



On the Improving of the Efficiency of FL Controller Based on Genetic Algorithms to Control (DC-DC) Converters

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Abstract

DC-DC converter circuits effectively convert the DC input voltage into a regulated output voltage more efficiently than linear regulators or magnetic transformers. The electronic switches of these converters are controlled to obtain the desired regulated output voltage value. In recent years, the concept of using Artificial Intelligence systems to control electrical circuits and their practical applications has expanded, as Fuzzy Logic Controller (FLC) is one of the most famous types of these systems because it uses inferential logic to simulate the work of the human brain by formulating the fuzzy rule and following the membership of the system's input and output and converting the output into a numerical value that controls it's in turn the duty cycle of the converter. The research proposes the use of Genetic Algorithms (GA) that simulate the principle of natural inheritance (the survival of the fittest principle) to improve the accuracy of the fuzzy controller and thus the efficiency of the step-down converter (Buck) by finding the ideal values for its coefficients in order to obtain the closest value for the reference voltage by improving the parameters of the gain constants and changing the shape of membership. The results of the research using MATLAB show the improvement provided by the Genetic-Fuzzy controller (GA-FLC) compared to the fuzzy logic controller in terms of the response parameters and output curves of the Buck converter.

Keywords: Fuzzy logic; Fuzzy set; Fuzzy controller; Genetic algorithm

1. Introduction

DC-DC converters are generally based ON electronic switches such as transistors and diodes that operate in ON-OFF mode, and they use energy storage elements such as capacitors and coils to store energy in addition to acting as low-pass filters. There are several types of switches, the most famous of which are the buck converter, the boost converter and other forms derived from these two types [1], and they also have many uses in applications that are powered by batteries in general (such as laptops and Electric Cars) [2] or solar power maximum capacity point tracking systems [3].

Artificial intelligence researchers realized the importance of logic in the performance of many applications, and the most important shift of the interaction between artificial intelligence and fuzzy Logic was precisely because of its ability to control many artificial intelligence applications in a way that simulates human logic, as it assumes that facts may not be conclusive and may be achieved between the values of 0 and 1, mathematician lotfizadeh formulated fuzzy logic in the Sixties as part of his research on language understanding by computers, where he proposed designing a model that works with logic closer to the work of the human brain, where it tends to collect partial facts to reach to a logical decision [4,5].

Fuzzy Logic has many advantages that have made it widely spread since the sixties of the last century in the field of expert systems, medical diagnostics, Meteorology, control systems, information retrieval, Robotic Systems, decision-making systems and others [6]. The most prominent of these advantages is the ability to deal with fuzzy input, the

lack of the need for an accurate mathematical model, the ability to deal with nonlinearities and approach the standard value with the least possible fluctuation compared to traditional control systems such as PID [7].

Genetic Algorithms are intelligent search algorithms that use processes found in natural genetics to guide the journey through the search space. Genetic algorithms have many applications, the most famous of which are prediction of nonlinear dynamic systems, data analysis and robot path planning [8] perhaps one of their most prominent advantages is the possibility of combining them with other control systems such as fuzzy controllers to obtain outputs that are more accurate.

The research provides an analysis of the operation of a voltage-reducing switching system (Buck Converter) whose duty cycle (α) be controlled using a fuzzy controller (FLC) and a GA – fuzzy controller (GA-FLC). The research shows the steps of modeling the operation of the system using the SIMULINK/MATLAB environment. As a result, the modeling parameters show the importance of applying genetic algorithms to raise the reliability of the fuzzy controller and thus obtain the best efficiency of the Switch (Buck).

2. The importance of research and its goals

- The research provides a model for developing practical applications of control systems in electrical circuits by linking them with artificial intelligence tools and ensuring the integration of the work of these tools to obtain more accurate results compared to traditional control systems.
- The research is aimed at developing the work of DC alternators and improving their efficiency for operation in nonlinear systems.
- The research results show the ability of the fuzzy logic controller to respond to sudden changes with satisfactory efficiency and dynamics.
- The research shows the importance of applying genetic algorithms (GA) because they provide powerful and fast search capabilities to obtain more results that are accurate and therefore a more efficient system.
- The main objective of the research is to test the response of the GA-FLC and the modeling parameters have shown more accurate and stable results compared to the efficiency of the logical controller (FLC).

3. Research methods and materials

A. Analytical approach

- The research provides a detailed study and analysis of the work of the voltage-reducing commutator (DC-DC Buck Converter).
- Analysis of the work of the fuzzy logic controller (FLC).
- Analysis of the work of genetic algorithms (GA).

B. Experimental approach

In modeling, we relied on MATLAB libraries at several levels: (basic software files M-files, function M-file software dependency files, modeling system stages within the Simulink library).

4. Results and discussion

4.1. Analysis of the components of the voltage-reducing commutator control system:

Figure (1) shows the components of the control addressed by the research and consists of three main sections:

(Low-voltage switch (Buck Converter), fuzzy controller (FLC), genetic algorithm (GA)) the work of the system components will be analyzed in addition to connecting the fuzzy controller to the genetic algorithm within a GA – fuzzy controller (GA-FLC).

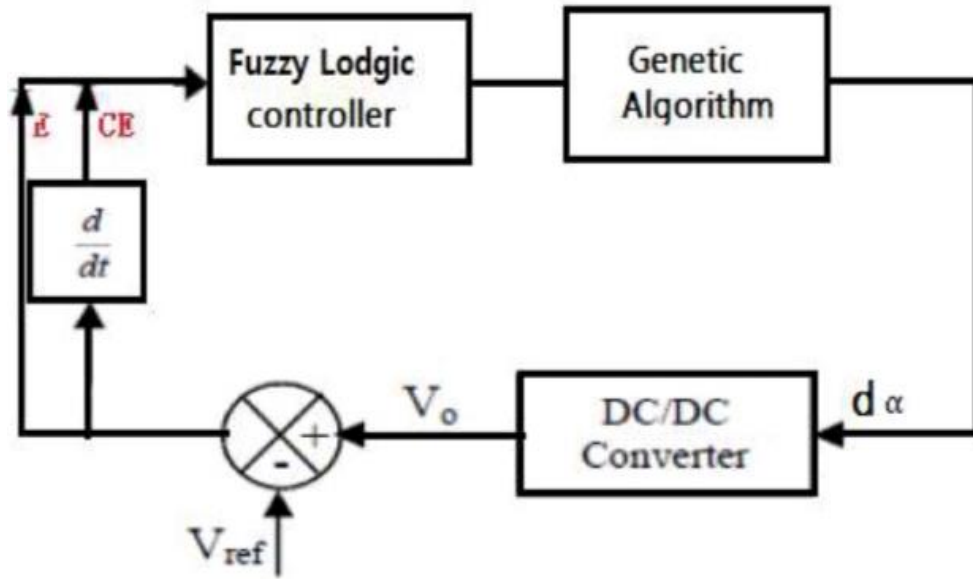


Figure 1. Components of the voltage-reducing commutator control system.

4.1.1. Low voltage switch (DC-DC Buck Converter):

Figure (2) shows a typical buck Converter consisting of an input voltage source V_i , a control switch, a transistor (T_1), a coil (L), a capacitor (C), a diode (D_1) and a load R.

The average voltage on the load in such commutators is less than the input voltage on them as reduction commutators. Figure (2) shows the equivalent circuit of the commutator, and Figure (3) shows the voltages and currents depending on the state of the Switch in the buck commutator [9].

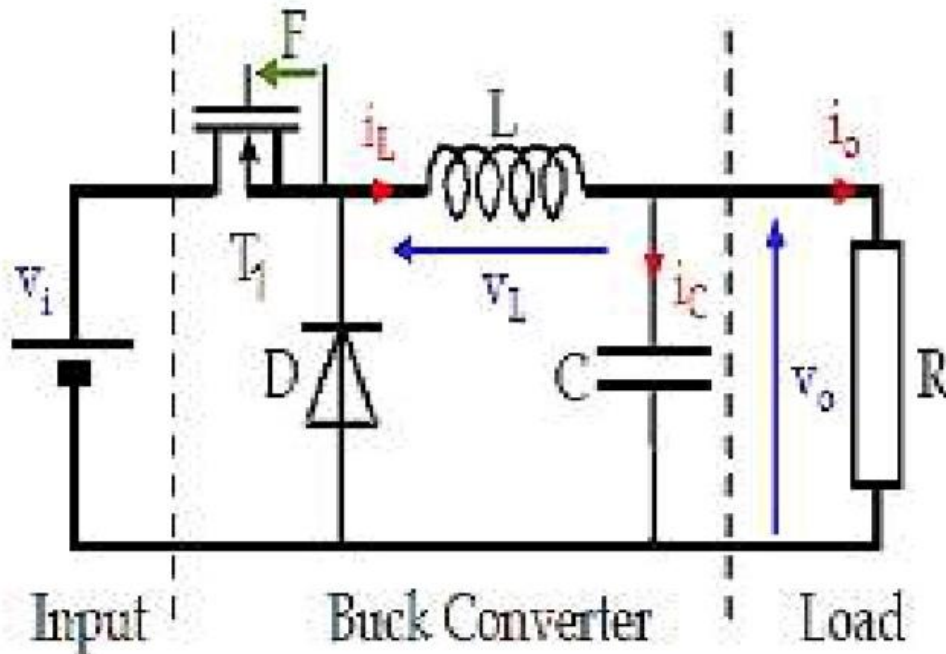


Figure 2. A typical Buck changer.

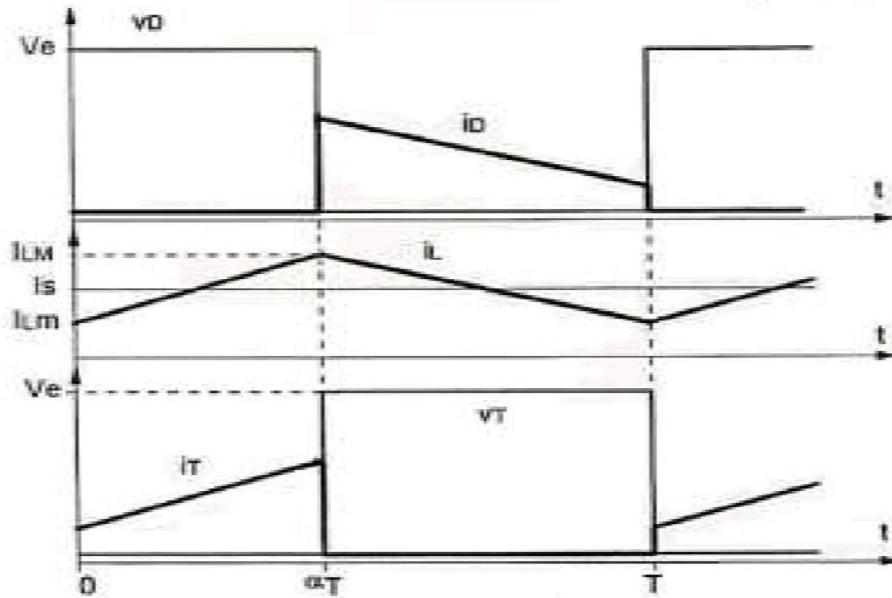


Figure 3. The voltages and currents of the Buck circuit depending on the state of the Switch.

• **Analysis of the work of a voltage-reducing commutator:**

As shown in Figure (4), the work of the voltage-reducing commutator can be summarized by relying on the connection and disconnection cycles of the two-phase Transistor T_1 :

- **The first stage ($0 < t < \alpha T$):**

The first stage begins when the transistor T_1 is connected at the moment $t=0$ where the input current i_T begins to flow through the transistor T_1 , the filter L-C and the load R. The energy is stored inside the coil L and the diode D is in the no-pass state.

- **The second stage ($\alpha T < t < T$):**

The second stage begins now of disconnection of the transistor T_1 at the moment αT where the free diode D secures the closed loop of the load current by means of the filter L-C and the load R. The current of the inductor i_L decreases until it reaches the initial value of the input current at the moment $t=T$.

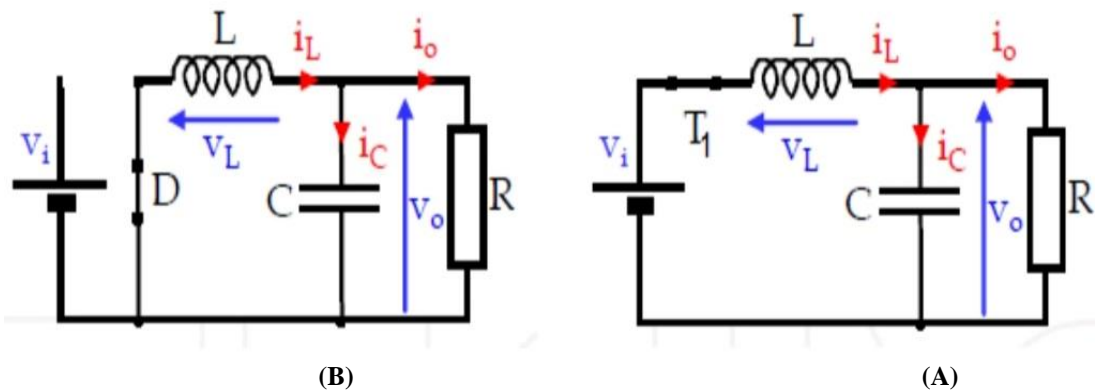


Figure 4. Two stages of the commutator operation (A) the first stage, (B) the second stage

The voltage-lifting commutator can also work with one of two systems:

Continuous Conduction Mode (CCM) or Discontinuous Conduction Mode (DCM), depending on the values of the elements and the work cycle specified by the user.

The research deals with the case of a Continuous Conduction Mode (CCM) where the pulse width applied to the Switch is controlled by transverse pulse modulation (PWM) via a pulse train controlled by the FLC fuzzy logic controller.

The relation determines the voltage on the inductive filter curve:

$$V_L = L \frac{di_L}{dt} \quad (1)$$

At the first stage, the induction current increases from the value $I_1 = i_{Lm}$ to the value $I_2 = I_{1m}$ during the time $t_1 = \alpha T$

$$V_i - V_o = L \frac{I_2 - I_1}{t_1} = L \frac{\Delta I}{t_1}$$

$$t_1 = \alpha T = L \frac{\Delta I}{V_i - V_o}$$

In the second stage: the current of the inductor decreases from the value $I_2 = I_{1m}$ to the value $I_1 = i_{Lm}$ during time ($t_2 = T - \alpha T$)

$$t_2 = T(1 - \alpha) = L \frac{\Delta I}{V_o}$$

From the two previous equations, we deduce the following:

- The average value of the output voltage:

$$V_o = \alpha V_i \quad (2)$$

- The ripple-current relationship:

$$\Delta I_L = \frac{V_i - V_o}{L} \alpha T = \frac{\alpha(1-\alpha)V_i}{LF} \quad (3)$$

- Output voltage ripple relationship:

$$\Delta V_o = \frac{\alpha(1-\alpha)V_i}{8LCF^2} \quad (4)$$

- The average value of the output current:

$$I_o = \frac{1}{\alpha} I_i \quad (5)$$

- Reverse stresses on the diode V_{dM} , I_{Dmax} and the transistor V_{TM} , I_{Tmax} :

Interpreter

$V_{tmax} = V_i$	$V_{dmax} = V_i$	
$I_{Tmax} = I_i + \frac{\alpha(1-\alpha)V_i}{2LF}$	$I_{Dmax} = I_i + \frac{\alpha(1-\alpha)V_i}{2LF}$	(6)

In order to select the values of the limit elements of the commutator and as a continuous-mode commutator design CCM:

The smallest value of the coil and capacitor is given based on the limit values of the current deviation on the coil shown in relation (3) and the voltage deviation on the capacitor shown in relation (4) [13]:

- The value of the opposition file L:

$$L \geq \frac{\alpha(1-\alpha)V_i}{\Delta I \times F} \quad (7)$$

- Input capacitor: (usually used for filtering input voltage) C_1 :

$$C \geq \frac{\Delta I}{8 \times \Delta V_i \times F} \quad (8)$$

4.1.2. Fuzzy Logic Controller:

Fuzzy logic control generally consists of four stages as shown in Fig. 5: (Fuzzification - fuzzy inference system-knowledge base – Defuzzification)

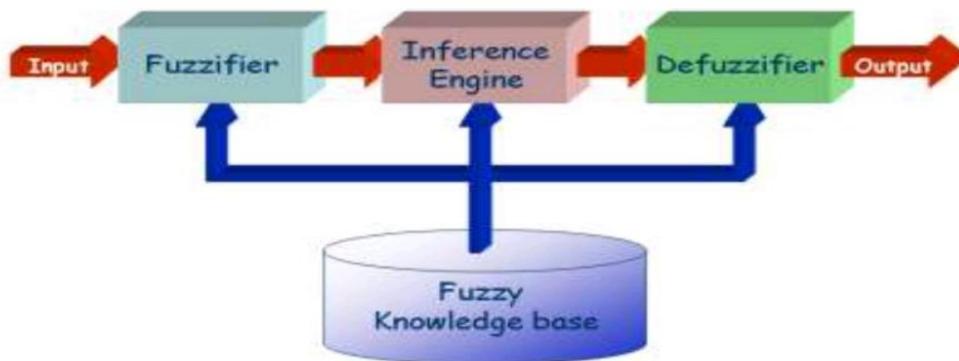


Figure 5. General structure of fuzzy system

- **The coding phase (Fuzzification):** in which numerical input variables are converted into language variables based on the membership function stored in the fuzzy knowledge base, which is the basis of inference for fuzzy control.
- **Fuzzy Knowledge Base:** in which expert knowledge is stored related to each other on the basis of Affiliate Membership (MF) within:
 1. **Database:** represents a number of rules of conditions (probabilities) in an ambiguous rule, and the rules may use several variants of input or output rules. For example, seven fuzzy levels can be used.
 2. **Rule base:** represents the rules for associating the values of output variables with input variables, which depend on the work cycle of the commutator and on the knowledge of the designer.
- **Stage (Fuzzy Inference System):** called fuzzy inference system: there are two main types of fuzzy inference systems: (Mamdani FIS) and (Sugeno FIS).
- **Decoding stage (Defuzzification):** in which the output of the fuzzy logic controller switches from the language variable to the numerical one that uses the membership dependent. This variable provides the value necessary to set the pulse width value that drives the key T_1 [4, 5, 10].

Note: In this search, there will be two inputs (Error, Chang of Error) and one output is the duty cycle change (α). The Mamdani model will be used as a fuzzy inference system; the input and output have seven organic functions.

Centroid will be used to decode the (Rule base) will be as follows:

IF error is zero AND change of error is zero THEN change of duty cycle is zero

4.1.3. Genetic Algorithms:

Figure (6) shows a systematic scheme of the structure of the work of genetic algorithms, which adopts the biological principle (survival of the fittest) and therefore proposes some solutions to the problem randomly and initially during the first stage, which is called the initial population Generation, the problem of the so-called chromosomes, and then evaluates these solutions through the fitness function developed by the designer, and accordingly the most the least important.

The next step is to pair the solutions chosen as the most efficient solutions (Crossover) to produce new solutions as happens in living organisms by mixing their genes so that the new organism carries traits that are a combination of the Traits of its parents.

If the efficiency of the new solution is proven, it remains otherwise it is neglected, and at the next stage genetic mutations (Mutation) are induced to create new offspring, and so mating and selection processes take place until the process reaches either a certain number of repetitions (determined by the user of the system) or the resulting solutions or one of them reaches an efficiency ratio or a small error ratio (also determined by the user) or even the best solution [8, 11].

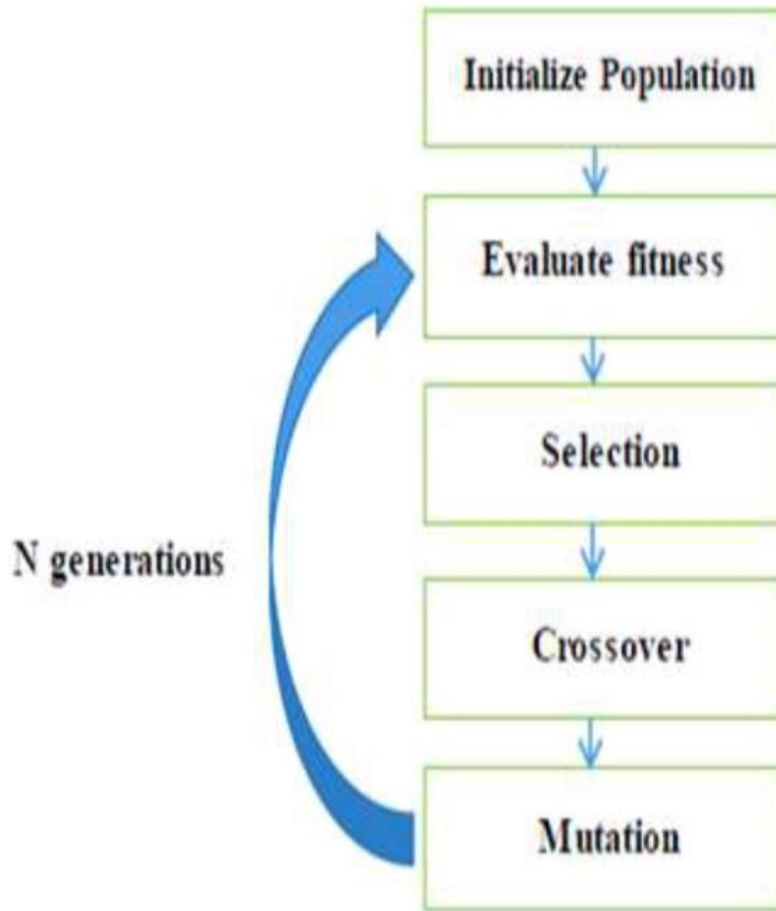


Figure 6. General structure of Genetic Algorithms

4.2. Fuzzy genetic controllers:

The research proposes to develop the operation of the fuzzy system (FLC) using genetic algorithms (GA) to obtain results that are more accurate by improving the components of the cognitive fuzzy base, organic dependent determinants, or both.

The genetic adjustment of the fuzzy rule is usually done by adjusting the system profit constant (GA), which is applied to the input and output (FLC), where the genetic individual refers to the constant (G) and using the efficiency dependent, the best individual can be calculated that gives the best value of this constant, but in the case of the membership dependent, the coefficients of the membership dependent are adjusted in this way, the membership of the input and output fuzzy and the system profit constant do not change, but the sequence of rules (IF-THEN) is adjusted to give the best result. In a way an individual is represented for one rule or for all rules and (RB) is represented by a relational Matrix, a decision table or a list of rules [12].

4.2.1. Modeling of components of a voltage-reducing commutator control system:

Based on the relationships (7,8) and on the limit values of the current and voltage deviation shown in the relationships (3,4), the elements of the commutator and circuit modeling were selected within the MATLAB/Simulink environment as shown in Figure (7), the circuit modeling of the transverse pulse controller (PWM) shown in Figure (8) and the control system designed in two stages was tested[13]:

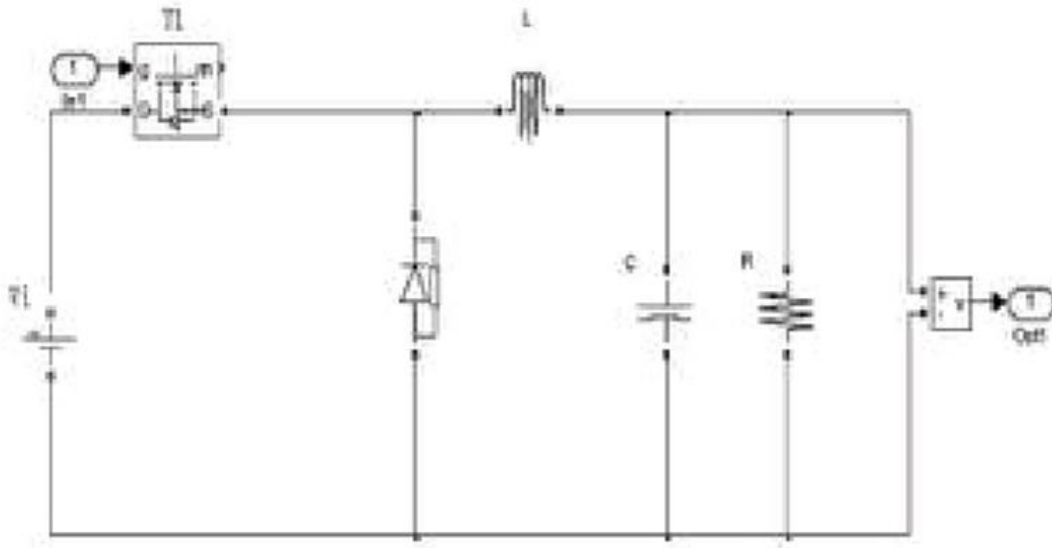


Figure 7. Buck Converter

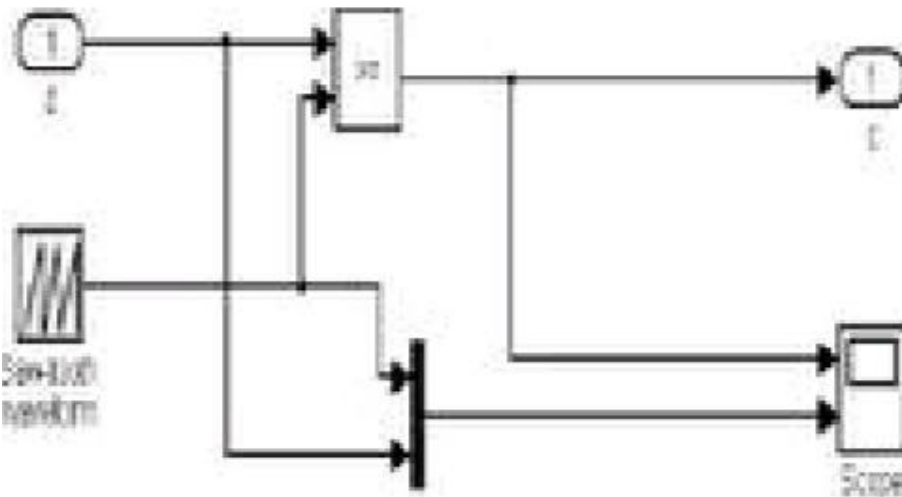


Figure 8. Transverse pulse controller circuit (PWM)

The first stage: a logic controller (FLC) is LED based on the error value of the voltage and the error change:

A fuzzy controller is designed with **two inputs**: the error signal (E) and the error signal change the relations (9) and (10) calculate (ΔE) and their value:

$$E = V_O - V_{REF} \tag{9}$$

$$\Delta E = E_{(n)} - E_{(n-1)} \tag{10}$$

Where: V_O is the output voltage of the fuzzy logic controller V_{REF} the reference signal of the input voltage.

$\Delta E(n)$ The error has changed.

n: the value taken at the beginning of the operating cycle n^{th}

While the **output** of the fuzzy controller is the change of the operating cycle of the commutator switch $\Delta\alpha$, which is given by the relation (11)

$$d\alpha = d_{\alpha-1} + h\Delta d_{\alpha} \tag{11}$$

Each of the control values was divided into seven fuzzy subgroups (organic dependent): NB (large negative)-NIM (medium negative)-NS (small negative) -ZE (zero) – PS (small positive)-PM (medium positive) and PB (large positive). Figure (9) shows the organic relationship of the inputs and outputs of the fuzzy logic controller [14].

The fuzzy base of the controller (FLC) is also scheduled in 49 base as shown in Figure (10).

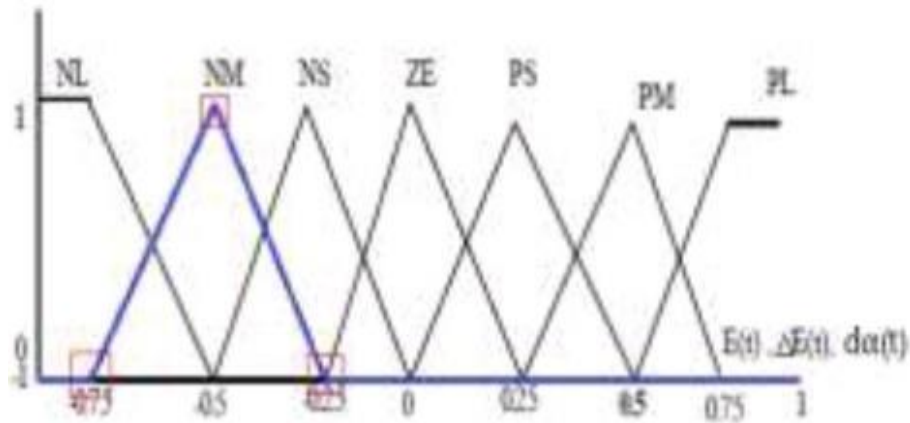


Figure 9. Organic relationship of inputs and outputs of the fuzzy logic controller.

		ERROE						
		NL	NM	NS	ZE	PS	PM	PL
CHANGE ERROR	NL	NL	NL	NL	NL	NM	NS	ZE
	NM	NL	NL	NL	NM	NS	ZE	PS
	NS	NL	NL	NM	NS	ZE	PS	PM
	ZE	NL	NM	NS	ZE	PS	PM	PL
	PS	NM	NS	ZE	PS	PM	PL	PL
	PM	NS	ZE	PS	PM	PL	PL	PL
	PL	ZE	PS	PM	PL	PL	PL	PL

Figure 10. The fuzzy basic rule.

Figure (11) shows the modeling of the Circuit of the Buck converter driven using the fuzzy logic controller (FLC). **Note:** (in order to simplify the final circuit, the switch circuit shown in Figure (7) and the (PWM) circuit shown in Figure (8) above were converted to (Subsystem block).

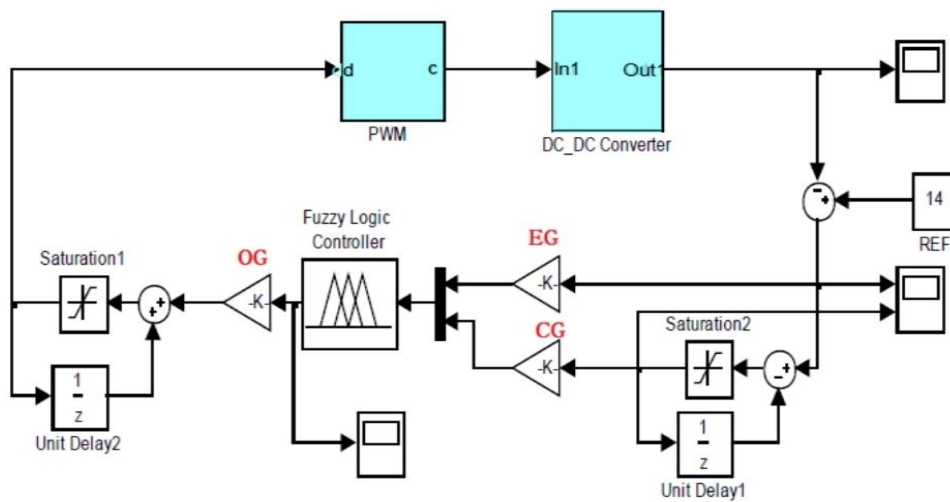


Figure 11. Modeling the circuit of the buck converter driven using the fuzzy logic controller (FLC).

The modeling was tested for different reference voltage values (12v, 13v, 14v, 15v), Table (1) shows the modeling parameters provided by the controller (FLC): (maximum bypass, Rise Time, stability time).

Table 1: modeling parameters provided by the controller (FLC)

V_i	V_{ref}	maximum overshoot	height (ms)	time	stability time (ms)
24	12	0.225%	0.027		0.037
24	13	0.235%	0.029		0.038
24	14	0.88%	0.032		0.040
24	15	0.88%	0.033		0.045

- The second stage: design and modeling of the Gini-fuzzy controller (GA-FLC) to control the commutator (Buck):

There are many parameters that affect the control process in the buck model, in addition to The Shape of the inputs and outputs of the fog controller, such as the error gain constant (EG), the change in the error gain constant (CG) and the output constant of the fuzzy controller (OG). These parameters can be adjusted to give almost perfect results. (GA) was used to improve these parameters and improve the form of membership of the fuzzy controller, by improving the accuracy of profit constants and changing the form of membership, where M-File code was designed within the MATLAB environment divided into two parts: a main section dedicated to the selection of intersection points, mutations and the formation of a new group, and a section responsible for the selection of new populations by calculating efficiency and selecting the best value efficiency [15,16] according to the sequence of steps shown in Figure (12):

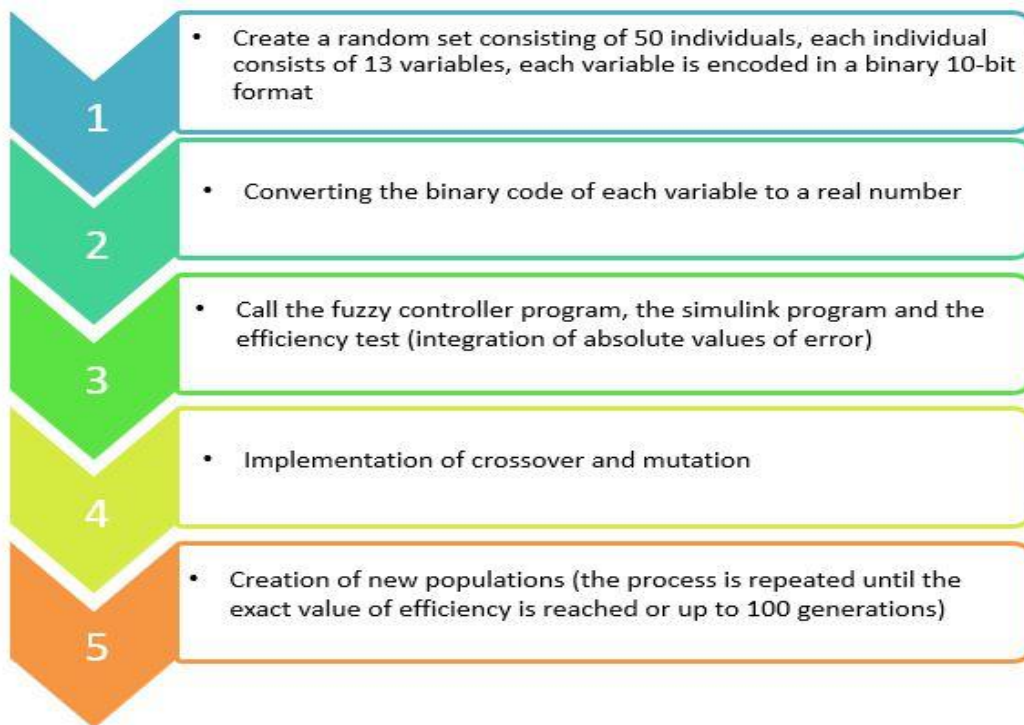


Figure 12. Steps for designing a genetic algorithm (GA)

Note: some rules were adopted to simplify writing GA code, as the time interval of inputs and outputs remained in the range [1-1] and the symmetric point is at zero, and the inputs and outputs have the same form after maintaining these parameters, the number of variables became 7 for membership functions and 3 for profit constants, the number of individuals 50, the number of generations 100 and the probability of intersection 0.7.

Comparison of results by output curves: for reference output voltage (14V):

Figure (13) shows the response curve of the output voltage of the Switch (Buck) controlled using the controller (FLC). As shown in Figure (13), the response curve of the output voltage of the alternator (Buck) using the GA-fogging controller (GA-FLC). In addition, Figure (14) the output voltage of the alternator (Buck) controlled using the microcontroller (FLC) Figure (15) oscillation of the output voltage of the alternator (Buck) using the GA-fog controller (GA-FLC).

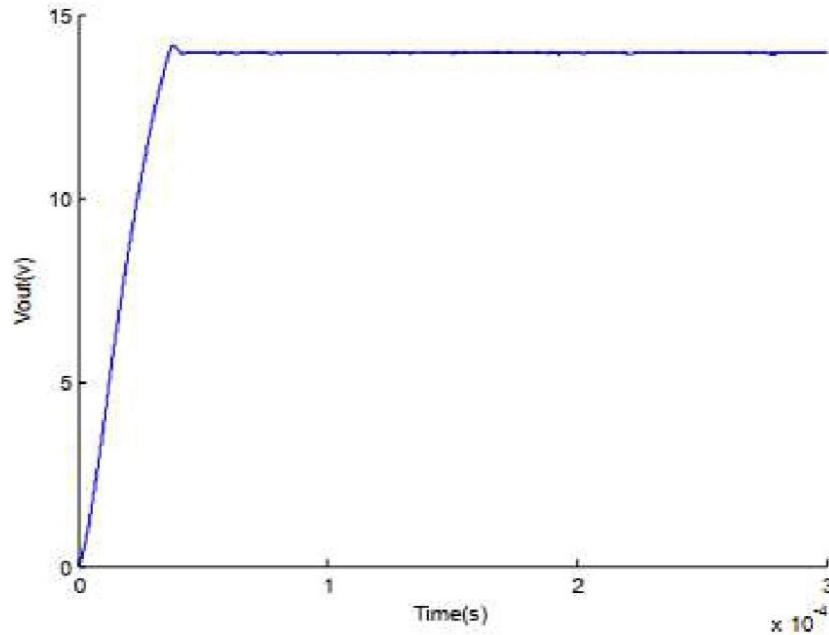


Figure 13. The output voltage response of the alternator (Buck) controlled using the microcontroller (FLC).

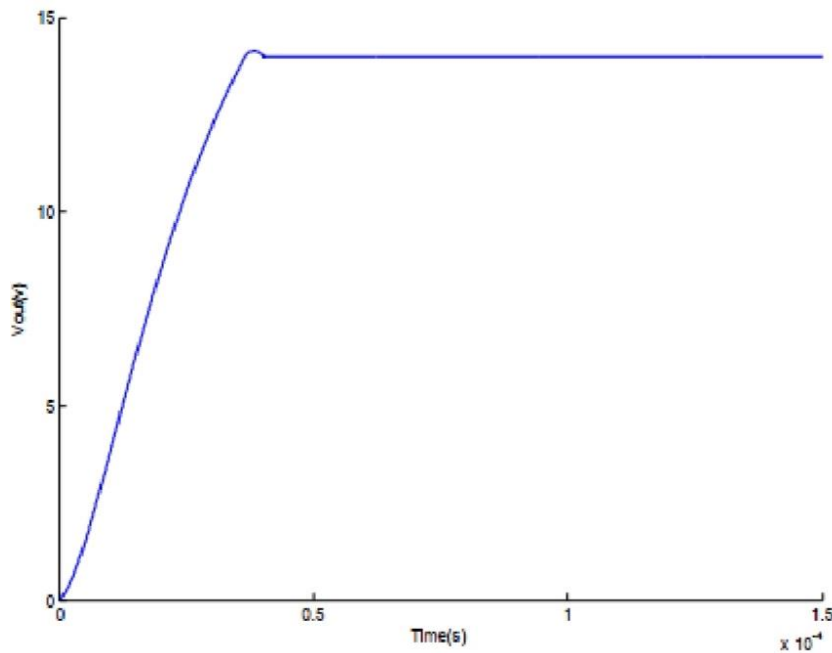


Figure 14. The output voltage response of the alternator (Buck) controlled using the microcontroller (GA-FLC)

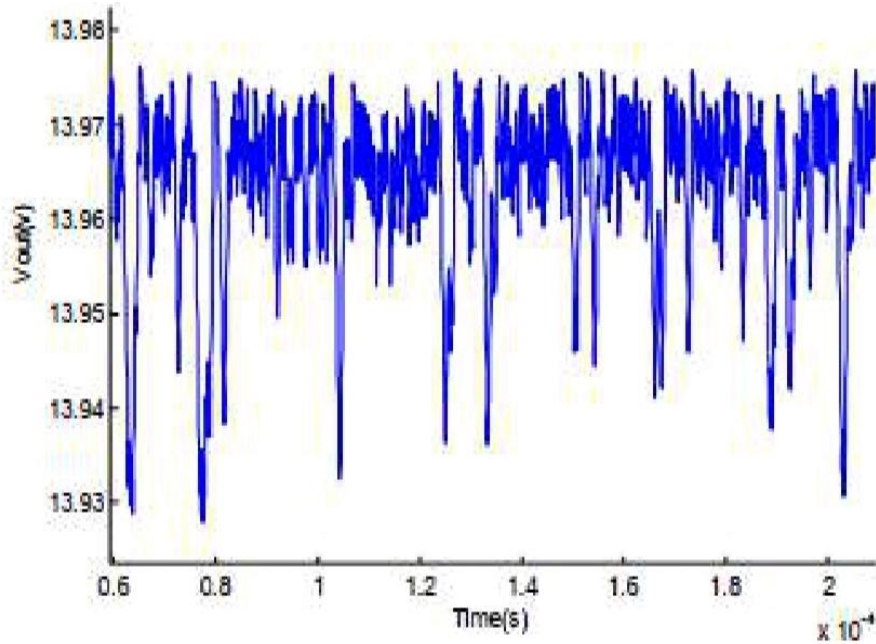


Figure 15. Alternator output voltage ripple (Buck) controlled using the microcontroller (FLC).

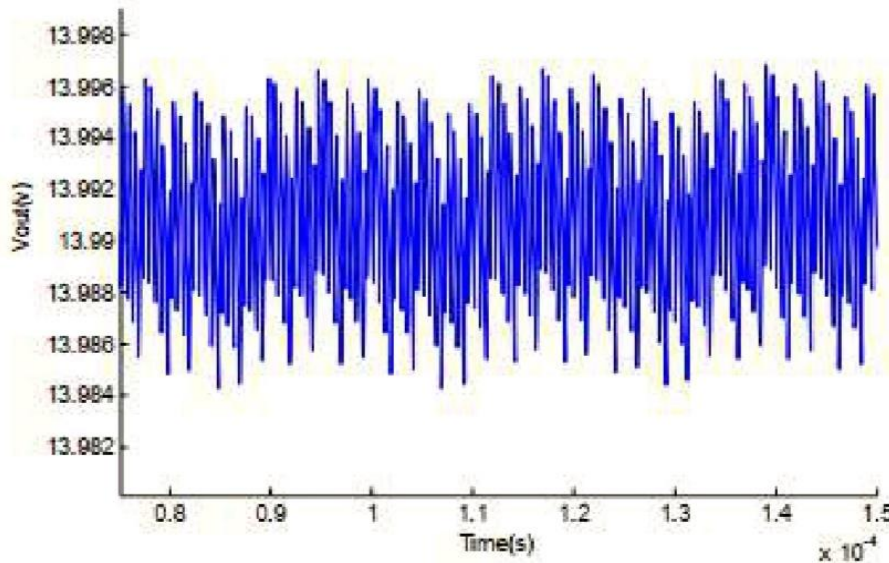


Figure 16. Ripple of the output voltage of the alternator (Buck) using the microcontroller (GA-FLC).

Table (2) shows a comparison of the modeling parameters provided by the fuzzy logic controller (FLC) and the fuzzy-genetic controller (GA-FLC).

Table 2: comparison of the modeling parameters provided by the fuzzy logic controller (FLC) and the fuzzy-genetic controller (GA-FLC)

	FLC	GA-FLC
Maximum yield	0.88%	0.1%
Stability time	0.040	0.039
Rise Time	0.033	0.032
Ripple voltage	53mv	10mv
Error	1.6%	0.4%

5. Conclusion

- Search results:

The genetic blur controller was designed using the MATLAB program to control the voltage-reducing switch (Buck), after analyzing the work of the switch, the blur controller and the genetic algorithm, and the modeling results showed the following:

Based on curves (12 and 14) and Table (1), we conclude that the voltage-reducing commutator (Buck) provided a satisfactory response when using the fuzzy logic controller (FLC) in terms of stable output voltage and proximity to the reference voltage, the maximum bypass of the output voltage, the rise time and the stabilization time. This proves that Fuzzy Logic Control is considered one of the most effective artificial intelligence technologies and it offers an alternative solution to classical control methods in terms of response speed and low complexity.

Genetic algorithms (GA) were used to improve the work of the controller (FLC) by optimizing the organic follower of the input and output of the fog controller and the profit constants. The modeling results in Table (2) showed the superiority of the genetic fog controller (GA-FLC) over the fog controller (FLC) in terms of reducing the stability and Rise Time and reducing the value of the maximum bypass, Ripple and error value of the output voltage, which is shown when comparing the output curves(13,15) with the output curves (12,14).

Thus, we conclude that the use of the genetic algorithm has raised the efficiency of the fuzzy logic controller and thus radically raised the efficiency of the system, which is the main goal and the essence of the research.

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