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Soft Computing Technique for the Control of Triple-Lift Luo Converter

N. Dhanasekar *, R. Kayalvizhi **
** Associate Professor, Electrical and Electronics Engineering, A.V.C College of Engineering, Mayiladuthurai, India.*
Email: n_dhanasekar@yahoo.com
*** Professor of Electronics and Instrumentation Engineering, Annamalai University, India,*

ABSTRACT
Positive output Luo converters are a series of new DC-DC step-up (boost) converters, which were developed from prototypes using voltage lift technique. These converters perform positive to positive DC-DC voltage increasing 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 behaviour becomes highly non-linear. 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. A fuzzy logic controller is a soft computing technique which neither requires a precise mathematical model of the system nor complex computations. The performances of the Triple-lift Luo converter with fuzzy logic controller are evaluated under line and load disturbances using Matlab-Simulink based simulation. The results are presented and analyzed.
***Keywords**:* DC-DC Converter, Fuzzification, Fuzzy logic controller, Membership function , Triple-Lift Luo converter.

I. INTRODUCTION

DC-DC converters are used to convert power from one voltage level to another voltage level. The output voltage of Pulse Width Modulation (PWM) based DC-DC converters can be varied by varying their duty cycle. In recent years, all modern electronic systems require power supply with high reliability, low weight with high quality and easy control capability Triple-Lift Luo converters are new series of DC-DC Converters that have very low ripple voltage and current and high voltage transfer gain in a geometric progression on stage-by-stage. 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. In this research work, a fuzzy Logic controller is used to control the voltage level of a Triple-Lift Luo converter. The controller performance is improved by good design of input, output and brain of the fuzzy controller Parameters. Traditional controllers of DC-DC converters are based on small signal model. Frequency domain based controllers depend on the system operating points, characteristics of parasitic elements and load and line changes. Since, the fuzzy logic controller work very well for nonlinear, time variant and complex systems, this research work presents fuzzy control of a Triple-Lift Luo Converter for controlling of the DC output voltage. Simulations are made in MATLAB. Test for load regulation and line regulation are carried out to evaluate the performances of the controller.

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.

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_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 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 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 $V_{C1} = V_{C2} = V_{C3} = V_1$ 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:

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

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

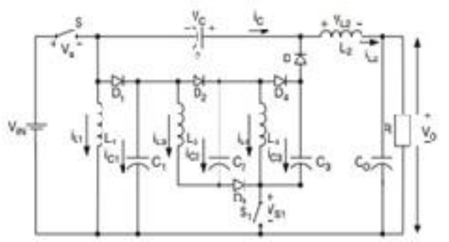

Fig 1 Triple - Lift LUO converter

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. FUZZY LOGIC CONTROL

The control action is determined in a fuzzy logic controller from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled but it does not require a mathematical model of the system.

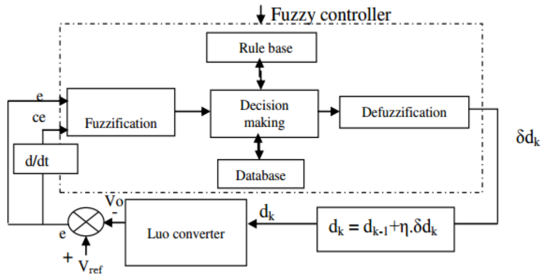

Fig. 2 Block diagram of fuzzy logic control for a Luo converter

The block diagram of the fuzzy logic control scheme for a Luo converter is shown in Fig.2. 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:

A. Identification of Inputs and Output

The inputs to the fuzzy controller are the error in output voltage e and the change of error ce which are defined as

$$e = V_{ref} - V_o \quad (5)$$

$$ce = e_k - e_{k-1} \quad (6)$$

where V_o is the present output voltage, V_{ref} is the reference or desired output voltage and subscript k denotes values at the sampling instants. □$\mathbf{d}_k$ is the output of the fuzzy controller at the k^{th} sampling instant and η is the gain factor of the fuzzy controller.

B. Fuzzification of Inputs and Output

Mamdani type input and output membership functions are used for control of Luo converters. In the present work, seven triangular fuzzy sets are chosen as shown in Fig. 3 and Fig. 4 and are defined by the following library of fuzzy set values for the error e, change in error ce and for the change in duty cycle δd_k.

NB: Negative Big NM: Negative Medium
NS: Negative Small ZE: Zero
PS: Positive Small PM: Positive Medium
PB: Positive Big

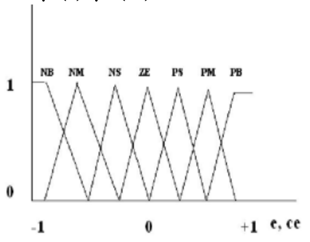

Fig. 3 Membership functions for e, ce

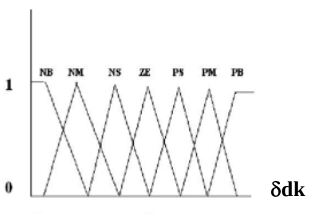

Fig. 4 Membership functions for δd_k

C. **Rule Base and Inference Mechanism**

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 2

Table 2 Rule base for FLC

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

D. Defuzzification

A crisp value for the change in duty cycle is calculated in this work using the center of gravity method. The resultant change of duty cycle can therefore be represented by

$$\delta d_k = \frac{\sum_{i=1}^{4} w_i m_i}{\sum_{i=1}^{4} w_i} \qquad (7)$$

Where W_i - Weighting factor, m_i- Centroid.

IV. SIMULATION RESULTS

Figs. 5 and 6 show the start up as well as transients of the converters with fuzzy controller under small signal step disturbances in supply and load. Fuzzy control has been implemented for positive output

Triple-Lift Luo converter. Converter has been modeled using MATLAB-Simulink and fuzzy control is developed through the fuzzy toolbox. From the closed loop responses of positive output Triple-Lift Luo converter with 20% step increase in input voltage and vice versa applied at t= 35ms and t=70ms (Fg. 5), the line disturbances are rejected with in 4ms for a step change of 10-12v and 8ms for a step change of 10-8v. The peak overshoots are 8.33% and 6.66% for ±20% step change in the rated supply voltage. Fig.6 shows the closed loop response of Triple-Lift Luo converter with sudden disturbances of 25% of rated load. The output voltage is regulated under load disturbance with in 10msec and the peakovershoot is 20% for a step change of load from 10-12.5Ω. The settling time is 7msec and the peakovershoot is 15% for a step change of load from 10-7.5Ω.

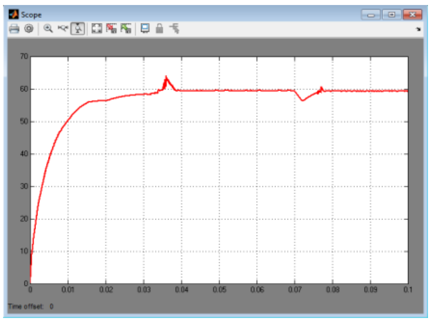

Fig.5 Closed loop response of Triple-Lift Luo converter with sudden disturbances of 20% of rated supply.

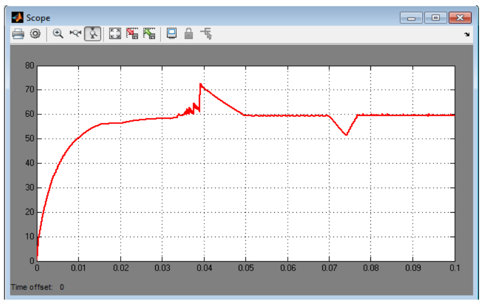

Fig.6 Closed loop response of Triple-Lift Luo converter with sudden disturbances of 25% of rated load.

V. CONCLUSION

The performance of the soft computing technique for Triple-Lift Luo converter has been presented. From the simulation results, it can be concluded that the line and load disturbances are satisfactorily and effectively rejected by the fuzzy controller designed for the chosen converter.

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N.DHANASEKAR received his B.E (Electronics and Instrumentation) from Annamalai University in 2002 and M.E (Electronics and Control) from Sathyabhama University in 2006. He is presently working as an Associate Professor in Department of Electrical and Electronics Engineering, A.V.C College of Engineering, Mayiladuthurai. He is presently pursuing Ph.D in the Department of Electronics and Instrumentation Engineering, Annamalai University. His areas of interest are modeling, simulation and implementation of intelligent controllers for power electronics converters. He is a life member of Indian society for Technical Education.

Dr. R. KAYALVIZHI has obtained B.E (Electronics and Instrumentation), M.E (Power Systems) and PhD in Instrumentation Engineering from Annamalai University in 1984, 1988 and 2007 respectively. She is currently working as a Professor in the Department of Electronics and Instrumentation Engineering at Annamalai University where she has put in 32 years of service. She produced 5 PhDs and presently guiding 5 PhD scholars. Her research papers 25 has been presented in the International and National conferences. She has 35 publications in National Journals and 30 in International Journals. Her areas of research interest include Power Electronics, Power Systems and Digital Image Processing. She is a life member of Indian society for Technical Education.