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Original Article

An Improved Current Control Charging Scheme Using Neuro-fuzzy and Fopid Based Mppt System for EV Charging

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***Abstract** - In this paper, a novel and enhanced current control method is proposed that is based on the adaptive neuro-fuzzy inference system (ANFIS) and fractional order proportional integral derivative (FOPID) systems. The main contribution of this paper is to reduce the oscillations and increase the efficiency, response time, and lifespan of the battery by providing optimum current to the batteries. For this, an intelligent neuro-fuzzy system is utilized in the model that takes power & voltage error and power& voltage change in error as two inputs to give a single output of reference voltage. Any voltage below or above the reference voltage can damage the battery of the EV. To tackle this issue, MPPT and De-rating operations are performed in the proposed work when the output voltage is below and above the reference voltage, respectively. In addition to this, the FOPID controller produces control signals that improve response time and efficiency of the entire system. The efficacy of the suggested hybrid ANFIS-FOPID approach is analyzed and compared with the state of an art method in the MATLAB software. The simulated outcomes determine that the proposed ANFIS-FOPID model is more efficient and convenient for charging the batteries of EVs.*

Keywords — *Electrical vehicles, Battery charging issues, FOPID controller, renewable energy, Intelligent systems, etc.*

I. INTRODUCTION

The evolution of human civilizations in the twenty-first century faces two fundamental impediments, one is related to the increasing energy demand, and the other is related to the environment[1]. The dependence of traditional vehicles on fossil fuels as the primary energy source leads to a rise in market prices of oil and energy and is considered a significant challenge in the automobile sector. The automobile sector releases a huge amount of carbon dioxide into the atmosphere, triggering greenhouse gas (GHG) concentrations to rise significantly [2]. At present, around 23% of the CO2 emissions are released by vehicles and are expected to increase up to 40% by the end of 2040. Suppose necessary steps towards the development of Electric mobility are not taken. Almost every sector of the country is attempting to minimize their respective GHG emissions by utilizing eco-friendly resources. Among all the sectors, electric mobility or e-mobility is the one sector that’s mostly driven by climatic actions[3]. As a result, the necessity to replace traditional vehicles with electric vehicles (EVs) arises in order to address climatic difficulties, prevent premature deaths, or address any other impediment related to the usage of conventional fuels. [4].

The concept of electric vehicles is not new, as the first electric car was driven in the late 1830s with no concept of battery recharging. Electric cars have not yet experienced the widespread popularity that of internal combustion (IC) vehicles, which typically have the capability to cover larger distances and are simple and convenient to refuel. Over the years, various types of electric vehicles have been developed based on battery advancement, electronics, and various control technologies. The main reasons behind electrifying this sector are the increase in greenhouse gas emissions and oil prices[5]. However, the major challenge for researchers is the charging of these vehicles. An electric vehicle (EV) can be recharged by either AC power or DC power. It is extremely important to decide which charger should be used for recharging EVs, especially in countries where the probability of installing any private charging facility is minimum. Basically, there are two types of chargers, one is called an on-board, and another is called an off-board charger. The onboard chargers, also called AC chargers, are deployed inside the vehicle and are capable of charging the electric vehicle when there is an unavailability of power. The onboard chargers have certain limitations like weight, space, and high cost, due to which they are not used widely in EVs.On the other hand, off-board chargers, also called DC chargers, provide a fast charging facility and are used widely. Irrespective of the fact that these charging stations are very costly, these stations provide some essential facilities such as being light-weight, able to charge at higher power levels, fast charging capability, an enhanced mechanism for battery management such as heating concerns [6].

A. Solar PV arrays and EVs

As the main motive of the researchers is to decrease the GHG emissions and increase the stability of EVs, therefore it is necessary to opt for a clean energy resource like solar energy. The energy generated from the Photovoltaic solar energy panels (PV- arrays) has already been proven to be an effective option. With the growing popularity of electric vehicles, it is expected that the power produced by Photovoltaic solar panels can be used for charging and grid assistance. A majority of researches have been provided to demonstrate that installing solar panels on the roofs of parking areas to charge electric vehicles is a good idea. Furthermore, these photovoltaic solar systems can provide feasible transactions in V2G systems and optimum production scheduling in order to minimize the functional cost and increase the operational feasibility of electrical grid systems [7]. The solar energy is converted into electrical energy by utilizing semiconductor cells in a PV system. The PV system comprises a PV panel, a tracking system, an AC/DC power converter which is also called an inverter, electrical interconnections, and mounting for several other parts. Based on the desired variable, voltage, or current, the PV panel is linked in series or parallel [8][9]. Moreover, the PV panel has low efficiency, so it cannot provide a large amount of power, prompting the use of MPPTsystem. Then in a renewable energy system (RES), the power electronics is applied for comparing the PV panel's output voltage with the threshold value that is fixed close to the load value, and for regulating voltage in DC/DC converter, an error signal is applied. To provide extra power during the night or in gloomy weather, a battery pack is connected to the PV system. Whenever the power produced from the PV array is more than maximum power, the battery is employed as an energy buffer that can store energy. On the other hand, when power generated by solar power is much less than the desired load power, the battery pack would be discharged to meet persistent load demands [10].

Maximum Power Point Tracking (MPPT) systems are an essential part of a solar Photo Voltaic system, regardless of the fact that, whether one or more energy sources are used. As PV solar energy is nonlinear, it necessitates the need for an intermediary converter with a controlled algorithm in order to run the Photovoltaic cells at their maximum power point (MPP) under varying environmental scenarios. Different methods were proposed to monitor the MPP in a system like P&O, incremental conductance, Hill-climbing, open-circuit voltage methods. In addition to this, some smart algorithms were also developed to track the MPP in a system which includes fuzzy control, artificial neural networks, and genetic algorithms. This paper presents an overview of the need for electrical vehicles and problems in current systems. The remaining section of this paper represents the literature review in section Ⅱ, followed by the proposed work and results and discussions in sections Ⅲ and Ⅳ. Finally, a conclusion is also added in section Ⅴ.

II. RELATED WORK

Over the years, a large number of methods have been proposed that can effectively charge the batteries of EVs. Some of them are discussed here. H.K.Singh et al. [11] proposed a current-controlled hill-climbing method to track the MPPT of solar PV panels so that the OFF- Board EV lithium-ion batteries can be charged within safety limits. Lee H-S et al. [12] proposed an advanced MPPT algorithm for fast and effective response, low oscillations, and highly efficient tracking of Maximum Power Point (MPP). Singh, Pulkit & Singh, Rajendra et al. [13], Proposed an improved MPPT control technique that is based on ANFIS. The proposed scheme monitors maximum power point (MPP) in solar PV panels with the least response time. Ramesh, Suguna[14] proposed an upgraded P&O maximum power point monitoring and controlling approach along with the super lift Luo converter in order to obtain extract MPP. P. E Sarika et al. [15] suggested a unique approach that is based on zero oscillation, P&O MPPT, and lookup table for independent solar PV panels along with the boost converter to combat the inconsistencies in terminal voltage owing to the differences in operational current and voltage of PV arrays that are caused by the changing light intensity and temperature.M. Aquib, et al. [16], introduced a novel global MPPT (GMPPT) system for systems that are operating under uniform and non-uniform solar irradiation. In this scheme, current and voltage characteristics of solar panels are analyzed to monitor their peak value.A. M. Khatab et al. [17] proposed a battery charger for EVs that is based on the Zeta Converter to track the MPP in the system and increase its efficiency. Sadeq D et al. [18] suggested a unique method that is based on fuzzy logic and P&O methods for tracking the MPP in solar panels. The suggested technique combines the benefits of the P&O-MPPT for accounting for slow and quick variations in solar irradiation with the FL-faster MPPT's computation for complicated technical challenges. S. S. Nadkarni et al. [19] proposed an MPPT technique that's used in the solar PV arrays to address the various temperature and irradiance scenarios. Also, the author used the P&O algorithm along with the Incremental Conductance Algorithm (INC) to extract the MPP from solar PV panels. R.Kanimuthu and P.Madasamy[20] developed an enhanced MPPT tracking approach in which maximum or peak power tilt angle and MPA were utilized in order to minimize the different current and voltage sensors requirements.D.Thamizhthendral, V.ashokkumar, [21] established a grid-connected single-stage converter model by utilizing the Luo converter so that the output and efficacy of the solar panels can be increased and unwanted surges in current are suppressed.

From the literature survey conducted, it is analyzed that the majority of researchers suggested methods for tracking the maximum power point of solar panels. However, these systems were able to track the MPP of solar panels effectively but had several issues that degraded their performance. The conventional methods had huge fluctuations in their voltage, current, and power outputs even when the MPPT operations and De-rating operation were performed on it. This led to an unstable current that can harm the batteries of EVs. Furthermore, the performance of the traditional models was also affected by the limitations like slow rise time, settling time, and response time which further degraded their performance. Inspired by these findings, it is analyzed that there is a need to develop a model that increases the efficiency of the model by decreasing the fluctuations in currency values.

III. PROPOSED WORK

In order to overcome the limitations of the traditional models, an enhanced model is proposed in this paper. In the proposed work, a hybrid model that is based on the Adaptive Neuro-Fuzzy Inference System (ANFIS) and Fractional Order Proportional Integral derivative (FOPID) is used to monitor the MPP in the solar PV panels. The main contribution of this work is to reduce the oscillation in the current so that it can be utilized for charging the batteries of EV without damaging them. The proposed model basically performs two operations; one is MPPT operation, and the second one is De-rating operation. When the current obtained from the solar PV panels is less than the reference current (14A), an MPPT operation is performed that boosts the current value to reference current value so that batteries can be charged effectively. On the other hand, when the solar irradiance is increased to 1000W/m2, and the current is produced in more than the reference current (14A), a De-rating operation is performed, which decreases the current value to its optimum reference value. The circuit diagram of the proposed hybrid ANFIS-FOPID model is given in figure 1.1.

Figure 1.1 represents the circuit diagram of the suggested Hybrid ANFIS and FOPID model in which different components such as solar panels, dc-dc boost converter, EV battery, etc., are installed. The proposed model is designed so that the batteries of EV can be charged effectively and efficiently even when there are multiple EVs that need to be charged simultaneously. This is done by using an intelligent hybrid Neuro-Fuzzy and FOPID model in which two membership variables, i.e., power & voltage error and power & voltage change in error, are taken as two inputs. Figure 1.2 represents the block diagram of the proposed ANFIS model with 2 inputs, 49 rules, and one output.

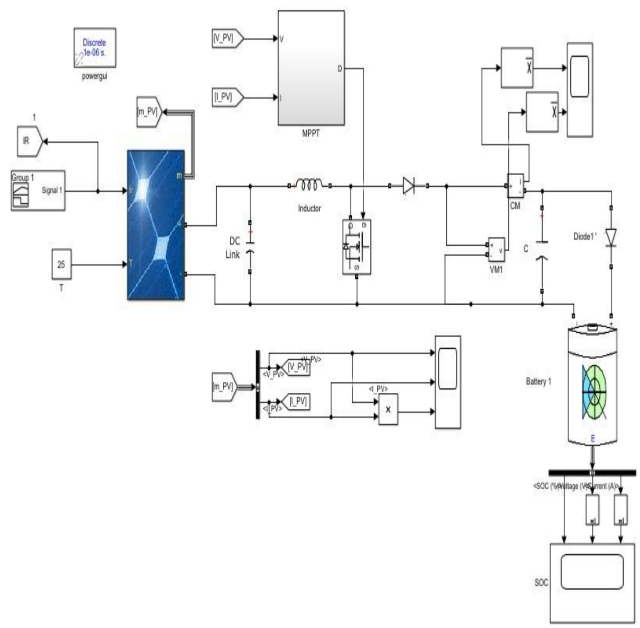

Figure 1.1 Proposed Hybrid ANFIS-FOPID model

The power & voltage error and power & voltage change in error serve as the two inputs for the proposed system. These inputs are then processed by the Sugeno type of ANFIS to yield a single output of reference voltage. Some rules that are defined in the neuro-fuzzy system are given below:

1. If (power & voltage error is NB) and (power & voltage change in error is NB), then (voltage reference is NB)

2. If (power & voltage error is NB) and (power & voltage change in error is NM), then (voltage reference is NB)

3. If (power & voltage error is NB) and (power & voltage change in error is NS), then (voltage reference is NB)

4. If (power & voltage error is NB) and (power & voltage change in error is ZE), then (voltage reference is NB)

5. If (power & voltage error is NB) and (power & voltage change in error is PS), then (voltage reference is NM)

6. If (power & voltage error is NB) and (power & voltage change in error is PM), then (voltage reference is NM)

7. If (power & voltage error is NB) and (power & voltage change in error is PB) then (voltage reference is NS) and so on.

Where NB represents negative big, NS represents negative small, and NM represents negative medium, and PB represents positive big, PM represents positive medium and PS small positive values, ZE represent the Zero.

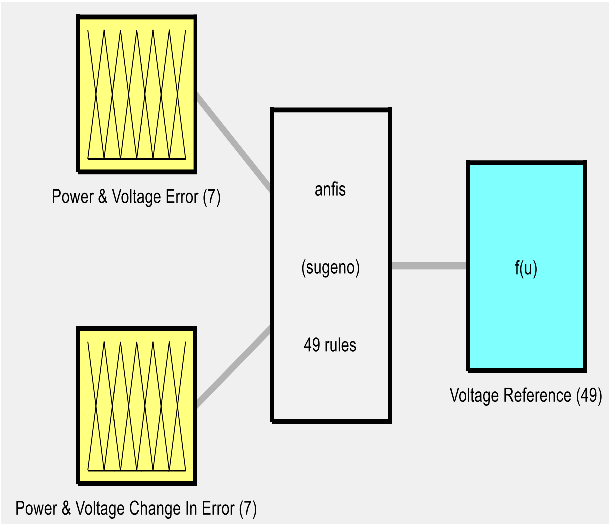

Figure 1.2 Proposed ANFIS model

In addition to this, the rising time, settling time, and response time of the proposed model are enhanced by utilizing the FOPID controller and are depicted in figure 1.3. The FOPID controller generates the three controller signals kp with value 1.856, Ki with value 0.72, and Kd with value 0.5268. In addition to this, lamda and Mu signals are also generated whose values are -0.6778 and 0.5, respectively.

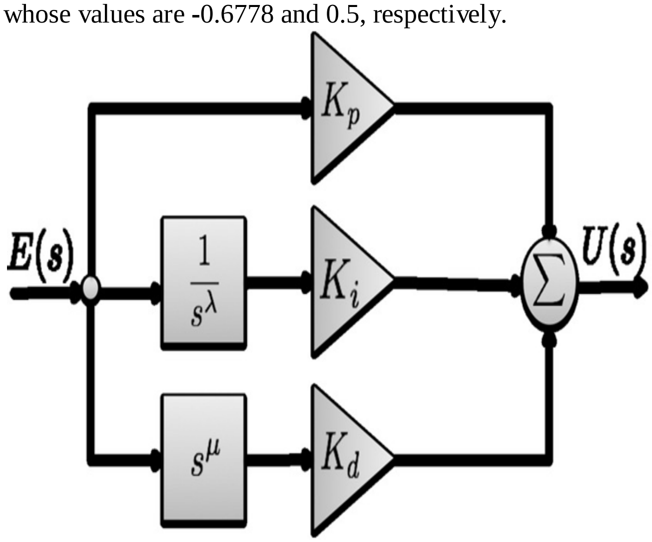

Figure 1.3 FOPID controller [22]

The step-by-step working of the proposed model is given in the followed section of this paper.

A. Methodology

This section presents a brief description of how the proposed hybrid ANFIS-FOPID model works to attain the desired results.

1. In the proposed work, the very first step is to start the network in which different parameters of solar PV panels like solar irradiance, temperature, power, and many other parameters are defined, which are mentioned in table 1.

TABLE I: DIFFERENT SOLAR PV PARAMETERS

Solar Panel Parameter	Value
Input Irridaince (w/m^2)	[850,900,600,1000,700]
Input Tempearture(deg.C)	25
Parallel strings	5
Series-connected modules per string	12
Maximum Power (W)	129.94
Open circuit voltage Voc (V)	36.3
Cells per module (Ncell)	60
Short-circuit current Isc (A)	4.82
Current at maximum power point Imp (A)	4.45
The voltage at maximum power point Vmp (V)	29.2
Temperature coefficient of Voc (%/deg.C)	-0.3651
Temperature coefficient of Isc (%/deg.C)	0.045996

2. In addition, many EV battery characteristics such as voltage, type of battery, SOC, and battery reaction time are specified. Table 2 shows the important precise parameters.

TABLE 2: EV BATTERY ATTRIBUTES

EV Battery Parameter	Value
Type	Lithium-Ion
Nominal voltage (V)	500
Rated capacity (Ah)	7
Initial state-of-charge (%)	80
Battery response time (s)	0.00013

3. Once the network is initialized completely, the sunlight is trapped by the solar PV panels and is converted into electrical power. The power generated is highly fluctuating and hence needs to be modulated before passing it to the next stage.

4. To regulate the power generated by the solar PV panels, an MPPT algorithm based on ANFIS and FOPID is designed that performs the MPPT operation and De-rating operation on it.

5. The decision of selecting which operation needs to be performed on the power is determined by comparing the output power of solar panels with the reference voltage generated by the ANFIS model.

6. The next step is to produce the duty cycles and pass them to the DC-DC boost converter, which boosts the

voltage for its load. The power generated finally should be optimum and near to the threshold voltage.

7. Finally, the efficacy of the developed method is assessed and compared to that of standard methods in terms of voltage, current, and power generation.

IV. RESULTS AND DISCUSSION

This section shows the supremacy of the suggested PV-ANFIS based FOPID model, whose simulations are done in the MATLAB software. Also, the efficacy of the suggested model is also validated by comparing it with the standard PV-Hill-climbing methods for three scenarios; first determines the output of the solar PV panel, second determines the output generated by the DC-DC boost converter, and last depicts the battery SOC in the traditional and proposed model. A detailed description of the results is given below.

A. Performance Analysis

a) Outputs generated by solar PV panels

Figure 1.4 shows the output waveforms of the solar panels where the first graph represents the voltage output of PV panels (Vpv), the second graph produces the current produced by panels (Ipv), and the last graph represents the power produced by the solar PV arrays (Ppv) which is the product of voltage and current (Vpv and Ipv). The graph is obtained under varying solar irradiance, which in turn varies the voltage, current, and power of solar PV panels. After analyzing the graph, it is observed that voltages produced by the two systems are nearly identical in range, with the only variation being oscillation. Even after executing the MPPT and De-rating operations, the voltage produced by the classic PV Hill climbing technique has a huge number of fluctuations, making it problematic for batteries. The voltage produced by the suggested PV-ANFIS-FOPID technique, on the other hand, is steady and does not fluctuate much even when the irradiance changes. Likewise, the value of current is up to 17A between time 0 to 1sec with input irradiance equal to 850w/m2. However, after 1s, the irradiance is increased to 900 w/m2 for 1.5s, and the current generated in this case is around 20A. Moreover, when the solar irradiance is lowered to 600 w/m2 between 1.5-2sec, the current is also decreased to 14A. Again, after 2s, the solar irradiance is increased to 1000 w/m2 for 1.5s, and in this case, the current value is more than 20A for few milliseconds, but soon after that, De-rating MPPT is applied, which regulates its value to 20A. In the last 1.5s (2.5 – 3s), the solar energy is reduced to 700 w/m2, and there is a certain drop in the current value as well. Whenever the current generated by solar panels is more than the reference voltage of 14A, it needs to be regulated so that batteries can be charged efficiently.

Moreover, when the irradiation is 850w/m2, the maximum energy provided by the solar photovoltaic panels in the suggested fuzzy-FOPID approach and conventional Hill-climbing approach came out to be 6000W, but there were huge fluctuations in power generated by the classic model.

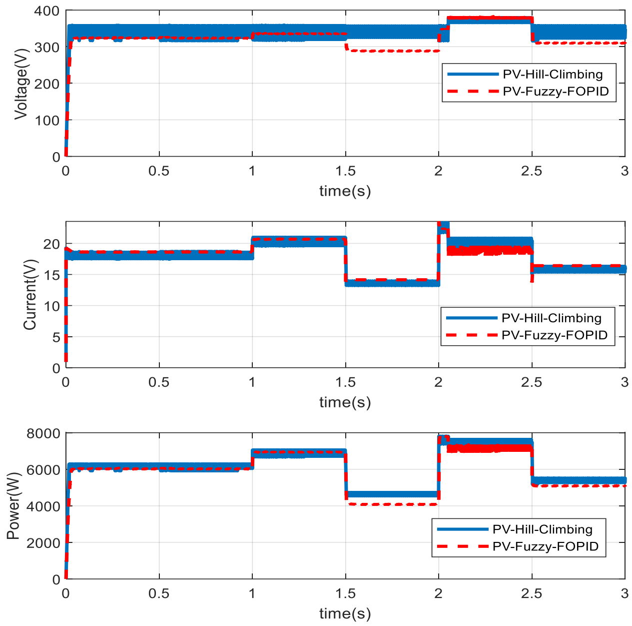

Figure 1.4 Voltage, current, and Power values of PV panels

In addition to this, the traditional model is unable to mitigate these oscillations even during the MPPT and De-rating operations that occur between 1.5-2s and 2-2.5s, respectively. This proves the supremacy of the proposed Fuzzy-FOPID approach.

b) Outputs generated by the DC-DC boost converters

Since the output produced by the Solar PV panels does not meet the needs, therefore, it is channeled to the DC-DC boost converter that optimizes the current and voltage values. The results obtained in this case are shown in figure 1.5.

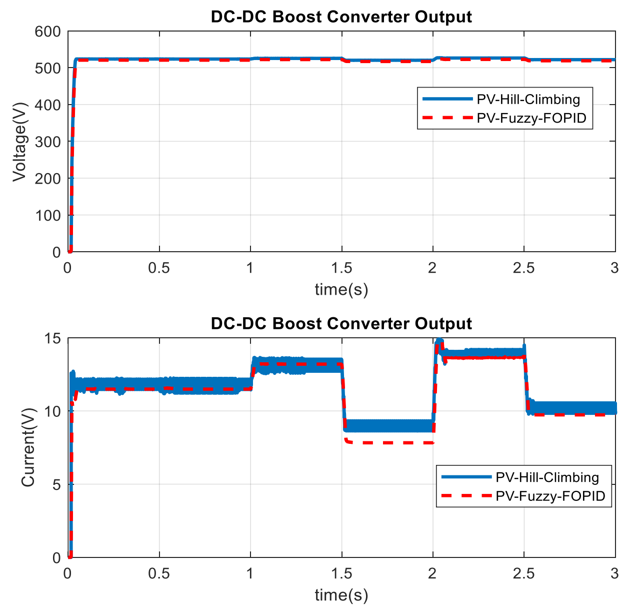

Figure 1.5 Output generated by Dc-DC boost converter

After examining the graph closely, it is observed that the voltage produced by the suggested ANFIS-FOPIS approach is consistent and efficient because it doesn't fluctuate much. Similarly, the current generated by the proposed PV-Fuzzy-FOPID model has fewer oscillations than traditional PV-Hill-Climbing methods under changing irradiance. The proposed system operates normally when the solar irradiance is 800W/m2 between 0-1s and generates current up to 12A. However, after 1.5s, when the solar irradiance is decreased to 600w/m2, the current also decreases to 8A but is soon regulated by performing the MPPT operation. Similarly, when irradiance is increased to 1000 for 0.5s, the current value obtained may be more than the reference current and hence needs to be decreased by using the De-rating operation. On the other hand, the values of current generated by the dc-dc boost converter in standard pv-Hill-climbing methods are 12A, 14A,9A 14A, and 11A when irradiance is 850, 900, 600, 1000, and 700/m2, respectively. These values prove that the proposed method is more effective and convenient than traditional models. The proposed system keeps on performing the MPPT and De-rating operations depending on the input solar irradiance and hence generates optimal current and voltage values with the least oscillations. The specific values of current generated by the two systems, i.e., convention PV-Hill-Climbing method and proposed PV-Fuzzy-FOPID method, are recorded in the tabular form and are given in table 3.

TABLE 3: COMPARISON OF CURRENT VALUES WITH CHANGING SOLAR IRRADIANCE FOR 14A BATTERY

Input irradiance	Pv-Hill climbing	PV-ANFIS-FOPID
	Current(A)	Current(A)
800	12	12
900	14	13
600	9	8
1000	14	14
700	11	10

In addition to this, the efficiency of the suggested ANFIS-FOPID model is also analyzed by changing the battery rating to 9A and 5A. The values are recorded in tabular form and are mentioned in Tables 4 and 5.

TABLE 4: COMPARISON VALUES WITH BATTERY RATING 9A

Input irradiance	Pv-Hill climbing	PV-ANFIS-FOPID
	Current(A)	Current(A)
800	7.76	7.54
900	8	7.84
600	7.15	7.18
1000	8.11	7.897
700	7.57	7.23

TABLE 5: COMPARISON VALUES WITH BATTERY RATING 5A

Input irradiance	Pv-Hill climbing	PV-ANFIS-FOPID
	Current(A)	Current(A)
800	4.89	4.59
900	5.122	4.67
600	4.59	4.47
1000	5.25	4.74
700	4.77	4.615

c) Battery SOC

The effectiveness of the suggested PV-FUZZY-FOPID method is also analyzed and compared with the traditional PV-Hill-Climbing method in terms of their battery SOC under MPPT and De-rating operations and is shown in figure 1.6.

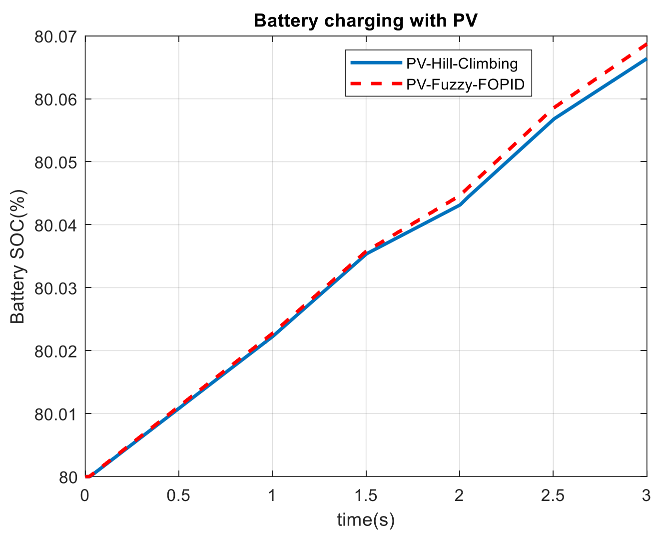

Figure 1.6 Comparison of battery SOC

From the graph, it is found that the battery is getting charged effectively in both models when solar irradiance is 850W/m^2. Although by varying the solar irradiance value, the charging state of batteries also changes, the batteries are getting charged more effectively and efficiently in the proposed model when compared with the traditional model. This enhances the lifespan of batteries and protects them from any harm.

After analyzing the graphs and tables, it is observed that the proposed PV-Fuzzy-FOPID model outperforms the traditional PV-Hill-Climbing methods in all attributes by proving a stable and optimum current with the least oscillations for charging the batteries.

V. CONCLUSIONS

This paper presents a control controlling method for tracking the MPP in solar PV panels. The developed method is a combination of ANFIS and FOPID together. Using the MATLAB software, the effectiveness of the suggested ANFIS-FOPID model is determined, which is later on also compared with the traditional Hill-climbing current control method in terms of their current, voltage, and power values. After analyzing the results closely, it is observed that the fluctuations are reduced to a great extent in the proposed ANFIS-FOPID model during the MPPT and DE-rating operations. When the solar irradiance is 850w/m2, an optimum current with a value of 14A is generated. However, by varying the solar irradiance, the current also changes, and when the irradiance is set at 1000 w/m2, the current value may also spike and reach more than 14A value; in this case, the de-rating operation is performed. Similarly, when irradiance is decreased to 700w/m2, an MPPT operation has performed that boosts the current value to its reference value with fewer fluctuations. This proves the efficacy and effectiveness of the proposed approach and hence can be utilized in the near future.

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