Design And Development of a Feeding Unit for Medical Devices Implanted Inside Human Body Using Artificial Intelligence Theories

Abdulkarim Almuhammad*, Mohanad Alrasheed*

*Computer Engineering Dept., Faculty of Informatic, Ittihad Private University, Aleppo, Syria.

Abstract: In this research paper, we present the design and development of a power unit for medical devices that are implanted inside the human body. It uses a micro-electromagnetic generator to generate electrical energy by taking advantage of natural vibrations to generate electrical energy in order to supply these applications that need electrical supply for a long period without human intervention. We used a direct lever rectifier switch. Direct AC-DC Step Up Converter for low voltage amplitude to reach a value suitable for the application in the open loop. The voltage in the closed loop was then regulated using a fuzzy controller based on digital signal processing chips, which allowed improving the performance of the converter. To calculate the fuzzy controller, we used the Fuzzy Logic tool of MATLAB.
Interconnection circuits were proposed to adapt low-level signals to control circuits and power switches. We performed a simulation of the entire system, represented by the control circuit based on digital signal processing chips, the fuzzy control algorithm, and the switcher using the Proteus program in the open and closed loop, and then we compared and discussed the results.

Keywords: Micro-electromagnetic, Direct AC-DC Step Up Converter, dsPIC, Biomedical Implants, micro-generator, Artificial Intelligence Theories.

تصميم وتطوير وحدة تغذيه للأجهزة الطبية المزروعة داخل جسم الانسان باستخدام نظريات الذكاء الصناعي

الملخص: نقدم في هذه الورقة البحثية تصميماً وتطويراً لوحدة تغذية للأجهزة الطبية التي تزرع داخل جسم الانسان تستخدم المولد الكهرومغناطيسي الميكروي لتوليد الطاقة الكهربائية بالاستفادة من الاهتزازات الطبيعية لتوليد الطاقة الكهربائية بغية تغذية هذه التطبيقات التي تحتاج للتغذية الكهربائية لفتره طويله وبدون التدخل البشري، وقمنا باستخدام مبدلة مقوّمة رافعة المباشرة Direct AC-DC Step Up Converter للجهد المنخفض المطال للوصول إلى قيمة مناسبة للتطبيق في الحلقة المفتوحة، تم بعد ذلك تنظيم الجهد في الحلقة المغلقة باستخدام المتحكم الضبابي اعتماداً على شرائح معالجة الإشارة الرقمية مما سمح بتحسين أداء المبدّلة.

استخدمنا من أجل حساب المتحكم الضبابي أداة المنطق الضبابي لبرنامج MATLAB.

تم اقتراح دارات ربط لملائمة الإشارات ذات المستوى المنخفض مع دارات التحكم والمبدلة الاستطاعّية أجرينا عملية محاكاة للنظام كاملاً ممثلاً بدارة التحكم المعتمدة على شرائح معالجة الإشارة الرقمية وخوارزمية التحكم الضبابي والمبدلة باستخدام برنامج Proteus في الحلقة المفتوحة والمغلقة ومن ثم قمنا بمقارنة النتائج ومناقشتها.

1. Introduction

The idea has recently emerged of using internal resources such as vibration, pressure and heat available in places where medical equipment is installed to obtain the electrical energy needed to operate them.

The Micro Electromagnetic Generator is one of the proposed solutions for generating electrical energy, as the vibration resulting from movement is converted into low electrical energy of the order of tens of millivolts, which can be used to charge a small battery [1].

One of the problems with these microgenerators is that they produce an alternating voltage with low amplitude and insufficient to operate electronic circuits on the one hand, and cannot be rectified using traditional rectifier circuits on the other hand. Therefore, it is necessary to use circuits that can raise and rectify the voltage with high efficiency, allowing to overcome problems arising from a weak voltage signal. Among the proposed circuits that perform this purpose, Direct AC-DC Step Up Converters stand out strongly[2].

In the research [4], a design was made for a micro electromagnetic generator to generate electrical energy, but the generated voltage was weak, of the order of millivolts, insufficient to benefit from it. To solve this problem, the researchers proposed in the research [1] the use of a closed-loop lever switch in order to obtain a voltage from Voltage arrangement, considering the input voltage as constant. Then the researchers in the research [2] simulated this system using MATLAB. Many researchers have presented different designs for the voltage raising system. The most prominent of these researches is the research [11] that designed a design to improve the efficiency using classical control methods, and the researcher [12] improved the design of the Micro Electromagnetic Generator, but the main problem in the previous proposals was the poor efficiency and low voltage. Unregulated variable output due to variations in the micro generator output.

2. The importance of the research and its objectives

The importance of the research lies in finding a practical design for a power unit for medical devices that are implanted inside the human body. The digital signal processor (DSP) is used to control the Direct AC-DC Step Up Converter in terms of regulating the output voltage of the switch within the closed loop, and proposing a simplified working method for generating control pulses. With electronic breakers in the switch using PWM (Pulse Width Modulation) technology.

In this research, we also took advantage of the DSP digital signal processor to implement an advanced real-time control algorithm based on Fuzzy Logic, where we were able to increase the output and response speed of the AC-DC Step Up Converter, which made it possible to make the most of the energy generated by the microgenerator.

In this research, a simulation model of the Fuzzy Controller was also built using Matlab, so that this model will be the nucleus for practical applications in future research.

3. Search method

This research was based in its stages on the following topics:

1. Study the working principle and components of the microelectromagnetic generator.
2. Study and analyze the operation of the AC-DC Step Up Converter Direct
3. Design and simulation of the Fuzzy Controller.
4. Design a circuit to generate control pulses for the open-loop switch.
5. Design the switch control circuit using a closed-loop DSP controller.
6. Results and discussion.
7. Practical recommendations and proposals.

4. Working principle of the microelectromagnetic generator

The Micro-electromagnetic generator (Figure 1) consists of a permanent magnet, a damping element, a spring, and a primary coil, where the permanent magnet is fixed at one end by the spring to the generator body and free to move at the other end within the primary coil [1].

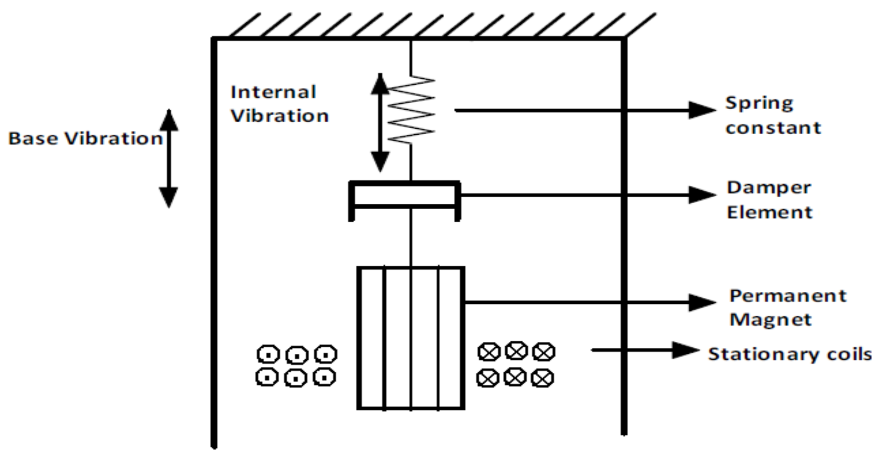

Figure (1): Micro-electromagnetic generator

When the generator is exposed to vibration, the permanent magnet within the coil vibrates, which, according to Faraday's law, generates an alternating voltage between the two ends of the coil. Its value depends on the number of turns of the coil, the magnetism of the permanent magnet, and the intensity of the vibration. The generated voltage is usually sinusoidal and has a low amplitude of the order of tens of millivolts and cannot be used directly to supply electrical equipment.

5. Study and analyze the work of the AC-DC Step Up Direct Converter

This converter, one of whose structures we show in Figure (2), performs the processes of raising and rectifying the low alternating voltage at the same time. The converter consists of a boost converter containing the elements (L1, T1, D1) in parallel with a buck-boost converter containing the elements (L2, T2, D2). Capacitor C acts as a filter to smooth the output voltage [3].

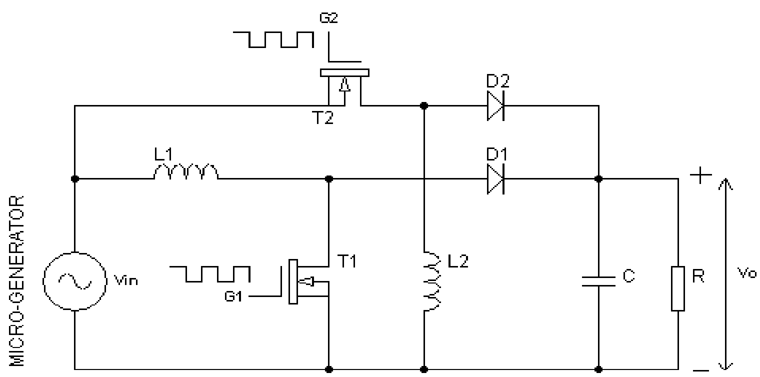

Figure (2): AC-DC Step Up Direct Converter

Transistors T1 and T2 are used as electronic circuit breakers whose passing and cutting are controlled using PWM pulse width modulation technology, where T1 works in the positive part of the input voltage and T2 in the negative part of the input voltage [4]. The voltage generated by the micro-electric generator is expressed in terms of Vin. The work of the switch can be divided into four stages [8]:

- The first phase (Figure 3-A): Transistor T1 is switched through the positive part of the input voltage Vin, which leads to charging the coil L1.
- Second phase (Figure 3-B): The control voltage of transistor T1 is canceled through the positive part of the input voltage Vin, which leads to the current stored in coil L1 being discharged into the load by D1.
- The third phase (Figure 3-C): The transistor T2 is switched through the negative part of the input voltage Vin, which leads to the coil L2 being charged with current by T2.
- Fourth phase (Figure 3-D): The control voltage of the transistor T2 is canceled through the negative portion of the input voltage Vin which results in the current stored in coil L2 being discharged into the load by D2.

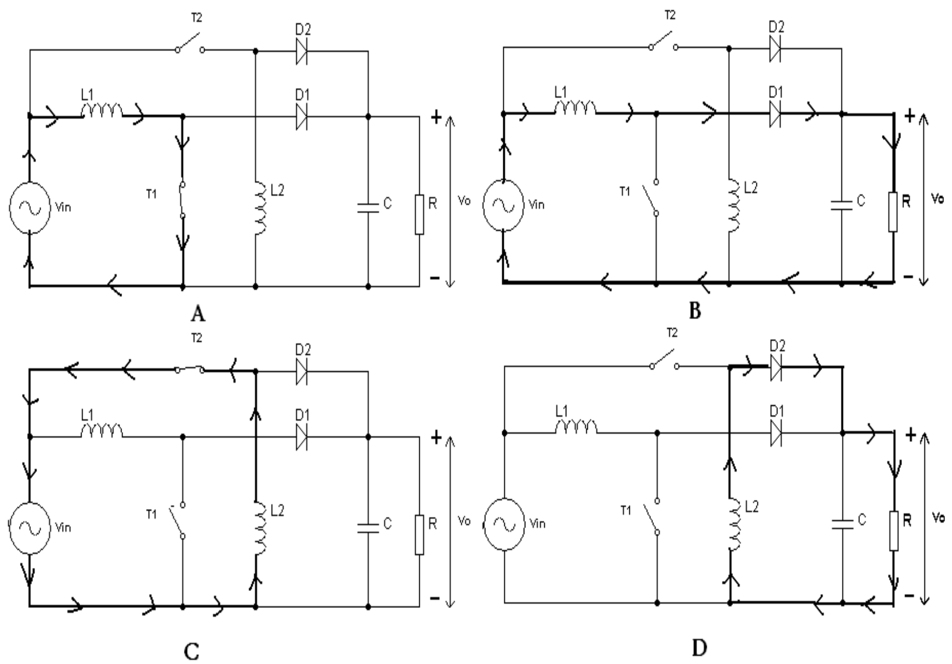

Figure (3): AC-DC Step Up Converter operating phases

Figure (4) shows the input voltage, the pulses applied to the gates G1 and G2, the currents passing through L1 and L2 for the four phases, and the output voltage.

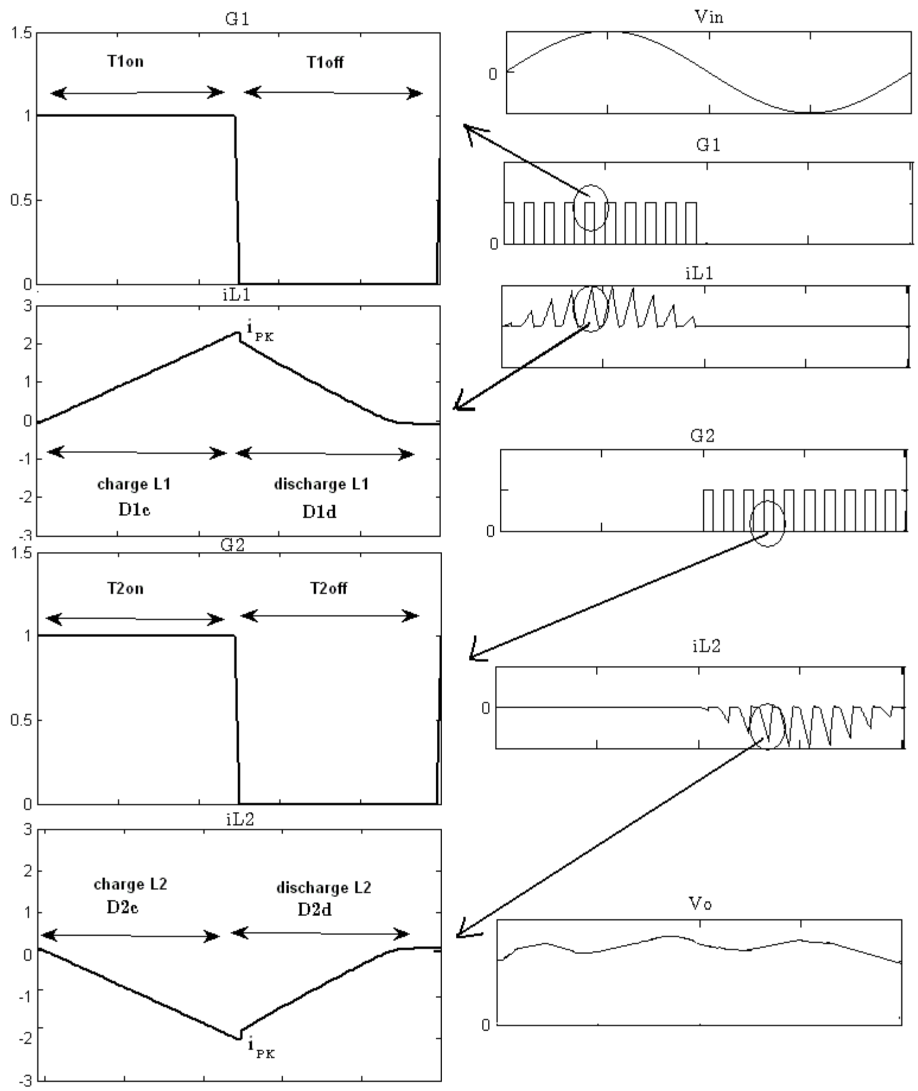

Figure (4): The pulses applied to the gates G1 and G2 and the currents passing through L1 and L2 in the lever rectifier switch

6. Design and simulation of the Fuzzy Controller:

Intelligent control algorithms are sometimes resorted to when the model of the system to be controlled is difficult to deduce mathematically or is simply unknown. Fuzzy control is one of the high-performance methods used in these cases, as it is used to avoid mathematical complexity in designing the control system [5].

Since our system to be controlled, which is the lever rectifier switch, contains several modes of operation, which complicates the mathematical model and thus the design of the controller, in this research a fuzzy controller was used to control this system according to the box diagram shown in Figure (5).

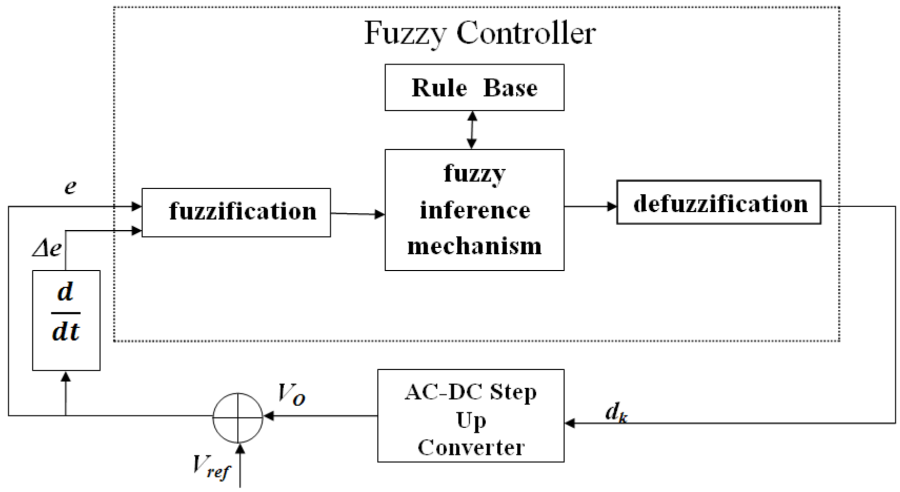

Figure (5): Block diagram for controlling AC-DC Step Up Converter using a fuzzy controller

The control system based on fuzzy logic is divided into several parts:

Fuzzification - rule base - fuzzy inference mechanism - defuzzification.

The fuzzy controller has two inputs, one for the error e and for the error change Δe, which are defined as follows [2]:

$$e = v_o - v_{ref} \quad (1)$$

$$\Delta e = e_k - e_{k-1} \quad (2)$$

Where V_o [volt], V_{ref} [volt] are respectively the switch output voltage and the reference voltage to be reached, taking into account the cut-off frequency of 10KHz.

The fuzzy controller output is expressed as the change Δdk in the duty cycle at sample k, and thus the duty cycle relationship for the PWM control signal at sample k is given by the following relationship [2]:

$$d_k = d_{k-1} + n.\Delta d_k \quad (3)$$

Where n is a calibratorable quantity called the gain of the fuzzy controller.

The fuzzification process determines the degree to which the error values e and the error change values Δe belong to the fuzzy membership functions shown in Table (1):

Table (1): Table of fuzzy affiliation functions for the fuzzy controller

PB	PS	ZE	NS	NB
Positive Big	Positive Small	Zero	Negative Small	Negative Big

Figure (6) shows the functions used in the fuzzification process for e and Δe.

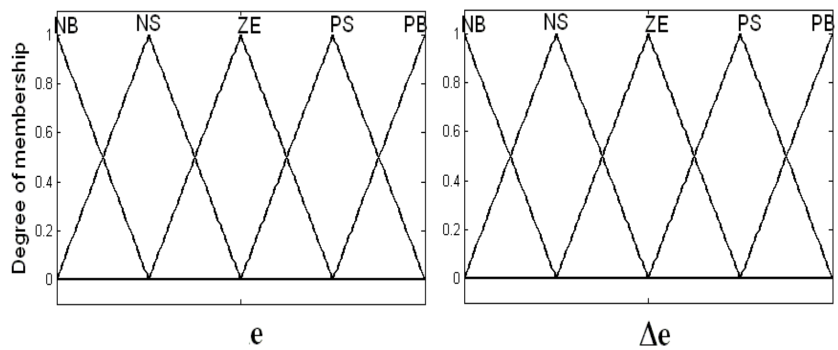

Figure 6: membership functions for e and Δe

The rules of fuzzy control are derived from human experience and expertise [9], and the design of the fuzzy controller was based on the following criteria:

1- When there is a large difference between the converter output value and the required output value, the duty cycle change Δdk of the PWM must be large in order to quickly reach the required value.
2- When the converter output value approaches the required value, the duty cycle change Δdk of the PWM should be small.
3- When the converter output value is close to the required value and is approaching quickly, the duty cycle must not change in order to prevent exceeding the required value.
4- When the required output value is reached and the output is still changing, the duty cycle must be changed slightly to prevent deviation from the required value.
5- When the required output value is reached and the output is constant, the duty cycle remains unchanged.
6- When the converter output value is greater than the required value, the duty cycle change Δdk for the PWM must be negative, and vice versa.

Based on the previous criteria, the following table of conditional rules was derived:

Table (2): Table of conditional rules for the fuzzy controller

Δe \ e	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NB	ZE
NS	NB	NS	NS	ZE	NS
ZE	NB	NS	ZE	PS	PB
PS	NB	EZ	PS	PS	PB
PB	NB	NS	ZE	PS	PB

The table of conditional rules is expressed using Fuzzy If-Then. Considering that C is the fuzzy output of a single conditional rule, we get the following relationships:

Rule1: If e is NB and Δe is NB then C1 is NB.

Rule2: If e is NS and Δe is NB then C2 is NB.

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Rule25: If e is PB and Δe is PB then C25 is PB.

We note that the conditional link And is used in the previous conditional rules only, where the min method was used and the Sugeno inference engine methodology was used to express the previous condition according to the following [7]:

$$Z_i = \min\{\mu(e_i), \mu(\Delta e_i)\} \quad (4)$$

Where

$\mu(e_i)$ The degree of membership ei to fuzzy membership functions.

$\mu(\Delta e_i)$ Degree of membership Δei to fuzzy membership functions.

Z_i The result of the conditional rule And.

Using the weighted average method, which depends on the average of the sum of the output values of the conditional rules in the defuzzification process, we obtain the fuzzy controller output relationship as follows [7]:

$$WA = \Delta d_k = \frac{\sum_{i=1}^{25} z_i c_i}{\sum_{i=1}^{25} z_i} \quad (5)$$

The fuzzy controller was designed and simulated using MATLAB's Fuzzy ToolBox[6]. We show in Figure 7 the membership functions used in this research paper, which are of the triangle type, where we determined the input values of the fuzzy controller within the domain [-3.5V , +3.5V] Considering that we preset the switch output voltage to 3.5V.

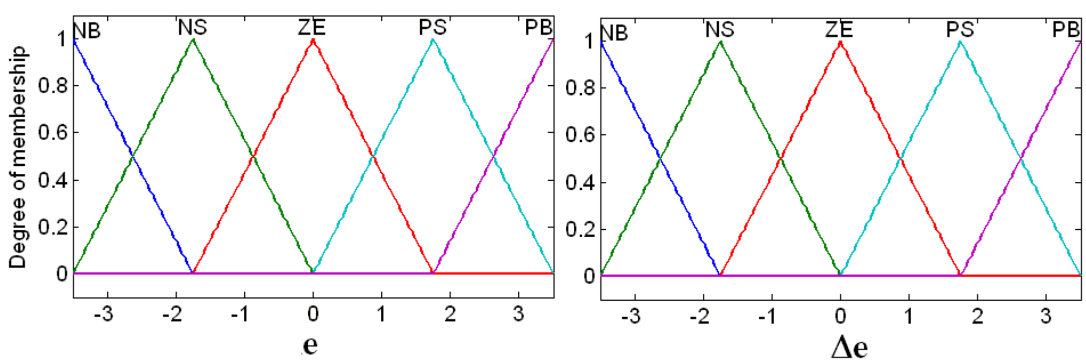

Figure (7): Triangle membership functions within the domain [-3.5V, +3.5V]

Considering that the output membership function takes fixed values for C according to Table (3)

Table (3): Values of the output membership function

NB	NS	ZE	PS	PB
0%	25%	50%	75%	100%

Using the conditional rules table (2) to construct the Fuzzy If-Then conditional rules, then the relationship of the fuzzy controller's output with respect to its two inputs, the error e and the error change Δe, is according to Figure (8), which represents the simulation [10].

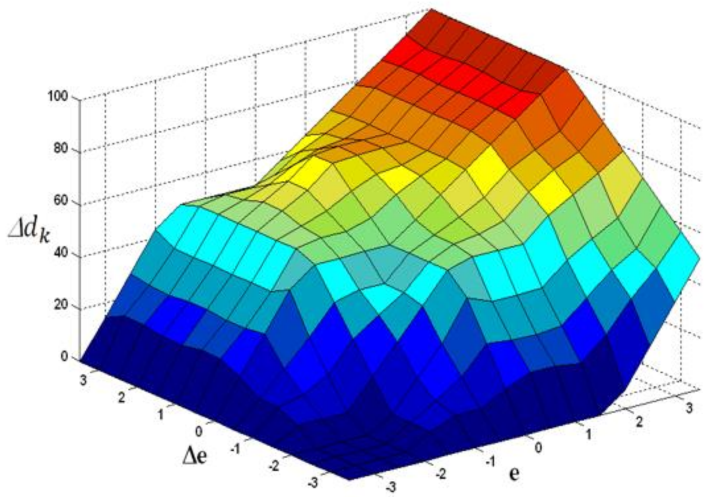

Figure (8): The relationship of the fuzzy controller output with respect to its input error e and the error change Δe

7. Design of a circuit for generating switch control pulses in an open circuit

In this research, an appropriate circuit was proposed that passes control pulses to the switch, as shown in Figure (9). This circuit consists of two comparators (OP1, OP2) to determine the positive and negative part of the alternating input voltage generated by the micro-generator and two logic gates (AND1, AND2) that act as pass switches for the PWM signal.

The work of the converter control pulse generation circuit can be divided into two parts:

1- At the positive part of the input voltage, the positive input voltage of the comparator OP1 becomes greater than the negative input voltage, then the output of this comparator becomes Logic 1. Thus, the AND1 gate passes the PWM pulses to the G1 gate, while the output of the comparator OP2 becomes Logic 0, and thus the AND2 gate blocks the signal. PWM for G2 gate.

2- At the negative part of the input voltage, the positive input voltage of the comparator OP2 becomes greater than the negative input voltage. Then the output of this comparator becomes in the Logic 1 state, and thus the AND2 gate passes the PWM pulses to the G2 gate. As for the comparator OP1, its output is in the Logic 0 state, so the AND1 gate blocks PWM signal from gate G1.

In this way, the boost converter works on the positive part of the AC input voltage, while the buck-boost converter works on the negative part of the input voltage.

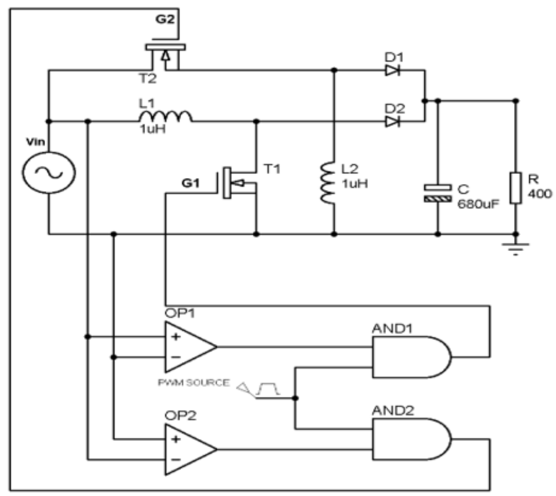

Figure (9): Circuit for generating control pulses and AC-DC Step Up Direct Converter in an open circuit

We simulated the circuit using the Proteus program, which is a simulation program for electronic circuits and microcontrollers that runs in real time. We assumed the values of the elements as shown in Figure (9). We also assumed that the frequency of the PWM signal is 2 kHz with duty cycle = 0.18, and assuming the load current changes within The range of [8.75-93.3] mA, which corresponds to a change in the load resistance [8.75-93.3]Ω At VODC output voltage=3.5V and using the ANALOGUE ANALYSIS tool to analyze the transient and steady state as follows:

Initially, an ohmic load of R = 400 Ω was used. The average value of the steady-state output voltage was VODC = 3.503V, with a peak-to-peak fluctuation of 0.15V. While the circuit was running, we changed the value of the load so that it became R = 375Ω, so the average value of the output voltage in the steady state was VODC = 3.398V, with a peak-to-peak fluctuation of 0.17 V. We notice from the voltage curve shown in Figure 10 that the value of the output voltage in the open loop is affected by the change in the value of the load. We also notice that the time for the output voltage to reach the final state from zero to the final state took about 600ms.

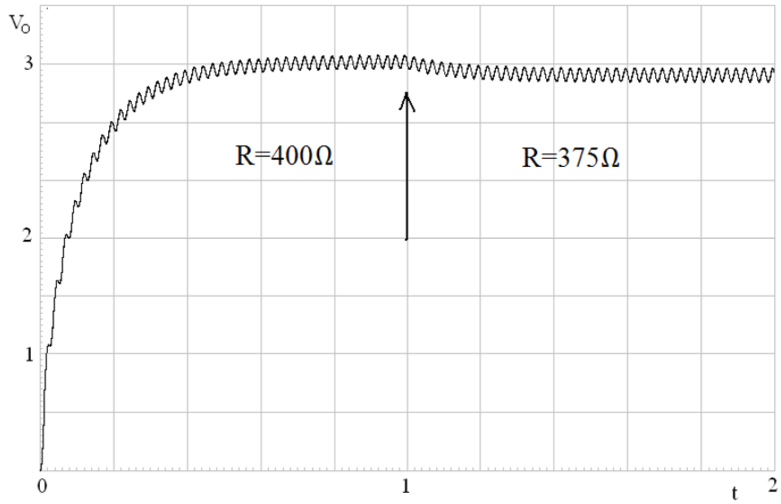

Figure (10): The effect of the open-loop Converter output signal when switching the load value from 400 Ω to 375 Ω

8. Design of the Converter control circuit using a closed-loop DSP controller

We show in Figure (11) the practical implementation of the closed-loop switch circuit. The fuzzy switch control algorithm was applied using the DSPIC33F12C202 chip from MICROCHIP. This chip is distinguished by its DSP core and high processing speed of up to 40 MIPS. It can also operate at a low supply voltage of 2.5V and draws a working current of the order of milliamps, which is suitable for applications that use small electronic equipment, including our application.
From this chip, we used the 10-bit ANO terminal to measure the output voltage of the switch. The PWM1L1 terminal was also used to generate the work pulses applied via the trapping circuit to the transistor gates.

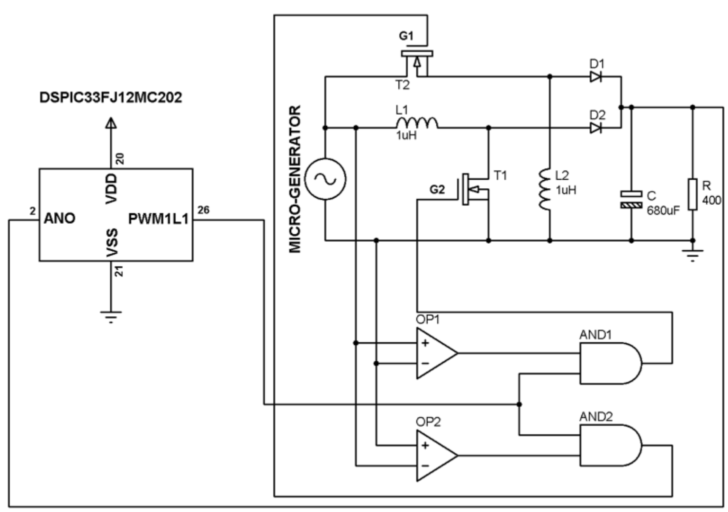

Figure (11): Ring Converter circuit using a DSP controller

The processor was programmed in C language using the mikroC PRO for dsPIC compiler in an optimal way so that the DSP instructions for the control algorithm worked in real time.

At a sampling frequency equal to 0.1 ms, the time required to implement the control algorithm took 0.891 ms. Below we show the program steps during one programming cycle:

1- Measure a sample of the converter's output voltage VO and convert the analog value VO into a digital value.
2- Calculate the error e and the error Δe changes depending on the previous sample.
3- Determine the degree of membership to e and Δe according to the functions of membership (fuzzification) in Figure (8).
4- Apply fuzzy control rules to fuzzy inputs using the Sugeno inference engine according to Table (2).
5- Calculating the change in the duty cycle (Δdk) according to the Weighted average (defuzzification) method.
6- Calculate the new duty cycle Δdk and update the value of the pulse width control register.
7- Return to step 1.

Another advantage of this chip is that it is available within the Proteus libraries, which enabled us to repeat the simulation as we explained in Section 7 using the closed-loop fuzzy control algorithm as follows:

Initially, an ohmic load of R = 400 Ω was used, so the average value of the output voltage in the steady state was VODC = 3.509 V, with a peak-to-peak fluctuation of 0.13 V.

Later we changed the load value to R=375 Ω, so the average value of the continuous output voltage was VODC=3.507V, with a peak-to-peak fluctuation of 0.14V.

We show in Figure (12) the output voltage curve, where it is clear that placing the system within a closed loop and using fuzzy control to regulate the voltage has led to an improvement in the shape of the output voltage compared to the open loop, as this voltage maintained its constant value despite the change in the load value.

On the other hand, we notice an improvement in the time for the output voltage to reach the final state, as it took about 100ms.

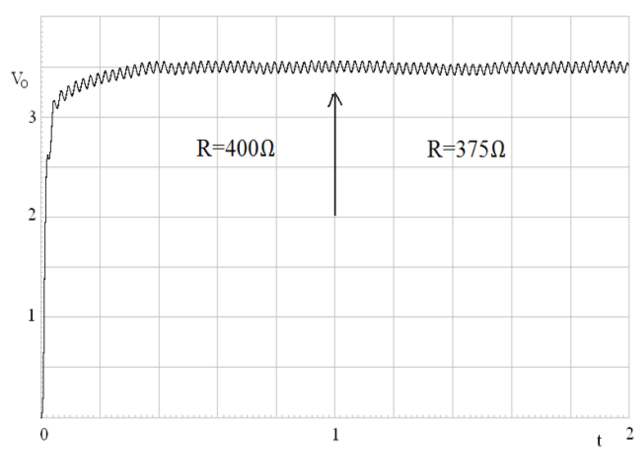

Figure (12): Output signal shape of the closed-loop converter at load R=400Ω and R=375Ω

9. Results and discussion

It is clear to us through this theoretical study and the simulation results presented in this research paper that the use of a digital signal processor (DSP) and a fuzzy control algorithm to regulate the output voltage of a closed-loop AC-DC Step Up Converter Direct is characterized by the following:

• The response time of the switch improved from 600ms in the open loop to 100ms in the proposed method, which leads to an increase in the performance of the feeder system (converter, micro-generator), especially when the micro-generator operates intermittently Compared to search [2] which ranks 1 second.

• The proposed control method provides better regulation of the switch's output voltage, and reduces the fluctuation of the output voltage Compared to the open-loop circuit, the rate reaches 97 percent, compared to research [1], which had a high rate of 76 percent.

• Better stability of the output voltage at the required value when the load changes in the closed loop (the proposed method) compared to the circuit in the open loop .

This research presented an integrated system for a feeding unit with sustainable energy, unlike previous research that provided improvement in certain stages, such as research [1], [2], [3], [4].

10. Practical recommendations and proposals

This design can be used to implement a practical product in medical engineering, and in many other fields such as studying animal behavior and collecting data. It can also be greatly benefited from in industrial fields.

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