Control of a BLDC Motor of an Electric Vehicle Powered by a Photovoltaic System based on Fuzzy Logic MPPT (FLC-MPPT)

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Abstract: - Photovoltaic Systems (PV) represent a viable solution for converting solar energy into electricity without emitting harmful gases. This technology remains highly sought-after in the market, primarily due to its renewable characteristics and the absence of movable components, which renders it a low-maintenance option. This produced energy can be stored in batteries tobe used for example in operating electric vehicles. If the generated voltage is inadequate or requires regulation, a boost converter may be employed or a buck boost To manage energy during storage and discharge to provide the energy needed to run the induction motor. In this paper, we proposed the field-oriented control as an approach for controlling the speed of BLDC Motor drive electrical vehicles to improve the overall effectiveness of the proposed system, The BLDC Motor is powered by battery storage from a photovoltaic system. Furthermore, this work also addresses the specifics of modeling the Fuzzy logic control MPPT (FLC-MPPT) used for the energy management system (PV and batteries), as well as the proposed control approach for the electric vehicle motor, which are subsequently simulated in the MatLab environment.

Key-Words: - FLC-MPPT, Field oriented control (FOC), Electrical vehicle (EV), BLDC Motor, Battery, DC Converter.

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1 Introduction

Currently, energy production is based largely on finite fossil resources: oil, gas, and coal. These sources are becoming increasingly scarce as the world's energy demands continually rise actually. Today, the globe witnesses significant industrial development, which increases our dependence on energy. However, the use of renewable energies (ER) as an alternative to fossil fuels offers numerous advantages environmentally, economically, and socially. By adopting a holistic and proactive approach, we can progress towards a global energy transition to a cleaner, safer, and more prosperous future. The solar cell industry is presently the focus of extensive research aimed at developing panels with optimal price/performance ratios, [1], [2], [3]. Based on the electrical properties of photovoltaic cells and their arrangement, the performance of photovoltaic (PV) systems can be improved by-called Maximum Power Point Tracking (MPPT) methods, [4]. In most PV energy conversion systems, there is a special algorithm called "MPPT", [5]. This technique, as its name suggests, allows you to get the maximum power that the panel is able to provide. The requisite power generally depends on the change in climatic conditions. Consequently, the MPPT approach, designed to regulate the duty cycle of the DC-DC converter, is essential for the best performance of the PV system across various operating, [6], [7], [8]. Although having the same objectives, the different MPPT techniques differ significantly in terms of convergence speed, state oscillations, and cost effectiveness. Among them, Perturb and Observer (P&O) was applied. Incremental Conductivity (INC), and fractional open/short circuit control methods. These methods show high performance in steady-state operation. However, these algorithms have been determined in powerful in the course of adversarial climate situations as a gradual conversion ratio and an inability to achieve a comprehensive MPP with partial shading, resulting in increased fluctuations, [9], [10], [11].

In particular, AC motors and DC motors. There is a variety of DC motors suitable for various applications. However, in industrial settings, two main types of DC motors are typically employed. The initial category generates magnetic flux through the current passing via the field winding in a stationary pole arrangement, while the secondary utilizes permanent magnets to provide the necessary air gap flux, [12]. So, Brushless DC motors (BLDC) have numerous benefits compared to conventional brushed DC motors, such as enhanced efficiency and extended longevity due to the absence of brushes, and reduced electromagnetic interference. Additionally, BLDC motors provide smoother operation and greater reliability, making them ideal for various applications ranging from electric vehicles to industrial automation. Certainly, a BLDC motor is a distinct variant of a DC motor that eschews brushes for commutation, employing an electronic control system instead. Typically synchronous, a BLDC motor features a trapezoidal back EMF waveform and relies on permanent magnets. Current trends indicate the widespread adoption of high-performance BLDC motor technologies across various global industrial sectors, as well as in variable speed drives for electric vehicles, [13], [14].

This system utilizes a photovoltaic (PV) system to power a brushless direct current (BLDC) motor for electric cars. The P&O method is implemented to improve the system's overall efficiency, [15]. This study delineates the characterization and modeling of the proposed global system, outlines the suggested algorithm, and discusses its application in MPPT for control management and energy storage systems to regulate charge levels under dynamic climatic conditions. Furthermore, the required control technique for the BLDC motor is studied. Following the presentation and thorough discussion of the simulation results, we meticulously assessed the performance of the entire system. In the subsequent discussion section, we delve into a comprehensive analysis of the system's overall efficacy, highlighting its strengths and potential areas for improvement. In the concluding remarks, we reflect on the overall efficiency and performance of the proposed system, ensuring it meets the desired operational standards and objectives. Drawing insightful conclusions and offering practical recommendations for further enhancements

2 Description and Modeling

Figure 1 illustrates the schematic representation of the entire system configuration, providing a clear overview of its components and their interconnections, which collectively contribute to the system's functionality and operational framework. This setup, designed specifically for electric vehicles, primarily incorporates a BLDC motor powered by batteries and a solar system where the components are arranged from left to right as follows: PV array, boost converter (BC), battery, voltage source inverter (VSI) and BLDC motor. The PV array generates electrical energy, which is then transferred to the BC.

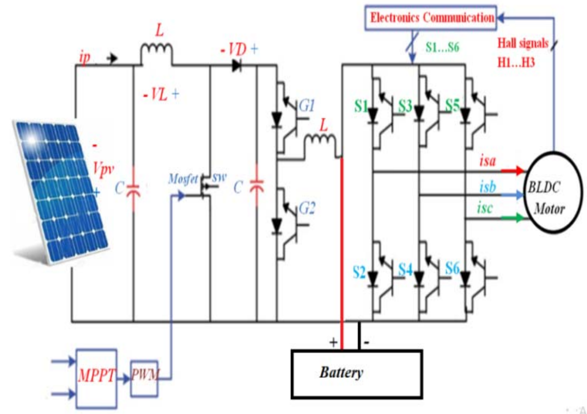

Fig. 1: Proposed and Analyzed Structure Diagram

The operation of the MOSFET switch in the BC operates under the control of a P&O algorithm, which tracks and utilizes the maximum power from the photovoltaic (PV) array through the MPPT algorithm, [16]. Additionally, the BC ensures the electrical power supply of the storage system, connected in series via the PV, to energize the BLDC motor via the VSI. The electronic switch in the BLDC motor generates the sequence of switching pulses for the VSI, [17]. The design and control activities of the suggested system are elaborated in the subsequent sections of the study.

2.1 Design of Solar Photovoltaic PV Array

Regarding the design of the photovoltaic system and the sizing of the photovoltaic panels, the corresponding parameters are evaluated based on the standard irradiation level (E = 1000 W/m²). Thus, the set of photovoltaic panels is determined as follows: the peak power (MPP) is 250.205 W for each panel, the peak voltage (V_{max}) is 30.7 V, while the peak current (I_{max}) is 8.15 A., taking into account that The initial voltage of the solar system at the maximum power point is designated as the DC link voltage of the boost converter, [17].

2.2 Modeling of PV System

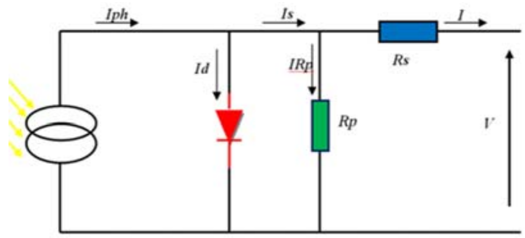

Fig. 2: PV Cell Equivalent Circuit

Figure 2 illustrates the actual circuit diagram of the PV cell.

The generated PV current is:

$$I_{ph} = I_d + I_{Rp} + I \quad (1)$$

$$I = I_{ph} - I_{Rp} - I_d \quad (2)$$

$$I = I_{ph} - I_0 - \left[e^{\left(\frac{V+R_S I}{V_T}\right)} - 1\right] - \frac{V+R_S\, I}{Rp} \quad (3)$$

2.3 Design and Modeling of the Boost Converter

At the MPP, the input voltage to the DC link is sourced from the PV array voltage, while the output voltage is regulated by the BC. The connection between the input and output voltages of the boost converter (BC) can be characterized by a mathematical relationship that describes how the input voltage is transformed into a higher output voltage. This relationship is crucial for understanding the converter's performance, as it indicates how effectively the BC can elevate the voltage level to meet specific load requirements while maintaining efficiency, determined by the duty ratio (D)expressed by the following mathematical relationship, [18]:

$$\frac{V_{dc}}{V_{pv}} = \frac{1}{1-D} \quad (4)$$

$$D = \frac{V_{dc}-V_{pv}}{V_{dc}} \quad (5)$$

Inductor value calculated as follows:

$$L = \frac{D*V_{pv}}{f_{sw}\Delta I_L} \quad (6)$$

Capacitor value calculated as follows:

$$C = \frac{D*V_{pv}}{(f_{sw}\Delta V_O)*D} \quad (7)$$

2.4 Fuzzy MPPT Control

The FLC-MPPT comprises three components: fuzzification, inference system, and defuzzification. The variations in power (ΔP) and voltage (Δv) act as input variables for the fuzzy inference system, while ΔD functions as the output. The relationship between these variables is delineated according to fuzzy set theory. The inputs and output of the fuzzy system are specified as follows:

$$\begin{cases} \Delta P = P(k) - P(k-1) \\ vP = v(k) - v(k-1) \\ \Delta D = D(k) - D(k-1 \end{cases} \quad (8)$$

Using the membership function makes it simpler to transform numerical input variables to fuzzy variables during fuzzification. The specifications provided are verified by equations (8) and (9):

$$\mathrm{E(k)} = \frac{\mathrm{P(k)-P(K-1)}}{\mathrm{I(k)-I(k-1)}} \quad (9)$$

$$\Delta\mathrm{E(k)} = \mathrm{E(k)} - \mathrm{E(k-1)} \quad (10)$$

It is shown that with this method, the error is represented by E (k), and the error variance at time k is represented by ΔE (k).

The MP operational point can be reached in time (k). It has been demonstrated, nevertheless, that E (k) provides both the direction of change and the value of the optimal yield point. Regardless matter how the dynamics of the operating cycle alter in response to weather conditions, E (k) is always zero, [19], [20]. The flowchart illustrating the implementation of the FL controller is depicted in Figure 3.

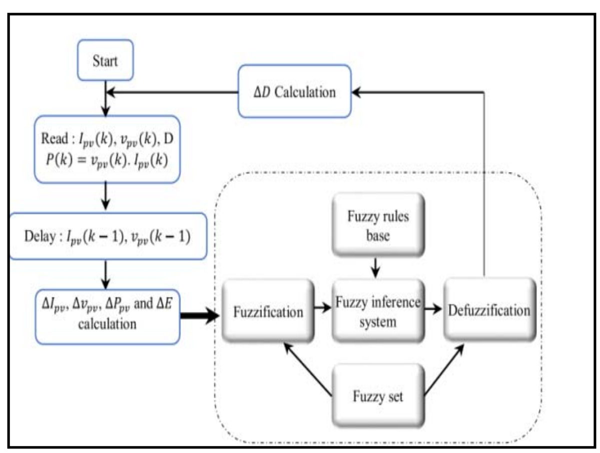

Fig. 3: Flow chart of FLC-MPPT Algorithm

Finally, the ΔD is defuzzifed using Equation 10.

$$\Delta D = \frac{\sum_{j=1}^{n} \mu(\Delta D_j)\Delta D_j}{\sum_{j=1}^{n} \mu(\Delta D_j)} \quad (11)$$

Table 1 shows that the linguistic variables' membership function (MF) is:
NB = Negative Big; N = Negative; Z = Zero = positive; PB = Positive Big.

Table 1. Fuzzy Rules Base

ΔV/ΔP	**NB**	**N**	**Z**	**P**	**PB**
NB	P	PB	NB	NB	N
N	P	P	N	N	N
Z	Z	Z	Z	Z	Z
P	N	N	P	P	P
PB	N	NB	PB	PB	P

Figure 4 illustrates the variables inputs membership functions (MFs) of the fuzzy inference system as power variation ΔP and voltage variation Δv and ΔD as the output

This type of command has the advantage of precision and speed of reaction compared to other classic algorithms. This algorithm effectively operates at the optimal point with minimal oscillations and exhibits favorable performance during transient states. However, its implementation is more complex compared to traditional algorithms and is heavily reliant on the selected size of the inference table.

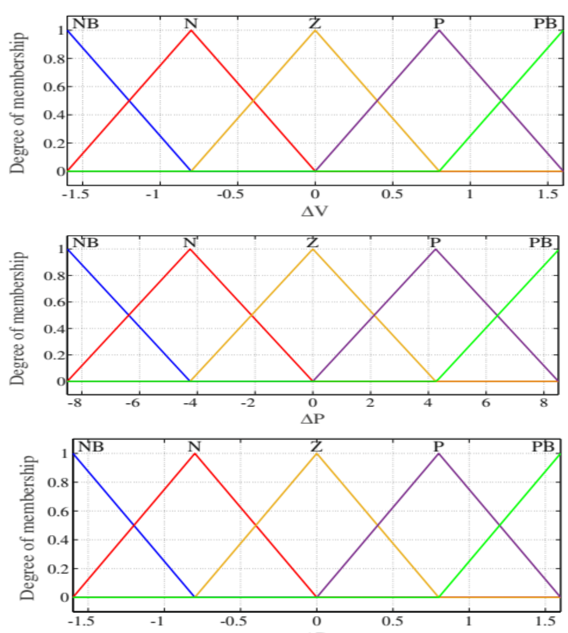

Fig. 4: Output membership variable

3 Modelling and Control of BLDC Motor

3.1 Modeling of BLDC

The Brushless motor belongs to the category of synchronous motors. The armature winding of the motor receives a three-phase power supply from an inverter, which is powered by a DC source. BLDC motors share similarities with DC motors in terms of their torque-current characteristics, making them effectively analogous or even superior to conventional DC motors, [21], [22], [23].

Three phase voltage equation is:

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} . \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (12)$$

$I_{a,b,c}$: Stator currents where $I_a+I_b+I_c= 0$; $L_{aa,bb,cc}$: phases self-inductance where $L=L_{aa},=L_{bb}=L_{cc}$; e_a ,e_b *and* e_c*: efms.* L_{ab}, $_{bc,\ ca}$: Mutual inductances where M= $L_{ab},=L_{bc}=L_{ca}$

The trapezoidal back EMFs are represented as follows:

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = w_m . \lambda_m \begin{bmatrix} f_{as}(\theta_r) \\ f_{bs}(\theta_r) \\ f_{cs}(\theta_r) \end{bmatrix} \quad (13)$$

With,
w_m: angular rotor speed;λ_m:flux linkage;θ_r:rotor position. $_{As}$,V_{bs} and V_{cs}: stator phase voltages.

The dynamic equation can be represented as:

$$J . \frac{dw_s}{dt} = T_e - T_L = f_r . w_r \quad (14)$$

3.2 Control of BDLC Motors

The field-oriented control (FOC) method is utilized for BLDC motors via electronic commutation, facilitating accurate regulation of motor speed and torque. The field-oriented control is widely adopted as the preferred method for regulating both torque and speed in BLDC motors due to its effectiveness and versatility, [24].

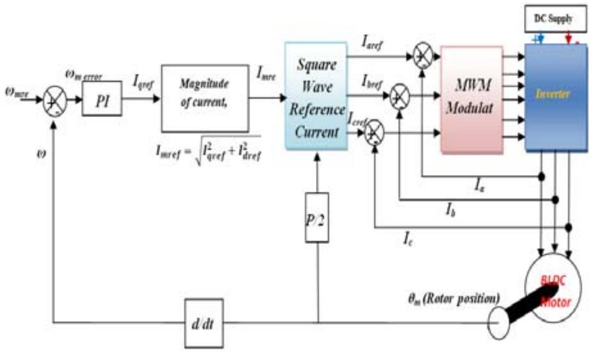

Fig. 5: Schematic of proposed field-oriented control

This approach involves aligning the stator flux vector with the rotor flux vector, allowing for accurate control of motor performance across a wide range of operating conditions. By utilizing FOC, BLDC (Figure 5) motors can achieve enhanced efficiency, improved dynamic response, and smoother operation in various applications. This technology finds application across a diverse range of fields, such as electric vehicles, where it enhances efficiency and performance; industrial automation, where it optimizes production processes and improves operational reliability; and renewable energy systems, where it plays a crucial role in maximizing energy conversion and integration into the grid. Its versatility and effectiveness make it a valuable asset in modern technological advancements.

4 Results and Discussion

This section is reserved for the discussion of the operation of the global system under a variable irradiation profile and the change of the machine speed reference. To do this, the behavior of different quantities relating to the system studied is visualized and analyzed. The irradiation profile under which the photovoltaic installation is exposed is represented in Figure 6. Under these conditions the electrical machine which is powered by the inverter and the storage system are characterized specifically by the evolution of their characteristics which is represented by the Figure 7 and Figure 8.

Figure 7 shows the power delivered by the photovoltaic generator and the voltage at the output of the DC bus (Figure 8) which is simultaneously the output of the Boost chopper and voltage at the input of the inverter powering the machine. We note that despite the random change in irradiation, the DC voltage is maximum at the desired level and that moreover, the GPV develops the maximum power corresponding to the respective levels of imposed irradiation.

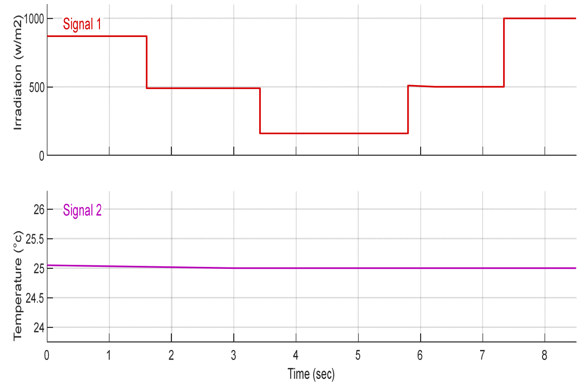

Fig. 6: Variable solar irradiance

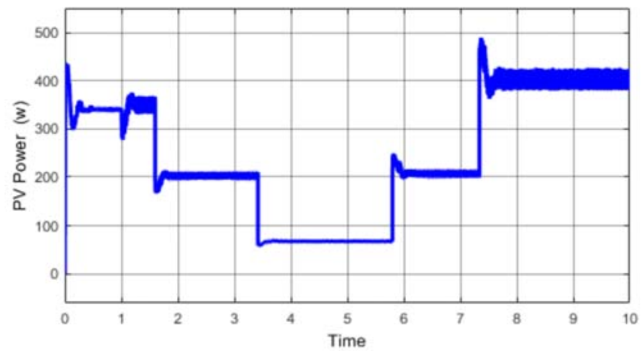

Fig. 7: Evolution of the produced power by the panelPV

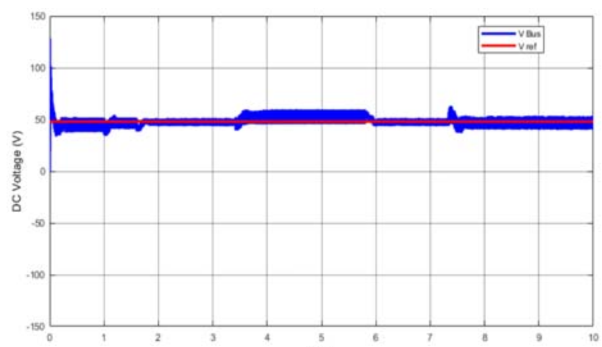

Fig. 8: Boost converter output voltage with Optimal MPPT

Concerning the sizes of the storage batteries, the charge threshold is discharge (Soc) as well as the battery current and its reference as well as the battery voltage are, respectively, shown in Figure 9. Their appearance correctly follows the conditions of functioning.

For the last part, relating to the behaviour of the machine under the conditions imposed by the Irradiation profile adopted, Figure 10 shows the superposition of the appearance of the reference speed and the real speed of the machine. We notice that the latter perfectly follows the set point signal with the response time.

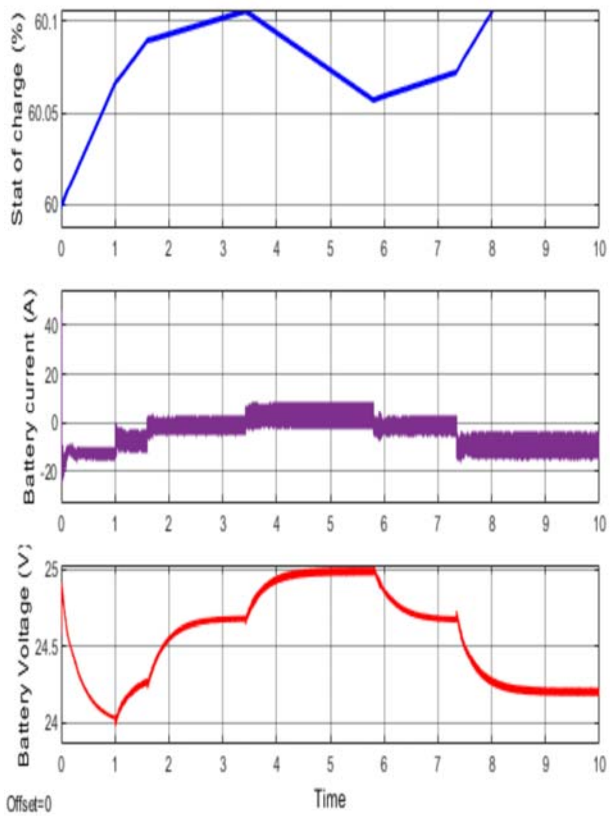

Fig. 9: Parameters of Battery Storage

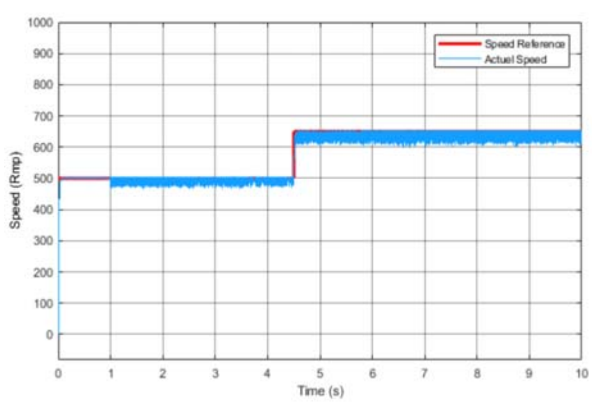

Fig. 10: Speed for FOC sinusoidal current regulated PWM

5 Conclusion

The use of photovoltaic energy to operate electrical systems is considered to be among the most crucial areas of research in renewable energies, especially related to the operation of electric vehicles.

In this research paper, we are interested in studying the control of an electric car engine using a battery that is charged through a photoelectric system under the application of the MPPT techniques. In order to improve the efficiency of the photovoltaic system. The power generated by the photovoltaic system is used to charge the storage batteries, which in turn power the motor. The analysis of the performance of the proposed system is based on numerical simulations conducted in a Matlab/Simulink environment. The performance of the BLDC motor was assessed with regard to its behavior during startup, transient, and steady-state operation, as well as during periods of acceleration and deceleration under varying speed and torque conditions using field-oriented control. Based on the analysis, the FLC- MPPT technique ensures efficient charging and discharging of the batteries and provides superior results in terms of motor speed response.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work the authors the authors made partial use of the ChaptGPT platform in order to improve some areas of writing and improve English. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Merabet Hichem and Bahi Tahar: Modeling and simulation global systems using Matlab Simulink, as well as formulating and writing the texts of this paper. Development and implementation of control algorithms for electric motors of the type BDLC.
- Drici Djalel and Bedoud Khouloud: Analysis and interpretations of obtained results, and comparing them with other works in the same field.
- Oudjani Brahim: Linguistic review and organizing references and ensuring their conformity using plagiarism programs.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

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