VOL. 10, NO. 8, MAY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

COMPARISON OF TUNING ALGORITHMS OF PI CONTROLLER FOR POWER ELECTRONIC CONVERTER

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ABSTRACT

The Negative Output Elementary Luo converter is a newly developed DC-DC converter. Due to the time-varying and switching nature of the above converter, its dynamic behavior becomes highly non-linear. Conventional controllers are incapable of providing good dynamic performance for such a converter and hence optimized techniques have been developed to tune the PI parameters. In this work, Bacterial Foraging (BF) algorithm and Modified Bacterial Foraging (MBF) algorithum are developed for PI optimization. Simulation results show that the performances of BE-PI controller and MBF-PI controller are better than those obtained by the classical ZN-PI controller.

Keywords: PID controller, DC-DC converter, negative output elementary Luo converter and soft computing techniques.

1. 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. Negative output Elementary Luo converter is a newly developed subset of the DC-DC converters. This converter provides Negative 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 technique is used for regulating the Negative Output Luo Converter. In this work, 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).

2. MODELING OF NEGATIVE OUTPUT ELEMENTARY LUO CONVERTER

A Negative output elementary Luo converter (Figure-1) performs step-up/step-down conversions from positive input DC voltage to Negative output DC voltage.

The voltage transfer ratio of the above converter is (k/ (1-k)) where k is the duty ratio. The circuits (Figure-2 and Figure-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:

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

$U = Vi\ Y = Vo$

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.

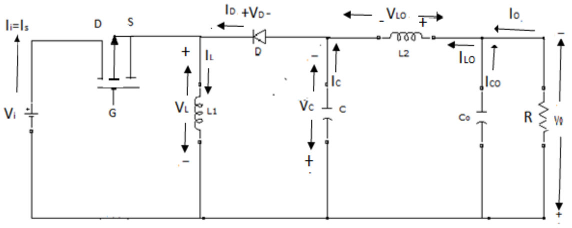

Figure-1. Negative output elementary LUO converter.

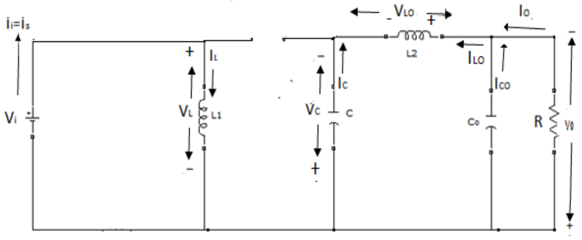

Figure-2. Negative output elementary LUO converter (On Mode).

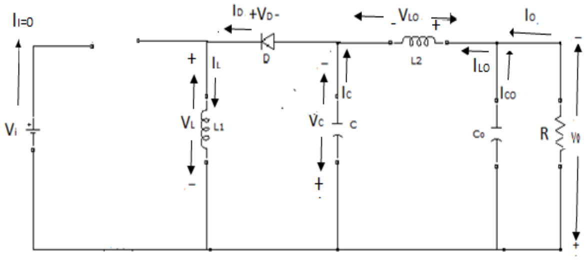

Figure-3. Negative output elementary Luo converter (Off Mode).

3. DESIGN OF ZN-PI CONTROLLER

The converter is modeled in On-mode and Off-mode using state-space approach and the corresponding state matrices are obtained. Using the average of these matrices and the circuit parameter of the chosen converter, the corresponding PI controller setting are designed using Ziegler-Nichols tuning technique based on the converter's open loop step response. Converters are modeled using the Simulink-Power system block set of Matlab software and PI control is developed using the control system toolbox. Error in the output and the duty cycle of the MOSFETs are respectively the input and output of PI controller.

4. 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 ϕ (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 ith bacterium, at jth chemotactic, kth reproductive, and lth 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,

$$J_{cc}(\theta, D(j, k, l)) = J^i_{cc}(\theta, \theta^1(j,k,l))) = X+Y \qquad (2)$$

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

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.

5. 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

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

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

$$\theta^i(j+1, P) = \theta^i(j, P) + B(i)\phi(i) \quad (5)$$

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.

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

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

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

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.

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.

6. 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)

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

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

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

7. SIMULATION RESULTS

The circuit parameters of the Neagtive 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 Negative 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 negative 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

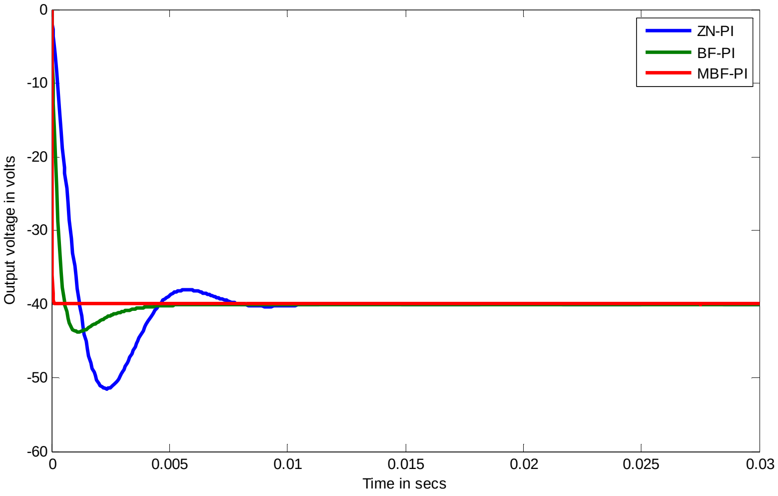

Figure-4. Closed loop responses of conventional ZN-PI, BF-PI and MBF-PI controllers.

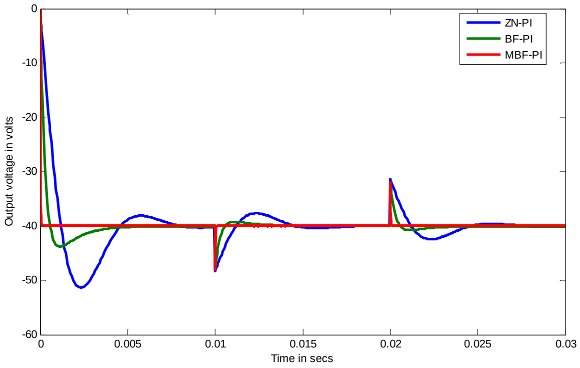

Figure-5. Closed Loop responses of conventional ZN-PI, BF-PI and MBF-PI controllers with sudden disturbances of ±20% of rated supply voltage.

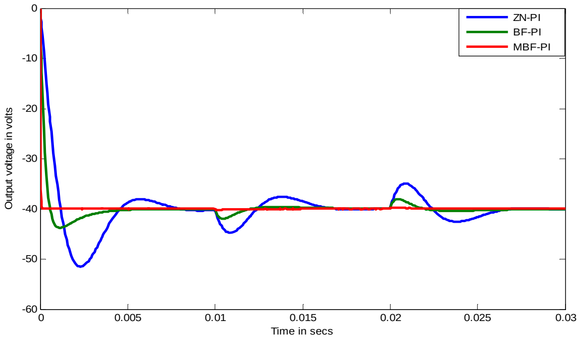

Figure-6. Closed loop responses of Conventional ZN- PI, BF-PI and MBF-PI Controllers with sudden disturbances of ±20% of rated load.

Table-2. Performance evaluations of PI controllers for negative output elementary Luo converter.

		Tuning parameters	**ZN-PI controller**	**BF-PI controller**	**MPF-PI controller**
Start up Transient		**Rising time** (m sec)	**4**	**2**	**1.4**
		Setting time (m sec)	**4.2**	**0.5**	**3**
		Peak Over shout %	24.8	0	0
		ISE	0.129	0.029	0.015
		IAE	0.011	0.002	0.001
Line disturbance	Supply increase 20%	Setting time (m sec)	1.6	0.4	0.2
		Peak Over shout %	10	9.72	10
		ISE	0.0585	0.0132	0.0069
		IAE	0.0084	0.0018	0.0009
	Supply decrease 20%	Setting time (m sec)	1.1	0.5	0.3
		Peak Over shout %	8	10.27	10.14
		ISE	0.0587	0.013	0.006
		IAE	0.0084	0.0018	0.0010
Load disturbance	Load increase 20%	Setting time (m sec)	0.5	0.4	0.35
		Peak Over shout %	3.3	1.6	1
		ISE	0.0398	0.0081	0.0045
		IAE	0.0046	0.0020	0.0011
	Load decrease 20%	Setting time (m sec)	0.7	0.6	0.4
		Peak Over shout %	3.4	2.33	1.5
		ISE	0.0394	0.0086	0.0045
		IAE	0.0044	0.0016	0.0009

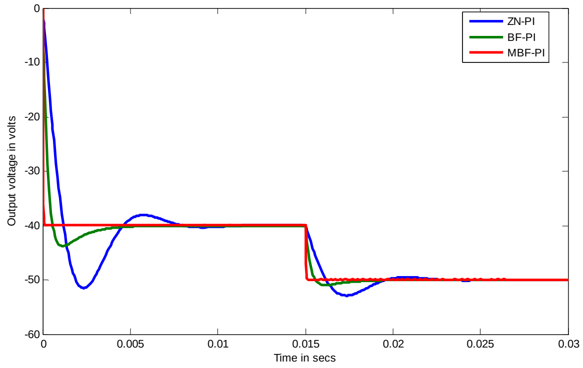

Figure-7. Servo responses of conventional ZN-PI, BF-PI and MBF-PI controllers from 40V-50V.

8. CONCLUSIONS

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 Negative 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 Negative Output Elementary Luo converter according to the desired voltage.

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