# Electric Vehicle Energy Harvesting Using a Meta-heuristic MPPT Controller Based on DM Optimization

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**Abstract**— In this paper, a novel Maximum Power Point Tracking (MPPT) control scheme for electric vehicles (EVs) powered by Proton Exchange Membrane Fuel Cells (PEMFCs), using the Dwarf Mongoose Optimization Algorithm (DMOA). The proposed algorithm enhances energy extraction by dynamically adapting to operating conditions with reduced computational complexity. The system integrates an interleaved SEPIC converter and a three-phase inverter for Brushless DC (BLDC) motor drive, achieving 500 W output at 400 V and 2000 rpm with low THD (<5%). Compared to conventional MPPT methods, DMOA demonstrates faster convergence, smoother performance, and higher efficiency under varying temperature.

**Keywords** Electric vehicle (EV), maximum power point tracking (MPPT), proton exchange membrane fuel cells (PEMFC), dwarf mongoose optimization algorithm (DMOA), renewable energy source (RES).

## 1. Introduction

Hydrogen fuel cells are a primary energy source for high-density power systems and are considered a strong competitor for zero-emission vehicular applications due to their low operating temperature, which makes them suitable for automotive use [1]. Among different fuel cells, Exchange PEMFCs are increasingly adopted for vehicles because they operate at lower temperatures and pressures, offer better safety, are easy to integrate into modular systems, emit less pollution, and convert chemical energy to electrical energy efficiently [2], [3]. PEMFCs exhibit non-linear voltage-current characteristics, with a unique operating point where maximum power is achieved [4]. Their performance is controlled by elements such as temperature and the level of water in the membrane, so complex control systems are necessary to maintain optimal power production. [5]. Maximum Power Point Tracking (MPPT) techniques are critical to adapt to changing operating conditions and extract maximum energy [6]. Conservative MPPT methods like Incremental Conductance (IC) and Perturb & Observe (P&O) are simple but can converge to local maxima and oscillate around the

MPP, reducing efficiency. Model-based approaches, such as fuzzy logic controllers and Artificial Neural Networks (ANN), improve adaptability but require large datasets and are computationally intensive, limiting real-time applicability. Evolutionary algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) provide global optimization but often suffer from slow convergence and high computational cost in dynamic EV environments. The improvement related to the EV energy management systems becomes highly vital, especially in the current scenario when the transformation towards green and sustainable modes of transportation is taking pace. In fact, in view of growing concern for global warming and rapidly depleting fossil fuel, there is an urgent requirement for an energy-efficient solution which can help assure reduced carbon footprints along with optimization in vehicle performance. Of these, the PEM Fuel Cells exhibit promising technology for the efficient conversion of hydrogen fuel into electrical energy [7]. However, several challenges stand in the way of practical application of PEMFCs as regards the optimization of power extraction and system efficiency in electrical vehicles. That is a sure indication of the need for sophisticated control methodologies that would adapt dynamically to operating conditions while smoothing the performance. Though much efficient to enhance energy extraction while managing power output from PEMFCs [8], it will be highly related to overall efficiency in EV systems and has been considered a key contributor toward sustainable mobility [9].

The interest in research in this work is inspired by the growing demand for electric vehicles that are not only environmentally friendly but also boast superior performance and efficiency [10]. In addition, the conventional energy management system can hardly adapt to complexities and variability's that relate to fuel cell operation [11]; hence, further deterioration of performance and high operational cost usually occurs. It is within this context that this research has proposed a new MPPT approach applied through the capability for fast computation through DMOA, considering both technical challenges and practical limitations imposed by existing approaches. Besides, increased electrification and interest in renewable energy sources within the automotive industry mean that there is a need for methodologies that enable the integration of novel optimization techniques within established fuel cell technologies. In this respect, the development of a DMOA-based MPPT technique should be realized in such a way that it will contribute not only to the maximization of energy produced by the PEMFCs but also to the smoothing of torque fluctuations for a much smoother driving experience by any customer. The final objective of the present work thus consists of contributions it will make to the general area of electric mobility in such a form that it will participate in opening futures for the development and use of fuel cell technologies in sustainable transportation systems.

### *1.1. Major Contribution*

The contribution of the present work has been the implementation and development of the new MPPT technique based on the DMOA algorithm in the case of PEMFCs for electric vehicle applications. In this respect, an innovative proposal has been developed that, by means of an intelligent optimization of the power output, realizes with high efficiency the extraction of energy from the PEMFCs which influences directly the overall performance and efficiency in EV systems. Novelty is by far the DMOA-based MPFT technique and makes a good trade-off between the computational efficiency and dynamic operation of the fuel cell toward minimizing torque fluctuation to realize a smooth response against load condition variations. It includes an interleaved SEPIC converter able to provide adaptive energy regulation and further enhance system capability with respect to minimum loss of power when energy conversion takes place. The employment of a three-phase inverter with a BLDC drive would provide less total harmonic distortion to help stability and performance within the system. In fact, these contributions can be put together to represent an integrated solution for energy management to respond to most of the problems that occur in the optimal performance of a PEMFC onboard of an electrical vehicle. This should be considered one great step in the search for effective and sustainable technologies in transport. Not only does it move the frontiers for fuel cell technology, but it also represents a milestone regarding future developments of energy management systems within electric mobility.

### *1.2. Objectives and Novelty*

In this paper, a new MPPT control algorithm using Dwarf Mongoose Optimization Algorithm (DMOA) is presented. The aim of this design is to maximize energy production from PEMFCs in electric vehicle (EV) scenarios. The MPPT algorithm based on DMOA tries to make sure that fuel cells produce maximum energy and provides a smooth response with less torque changes [12]. This method which requires low computation power, is appropriate for EV use where performance and efficiency are critical factors. Incorporating an interleaved **S**ingle-**E**nded **P**rimary-**I**nductor Converter DC-DC converter boosts the system. It handles voltage control with less power loss, working efficiently in both buck and boost methods. Also, a three-phase inverter is used to run a Brushless DC (BLDC) motor. This helps to lower total harmonic distortion and improve general system performance. The objectives of this paper are:

- Develop and implement a novel DMOA-based MPPT algorithm for PEMFCs.
- Maximize the energy output of PEMFCs while ensuring minimal torque ripples.
- Integrate a SEPIC DC-DC converter for efficient voltage regulation.
- Improve performance of EV systems with smart control methods and power electronics elements.

Fuel cell technology, specifically the PEMFC, is one of the most valuable technologies that convert chemical energy into electrical energy and hence finds their crucial role in developing electric vehicles with better efficiency and performance. This paper proposes a novel MPPT control approach using the Dwarf Mongoose Optimization Algorithm. This algorithm is designed to maximize the energy extracted from PEMFC, which is vital for maintaining the overall efficiency of the EV system. In electric vehicles, power extracted from fuel cells plays a major role in performance; hence, effective extraction strategies for the extracted power are very vital. Since hydrogen is converted into electrical energy through electrochemical processes, sophisticated techniques are required in control for the optimal performance of PEMFCs. The proposed DMOA-based MPPT method has been designed to increase energy production from fuel cells with smooth response and low fluctuations in torque. This will be a major improvement compared with existing techniques, due to the fact that not only does it save computational power, but effectively manages energy, which is extremely useful in real electric vehicle applications.

Important in our work is the integration of the DMOA with an interleaved SEPIC DC-DC converter. The latter efficiently controls the output voltage while minimizing power loss after power extraction is maximized from the fuel cell. Its further efficiency is enhanced by being able to operate either in buck or boost mode in accordance with its duty cycle, which provides versatility in energy management. Further, the three-phase inverter used for driving a BLDC motor in our system shows very low total harmonic distortion, hence improving system stability. The synergy of a DMOA-based MPPT algorithm with the SEPIC converter provides an integrated approach that has helped not only in improving the efficiency and performance of the EV system but also taking care of the challenges related to energies handling in electric vehicles. This novel approach sets, therefore, a new benchmark of energy optimization in the PEMFCs and turns out to be one of the promising solutions for advanced energy management in the broadening field of electric mobility.

The paper's organization is designed in a way that gives a full comprehension of the suggested DMOA-based MPPT control system for PEMFCs applied in EVs. In Section 2, we look at normal MPPT methods used for EV systems. We show their benefits and drawbacks via comparing different models. In Section 3, we present the new DMOA-MPPT controlling system and explain how it works with PEMFCs. This section tells about the theory base and algorithmic process of DMOA-MPPT. In Section 4, we check our system by comparing its results with different parameters. At last in Section 5, it shows the outcomes and talks over what could come next for this study's scope - highlighting how DMOA-MPPT technique may advance and be used more effectively to increase EV system's effectiveness.

## 2. Related Works

Different techniques have been suggested in the literature for performance optimization with the aim to enhance efficiency in PEMFC energy management, especially for EV applications [13]. MPPT represents one of the commonly applied methods to maximize the energy output from fuel cells by making the fuel cells operate at their optimal power point irrespective of the operating conditions. Most of the conventional MPPT techniques use methods like P&O, or Incremental Conductance [14]. These techniques have gained favor because of their easiness and comfort of implementation, but they also have serious shortcomings. For example, the P&O technique may converge to a local maximum rather than the true global maximum; moreover, this may happen in rapidly changing conditions, thus preventing optimal energy extraction. More important, however, is the fact that both the P&O and IC approaches can also exhibit oscillations around the MPP, introducing undesirable ripple into the torque produced, which can then have a direct impact on the performance of the electric motor driving the vehicle. Another class involves model-based control methodologies, including ANN and fuzzy logic systems [15]. These techniques brought in both the capability of machine learning and adaptive control methods to model the behavior for PEMFCs with a view to predicting optimal operating points [16]. While all these techniques have promising perspectives concerning flexibility and predictive power, most of them require huge training datasets; hence, they are computationally intensive and not well-suited for real-time applications. Besides that, sometimes the quality of the training data is a decisive factor in models' precision, and this data does not always represent real operating conditions; hence, it limits their efficiency. Another alternative to MPPT in PEMFCs has been the application of evolutionary algorithms and swarm intelligence techniques during the last years. Methods such as PSO or GA try to surmount some of the limitations of classic methods by exploring higher solution spaces in order to retrieve global maxima. However, they usually require high computational efforts and could fail when working under dynamic environments where fast adjustments are needed [17]. Their convergence rates can also be quite poor, thus delays in response to changes in load or fuel cell performance are quite important within the fast-moving context of electric vehicle operation.

More advanced optimization algorithms, like the Dwarf Mongoose Optimization Algorithm (DMOA) [18], are proposed to overcome many of the drawbacks associated with existing techniques. DMOA can be prone to effectiveness in the search for optimal solutions with computational efficiency for real-time applications compared to ordinary procedures [19]. Its novelty is in the minimization of torque fluctuations to develop a much smoother energy output from PEMFCs, one of the very key requirements to improve electric vehicles' overall performance [20]. The study emphasizes PV model parameter extraction via IDMO, with enhancements in accuracy and convergence suggesting that optimization-driven methods may bolster advanced MPPT strategies and establish a basis for effective energy management in renewable-integrated EV systems, particularly when integrated with traditional MPPT control in future investigations [21]. In general, remarkable advances have been achieved in the optimization techniques of PEMFC performance; however, there are still challenges that pose the need for advances that have to be made to improve efficiency and reliability for practical applications [22].

*Aly.., et al* [23] employed a differential evolution-based algorithm integrated with a fuzzy logic control technique for MPPT control, achieving enhanced optimum power extraction and quick tracking performance for PEMFCs. *Srinivasan, et al* [24] deployed a Radial Basis Function Network (RBFN) to maximize power extraction from fuel cells under various operating conditions by locating the peak power point. Their configuration included a unique high step-up DC/DC converter to achieve substantial voltage ratings, significantly increasing voltage with a reduced duty ratio for fuel cell applications. The proposed control technique aimed to optimize the fuel cell's output power under diverse operating conditions. *Farajdadian, et al* [25] developed a fuzzy-based MPPT controller to improve power tracking in stand-alone PV systems, utilizing a new Teaching Learning Optimization (TLO) based fuzzy controller to achieve increased power tracking accuracy and a high convergence rate. For monitoring the highest energy generation from fuel cells, a Neural Network - Elman Back Propagation (NN-EBP) based MPPT regulating technique was employed by the authors in [26]. In [27], a non-iterative MPPT technique was used to enhance power extraction from PEMFCs, with a boost DC-DC converter architecture supplying the load unit with high gain voltage and power density. To improve power tracking efficiency, the authors in presented a computationally efficient MPPT method based on the jaya optimization technique [28]. This work established an optimization-based control mechanism to achieve maximum output power, with PWM control signals operating the switching components. Finally, in [29], an ANFIS-MPPT regulating method was used to provide maximum output power to EVs. The primary goal was to enhance the hydrogen cell's energy efficiency and power tracking capability using the ANFIS algorithm.

Energy management in PEMFC has, until now, suffered from a crucial issue related to the optimization of power, especially in electric vehicle applications. Classic MPPT approaches, such as P&O and IC, very seldom lead to robust results in a dynamic operation scenario and, thus yield very inefficient or even suboptimal energy output. In such techniques, there exist several disadvantages, which include convergence to local maxima, energy losses, torque fluctuations that can adversely affect vehicle performance. Furthermore, these model-based approaches have dependencies on data and intensive computation with the use of AI and adaptive control, which may be a restrictive means in real-time applications. The main weakness that characterizes the evolutionary algorithms, such as PSO and GA, is that, while more adequate search capabilities are achieved, they generally face a slow convergence rate with high computational cost, further complicating their implementation in fast conditions. Thus, the existing techniques are not efficient and flexible to achieve an optimum energy harvester from PEMFCs. This condition creates the imminent need for developing newer optimization techniques that will be capable of overcoming the limitations and thereby enhancing overall performance in the electric vehicle fleet.

## 3. Proposed Methodology

The proposed model includes a unique Dwarf Mongoose Optimization Algorithm (DMOA) based MPPT control system for PEM Fuel Cells. The main focus of this design is to maximize power extraction and improve overall efficiency in Electric Vehicle (EV) application by reducing energy losses. After the optimization process, which finds best parameters for training classifier, we use an interleaved Single-Ended Primary-Inductor Converter to control output voltage with minimum loss of power. This kind of converter has special benefits because it can work in both buck and boost modes depending on its duty cycle. So, it offers more flexibility and effectiveness in controlling voltage. Moreover, there is a three-phase inverter given in the model to offer power for Brushless DC (BLDC) Motor [30]. This inverter has been made with an aim of decreasing total harmonic distortion. It makes sure that power reaches the motor smoothly and effectively, which is very important for how well EV system works and its trustworthiness. The Proposed topology and schematic of the suggested model are shown in Fig. 1 and Fig. 2 respectively.

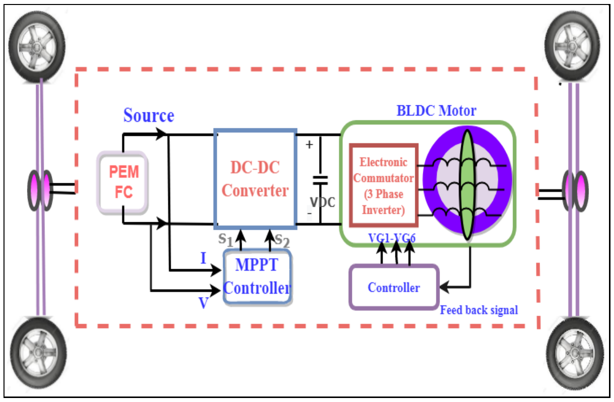


**Fig. 1.** The proposed topology of PEMFC- MPPT based EV system.

As a block diagram and schematic representation of the proposed model have been presented in this paper, these diagrams explain the overall system construction and functional components of the individual systems and how they cooperate to deliver the best extraction by DMOA for the extraction of maximum power from PEMFCs. This is they work by converting the hydrogen fuel into electrical energy through electrochemical reactions. The DC output from the PEMFC is inputted to a DMOA control for the fuel cell operations at the maximum power point and optimum energy extraction. It makes intelligent adjustments for efficiency using real time data from the fuel cell to maintain a minimum fluctuation in output power in this controller. The output from interleaved SEPIC converter would then be supplied. This would therefore form the most stringent control in determining the output voltage. This is so because it is designed that a SEPIC converter can buck or boost in different loads for optimum performance with least power losses.

Then, the regulated output voltage shall rectify through a three-phase Voltage source inverter, which will transform the direct current voltage into three-phase AC voltage adequate for driving a BLDC motor. The extent of this component of distortion of this inverter will be kept as low as possible so as to improve on the efficiency of this motor and operation. Specified integration of such advance components into one compatible framework will be designed in the proposed model with an objective to augment the energy management of the PEMFC in electric vehicles in further more way towards realization of efficiency performances in real world applications. This exhaustive design supports the innovation of the proposed system but, at the same time, rests on a comprehensive base that might be further developed in fuel cell technology and electric vehicle energy management systems.

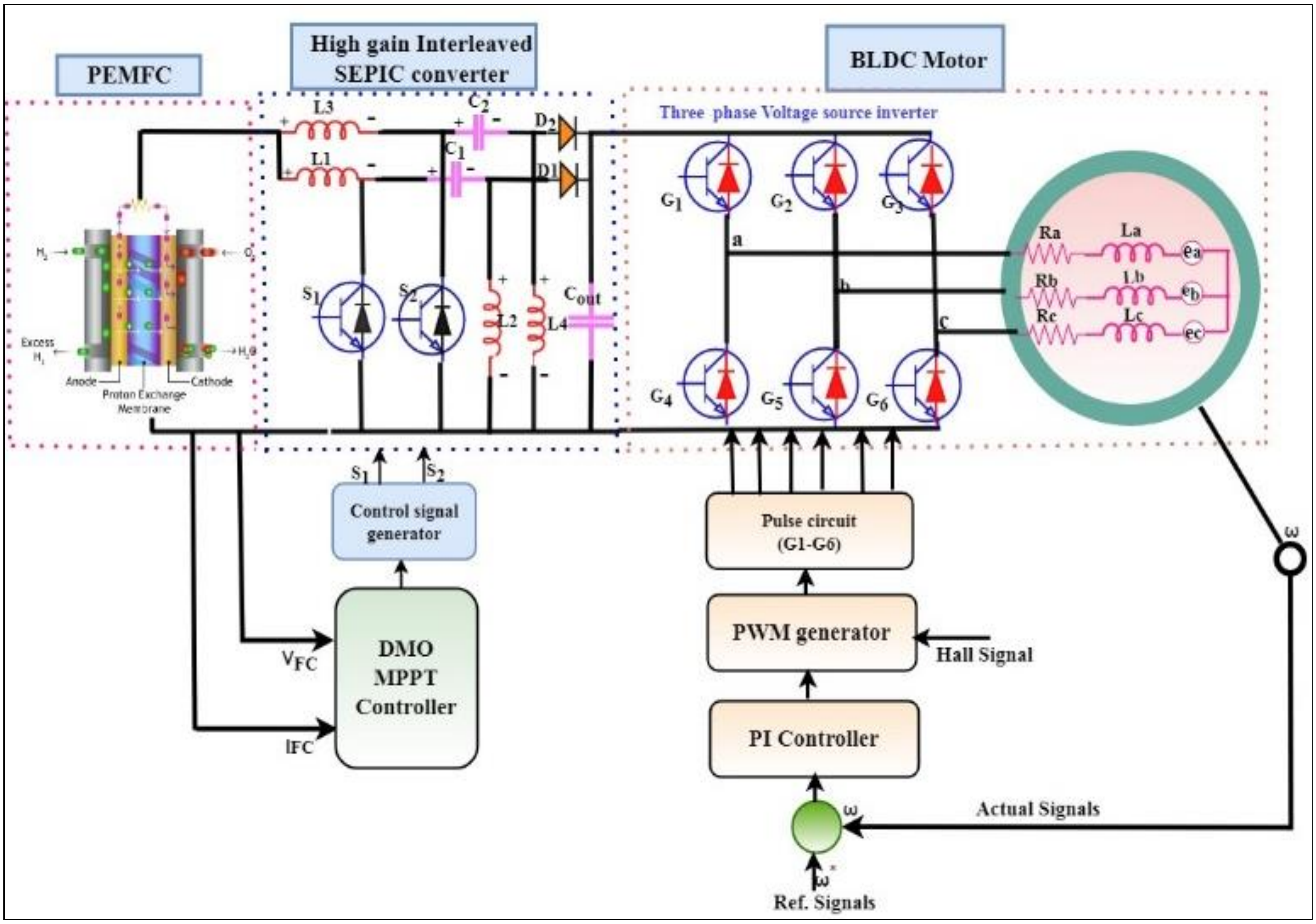


**Fig. 2.** Schematic representation of DMOA MPPT-PEMFC based EV system driven by BLDC motor.

*3.1. PEMFC Power Tracking*

As the performance and effectiveness of electric vehicles (EVs) are greatly linked to the output power from fuel cells, taking out power efficiently from these fuel cells becomes a crucial part of EV application systems. The term fuel cell usually refers to an electrochemical device that transforms Hydrogen-based fuels into electrical energy. A typical fuel cell takes in air and hydrogen as inputs, using a chemical method to produce electrical energy. A fuel cell is made up of one electrolyte, two electrodes (an anode and a cathode), and an electrolyte that divides positive and negative ions. When chemical reactions occur in the fuel cell, hydrogen molecules located at the anode are split into protons and electrons. Protons pass through the electrolyte to reach the cathode, while electrons go along an outside pathway or circuit, resulting in electrical flow [31]. At the negative terminal, protons and electrons combine with oxygen from the environment to produce water and heat. [32]. The layout of a Proton Exchange Membrane Fuel Cell (PEMFC) is drawn in Fig. 3, which shows the basic parts and activities that happen inside a PEMFC. A 1.2 KW PEMFC The module is used as the reference model for the simulation setup; specifications are provided in Table 2. The output voltage can be expressed by the following equation:

$$V_{FC.ot} = E_{OV} - V_{act.ov} - V_{ohm.ov} - V_{con} \quad (1)$$

In this equation $V_{FC.ot}$ represents the output voltage of fuel cells, $E_{OV}$ represents the rev. open circuit voltage, $Vo_{ac}$ is the combination of anode and cathode voltage, $Vo_{ohm}$ defines the ohmic voltage, and, and $Vo_{con}$ is the is the concentration voltage. Then, these parameters are calculated as follows:

$$E_{OV} = 1.229(8.5 \times 10^{-4})(T - 298.15) + (4.385 \times 10^{-5}T)lnPH_2 + 0.5ln(Po_2) \quad (2)$$

$$V_{FC.act} = [\rho_1 + \rho_2 T + \rho_3 T ln(Co_2) + \rho_4 T ln(I_{FC})] \quad (3)$$

Where, $\rho_1, \rho_2, \rho_3, \rho_4$ indicates the empirical coefficients, and $Co_2$ represents the dissolved oxygen concentration.

$$V_{ohm.OV} = I_{FC}(R_C + R_M) \quad (4)$$

Where, $I_{FC}$ is the current of fuel cell, $R_C$ indicates the proton resistance, and $R_M$ is the electron flow equivalent resistance.

$$Vo_{con} = -\frac{GT}{nF} ln\left(1 - \frac{K}{K_{max}}\right) \quad (5)$$

Where G is the universal gas constant, F is Faraday's constant, K is the current density, and $K_{max}$ is the maximum current density.

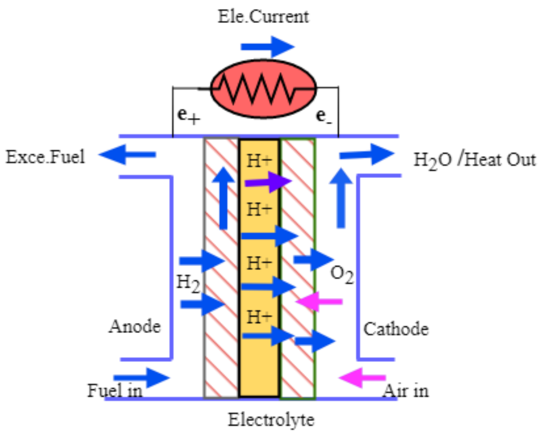


**Fig. 3.** Ideal representation in process of PEMFC model.

### *3.2. DMOA-MPPT Controlling*

This research work employs a novel Dwarf Mongoose Optimization Algorithm Maximum Power Point Tracking (MPPT) control technique to improve the energy extraction performance of Proton Exchange Membrane Fuel Cells (PEMFCs). The suggested DMO-MPPT algorithm control technique is well demonstrated by the flow chart in Fig. 4 and Table 1. Existing works use a variety of meta-heuristics optimization algorithms to solve complicated problems [33]. But, they having the major problems such as low convergence, increased searching time for solution identification, and reduced speed. Therefore, the proposed work intends to use a new optimization algorithm for MPPT controlling. Selection of the Dwarf Mongoose Optimization Algorithm within this work is dictated by its incomparable capabilities to handle the challenges of optimization of power extraction from Proton Exchange Membrane Fuel Cells for electric vehicle applications [34]. It achieves this by fusing the best features of the individual contributions from conventional optimization methods to advanced search strategies in DMOA so that the solution space is better explored to converge faster to optimal solutions. Unlike most conventional approaches, which often get caught up in local maxima and oscillatory behavior, DMOA provides a far more stable and responsive control mechanism with minimal fluctuation in torque for a better drive feel. It is, therefore, also much more suitable in terms of computational efficiency for real-time applications, as this enables the algorithm to make quick adjustments for changing operating conditions without sacrificing any performance. In this paper, new features of the DMOA are used to realize energy management in PEMFCs that is notably enhanced which realizes higher energy output with higher overall efficiency for electric vehicles and ultimately contributes to the advancement of sustainable transportation technologies.

The dwarf mongoose's behavior in deciding what to eat is an inspiration for the DMO method. Typically, the DMO begins by applying the following equation to a set of solutions to figure out their principal value:

$$k_{i,j} = Low_i + \delta \times (Up_j - Low_j) \quad (6)$$

Where, $\delta$ indicates the random number, $Up_j$ and $Low_j$ are the upper and lower bounds. Three groups, including scouts, the alpha group, and babysitters, make up the DMO swarm. The details of these groups are as follows, and each group has its own unique performance for capturing the food:

- Alpha group
- Scout group
- Babysitters group

If the population was formed, the fitness of each solution was calculated. Here, the alpha female $\vartheta$ is selective and reliant on this likelihood, which is computed for all fitness populations.

$$\vartheta = \frac{H_i}{\sum_{i=1}^{n} H_i} \quad (7)$$

Where, $n$ indicates the number of mongooses obtained from the alpha group, and $H_i$ is the fitness value. Moreover, babysitters served as a representation of the number of nannies. The family runs smoothly because of Peep, the dominating female in the area. The main fixed sleeping mound is where all the mongooses sleep, where the DMO used to create a potential food location.

$$G_{i+1} = G_i + \pi \times p \quad (8)$$

Where, $G_{i+1}$ indicates the number of population, $\pi$ is the uniformly distributed arbitrary value ranging from -1 to 1 and $p$ represents the peep that is vocalization of dominant people.

$$u_i = \frac{H_{i+1} - H_i}{\max\{|H_{i+1}, H_i|\}} \quad (9)$$

$$\rho = \frac{\sum_{i=1}^{n} u_i}{n} \quad (10)$$

Where, $u_i$ is the sleeping mound, and $\rho$ is the average value sleeping mound. The technical process progresses to the scouting phase, during which the next source of sustenance or sleeping mound is assumed to exist if the childcare changes condition is fulfilled. The scout appears for the next sleeping mounds, making sure to seek, as mongooses have been observed not to return to prior sleep mounds. In this method, foraging and scouting were carried out simultaneously. This approach led to either a successful or unsuccessful quest for a brand-new sleeping mound. Mongoose migration, in particular, relies on their overall effectiveness. The following equation gives a definition of the scout mongoose:

$$G_{i+1} = \begin{cases} G_i - B \times \pi \times r1\left[G_i - \vec{Q}\right] if\, \rho_{i+1} > \rho_i \\ G_i + B \times \pi \times r2 \times \left[G_i - \vec{Q}\right] \end{cases} \quad (11)$$

Where, $B$ indicates the parameter that is used to mongoose group is represented as follows:

$$B = \left(1 - \frac{t}{Max_t}\right)^{\left(2\frac{t}{Max_t}\right)} \quad (12)$$

$$\vec{Q} = \sum_{i=1}^{n} \frac{G_i \times u_i}{G_i} \quad (13)$$

Where, $\vec{Q}$ indicates the mongoose movement. The inferior group members who looked for younger people and frequently cycled gave the alpha female (mother) the opportunity to lead the other members of the group on daily foraging trips. Babysitter availability was inversely correlated with population size, which can serve as motivation for the strategy by reducing the size of the overall population in accordance with the target percentage. By resetting the use of the babysitter interchange parameter, the scout and food basis values that were previously provided by the family fellows take their place. By using this algorithm, the maximum possible energy is obtained from the fuel cells.

Fig. 4 depicts the operational workflow of the proposed Dwarf Mongoose Optimization-based Maximum Power Point Tracking (DMO-MPPT) control strategy employed for maximizing power extraction from the photovoltaic system. The process commences with the initialization of algorithm parameters, including population size, upper and lower limits, maximum iterations, and learning coefficients. Upon establishing these parameters, a random initial population of candidate solutions (potential operating points) is generated.

The fitness value of each solution is determined by the power output of the photovoltaic system, facilitating the assessment of its proximity to the maximum power point. The population is categorized into functional groups—scouts, alphas, and babysitters—each denoting distinct behavioral roles within the mongoose species. These groups jointly investigate and utilize the search space.

Equation (6) is used to generate a new position (food location) for each candidate solution, signifying progress toward an improved operating point. The new location replaces the old one if it offers greater fitness (higher PV power). If not, the algorithm uses Equation (11) to activate the scouting mechanism in order to find new possible points and break free from local stagnation.

Until the stopping criteria are met, the procedure is repeated. The search keeps refining the solution if the number of iterations is less than the maximum threshold (T < Tmax); if not, convergence is declared. The algorithm successfully determines the global optimal operating point, which is equivalent to the PV system's Maximum Power Point (MPP), once it has stabilized.

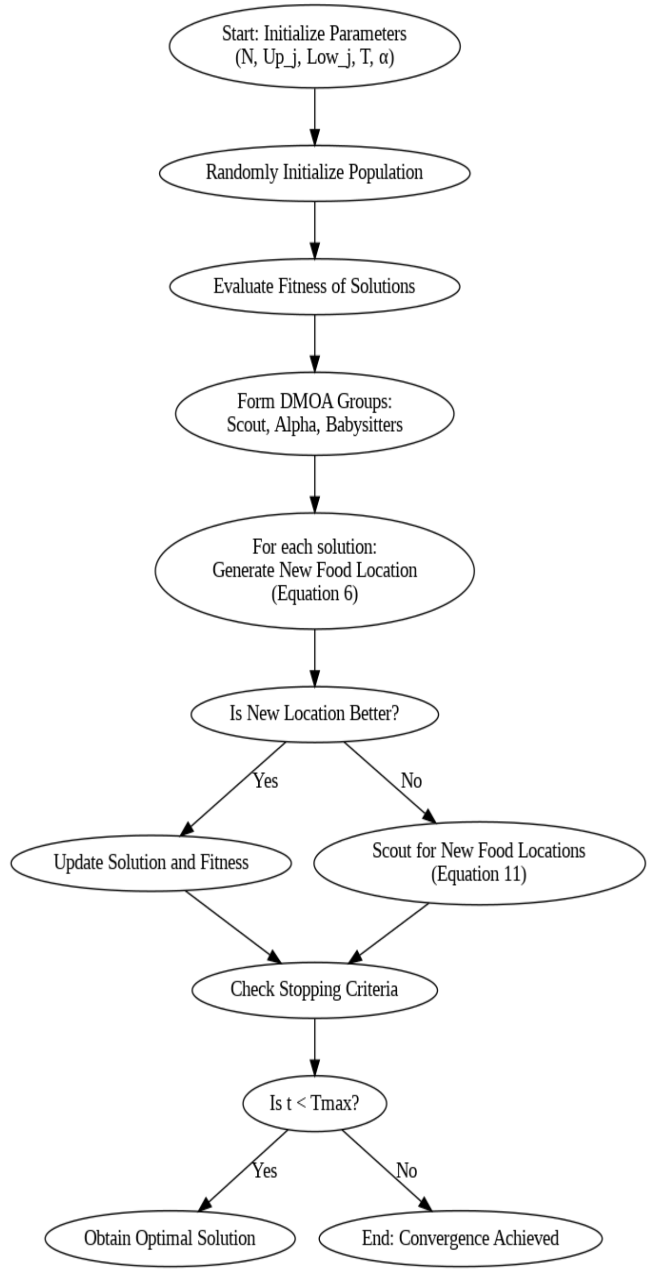


**Fig. 4.** Flow chart of proposed DMOA-MPPT control method.

**Algorithm of DMOA-based MPPT for PEMFC**

Inputs: N (population size), $t_{max}$, $D_{min}$, $D_{max}$, α, β
Initialize: for i=1..N: a_i^0 ← random uniform($D_{min}$, $D_{max}$)
Evaluate fitness f(a_i^0) for all i
a_best^0 ← argmax i f(a_i^0)

for t = 0 .. t max-1 do
  for i = 1 .. N do
    **// Exploration**
    choose distinct j, k ∈ {1..N}\{i} at random
    $r_1$ ← rand. (0, 1)
    $b_i$ ← a i^t + α * $r_1$ * (a.j^t – a k^t)

    **// Exploitation (move toward best)**
    $r_2$ ← rand. (0,1)
    $c_i$ ← a_i^t + β * $r_2$ * (a_best^t - a_i^t)

    **// Clamp to duty bounds**
    $b_i$ ← clamp($b_i$, $D_{min}$, $D_{max}$)
    $c_i$ ← clamp($c_i$, $D_{min}$, $D_{max}$)

    **// Evaluate candidates by measuring / computing power**
    evaluate f($b_i$), f($c_i$)

    **// Greedy selection**
    $a_i$^(t+1) ← argmax {u∈{a_i^t, b_i, c_i}} f(u)
  end for

  **// Update global best**
  a best^(t+1) ← argmax_i f(a_i^(t+1))

  **// Optional: check stall criterion**
  if improvement < ε over last T stall iterations then break
end for
Output: D opt ←a best

**Table 1.** Example parameters of DMOA-MPPT control method

| Symbol | Suggested value (example) | Description |
|---|---|---|
| (N) | 12 | Population size |
| (\alpha) | 0.6 | Exploration coefficient |
| (\beta) | 0.3 | Exploitation coefficient |
| (t_{\max}) | 100 | Max iterations |
| (D_{\min},D_{\max}) | 0.05,0.95 | Duty cycle bounds |
| (\epsilon) | (1\times10^{-4}) | Relative improvement threshold |
| (\eta) | 0.92 | Converter efficiency (simulation) |

**Table 2.** Specifications of proton exchange membrane fuel cells

| Factors | Values |
|---|---|
| $P_{max}$ | 1.899 KW |
| $I_{max}$ | 50.8A |
| $V_{max}$ | 24.88V |
| $O_2$ | 1.0 bar |
| $H_2$ | 1.488 bar |
| $V_{OC}$ | 35V |
| Temperature | $55^0$ C |
| Number of Cells | 42 |

### *3.3. Interleaved SEPIC Converter*

To control the output voltage and reduce power loss, we use a SEPIC converter that is interleaved with Single-Ended Primary-Inductor Converter (SEPIC). This converter adjusts the voltage after getting maximum power from Proton Exchange Membrane Fuel Cells (PEMFCs). The main benefit of using this type of converter is its flexibility to work in either buck or boost modes based on duty cycle. It changes output voltage efficiently according to needs, making sure high performance is maintained when there are changes in load conditions. One of the main goals of using the interleaved SEPIC converter is to decrease power losses and control output voltage. The suggested setup helps in reducing ripple present in converter's output voltage, which indirectly aids in decreasing torque ripple. This is very important for keeping smooth and steady function in EV systems.

$$V_{DC} = \frac{D \cdot V_{FC}}{1-D} \tag{14}$$

Where, $V_{DC}$ represents the output DC voltage, $D$ represents the duty cycle ratio, and $V_{FC}$ is the voltage of the fuel cell. Using the inductor circuit, the ripple current is restricted to 10%, as shown below:

$$\Delta I_L = I_O \frac{(V_O \times 10\%)}{V_{FC}(min)} \tag{15}$$

Based on eqn.15, the inductor value is achieved as follows:

$$L_1, L_2, L_3, L_4 = \frac{V_{FC}(min)}{\Delta I_L \cdot F_S} \times D_{(max)} \tag{16}$$

Where, $L_1, L_2, L_3, L_4$ are the inductors, $I_L$ represent the inductor current, and $F_s$ indicates the switching frequency. Consequently, the RMS value of current is estimated by.

$$I_{Cin}(rms) = \Delta I_L / \sqrt{12} \tag{17}$$

Here, the capacitor value is considered (i.e. Greater than 10mf) for avoiding the impedance mismatch. For the capacitor discharge design, the resulting current is computed as follows:

$$I_{Co}(RMS) = I_O \sqrt{\frac{V_{Dc}+V_D}{V_{FC(min)}}} \tag{18}$$

$$V_{ripple} = \frac{I_O \cdot D_{(max)}}{C_O \times F_s} \tag{19}$$

The proposed system uses the interleaved SEPIC converter, shown in Fig. 5, for keeping a stable output voltage while wasting less power. Its working modes are displayed in Fig. 5 (a) to (d), showcase its versatility in effectively managing voltage conversion. The main advantage of an interleaved converter is that it can increase the output gain while also addressing the reverse voltage polarity issue with an additional filter component.. This makes sure there is effective working and dependable voltage control which are very important for getting most energy out from PEMFCs. For Mode 1, as shown in Fig. 5 (a), switches S1 and S2 are turned off and on, respectively. This permits the inductors to discharge through the load. At this phase, fuel cells charge up capacitors for getting ready for next operation cycle. Next, we have Mode 2 which is displayed in Fig. 5 (b). Here, current passes via diode D1 to supply energy for forward-biased load unit. Meanwhile, diode D2 stops the returning current. This one-way direction of flow guarantees effective transmission of power to the load and keeps system steady and efficient.

In essence, the PEMFC system's interleaved SEPIC converter helps with good voltage control and power handling. This makes sure energy is taken out well from fuel cell to use in EV system without many losses. Its' working modes show how it can convert and give power efficiently, adding to overall effectiveness and performance of EV system. The Switching pulses and current flows through the each component in the mode of Interleaved - SEPIC converter, as shown in the Figure 6. The specifications of interleaved SEPIC DC-DC converter are shown in Table 3.

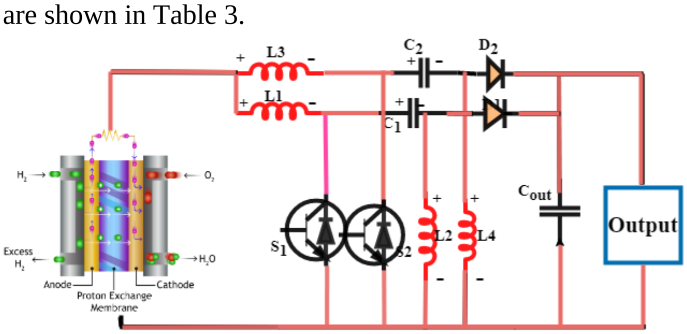


**Fig. 5.** Schematic representation of interleaved SEPIC DC-DC converter.

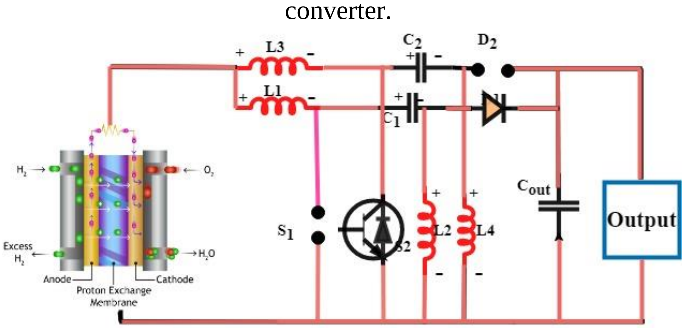


**Fig. 5 (**a). Mode 1.

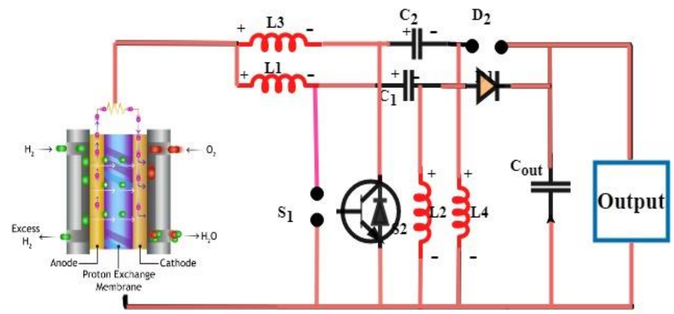


**Fig. 5 (b**). Mode 2.

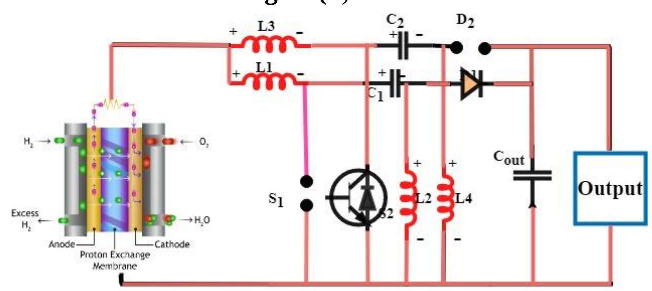


**Fig. 5 (**c). Mode 3.

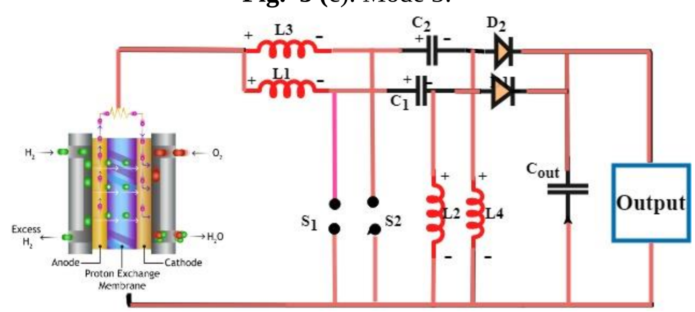


**Fig. 5** (d). Mode 4.

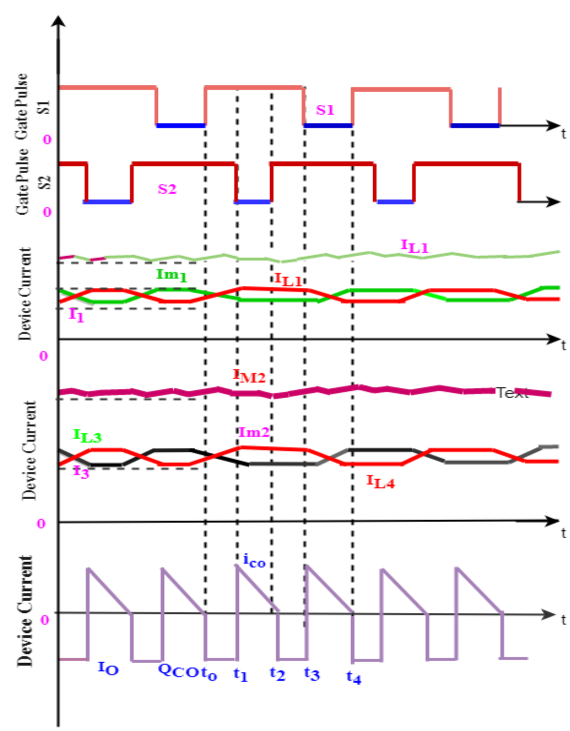


**Fig. 6**. Switching pulses and current waveform of converter.

**Table 3.** Specifications of interleaved SEPIC converter

| ***Parameters*** | ***Values*** |
|---|---|
| Converter ($V_{oc}$) Output voltage | 440V |
| Inductance(L) | 4mH($L_1$,$L_2$), 1.5mH($L_3$,$L_4$) |
| Capacitance(C) | 10µF |
| Output $C_{(out)}$Capacitance | 6000µF |
| Converter Switching Frequency | 20kz |
| Ripple Current | 10% |

## 4. Result and Discussion

In this research, we did simulation analysis with MATLAB 2020 to check how good the DMOA based -MPPT control method for Proton Exchange Membrane Fuel Cells (PEMFCs) works. We used many validation indicators such as PEMFC voltage, current and power along with converter voltage and power to measure how well this optimization-focused control plan functions. The simulation analysis shows the results in different figures, such as Fig. 7 and Fig. 8. These two images demonstrate how the output power and voltage of PEMFCs change at different temperatures. They give insight into how well the suggested DMOA-MPPT control strategy works under diverse operating conditions, particularly with various temperatures. Furthermore, Fig. 9 displays a graphical representation of time-varying PEMFC voltage and power with DMO-MPPT; this graph shows how the system reacts to changes in its environment over a period of time. The main goal of the simulation analysis is to check how well the optimization-based control technique can follow MPP for PEMFCs. When we use DMOA and get our best optimal solution, this one is applied by MPPT controller for finding MPP accurately. This guarantees that fuel cells are working at their maximum energy production rate. From looking at the data we have, the suggested DMOA-MPPT control plan shows better performance in getting the most energy across different temperature conditions. The optimization-centered control method enhances the output power and voltage of PEMFCs, pointing to improved power tracking efficiency and general system performance. These results confirm that this suggested method is effective and it has a lot of possibility for improving how much energy we can get from PEMFCs in electric vehicle uses.

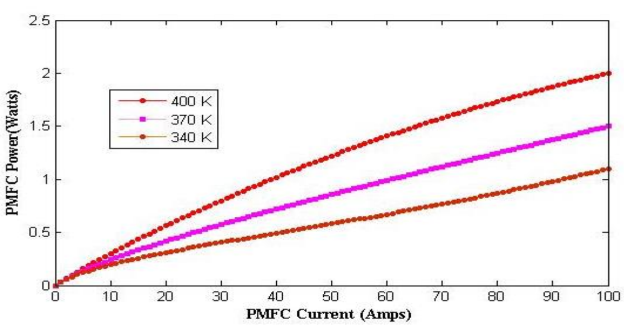


**Fig. 7.** PEMFC output of Power vs. current at different temperatures.

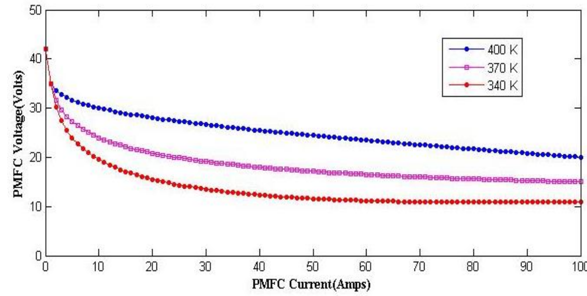


**Fig. 8.** PEMFC output of voltages vs. current at different temperature levels.

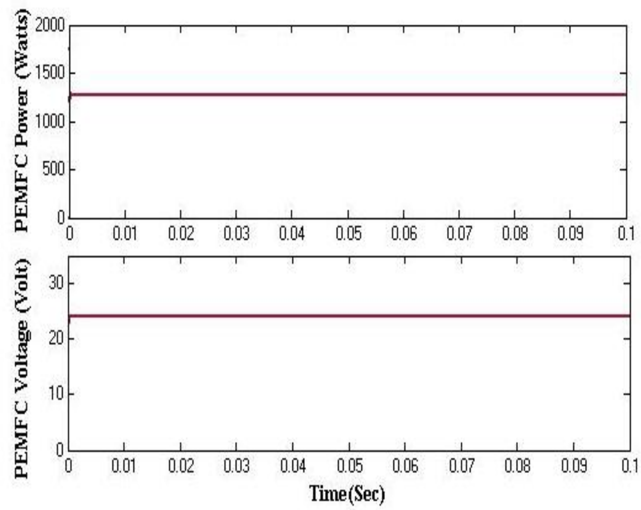


**Fig. 9.** PEMFC output voltage and power with DMOA-MPPT controller.

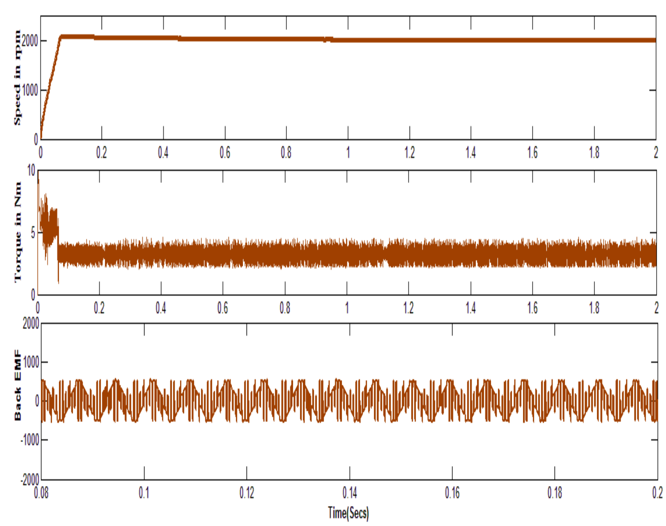


**Fig. 10.** BLDC motor performance analysis in speed, torque and back EMF.

The verification of the BLDC motor performance is presented in Fig. 10 in context to torque, speed and back-EMF. The suggested DMOA-MPPT technique has two primary purposes: regulatory the speed and decreasing torque ripples of BLDC driving. In this study an optimization-based controlling technique is utilized for these objectives which assist to diminish output harmonic distortions as well as power loss. The BLDC motor receives a boost in its performance due to the lowering of noise when an interleaved SEPIC converter is able to handle the output voltage derived from fuel cells. The elements of speed, torque and EMF help in achieving more motor performance.

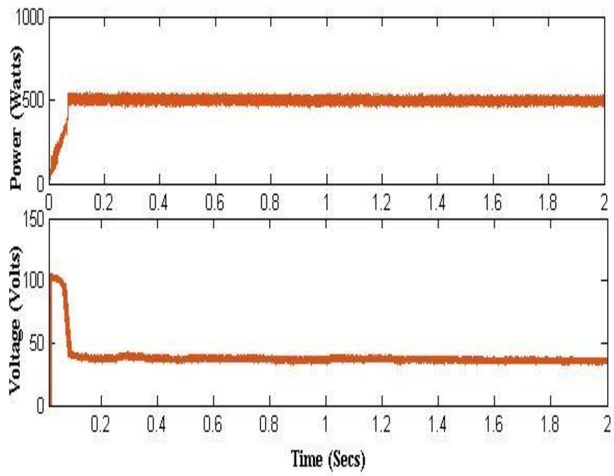


**Fig. 11.** Output characteristics of PEMFC.

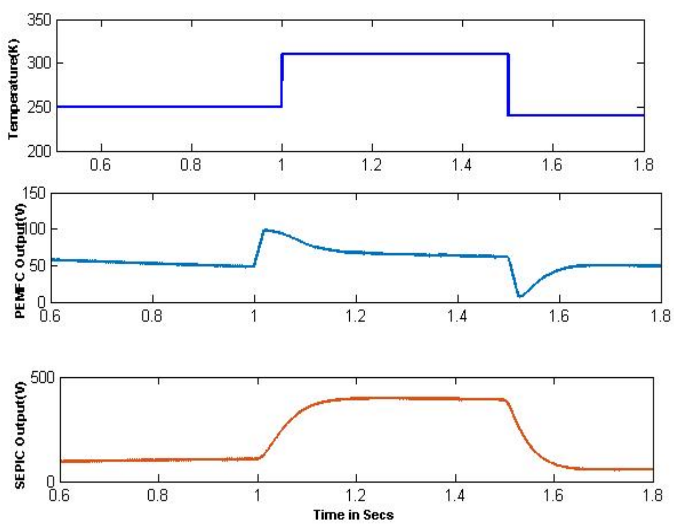


**Fig. 12.** PEMFC voltage comparison in 250K, 310K and 230K temperatures.

This optimization-based approach towards control has been mainly aimed at the improvement of overall efficiency in the BLDC motor through a reduction in harmonic distortions and associated power losses in operation. It can be observed that the introduction of an interleaved SEPIC DC-DC converter yields higher performance of the motor as it provides efficient control of the output voltage extracted from PEMFCs, which also contributes to noise reduction and a much smoother profile of operation. This relationship between speed, torque, and back EMF is very important because these three variables together interact in order to drive the performance and stability of the running drives Fig. 11 represents the output characteristics of PEMFC; it shows the output voltage and power versus time for different intervals of time. The graph has shown that the DMOA-MPPT technique plays a significant role in extracting better power and output voltage from the fuel cells, which proves the fuel cells as the main source of energy in the proposed system. Further, Fig. 12. PEMFC output power as a function of temperature deviation using DMOA Controller under MPPT conditions. Large temperature deviation for example from 0 to 1 second at 250 K, from 1 to 1.5 seconds at 310 K and from 1.5 seconds onward to 1.8 seconds at 230 K shows the dynamic response of DMOA-MPPT controller. These oscillations prove that the DMOA-MPPT algorithm is very effective in following real-time changes for optimum performance of the PEMFC system, and thereby assuring overall efficiency and responsiveness of the energy management strategy. A holistic analysis underlines the effectiveness of the proposed control technique for energy maximization with maintenance of operational stability at a wide range of environmental conditions.

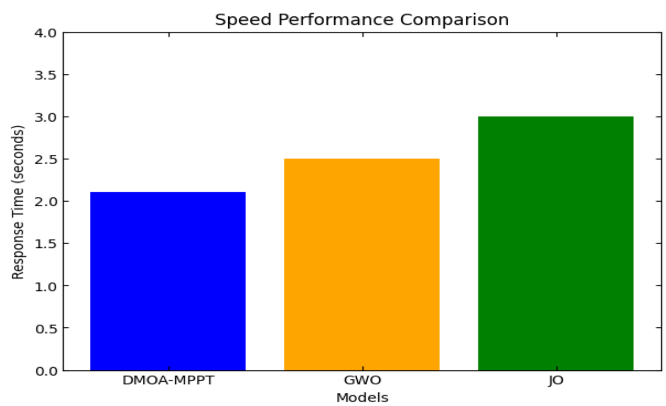


**Fig. 13.** Speed performance comparison of different MPPT with DMOA-MPPT.

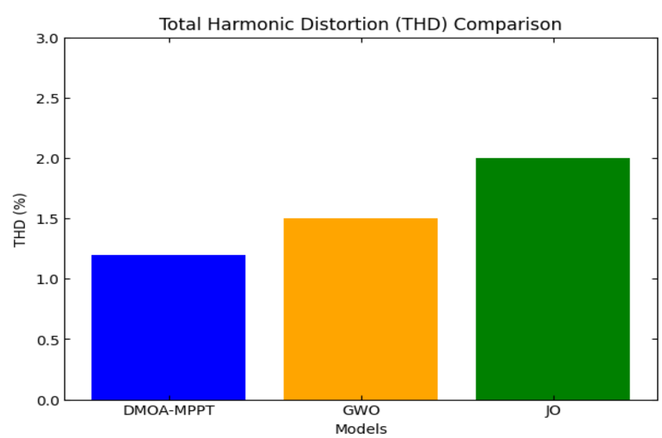


**Fig. 14.** THD comparison of different MPPT with DMOA-MPPT.

In the presented graphic named in Fig. 13 Speed Performance Comparison, it is possible to compare response times of the DMOA-MPPT model with two reference models. The results signify that DMOA-MPPT model has improved speed performance by making minimum response time, therefore, able to track MPPT with additional speed. This improved responsiveness is essential in change circumstance like fluctuating solar intensity conditions because it improves the power collection efficiency. THD Comparison displayed in Fig. 14 compare the Total Harmonic Distortion (THD) of the DMOA-MPPT model with the reference models. The findings suggest that while implementing the DMOA-MPPT model that ensures the servo-voltage control is achieved, the output power is near the ideal of a sinusoidal waveform with much lower THD. This characteristic is crucial for operation together with various electrical systems and for increasing the quality of the generated power which in its turn increases the endurance and reliability of the energy systems in which it is used. The numerical comparison of the MSE, RMSE, Tracking Efficiency and Convergence Time in different methods with DMOA-MPPT is shown in Table 4. Compared to the different optimization methods, the proposed controller increased the Tracking efficiency of 94.2% to 98.9%.

**Table 4.** Comparative performance metrics of various optimization methods with proposed DMOA –MPPT method

| Method | MSE (V) | RMSE (V) | Tracking Efficiency (%) | Convergence Time (ms) |
|---|---|---|---|---|
| P&O | 0.0132 | 0.1149 | 94.2 | 120 |
| GA | 0.0087 | 0.0933 | 96.8 | 160 |
| PSO | 0.0063 | 0.0794 | 97.5 | 140 |
| **DMOA** | **0.0038** | **0.0616** | **98.9** | **100** |

**Table 5.** Analysis of converges from 0.35 to 0.448 within 60 iterations for Optimal DMOA-MPPT

| Iteration (t) | Candidate Duty (D) | Measured Power (P) (W) | Best Power (W) | Improvement (%) |
|---|---|---|---|---|
| 0 | 0.35 | 445.2 | 445.2 | — |
| 10 | 0.41 | 471.8 | 471.8 | +5.97 |
| 20 | 0.43 | 488.6 | 488.6 | +3.56 |
| 30 | 0.44 | 496.1 | 496.1 | +1.53 |
| 40 | 0.445 | 499.0 | 499.0 | +0.58 |
| 50 | 0.447 | 499.7 | 499.7 | +0.14 |
| 60 | 0.448 | 499.9 | 499.9 | +0.04 |
| **Optimal (DMOA)** | **0.448** | **500.0 W** | **500.0 W** | **98.9 % Tracking Efficiency** |

The duty cycle rapidly converges from 0.35 to 0.448 within 60 iterations, achieving near-maximum PEMFC power (500 W at 400 V) shown in Table 5. The power curve flattens after iteration 50, demonstrating DMOA's stable convergence and minimal oscillation around the MPP.

## 5. Conclusion

This work proposed a novel energy harvesting approach for EVs using a DMOA-based MPPT controller for PEMFCs. Integrated with an interleaved SEPIC converter and a three-phase inverter-driven BLDC motor, the system achieved efficient voltage regulation and minimized power losses. Simulation results confirmed superior performance in convergence speed, tracking accuracy, and THD, with a maximum output of 500 W at 400 V and 2000 rpm. Compared to traditional MPPT methods, the proposed DMOA-based controller demonstrates superior responsiveness and stability, consistent with recent findings in fuzzy and neural-based MPPT systems.

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