Dragonfly Algorithm Based Fuzzy Logic Controller for Power Electronic Converter

N. Nachammai, R. Kayalvizhi

Abstract: ***Due to the time varying and switching nature of the Luo converters, their dynamic behavior becomes highly non-linear. Conventional controllers require a good knowledge of the system and accurate tuning in order to obtain the desired performances. A fuzzy logic controller neither requires a precise mathematical model of the system nor complex computations. Swarm Intelligence [SI] is a branch of evolutionary computing that inspired by the behavior of swarms in real life to search or optimizean objective function. The Dragonfly Algorithm [DA] is a global optimization technique based on swarm intelligence. Two essential phases of optimization, exploration and exploitation, are designed by modelling the social interaction of dragonflies in navigating, searching for foods, and avoiding enemies when swarming dynamically or statistically. The drawback of fuzzy controller has the tendency to oscillate around the final operating point. Proper selection of the normalizing gains for the inputs avoids oscillations. Hence Dragonfly Algorithm, an optimization technique is required to tune the fuzzy parameters. An attempt has been made in this work to design, simulate and implement, fuzzy logic and DA-fuzzy logic controllers for regulating the output voltage. The performances of the Luo converter with Fuzzy and DA-Fuzzy controllers are evaluated under line and load disturbances using Matlab-Simulink based simulation and compared. Comparison clearly shows the superiority of the proposed Dragonfly Algorithm over fuzzy controller applied for the control of Luo converter.***

Keywords: Dragonfly Algorithm, Fuzzy Logic Controller, Positive Output Elementary LUO Converter.

I. INTRODUCTION

DC-DC converters are widely used in computer peripheral power supplies, car auxiliary power supplies, servo motor drives and medical equipments. The output voltage and power transfer efficiency of such DC-DC converters are restricted because of the effects of parasitic elements. The voltage lift technique is a popular method widely used to improve the converter characteristics. Luo converters [1] belong to a new series of DC-DC converters which have been developed from prototypes using the voltage lift technique.

The classical control methods employed to design the controllers for Luo converters depend on the operating point so that the presence of parasitic elements, time varying loads and variable supply voltages can make the selection of the control parameters difficult. Intelligent controllers using fuzzy technique has been suggested to serve as a controller for improving the performances of these converters.

Revised Version Manuscript Received on February 06, 2017.

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In recent years, efforts were being made to carry out significant research in the area of nature inspired non-deterministic (heuristic) optimization techniques to control power electronic converter [3].

DA is a random search optimization algorithm which replicating the flight movement of dragonfly swarm [2]. The swarming behaviors of dragonflies has two objective, which are hunting and migration. When they are in hunting mode, they form small groups and forage over an area repeatedly to find their prey. In migration mode, they form a big group that will travel in long distance with one destination place[4].This unique swarming behaviors become the inspiration of exploration and exploitation technique in DA. SI based algorithm is equipped with few controlling parameters compared to EA algorithms. The effectiveness and validity of the proposed Dragonfly Algorithm has been tested for the Luo converter. Hence Dragonfly Algorithm is used to optimize the fuzzy parameters for improving the control of LUO converter Simulations were carried out and from the results, it is observed that ISE, IAE, settling time and peak overshoot are minimum in the DA-fuzzy controller. DA based fuzzy controller effectively rejects both line and load disturbances of the Luo converter. The results are presented and analysed.

II. POSITIVE OUTPUT ELEMENTARY LUO CONVERTER

Positive output Luo converters perform the conversion from positive DC input voltage to positive DC output voltage. The elementary Luo converters perform step-down or step-up DC-DC conversion.

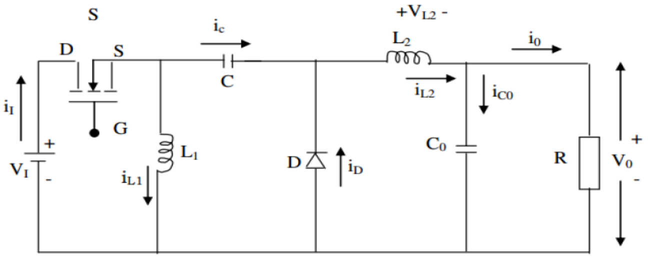

Fig. 1 Positive Output Elementary Luo Converter

Table I: Circuit Parameters of Positive Output Elementary Luo Converter

Parameter	Symbol	Value
Input Voltage	Vin	10 V
Output Voltage	V_o	20V
Inductor	L	100µH
Capacitor	C	5µF
Load resistor	R	10Ω
Duty ratio	D	0.67

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The elementary circuit is shown in Fig.1 Switch S is a N-channel power MOSFET (NMOS) device. It is driven by a PWM switching signal with repeating frequency 'fs' and duty ratio 'd'. The switching period is T=1/fs so that the switch-on period is dT and the switch-off period is (1-d)T. The load R is resistive. R=Vo / Io where Vo and Io are the average output voltage and current.

III. DESIGN OF FUZZY LOGIC CONTROLLER

The control action is determined in a fuzzy logic controller from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled [9] but it does not require a mathematical model of the system.

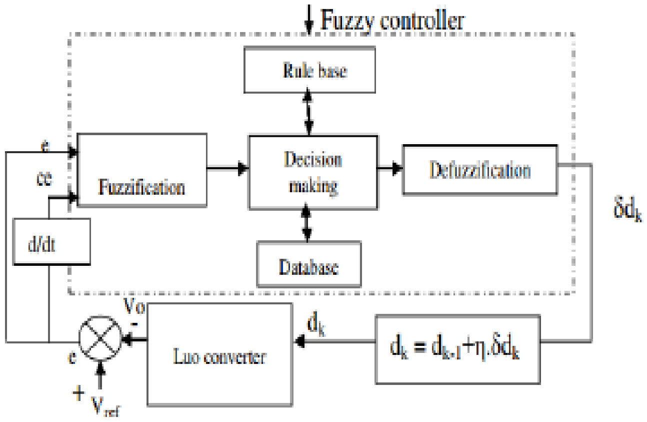

Fig. 2 Block Diagram of Fuzzy Logic Control for a Luo Converter

The block diagram of the fuzzy logic control scheme for a Luo converter is shown in Fig.2The fuzzy controller is divided into five modules: fuzzifier, data base, rule base, decision maker and defuzzifier. Various steps in the design of FLC for chosen Luo converter are stated below.

A. Identification of Inputs and Output

The inputs to the fuzzy controller are the error in output voltage e and the change of error ce which are defined as

$$e = Vref - Vo \quad (1)$$

$$ce = ek - ek-1 \quad (2)$$

where Vo is the present output voltage, Vref is the reference or desired output voltage and subscript k denotes values at the sampling instants.

B. Fuzzification of Inputs and Output

The inputs and output of the controller are not quantized in the classical sense that each input or output is assigned a "membership grade" μ to each fuzzy set. Mamdani type input and output membership functions are used for control of Luo converters. In the present work, seven triangular fuzzy sets are chosen as shown in Fig. 3 and Fig. 4 and are defined by the library of fuzzy set values such as NB -Negative Big, NM -Negative Medium, NS -Negative Small, ZE -Zero, PS -Positive small, PM -Positive Medium and PB -Positive Big for the error e, change in error ce and for the change in duty cycle δdk.

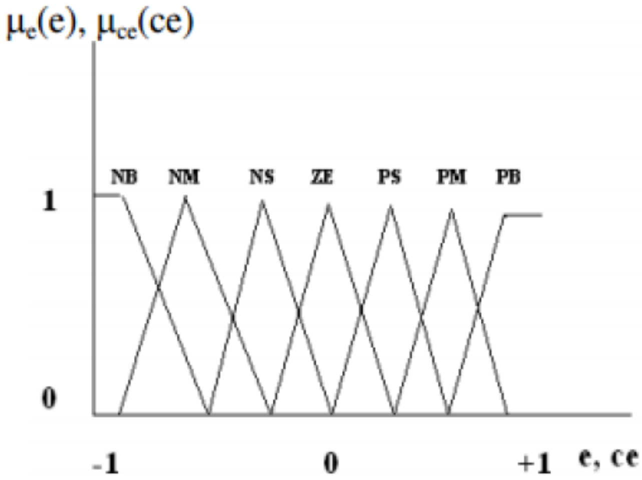

Fig. 3 Membership functions for e, ce

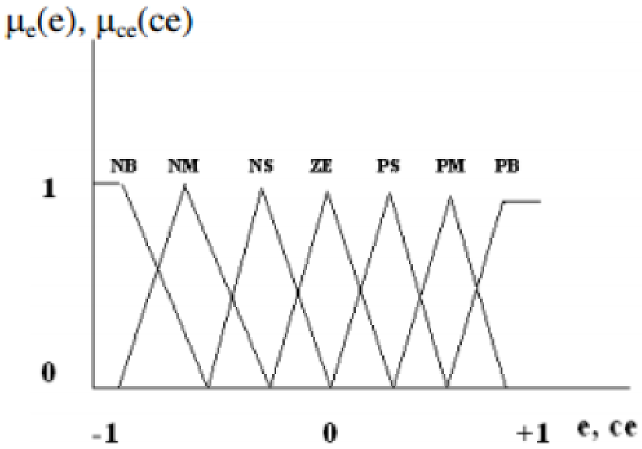

Fig. 4 Membership functions for δd

A rule table is derived and is shown in Table II. Since every e and ce belongs to almost two fuzzy sets, a maximum of four rules are considered at any sample to process any combination of input variables (e, ce). The inferred output of each rule using Mamdani's min fuzzy implication is written as z_i= min $\{\mu_e(e),\mu_{ce}(ce)\}.c_i = w_i\ c_i$ where z_i denotes the fuzzy representation of change in duty cycle inferred by the i^{th} rule.

Table II: Rule base for FLC

ce \ c	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

C. Defuzzification

In the defuzzification operation, a logical sum of the inference result from each of the four rules is performed. This logical sum is the fuzzy representation of the change in duty cycle (output).

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A crisp value for the change in duty cycle is calculated in this work using the center of gravity method

$$\delta d_k = \frac{\sum_{i=1}^{4} w_i m_i}{\sum_{i=1}^{4} w_i} \quad (3)$$

IV. DRAGONFLY ALGORITHM

The swarm consists of N dragonflies as search agents. The location and step vector of a search agent is X and ΔX respectively with 1 ≤ I ≤ N. The movement of a search agent is modeled after five individual behaviors in swarm [8],

- Separation, is the tendency of an individual to keepa distance away from neighboring search agents [6] , with calculation as follows:

$$S_i = -\sum_{j=1}^{j} X_i - X_j \quad (4)$$

Where i€ {1, 2, ...,N} is the index of current individual and j € {1, 2, ..., J} is the index of neighboring search agent.

- Alignment, is the tendency of an individual to match its velocity with velocity of neighboring search agents, with calculation as follows:

$$A_i = \frac{1}{J}\sum_{j=1}^{J} \Delta X_j \quad (5)$$

- Cohesion, is the tendency of an individual to fly toward the center of mass of neighboring search agents, with calculation as follows:

$$C_i = \left(\frac{1}{J}\sum_{j=1}^{J} \Delta X_j\right) - X_i \quad (6)$$

- Attraction toward a food source, is the tendency of an individual to fly toward a food source, with calculation as follows:

$$F_i = F_{loc} - X_i \quad (7)$$

where F_{loc} is the location of food source.

- Distraction outward an enemy, is the tendency of an individual to fly away from an enemy, with calculation as follows:

$$E_i = E_{loc} - X_i \quad (8)$$

Where E_{loc} is the location of enemy.

The food source fitness value F_{fit} and location Floc are updated [7] by using the search agent with the best fitness value. The enemy fitness value E_{fit} and location E_{loc} is updated using the search agent with the worst fitness value. At iterationk, the step and location of each search agent are updated as follows:

$$\Delta X_i(k+1) = {}_S S_i(k) + {}_a A_i(k) + {}_C C_i(k) + {}_f F_i(k) + {}_e E_i(k) + \omega \Delta X_i(k) \quad (9)$$

$$X_i(k+1) = X_i(k) + \Delta X_i(k+1) \quad (10)$$

where w is the inertia weight of search agent, S_i, A_i, C_i, F_i, and E_i are the behaviors fitness values of search agent i, and w, a, c, f, and e are the weights of the behaviors. The search agent's location is updated as shown in the eqn. (10) if the number of neighboring search agent J is at least one. If it does not have a neighboring search agent, it will update its location by using Levy flight [5], with the equation as follows:

$$X_i(k+1) = X_i(k) + Levy(k) \quad (11)$$

$$Levy(k) = 0.01 \frac{r_1 \sigma}{|r_{23}|^{\frac{1}{\beta}}} \quad 2)$$

$$\sigma = \left(\frac{\Gamma(1+\beta)\sin\left(\frac{\pi\beta}{2}\right)}{2\left(\frac{\beta-1}{2}\right)\beta\Gamma\left(\frac{1+\beta}{2}\right)} \right)^{\frac{1}{\beta}} \quad (13)$$

$$\Gamma(x) = (x-1)! \quad (14)$$

where r_1 and r_2 are random numbers from normal distribution and β is a constant number. The pseudo-code of DA is as follows:

PSEUDO-CODE OF DA

1. initialize size of swarm N
2. initialize food source fitness F_{fit} and location F_{loc}
3. initialize enemy fitness E_{fit} and location E_{loc}
4. initialize number of neighbor J
5. initialize maximum iteration k_{max}
6. initialize objective function func(X)
7. **for** search agent i **to** N **do**
8. initialize search agent location X_i
9. initialize search agent step vector ΔX_i
10. **end for**
11. **for** iteration k = 1 **to** k_{max} **do**
12. define w, s, a, c, f, e
13. **for** each search agent i**do**
14. calculate fitness value func(X_i)
15. **if** func(X_i) is better than F_{fit} **then**
16. $_{fit}$ ← func(X_i)
17. F_{loc}← X_i
18. **end if**
19. **if** func(X_i) is worse than E_{fit} **then**
20. E_{fit} ← func(X_i)
21. E_{loc}← X_i
22. **end if**
23. **end for**
24. **for** each search agent X_i **do**
25. calculate J

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calculate S_i, A_i, C_i, F_i, E_i using Equation (4-8)
if J >0 **then**
update ΔX_i using Equation (9)
update X_i using Equation (10)
else
update X_i using Equation (11)
end if
end for
end for

V. DA-FUZZY CONTROLLER

A critical disadvantage of the fuzzy control is that prior information of the controlled system or expert knowledge is needed. Furthermore, even when the expert knowledge is known, the framing of fuzzy rules and assigning membership values are based on trial and error. Hence DA is used to optimize the fuzzy parameters by adjusting fuzzy rules and fuzzy set values to get the desired performance of the LUO converter

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)

$$ISE = \int_0^t e^2 dt \qquad (15)$$

$$IAE = \int_0^t |e|\, dt \qquad (16)$$

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

VII. SIMULATION RESULTS AND DISCUSSION

Figs. 5-7 show the start up as well as transients of the converter with fuzzy, and DA-Fuzzy controllers under small signal step disturbances in supply and load. The circuit parameters of the chosen positive output Luo converter is listed in Table I. The parameter settings of DA are listed in Table III .Converter has been modeled using Simulink-Power System block set of Matlab, Fuzzy control is developed through the fuzzy toolbox and Matlab coding is developed for DA. Figs.6 and 7 show the closed loop responses of positive output Luo converter with 25% step increase in input voltage and vice versa applied at t= 40ms and t=70ms respectively for fuzzy and DA-Fuzzy controllers. The line disturbances are rejected within a maximum of 21ms and 19ms respectively with Fuzzy and DA-Fuzzy controllers and the output voltage is regulated under load disturbances within a maximum of 25ms and 19ms respectively for the above controllers. Performance comparison between Fuzzy and DA-Fuzzy controllers are shown in Table IV. It is observed that DA performs better with lower ISE, IAE, Settling time and peak overshoot compared to fuzzy. Because of the effect of the five individual behaviors in the swarm, fuzzy parameters are updated in the every search agent.

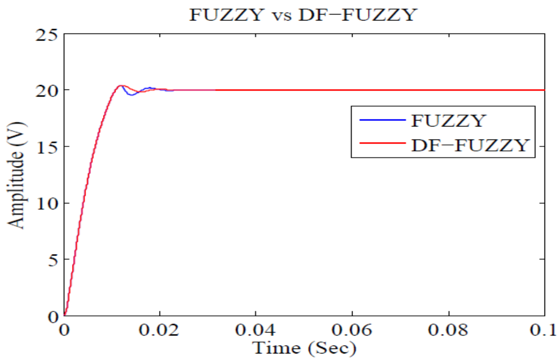

Fig.5 closed loop responses of Fuzzy and DF-Fuzzy Controllers

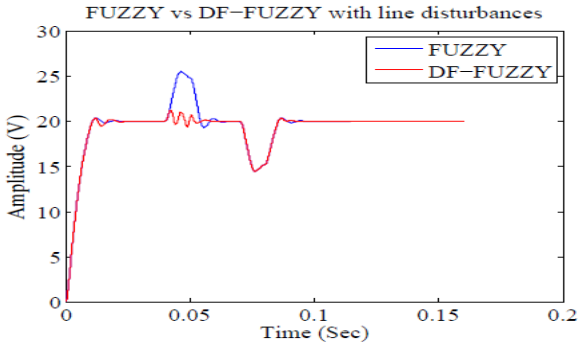

Fig.6 closed loop responses of Fuzzy and DA-Fuzzy controllers with sudden line disturbance (25%) at 0.04 sec and at 0.07 sec.

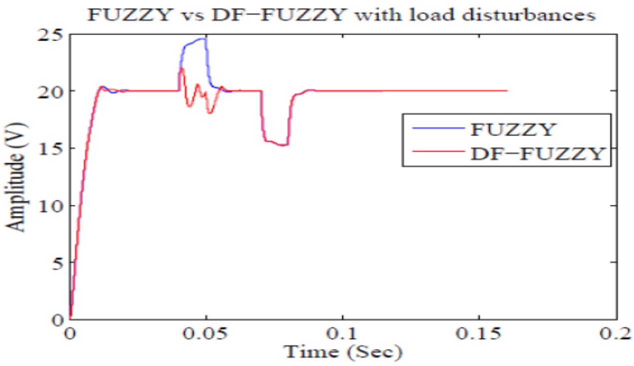

Fig.7 Closed Loop responses of Fuzzy and DA-Fuzzy controllers with sudden load disturbance from 10Ω-11Ω (10%) at 0.04 sec and 10Ω-9Ω(10%) at 0.07sec.

Table III : DA Parameter values

Parameters	Values
No. of Dragonflies	50
Separation factor (s)	0.1
Alignment factor (a)	0.1
Cohesion factor (c)	0.7
Food factor (f)	1
Energy factor (e)	1
No. of iterations	100

Table IV: Performance Evaluation of Positive Output Elementary LUO Converter

		Tuning Parameters	FUZZY Controller	DA-FUZZY Controller
Start up Transient		Rising time (msec.)	10.9	10.9
		Settling time (msec.)	19	17
		Peak Overshoot %	1.75	1.8
		ISE	1.205	1.195
		IAE	0.095	0.090
Line Disturbances	Supply Increase 25% at 0.04 sec	Settling time (msec)	19	15
		Peak Overshoot%	27.3	6
		ISE	1.241	1.208
		IAE	0.1044	0.09748
	Supply Decrease 25% at 0.07 sec	Settling time (msec)	21	19
		Peak Overshoot%	27.94	26.19
		ISE	1.459	1.249
		IAE	0.1561	0.1132
Load Disturbances	Load Increase 25% at 0.04 sec	Settling time (msec)	25	17
		Peak Overshoot%	22.63	10
		ISE	1.265	1.214
		IAE	0.1099	0.09911
	Load Decrease 25% at 0.07 sec	Settling time (msec)	21	19
		Peak Overshoot %	23.91	22.15
		ISE	1.453	1.305
		IAE	0.1566	0.1273

VIII. CONCLUSION

The use of Dragonfly Algorithm for control of Luo converters has been proposed in this paper because of its good exploration and exploitation characteristics. This technique is fast and system independent. DA-Fuzzy is compared with the Fuzzy control and is proven to be superior in terms of rejection of line and load disturbances.

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