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Moth Flame Optimisation Algorithm for Control of LUO Converter

N. Nachammai, R. Kayalvizhi

Abstract: Because of the effects of the parasitic elements, the output voltage and power transfer efficiency of all DC-DC converters are restricted. In order to eliminate the limitations caused by parasitic elements, the voltage lift technique is successfully applied to DC-DC converters resulting in a new series called Luo converters. Linear control methods ensure stability and good control only in small vicinity around the operating point. These classical controllers are designed using mathematical models by linearising non-linearities around the nominal operating point. Since these controllers are also sensitive to the operating points and parameters variations, a high degree of accuracy cannot be guaranteed from them. To ensure that the controllers work well in large signal conditions and to enhance their dynamic responses, intelligent method using fuzzy technique is suggested.The performance of a fuzzy logic controller depends on its control rules and membership functions. Hence, it is very important to adjust these parameters to the process to be controlled. A method is presented for tuning fuzzy control rules by Moth Flame Optimization(MFO) algorithm to make the fuzzy logic control systems behave as closely as possible to the operator or expert behavior in a control process. The tuning method fits the membership functions of the fuzzy rules given by the experts with the inference system and the defuzzification strategy selected, obtaining high-performance membership functions by minimizing an error function. Moth-flame Optimization (MFO) algorithm is one of the newest bio inspired optimization techniques in which the main inspiration of this optimizer is the navigation method of moths in nature called transverse orientation.MFO has a fast convergence rate due to use of roulette wheel selection method. Moth-Flame Optimizer (MFO) is used to control the LUO converter. MFO-Fuzzy is used to search the fuzzy rules and membership values to achieve minimum ISE, ITAE, settling time and peak overshoot. The proposed method is compared with fuzzy controller. Simulation results prove that the MFO algorithm is very competitive and achieves a high accuracy.

Keywords: Moth Flame Optimisation Algorithm, Fuzzy Logic Controller, Positive Output Elementary LUO Converter.

I. INTRODUCTION

All the modern electronic systems require high quality, small, light weight, cheap, reliable and efficient power supplies. DC-DC converters are widely used in computer peripheral power supplies, car auxiliary power supplies, servomotor drives and medical equipments. Because of the effects of the parasitic elements, the output voltage and power transfer efficiency of such converters are restricted.

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In order to eliminate these limitations, the voltage lift technique has been successfully applied to DC–DC converters resulting in a new series named as Luo converters[1].Recently fuzzy control technique has been applied to many industrial processes. Fuzzy logic controller (FLC) are rule - based systems which are useful complex ill-defined processes, especially those which can be controlled by a skilled human operator without knowledge of their underlying dynamics. The essential part of the FLC system is a set of fuzzy control rules related by means of a fuzzy implication and compositional rule of inference. The correct choice of the membership functions of the linguistic label set plays an essential role in the performance of an FLC, it being difficult to represent the experts knowledge perfectly by linguistic control rules. An FLC contains a number of sets of parameter that can be altered to modify the controller performance. A tuning method for obtaining high performance fuzzy control rules by means of MFO algorithm has been proposed. Moth-flame optimization MFO algorithm has been developed by seyedalimirjalili in 2015 is a nature inspired method[2] from navigating mechanism of moths in nature called transverse orientation, which has not received yet much attention in the control of power electronic converters. MFO algorithm has two main advantages[3] such as MFO avoids the local optima problem, while many other optimization algorithms such as Genetic Algorithm (GA) still face this problem and MFO has high exploration and exploitation which may assist to outperform other algorithms.

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.

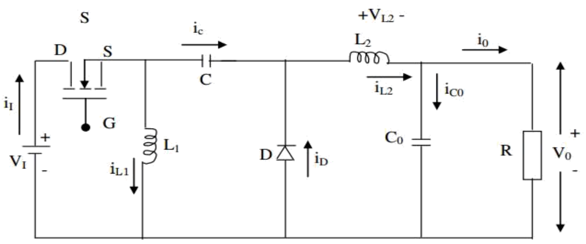

Fig. 1 Positive Output Elementary Luo Converter

Table I: Circuit Parameters of positive Output Elementary Luo Converter

Parameter	Symbol	Value
Input Voltage	Vin	10 V
Output Voltage	Vo	20V
Inductor	L	100µH

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Capacitor	C	5μF
Load resistor	R	10Ω
Duty ratio	D	0.67

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 „f_s" and duty ratio „d". The switching period is $T=1/f_s$ so that the switch-on period is dT and the switch-off period is (1-d)T. The load R is resistive. $R=V_o / I_o$ where V_o and I_o are the average output voltage and current.Table I gives the circuit parameters of positive output elementary Luo converter.

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 [11] but it does not require a mathematical model of the system.

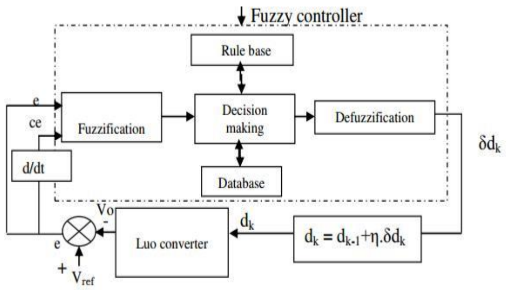

Fig. 2 Block diagram of fuzzy logic control for a Luo converter

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

$$e = V_{ref} - V_o \qquad (1)$$

$$ce = e_k - e_{k-1} \qquad (2)$$

where V_o is the present output voltage, V_{ref} 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 δd_k.

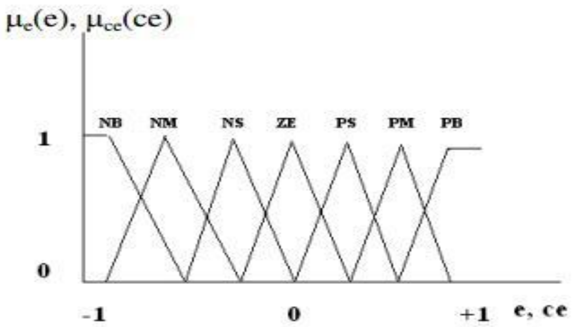

Fig. 3 Membership Functions for e, ce

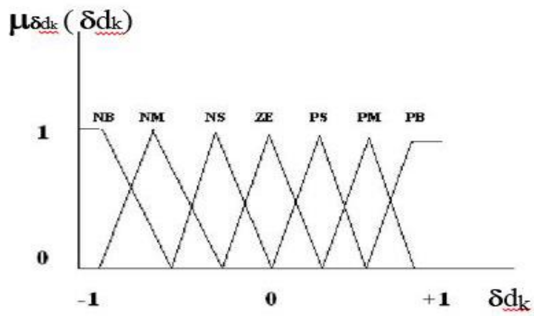

Fig. 4 Membership functions for δd_k

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

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

IV. OVERVIEW OF MFO ALGORITHM

MFO algorithm based on the navigation method of moths in nature. Moths fly in night by maintaining a fixed angle with respect to the moon, a very effective mechanism for travelling in a straight line for long distances[4]. But moths fly spirally around the light, because the light source is very near. The moth eventually converges towards the light. Moths and flames are both solutions. The moths are actual search agents, whereas flames are the best position for moths that obtains so far. Therefore, each moth searches around a flame and updates it in case of finding a better solution. Different steps involved in the proposed algorithm are as follows[5]:

The set of moths represented in a matrix form is ,

$$M = \begin{bmatrix} m_{1,1} & m_{1,2} & \cdots & \cdots & m_{1,d} \\ m_{2,1} & m_{2,2} & \cdots & \cdots & m_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ m_{n,1} & m_{n,2} & \cdots & \cdots & m_{n,d} \end{bmatrix} \qquad (4)$$

Where, n is the number of moths and d is the number of variables (dimension).

For all the moths it is assumed that there is array for storing the corresponding fitness values as

$$OM = \begin{bmatrix} OM_1 \\ OM_2 \\ \vdots \\ OM_n \end{bmatrix} \qquad (5)$$

A matrix similar to the moth matrix is considered as

$$F = \begin{bmatrix} F_{1,1} & F_{1,2} & \cdots & \cdots & F_{1,d} \\ F_{2,1} & F_{2,2} & \cdots & \cdots & F_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ F_{n,1} & F_{n,2} & \cdots & \cdots & F_{n,d} \end{bmatrix} \qquad (6)$$

The dimension of M and F arrays are equal. For the flames, it is also assumed that there is an array for storing the corresponding fitness value as

$$OF = \begin{bmatrix} OF_1 \\ OF_2 \\ \vdots \\ OF_n \end{bmatrix} \qquad (7)$$

The MFO algorithm is a three-tuple that approximates the global optimal of the optimization problems and defined as

MFO= (I, P, T)

I is a function that generates a random population of moths and corresponding fitness value. The methodical model of this function is

$$I : \phi \rightarrow \{M, OM\} \qquad (8)$$

The P function, which is the main function, moves the moths around the search space. This function received the matrix of M and returns is updated one eventually.

$$P: M \rightarrow M \qquad (9)$$

The F function returns true if the termination criterion is satisfied and false if the termination criterion is not satisfied.

$$T: M \rightarrow \{true, false\} \qquad (10)$$

The matrixes which define the upper and lower bounds of the variables are as

$$ub = [ub_1, ub_2, ub_3, \ldots. ub_{n-1}, ub_n] \qquad (11)$$

Where ub_1 indicates the upper bound of the i *th* variable.

$$lb = [lb_1, lb_2, lb_3, \ldots. lb_{n-1}, lb_n] \qquad (12)$$

Where lb_i indicates the lower bound of the *ith* variable.

The position of each moth is updated with respect to a flame using the below equation,

$$M = S(M_i, F_i) \rightarrow M \qquad (13)$$

Where M_i indicate the i *th* moth, F_j indicates the j *th* flame, and S is the spiral function.

A logarithmic spiral is defined for the MFO algorithm [6] as

$$S(M_i, F_i) = D_i, e^{bt}, cos(2\pi t) + F_j \qquad (14)$$

Where D_i indicates the distance of the i *th* moth for the j *th* flame, b is a constant for defining the shape of the logarithmic spiral, and t is a random number in [-1, 1].

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D is calculated as

$$D_i = \left| F_j - M_i \right| \qquad (15)$$

The spiral equation allows a moth to fly "around" a flame and not necessarily in the space between them[7]. The best solutions obtained so far are considered as the flames and stored in F matrix. The number of flames is decreased adaptively over the course of iterations are

$$flames\ no = round\left(N - l * \frac{N-1}{T} \right) \qquad (16)$$

Where, l is the current number of iteration, N is the maximum number of flames and T indicates the maximum number of iterations[8]. In the initial steps of iterations there is N number of flams. The moths update their positions only with respect to the best flame in the final steps of iterations. The gradual decrement in number of flames balances exploration of the search space [9].

PSEUDO-CODE OF MFO [10]

```
Initialize the position of moths
While (Iteration <= Max_iteration)
Update flame no using (8)
OM = FitnessFunction(M);
if iteration = = 1
    F = sort(M);
    OF = sort(OM);
else
    F = sort(M_t − 1, M_t);
    OF = sort(M_{t−1}, M_t);
end
for i = 1 : n
    for j = 1 : d
        Update r and t
        Calculate D using (7) with respect to the corresponding moth
        Update M(i, j) using (5) and (6) with respect to the corresponding moth
    end
end
```

V. MFO-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 arbitrary and not robust. The fuzzy-control-rule base has many parameters such asscaling factors for each variable, fuzzy set and IF-THEN rules and their control depends on the tuning of the control system. Hence MFO is used to optimize the fuzzy parameters by adjusting fuzzy rules and fuzzy set values to get the desired performance of the LUO converter. Table III list out the parameters of MFO.

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)

$$\textbf{ISE} = \int_0^t e^2 dt \qquad (17)$$

$$\textbf{IAE} = \int_0^t |e| dt \qquad (18)$$

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

VII. SIMULATION RESULTS AND DISCUSSION

Different objectives considered in this work are minimization of ISE, ITAE, settling time and peak overshoot. This method is simulated and tested on the LUO Converter.Figs.5-7 show the simulated output voltage of the Luo converters with MFO-fuzzy controller under line and load disturbances. The above responses are compared with corresponding responses with fuzzy controller. The MFO-fuzzy controller implemented regulates the output voltage within a maximum of 21ms and 20ms after line and load disturbances respectively. Fig.5 display the start up transient in the output voltage of positive output elementary Luo converter. The start up transient exists for a maximum of 17.5ms. From the Table IV, it is also observed that the peak overshoot for MFO-fuzzy (3.7%) is less than the fuzzy controller (25.9%) with sudden increase in the line disturbance.

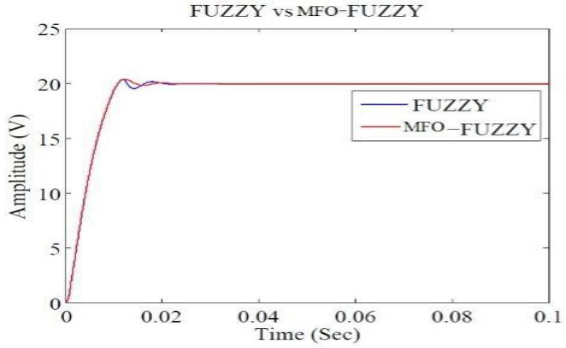

Fig.5 Closed loop responses of Fuzzy and MFO-Fuzzy Controllers

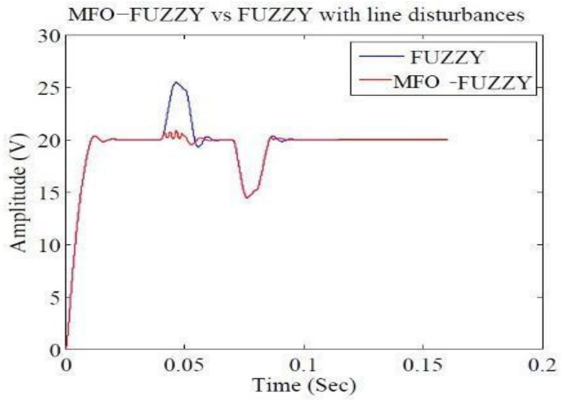

Fig.6 Closed loop responses of Fuzzy and MFO-Fuzzy controllers with sudden line disturbance (25%) at 0.04 sec and at 0.07 sec.

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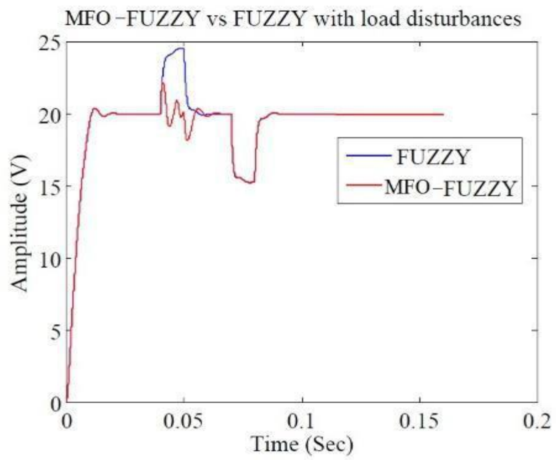

Fig.7 Closed loop response of Fuzzy and MFO-Fuzzy controllers with sudden load disturbance (25%) at 0.04 sec and at 0.07sec.

Table III: Parameter Settings

Parameters	Values
Number of moths and flames(Agents_no)	50
Number of variables(dim)	7
Maximum iteration number(Max_iteration)	500
Lower bound (lb)	Min.value of control variables
Upper bound (ub)	Max.value of control variables

Table IV. Performance Evaluation of Positive Output Elementary LUO Converter

		Tuning Parameters	FUZZY Controller	MFO-FUZZY Controller
Start up Transient		Rising time (msec.)	10.9	10
		Settling time (msec.)	20	17.5
		Peak Overshoot %	2.6	2.5
		ISE	1.205	1.190
		IAE	0.095	0.080
Line Disturbances	Supply Increase 25% at 0.04 sec	Settling time (msec)	0.22	19
		Peak Overshoot%	25.9	3.7
		ISE	1.241	1.20
		IAE	0.1044	0.090
	Supply Decrease 25% at 0.07sec	Settling time (msec)	23	21
		Peak Overshoot%	27.7	27
		ISE	1.459	1.247
		IAE	0.1561	0.1111
Line Disturbances	Load Increase 25% at 0.04 sec	Settling time (msec)	22	20
		Peak Overshoot%	21.8	10.4
		ISE	1.265	1.20
		IAE	0.1099	0.09892
	Load Decrease 25% at 0.07 sec	Settling time (msec)	19.2	18
		Peak Overshoot %	22.8	22
		ISE	1.453	1.305
		IAE	0.1566	0.1273

VIII. CONCLUSION

A new nature inspired algorithm named Moth-Flame Optimization (MFO) algorithm has been used for tuning the fuzzy controller for LUO converter. The performance of MFO – Fuzzy and Fuzzy controllers have been investigated. The results show that MFO tuned fuzzy controller provides better dynamic response in terms of less settling time and less peak overshoot. The performance of MFO algorithm misevaluated by comparing with fuzzy controller for LUO converter. The simulation results infer that the line and load disturbance reject in faster rate and settles very quickly, which shows superiority of MFO tuned fuzzy controller over fuzzy controller.

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