Development of Genetic Algorithm based Fuzzy Controls for LUO Converters

N. Nachammai, R. Kayalvizhi

Abstract*: *Positive output elementary Luo converters perform the conversion from positive DC input voltage to positive DC output voltage. Since Luo converters are non-linear and time-variant systems, the design of high performance controllers for such converters is a challenging issue. The controllers should ensure system stability in any operating condition and good static and dynamic performances in terms of rejection of supply disturbances and load changes. To ensure that the controllers work well in large signal conditions and to enhance their dynamic responses, soft computing techniques such as Fuzzy Logic Controller (FLC) and Genetic Algorithm based FLC (GA-FLC) are suggested. Fuzzy logic is expressed by means of the human language. A fuzzy controller converts a linguistic control strategy into an automatic control strategy and fuzzy rules are constructed by expert experience or knowledge database. Genetic Algorithm is a powerful optimizing tool that is based on the mechanism of natural selection and natural genetics. Since fuzzy parameters are obtained by trial and error method, Genetic Algorithm can be used to optimize the fuzzy rules, membership functions and scaling gains thereby improving the performance of the Luo converter. In order to test the robustness of the designed GA-Fuzzy and Fuzzy based Luo converter, the controllers and converter have been modeled using Matlab – Simulink software. From the simulation results, it is seen that GA- FLC gives fast response, good transient performance and robustness to variations in line and load disturbances. Performance comparison show improvement of transient responses in terms of settling time, peak overshoot and ISE in the GA-Fuzzy than FLC for Luo converter.

Index Terms*: *Fuzzy Logic controller, Genetic Algorithm, Luo Converter, Membership function

I. INTRODUCTION

The tuning of the parameters of PID accurately becomes difficult because most of industrial plants are highly complex, non linear and higher order system with time delay. Due to the complexity of most industrial plants and the limitation of PID controller, soft computing techniques such as FLC, GA, PSO, BF etc. are introduced for intelligent regulation of power electronic converter. The FLC does not require complete mathematical model of the system to be controlled and it can work properly with nonlinearities and uncertainties. Although fuzzy logic controllers have been applied in many complex industrial processes, they experience a deficiency in knowledge acquisition and depend to a great extent on empirical and heuristic knowledge. There is no generalized method for the formulation of fuzzy control strategies and design of fuzzy parameters are based on trial-error method.

Genetic algorithm is a search algorithm based on the mechanism of natural selection and genetics. These are easy to implement and efficient for multivariable optimization problems. Hence by strengthening fuzzy logic controllers with genetic algorithm, the searching and attainment of optimal fuzzy logic rules, scaling gains and high-performance membership functions can be obtained. The performance of the GA optimized fuzzy logic controller is compared with that of the fuzzy controller. MATLAB/ SIMULINK software is used to design the controller and converter. The objective of optimization is to reduce settling time, peak overshoot and ISE and the results demonstrate that compared with fuzzy logic control strategy, genetic-fuzzy control strategy gives better control of Luo converter. Simulation results indicate that the output voltage of the closed loop system can be regulated to a desired reference voltage regardless of the variations in input voltage and changes in output load.

II. POSITIVE OUTPUT ELEMENTARY LUO CONVERTER (POELC)

Luo converters belong to a series of new DC-DC converters that are developed from the basic converters using the voltage lift technique. Voltage lift technique is a popular method that is applied in electronic circuit design to improve the circuit characteristics. Luo converters overcome the effects of the parasitic elements that limit the voltage conversion ratio. Positive output Luo converters performs the conversion from positive DC input voltage to positive DC output voltage. They work in the first quadrant with large voltage amplification. The elementary Luo converters perform step-down or step-up DC-DC conversion.

The positive output elementary circuit is shown in Fig. 1. Switch S is a N-channel power MOSFET (NMOS) device. It is driven by a PWM switching signal with repeating frequency 'f_s' and duty ratio 'd'. The switching period is $T = 1/f_s$ so that the switch-on period is dT and the switch-off period is $(1-d)\,T$. The load R is resistive, where $R = V_o/I_o$; V_o and I_o are the average output voltage and current. The elementary circuit consists of a positive Luo pump S-L_1-C-D and a low pass filter L_2-C_0. The pump inductor L_1 transfers the stored energy to capacitor C during the switch-off period and then the energy stored on capacitor C is delivered to load R during the switch-on period. Therefore if the voltage $V_c$is higher, the output voltage V_o should be higher.

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When switch S is ON, the source current $i_1 = i_{L_1} + i_{L_2}$ (Fig. 2). Inductor L_1 absorbs energy from the source and inductor L_2 absorbs energy from the source and capacitor C. Both currents i_{L_1} and i_{L_2} increase. When switch S is OFF (Fig. 3) source current $i_1 = 0$. Current i_{L_1} flows through the freewheeling diode D to charge capacitor C. Inductor L_1 transfers its stored energy to capacitor C. Current i_{L_2}flows through the (C_o-R) circuit and freewheeling diode D to keep itself continuous. Both currents $i_{L_1}$and i_{L_2} decrease.When switch S is turned off, current i_{L_1} flows through the freewheeling diode D. This current descends in the switch-off period $(1-d)\,T$. If current i_{L_1} does not become zero before switch S is turned on again, this working state is defined as the Continuous Conduction Mode (CCM). If current i_{L_1} becomes zero before switch S is turned ON again, the working state is defined as Discontinuous Conduction Mode (DCM). The average output voltage of the converter in Continuous Conduction Mode is

$$V_o = \frac{d}{(1-d)} V_I$$

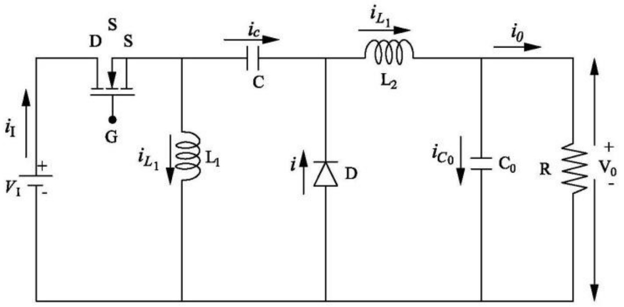

Fig. 1 Schematic Diagram of Positive Output Elementary Luo Converter

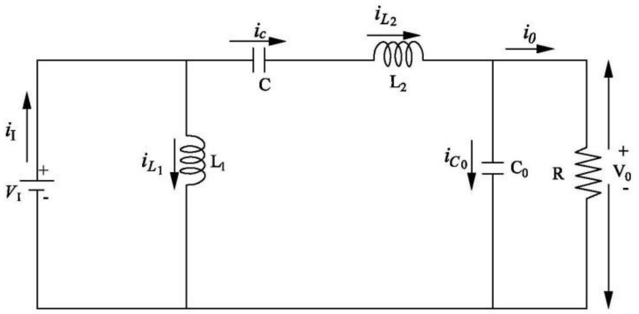

Fig. 2 Equivalent circuit during switch-ON (Mode 1)

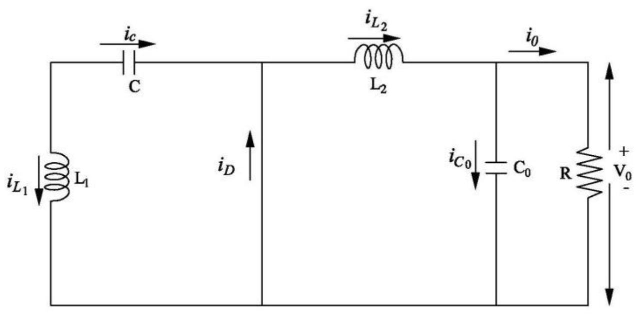

Fig. 3 Equivalent Circuit During Switch-OFF (Mode 2)

III. FUZZY LOGIC CONTROLLER

Fuzzy logic is a form of many-valued logic which is derived from fuzzy set theory. In contrast with "crisp logic", where binary sets have two-valued logic, fuzzy logic variables may have a truth value that ranges in degree between "0" and "1" fuzzy logic controller is a control tool for dealing with uncertainty and variability in the plant. The implementation of the proposed controller does not require any specific information about the converter model as well as circuit parameters and works independent of the operating point of the Luo converter.

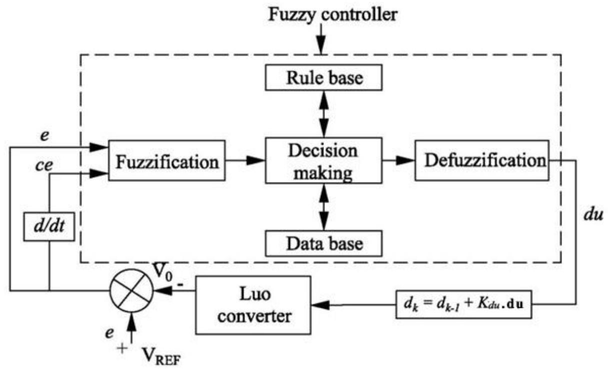

Fig. 4 Block Diagram of Fuzzy Logic Control for Luo Converter

Design of fuzzy logic controllers mainly involves three steps, namely fuzzification, fuzzy rule base and defuzzfication which is shown in Fig.4. Fuzzification is a process in which the inputs are fuzzified between a range of 0 to 1. Rule base is formed by the experts knowledge and depending on the inputs, the rule base generates the corresponding linguistic variable output. This output is defuzzified from 0 to 1 to a global value. The designed FLC has two inputs, error (*e*) and rate of change of error (*ce*) and a controller output (*du*). The number of necessary fuzzy sets and their ranges are designed based upon the experience gained on the process. A Mamdani based system architecture has been realized. Max-min composition technique and center of gravity method have been used in the inference engine and defuzzification. In the present work, seven triangular fuzzy sets are chosen as shown in Fig. 5 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 du.

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

The fuzzy rule base consists of 49 rules which are used to produce change in duty cycle (du) of the MOSFET of the Luo converter

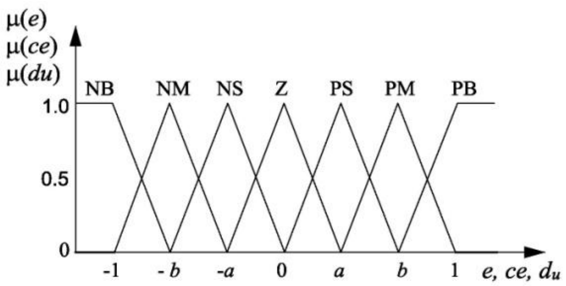

Fig. 5 Triangular Type Membership Function for Error, Change in Error and Change in Duty Cycle

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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 1.

The inference mechanism seeks to determine which rules fire to find out which rules are relevant to the current situation. The inference mechanism combines the recommendations of all the rules to come up with a single conclusion.

Table 1.Rules for Mamdani-Type Fuzzy System

e \ ce	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Since the inferred output is a linguistic value, a defuzzification operation is performed to obtain a crisp value. In this work, the centre of gravity or centroid method is used for de-fuzzification. As a result the control increment is obtained by the equation.

$$du = \frac{\sum_{i=1}^{m} d_i A\,(\mu_i)}{\sum_{i=1}^{m} A\,(\mu_i)}$$

Here $d_i$is the distance between i^{th}fuzzy set and the centre. $A\ (\mu_i)$is area value of i^{th} fuzzy set.

IV. GENETIC ALGORITHM

GA is a simulation of biological genetic and evolution in the natural environment and formation of an adaptive global optimization probability search algorithm.

The basic process of GA is shown in Fig. 6. GA uses three main operators which are selection, crossover and mutation:

a) Selection: It is the mechanism for selecting the individuals with high fitness to produce new individuals for the next population. There are several types used for selection such as (1) fitness proportionate selection or roulette-wheel selection (a single random number is used) (2) stochastic universal sampling (multiple random numbers are generated for selection) (3) tournament selection (best individuals are always selected) (4) truncation selection (a portion of the population is selected) and (5) elitism or elitist selection (where the best mdividual (s) are always selected). The selection type used in this work is the roulette wheel method.

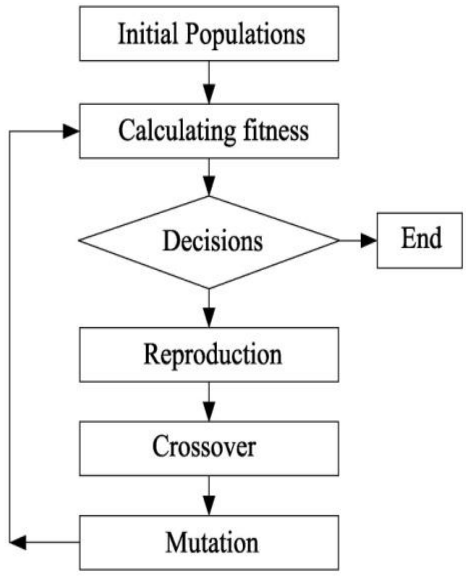

Fig. 6 Flow Chart of Genertic Algorithm

b) Crossover: This operation involves the combination of genes from two parents to produce off springs. There are several variants of crossover (1) single point crossover where a fixed position is selected in both parents and then the contents beyond that crossover point are swapped (2) multiple crossover points (3) cut and slice crossover (change in length between the parents and the children) and (4) uniform crossover where a random number is generated and if it is greater than a threshold value then swapping is performed.

c) Mutation: This process involves the reproduction of an erroneous copy of the individual, in which a random number is generated where if it is greater than a threshold value then the zero binary value is changed to one. This part is added to increase the diversity.

d) Copying: This process involves the reproduction of an exact copy of the individual.

e) Termination: Where a certain number of generations is reached or an acceptable solution is reached or no change in the optimal solution is reached.

The fitness function is defined as

$$ISE = \int_0^T e^2(t)\,dt$$

$$e(t) = V_{ref} - v_o(t)$$

where$e(t)$ is the error ,V_{ref} is the reference voltage and $v_o(t)$ is the actual output voltage.

V. GA BASED FUZZY LOGIC CONTROLLER

Genetic Algorithm is employed to perform a comprehensive and complete search in finding an optimal set of solution for the fuzzy logic rules, membership functions and scaling gains for the specified fuzzy logic controller (Fig. 7). The bottom points of the membership functions to be tuned are a_e and b_e for error (e). a_{ce} and b_{ce} for change in error (*ce*) and a_{du} and b_{du} for change in output (*du*).

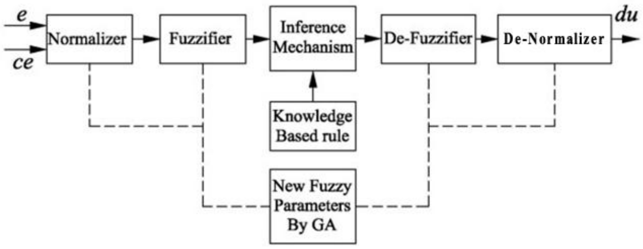

Fig. 7 Block Diagram of GA Optimized Fuzzy Controller

Two normalization parameters (k_e, k_{ce}) for inputs (*e*, *ce*) and one de-normalization parameter (k_{du}) for output (*du*) are defined. In normalization process, the input variables are scaled in the range of (-1, +1) and in de-normalization process, the output values of fuzzy controller are converted to a value depending on the terminal control element. The determination of normalization and de-normalization parameters of fuzzy controller is important for system stability. Hence a performance index is defined along with an algorithm to search for the optimal values of ($K_e K_{ce} K_{du}$), (a_e, b_e, a_{ce}, $b_{ce} a_{du}$, b_{du}) and (*C1 C2 ……..C49*) corresponding to normalization factors, membership functions and control rules. The optimized fuzzy logic rules are listed in Table 2.

Table 2. Optimized Fuzzy Logic Rules

e \ *ce*	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NS	Z	PS
NM	NB	NB	NB	NM	Z	PS	PM
NS	NB	NB	NM	NS	Z	PM	PB
Z	NB	NM	NS	Z	PS	PM	PB
PP	NB	NM	Z	PS	PM	PB	PB
MS	NM	NS	Z	PM	PB	PB	PB
PB	NS	Z	PS	PM	PB	PB	PB

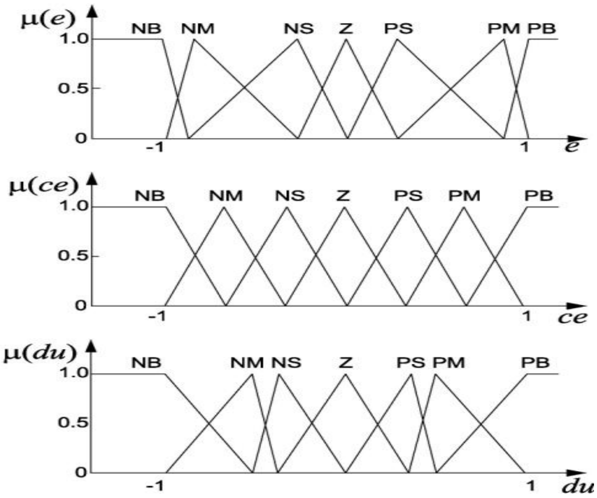

Fig. 8 GA Optimized Membership Functions of FLC

Table 3 Circuit Parameters for POELC

Parameters	*Values*
Inductors (L_1& L_2)	100 μH
Capacitors (C & C_0)	5 μF
Load resistance (R)	10Ω
Input Voltage (V_I)	10V
Output Voltage (V_O)	20V
Switching frequency (f_s)	50KHz
Range of duty ratio (*d*)	0.1-0.9
MOSFET	IRF250N
Diode	UF5042

Table 4 GA Parameters

Number of Generations	100
Population Size	50
Crossover Rate	0.9
Crossover Type	Single Point
Mutation Rate	0.004
Selection Type	Roulette wheel

VI. SIMULATION RESULTS AND DISCUSSION

In order to evaluate the performance of the proposed controllers, simulation has been carried out for set point change, source and load variations. The circuit parameters of the chosen Luo converter is listed in Table 3. Table 4 shows the searched parameters of a GA-fuzzy controller for the Luo converter. The controllers were made to maintain the output voltage constant at 20 V which is shown in Fig. 9. Figs. 10 and 11 show transients of the converters with fuzzy and GA-Fuzzy controllers under small signal step disturbances in supply and load.

Fig. 10 shows the measured responses of the output voltage with fuzzy and GA-fuzzy controllers with ± 25% supply disturbances at 0.02 sec and 0.04 sec. For the supply change from 10 V to 12.5 V and R = 10 Ω, the output voltage is regulated within 4.4 msec and 2.66 msec and the % peak overshoot is 32.9 and 23 for fuzzy and GA-fuzzy controllers respectively. When the supply voltage is changed from 12.5 V to 10 V, the settling time is 4.4 msec and 2.66 msec with % peak overshoot of 30.75 and 21.97 % for FLC and GA-FLC.

Fig.11 shows the output voltage of the converter with fuzzy and GA-fuzzy controllers with a step change of ± 20% of rated load at 0.02 sec and at 0.04 sec. It can be seen that the % peak overshoot is 27.45 and 18.68 and the settling time 4.44 msec and 2.2 msec for a step change of 10-12 Ω and for the step change of 12-10 Ω, the % peak overshoot 27.45 and 8.25, the settling time is 2.66 msec and 2.2 msec for fuzzy and GA-fuzzy controllers respectively. The Table 5 shows the performance comparison of GA-Fuzzy and Fuzzy controller. It is seen that FLC with GA gives satisfactory performances with less settling time, minimal overshoot and low ISE.

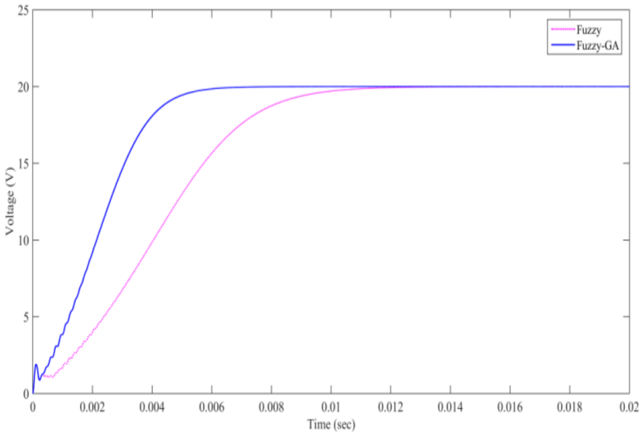

Fig.9 Closed Loop Responses of Fuzzy and GA-Fuzzy Controllers

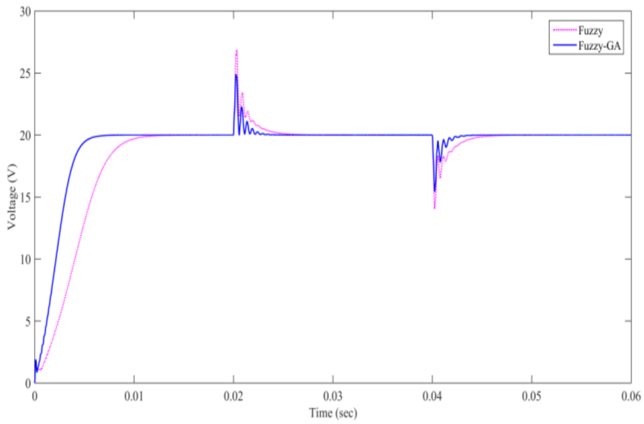

Fig. 10 Output Voltage Regulation under ± 25% Line Disturbances at 0.02 sec and 0.04 sec.

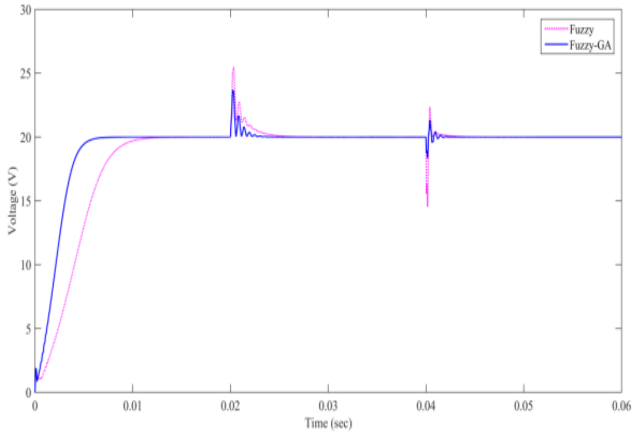

Fig. 11 Regulatory Responses of Luo Converter Under ± 20% Load Disturbances at 0.02 sec and 0.04 Sec

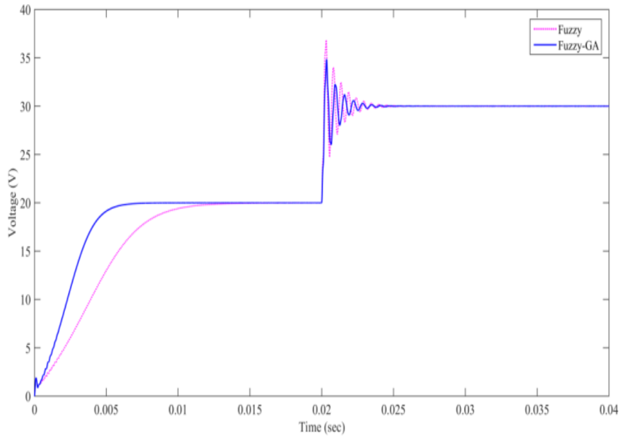

Fig. 12 Servo Responses of Fuzzy and GA-Fuzzy Controllers from 20V to 30 V at 0.02 sec

Table 5. Performance Comparison of GA-Fuzzy and Fuzzy Controllers

		Parameters	Fuzzy	GA Fuzzy
Start up Transient		Settling time (msec.)	10.9	5.45
		% Peak overshoot	-	-
		Rising time (msec.)	6	3.1
		ISE	1.0637	0.5728
		IAE	2.3501	1.1953
Line Disturbance	25%Supply Increase at 0.02 sec	Settling time (msec.)	4.44	2.66
		% Peak overshoot	32.9	23.0
	25% Supply Decrease at 0.04 sec	Settling time (msec.)	4.44	2.66
		% Peak overshoot	30.75	21.97
	ISE		1.1188	0.5895
	IAE		0.9704	0.484
Load Disturbance	20% Load Increase at 0.02 sec	Settling time (msec.)	4.44	2.2
		% Peak overshoot	27.45	18.68
	20% Load Decrease at 0.04 sec	Settling time (msec.)	2.66	2.2
		% Peak overshoot	27.45	8.25

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	ISE		1.1058	0.584
	IAE		1.057	0.5419
Servo response	50% set point change	Settling time (msec.)	3.85	3.57
		% Peak overshoot	21.23	14.49
	ISE		1.0339	0.6272
	IAE		1.3838	0.7673

VII. CONCLUSION

In this research work, the output voltage of Luo converter is controlled by means of two different fuzzy controllers. A new method for optimizing FLC using genetic algorithm has been presented. Membership functions, scaling gains and control rules are used in the optimization mechanism. Simulation results show that the performance of Luo converter is improved by optimizing the fuzzy parameters with GA. According to the results of the computer simulation, the FLC with GA is better than FLC.

It is seen that FLC with GA gives satisfactory performances with less settling time, minimal overshoot and low ISE.

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