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Particle Swarm Optimization based PI Controller for Negative Output Elementary Luo 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, Particle swarm optimization (PSO) technique is developed for PI optimization. The performance evaluation of the above converter using ZN-PI and PSO-PI controller is compared. The results validate the superiority of the PSO-PI controller.*

Keywords: *PID controller, DC-DC converter, Negative Output Elementary Luo converter and Particle swarm optimization.*

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, PSO 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).

$X_1 = I_L,\ X_2 = V_C,\ X_3 = I_{Lo},\ X_4 = V_{co}$

$U=V_i \qquad Y=V_o$

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. From the state space model used to obtained the transfer function.

2. MODELING OF 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 (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:

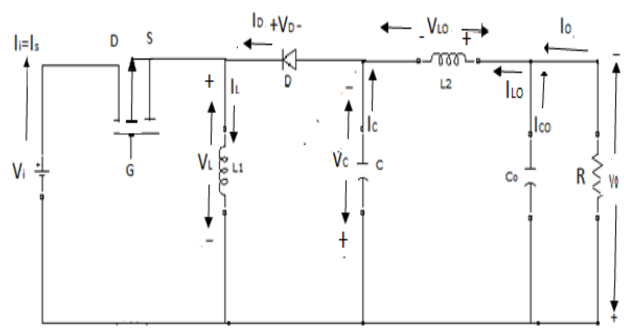

Fig.1 Negative Output Elementary LUO Converter

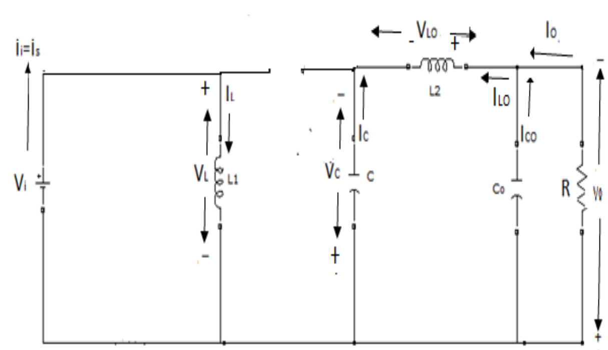

Fig.2 Negative Output Elementary LUO Converter (on mode)

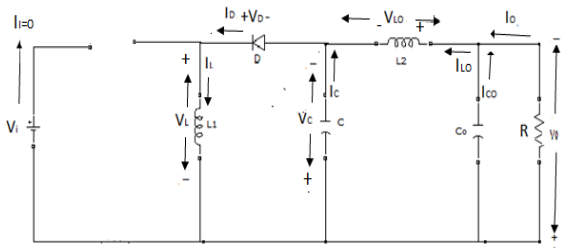

Fig.3 Negative Output Elementary Luo converter (off mode)

3. 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 input 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.

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

Where T_i is the integral time constant or reset time and 1/Ti is called repeats per minute. After a period of T_i minutes for a constant error E, the contribution of integral term is

$$K_c / T\int_0^{T1} e(t)dt = (K_c / T_i)ET_i = K_c E \qquad (2)$$

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

$$G_c(s)=K_c[1+1/T_i s] \qquad (3)$$

4. DESIGN OF ZN-PI CONTROLLER

The converter is modeled in on-mode and off-mode using state-space approach and the corresponding transfer function are obtained. Using the transfer function and the circuit parameter of the chosen converter, the corresponding PI controller setting Kp and Ti 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.

5. DESIGN OF PSO-PI CONTROLLER

Particle Swarm Optimization (PSO) was originally developed by Kennedy and Eberhart in 1995 is a population-based evolutionary algorithm. It was inspired by the social behavior of bird and fish schooling, and has been found to be robust in solving continuous nonlinear optimization problems.

In PSO, the swarm is initialized with a population of random solutions. Each particle in the swarm is a different possible set of the unknown parameters to be optimized. Representing a point in the solution space, each particle tries to adjust its flying toward a potential area according to its own flying experience and shares social information among particles. The objective is to efficiently search the solution space by swarming the particles toward the best fitting solution encountered in previous iterations with the intent of encountering better solutions through the course of the process and finally converging on a single minimum error solution.

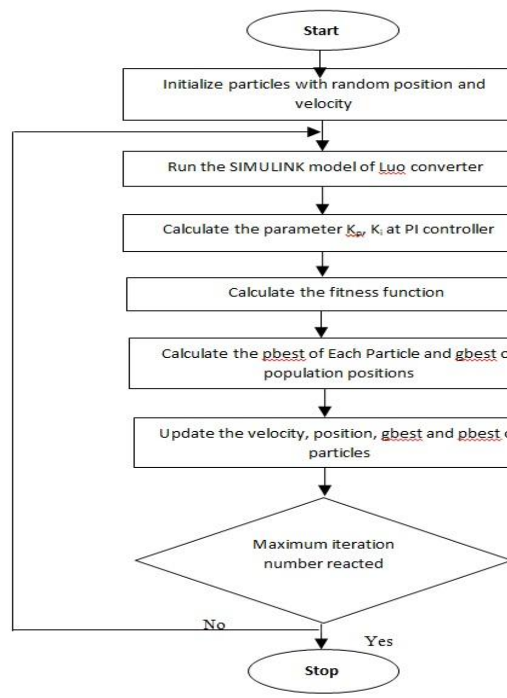

Fig.4 Flow chart of PSO

For a multidimensional problem, the velocity and position of each particle in the swarm are updated using the following equations:

$$V_i^{k+1}=WV_i^k+C_1 rand(pbest_i-S_i^k)+ C_2 rand(gbest_i-S_i^k) \qquad (4)$$

$$X_i^{k+1}=X_i^k+V_i^{k+1} \qquad (5)$$

Where,

V_i^{k+1} is the velocity of the ith particle at (k+1) iteration, Xi(k+1) is the position of the ith particle at (k+1) iteration, w is the inertial weight factor (weighting function), C1 and C2 are acceleration constants called cognitive learning rate and social learning rate respectively, rand is the random function in the range [0,1], pbest is the individual best position of the particle, gbest is the global best position of the swarm of the particles. The flow chart of PSO based PI control algorithm as shown in Fig.4. The weighting function, w is responsible

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for dynamically adjusting the velocity of the particles, hence it is responsible for balancing between local and global search. Applying a large inertia weight at the start of the algorithm and decaying to a small value through the PSO execution makes the algorithm search globally at the beginning and locally at the end of the execution. The weighting function w is calculated as:

$$w = w_{max} - \frac{(w_{max} - w_{min}) \cdot iter}{iter_{max}} \quad (6)$$

Here, w_{max} and w_{min} are the initial and final weights, iter is the current iteration time and $iter_{max}$ is the maximum number of iterations. The proposed Fitness function for the optimization of parameters of PI controller is defined as:

$$F(s)=w_{max}(Mp+ISE+IAE)+w_{min}(T_R+T_S) \quad (7)$$

6. 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)

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

$$IAE = \int_0^t |e| dt \quad (9)$$

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 Negative Output Elementary Luo Converter are shown in the Table I. The controller parameter values of the conventional ZN-PI and GA-PI controllers are obtained. The responses of Negative output elementary Luo converter using conventional ZN-PI and GA-PI controls are shown in Figures 5, 6, 7 and 8. Table II shows the performance evaluation of Negative elementary output Luo converter using conventional ZN-PI and GA-PI controllers. Figures show that GA-PI controller will drastically reduce the overshoot, ISE and IAE values as compared to the conventional PI controller.

TABLE 1. CIRCUIT PARAMETERS OF NEGATIVE OUTPUT ELEMENTARY LUO CONVERTER

Parameter	Symbol	Value
Input Voltage	V_{in}	10 V
Inductor	L	100μH
Capacitor	C	5μF
Frequency	F	50khz
Load resistor	R	10Ω
Duty ratio	D	0.8

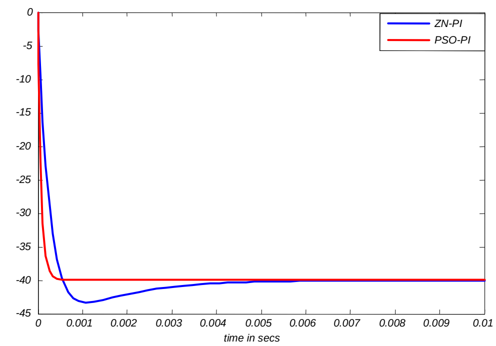

Fig.5 Closed Loop Responses of Negative output Elementary Luo Converter

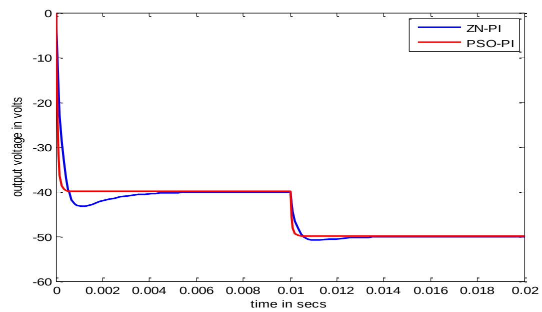

Fig.6 Servo responses of Negative Output Elementary Luo Converter from 40V-45V at 0.01sec

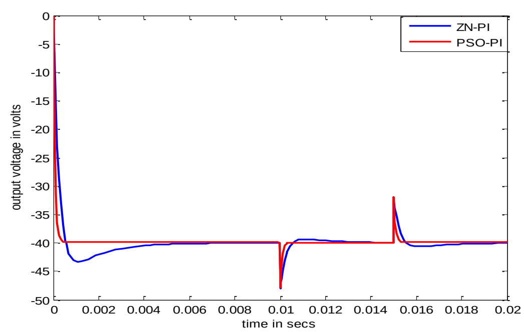

Fig.7 Closed Loop Responses of Negative Output Elementary Luo Converter with Sudden line disturbances from 10V-12V (20%) at 0.01 sec and 10V-8V (20%) at 0.015sec.

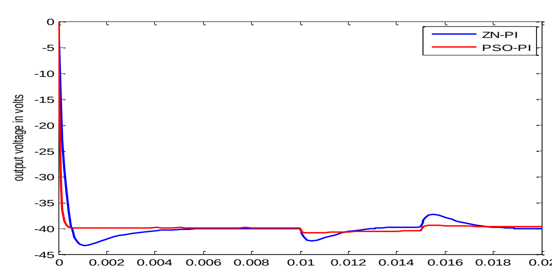

Fig.8 Closed Loop Responses of Negative Output Elementary Luo Converter with Sudden Load Disturbances from 10Ω-12Ω (20%) at 0.01sec. and 10Ω-8Ω (20%) at 0.015sec

TABLE 2. PERFORMANCE EVALUATION OF NEGATIVE OUTPUT ELEMENTARY LUO CONVERTER

	Tuning Parameters	*ZN-PI Controller*	*PSO-PI Controller*
Startup Transient	*Rising time (m.sec)*	*0.6*	*0.4*
	Settling time (m.sec)	*7*	*1*
	Peak Overshoot %	*7.5*	*0*
	ISE	*0.01394*	*0.0044*
	IAE	*0.03734*	*0.0083*
Line Disturbance 20%	*ISE*	*0.01938*	*0.0061*
	IAE	*0.1442*	*0.04557*
Load Disturbance 20%	*ISE*	*0.02218*	*0.0097*
	IAE	*0.0552*	*0.0208*

8. CONCLUSION

In this work, Particle swarm (PSO) optimization is 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 PSO is rejects satisfactorily both the line and load disturbances. Also the results proved that PSO-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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