziegler –Nichols tuning technique based on the converter's open loop step response. The optimal controller settings are then found after evaluation of the minimum values of ISE and IAE. Converters are modeled using the MATLAB-SIMULINK and PI control is developed using the control system toolbox. Errors in the output voltage and duty cycle of the MOSFET are respectively the input and output of the PI controller.

DESIGN OF FUZZY LOGIC CONTROLLER

The block diagram of the fuzzy logic control scheme for the POTLLC is shown in Fig.2.The output voltage of the Luo converter is compared with the reference voltage. After comparison, the error (e) and the change in error (ce) are calculated and are given as inputs to the fuzzy controller. In this work, the error is normalized to a per-unit value with respect to the reference voltage, which helps in using the fuzzy controller for any reference voltage. The fuzzy controller will attempt to reduce the error to zero by changing the duty cycle of switching signal. The fuzzy controller is divided into five modules: fuzzifier, data base, rule base, decision maker and defuzzifier. Various steps in the design of FLC for chosen Luo converter are stated below:

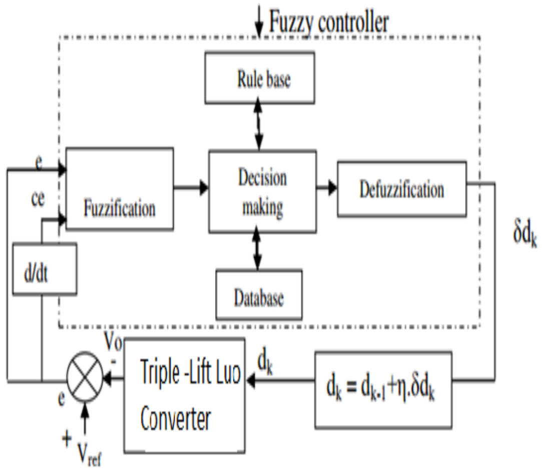

Fig.2 Block Diagram of fuzzy logic control for a Positive output Triple- Lift Luo converter

A,Fuzzification

FLC uses linguistic variables instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called fuzzification. In the present work, the error and change in error of voltage are fuzzified. Seven linguistic fuzzy sets with triangular membership function are as shown in Fig. 3. The seven fuzzy variables for 'error', 'change in error' and change in the duty cycle are Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Big (PB), Positive Medium (PM) and Positive Small (PS).

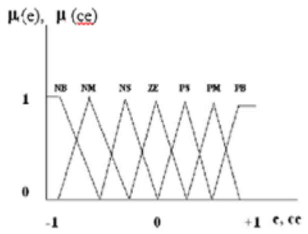

Fig. 3 Membership functions for e,ce

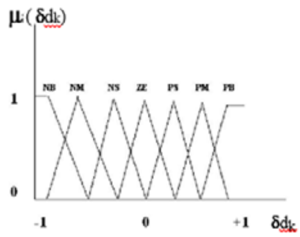

Fig. 4 Membership functions for δd_k

B .Rule Table and Inference Engine

The derivation of the fuzzy control rules is heuristic in nature and based on the following criteria:

1. When the output of the converter is far from the set point, the change of duty cycle must be large so as to bring the output to the set point quickly.
2. When the output of the converter is approaching the set point, a small change of duty cycle is necessary.
3. When the output of the converter is near the set point and is approaching it rapidly, the duty cycle must be kept constant so as to prevent overshoot.
4. When the set point is reached and the output is still changing, the duty cycle must be changed a little bit to prevent the output from moving away.
5.When the set point is reached and the output is steady, the duty cycle remains unchanged and when the output is above the set point, the sign of the change of duty cycle must be negative and vice versa.

According to these criteria, a rule table is derived and is shown in Table II.From the rule table, the rules are manipulated as follows: If error is NB, and change in error is NB, then output is NB.

TABLE II RULE TABLE

ce / c	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

C.. Defuzzification

The FLC produces the required output in a linguistic variable (fuzzy number). According to real-world requirements, the linguistic variables have to be transformed to crisp output. Center of gravity method is used for defuzzification in this work. The defuzzified output is the change in duty cycle.

$$\delta d_k = \frac{\sum_{i=1}^{4} w_i m_i}{\sum_{i=1}^{4} w_i} \qquad (6)$$

DESIGN OF NEURAL CONTROLLER

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 neural controller 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 neuro 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. 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

The activation functions are bipolar sigmoid type 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 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.

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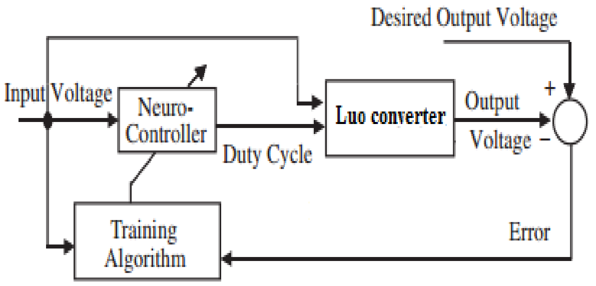

Fig. 5 Block Diagram of Neuro for Luo converter

SIMULATION RESULTS AND DISCUSSION

Fig 6 shows the POTLLC with PI control under line regulation. When converter subject to the step change of the line voltage is increased suddenly from 10 V to 12.5 V, it is observed that the settling time is 6ms and peak overshoot is 10% and when the input voltage is decreased from 10V-7.5V the settling time is 8ms and the peak overshoots 8.33% .

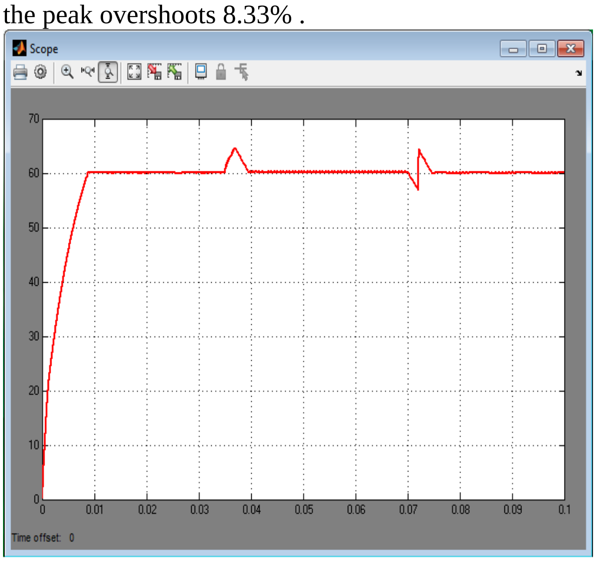

Fig. 6 Line regulation of POTLLC with PI control: Step change of supply voltage from 10-12.5V at 0.035sec and 10- 7.5v at 0.07sec

Triple-Lift Luo converter with PI control under load regulation is shown in Fig. 7. When the load resistance increases suddenly from 10 Ω to 12 Ω at 0.035 sec,the settling time and % peak overshoot are 6 ms and 7.5. When the load suddenly decreases from 10 Ω to 8 Ω at time 0.07 sec.,the settling time and the % peak overshoot are 7ms and 6.66.

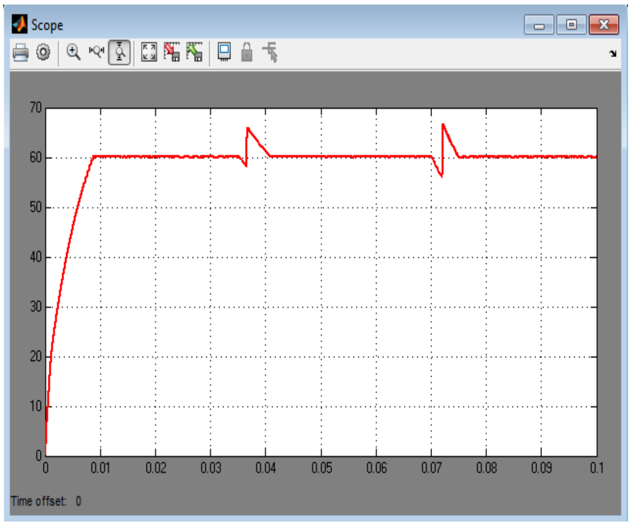

Fig.7 POTLLC under load regulation with PI control: Step change of resistance from 10-12Ω at 0.035 sec and 10- 8Ω at 0.07sec

Fig.8 shows the output voltage for the POTLLC subject to the step change of the line voltage when the controller is Fuzzy .The input voltage is increased suddenly from 10 V to 12.5 V,it is observed that the settling time is 4ms and peak overshoot is 8.33% and when the input voltage is increased from 10V-7.5V the settling time is 7ms and the peak overshoot 5.83%.

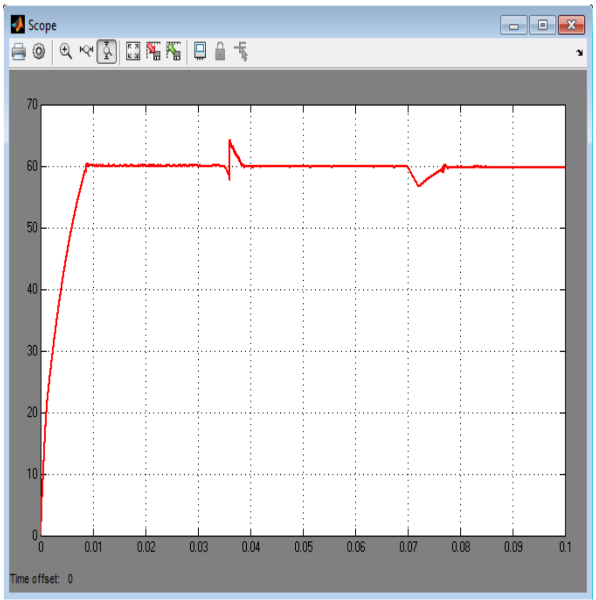

Fig. 8 Line regulation of POTLLC with Fuzzy controller : Step change of supply voltage from 10-12.5V at 0.035 sec and 10- 7.5v at 0.07sec.

Fuzzy logic controller for a Triple- Lift Luo converter under load regulation is shown in Fig.9. When the load resistance increases suddenly from 10 Ω to 12 Ω at 0.035 sec, the settling time and % peak overshoot are 3 ms and 5. When the load suddenly changes from 10 Ω to 8 Ω at time 0.07 sec, the settling time and the % peak overshoot are 6ms and 5.83.

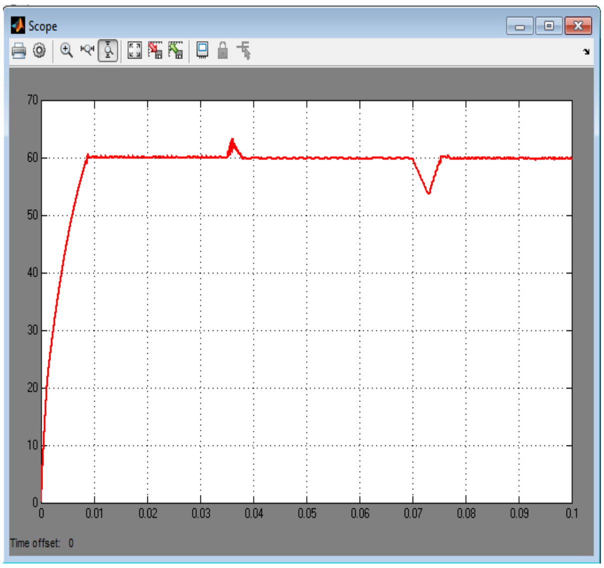

Fig.9 POTLLC under load regulation with Fuzzy controller : Step change of resistance from 10-12Ω at 0.035 sec and 10- 8Ω at 0.07sec.

Fig.10 shows the output voltage for the POTLLC subject to the step change of the line voltage when the controller is neuro .The input voltage is increased suddenly from 10 V to 12.5 V,it is observed that the settling time is 3ms and peak overshoot is 8.03% and when the input voltage is increased from 10V-7.5V the settling time is 4ms and the peak overshoot 3.3%.

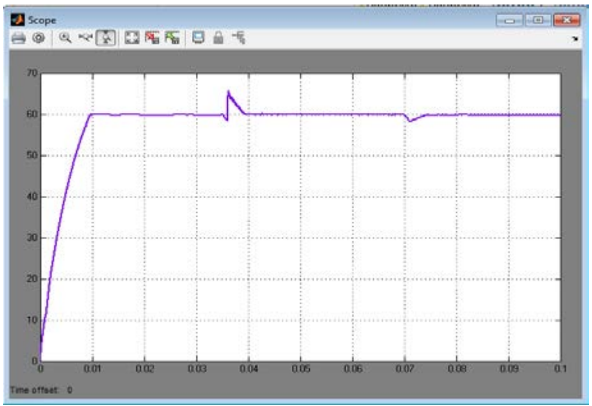

Fig. 10 Line regulation of POTLLC with neuro controller : Step change of supply voltage from 10-12.5V at 0.035 sec and 10- 7.5v at 0.07sec.

Neuro controller for a POTLLC under load regulation is shown in Fig.11. When the load resistance increases suddenly from 10 Ω to 12 Ω at 0.035 sec, the settling time and % peak overshoot are 2 ms and 4.1. When the load suddenly changes from 10 Ω to 8 Ω at time 0.07 sec, the settling time and the % peak overshoot are 2ms and 3.3.

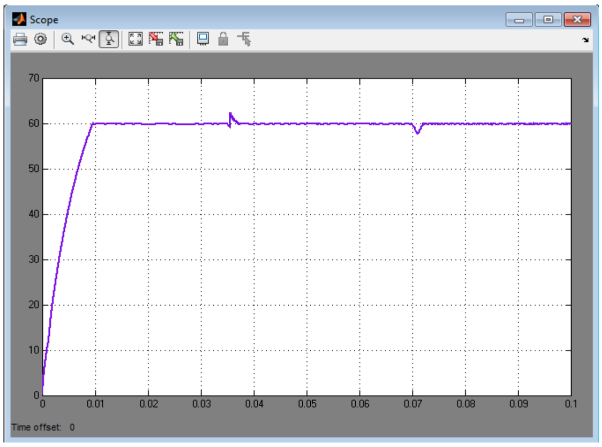

Fig.11 POTLLC under load regulation with neuro controller : Step change of resistance from 10-12Ω at 0.035 sec and 10- 8Ω at 0.07sec.

Fig 12 and 13 show the line regulation and load regulation of POTLLC with PI , fuzzy and neuro controllers.

Fig 12 Closed loop responses of POTLLC with various controllers under line variations

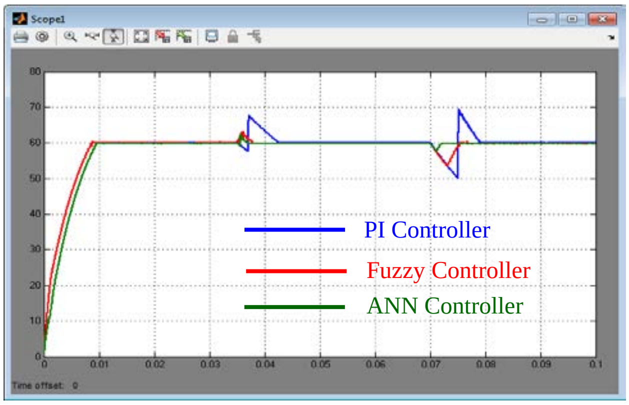

Fig 13 Closed loop responses of POTLLC with various controllers under load variations

TABLE III PERFORMANCE EVALUATION OF VARIOUS CONTROLLERS

	Parameters	PI controller	Fuzzy controller	Neuro controller
Supply increase (25%)	Peak over shoot (%)	10	8.33	8.03
	Settling time (ms)	6	3	3

	IAE	0.259	0.208	0.182
	ISE	6.11	5.94	5.32
Supply decrease (25%)	Peak over shoot (%)	8.33	5.83	3.33
	Settling time (ms)	8	7	4
	IAE	0.219	0.212	0.201
	ISE	6.2	5.96	5.41
Load increase (20%)	Peak over shoot (%)	7.5	5	4.1
	Settling time (ms)	6	3	2
	IAE	0.220	0.205	0.196
	ISE	6.05	5.87	5.212
Load decrease (20%)	Peak over shoot (%)	6.66	5.83	3.33
	Settling time (ms)	7	6	2
	IAE	0.256	0.240	0.201
	ISE	6.25	5.91	5.31

CONCLUSION

POTLLC overcomes the effects of parasitic elements and greatly increases the output voltage of the DC-DC converters. Positive output Triple-Lift Luo converter with PI, fuzzy logic and neuro controller were built on Matlab environment for load and line regulation. Neuro controller has satisfactory results for regulating the output voltage.

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