Hardware Implementation of Fuzzy Logic Controller for Triple-Lift Luo Converter

N. Dhanasekar, R. Kayalvizhi

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 behavior 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(FLC) is a soft computing technique which neither requires a precise mathematical model of the system nor complex computations. Hence in this research work, design and hardware implementation of fuzzy logic controller have been carried out using TMS320C242 DSP for the Triple-lift Luo converter .The experimental results are presented and analyzed under line and load disturbances.

Keywords: Fuzzy Logic Controller, Triple-lift Luo converter, Digital Signal Processor (DSP).

I. INTRODUCTION

DC to DC step-up converters are widely used in computer hardware and industrial applications such as computer peripherals power supplies, car auxiliary power supplies, servo-motor drives and medical equipments. Because of the effect of parasitic elements, the output voltage and power transfer efficiency of all DC-DC converters is restricted. The voltage lift technique is a popular method that is widely applied in electronic circuit design. It can lead to improvement of DC-DC converter characteristics. The elementary 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). 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 the DC output voltage. Fuzzy logic control offer stability, robustness to large line and load variations and good dynamic response. Fuzzy logic control is chosen to ensure fast dynamic response with output voltage regulation. Hence hardware implementation of fuzzy logic controller for Triple-lift LUO converter has been developed.

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 (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

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

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

The voltage transfer gain in continuous mode is

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

(3)

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Other average voltages:

$$V_C = V_0; \qquad V_{C1} = V_{C2} = V_{C3} = V_I \qquad (4)$$

Other average currents:

$$I_{L2} = I_0 \,; \qquad I_{L1} = \frac{k}{1-k} I_0 \qquad (5)$$

$$I_{L3} = I_{L4} = I_{L1} + I_{L2} = \frac{1}{1-k} I_0 \qquad (6)$$

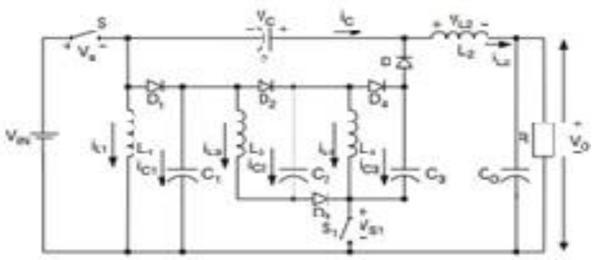

Fig.1 Triple - Lift LUO converter

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.

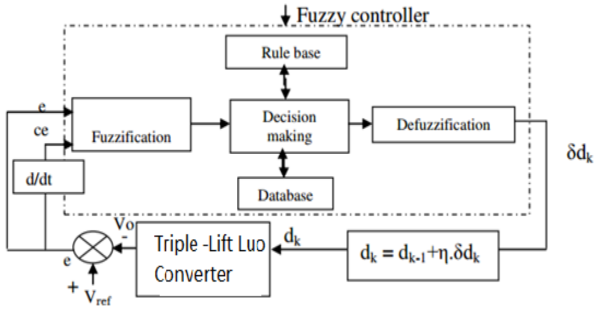

Fig. 2 Block Diagram of Fuzzy Logic Control for a Triple –Lift Luo Converter

The block diagram of the fuzzy logic control scheme for a Triple–Lift 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

$$e = V_{ref} - V_o \qquad (7)$$

$$ce = e_k - e_{k-1} \qquad (8)$$

(3)

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.

δd_k is the change in duty cycle which is the output of the fuzzy controller at the k^{th} sampling instant.

The updated duty cycle is

$$d_k = d_{k-1} + \eta\, \delta d_k \qquad (9)$$

where η is the gain factor of the fuzzy controller.

B. Fuzzification of Inputs and Output

This 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. Mamdani type input and output membership functions are used. 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).

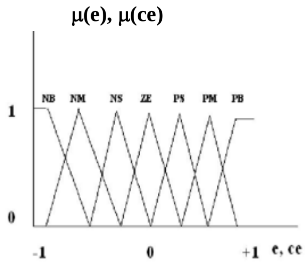

Fig. 3 Membership functions for e, ce

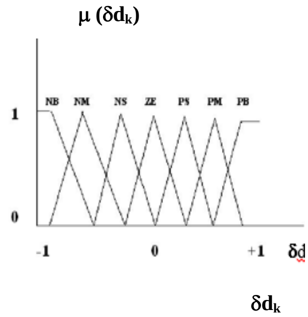

Fig. 4 Membership functions for δd_k

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 fuzzy logicdly, 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.

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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. TMS320C242 DSP CONTROLLER

The Texas Instruments TMS320C242 DSP is a programmable digital controller with C2xx DSP as the core processor. The DSP core is a 16-bit fixed-point processor. It contains on-chip memory and useful peripherals integrated onto a single piece of silicon. The speed of operation is 20 Million Instructions Per Second (MIPS). This high processing speed of the C2xx CPU allows user to compute parameters in real time. The following characteristics make this DSP the right choice for a wide range of applications:

- Very flexible instruction set
- Inherent operational flexibility
- High speed
- Innovative parallel architecture
- Compactness and cost effectiveness
- 50 ns Instruction cycle time

Fig.5 shows the architectural overview of TMS320C242 DSP. The peripheral set includes:

- Event-Manager Module which contains Eight Compare / Pulse-Width Modulation (PWM) Channels, Two 16-Bit General-Purpose Timers , Three 16-Bit Full Compare Units , Three Capture Units
- 10 bit Analog to digital converter with conversion time of 1µs
- Control Area Network (CAN) interface
- Serial Peripheral Interface (SPI)
- Serial Communication Interface (SCI)
- General Purpose bi-directional digital I/O (GPIO) pins
- Watchdog timer

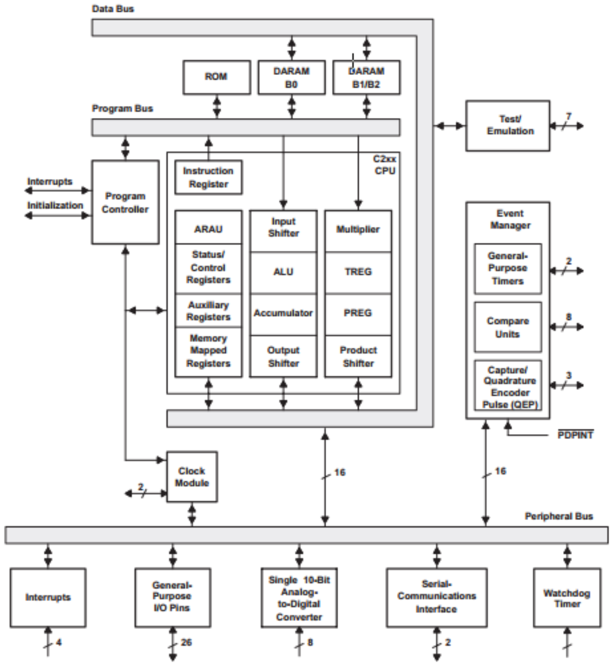

Fig. 5 Functional Block Diagram of TMS320C242 DSP

V. HARDWARE IMPLEMENTATION

The block diagram for the TMS320C242 DSP based implementation of closed loop control of a triple-lift Luo converter is shown in Fig.6 . The output voltage of the converter is scaled down to 0–5volts and read by the 10-bit ADC of DSP. The DSP executes 20 MIPS with 50 ns instruction cycle time. The conversion time of the on-chip ADC is 1µs. The DSP takes an average of 500µs to execute the fuzzy logic control algorithm, which involves sampling the output voltage, calculating the new duty cycle and updating the PWM output. The switching device S_1used is a N-channel MOSFET (enhancement type) IRF540N and S is a P-channel MOSFET IRF9630.In order to provide isolation between the Triple-Lift Luo converter circuit and the DSP, the isolation amplifier HCPL7840 is needed in the feedback path. The opt coupler MCT2E provides the isolation between the DSP and MOSFET of the Triple-Lift Luo converter. The PWM signal from the DSP is not capable of driving MOSFET. In order to strengthen the pulses, MOSFET driver IC IR2110 is used.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

A snapshot of the experimental setup for a Luo converter is displayed in Fig. 7. Fig.8 shows the output voltage for the LUO converter with a step change of ±25% of rated supply voltage at 0.02 sec and at 0.03 sec. The experimental results show that the output voltage is regulated within a maximum of 4msec and the % peak overshoot is 8.33 after line disturbances of the converter. Fig. 9 shows the output voltage of the LUO converter with a step change of ±20% of rated load at 0.02 sec and at 0.03 sec. It can be seen that the %peak overshoot is 8.33 and the settling time is 2msec for a step change of 10-12 Ω. The %peak overshoot is 6 and settling time is 1msec for a step change of 10 – 8 Ω.

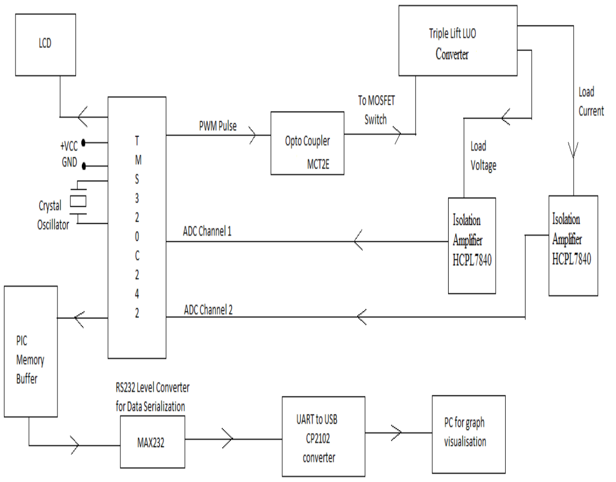

Fig.6 Block Diagram of closed loop control for Triple –Lift Luo converter

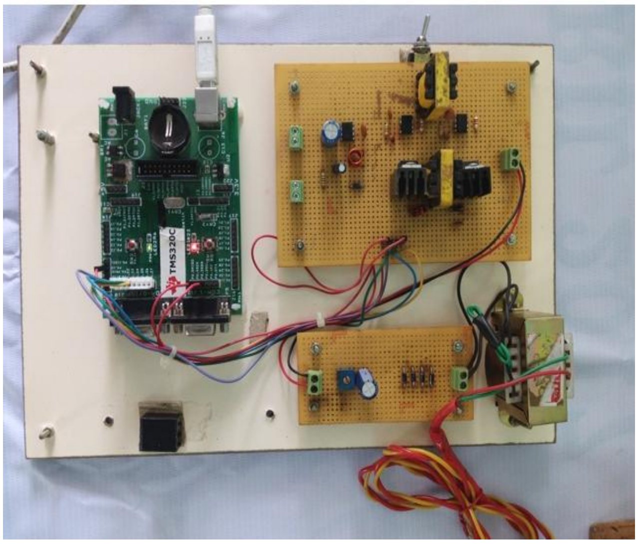

Fig.7 Hardware set up for Triple –Lift Luo converter

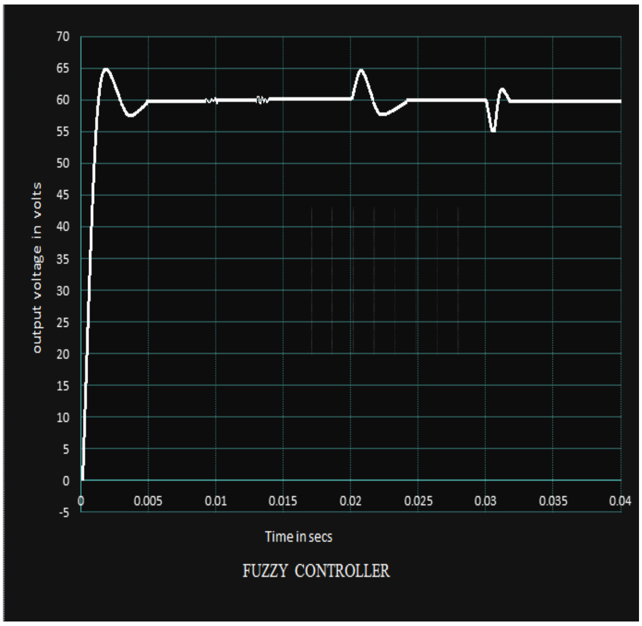

Fig. 8 Closed loop response of Triple-Lift Luo converter with fuzzy logic-controller under sudden disturbances of ±25% of rated supply voltage at 0.02 sec and 0.03 sec

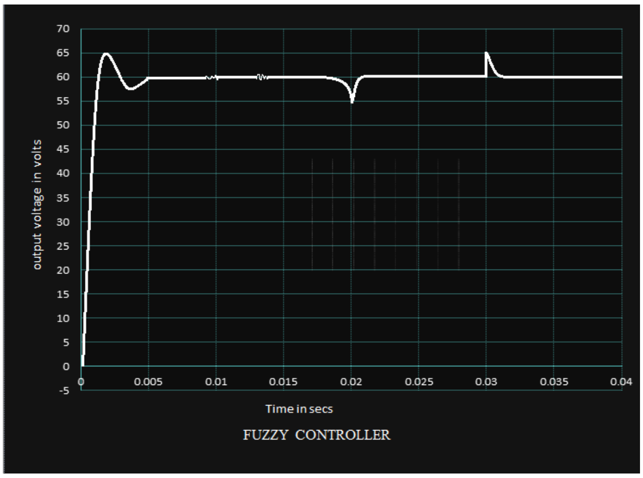

Fig. 9 Closed loop response of Triple-Lift Luo converter with fuzzy logic controller under sudden disturbances of ±20% of rated load at 0.02 sec and 0.03 sec

VII. CONCLUSION

The performance of the fuzzy logic controlled Triple-Lift Luo converter has been presented. Fuzzy logic control gives output voltage regulation for both line and load disturbances with less settling time and less peak overshoot. The hardware model of the Luo converter with its control circuit was implemented using TMS320C242 DSP.

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