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Hardware Implementation of Optimized PI Controller for Luo Converter

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Abstract: The Negative Output Elementary(NOE) 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. PI controller is incapable of providing good dynamic performance for such converter and hence optimized techniques have been developed to tune the PI parameters. In this work, design and implementation of ZN-PI, Bacterial Foraging algorithm based PI (BFOA-PI), Modified Bacterial foraging algorithm based PI (MBFOA-PI)using and TMS320C5420 DSP have been developed and experimental results of the closed loop performances of the NOE Luo converter under supply disturbances and load disturbances are presented and analyzed.

Keywords: PID Controller, DC-DC Converter, Negative Output Elementary Luo Converter, Soft Computing Techniques, and Optimization Techniques.

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. NOELuo 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 controller do not provide satisfactory response for this converter which are time varying systems. Hence optimized technique is used for regulating the NOELuo Converter. In this work, BF based PI controller and MBF based PI controller is designed and hardware implementation using TMS320C5420 DSP for the above Luo converter.

Negative Output Elementary Luo converter

A Negative output elementary Luo converter (Fig.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 (D/(1-D)) where D is the duty ratio. The parameters of the converter are shown in table 1.

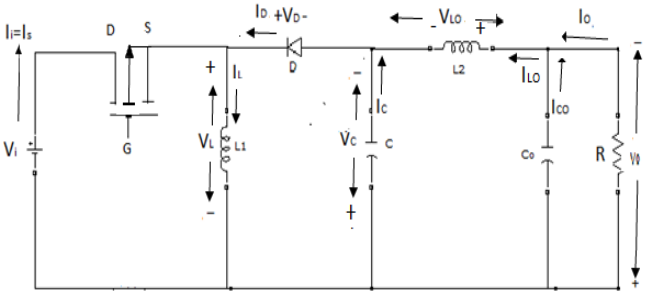

Figure .1 Negative Output Elementary LUO Converter

Table .1 parameters of LUO converter

parameters	*symbol*	*value*
Input Voltage	V_{in}	*10 V*
Output Voltage	V_o	*-40V*
Inductor	*L*	*100µH*
Capacitor	*C*	*5µF*
Load resistor	*R*	*10Ω*
Switching frequency	*fs*	*50KHZ*
Duty ratio	*D*	*0.1-0.9*

Bacterial foraging optimization algorithm

Bacterial Foraging algorithm is a new division of bio-inspired algorithm. This algorithm is developed by inspiring the foraging behavior of Escherichia coli (E.coil) bacteria. It consists of four steps: chemotaxix, swarming, reproduction, and elimination – dispersal [5].

The chemotaxis step was modeled by passion with the generation of a random path search in equation 1. This equations represents a tumble (search path).

$$\phi(i) = \frac{\Delta\,(i)}{\sqrt{\Delta\,(i)^{T}\Delta\,(i)}} \qquad (1)$$

Where$\Delta(i)^n$ is a randomly generated vector with elements within the following interval [-1.1]. After that each bacteria ϕ^i(j,k,l) modifies its positions as indicated in equation 2.

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i) * \emptyset(j) \qquad (2)$$

Where,

$\theta^i(j,k,l)$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).Equations 1 represents a tumble (search direction) and Equations 2 represents a swim. The swim will be repeated N_s times if the new positions is better than the previous one:

$$f\ \theta^i(j+1,k,l) < f\ \theta^i(j,k,l)) \qquad (3)$$

The reproduction steps consists on sorting bacteria in the population$\theta^i(j+1,k,l)$, i = 1, -----N_b based on their objective function value $f\ \theta^i(j,k,l)$and to eliminate half of them with the worst value. The remaining half will be duplicated as to maintain a fixed population size.

The elimination – dispersal loop consists on elimination each bacteria $\theta^i(j,k,l), i = 1,$------------N_b with a probability $0 \le P_{ed} \le 1$. The parameters of BFOA as shown in table 2. The implementation of BFO algorithm steps in below.

```
Begin
Initialize the parameters
Create a random initial swarm of bacteria $\theta^i(j,k,l)$, i = 1,------------$S_b$
Evaluate $f\ \theta^i(j,k,l)$, i = 1,------------$S_b$
For j = 1 to $N_c$ Do
    For k = 1 to $N_{re}$ Do
        For l = 1 to $N_{ed}$ Do
            For i = 1 to $S_b$ Do
                Perform the chemotaxis setp(tumble-swim or tumble –tumble) for bacteria $\theta^i(j,k,l)$
    End For
End For
Perform the reproduction step by eliminating the $S_r$ (half) worst bacteria and duplicating the other half.
End For
Perform the elimination – dispersal step for all bacteria $\theta^i(j,k,l)$, i = 1,------------$N_b$, with probability $0 \le P_{ed} \le 1$
End for
End
```

Table.1 parameter of BFOA

Parameters	values
Number of bacteria, S	99
Maximum number of steps, Ns	3
Number of chemotactic steps,Nc	4
Number of reproduction steps, Nre	6
Number of elimination-disperse steps, Ned	2
Probability, Ned	0.25
Size of the step, C(i)	0.1

Modified bacterial foraging optimization algorithm

The main drawback in the BFO algorithm, Requires large number of parameters and more step sizes. The BFO algorithm and modified BFO algorithm is also based on the four processes. But MBFO algorithm simplifications and modification to the original approach.

Instead of having four nested loops controlled by the number of chemotaxis , reproduction, elimination-dispersal and population size loops, a single generation loop is proposed where each bacteria will perform its own chemotaxis loop. After that a, single reproduction step and a single elimination-dispersal loop are performed within this generation loop. In this way the N_S parameter is eliminated as the tumble-tumble or tumble-swim step will be only limited by N_C for each bacteria. Furthermore, the elimination-dispersal step is simplified as to only eliminate the worst bacteria in the population. Then, the $N_{re,}$ N_{ed} and P_{ed} parameters are eliminated and just the Gmax (number of generations) parameter is added.

The stepsize C(i) for each decision variable $x_i$is defined by considering the lower and upper limits Li and Ui by using the following formula proposed in [8].

$$C_{new}(i) = R*(\Delta\vec{x_i}/\sqrt{n}) \qquad (4)$$

Where $C_{new}(i)$ is the step size now not defined by the user, $\vec{x_i}$ is computed as Ui – Li, n is the number of decision variable in the optimization problem and R is the percentage of the total stepsize to be used, as small initial stepsize are more convenient in constrained optimization.

A simple swarming mechanism was added to the redefined chemotaxis step for each bacteria in the population. At the half and end of the chemotacic loop, instead of each bacteria to determine its search direction as pointed out in equations 1 and 2 a communication step is modeled as to allow this bacteria to bias its directions search to the neighborhood of the best bacteria so far in the current population. This search direction s defined in equation 5.

$$\theta^i(j+1,G) = \theta^i(j,G) + \beta\left(\theta^B(G) - \theta^i(j,G)\right) \qquad (5)$$

Where,

$\theta^i(j+1, G)$ is the new position of bacterium i, $\theta^B(G)$ is the current position of the best bacteria in generation G so far and $0 \leq \beta \leq 1$ is a scaling factor which regulates how close will be the bacteria *i* from the best one B. the remaining steps in the chemotaxis loop performed as in equation 6.

$$\theta^i(j+1,G) = \theta^i(j,G) + C(i(i)\emptyset(i) \qquad (6)$$

```
Begin
Initialize the parameters
Create a random initial swarm of bacteria$\theta^i(j,G)$, i = 1,-------------$S_b$
Evaluate $f\ \theta^i(j,G)$, i = 1, ……….$S_b$
For j = 1 to $N_c$ Do
   For G = 1 to GmaxDo
      For i = 1 to $S_b$ Do
         Perform the chemotaxis step (tumble-swim or tumble – tumble ) for bacteria $\theta^i(j,G)$ and the set of feasibility criteria
      End For
End For
Perform the reproduction step by eliminating the $S_r$ (half) worst bacteria and duplicating the other half, based on the feasibility criteria Eliminate the worst bacteria $\theta^w(j,G)$ in the current population, based on the feasibility criteria.
End For
End
```

The implementation of MBFO algorithm steps in above. The MBFOA parameters values in table 3 and BFO and MBFO algorithm based PI controller as shown in figure 2. MBFO algorithm is number of parameters is decreased and optimized PI controller value it provides better solutions than the BFO algorithm.

Table. 3 parameter of MBFOA

parameters	values
Number of bacteria, S	10
Number of chemotactic steps, NC	4
Gmax	50
R	0.5
B	0.8

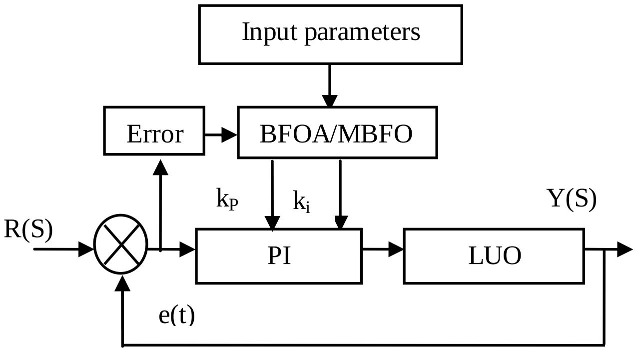

Figure.2 BFOA/MBFOA based PI controller

Hardware Implementation

The proposed PI, BF-PI and MBFOA-PI controllers for the NOE Luo converter are implemented using TMS320C5420 DSP which is a 16-bit fixed point DSP that combines the flexibility of a high-speed controller with the numerical capability of an array processor there by offering an inexpensive alternative to multichip bit-slice processors. The highly paralleled architecture and very flexible set provide a speed of 40MIPS. This high processing speed of CPU allows the user to compute parameters in real time rather than look up approximation from tables stored in memory. The converter output voltage is initially 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 equivalent of output voltage. This is compared with reference voltage to compute the error which are processed by the DSP based PI, BFOA-PI and MBFOA-PI control algorithm 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 provides 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. Figs.5-13show the responses of the NOE Lou converter with PI, BFA-PI and MBFA-PI controls implemented DSP. It is observed that the peak overshoot and settling time are very much reduced in the in the MBF-PI controller as compared to the PI controller and BF-PI controller. The close loop control for Luo converter as shown in Figure3. The hardware model is shown in figure 4. Table 2 shows the performance analysis of Negative Output Elementary LuoConverter with PI,BFOA-PI, and MBFOA-PI controllers.

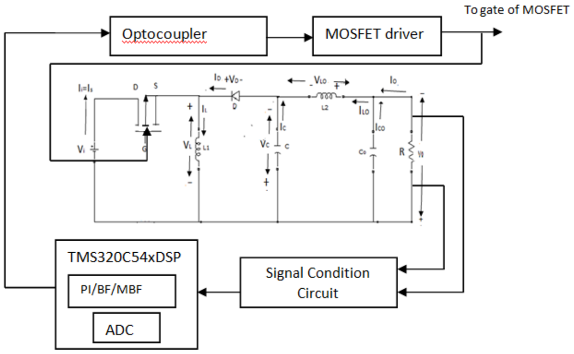

Figure. 3 close loop control for Luo converter.

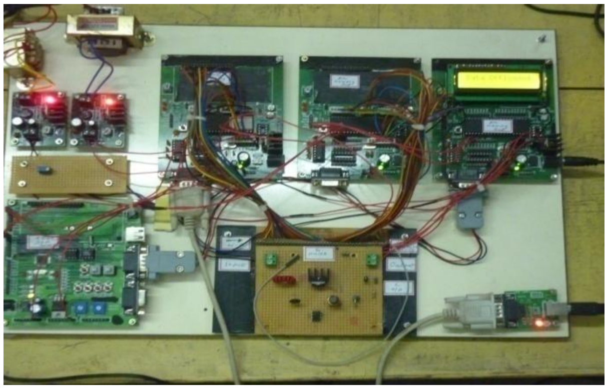

Figure.4 Hardware kit

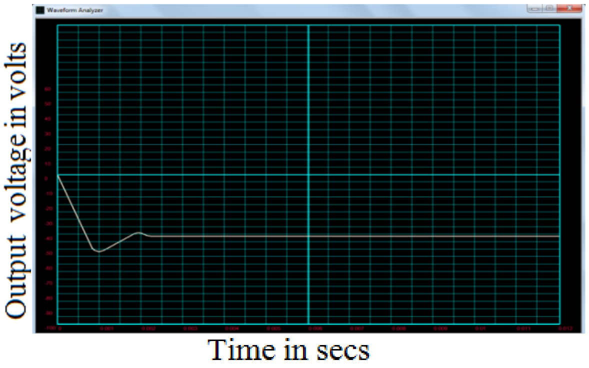

Figure. 5Closed Loop response of conventional PI Controller

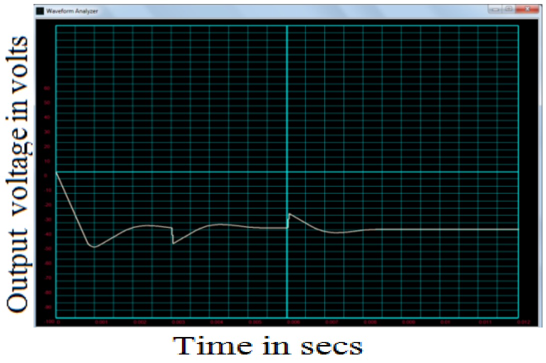

Figure.6 Closed Loop response of conventional PI Controller with sudden disturbances of ±20%of rated supply voltage at 0.003sec and 0.005sec.

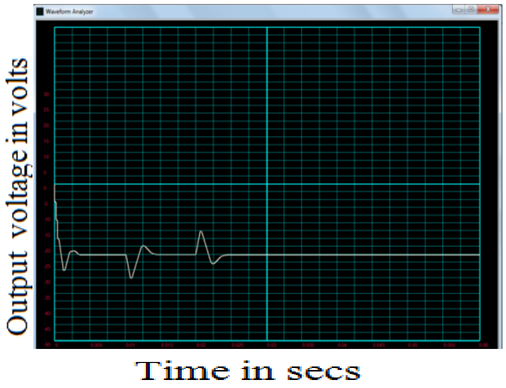

Figure.7 closed loop response of ZN-PI Controller with sudden disturbances of ±20%of rated load at 0.01sec and 0.02sec.

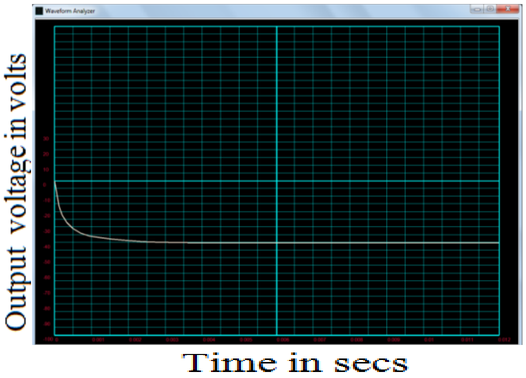

Figure. 8Closed Loop response of conventional BFOA-PI Controller

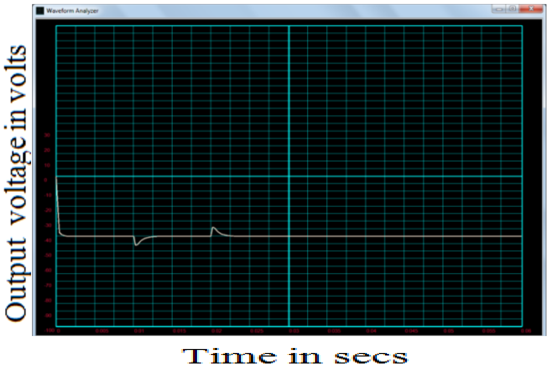

Figure.9 Closed Loop response of BFOA- PI Controller with sudden disturbances of ±20%of rated supply voltage at 0.003sec and 0.006sec.

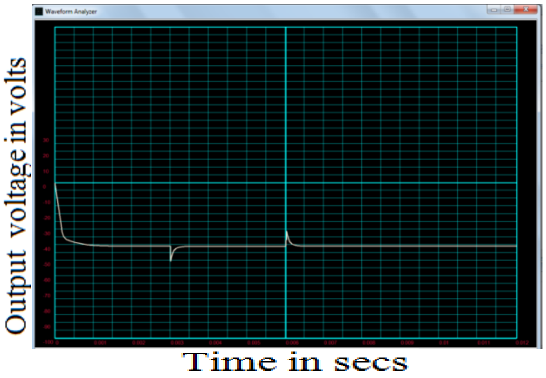

Figure.10 closed loop response of BFOA-PI Controller with sudden disturbances of ±20%of rated load at 0.01sec and 0.02sec.

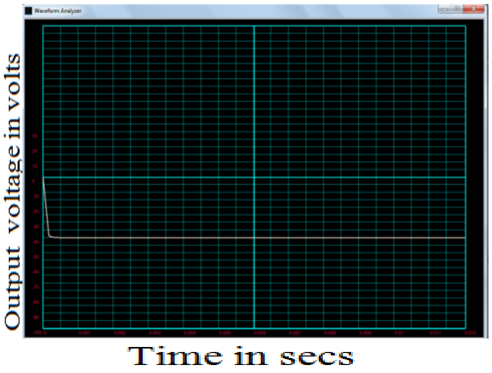

Figure. 11Closed Loop response of conventional MBFOA-PI Controller

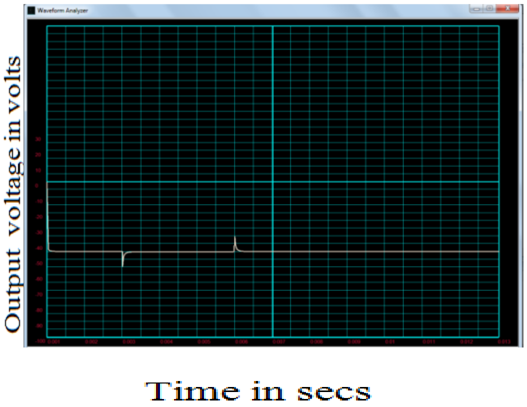

Figure.12 Closed Loop response of MBFOA- PI Controller with sudden disturbances of ±20%of rated supply voltage at 0.003sec and 0.006sec.

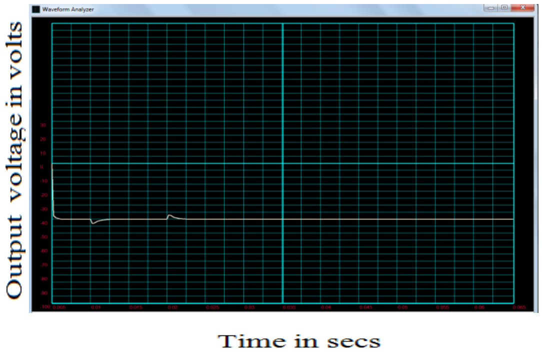

Figure.13 closed loop response of MBFOA-PI Controller with sudden disturbances of ±20%of rated load at 0.01sec and 0.02sec.

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 Negative Output Elementary Luo converter. The experimental 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 and maintains the output voltage of the Negative Output Elementary Luo converter according to the desired voltage.

Table .2 Performance evaluations of PI controllers for NOE Luo converter

		Tuning Parameters	PI controller	BFOA-PI controller	MBFOA-PI controller
Start-up Transient		Rising time (m sec)	0.25	1	0. 1
		Settling time (m sec)	2.5	2.3	0.25
		Peak Overshoot %	30	0	0
Line Disturbance	Supply increase 20%	Settling time (m sec)	2.7	0.35	0.25
		Peak Overshoot %	25	24	22
	Supply decrease 20%	Settling time (m sec)	2.3	0.5	0.2
		Peak Overshoot %	28	25	21
Load Disturbance	Load increase 20%	Settling time (m sec)	4.5	3.2	2.5
		Peak Overshoot %	36	15	7.5
	Load decrease 20%	Settling time (m sec)	5	3	2.5
		Peak Overshoot %	35	14	7.5

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