Optimal Tuning of PI Controller using Bacterial Foraging Algorithms for Power Electronic Converter

B. Achiammal, R.Kayalvizhi

***Abstract-* DC-DC converters are widely used in application such as computer peripheral power supplies, car auxiliary power supplies and medical equipments. Positive output element Luo converter performs the conversion from positive source voltage to positive load voltage. Due to the time- varying and switching nature of the power electronic converters, their dynamic behaviour is highly non-linear. Conventional controllers are incapable of providing good dynamic performance and hence optimized techniques have been developed to tune the PI parameter. In this work, Bacterial Foraging (BF) algorithm and Modified Bacterial Foraging (MBF) algorithm are developed for PI optimization. Simulation results show that the performances of BF-PI and MBF-PI controllers are better than those obtained by the classical ZN-PI controller.**
***Keywords:* PID controller, DC-DC converter, positive elementary Luo converter, Bacterial Foraging Algorithm, Modified Bacterial Foraging Algorithm.**

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 are also used as interface between DC systems of different voltages levels. Positive output Luo converter 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 limit 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 optimized techniques are used for regulating the positive Luo converter. In this work, PI controller, BF based PI controller and MBF 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)

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II. MODELLING OF POSITIVE OUTPUT ELEMENTARY LUO CONVERTER

A positive output elementary Luo converter (Fig.1) performs step-up/step-down conversions 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:

$X_1 = i_{L1}, X_2 = i_{L2}, X_3 = V_o, X_4 = V_{co}$ (1)

Using 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.

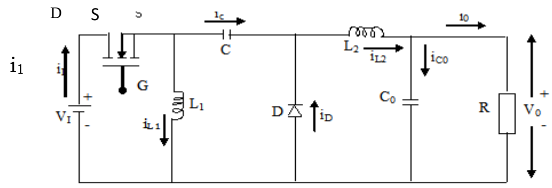

Fig.1 positive output elementary Luo converter

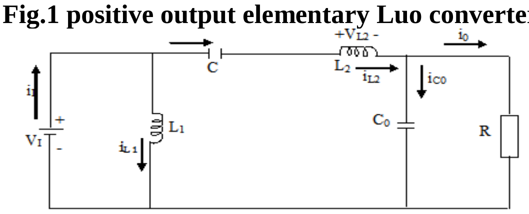

Fig.2 Positive output elementary Luo converter – mode 1

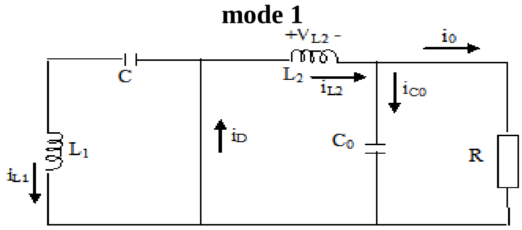

Fig.3 Positive output elementary Luo converter– mode 2

III. DESIGN OF PI CONTROLLER

The function of a controller is to receive the measured process variable (PV) and compare it with the set point (sp) to produce the actuating signal (m) so as to drive the process variable to the desired value. Therefore the inputs to the controller is the error (sp-pv). It is also known as proportional plus reset controller the actuating signal m(t) is related to the error e(t) by the equation.

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$$m(t) = K_C e(t) + (K_C/T_i)\int_0^1 e(t)dt + ms \qquad (2)$$

where T_i is the integral time constant or reset time and I/Ti is called repeats per minute.

After a period of T_i minutes for a constant error E, the contribution of integral term is

$$K_C / T\int_0^{Ti} e(t)dt = (K_C / T_i)ET_i = K_C E \qquad (3)$$

The integral action has repeated the response of the proportional action. Reset time is the time needed to repeat the initial proportional action change in its output.

The integral action causes the controller output m(t) to change as long as an error exists the process output.

The transfer function of a PI controller

$$G_c(s)=K_c[1+1/T_i s] \qquad (4)$$

IV. 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 behaviour are mimicked:-

A. 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

$$\theta^1(j+1,k,l) = \theta^1(j,k,l) + C(i) * \phi(j) \qquad (5)$$

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).

B. 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,

$$J_{cc}(\theta,D(j, k, l)) = J^i_{cc}(\theta, \theta^1(j,k,l))) = X+Y \qquad (6)$$

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, $J_{cc}(\theta,D(j, k, l))$ 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.

C. 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.

D. 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 chemotaxis, 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 behaviour.

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,

$$\theta^i(j,P) = \vec{x_i} \qquad (7)$$

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

A. *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.

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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

$$\phi(i) = \frac{\Delta(i)}{\sqrt{\Delta(i)^T \Delta(i)}} \quad (8)$$

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

$$\theta^i(j+1,p) = \theta^i(j,P) + \beta(i)\theta(i) \quad (9)$$

Where,
$\theta^i(j+1, P)$ 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 7 by considering the valid limits per each design variables.

$$B(i)_k = S * \left(\frac{\Delta xk}{\sqrt{m}}\right), k = 1,........m \quad (10)$$

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

$$\theta^i(j+1,p) = \theta^i(j,P) + \beta(\theta^B(p) - \theta^i(j,p)) \quad (11)$$

Where,
θ^i (j + 1, P) is the new position of bacterium i, θ^i (j,P) is the current position of bacterium i, θ^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 θ^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.

B. *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.

C. 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.

The limitations of BF algorithm have been augmented through the swarming and reproduction processes. The global searching of the MBF algorithm has been improved owing to the fact that it provides better solutions than the BF algorithm. The MBF algorithm thus has been framed to eliminate the role of complex computations in the BF algorithm.

VI. PERFORMANCE INDICES

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)

$$\text{ISE} = \int_0^t e^2 dt \quad (12)$$

$$\text{IAE} = \int_0^t |e|\, dt \quad (13)$$

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

VII. 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.
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 positive elementary output 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	30V
Inductor	L	100μH
Capacitor	C	5μF
Load resistor	R	10Ω

Duty ratio	D	0.75

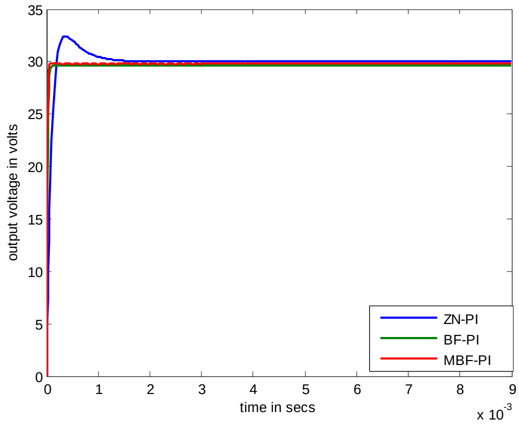

Fig.4 closed loop responses of Conventional ZN-PI, BF-PI and MBF-PI Controllers

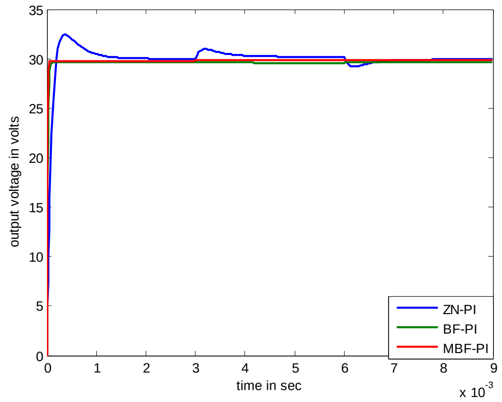

Fig.6 closed loop responses of Conventional ZN-PI,BF-PI and MBF-PI Controllers with sudden load disturbance from 10Ω-11Ω (10%) at 3msec and 10Ω-9Ω (10%) at 6msec.

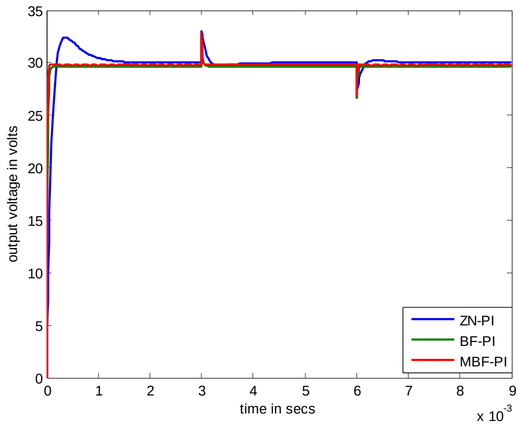

Fig.5 Closed Loop responses of conventional ZN-PI, BF-PI and MBF-PI controllers with sudden line disturbance from 10V-11V (10%) at 3msec and 10V-9V at 6msec.

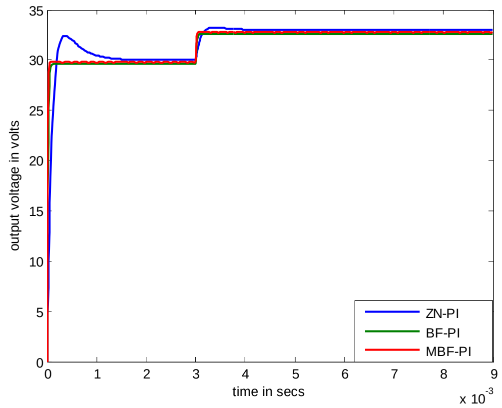

Fig.7 Servo response of Conventional ZN-PI, BF-PI and MBF-PI Controllers from 30V-33V at 3msec.

Table 2 Performance evaluation of positive output elementary Luo converter

		Tuning Parameters	ZN-PI controller	BF-PI controller	MPF-PI controller
Start up Transient		Rising time (m. sec)	0.19	0.13	0.08
		Settling time (m. sec)	1.8	0.18	0.1
		Peak Overshoot %	8	0	0
		ISE	0.129	0.029	0.015
		IAE	0.011	0.002	0.001
Line Disturbance	Supply increase 10%	Settling time (m sec)	1.7	0.2	0.1
		Peak Overshoot %	10	8.8	9.3
		ISE	0.0585	0.0132	0.0069
		IAE	0.0084	0.0018	0.0009
	Supply decrease 10%	Settling time (m sec)	1.3	0.16	0.08
		Peak Overshoot %	10	10.9	10.6
		ISE	0.0587	0.013	0.006
		IAE	0.0084	0.0018	0.0010
Load Disturbance	Load increase 10%	Settling time (m sec)	2	0.1	0.05
		Peak Overshoot %	3.3	1.2	0.6
		ISE	0.0398	0.0081	0.0045
		IAE	0.0046	0.0020	0.0011

	Load decrease 10%	Settling time (m sec)	1.25	0.2	0.1
		Peak Overshoot %	3	1	0.3
		ISE	0.0394	0.0086	0.0045
		IAE	0.0044	0.0016	0.0009

VIII. CONCLUSION

In this work, Bacterial Foraging algorithm (BF-PI) and Modified Bacterial Foraging algorithm (MBF-PI) are developed to tune the PI controller parameters which control the performance of positive output elementary Luo converter. The simulation results confirm that PI controller tuned with BF algorithm and MBF algorithm rejects satisfactorily both the line and load disturbances. Also the results proved that MBF-PI controller gives the smooth response for the reference tracking and maintains the output voltage of the positive output elementary Luo converter according to the desired voltage.

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