Simulation and Real Time Implementation of PI Controller for Power Electronic Converter Based on Genetic Algorithm

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Abstract: *All modern electronic systems require high quality, small, light weight, cheap, reliable and efficient power supplies. DC-DC converters are widely used in cellular phones, laptop computer, medical equipments etc. Positive Output Elementary Luo converter (POELC) is one of the DC-DC converter. Due to the time-varying and switching nature of the converter, its dynamic behavior becomes highly non-linear. Conventional PI controller has unsatisfactory dynamic performance for such converter. Hence in this paper, simulation and real time implementation of PI and optimized PI controllers using Genetic Algorithm (GA) for positive output elementary Luo converters have been developed. Simulation has been carried out using MATLAB (SIMULINK) software for modeling Luo converters and PI controller. Real time implementation has been done using TMS320C542 DSP for set point tracking and rejection of supply disturbances.*

Keywords: Genetic algorithm, Luo converter, optimization algorithm ,PI controller and Soft Computing techniques.

I. INTRODUCTION

DC-DC converters is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. POELC is a newly developed subset of the DC-DC converters. This converter provides Positive load voltage for positive supply voltage. Luo converter overcome the effects of the parasitic elements, the output voltage and power transfer efficiency of all DC-DC converters are restricted. In order to eliminate the limitations caused by parasitic elements, the voltage lift technique is successfully applied to DC-DC converters resulting in a new series called Luo converters.

It is necessary to operate these converters as a closed loop system to maintain the voltage constant irrespective of supply disturbances. Transfer function is obtained from state space averaging technique to study the dynamic characteristics and to analyze the closed loop behavior of the positive output elementary Luo converter. PI controller is used for improving the performance of the above converter but it cannot effectively control, systems with changing parameter and may need frequent on-line tuning. Hence the optimized PI

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controller using Genetic algorithm(GA) have been suggested to serve as controller for improving the performances of the converters. Genetic Algorithms is powerful search tools that can reduce the time and effort involved in designing systems for which no systematic design procedure exists. They can quickly find close-to-optimal solutions.

TMS320C542 DSP has many special features to implement optimized control algorithm in real time. Some of the features are very flexible instruction set, high speed performance, cost effectiveness and single-chip solution for control applications. Hence this DSP is the right choice for controlling Luo converters. Therefore an attempt has also been made in this work to design, simulation and hardware implement of PI and GA-PI controller for regulating the output voltage in Luo converter.

II. DESIGN OF POSITIVE OUTPUT ELEMENTARY LUO CONVERTER

The 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. $R=V_o / I_o$ where 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_o. 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_0 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. When switch S is on, the source current $i_1=i_{L1}+i_{L2}$ (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_{L1} and i_{L2} increase. When switch S is off (Fig.3 source current $i_1=0$. Current i_{L1} flows through the freewheeling diode D to charge capacitor C. Inductor L_1 transfers its stored energy to capacitor C. Current i_{L2} flows through the (C_o-R) circuit and freewheeling diode D to keep itself continuous. Both currents i_{L1} and i_{L2} decrease. When switch S is turned off, current i_{L1} flows through the freewheeling diode D. This current descends in the switch-off period (1-d)T. If current i_{L1} 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_{L1} 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 $V_o= (d /(1-d))V_1$..

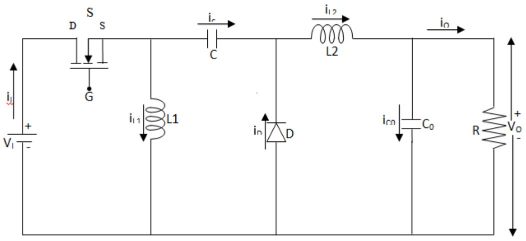

Fig.1 Positive Output Elementary LUO Converter

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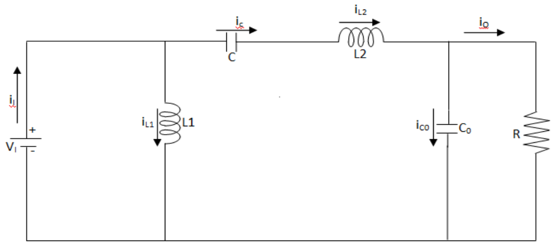

Fig.2 Positive Output Elementary LUO Converter (On Mode)

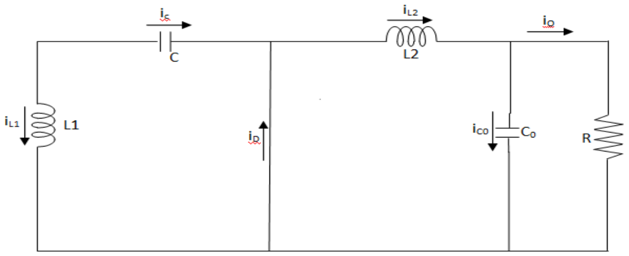

Fig.3 Positive Output Elementary Luo converter (Off Mode)

These converters are non-linear systems. However the circuit topology obtained for each mode is linear. Initially the circuits for the two modes are modeled using state-space approach. Then these two models are averaged over the switching period using the state-space averaging technique. The transfer function model is obtained from the state space model for positive output Luo converter. The state variables are

where

$x_1 = i_{L1}$, $x_2 = v_C$, $x_3 = i_{L2}$, $x_4 = v_{CO}$, $U = V_I$, $Y = V_O$.

Using the above state variables, the system matrices $_{A1}$ and A_2, input matrices B_1 and B_2 and output matrices C_1 and C_2 are obtained.

III . PI CONTROLLER

The proportional integral (PI) controller is mostly used for regulating output voltage of DC-DC power converter. The proportional controller improves the steady state tracking accuracy , load and line disturbance signal rejection. It is decreases the sensitivity of the system to parameter variations. The proportional control is not used alone because it produces constant steady state error. Hence proportional integral controller will eliminate forced oscillations i.e peak overshoot and steady state error.

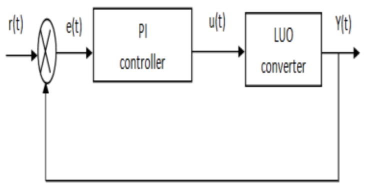

Fig.4 schematic PI controller

The PI controller works in a closed-loop system as shown in Fig.4. The variable (e) represents the tracking error, the difference between the desired input value (r) and the actual output (y). This error signal (e(t))

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will be sent to the PI controller and the controller compute integral error signal. The output of PI controller is now equal to the proportional gain(K_p) times the magnitude of the error plus the integral gain(K_i) times the integral of the error. The differential equation of PI controller equation is

$$u(t) = K_p e(t) + K_i \int_o^t e_p(t)dt$$

This signal (u) will be sent to the plant and the new output (y) will be obtained. This new output (y) will be sent back to the sensor again to find the new error signal (e). The controller takes this new error signal and competes its integral gain.

(i). DESIGN OF ZN-PI CONTROLLER

The converter is modeled in on-mode and off-mode using the state-space model approach and the corresponding state matrices are obtained. Using the average of these matrices and the circuit parameters of the above converter, transfer function model is obtained using MATLAB software. The corresponding conventional PI controller settings K_p and K_i are designed using Ziegler-Nichols (ZN) tuning method based on the converter open loop step response. The optimal controller settings are then found after evaluation of the minimum Values of rising time, settling time and Peak overshoot. The circuit parameters of the chosen positive output Luo converters are listed in Table 1. PI control is developed using the control system toolbox. Error in the output Voltage and the duty cycle of the MOSFETs are respectively the input and output of the PI controller.

Table .1 parameters of POELC

Parameters	Symbol	Value
Input Voltage	V_{in}	10 V
Output Voltage	V_o	40V
Inductor	L_1, L_2	100µH
Capacitor	C, C_0	5µF
Load resistor	R	10Ω
Switching frequency	f_s	50KHZ
Duty ratio	d	0.1-0.9

(ii). DESIGN OF GA- PI CONTROLLER

Genetic Algorithms (GAs) are a stochastic global search method that mimics the development of natural evolution. It is one of the methods used for optimization technique based PI controller. The computational systems keep on improving and this makes GA useful for optimization. The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its surroundings and evolution operators such as reproduction, crossover and mutation to arrive at the best solution. By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal solutions. GA starts with an initial chromosome and check for the fitness value. The fittest chromosomes are taken as parents further they are reproduced, crossed over & mutated. The offspring is checked for the value of the fitness & depending on the value it is either taken or neglected from the population.

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Given a clearly defined problem to be solved and a simple GA works as follows:

1. Start with a randomly generated population of chromosomes i.e. candidate solutions to a problem. Candidate Solution is the solution (values of K_p and K_i) after every iteration
2. Create the population size (i.e. No. of roots closer to the required root those are K_p and K_i). The limits of the roots (i.e. K_p and K_i) or the bounds are specified.
3. The roots (i.e. K_p and K_i) which are selected are the initial values of the roots required.
4. A selection method called Normalized Geometric Selection is applied so that any random value can be selected. Selection is based on the fitness value of the root.
5. Reproduce the selected roots (i.e. K_p and K_i) so as to get optimized solution.
6. Crossover called Arithmetic crossover & Uniform mutation are performed so as to alter the roots to get a optimized root (i.e. K_p and K_i)
7. Calculate the fitness $f(x)$ (using fitness function/ performance index) of each root (i.e. K_p and K_i) in the population.
8. Repeat the following steps until 'n' offspring have been created.
9. Using fitness function (performance index MSE) finds the value of the error in the generation (iteration).
10. The roots having the highest fitness value are chosen.
11. Thus the roots obtained are the final values of K_p and K_i
12. If the obtained value are not according to the required ones (fitness value is not up to the mark) then go to step 2

Each iteration of this process is called a generation. GA is typically iterated for anywhere from 0 to 500 or more generations. The entire set of generations is called a run. At the end of a run there are often one or more highly fit chromosomes in the population. Since randomness plays a large role in each run, two runs with different random−number seeds will generally produce different detailed behaviours. GA researchers often report statistics averaged over many different runs of the GA on the same problem.

Table.2 Parameters value of GA-PI

Parameters	Values
Population size	50
Variable bounds [K_p and K_i]	[0 100; 0 100]
Maximum Number of generations	100
Crossover probability	>0.8
Mutation probability	<0.05

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IV. IMPLEMENTATION OF ZN-PI AND GA-PI CONTROLLER

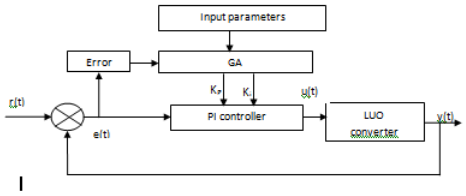

Fig. 5 Block diagram of Implementation of ZN-PI and GA-PI Controller

In this proposed work Luo converters model is called by a program which is coded in MATLAB for a fitness function i,e cost function. In order to use GA to tune the PI controller for Luo converter. A MATLAB m-file is developed based on GA algorithm with the specifications given in Table 2 Optimum values of controller tuning parameters of positive Output Elementary Luo converter with respect to time are estimated by executing the matlab file. The whole process is coded in matlab and after running the program we get the optimized values of K_p and $K_{i.}$

V. SIMULATION RESULTS AND DISCUSSION

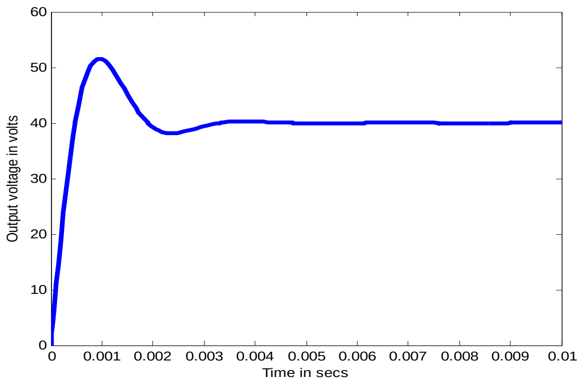

Fig 6 Closed loop response of POELC with ZN-PI controller

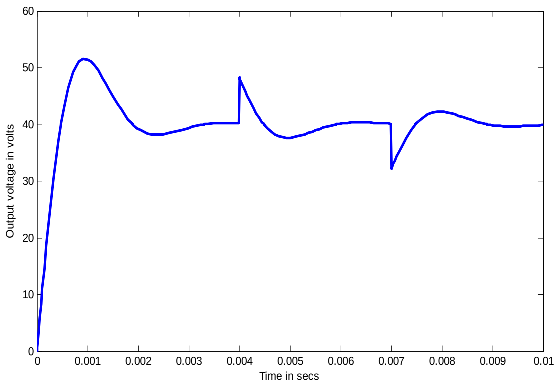

Fig 7 Closed loop response of POELC with ZN-PI controller under sudden line disturbance from 10V – 12 V (20%).

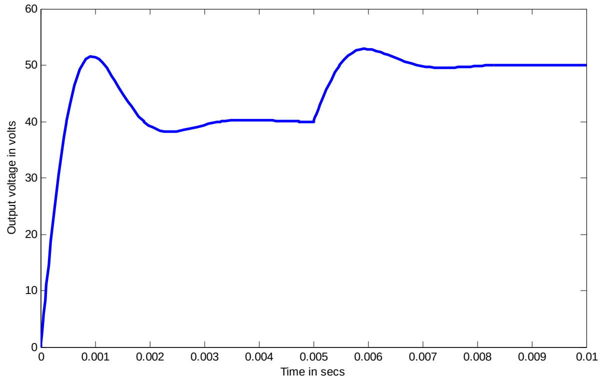

Fig 8. Servo response of POELC with ZN-PI controller under sudden increase in reference voltage from 40V – 50V

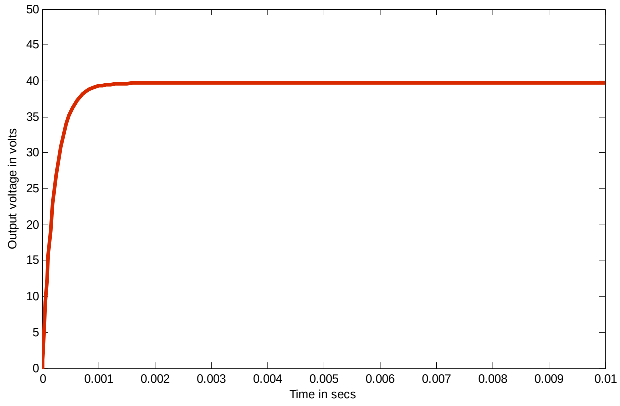

Figure 9 Closed loop response of POELCwith GA-PI controller

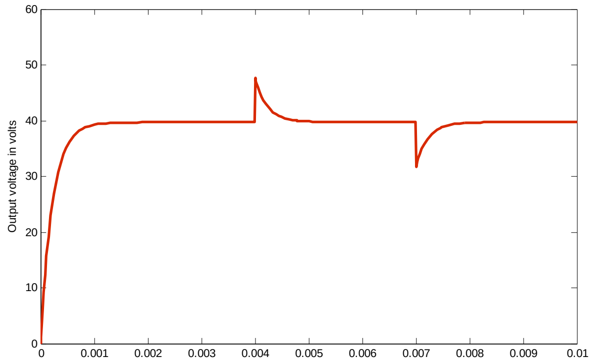

Fig 10 Closed loop response of POELC with GA-PI controller under sudden line disturbance from 10V – 12 V

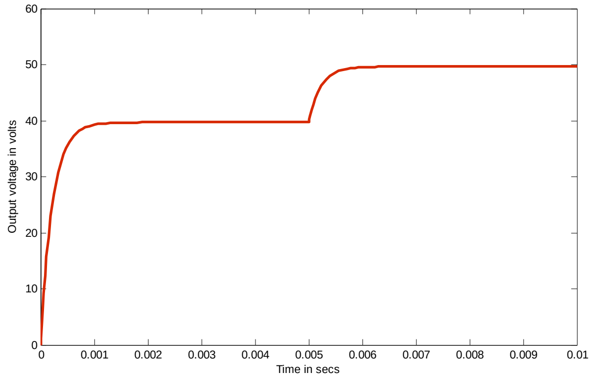

Fig 11. Servo response of POELC with GA-PI controller under sudden increase in reference voltage from 40V – 50V .

The converter output with PI controller under line disturbance and for set point tracking are carried out (Fig. 6-11). Fig 6 and Fig 8 shows the Closed loop response of positive output Elementary Luo converter with ZN-PI and GA-PI controller. Fig 7 and Fig 10 show the response of positive output elementary Luo converter with ZN-PI and GA-PI controller under sudden line disturbance from 10V – 12 V (20%) at 0.004 sec and 10V – 8V(20%) at 0.007 sec. For POELC the line disturbance is rejected within a maximum of 2.3 ms (ZN-PI) and 2.ms(GA-PI). Fig 8 and 11 show servo responses of above converter with ZN-PI and GA-PI controller under sudden increase in reference voltage from 40v-50v at 0.005 sec. The set point tracking occurs within 2.4ms (ZN-PI)and 2ms (GA-PI).

VI. HARDWARE IMPLEMENTION

The proposed PI and GA-PI controllers for the POELC are implemented use TMS320C5420 DSP which is a 16-bit fixed point DSP that combine the flexibility of a high-speed controller with the statistical ability of an array processor there by offering an inexpensive choice to multichip bit-slice processors. The highly paralleled architecture and very flexible set give a speed of 40MIPS. This high processing speed of CPU allows the user to compute parameters in real time rather than look up rough calculation from tables stored in memory. The converter output voltage is firstly scaled down suitably by a resistance divider network in the signal conditioning circuit. The output voltage of the divider circuit is fed to the on-chip ADC of DSP through the high impedance differential amplifier to compute the digital equal of output voltage. This is compared with reference voltage to compute the error which are processed by the DSP based PI control and GA-PI control method so suitably adjust the duty cycle of PWM signal. This PWM pulse of DSP is applied to the MOSFT through optocoupler and MOSFET driver. Optocoupler HCPL-3180 provide isolation between DSP and gate of MOSFET. In order to strengthen the pulse, IRF540 driver is used. The switching device is N- channel MOSFET IRF250N. It is experimental that the peak overshoot and settling time are very much reduced in the in the GA-PI controller as compared to the PI controller. The hardware kit for above converter is shown in figure 12. Table 3 shows the performance analysis of Positive Output Elementary Luo Converter with PI and GA-PI controllers using simulation and experimental result.

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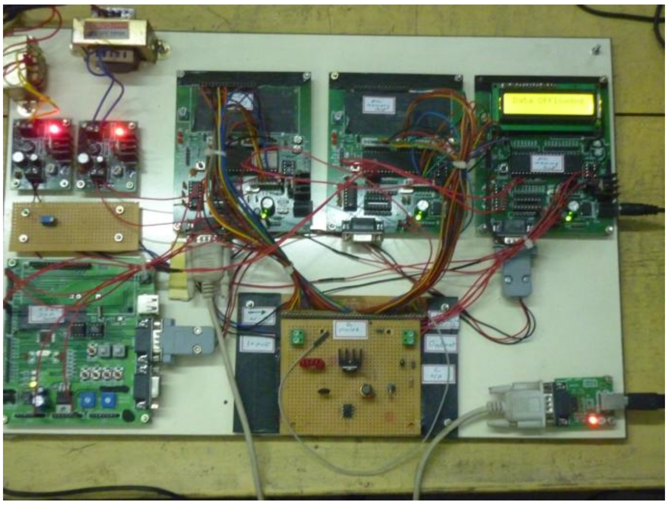

Figure.12 Hardware kit for POELC

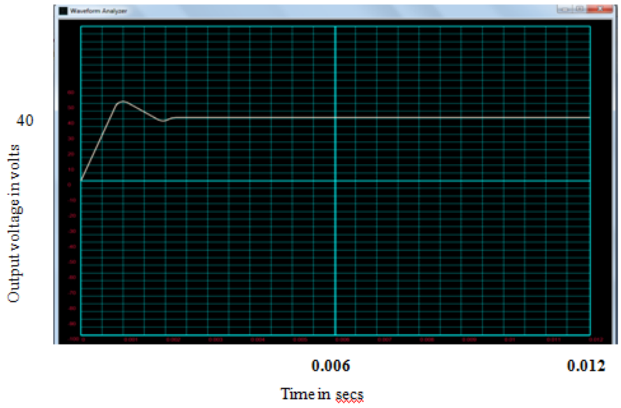

Fig.13 Closed loop response of POELC with ZN-PI controller

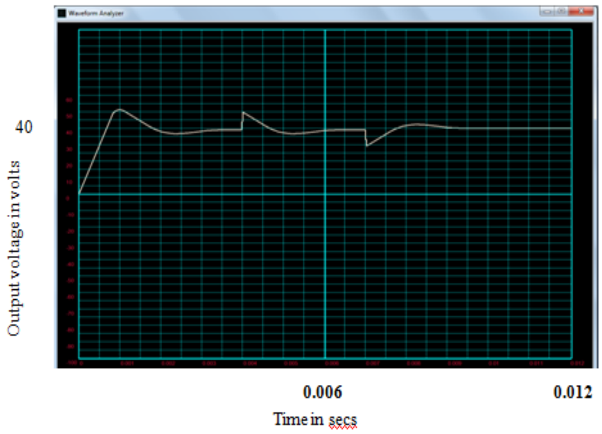

Fig 14 Closed loop response of POELC with ZN-PI controller under sudden line disturbance from 10V - 12 V (20%) at 0.003 sec and10V - 8V(20%) at 0.006 sec.

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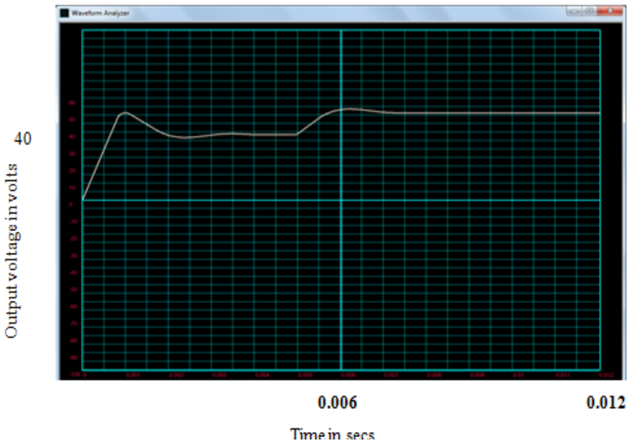

Fig 15 Servo response of POELC with ZN-PI controller under sudden increase in reference voltage from 40V – 50V

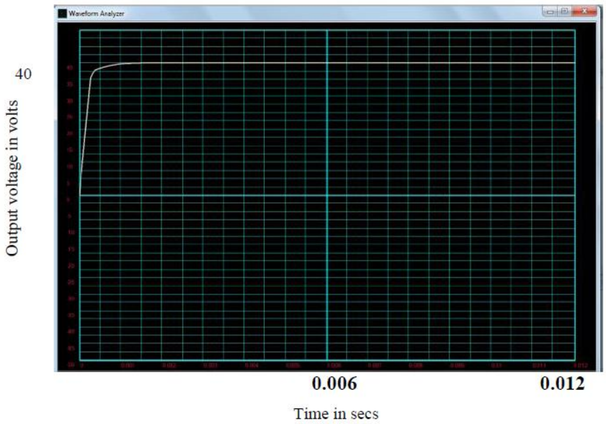

Fig. 16 Closed loop response of POELC with GA-PI controller

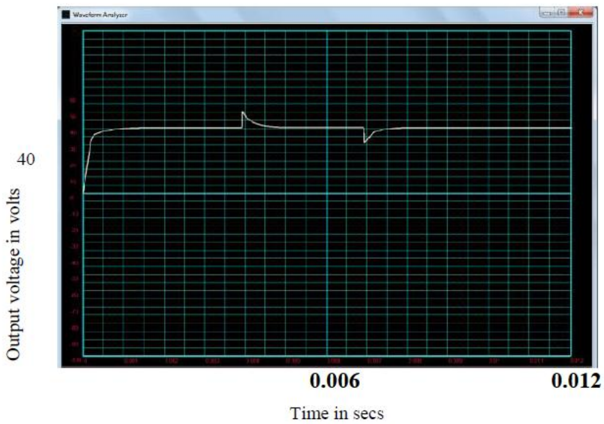

Fig 17 Closed loop response of POELC with GA-PI controller under sudden line disturbance from 10V - 12 V

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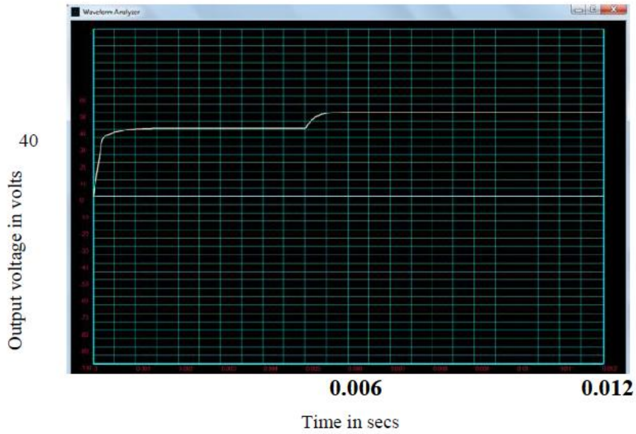

Fig. 18 Servo response of POELC with GA-PI controller under sudden increase in reference voltage from 40V – 50V

Table 3 performance analysis of Positive Output Elementary Luo Converter with PI and GA-PI controllers using simulation and experimental result**.**

		Tuning parameters	**ZN-PI controller**		**GA-PI Controller**	
			Simulation Result	**Experimental Result**	**Simulation Result**	**Experimental Result**
Start-up Transient		**Rising time (m sec)**	0.4	0.7	0.5	0.55
		Settling time (m sec)	4.8	5	4.5	4.8
		Peak Overshoot %	28.75	30	0	0
Line Disturbance	**Supply increase 20%**	**Settling time (m sec)**	2.3	2.7	2.1	2.2
		Peak Overshoot %	20.75	26	19.25	24
	Supply decreas e 20%	**Settling Time (m sec)**	2.5	2.8	2	2.3
		Peak Overshoot %	19.68	26	20.5	25
Servo Response	**20% set point**	**Settling Time (m sec)**	5	5.5	3.5	3.8
		Peak Overshoot %	35	37	0	0

VII. CONCLUSION

The aim of this research work is not to emulate conventional control where it can be applied but to suggest an alternative approach for those situations where conventional methods fail. However any control method whose results are not comparable with those of linear controllers for simple processes would probably not be effective when applied to more complex processes. Conventional proportional integral controller is widely used in much industrial applications due to its simplicity in structure and ease to design. However it is difficult to achieves the desired control performances. Tuning is important parameter for the best performances of PI controller. PI controllers can be tuned in a variety of ways, but these have their own limitations. Soft computing technique using Genetic Algorithm method have proved their steady excellence in given better results by improving the steady state characteristics and performance indices.

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