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Hardware Implementation of Intelligent Controllers for Elementary Luo Converter

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Abstract: *Positive output elementary Luo converter performs 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 controller 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 Particle Swarm Optimization based FLC (PSO-FLC) are suggested. In recent years, fuzzy logic has emerged as an important artificial intelligence tool to characterize and control a system, whose model is not known or ill defined. Fuzzy logic is expressed by means of if-then rules with the human language. In the design of a fuzzy logic controller, the mathematical model is not necessary. However, the rules and the membership functions of a fuzzy logic controller are based on expert experience or knowledge database. To ensure better performance of fuzzy controller, membership functions, control rules, normalizing and de-normalizing parameters are optimized using PSO. The main strength of PSO is its fast convergence than the other global optimization algorithms. Optimized PSO based fuzzy controller provide better performance and superior to the other control strategies because of fast transient response, zero steady state error and good disturbance rejection under variations of line and load and hence output voltage regulation is achieved.*

Keywords: *Fuzzy Logic Controller, Particle Swarm Optimization, Luo converter, Digital Signal Processor*

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I. Introduction

DC-DC converters are electronic devices used to change DC electrical power efficiently from one voltage level to another. These converters are widely used in switched-mode power supplies, adjustable speed drives, uninterruptible power supplies, telecommunication equipment, spacecraft power system etc. Fuzzy logic controller performs the control of nonlinear systems based on designer practical experience. The application of this technique does not require accurate models of the converter and is able to deal with its typical nonlinearities, showing less sensitivity to noise disturbances and parameters variations. In recent years, several heuristic optimization techniques such as Differential Evolution (DE), Ant Colony Optimization (ACO) and Genetic Algorithm (GA) were introduced in the field of fuzzy control applications because of their fast computability. Though GA-FLC approach performs well for complex optimization problems, recent research has identified certain problems where variables are highly correlated and GA crossover and mutation operators do not generate individuals with better fitness of offspring as the chromosomes in the population pool. This research work presents an approach to overcome the design problem of GA-FLC by means of PSO-FLC. PSO algorithm has several advantages such as speed of convergence, simplicity of implementation and less susceptibility of being trapped in local optima. PSO has more actual memory ability than the GA, since each particle recalls its best value in previous iteration and the neighbourhood best. As all particles use the information related to the most successful particle in order to improve them, the algorithm is more effective in preserving the variety of the swarm. The population evolves around a subset of the best individuals in PSO, since the poor solutions are discarded and only the good ones are preserved. In this work, two types of controllers are designed namely the Fuzzy controller and PSO-Fuzzy controller. Fuzzy controller parameters were optimized by PSO for regulating the output voltage of Luo converter.

II. Positive Output Elementary LUO Converter (POELC)

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 average output voltage of the converter in Continuous Conduction Mode is

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

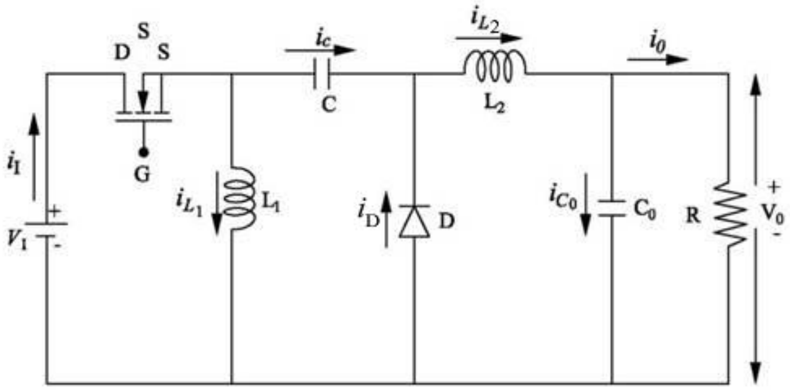

Fig. 1 Circuit Diagram of Positive Output Elementary LUO Converter

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 and works independent of the operating point of the Luo converter.

IV. Particle Swarm Optimization

Particle Swarm Optimization is a population based stochastic optimization technique, inspired by social behaviour of bird flocking or fish schooling. In PSO the individuals called particles, fly around in a multidimensional search space and change their position with time. During its flight, each particle adjusts its position according to its own experience and according to the experience of neighbouring particles. The position or value corresponding to its own experiences called *pbest* and corresponding to the experience of neighbouring particles is called *gbest*. The search for the optimal position advances as the velocities and positions of the particles are updated. The fitness of each particle's position and iteration is calculated using a pre-defined objective (fitness) function and the velocity of each particle is updated using the *pbest* and *gbest***,** which were previously defined. The flow chart of PSO algorithm is shown in Fig. 2.

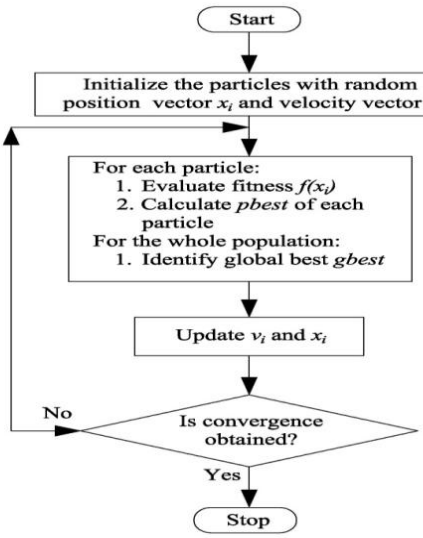

Fig. 2 Flow chart of PSO algorithm

V. PSO Based Fuzzy Logic Controller

The parameters representing the linguistic sets, scaling gains and fuzzy rules are represented by the optimization variable of the PSO, called particle. It is a vector of real numbers that consists of three parts, the first part is related to the real numbers required to identify the membership functions, the second part is related to the integer numbers required to identify the fuzzy rules and the third part is related to the real numbers to identify the scaling gains. With regards to the first part of the particle identifying the membership functions, a maximum number of seven fuzzy sets has been chosen. Tuning of the membership function can be carried out by expanding or shrinking the membership functions in relation to its universe of discourse. As each linguistic variable has been assumed to have a maximum of seven primary terms, two parameters are then required to represent the membership functions of a linguistic variable of the implemented fuzzy controller. Therefore, in order to represent the three linguistic variables, six parameters are needed to characterize the search space of the problem. With regards to the second part of the particle identifying the fuzzy rules, a total of forty-nine fuzzy rules are used. FLC can be optimized by adjusting the scaling gains K_e, K_{ce} and K_{du}. Totally 58 parameters are required to design the fuzzy controller and are represented by the particle. Integral square error (ISE) is used as an objective function. The mathematical equation of the ISE is given by

$$ISE = \int_0^T e^2\,(t)dt \qquad (1)$$

The structure of the fuzzy logic controller with PSO algorithm is shown in Fig. 3.

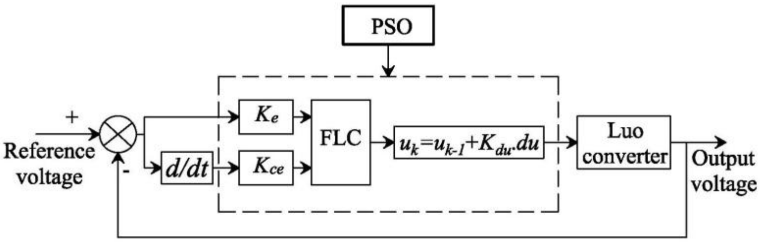

Fig. 3 Structure of FLC with PSO Algorithm

Table 1 lists the parameters of PSO algorithm used in this work Table 2 lists the fuzzy inference rules with PSO algorithm. Membership functions for inputs and output variables searched by PSO are shown in Fig. 4.

Table 1 Parameters of PSO Algorithm

Parameter	Particle dimension	Swarm size	Number of iterations	c_1 and c_2
Value	58	30	100	2

Table 2 Optimised Fuzzy Rules

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

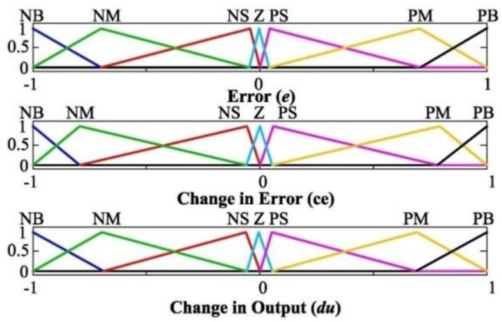

Fig. 4 PS Optimized Input and Output Membership Functions of Fuzzy Controller

VI. Architectural Overview Of TMS320C242 DSP

TMS320C242 device is a member of the 24x family of DSP controllers based on the TMS320C2xx generation of 16-bit fixed-point digital signal processors. This new family is optimized for digital motor/motion control applications. This continues the high performance of a DSP core with the on-chip peripherals of a microcontroller, yielding a high-performance DSP. The DSP controllers combine the enhanced TMS320 architectural design of the 'C2xx core CPU for low-cost, high-performance processing capabilities and several advanced peripherals optimized for motor/motion control applications. The peripherals include the event manager module, which provides general-purpose timers and PWM registers to generate PWM outputs and a single, 10-bit Analog-to-Digital converter (ADC), which can perform conversion within 1 μs. The instruction set of these DSP controllers, which incorporates both signal-processing instructions and general-purpose functions is coupled with the extensive development support available for the TMS320 DSP family. This reduces development time and provides the same ease of use as traditional 8- and 16-bit microcontrollers. Architectural overview of TMS320C242 DSP is shown in Fig. 5.

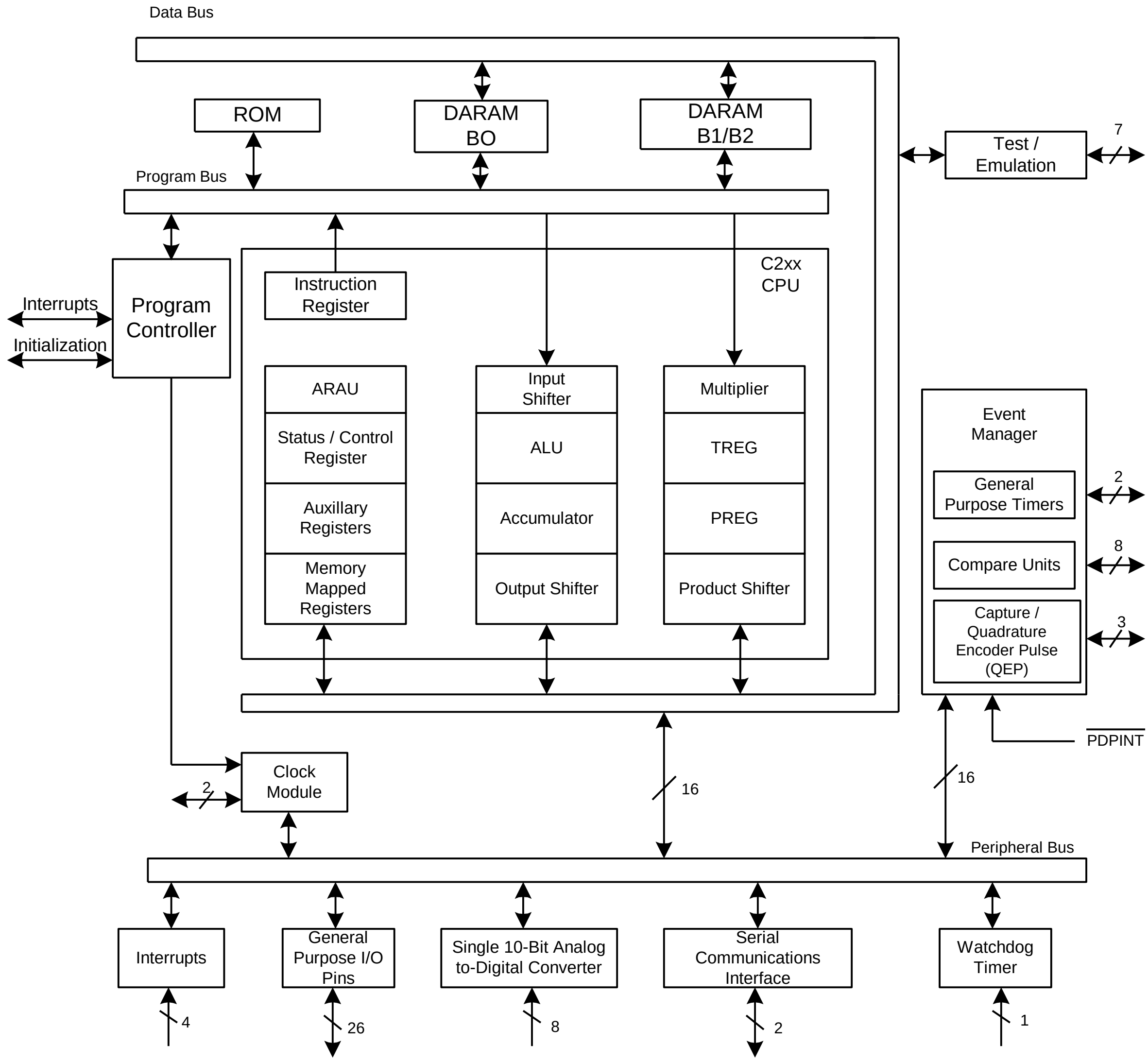

Fig. 5 Architectural Overview of TMS320C242DSP

VII. PWM Generation

To generate a PWM signal, an appropriate timer is needed to repeat the counting period that is the same as the PWM period. A compare register holds the modulating values. The value of the compare-register is constantly compared with the value of the timer counter. When the values match, a transition (from low to high or high to low) occurs on the associated output. When a second match is made between the values or when the end of the timer period is reached, another transition (from high to low or low to high) occurs on the associated output. In this way, an output pulse is generated whose ON or OFF duration is proportional to the value in the compare register. This process is repeated for each timer period with different modulating values in the compare register. As a result, a PWM signal is generated at the associated output. Compare operation is enabled by setting bit 1 in T1CON to 1.

VIII. Hardware Implementation

The block diagram of closed loop control of elementary Luo converter using TMS320C242 DSP is shown in Fig. 6. The switching device used is N-channel MOSFET (enhancement type) IRF540N. The PWM signal from the DSP based controller is not capable of driving MOSFET. In order to strengthen the pulses, MOSFET driver IC IR2110 is used. In order to provide isolation between the Luo converter and DSP, the isolation amplifier HCPL7840 is needed in the feedback path. The MCT2E optocoupler provides the isolation between the DSP and the MOSFET. Regulation of the output voltage of the Luo converter is done using a feedback arrangement. A resistance divider network scales down the output voltage suitably in the signal conditioning circuit. The output voltage of the divider is fed to the ADC of DSP through isolation amplifier. The DSP based controller computes the actual output voltage and compares it with the reference voltage. The error (*e*) and change in error (*ce*) are processed by the fuzzy and optimized fuzzy control algorithms in DSP to suitably adjust the duty ratio of the PWM signal applied to the MOSFET through optocoupler and MOSFET driver circuits. The previous value of error is used to calculate *ce*. The event manager module of the DSP is programmed to provide the PWM signal.

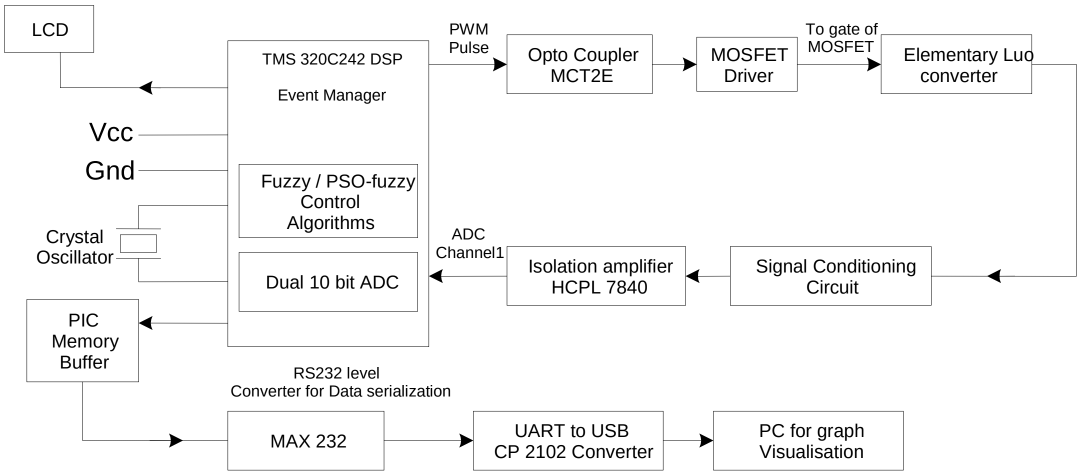

Fig. 6 Hardware Implementation of Elementary Luo Converter with Controllers

IX. Experimental Results and Discussion

To verify the real time performances of the proposed controllers, prototype of elementary Luo converter has been tested with controllers implemented using DSP.

Startup transient response with input voltage variations of ± 25% of supply voltage was evaluated as shown in Fig.7. It can be seen that the output voltage is compensated within 6.38 msec and 4.16 msec and the % peak overshoot is 39 and 15 for fuzzy and PSO-fuzzy controllers respectively for the step change of 10-12.5 V at 0.02 sec. For the step change in the supply voltage from 12.5 V to 10 V at 0.04 sec, the output voltage reaches the reference voltage within 5.55 msec and 3.05 msec and the % peak overshoot is 38 and19 for fuzzy and PSO-fuzzy controllers respectively.

Fig.8 shows the output voltage of the Luo converter with controllers for a step change ± 20% of rated load at 0.02 sec and at 0.04 sec. The experimental results show that the output voltage is regulated for the step change of 10Ω-12Ω within 6.11 msec and 3.21 msec and the % peak overshoot is 40 and 16 for fuzzy and PSO-fuzzy controllers respectively. It can be observed that for the load variation of 12Ω - 10Ω, the disturbance is rejected within 4.16 msec and 2.77 msec and the % peak overshoot is 33 and 8 for fuzzy and PSO-fuzzy controllers respectively. Table III shows the performance evaluation of Luo converter in terms of percentage overshoot, rise time and settling time under startup, change in the input and load.

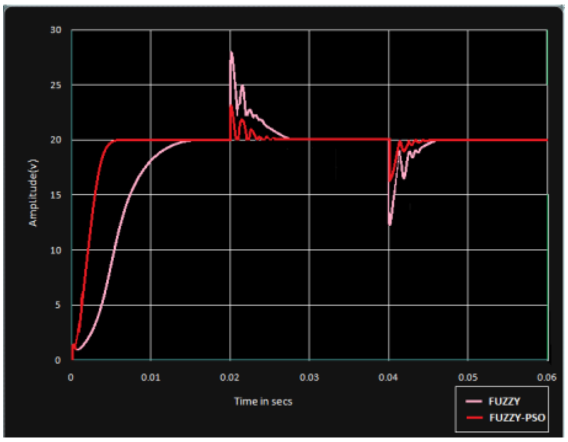

Fig.7 Closed Loop Responses Under ± 25% Line Disturbances

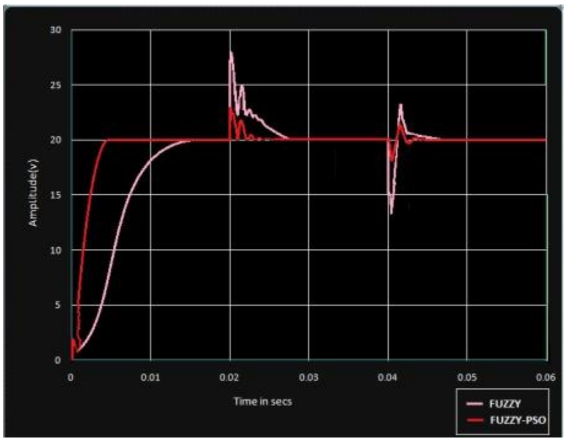

Fig.8 Closed Loop Responses Under ± 20% Load Disturbances

Table 3 Performance Comparison of PSO-Fuzzy and Fuzzy Controllers

		Parameters	**Fuzzy**	**PSO-Fuzzy**
Start up Transient		Rise time (msec.)	6.38	3.33
		Settling time (msec.)	13.88	4.72
		% Peak overshoot	-	-
Line Disturbance	25%Supply Increase at 0.02 sec	Settling time (msec.)	6.38	4.16
		% Peak overshoot	39	15
	25% Supply Decrease at 0.04 sec	Settling time (msec.)	5.55	3.05
		% Peak overshoot	38	19
Load Disturbance	20% Load Increase at 0.02 sec	Settling time (msec.)	6.11	3.21
		% Peak overshoot	40	16
	20% Load Decrease at 0.04 sec	Settling time (msec.)	4.16	2.77
		% Peak overshoot	33	8

X. Conclusion

In this work, Luo converter with fuzzy control system has been modeled and optimized using PSO algorithm. Comparative studies were made with the two proposed controllers for a sudden change in input voltage and load change. The PSO-fuzzy controller gives the better performance and was more robust for disturbances in comparison with the fuzzy controller. Experimental results obtained validate the effectiveness of the proposed PSO-fuzzy control strategy and the controlled converter behaves very well with very less overshoot and settling time. PSO method is an efficient global optimizer for continuous variable problems and it is easily implemented with few parameters to be tuned.

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