Hybrid Fuzzy Logic Based A Particle Swarm Optimization Controller Design for ZETA Converter

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Abstract

This paper presents the mathematical model of the ZETA converter circuit operating in the continuous conduction mode (CCM) in state-space form. The converter circuit output is investigated. Fuzzy Logic controller is designed for the converter circuit. Fuzzy Logic based Particle Swarm Optimization (FLC&PSO) Controller is proposed to design controller for controlling the switch operation of the ZETA converter circuit for regulation of its output voltage and getting good performance. Analysis and comparision between Simulation results of open loop, close loop fuzzy logic controller and fuzzy logic based particle swarm optimization controller results are performed for different resistive loads and reference voltages. The results show that there are a signification improvement in the results for the proposed method.

Keywords: Fuzzy Logic Controller(FLC), Particle Swarm Optimization (PSO), ZETA Converter.

تهجين المنطق المضبب وحشد الجزيئات المثالية لتصميم مسيطر للمغير زيتا

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الخلاصة

يقدم هذا البحث نموذج التحليل الرياضي لدائرة المغير ZETA والتي تعمل بنمط التوصيل المستمر بصيغة فضاء الحالة ودراسة استجابة دائرة المغير. لقد تم تصميم مسيطر منطقي مضبب لدائرة المغير، كما تم تصميم مسيطر منطقي مضبب مكيف مع تقنية حشد الجزيئات المثالية للسيطرة على عمل المفتاح لدائرة المغير ZETA لتنظيم فولتية الإخراج والحصول على أداء جيد. أن التحليل والمقارنة بين نتائج المحاكاة في حالة دارة الحلقة المفتوحة، الحلقة المغلقة للنظام بوجود المسيطر المنطقي المضبب والمسيطر المضبب المكيف مع مسيطر حشد الجزيئات المثالية تم انجازها عند عدة أحمال مقاومية وفولتية مرجعية مختلفة. النتائج تبين آن هنالك تحسن نوعي في أداء المنظومة للحالات المذكورة أنفا.

1. Introduction:

A DC-DC converter is widespread in modern portable electronic equipments and systems. The batteries are providing constant input voltage to the converter, then the converter converts it into a reliable output voltage .The output voltage can vary over wide range of values depending on the charge level. At low charge level, the voltage may drop below the battery voltage for continuously supplying the load with constant voltage[1 ,2]. There are many research works dealing with the DC-DC converters performances and their control. One of those works was that of .E. Vuthchhay and C. Bunlaksanusorn in 2010A.C [3].They studied ZETA converter circuit performance, Modeling and Control of the converter performance. O. A. Taha in 2007A.C[5]. Studied CUK converter circuit performances ,he designed and implemented a robust controller for it using H_∞ц synthesis technique. He studied the effects of CUK converter parameters changes on the circuit stability [5]. S. S. Sabri in 2008 A.C , studied the CUK converter circuit performance and designed control for it using Fuzzy Logic Controller based genetic algorithm to improve its performance [6]. R. Suresh Kumar, had studied BOOST converter circuit performance and its controller using PID controller, it used a particle swarm optimization technique for design and improved its performance [7]. Because of the lack of the studies about the ZETA converter circuit, the present work deal with the design of the Fuzzy Logic Controller and fuzzy Logic Adaptive Particle Swarm Optimization Controller proposed to control its output voltage for the purpose of improving its output performance.

2. ZETA Converter Mathematical Model :

The ZETA DC-DC converter is assumed to   operate in the continuous conduction mode(CCM).There exist two circuit states within one switch period T .First is when IGBT transistor switch is turned on form an interval DT, and another when it is turned off for an interval(1-D)T. The general state space mathematical model of the ZETA converter is given by:

$$x^{\bullet} = Ax + Bu \tag{1}$$

$$y = Cx + Eu \tag{2}$$

Where :

u is input signal;   y is output signal;   X is $n \times 1$ state vector;

A is $n \times n$ system matrix;   E is $L \times m$ matrix;

u is $m \times 1$ input vector;   B is $n \times m$ input matrix;

y is $L \times 1$ output vector;   C is $L \times n$ output matrix;

The ZETA converter circuit shown in Fig (1a),it consists of IGBT transistor (switch). Diode, two capacitors C_1 and C_2 ,two inductors L_1 and L_2 ,and load resistor R_L. In the first mode of operation, the converter circuit IGBT transistor is on. Shown in Fig (1b).During this interval (DT),the inductors L_1 and L_2 are in charging state[3].
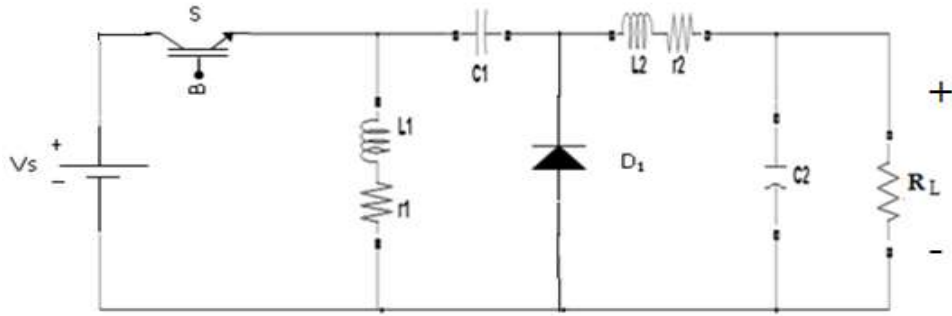
Fig. (1a): ZETA converter circuit

Let :

$$i_{L_1} = X_1 , \qquad\qquad\qquad i_{L_2} = X_2$$

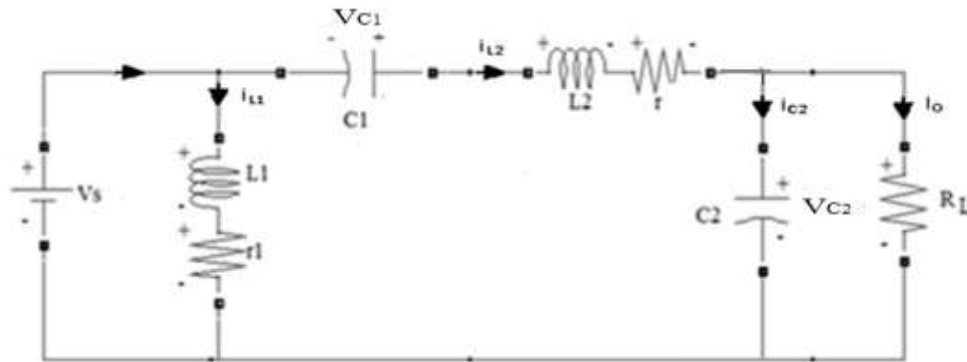$$V_{C_1} = X_3 , \qquad\qquad\qquad V_{C_2} = X_4$$

Fig.(1b): ZETA converter when switch is ON

Using the Kirchhoff's voltage law and writing the voltage equations for the open loop and rearranging the equation to be on the state space form. The system matrices become to be:

$$A1 = \begin{bmatrix} -\dfrac{r_1}{L_1} & 0 & 0 & 0 \\[2mm] 0 & -\dfrac{r_2}{L_2} & \dfrac{1}{L_2} & -\dfrac{1}{L_2} \\[2mm] 0 & -\dfrac{1}{C_1} & 0 & 0 \\[2mm] 0 & \dfrac{1}{C_2} & 0 & -\dfrac{1}{RC_2} \end{bmatrix}$$

$$B1 = \begin{bmatrix} \dfrac{1}{L_1} \\[2mm] \dfrac{1}{L_2} \\[2mm] 0 \\[1mm] 0 \end{bmatrix}, C1 = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}, E = 0$$

In the second mode of operation (1-D)T the IGBT transistor is off. The converter equivalent circuit is shown in Fig (1c). In this mode the inductors (L_1, L_2) are in the discharging state. L_1 is discharging its stored energy into the capacitor C_1, and the inductor L_2 transform energy to output section[3]. The ZETA converter circuit matrices are given by:
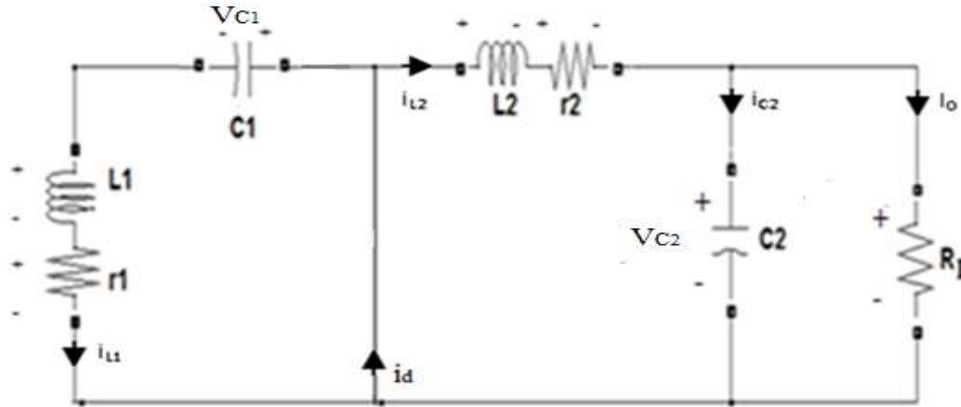

Fig. (1c): ZETA converter when switch is OFF

$$A2 = \begin{bmatrix} -\dfrac{r_1}{L_1} & 0 & -\dfrac{1}{L_1} & 0 \\ 0 & -\dfrac{r_2}{L_2} & 0 & -\dfrac{1}{L_2} \\ \dfrac{1}{C_1} & 0 & 0 & 0 \\ 0 & \dfrac{1}{C_2} & 0 & -\dfrac{1}{RC_2} \end{bmatrix}$$

$$B2 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}, C2 = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}$$

Using the following relation to Combine the on state and off state cases written as follows:

A= A1.D+ A2.(1-D)   (3)

B=B1.D+B2.(1-D)   (4)

C=C1.D+C2.(1-D)   (5)

The state space equivalent matrices are given: [3,4]

$$A = \begin{bmatrix} -\dfrac{r_1}{L_1} & 0 & \dfrac{D-1}{L_1} & 0 \\ 0 & -\dfrac{r_2}{L_2} & \dfrac{D}{L_2} & -\dfrac{1}{L_2} \\ \dfrac{1-D}{C_1} & \dfrac{-D}{C_1} & 0 & 0 \\ 0 & \dfrac{1}{C_2} & 0 & -\dfrac{1}{RC_2} \end{bmatrix}, B = \begin{bmatrix} \dfrac{D}{L_1} \\ \dfrac{D}{L_2} \\ 0 \\ 0 \end{bmatrix}, C = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}$$

4. ZETA Converter Circuit Design:

Writing the Kirchhoff's voltage low the following ZETA converter circuit equations may be introduced as the follows:[1]

$$L_1 \geq \frac{(1-D)^2 R_L}{2DF} \tag{6}$$

$$L_2 \geq \frac{(1-D)R_L}{2F} \tag{7}$$

$$C_1 \geq \frac{D}{8(1-D)FR_L} \tag{8}$$

$$C_2 \geq \frac{1}{8FR_L} \tag{9}$$

Where: F is the switching frequency. For $R_L=10\Omega$, F=5KHZ, D=0.5, the above components become: L_1=0.5mH , L_2=0.5mH, C_1=900μF, C_2=1000μF
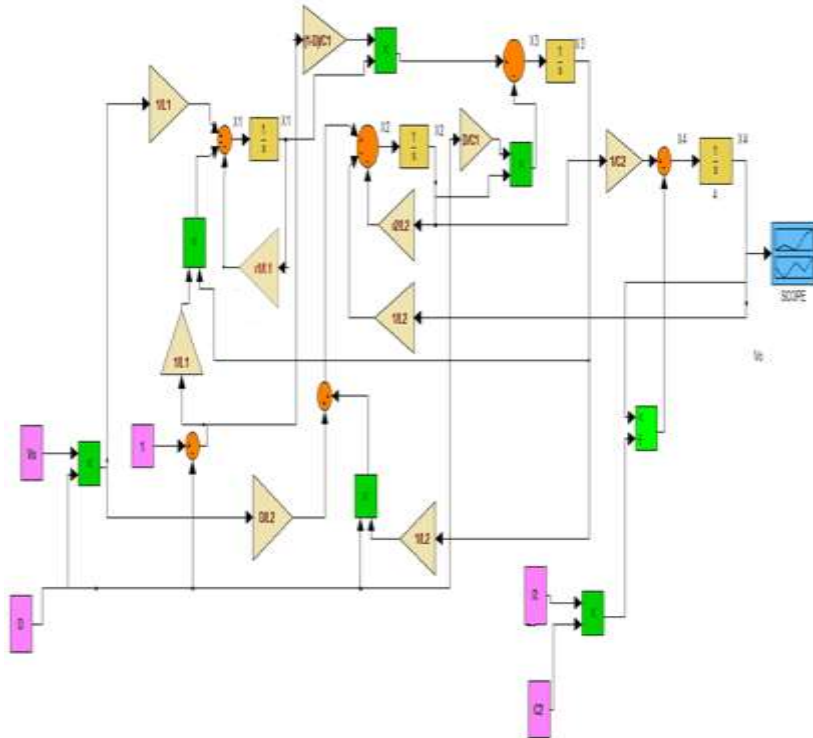

Fig. (2): ZETA converter circuit MATLAB Simulink model.

5. **Fuzzy Logic Controller Design**:

Fuzzy controller has been designed for writing its   input as : The error E(t) and the error   change DE(t) of the output voltage .The linguistic variables are defined as (N, NS, Z, PS, P) where N means negative ,NS negative small, Z zero, PS positive small, P positive . Triangular member ship functions of the fuzzy logic controller   are considered. The fuzzy rules are summarized in table(1). The mamdani type of fuzzy influence engine is considered [7,8,9,10].

The error range are taken between (-30 and 30) as shown in Fig (3a), and range of error change are taken between(-12 and 12) as shown in Fig (3b) The output duty ratio range between (0 and 1) as shown in Fig. (3c) .

Table (1)

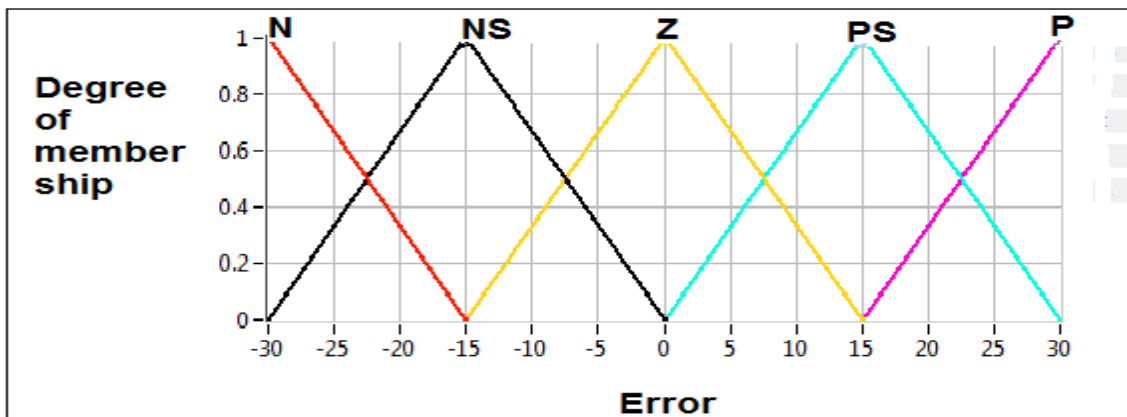| Fuzzy Logic Controller rule base table					
ΔE E	N	NS	Z	PS	P
NB	N	N	N	NS	Z
NS	N	N	NS	Z	PS
ZE	N	NS	Z	PS	P
PS	NS	Z	PS	P	P
PB	Z	PS	P	P	P

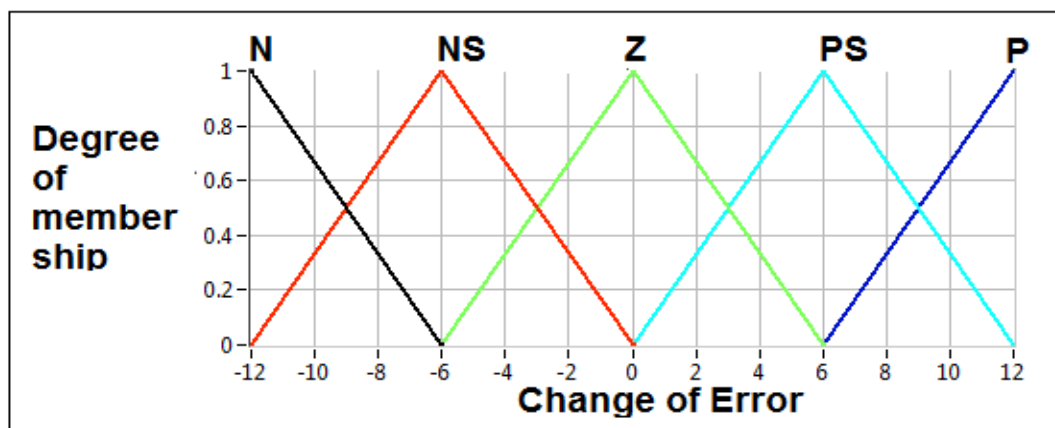Fig. (3a): The error membership function

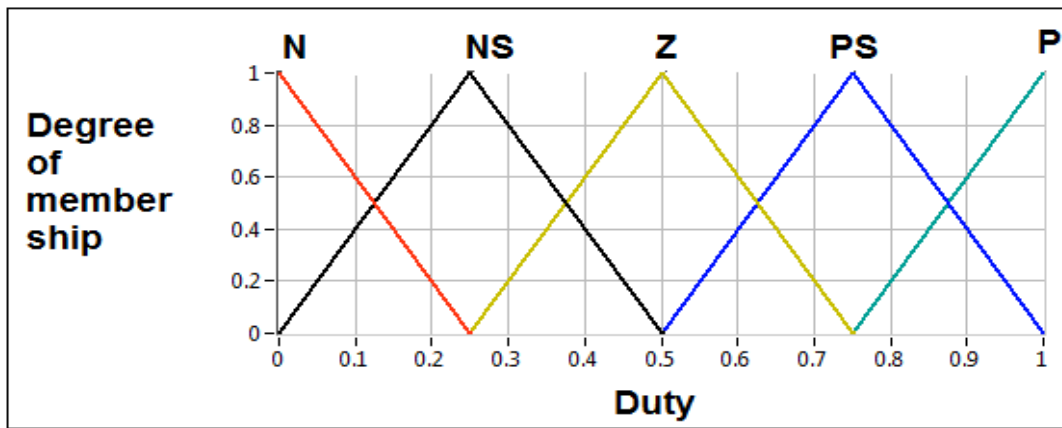Fig. (3b): The change of error member ship function

 Fig.

(3c): The output membership function

The output voltage responses for the open loop system and closed loop system with Fuzzy Logic Controller system of the state space model in the (MATLAB/SIMULINK) are given on the same graph in Fig (4a) when reference voltage is (8volt), Fig(4b) when reference voltage is (18volt) and load resistance (10Ω) . The closed loop and open loop responses when reference voltage is(12volt),and different load resistance (10,40 and 10Ω) are shwon in Fig (4c).
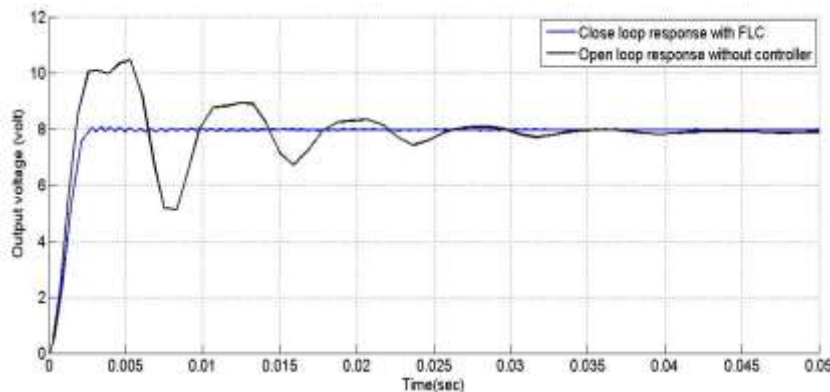

Fig. (4a): Open loop system and close loop system with FLC response for referense voltage =8volt when load resistance (10) Ω .
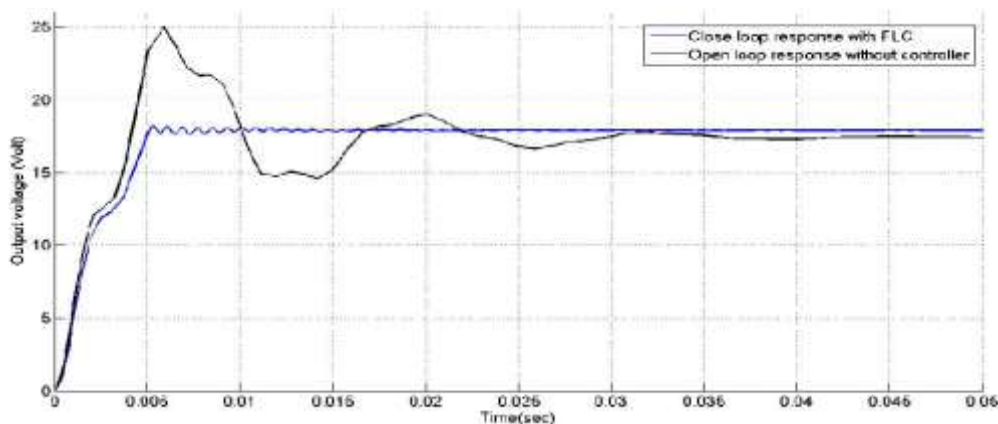

Fig. (4b): Open loop system and close loop system with FLC response for referense voltage =18volt when load resistance (10) Ω
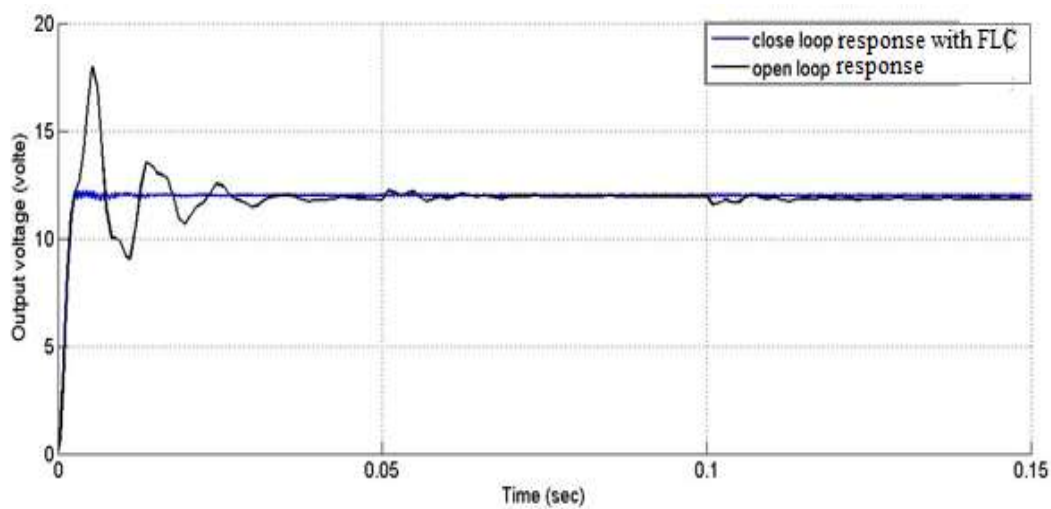
Fig. (4c): Open loop system and close loop system with FLC
response for referense voltage =12volt,when resistive load changed (10-40-10)Ω.

6. Particle Swarm Optimization Algorithm:

Particle swarm optimization technique, first developed by Kennedy and Eberhart (J. Kennedy and R. Eberhart, 1995) as one of the modern heuristic algorithms. It was inspired by the social behavior of the bird and fish schooling and has been found to be robust in solving continuous nonlinear optimization problems[7,11]. This algorithm is based on the following scenario: a group of birds are randomly searching for food in an area and there is only one piece of food. All birds are unaware where the food is, but they do know how far the food is at each time instant. The best and most effective strategy to find the food would be to follow the bird which is nearest to it. Based on such scenario, the PSO algorithm is used to solve the optimization problem.

In PSO, each single solution is a "bird" in the search space; this is referred to as a "particle". The swarm is modeled as particles in a multi-dimensional space, which have positions and velocities. These particles have two essential capabilities: their memory of their own best position and knowledge of the global best. Members of the swarm communicate good positions to each other and adjust their own position and velocity based on good positions according to equations (11,12): [7,13].

Let:
        i is be the number of particles
        j is be the number of iterations

$$v(k+1)_{i.j} = w.v(k)_{i.j} + C_1 r_1\big(\text{gbest} - \text{x(k)}_{i.j}\big) + C_2 r_2\big(\text{pbest}_i - \text{x(k)}_{i.j}\big) \qquad (10)$$
$$x(k+1)_{i.j} = x(k)_{i.j} + v(k+1)_{i.j} \qquad\qquad\qquad\qquad\qquad (11)$$

Where as:
 $v(k)_{i.j}$ is velocity of the particle i
 $x(k)_{i.j}$ is position of the particle i
 C_1, C_2 are the accelerating constants
 W is the ineratia weight facter

r_1, r_2 are the random number between 0 and 1

Pbest is the best position of the specific particle

Gbest is the best particle of the group

7. Fuzzy Logic Based Particle Swarm Optimization Controller Design:

To design an optimal fuzzy controller, the PSO algorithms are applied to search its globally optimal gains . The structure of the fuzzy logic controller with PSO algorithms is shown in Fig (5).The implementation of particle swarm optimization in this work is complex task, because the performance of the system must be examined in each particles and iteration position during the optimization process. Therefore, the optimization algorithm is implemented by using MATLAB m-file program and linked with the system simulation program in MATLAB SIMULINK, to check the system performance in each particle. The PSO produces the Fuzzy controller gains of the FLC which give optimal performance of the ZETA converter.
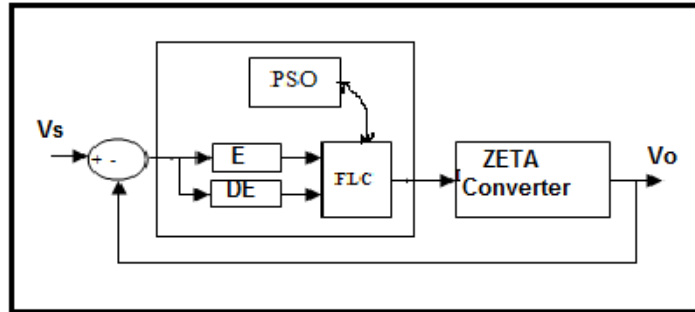

Fig. (5): System block daigram

The PSO technique has been programed MATLAB M-file to calculate the optimal gains then to connect with FLC, and the PSO with FLC flowchart shown in Fig(6).
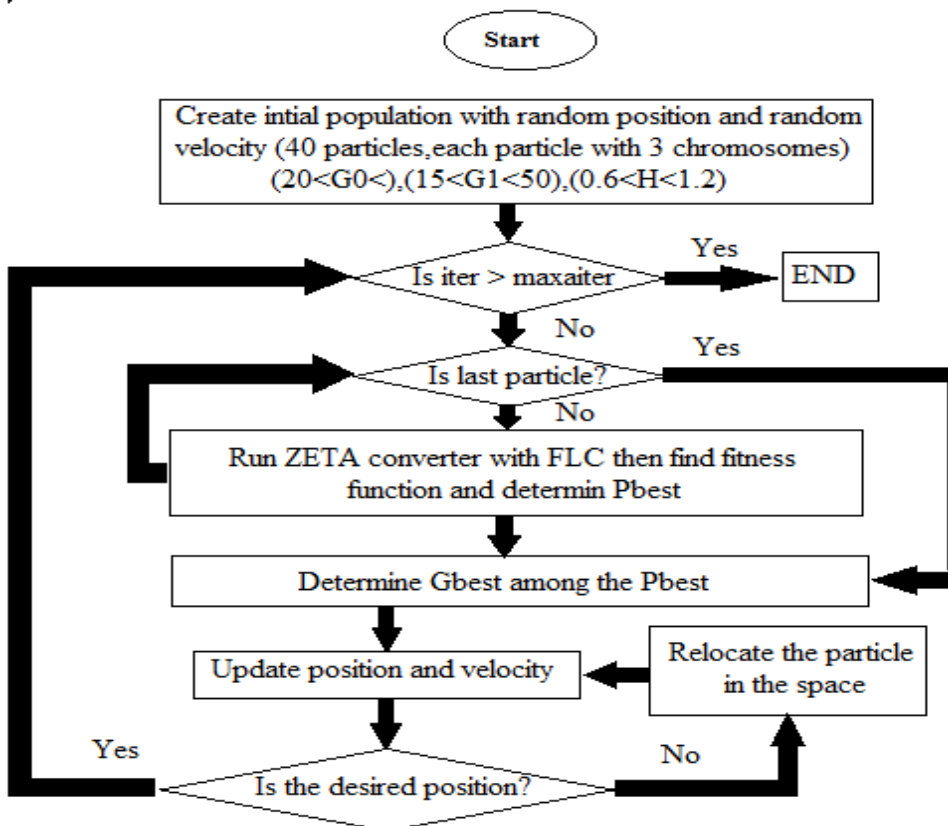

Fig. (6): FLC with PSO flowchart.

8. **Results and discussion**:

The output voltages for the simulated open loop and closed loop with Fuzzy Logic are in Fig (7a) ,when referance voltages (8,12and 18 volt). The fuzzy logic controller gains are chosen by trail and error method to get the best ZETA converter output performance. This process needed long time.The fuzzy logic based particle swarm optimization controller is proposed because of the fuzzy logic controller disadvantages such as (trail and error method ,long time to get the best gains). FLC with PSO controller produce best performance with less computing state time compared with FLC. The output voltage of the open system and closed loop system with FLC had been based using PSO technique when reference voltages (8, 12 and 18 volt) and the load resistance equal to(10Ω) as shwon in Fig. (7b).

The closed loop system and open loop system responses when reference voltages (12volt)) and changed load resistance (10,40 and 10Ω) shwon in Fig. (7c). Comparision between open loop, close loop FLC and FLC with PSO technique results when reference voltage (12 volt)) and the load resistance (10Ω) shwon in the table (2).
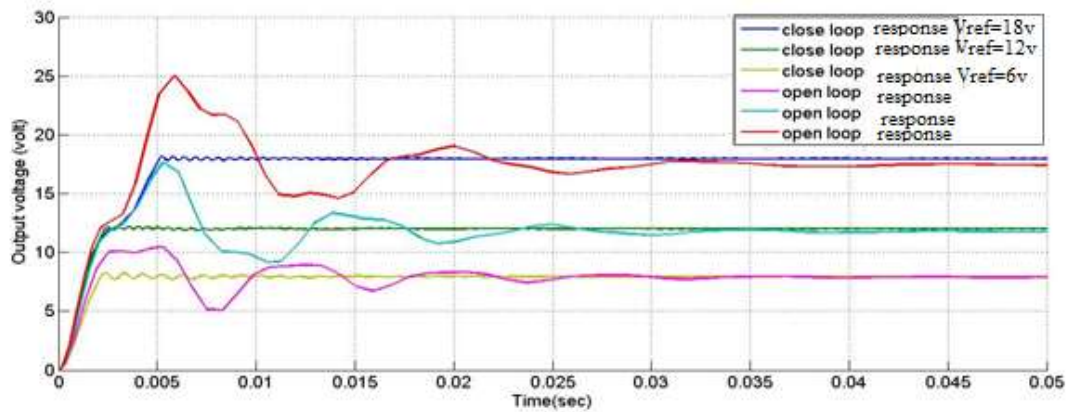

Fig. (7a): Open loop system and close loop system with FLC responses.
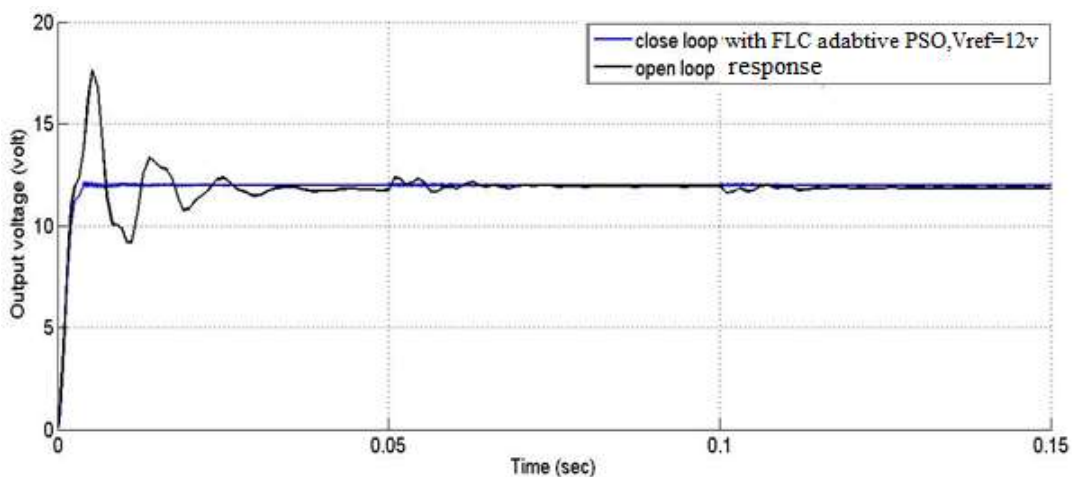

Fig. (7b): Open loop system and close loop system with FLC
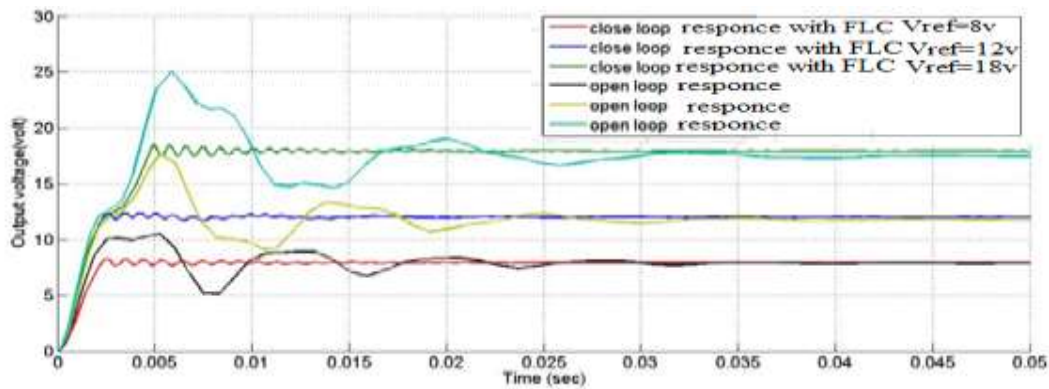adaptive PSO technique responses .

Fig. (7c): Open loop and close loop FLC with PSO
controller system for varaible loads.

Table (2)

Comparision of the system performance for the different techniques			
	Open loop	FL C	FLC with PSO
Setlling time[ms]	38	6	2.5
Peak Overshoot [%]	49	4	1
Steady state error[%]	1.33	0	0

7. Conclusion:

The mathematical of the ZETA converter circuit is analyzed and designed in the open loop system. Two different techniques have been used to design controller for the ZETA converter circuit output voltage: Fuzzy logic control technique and fuzzy logic control based particle swarm optimization technique .PSO technique has been used to determine the FLC gains which give the best output performance. The method by which one can overcome the problem of trial and error in determine the FLC constant gains. The FLC based PSO technique shows that the converter response is significantly better than that for the FLC technique and the FLC gains have been determined with very short time and with a scientific manner.

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