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Maximum Power Point Tracking Using Fuzzy Logic Controller

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Abstract – Due to energy crisis and environmental issues such as pollution and global warming effect, photovoltaic (PV) systems are becoming a very attractive solution and also electricity is a key driver of socio-economic development. The recent decades have seen the increase in demand for reliable and clean form of electricity derived from renewable energy sources. One such example is solar power. Now a day photovoltaic (PV) power generation is essential because it has more advantages over conventional methods. It is environment friendly, i.e. free from pollution, less maintenance cost and free fuel energy. But the major obstacles are high initial cost and low energy conservation efficiency, where maximizing the output power improves the efficiency. The maximum output power of a solar panel depends on the environmental conditions and load profile. Maximum power point tracking (MPPT) is one of the key functions of the solar power management system in solar energy development. The purpose is to design and optimize DC-DC converter for battery charging which will extract maximum power from solar panel. This is achieved by using fuzzy logic MPPT function is deployed using a SEPIC converter and computer simulations are conducted to verify the design. The experimental results present that the proposed fuzzy technique result in increasing of power delivery from the solar panel, causing a reduction in size, weight, and cost of solar panels in photovoltaic system.

Keywords— Maximum Power Point Tracking (MPPT); SEPIC Converter; Fuzzy Logic; Photovoltaic System.

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INTRODUCTION

Nowadays, using low cost energy sources in all industries is of interest. Renewable energy sources are suitable option to cover this request, where photovoltaic energy is one of them. The main problem of this source of energy are the low energy conversion efficiency and high installation cost. But these sources are difficult to tap, store and use. These resources of energy are freely available, it is necessary to utilize them, but it requires high initial cost. Their energy conservation effect is less. This motivates us to go ahead with this project to increase the efficiency in conservation and energy storage.

Electricity produced from photovoltaic (PV) systems has a far smaller impact on the environment than traditional methods of electrical generation. The most attractive features of solar panels are the non-existence of movable parts, the very slow degradation of the sealed solar cells and the extreme simplicity of its use and maintenance. Another advantage is the modularity. All desired generator sizes can be realized, from the milli-watt range to the megawatt range. Solar energy is a pollution-free source of abundant power. PV cells need no fuel, give off no atmospheric or water pollutants and require no cooling water, during their operation. The use of PV systems is not constrained by material or land shortages and the sun is a virtually endless energy source. All of the PV systems have the main problems affected by weather conditions such as dirt, changing irradiation, temperature and other factors. The PV systems have two main characteristics, P-V and I-V where P, V and I are PV output power, voltage and current respectively. The I-V curve is non-linear and there exists a single point in I-V that poses the maximum value and is called maximum power point. In changing weather conditions such as irradiation, the MPP controller should be capable of tracking MPP at minimum time in order to minimize the power loss. Maximum power tracking technique has advantage – it will increase solar cell efficiency, it will extract maximum power from p-v array, it will match source and load properly. Output of solar array is depends upon solar installation, cell temperature and load level.

All the solar power systems use batteries to store energy. Batteries provide power to the load when solar energy is less. In such a case there may be deep discharge of battery takes place. When solar power is more it may cause over charging of battery. For such situation battery life get reduces.

Generally batteries used are lead acid batteries as its cost is less but it requires more maintenance and less life. Nickel cadmium batteries can be used instead of lead acid batteries as it has low maintenance and long life. But, its cost is more.

Generally, for solar applications valve regulated lead acid batteries are used. It is low cost, maintenance free and most recyclable. To get long life of battery it should not be overcharged and deep discharged. In solar application battery life gets reduced when photo voltaic cell output is less. So converter requires maximum power point tracking control.

Fuzzy-based algorithms are selected for the mentioned controllers because of its high compatibility with nonlinear systems. Fuzzy logic is one of the suitable methods to find the maximum power point of a solar panel which has good stability and high response rate. The fuzzy system's capabilities are: online adaptive search of maximum power, robustness to solar intensity and temperature variation, and no need of external sensors for solar intensity and temperature measurements.

II. PROBLEM OVERVEW

Two important factors affect the implementation of photovoltaic systems. These are high initial cost and less efficient at energy conversion. So to reduce photovoltaic system cost and to increase the conversion efficiency of solar energy, the maximum power point tracking system of photovoltaic modules is one of the effective method.

Maximum power point tracking, frequently referred to as MPPT, is a system used to extract the maximum power of the PV module to deliver it to the load, and system efficiency increases.

III . SYSTEM ANALYSIS

A. Block Diagram of PV System without MPPT

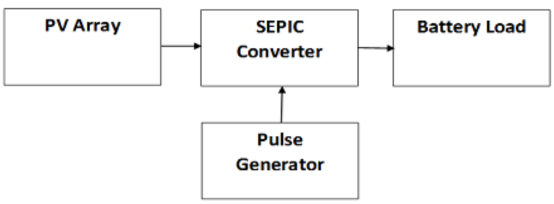

Figure 1.Block Diagram of PV System without MPPT

SEPIC converter is connected between the PV array and the load. SEPIC converter can increase or decrease voltage according to the load. A pulse generator is connected to the switch of the SEPIC converter to give the gate pulses to the switch(MOSFET). This is shown in above figure1.

B. *Block Diagram of PV System with MPPT*

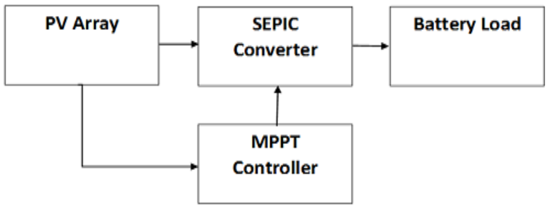

Figure2. Block Diagram of PV System with MPPT

Solar cell output voltage is not constant, it is variable and it will depend on solar installation, cell temperature and load level. Output Voltage must be maximum to the load, i.e., to charge the battery. Output voltage of the solar cell should be more, but, if solar cell output is less, then it is necessary to increase the output voltage. The SEPIC converter is connected in between PV array and load as shown in above figure 2. The SEPIC converter can boost output voltage when input is low i.e. MPPT controller will increases the output pulse width i.e. the duty cycle of the switch of SEPIC. SEPIC converter can operate in buck mode operation when input is high, i.e., controller will decrease duty cycle. MPPT controller uses sum of incremental conductance and conductance as the input to fuzzy. Here MPPT controller and SEPIC converter combined together to operate to extract maximum power from PV cell.

IV. SEPIC CONVERTER

There are 5 main types of dc-dc converters. Buck converters can only reduce voltage, boost converters can only increase voltage, and buck-boost, Cuk, and SEPIC converters can increase or decrease the voltage.

Some applications of converters only need to buck or boost the voltage and can simply use the corresponding converters. However, sometimes the desired output voltage will be in the range of input voltage. When this is the case, it is usually best to use a converter that can decrease or increase the voltage. Buck-boost converters can be cheaper because they only require a single inductor and a capacitor. However, these converters suffer from a high amount of input current ripple. This ripple can create harmonics; in many applications these harmonics necessitate using a large capacitor or an LC filter. This often makes the buck-boost expensive or inefficient. Another issue that can complicate the usage of buck-boost converters is the fact that they invert the voltage. Cuk converters solve both of these problems by using an extra capacitor and inductor. However, both Cuk and buck-boost converter operation cause large amounts of electrical stress on the components, this can result in device failure or overheating. SEPIC converters solve both of these problems.

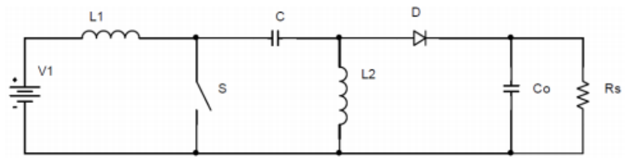

Figure 3. SEPIC Converter

A. Operation

All dc-dc converters operate by rapidly turning on and off a MOSFET, generally with a high frequency pulse. What the converter does as a result of this is what makes the SEPIC converter superior. For the SEPIC, when the pulse is high/the MOSFET is on, inductor 1 is charged by the input voltage and inductor 2 is charged by capacitor 1. The diode is off and the output is maintained by capacitor 2. When the pulse is low/the MOSFET is off, the inductors output through the diode to the load and the capacitors are charged. The greater the percentage of time (duty cycle) the pulse is low, the greater the output will be. This is because the longer the inductors charge, the greater their voltage will be.

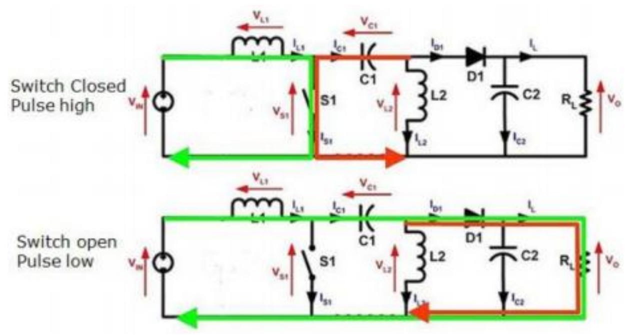

Figure4. Operation of SEPIC converter

V. MAXIMUM POWER POINT TRACKER

Maximum Power Point Tracker (MPPT) is often used to increase the energy conversion efficiency for a photovoltaic energy source. The maximum power is transferred to the load when the impedance source matches the load one. To accomplish this objective, a switching converter is placed between the PV source and the load. With an MPPT control, it is possible to reach the output panel characteristics around the optimal power point. The output power of photovoltaic (PV) panels varies with atmospheric conditions (solar irradiance level and temperature) as well as their optimum voltage (Vopt) and current (Iopt). It is crucial to operate the PV energy conversion systems near the maximum power point (MPP) to increase the power yield of the PV system. This problem has attracted the interest of several authors. Maximum power point tracking (MPPT) algorithms are usually implemented in the power electronic interface between the PV panel and a load.

Maximum power point matching of a PV array with the load maximizes the energy transfer by operating the load as closely as possible to the MPP line of the PV output, whatever the loads and working conditions. In our case, a Maximum power point tracker is a DC to DC convertor.

DIFFERENT MPPT TECHNIQUES

There are different techniques used to track the maximum power point. Few of the most popular techniques are: Perturb and Observe(hill climbing method), Incremental Conductance method, Fractional short circuit current, Fractional open circuit voltage, Neural networks & Fuzzy logic. The choice of the algorithm depends on the time complexity the algorithm takes to track the MPPT, implementation cost and the ease of implementation.

FUZZY LOGIC CONTROL

Microcontrollers have made using fuzzy logic control popular for MPPT over last decade. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity.

VI. METHODOLOGY

Algorithm for the fuzzy logic MPPT algorithm would use incremental conductance as the basis for the fuzzy controller design. According to the P-V curve, the power to voltage derivative would be zero at the MPP condition:

$$\frac{dP}{dV} = 0 \text{ where } P = V * I \qquad (7.1)$$

$$\text{->}\; I + V * \frac{dI}{dV} = 0 \qquad (7.2)$$

$$\text{->}\left(\frac{dI}{dV} + \frac{I}{V}\right) = 0 \qquad (7.3)$$

Figure 7.1 shows the characteristic P-V curve and the corresponding $\left(\frac{dI}{dV} + \frac{I}{V}\right)$ value. Algorithm uses this special characteristic in designing the fuzzy controller. The unique feature of this algorithm was when, $\left(\frac{dI}{dV} + \frac{I}{V}\right) > 0$, the operating point would on the left side of the MPP on the P-V curve. In other words, when output voltage of the PV cell becomes too low, the system must reduce duty ratio commands in order to raise the PV cell output voltage. If, $\left(\frac{dI}{dV}+\frac{I}{V}\right) < 0$, the operating point would be on the right side of the MPPT of the P-V curve. In other words, when PV cell output voltage becomes too high, the system must increase duty ratio commands in order to reduce the PV cell output voltage. This algorithm would provide the operating region of the PV cell. Only a single fuzzy input variable would be needed for the design of the fuzzy logic MPPT controller. Figure 7.2 shows the fuzzy rules database designed using this algorithm. The corresponding membership functions of the inputs and input are shown in Figure 7.3.

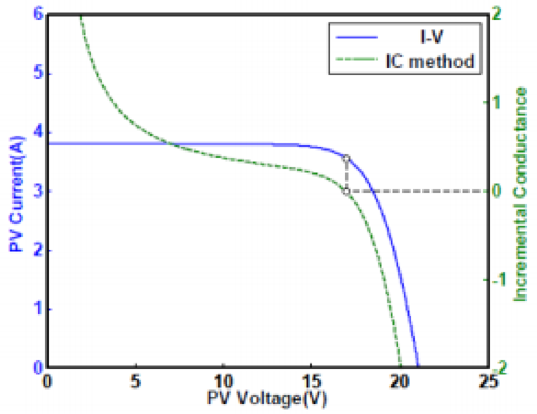

Figure5. PV cell current-voltage and characteristics

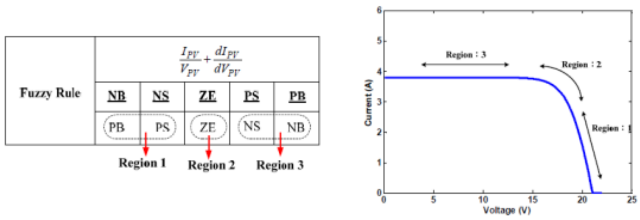

Figure 6. Fuzzy rules for Algorithm

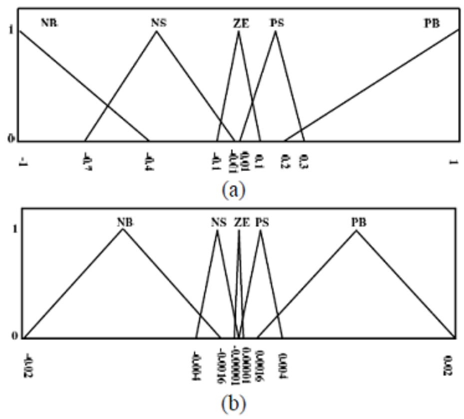

Figure 7 Membership functions for Algorithm (v): (a) Membership function for $\left(\frac{I}{V}\right)+\left(\frac{dI}{dV}\right)$. (b) Membership function for increment of duty ratio command.

This algorithm allows the system to directly identify the location of the operating point in relation to the MPP unlike previous algorithms described in this paper where variations were used to estimate whether the system has tracked the operating point to the MPP instead. Hence, when using this algorithm in designing the output variable, duty ratio increments or decreases could be designed with larger values in order to achieve efficient MPPT. The other advantage is that this algorithm would not require the use of a second set of MPPT input variables, allowing the design of a single-input and single-output system which could reduce computing loads. The rules database for this algorithm is divided into 3 regions.

Detailed analysis and discussions are provided below.

Region1: The operating point is located at the right of the MPP. The proximity of the operating point to the MPP is used to determine the degree of increase the duty ratio for the MPPT process.

Region 2: The operating point is located near the MPP. The output is thus set as ZE.

Region3: The operating point is located at the left of the MPPT .The proximity of the operating point to the MPP is used to determine the degree of decrease of the duty ratio for the MPPT process.

VII. SIMULINK MODELS AND RESULTS

A. PV Array without MPPT

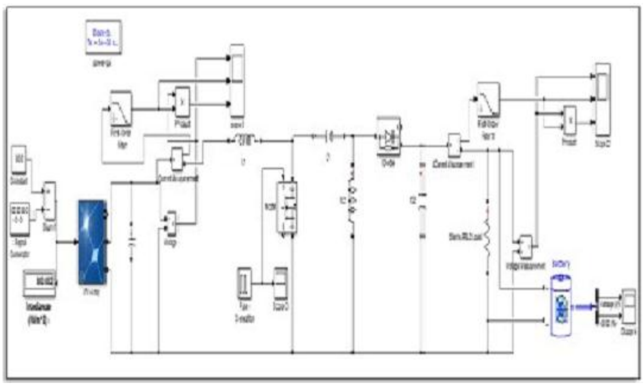

Figure 8. PV Array without MPPT

The below figure 8 shows the input from the PV array to the converter. The first graph is the solar voltage which is constant at ~30v. The second graph is the current which has ripple till 0.3 sec and the peak value being 6.3 amps. The final graph is the product of the two and hence the power of the PV panel.

Case 1: Running the system without MPPT

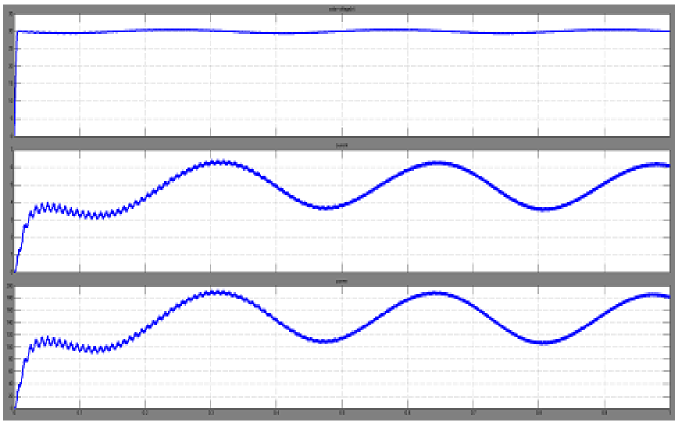

Figure 9. Input from the PV array to the converter

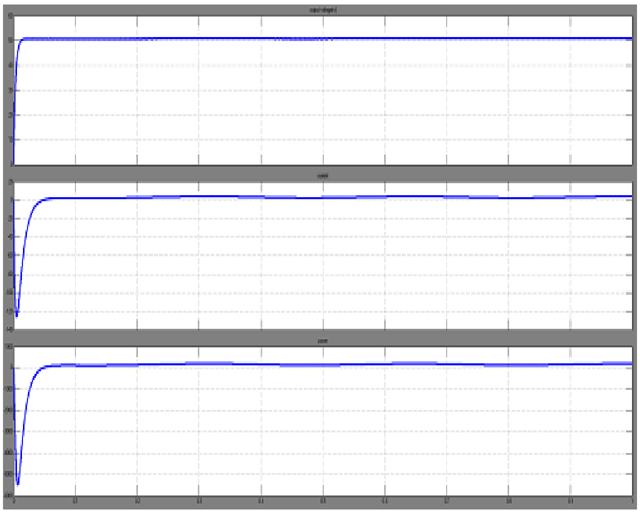

Figure 10.Output of the converter

The above figure 8.1.2 shows the output of the converter. The converter used gives a steady value of voltage and current having peak values as 50V and 3.5 Amps. Hence the total power peak value is 180W.

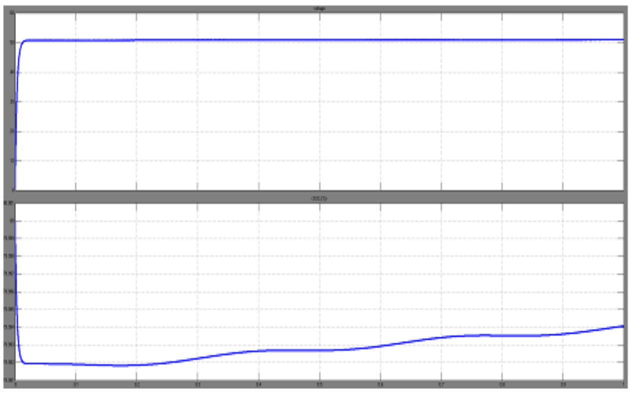

Figure11. Output of the Battery

The above figure 8.1.3 shows the charging state of the battery and the battery nominal voltage which is constant at 50v and the steady increase in the SOC from initially 80 with slight fluctuations

B. PV Array without MPPT

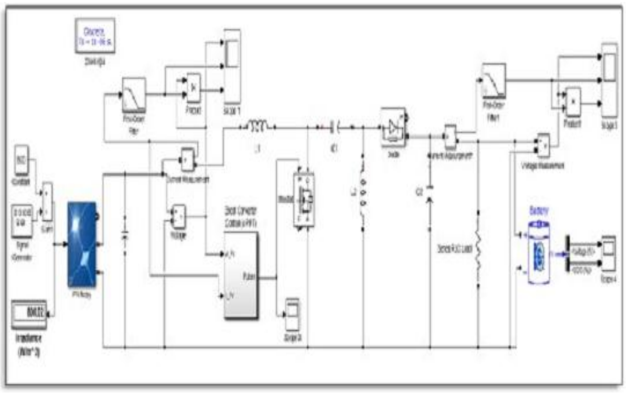

Figure12. PV Array with MPPT

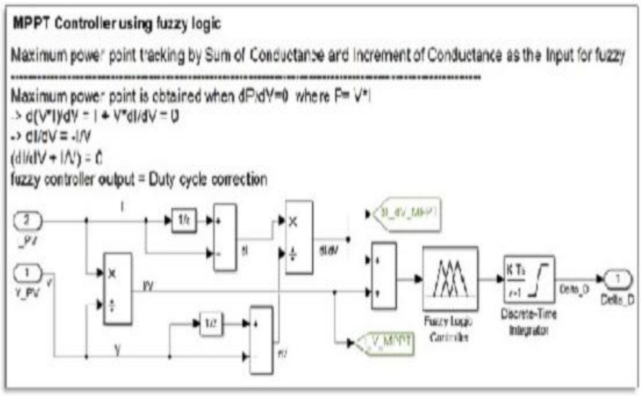

Figure 13. MPPT Controller using fuzzy logic with sum of conductance and incremental conductance as input

The below figure 8.2.2 shows the input from the PV array to the converter using MPPT. The first graph is the solar voltage which is constant at ~30V. The second graph is the current which has ripple till 0.1sec and the peak value being 16 Amps. The final graph is the product of the two and hence the power of the PV panel.

Case 2: Running the system with MPPT

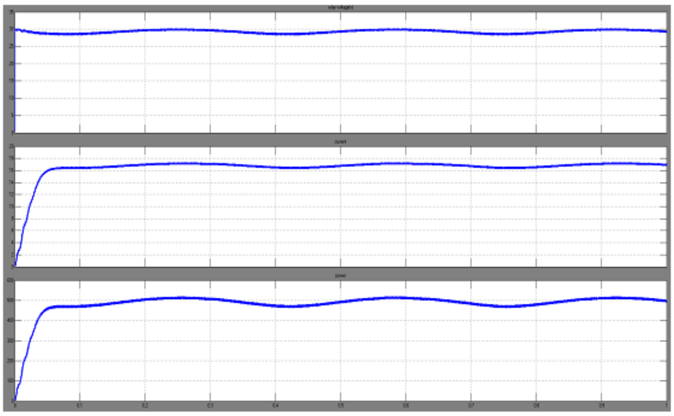

Figure 14. Input from the PV array to the converter

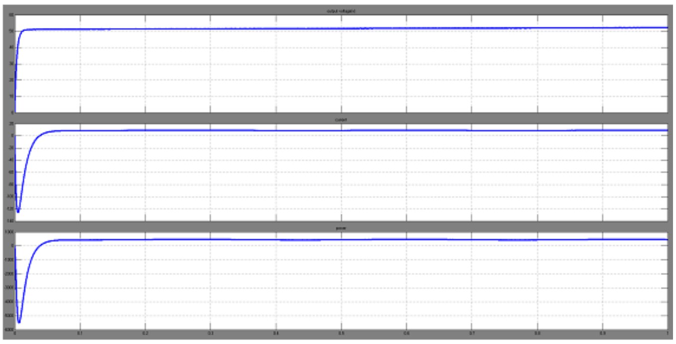

Figure 15. Output of the converter

The above figure 8.2.3 shows the output of the converter. The converter used gives a steady value of voltage and current having peak values as 50V and 9 Amps. Hence the total power peak value is 460W.

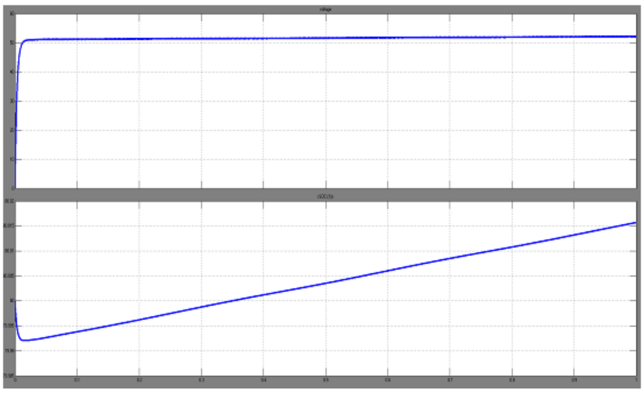

Figure16. Output of the Battery

The above figure 8.2.4 shows the charging state of the battery and the battery nominal voltage which is constant at 50v and the steady increase in the SOC from initially 80 without any fluctuations.

Above figures show the simulation results of using this single input fuzzy MPPT controller. Results show that under changing irradiation, this algorithm was capable of achieving MPPT quickly. The process of this algorithm in locating the operating point was also more direct compared to the previous methods, and would not require the use of variations in input variables to predict operating point locations. However, the determination condition would become extremely sensitive near the MPPT. Hence, the detection system must accurately calculate the determination results in order to track the operating point to the MPP, requiring the proper designs of the fuzzy domains and good precision of the measurement instruments used which could pose significant challenges to the design of this fuzzy controller. Additionally, extremely large or small values may possibly result from using this determination formula after division operations, making it important to perform detailed calculations.

VIII. CONCLUSION

The study presents a simple but efficient method to improve a photovoltaic system's operation. The aim is to reach the MPP rapidly using fuzzy controller, in real time and automatically. It is used to maximize the photovoltaic array output power, irrespective of the irradiation conditions and of the load electrical characteristics. Thus, a new concept to track the MPPT rapidly has been developed. The advantages of the fuzzy controller are that the control algorithm gives fast convergence and robust performance against parameter variation and can accept noisy and inaccurate signals. The system was found to reliably stabilize the maximum power transfer in all operating conditions and it is ready to be fitted in a larger installation. The purpose of the work is to optimize the system's operation.

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