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Performance Analysis of PI Controller for Power Electronic Converter Using Evolutionary Algorithms

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Abstract

The Positive Output Luo converter[POLC] is a newly series developed DC-DC converter. Due to the time-varying and switching nature of the above converter, its dynamic behavior become highly non-linear. Conventional controllers are incapable of providing good dynamic performance for such a converter and hence Evolutionary Algorithms have been developed to tune the PI parameters. In this work, Genetic algorithm (GA), Particle Swarm Optimization (PSO) algorithm, Bacterial Foraging (BF) algorithm and Modified Bacterial Foraging(MBF) algorithm. Simulation results show that the performances of GA-PI, PSO-PI BE-PI and MBF-PI controller are better than those obtained by the classical ZN-PI controller.

Keywords: PID controller, DC-DC converter, Luo converter and Soft computing techniques and optimization techniques.

I. INTRODUCTION

Many industrial applications require power from variable DC voltage sources. DC-DC converters convert fixed DC input voltage to a variable DC output voltage for use in such applications. DC-DC converters be also use as interface between DC systems of different voltages levels. **POLC** is a recently developed subset of the DC-DC converters. This converter provides positive load voltage for positive supply voltage. Luo converters overcome the effects of the parasitic elements that boundary the voltage conversion ratio. These converters in general have complex non-linear modes with parameter variation problems. PI controllers do not provide satisfactory response for these converters which are time varying systems. Hence Evolutionary Algorithms is used for regulating the POLC. In this work, Genetic algorithm (GA), Particle Swarm Optimization (PSO) algorithm, BF algorithm and MBF algorithm based PI controller is designed and simulated for the above Luo converter. The performance indices used is Integral Squared Error (ISE) and Integral Absolute Error (IAE).

II. DESIGN OF POSITIVE OUTPUT LUO CONVERTER

A positive output elementary Luo converter (Fig.1) performs step-up/step-down conversion from positive input DC voltage to positive output DC voltage. The voltage transfer ratio of the above converter is (k/(1-k)) where k is the duty ratio. The circuits (Fig.2 and Fig.3) for the switch-on and switch-off modes of the chosen converter are developed using a state-space approach. At this point, these two models are averaged over a single switching period T using a state-space averaging technique. The state variables are:

$$X_1 = I_{L,}\ X_2 = Vc_{,}\ X_3 = I_{Lo,}\ X_4 = V_{co}$$

$$U = Vi \qquad Y = Vo$$

sing the above state variables, the system matrices A_1 and A_2, input matrices B_1 and B_2 and output matrices C_1 and C_2 are obtained.

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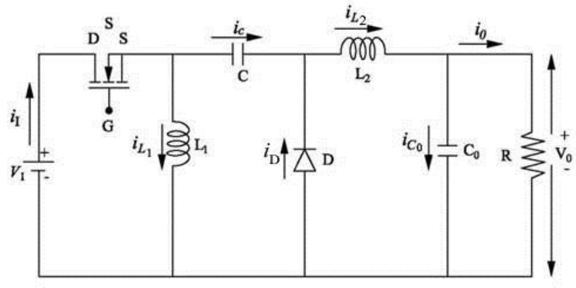


Fig.1 positive Output Elementary LUO Converter

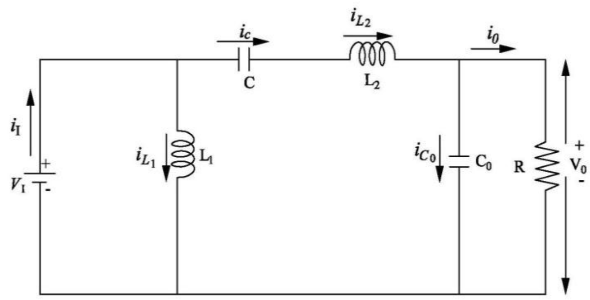


Fig.2 Positive Output Elementary LUO Converter (On Mode)

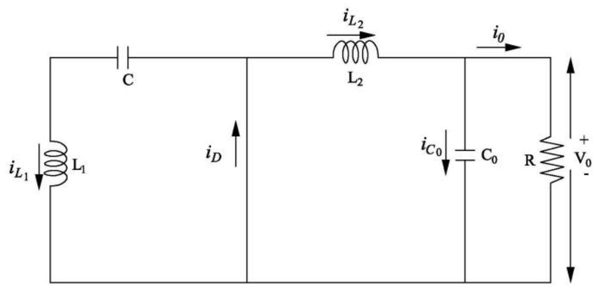


Fig.3 Positive Output Elementary Luo converter (Off Mode)

III. Design of PI CONTROLLER

The converter is modeled in on-mode and off-mode using the state-space approach and the corresponding state matrices are obtained. Using the average of these matrices and the circuit parameters of the chosen converter, transfer function model is obtained using MATLAB software. The corresponding PI controller settings K_p and K_i are designed using Ziegler-Nichols tuning technique based on the converter's open loop step response. The optimal controller settings are then found after evaluation of the minimum Values of ISE and IAE. 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.

IV.Optimization of PI Controller

In order to improve the dynamic performances of the conventional PI controller, Evolutionary Algorithms have been developed to tune the PI parameters. In this work, design and implementation of evolutionary algorithms have been developed for PI controller. The performance of the positive output Luo converter with optimized PI controller is evaluated under line and load disturbances and for set point tracking. The block diagram of optimized PI controller is as shown in Fig 4. The purpose of this work is to investigate an optimal controller design using GA, PSO, BF and MBF optimization techniques to tune K_p and K_i values. In order to improve the dynamic performances of the conventional PI controller, Evolutionary Algorithms have been developed to tune the PI parameters. In this work, design and implementation of evolutionary algorithms have been developed for PI controller. The performance of the positive output Luo converter with optimized PI controller is evaluated under line and load disturbances and for set point tracking. The block diagram of optimized PI controller is as shown in Fig 4. The purpose of this work is to investigate an optimal controller design using GA, PSO, BF and MBF optimization techniques to tune K_p and K_i values

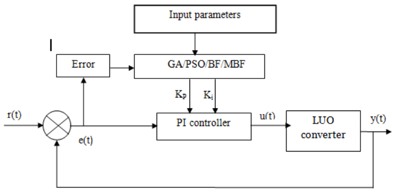


Fig. 4 Block diagram of optimized PI controller

IV. Design of Genetic algorithm

GA is a simulation of natural genetic and development in the natural environment and arrangement of an adaptive global optimization probability search algorithm. The fundamental process of GA uses three main operators which are selection, crossover and mutation:

i) Selection: It is the mechanism for selecting theindividuals with high fitness to create new individuals for the next population. There are several types used forselection 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.

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 anexact 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.

VI. DESIGN OF PSO-PI CONTROLLER

PSO is a method for optimizing hard numerical functions on metaphor of social behaviour of flocks of birds and schools of fish. The original PSO algorithm is discovered through simplified social model simulation. It was first designed to emulate birds seeking food which is defined as a cornfield vector. The bird would find food through social cooperation with other birds around it (within its neighborhood).It was then expanded to multidimensional search. In PSO each particle in swarm represents a solution to the problem and it is defined with its position and velocity. The main steps in the particle swarm optimization and selection process are described as follows. Initialize a population of particles (k_p and k_i) with random positions and velocities in m-dimensions of the problem space and fly them.

(a) Evaluate the fitness of each particle in the swarm.[ISE and IAE]
(b) For every iteration, compare each particle's fitness with its previous best fitness (p_{best}) obtained. If the current value is better than (p_{best}), then set (p_{best}) equal to the current value and (p_{best}) location equal to the current location in the m-dimension space.
(c) Compare (p_{best}) of particles with each other and update the swarm global best location with the greatest fitness (g_{best}).
(d) Update the velocity and position of the particle according to the equations (5.1 and 5.2).

$$V_{i,m}^{(It+1)} = W^* V_{i,m}^{(It)} + c_1 * rand * (p_{best\ i,m} - x_{i,m}^{(It)}) + c_2 * rand * (g_{best\ m} - x_{i,m}^{(It)}) \quad (5.1)$$

$$x_{i,m}^{(It+1)} = x_{i,m}^{(It)} + V_{i,m}^{(It)} \quad (5.2)$$

Where: $v_{i,m}$ & $x_{i,m}$ represent the velocity and position of the i_{th} particle with n-dimensions respectively.

i= 1,2,…..,n

m= 1,2,…..,d

n = Size of population.

d = Dimension.

rand= Random number between 0-1

It = Iteration Pointer.

W= The inertia weight factor that controls the exploration and exploitation of the search space because it dynamically adjusts velocity.

c1, c2 = Acceleration constant (positive constant) called the cognitive and social parameter respectively.

p_{besti} = Best previous position of i_{th} particle.

g_{bestm} = Best particle among all the particles in the population

(f) Repeat steps (a) to (e) until convergence is reached based on some desired single or multiple criteria.

VII. BACTERIAL FORAGING OPTIMIZATION TECHNIQUE

Bacterial Foraging algorithm is a new division of bio-inspired algorithm. This technique is developed by inspiring the foraging behaviour of *Escherichia coli (E.coil*) bacteria. In the bacterial foraging optimization process four motile behavior are mimicked:-

i. Chemotaxis

Chemotaxis process is achieved by through swimming and tumbling via Flagella. Depending upon the rotation of flagella in each bacterium, it decides whether it should move in a predefined direction (Swimming) or altogether in different directions (Tumbling), in the entire lifetime. To represent a tumble, a unit length random direction, say Ø(j), is generated; this will be used to define the direction of movement after a tumble. In particular

$$\theta^1(j+1,k,l) = \theta^1(j,k,l) + C(i)*\phi(j) \qquad (1)$$

Where,

$\theta^1(j,k,l)$ represents the i^{th} bacterium, at j^{th} chemotactic, k^{th} reproductive, and l^{th} elimination and dispersal step. C(i) is the size of the step taken in the random direction specified by the tumble(run length unit).

ii. Swarming

E.coli cells can cooperatively self organize into highly structured colonies with elevated environmental adaptability using an intricate communication mechanism. Overall, cells provide an attraction signal to each other so they swarm together. The mathematical representation for swarming can be represented by, J_{cc}(θ,D(j, k, l)) = J^i_{cc}(θ, $\theta^1(j,k,l)$)) = X+Y (2)

Where,

$$X = \sum_{i=1}^{s}[-D_{attract} * \exp(-W_{attract} * \sum_{m=0}^{p}(\theta m - \theta^i m)2]$$

$$Y = \sum_{i=1}^{s}[H_{repellant} * \exp(-W_{repellant} * \sum_{m=0}^{p}(\theta m - \theta^i m)2]$$

Where, J_{cc}(θ,D(j, k, l)) is the cost function value to be added to the actual cost function to be minimized to present a time varying cost function, S is the total number of bacteria, P is the number of parameters to be optimized which are present in each bacterium and $D_{attract}$, $W_{attract}$, $H_{repellant}$, $W_{repellent}$ are different coefficients that should be chosen properly.

iii. Reproduction

The least healthy bacteria die while each of the healthier bacteria (those yielding lower value of the objective function) asexually split into two bacteria, which are then placed in the same location. This keeps the swarm size constant.

iv. Elimination and Dispersal

It is possible that in the local environment the life of a population of bacteria changes either gradually (e.g., via consumption of nutrients) or suddenly due to some other influence. Events can occur such that all the bacteria in a region are killed or a group is dispersed into a new part of the environment. They have the effect of possibly destroying the chemotactic progress, but they also have the effect of assisting in chemotoxis,

since dispersal may place bacteria near good food sources. From a broad perspective, elimination and dispersal are part of the population-level long-distance motile behavior.

V. MODIFIED BACTERIAL FORAGING OPTIMIZATION TECHNIQUE

MBFOA emulates the foraging process of bacteria *E. coli* as follows: Within a cycle called generation (P) each bacterium performs a chemotactic step N_c times. After all bacteria went through their chemotactic step, the best bacteria are reproduced while the worst ones are eliminated and new ones are generated at random. It creates a procedure in which the best bacteria among all the chemotactic steps are passed to the subsequent generations.

MBFOA is based on the four processes, combining the chemotaxis and swarming into one loop and simplifying the reproduction and elimination-dispersal. MBFOA uses real-encoding to represent a solution, which is called *bacterium* and is represented by its position as,

$$\theta^i(j,P) = \vec{x_i} \qquad (3)$$

Where,

i represents the number of bacterium, j represents the chemotactic loop number, P is the cycle number of the algorithm.

i. *Chemotaxis*

The chemotactic cycle consists on tumble (search direction at random) and swim movements carried out by bacteria in the search space with the aim to find nutrients. The attractor movement applies twice in a chemotactic loop, while in the remaining steps the tumble - swim movement is carried out. The rules work as criteria in the chemotactic loop in the reproduction step and in the elimination of the worst bacterium in the swarm. The chemotactic process consists on tumble-swim movements carried out by bacteria in the current swarm.

The tumble movement is represented by

$$\phi\,(i) = \frac{\Delta\,(i)}{\sqrt{\Delta\,(i)^T \Delta\,(i)}} \qquad (4)$$

Where,

Δ (i) is a randomly generated vector of size m with elements within the following interval: [−1, 1]. After that, each bacterium i modifies its positions by swimming and is represented as

$$\theta^i(j+1,P) = \theta^i(j,P) + B(i)\emptyset(i) \qquad (5)$$

Where,

θ^i(j+1, P) is the new position of bacterium i (new solution) at chemotactic step j + 1, θ^i (j,P) is the current position of bacterium i at chemotactic step j. In MBFOA the step size values in vector B(i) are calculated using Equation 5 by considering the valid limits per each design variables.

$$B(i)_k = S * \left(\frac{\Delta x_k}{\sqrt{m}}\right), k = 1, \ldots..m \qquad (6)$$

Where, Δx_k is the difference between upper and lower limits for design parameter x_k: $U_k - L_k$, m is the number of design variables and S is a user-defined percentage of the value used by the bacteria as step size. MBFOA implements an attractor movement so as to let each bacterium in the swarm to follow the bacterium located in the most assuring region of the search space and is represented as

$$\theta^i(j+1,P) = \theta^i(j,P) + \beta\left(\theta^B(P) - \theta^i(j,P)\right) \qquad (7)$$

Where,

$\theta^i(j+1, P)$ is the new position of bacterium i, $\theta^i(j,P)$ is the current position of bacterium i, $\theta^B(P)$ is the current position of the best bacterium in the swarm so far at generation P, and β defines the closeness of the new position of bacterium i with respect to the position of the best bacterium $\theta^B(P)$.

The attractor movement applies twice in a chemotactic loop, while in the remaining steps the tumble-swim movement is carried out. The aim is to promote a balance between exploration and exploitation in the search.

ii. *Reproduction*

The reproduction process consists of sorting the swarm according to the rules of the constraint-handling technique. The first half of the population is replicated to maintain the same population size for the next generation. It consists of eliminating the second worst bacterium and replacing it with a copy of the best bacterium in the current population, while the worst bacterium is also eliminated and replaced with one generated at random.

iii. Elimination and Dispersal

The elimination - dispersal process eliminates only the worst bacterium, and a new randomly generated bacterium is inserted as its replacement. A single reproduction step and a single elimination- dispersal step are performed at the end of generation loop. The elimination – dispersal step is simplified because only the worst bacterium in the population is eliminated.

VIII. PERFORMANCE INDICES

The objective function considered is based on the error criterion. The performance of a controller is best evaluated in terms of error criterion. In this work, controller performance is evaluated in terms of Integral square error (ISE) and Integral Absolute Error (IAE)

$$\text{ISE} = \int_0^t e^2 dt \qquad (8)$$

$$\text{IAE} = \int_0^t |e|\, dt \qquad (9)$$

The ISE and IAE weight the error with time and hence minimize the error values nearer to zero.

IX. SIMULATION RESULTS

The circuit parameters of the Positive Output Elementary Luo Converter are shown in the Table 1. The controller parameter values of the conventional ZN-PI, BF-PI and MBF-PI controllers are obtained. The responses of positive Output Elementary Luo Converter using conventional ZN-PI, BF-PI and MBF-PI controls are shown in Figures 4,5,6 and 7.

The Figures show that MBF-PI controller will drastically reduce the overshoot, ISE and IAE values as compared to the conventional PI controller and BF-PI controller. Table 2 shows the performance analysis of Negative Output Elementary Luo Converter using conventional ZN-PI, BF- PI, and MBF-PI controllers.

Table 1: Circuit Parameters of positive Output Elementary Luo Converter

Parameter	Symbol	Value
Input Voltage	V_{in}	10 V
Output Voltage	V_o	40V
Inductor	L	100μH
Capacitor	C	5μF
Load resistor	R	10Ω
Duty ratio	D	0.1-0.9

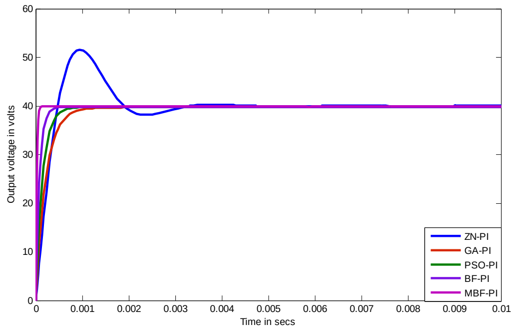
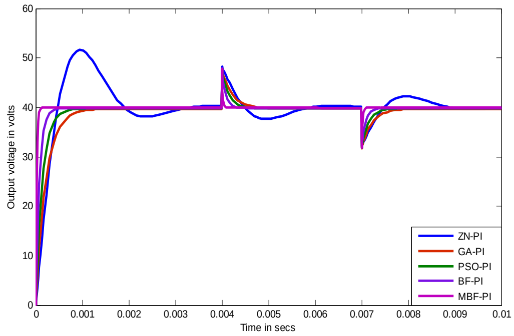


Fig.4 closed loop responses of Conventional ZN-PI, GA-PI, PSO-PI, BF-PI and MBF-PI Controllers



. **Fig.5 Closed Loop responses of conventional ZN-PI, GA-PI, PSO-PI, BF-PI and MBF-PI controllers with sudden disturbances of ±20%of rated supply voltage**

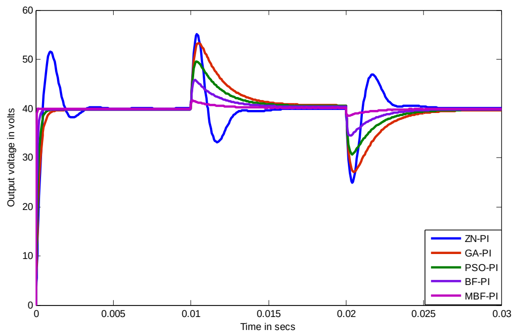


Fig.6 closed loop responses of Conventional ZN-PI, GA-PI, PSO-PI, BF-PI and MBF-PI Controllers with sudden disturbances of ±20%of rated load

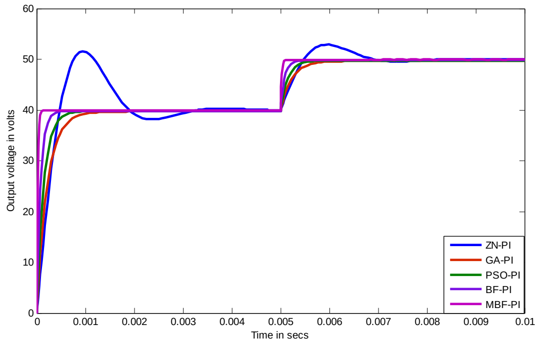


Fig.7 Servo responses of Conventional ZN-PI, GA-PI, PSO-PI, BF-PI and MBF-PI Controllers from40V-50V

Table 3 Performance comparison of various controllers for positive output elementary LUO converter

Controllers	Start up transient			Supply disturbance				Load disturbance			
	Rise time (ms)	Peak overshoot (%)	Settling time (ms)	Supply increase 20%		Supply decrease 20%		Load increase 20%		Load decrease 20%	
				Peak overshoot (%)	Settling time (ms)	Peak overshoot (%)	Settling time (ms)	Peak overshoot (%)	Settling time (ms)	Peak overshoot (%)	Settling time (ms)
PI	0.4	28.75	4.8	20.5	2.3	19.68	2.5	35	7	34	7.2
GA-PI	0.5	-	4.5	19.25	2.1	20.5	2.05	32	8.5	31	8
PSO-PI	0.3	-	4	19.42	1.5	20.4	1.6	23.75	6.8	23	7.15
BF-PI	0.25	-	2.5	19.55	0.75	20.25	0.6	12.5	6.5	11	6.3
MBF-PI	0. 1	-	0.4	19.75	0.44	20.10	0.3	3.75	4	3.5	4.2

Table 4 Performance measures of various controllers for positive output elementary LUO converter

Controllers	Start up transient		Supply disturbance				Load disturbance			
	ISE	IAE	Supply increase 20%		Supply decrease 20%		Load increase 20%		Load decrease 20%	
			ISE	IAE	ISE	IAE	ISE	IAE	ISE	IAE
PI	0.3087	0.0200	0.322	0.0240	0.3215	0.0246	0.652	0.050	0.653	0.054
GA-PI	0.4105	0.0258	0.1859	0.0125	0.1882	0.0135	0.409	0.029	0.475	0.0561
PSO-PI	0.2725	0.01803	0.1238	0.0087	0.1250	0.0094	0.375	0.025	0.441	0.0246
BF-PI	0.1494	0.01075	0.06815	0.00517	0.0686	0.0055	0.208	0.0158	0.274	0.0194
MBF-PI	0.0754	0.0055	0.03461	0.00216	0.0347	0.0028	0.0168	0.0018	0.0176	0.0027

X. CONCLUSION

In this work, five different controller structures are considered, developed and implemented for positive output elementary Luo converters. Results have been presented for all the five controllers and comparison shows that the modified bacterial foraging algorithm based PI controller has faster processing speed and fast rejection of line and load disturbances. In comparison with the PI controller, the proposed optimized controllers yield better dynamic performances with less rise time, settling time, zero steady-state error and less overshoot.

The results demonstrate the suitability of applying optimization techniques. Simulation results indicate the feasibility of the proposed control schemes

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