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# IMPROVING THE PERFORMANCE OF MPPT SYSTEMS THROUGH INTELLIGENT METAHEURISTIC BALANCED LEARNING APPROACH

[1]Sudhanshu Sharma, [2]Prof (Dr) Sukhvinder Kaur, [3]Mr. Prabh Simranjeet Singh

[1]Student, [2]HOD, [3]Principal

[1]EEE/EE,

[1]Swami Devi Dyal Institute of Engineering and Technology, Haryana, India

*Abstract:* This research paper presents a novel approach for maximum power point tracking (MPPT) in solar panels using a combined Artificial Neural Network (ANN) and Jaya algorithm-based model. The aim of this study is to overcome the limitations and challenges associated with traditional MPPT techniques and enhance the performance of solar panels in terms of efficiency, stability, and adaptability. Additionally, the integration of fuel cells as an alternate energy source is explored to ensure continuous power supply in the absence of solar irradiance. The proposed ANN-Jaya model is developed and validated through extensive simulations and comparisons with conventional MPPT models in MATLAB Software. The model's performance is evaluated based on various parameters, including voltage, current, power generation, and battery state of charge. The results demonstrate the superiority of the proposed model, as it consistently generates stable and optimal outputs, minimizing oscillations and maximizing power generation.

***Index Terms* – EVs, MPPT Tracking, Optimization Algorithms etc.**

## I. INTRODUCTION

The transportation sector plays a significant role in global energy consumption and greenhouse gas emissions. As concerns about climate change and air pollution continue to grow, there is an increasing demand for cleaner and more sustainable modes of transportation [1]. Electric vehicles (EVs) have emerged as a promising solution to address these challenges by offering a viable alternative to traditional internal combustion engine vehicles. EVs are powered by electricity stored in rechargeable batteries, eliminating the need for fossil fuels and reducing tailpipe emissions [2,3]. They offer several advantages, including lower operating costs, reduced dependence on oil, and improved energy efficiency. The integration of photovoltaic (PV) systems with electric vehicles (EVs), has gained significant attention in recent years. PV-EV systems combine the advantages of solar power generation and electric mobility, offering a sustainable and renewable solution for transportation [4,5]. In such systems, solar panels are used to harness sunlight and convert it into electrical energy, which is then used to charge the EV's battery. The role of PV-EV systems is multifaceted and holds great promise for the future of sustainable transportation. Firstly, PV-EV systems enable the generation of clean and renewable energy to power electric vehicles. By utilizing solar energy, PV-EV systems reduce dependency on fossil fuels, thereby reducing greenhouse gas emissions and mitigating the environmental impact associated with traditional vehicles [6]. Moreover, PV-EV systems offer the advantage of energy self-sufficiency. The ability to generate electricity from solar panels means that EV owners can rely on renewable energy sources for charging their vehicles, reducing their dependence on the power grid [7]. This independence not only contributes to a more sustainable energy ecosystem but also provides a sense of autonomy and resilience to EV owners, particularly in areas with limited charging infrastructure.

In the context of PV-EV systems, Maximum Power Point Tracking (MPPT) techniques are essential for ensuring efficient energy harvesting from solar panels. Solar panels have a unique operating characteristic where their output power varies with changes in solar irradiance and temperature [8]. MPPT techniques are designed to continuously track and maintain the solar panel's operation at the MPP, maximizing the energy conversion efficiency. By continuously monitoring and analysing the voltage-current (V-I) characteristic of the solar panel, MPPT algorithms determine the optimal operating voltage and current that result in the maximum power output. Moreover, MPPT techniques help overcome the inherent limitations of solar panels, such as non-linear behaviour and varying environmental conditions. These techniques enable the PV-EV system to adapt to fluctuations in solar irradiance, shading effects, temperature variations, and partial shading conditions, ensuring that the solar panels operate at their highest possible efficiency and power output. Numerous MPPT techniques have been proposed and studied over the years, each with its advantages and limitations [9, 10]. In recent years, researchers have explored the integration of advanced computational techniques and optimization algorithms to overcome the limitations of traditional MPPT techniques. Artificial Intelligence (AI) and machine learning algorithms, such as Artificial Neural Networks (ANNs) and Genetic Algorithms (GAs), have shown promise in enhancing

MPPT performance by providing adaptive and robust control mechanisms. These algorithms possess the ability to learn and adapt from the data, making them well-suited for dynamic and non-linear systems like solar panels.

The remainder of this paper is organized as follows: Section 2 provides an overview of the related literature and existing MPPT techniques. Section 3 presents the methodology and describes the proposed ANN-Jaya model. Section 4 presents the simulation results and performance analysis of the proposed model. Finally, Section 5 concludes the paper and outlines future research directions.

## II. Literature Survey

In recent years, numerous authors have put forth a range of MPPT approaches to optimize the power extraction capability of solar panels. This section delves into a selection of cutting-edge techniques that have been recently proposed and explores their potential in maximizing power output. **Phanden, Rakesh Kumar, et al. [11]**, proposed an enhanced Ant colony optimization (ACO)-based method for tracking MPP in PV systems. Results revealed that their suggested model showed good results than other similar approaches. **Chao, Kuei-Hsiang, et al. [12],** combined two optimization algorithms i.e., GA and ACO for enhancing the working of MPPT techniques. Their hybrid models showed improved results than P&O and standard ACO methods. **K. Fatima et al. [13],** proposed ANN based MPPT technique for tracking down the maximum power in solar PV panels. They used PI controller for supplying data to ANN and boost duty cycles to improve overall stability of the model. Results revealed that their model had an efficacy of 94.5%. **Abdullah, Ahmed G., et al. [14],** presented a NN based MPPT approach wherein P&O technique was used for developing standalone PV system connected with DC boost converter using MPPT. Likewise, **M. Premkumar, et al. [15],** employed a Whale Optimization algorithm (WOA) based MPPT approach when PV system was subjected to change in shade pattern. Results revealed that suggested model had faster convergence rate and tracking efficiency than other similar approaches. **Parimita Mohanty, et al. [16],** reviewed various MPPT techniques implemented to solar PV systems and developed an effective MPPT technique. The authors utilized different temperature and irradiance circumstances for different MPPT approaches. **S. Padmanaban et al. [17],** integrated PSO and ACO optimization algorithms for tracking the MPPT in solar PV systems. Results revealed that their suggested model is simpler, efficient accuracy and low computational complexity. **X. Ma, et al. [18],** proposed an improved GWO model for tracking the MPP in solar panels. The outcomes demonstrated that the proposed mechanism was successful in boosting tracking accuracy up to 99.88 percent, reducing voltage change by up to 158 volts, and improving tracking stability and a 0.46 percent reduction in tracking time. Also, **Neeraj Priyadarshi, et al. [19],** fuzzy logic control based on PSO were proposed for achieving the optimal control in PV systems. **S. K. Saha et al. [20],** proposed an MPPT techniques that was based on fuzzy logic system and P&O MPPT technique. The outcomes demonstrated the superior performance of MPPT based on FLC.

After conducting an analysis of the literature survey, it is evident that numerous techniques have been proposed in the past for tracking the maximum power point in solar panels. However, a significant drawback of the majority of these systems is the occurrence of large oscillations, which adversely affect the overall system performance. To address this issue, some researchers have incorporated optimization-based algorithms in their work. Nonetheless, these algorithms suffer from two key problems: slow convergence rate and a tendency to become trapped in local minima when searching for global solutions. Additionally, these models are unable to provide power to loads during periods of insufficient sunlight or low wind speeds. These factors emphasize the necessity for the development of a new and robust MPPT strategy that can effectively overcome these limitations.

## III. Proposed Work

This research presents a new MPPT approach designed to overcome the limitations of conventional models. The proposed model focuses on two key phases: MPPT and energy sources, with the primary objective of ensuring adequate power supply to the loads. In the MPPT phase, an Artificial Neural Network (NN) based technique is employed to enhance solar panel efficiency and reduce output oscillations. However, optimizing the initial weights and hyperparameters of the NN is crucial for achieving optimal performance. To address this, the Jaya algorithm, known for its ability to solve both constrained and unconstrained problems, is incorporated in the proposed work. The Jaya algorithm's reputation for maximizing or minimizing functions, coupled with its parameter-free population-based nature, makes it an ideal choice. Moreover, Jaya algorithm is used because it has high convergence rate and doesn't get trapped in local minima. The output of the solar panel is maximized by integrating ANN-Jaya MPPT technique. The circuitry diagram of suggested ANN-Jaya model is shown in figure 1. The envisioned hybrid Jaya-ANN model's Simulink diagram is shown in the above figure. The design is made up of a number of parts, including solar panels with two inputs: temperature and irradiance. A DC-DC boost converter and associated resistive loads are also included in the system. The solar panels are given inputs of 700W/m2 of solar irradiation and 25 degrees Celsius of temperature to facilitate model execution. The solar energy is subsequently transformed into electrical energy by the solar panels. In the proposed work, an improved MPPT technique is used to guarantee that the solar panels' potential power is utilized to the fullest extent possible.

The DC-DC boost converter controls the power supply and makes it easier for it to be transmitted to the load so that it can be charge. Furthermore, it was observed that existing models fail to provide necessary supply to loads in absence of sunlight. Therefore, in the second phase, additional energy sources i.e., fuel cell is integrated to ensure power supply when sunlight or irradiance is insufficient. This integration enhances system performance and enables energy storage during periods of low sunlight. Additionally, a comprehensive analysis of various energy storage systems including batteries, supercapacitors, and fuel cells will be conducted to assess their effectiveness in improving overall system performance. By combining the strengths of neural networks, the optimization capabilities of the Jaya algorithm, and advanced energy storage technologies, the proposed approach aims to maximize solar panel output efficiency and stability. This approach effectively overcomes the limitations of traditional methods, enabling optimized power generation even in challenging operational conditions. Figure 2 illustrates the Simulink diagram showcasing the integration of the proposed MPPT model based on ANN-Jaya algorithm, with a fuel cell connected to it.

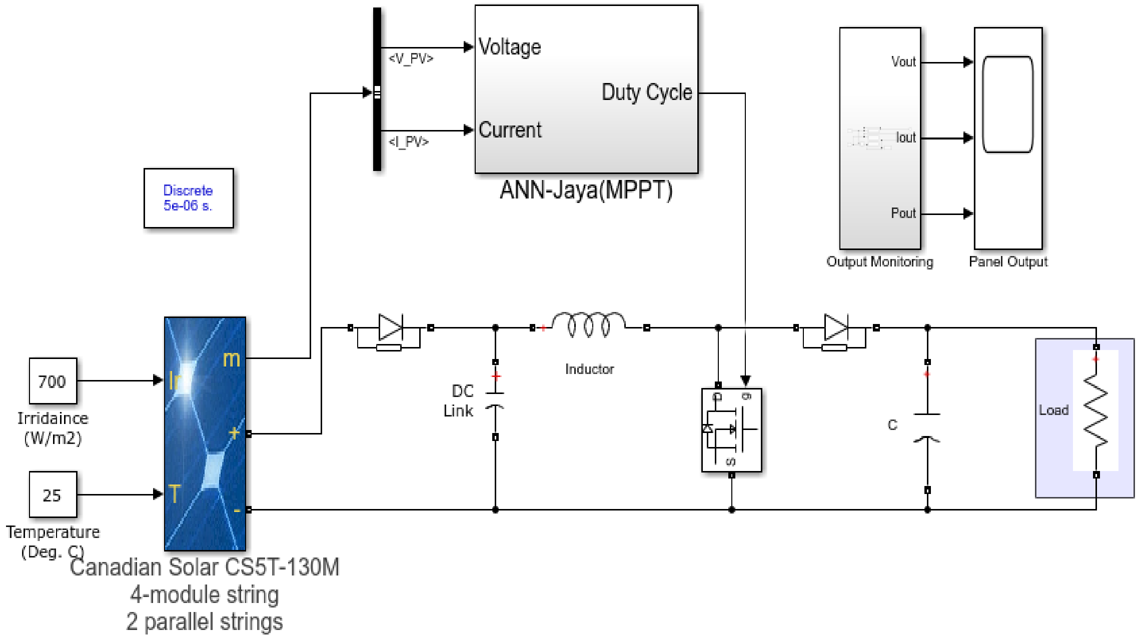


Figure 1. Proposed ANN-Jaya Model Circuit Diagram for Load Incorporation

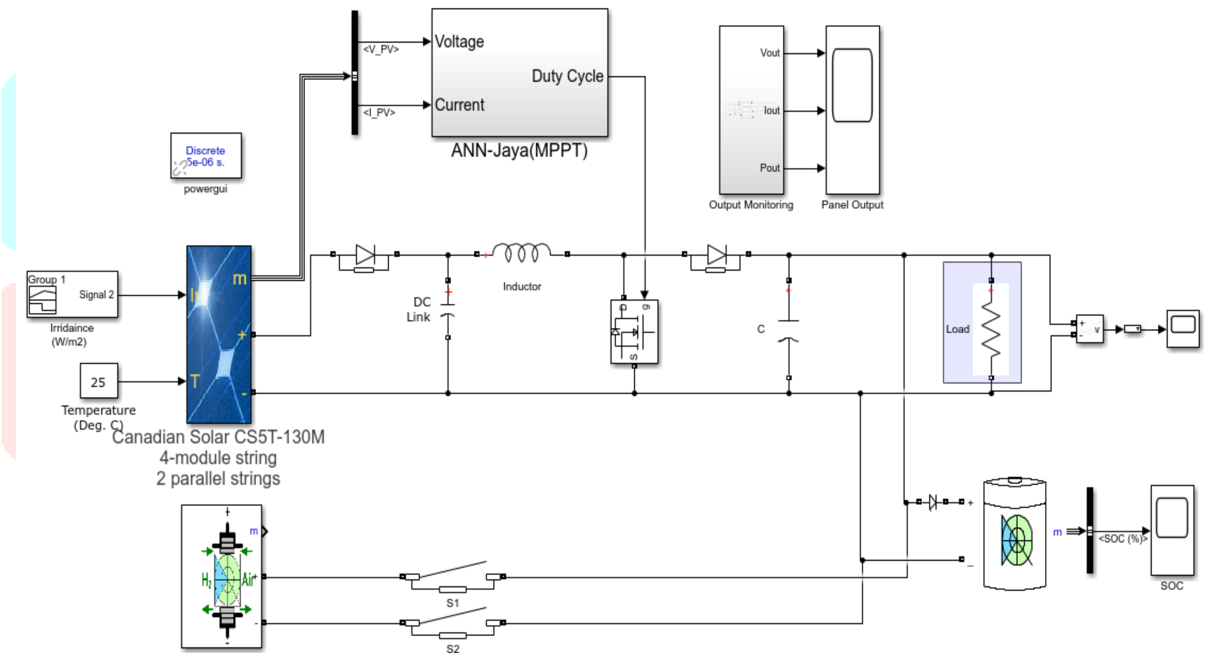


Figure 2. Proposed ANN-Jaya model with Fuel cell

All the constituents of the model remain unchanged; the sole augmentation lies in the incorporation of a fuel cell. The Maximum Power Point (MPP) of the solar panels is traced by the ANN-Jaya algorithm. The fuel cell employed within the system functions as an alternative energy reservoir, delivering power to the loads during instances of solar irradiance unavailability. A comprehensive elucidation of the operational mechanism pertaining to the proposed ANN-Jaya model can be found in the subsequent section of this paper.

# I. Methodology

The proposed MPPT approach undergoes several distinct phases to accomplish the desired outcomes. In this section of the paper, we will delve into a detailed examination of the step-by-step process employed by the proposed model.

- **Step 1:** Initially, it is essential to establish diverse parameters such as peak power, parallel arrays, voltage, temperature, and so on, for the solar panels. The values of these parameters, along with other pertinent ones, employed in the solar panel, are defined in table 1.

Table 1: Parameters of Solar Panels

| Parameters | Values |
|---|---|
| Parallel Strings | 2 |
| Series connected modules per string | 4 |
| Module | Canadian Solar CSST-130M |
| Maximum power | 129.94 |
| Open circuit voltage Voc (V) | 36.3 |
| Voltage at maximum power point Vmp (V) | 29.2 |
| Temperature coefficient of VoC (%deg.C) | -0.36581 |
| Cells per module (Ncell) | 60 |
| Short circuit current Isc (A) | 4.82 |
| Current at MPP Imp (A) | 4.45 |
| Temperature coefficient of Isc (%deg.C) | 0.045996 |

Moreover, we have also added a load to the suggested circuit in the form of an electric vehicle (EV). The existing structure is intended to recharge the lead acid battery of the EV. Table 2 lists the EV's different battery parameters.

Table 2: EV battery parameters

| Parameters | Values |
|---|---|
| Type | Lead Acid |
| Nominal Voltage (V) | 48 |
| Rated Capacity (Ah) | 6 |
| Initial state of charge (%) | 80 |
| Battery response time (s) | 5E-6 |

- **Step 2:** Once the model is initialized, it is time to extract maximum power from solar panels as solar irradiance fluctuates. In the suggested work, the ANN-Jaya algorithm has been employed to complete this task.
- **Step 3:** After this, Dc-DC boost converter is utilized in the proposed model for regulating and stabilizing the duty cycles. This DC-DC converter improves the conversion of voltage from one level to another in order to prevent users from sudden voltage spikes.
- **Step 4:** This controlled power source is then used to provide power to the resistive load and EV batteries for charging. This electricity is used by the EV to charge its batteries as well as provide necessary power to loads.
- **Step 5:** Moreover, we have incorporated fuel cells as an alternative energy source to ensure the provision of required power to the loads during periods of insufficient solar irradiance. When there is no solar radiation, this fuel cell is in charge of supplying essential power to loads, which in turn refills the batteries. The diverse parameters of the fuel cells utilized in the system are documented in tabular format, as depicted in Table 3.

Table 3: Parameters of Fuel cell

| Parameters | Values |
|---|---|
| Preset model | AFC-204kW-48Vdc |
| Model detail level | Detailed |
| Voltage at 0A and 1A | [64.6, 64] |
| Nominal operating point | [50,48] |
| Maximum operating point | [62,46] |
| Number of cells | 68 |
| Nominal stack efficiency | 56 |
| Operating temperature (c) | 65 |
| Nominal Air Flow (lpm) | 300 |
| Nominal supply pressure | [6,1] |

- **Step 6:** Lastly, the effectiveness and efficiency of the proposed ANN-Jaya model are assessed and verified by conducting a comparative analysis with conventional models using MATLAB software. The results for the suggested ANN-Jaya model are discussed in more detail in the following portion of this paper.

## IV. Results And Discussion

In this section, the paper showcases the results obtained for the proposed model, demonstrating its superiority over other existing models. The performance of the proposed model is thoroughly evaluated and validated using the MATLAB software. Simulated outcomes are achieved and compared with traditional models in terms of their voltage generation, current production, and power generation capabilities.

### 4.1 Performance Analysis

The efficacy of the proposed model is proved and validated by comparing with traditional ACO model in terms of their voltage generating ability. The comparative graph obtained for the same is shown in figure 3. Upon careful analysis of the provided graph, it becomes apparent that the proposed ANN-Jaya model consistently produces a stable voltage output of 90V without any fluctuations over its entire duration. In contrast, the traditional ACO model exhibits significant voltage fluctuations, posing a potential risk to batteries and output loads.

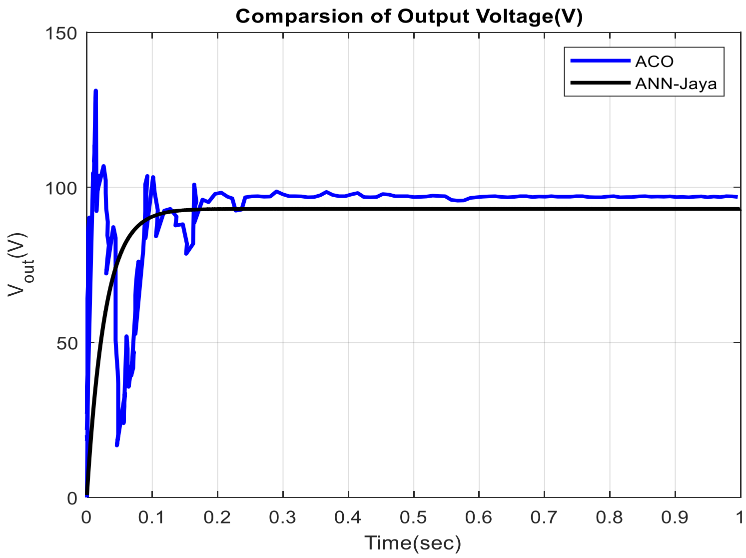


Figure 3. Comparative graph for output voltage

Furthermore, we conducted an analysis and comparison of the proposed ANN-Jaya approach and the traditional ACO model in terms of their current generation capabilities. The resulting comparison graph is displayed in Figure 4. The graph reveals that the traditional ACO model exhibits significant fluctuations in current values, rendering it unsuitable for batteries. The spikes generated in the current values of the traditional ACO model can potentially damage EV batteries or other loads, making it not recommended for practical use. In contrast, the proposed ANN-Jaya model consistently generates a constant and stable current output, ensuring the safety of batteries and effectively charging them.

Furthermore, we conducted a comprehensive examination and validation of the proposed ANN-Jaya model compared to the conventional ACO model in terms of their power generation capabilities. The obtained comparison graph is displayed in Figure 5. Upon careful analysis of the graph, it can be concluded that the power output in the proposed ANN-Jaya model swiftly increases from 0W to over 600W in just 0.1 seconds, with no fluctuations observed throughout. In contrast, the traditional ACO model exhibits significant power fluctuations until 0.2 seconds and then attempts to stabilize at 600W. These comparative results for output voltage, current, and power vividly illustrate the effectiveness of the proposed ANN-Jaya approach, which consistently generates stable and constant values for all parameters, facilitating effective battery charging.

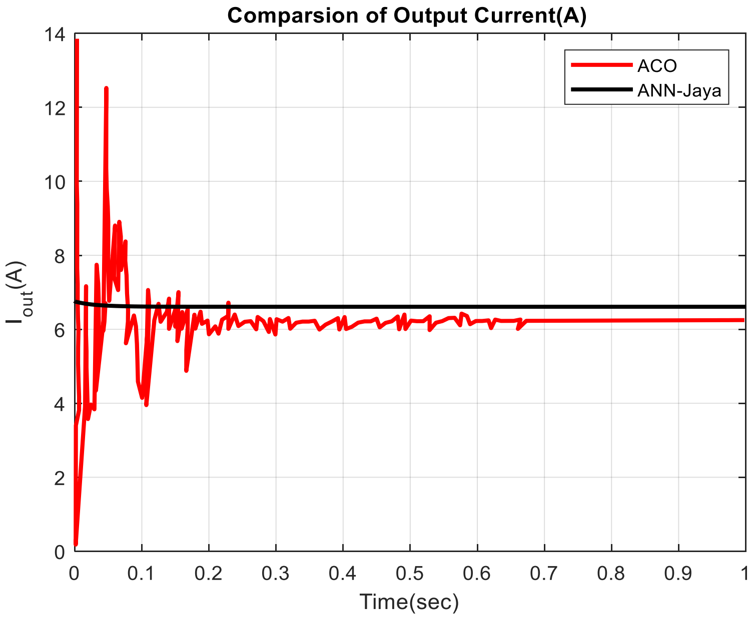


Figure 4. Comparative graph for output current

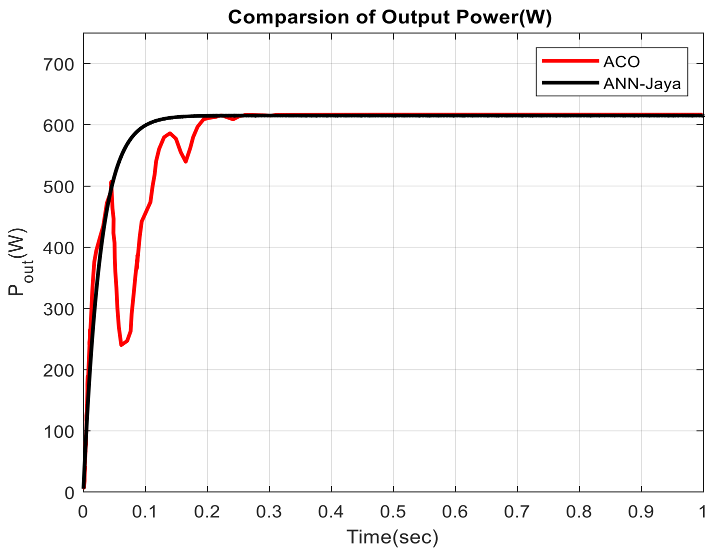


Figure 5. Comparative graph for Power

Furthermore, we conducted a comprehensive examination and validation of the proposed ANN-Jaya model compared to the conventional ACO model in terms of their power generation capabilities. The obtained comparison graph is displayed in Figure 5. Upon careful analysis of the graph, it can be concluded that the power output in the proposed ANN-Jaya model swiftly increases from 0W to over 600W in just 0.1 seconds, with no fluctuations observed throughout. In contrast, the traditional ACO model exhibits significant power fluctuations until 0.2 seconds and then attempts to stabilize at 600W. These comparative results for output voltage, current, and power vividly illustrate the effectiveness of the proposed ANN-Jaya approach, which consistently generates stable and constant values for all parameters, facilitating effective battery charging.

Furthermore, fuel cells have been utilized in the proposed model for providing necessary supply to loads when solar irradiance is low. Figure 6 shows the comparison graph for the same. By analyzing the provided graph, it is evident that initially, the solar system operates efficiently until 0.4s, delivering a voltage of 50V. However, immediately thereafter, the solar irradiance diminishes rapidly, ultimately reaching zero. Consequently, the proposed system ceases to generate any voltage from 0.5 to 0.7s. At the onset of 0.7s, the fuel cell activation is initiated, resulting in a resumption of voltage output, rising from 0V to 55V consecutively. This highlights that when the solar module becomes incapable of generating voltage for the loads, the fuel cell serves as a savior, supplying the necessary power to the loads for charging purposes.

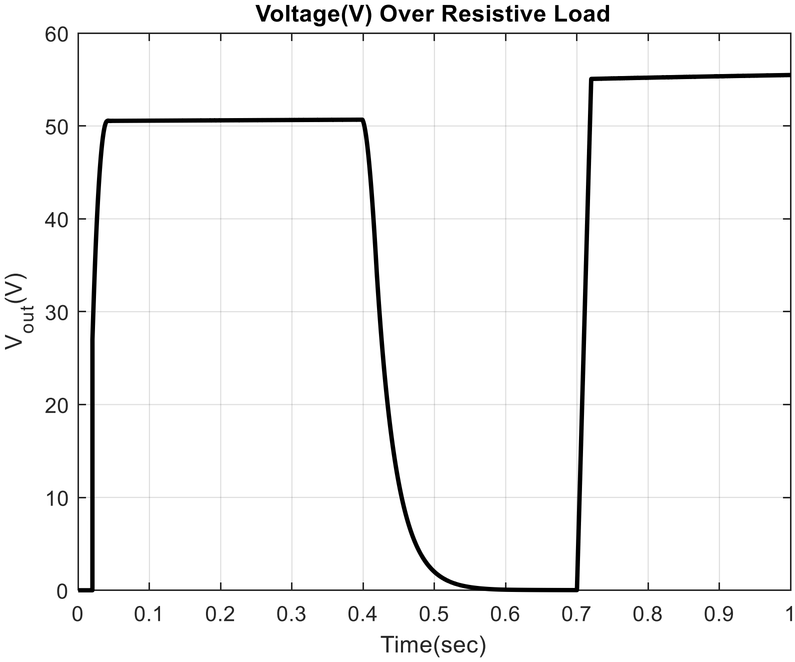


Figure 6. Voltage over resistive load

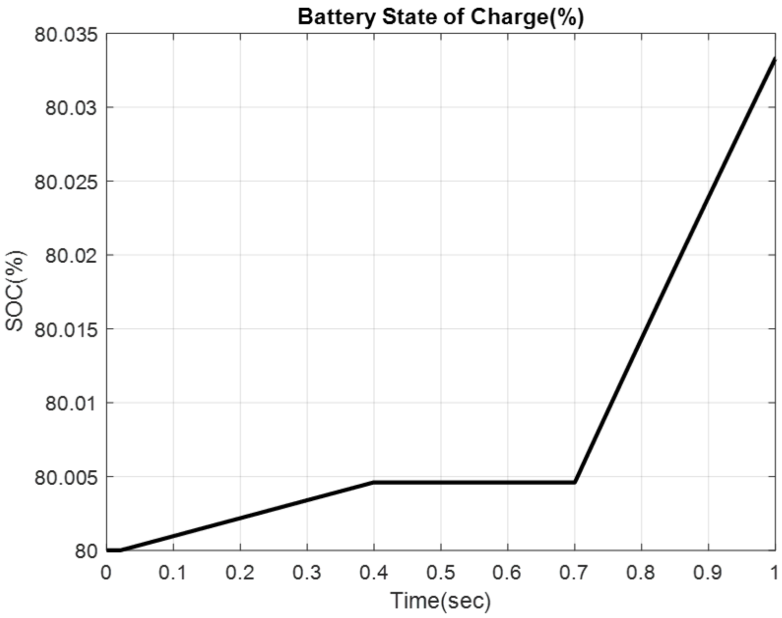


Figure 7. Graph for Battery SOC

Additionally, a thorough analysis and validation of the proposed ANN-Jaya model is conducted by examining the battery state of charge (SOC). The obtained graph for the battery SOC with both solar and fuel cell connections is presented in Figure 7. Upon examining the graph, it becomes apparent that the battery undergoes effective charging until 0.4s when the solar module is actively providing power. However, once the solar module ceases to supply power, the battery SOC remains stable at 80.005%. Shortly after this, the battery resumes charging as the fuel cell becomes connected to it. The batteries are efficiently recharged, resulting in the battery SOC increasing from 80.005% to above 80.03%. This demonstrates that the batteries are effectively charged even in the absence of solar module operation.

## V. Conclusion

This paper presents an improved MPPT approach wherein ANN and Jaya algorithms were used together for tracking the Maximum power in solar panels. The proposed model addresses the limitations and challenges associated with traditional MPPT techniques by integrating the strengths of neural networks and the optimization capabilities of the Jaya algorithm. Through extensive simulations and comparisons with conventional models, the superiority of the proposed ANN-Jaya model has been demonstrated. The model consistently generates stable and optimal voltage, current, and power outputs, ensuring efficient charging of batteries and reliable power supply to the loads. The utilization of fuel cells as an alternate energy source further enhances the robustness and reliability of the system, providing continuous power supply even in the absence of solar irradiance. The ANN-Jaya model outperforms traditional models by eliminating oscillations, improving stability, and maximizing power generation under diverse operating conditions. The proposed ANN-Jaya model serves as a foundation for future research and development in the optimization of power generation systems, ensuring the sustainable and efficient utilization of solar energy.

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