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Application of Hybrid Machine Learning Approach for Maximum Power Tracking

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Abstract
In this paper the major goal of this study is to develop and apply a maximum power point tracker for a solar power supply based on fuzzy logic. An MPPT model made up of a dc-dc converter and a fuzzy logic controller is simulated in order to complete this task. Then, dc-dc converter characteristics are examined to determine the best topology for the complete PV system's component parts. The optimal design is obtained by simulating a combined model of the PV module and the chosen converter, and using the findings, formulating and fine-tuning the fuzzy logic control method for tracking the maximum power. Additionally, the suggested fuzzy logic controller is tested with several dc-dc converter topologies before being tweaked for best performance with a suitable converter. The outcomes show that the proposed method outperforms the traditional way in terms of the system's maximum power derivation and speed of reaction.

Keywords: MPPT, fuzzy logic control, photovoltaic effect, Solar Module

1. Introduction:

Due to a growth in industrial development and human consumption, there is a discernible rise in energy consumption. The optimization of energy efficiency and the utilisation of sustainable and renewable energy sources have generated interest in research and technology investments. Fossil fuels are used less frequently and more expensively to produce electricity at the same period. Finding the best way to extract the most energy and provide the most power at the lowest cost for the intended load is the most crucial factor in replacing conventional energy sources with more ecologically friendly renewable sources (such as solar and wind energy). By adjusting the contribution from each energy source in accordance with the load demand, integration of two or more energy sources may provide the optimum means of enhancing power generation. Developing and optimising maximum power point tracking and control of a multi-source alternative energy generating system made up of photovoltaic (PV) modules, wind turbines, and other sources is the major goal of this effort. A renewable energy source called PV power has recently attracted a lot of interest and may soon displace nonrenewable sources like fossil fuels. The cost of PV power per kilowatt-hour must be competitive with fossil fuel energy sources in order to achieve this switchover.

The technology and material utilised to construct solar cells are two important aspects that are thought to have a significant impact on how efficient PV modules are. PV modules currently only convert solar irradiance to electricity with an efficiency of 12–26%, which is very poor [1]. The efficiency of silicon sun cells ranges from 12 to 14 percent, but gallium arsenide solar cells have a high efficiency of 29% [2]. Additionally, efficiency may decline as a result of changes in solar insulation, temperature changes in PV modules, or load circumstances. A PV module must be operated at its optimal power point in order to produce the maximum amount of power that is rated for it. A controller known as a maximum power point tracker is needed to accomplish this. The output power of PV modules, which are nonlinear power sources, is influenced by the terminal operating voltage. As a result, the MPPT's job is to account for the solar cell's variable current-voltage characteristics. The MPPT changes the PV module's output voltage and current and chooses the operating point that will provide the most electricity. To boost the PV module's efficiency, the MPPT must be able to precisely track the operating point where the highest power is delivered, which changes frequently.

Due to their low efficiency and relatively high cost per watt in comparison to fossil fuels, PV power systems are used comparatively infrequently. As a result, there is still much to be done to improve PV systems' reliability and efficiency. Modeling and simulation are the initial steps in understanding and debating how to increase PV module efficiency. It is feasible to build and develop several strategies to optimise the performance of the system once a PV module has undergone accurate modelling and simulation. In the literature, a variety of maximum power tracking techniques for PV power applications have been published. However, the majority of the present approaches have flaws including low efficiency, low accuracy, and long response times. Therefore, the goal of this research is to identify more dependable and accurate methods of achieving the desired power that a PV system is capable of producing in a variety of weather situations. It is known as MPPT-based fuzzy logic control. The control algorithm uses fuzzy logic's outstanding representation and deduction skills to address the shortcomings of prior approaches.

2. Methodology

2.1 Photovoltaic Modelling

Solar panels and solar arrays that provide clean, renewable electricity mostly consist of solar cells. DC power can be produced by solar cells by converting the light energy they receive into electricity. The cost of solar panels per watt on the market for solar energy now ranges from 0.36 to 1.44 dollars. Customers pay only the cost of the solar panels; there are no additional fees for using solar energy that is permanently renewable. Solar panels continue to be expensive, though. A six kilowatt-per-hour photovoltaic (PV) system, for instance, might cost around $6,000 to install.

2.2. Photovoltaic' Composition:

The photovoltaic effect describes how PVs convert the light energy they receive into electricity. A portion of the photons of the light may be reflected or directly consumed when they hit the surface of a solar cell when it is illuminated. This is due to the fact that the energy they contain cannot be transformed into electricity. The photovoltaic effect can only be produced by photons that are absorbed close to the solar cell's P-N junction. The atoms in the P-N junction produce lots of hole-electron pairs by absorbing the energy of the photons. The holes carry the positive charge and move from the N-type layer to the P-type layer under the influence of the electrical field of the P-N junction. The negatively charged electrons travel to the N-type layer after ejecting themselves from the P-type layer [16]. When an electrical load, such as a resistor, is connected to the P-N junction, electrons from the N-type layer travel through the load and eventually enter the P-type layer. The incoming electrons combine with the holes in the P-type layer. Figure 1 depicts a PV cell's P-N junction.

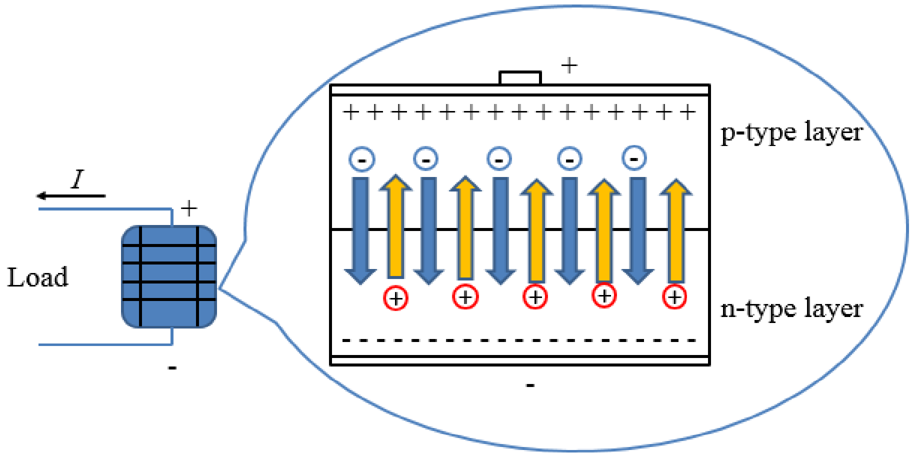

Figure 1: P-N junction of a solar cell [16]

3. Result and Discussions

3.1. Solar Module Design:

The following fundamental equations, derived from the principles of semiconductors and photovoltaics, quantitatively define the relationship between current and voltage in a PV module.

I The PV module's output current is indicated as follows:

$$I = \text{Np Iph} - \text{Np Is}\left[\exp\frac{q(V+\text{IRs})}{\text{Ns } kTA} - 1\right] \qquad (1)$$

where, Iph: photocurrent or light-generated current;

Is is the module saturation current, q is the electron charge (1.38 x 1023 J/K), k is the Boltzmann constant, and T is the temperature.
A: optimal cell factor
Rsh stands for series resistance, and Rs
Ns: number of connected series' cells
Np: the quantity of parallel cell connections.
PV array is created using Simulink and the aforementioned equation, as illustrated in Figure 2:

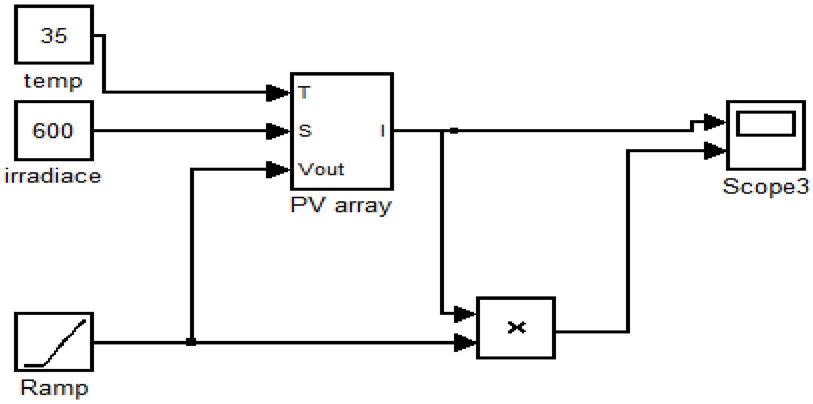

Figure 2: Simulink Model For PV array subsystem.

Irradiance in W/m2 is presented as S, temperature is given at input T, and a ramp signal is given to Vout in Figure 1. The PV array sub-internal system's connection schematic is displayed below:

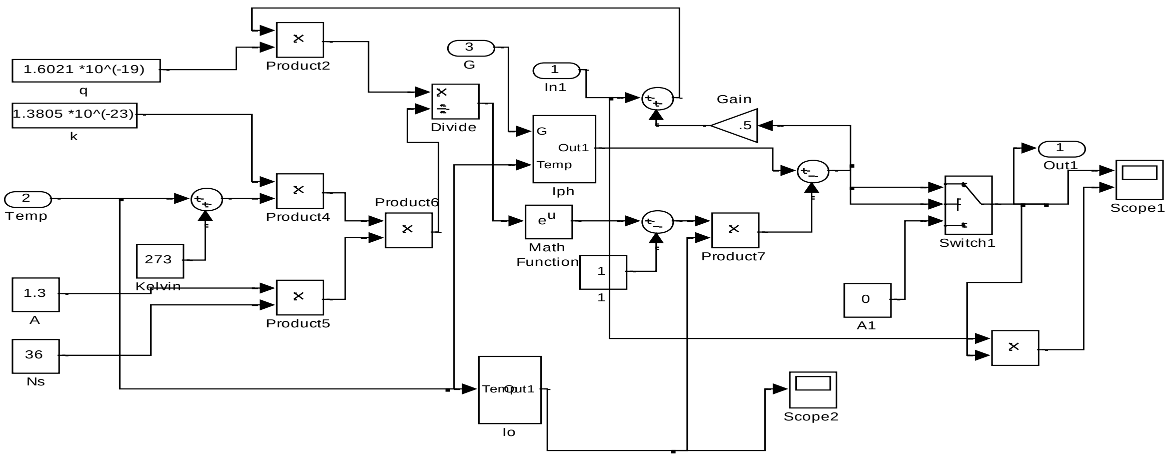

Figure 3: Simulink based block Model of solar module.

Below is a list of the PV array's specifications:
Sref stands for "Reference Irradiance" (1000W/m2), "Reference Temperature" (250C), "Open Circuit Voltage" (19V), "Short Circuit Current" (2.3A), "Maximum Power at Standard S and T" (16V), and "Maximum Power at Standard S and T" (1.3A). The aforementioned PV array model's I vs. V and P vs. V characteristics are displayed at standard S and T.

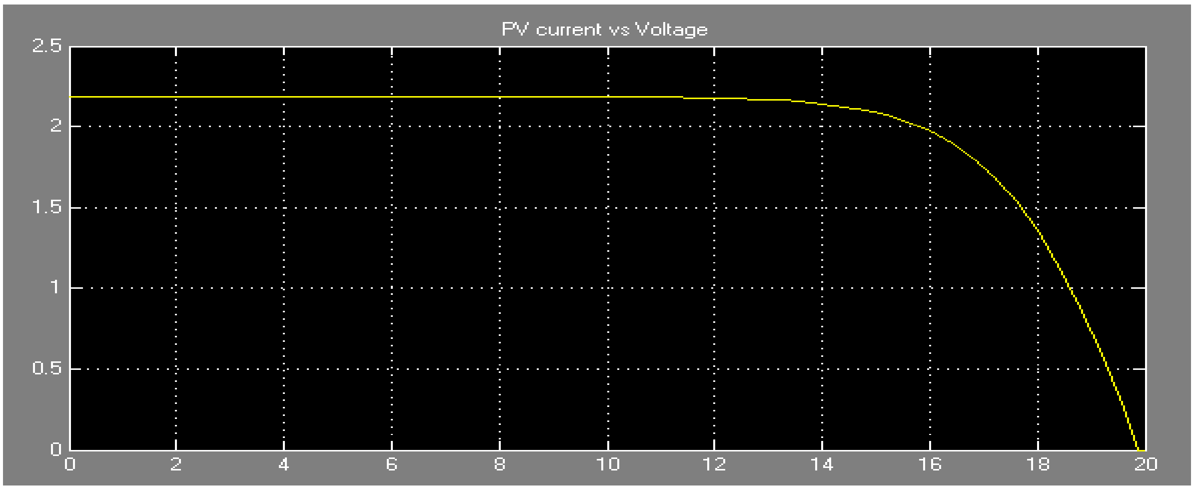

Figure 4 : PV Array Current vsVoltage Characteristics.

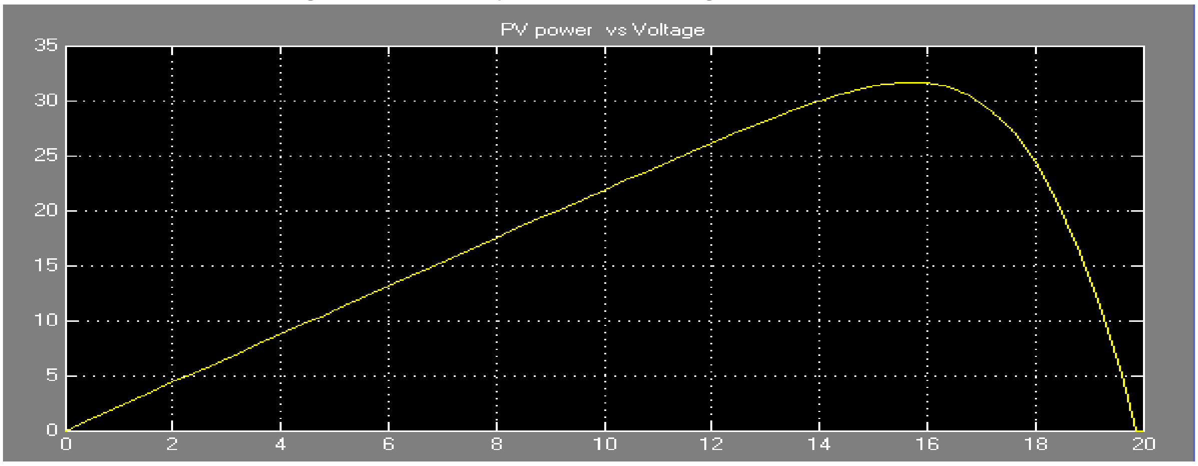

Figure 5: PV Array Power vs. Voltage Characteristics.

3.2 Controller for MPPT:

P&O method is the MPPT algorithm that is most frequently utilised. This algorithm uses a straightforward feedback system with few parameters that can be measured. This method involves periodically perturbing the module voltage and comparing the resulting output power to that from the preceding perturbing cycle. This algorithm introduces a small disruption to the system. The power of the solar module varies as a result of this perturbation. If the perturbation results in an increase in power, the perturbation will continue in the same direction. The perturbation then reverses as illustrated in Figures 6 after the peak power is attained, the power at the MPP is zero, and the following moment decreases.

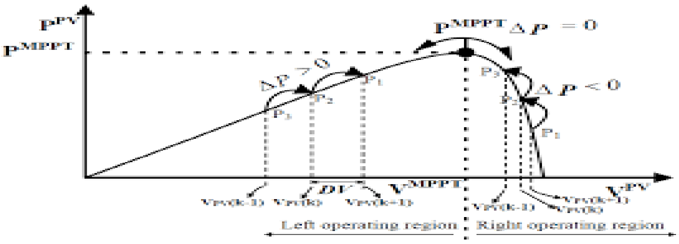

Figure 6. Perturb and Observe Algorithm for tracking MPPT point.

3.3 DC DC Converter:

For connecting to the regulated gate pulses produced at the output of the MPPT controller, a buck converter has been created using Simulink.

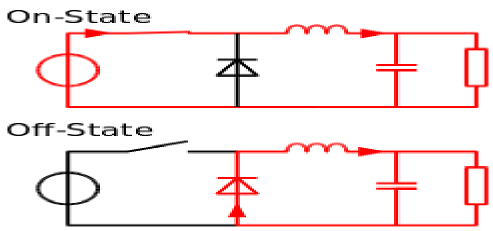

Figure 7: Buck Converter Function states.

In this converter, the R1, C, and C are filters that reduce input voltage and current fluctuation ripples. C is also used to filter output voltage ripples. R1 = 1 ohm, C1 = C=0.007 farads, L =0.0618 H, and R are the load resistances. The I/P voltage is maintained at 100 V DC. Figure 7 displays the I/p voltage at scope 1 with a 50% duty cycle. As we can see, Vin is a constant 100V DC value. The figure for the buck converter's o/p power current and voltage is shown in Figure 8. We can observe that at a 50% duty cycle, the output voltage is lowered to about 50% of the input voltage, or 50V.

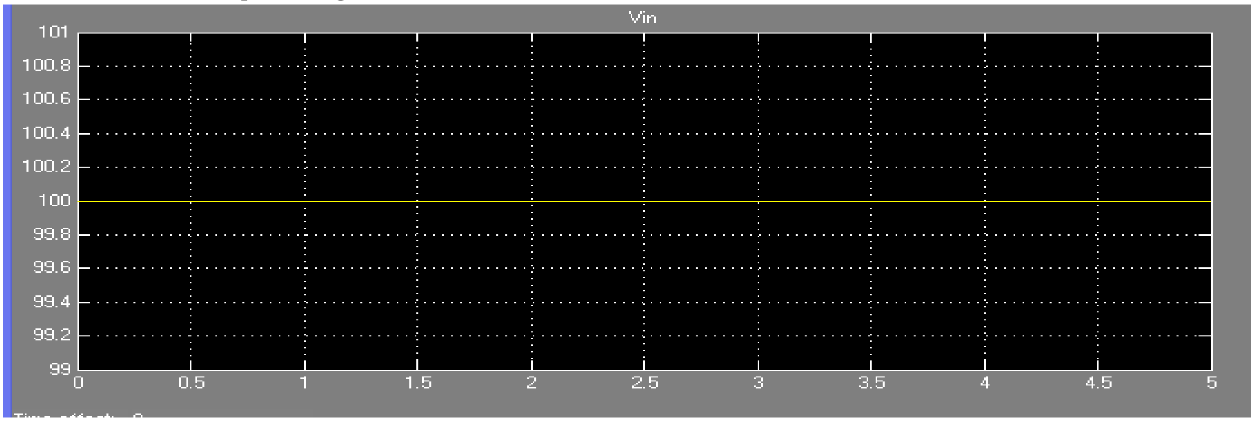

Figure 8: Input voltage Vin.

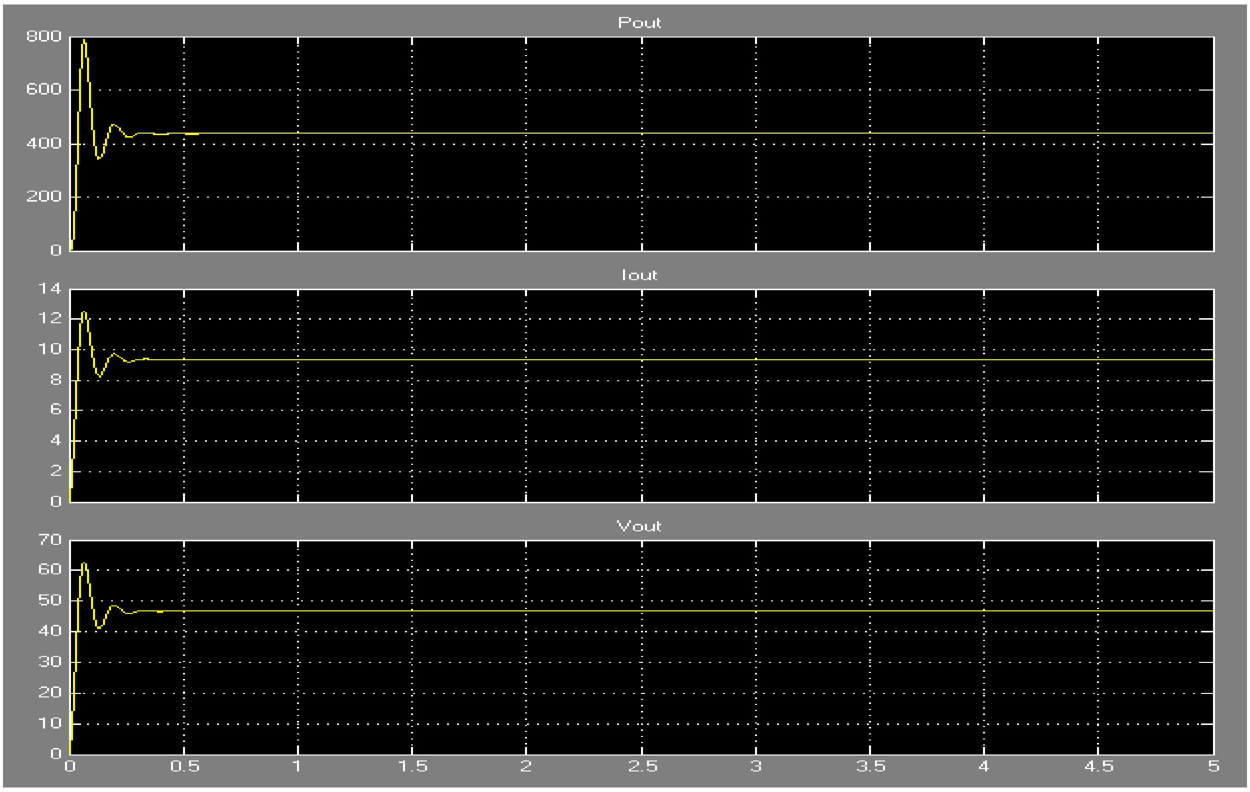

Figure 9: Output power, current and voltage of buck converter at duty cycle 50%.

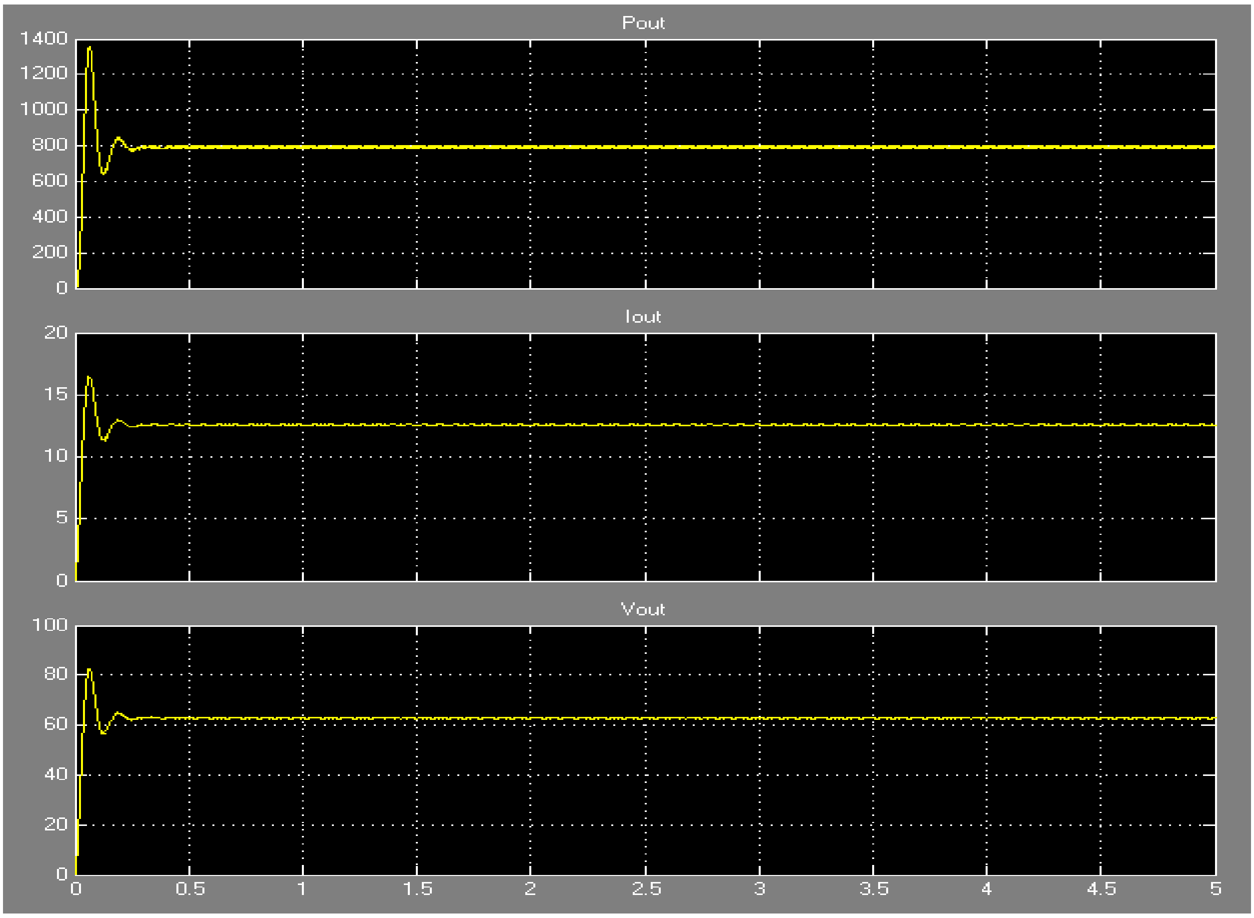

Figure 10: Output power, current and voltage of buck converter at duty cycle 70%.

3.4 PV array with MPPT controller:

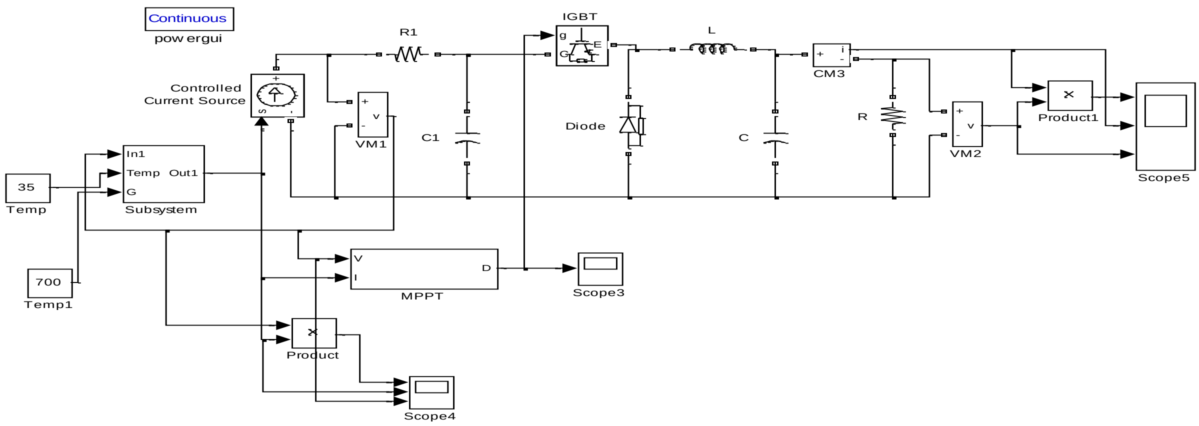

Figure 11: PV array with MPPT controller.

After connecting the PV array MPPT controller to the buck converter, the model architecture is shown in its entirety in Figure 11. The current model is run at a temperature of 35 C and an irradiation of 700 W/m2. The PV array's output in terms of power, current, and voltage is depicted in scope 4 in Figures 12 and 13, while the output of the converter is depicted in scope 5. As we can see, the uppermost plot in Fig12 represents the power input to the buck converter from the MPPT-controlled PV array. Iin and vin, in a similar manner, represent the PV array's output current and voltage inputs to the DC-DC converter. When there has been an iterative change in voltage, the MPPT controller adjusts the duty cycle of the gate pulse in accordance with Vin and Pin values such that the converter input condition reaches the maximum power point. As a result, we can see fluctuations in Vin, Iin, and Pin near the beginning of the plot in Figure 12. After a while, as the maximum power point is reached, the perturbation is only needed to keep the duty cycle at the desired voltage Vin. We can observe that Vin is at 16V and Pin is at 30W in steady state (approx.).

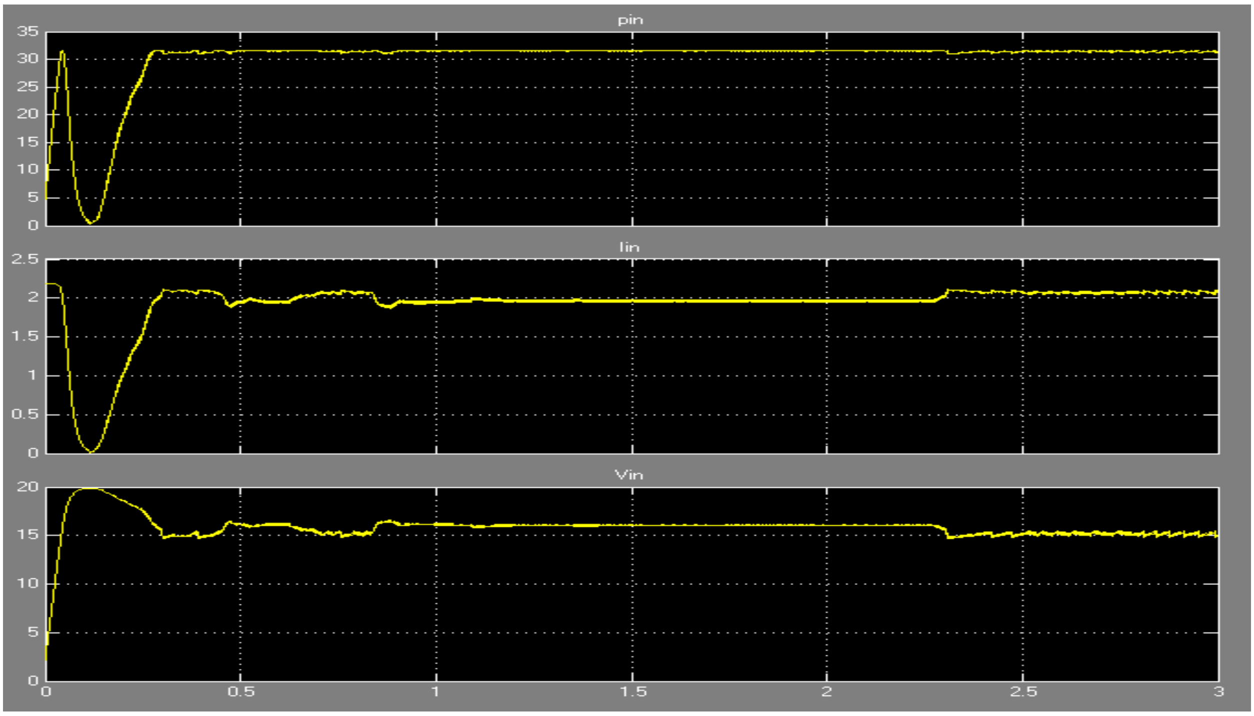

Figure 12: PV array with MPPT controller and Buck converter input power, current and voltage.

The output of the converter, designated as Pout, Iout, and Vout, is shown in Figure 4.12. The Vout is 10 volts, and the Pout is close to 20 Watts.

As can be seen, the MPPT controller aids in keeping the PV array's power at the required maximum power point for the associated irradiance and temperature. The MPPT adjusts the duty cycle at a value where we can get V and I when the irradiance and temperature vary.

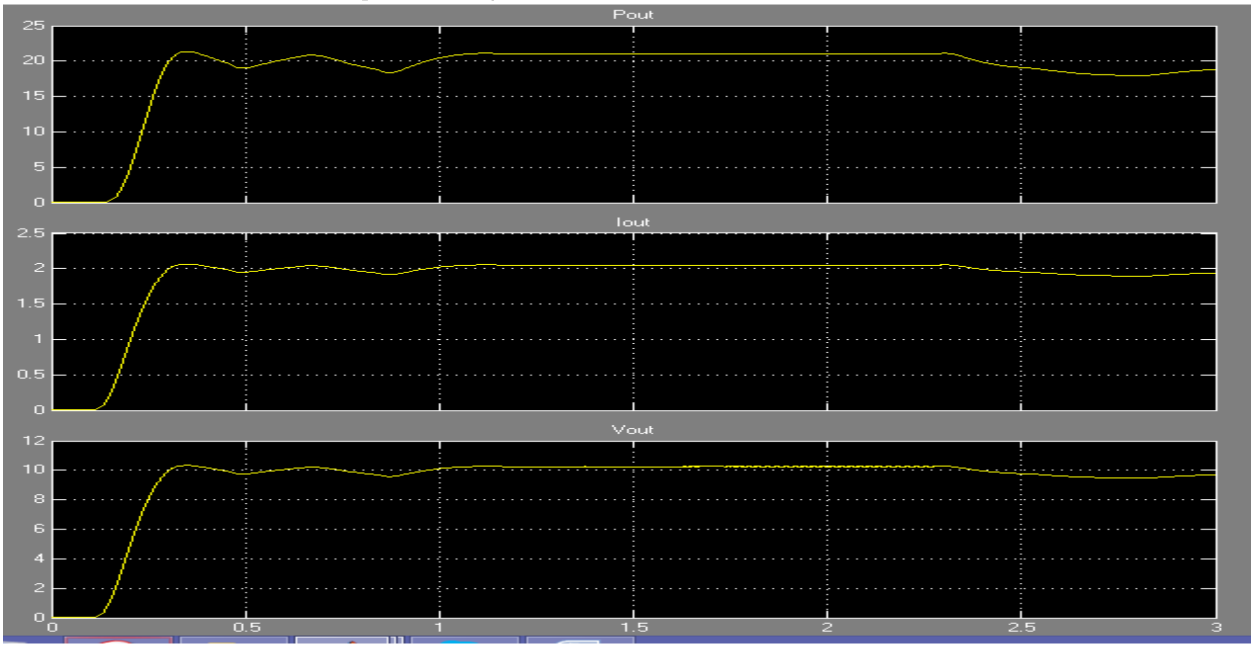

Figure 13: PV array with MPPT controller and Buck converter output power, current and voltage.

Maximum power can be produced at a certain spot. However, a substantial amount of ripple is present at the PV array output as a result of frequent perturbations; these ripples are diminished by converter regulation and the employment of filters at the input and output ends of converters. In light of this, it can be said that the MPPT controller and DC-DC converter can assist in operating the PV array at its maximum power point with a notable reduction in voltage and current signal variations. The fuzzy controller will eventually replace the MPPT and provide quick and reliable control of converter duty cycle with little time and signal variations. In the future, we will build the fuzzy rules for the MMPT algorithm in this manner.

3.5 PV array with Fuzzy controller and Buck converter:

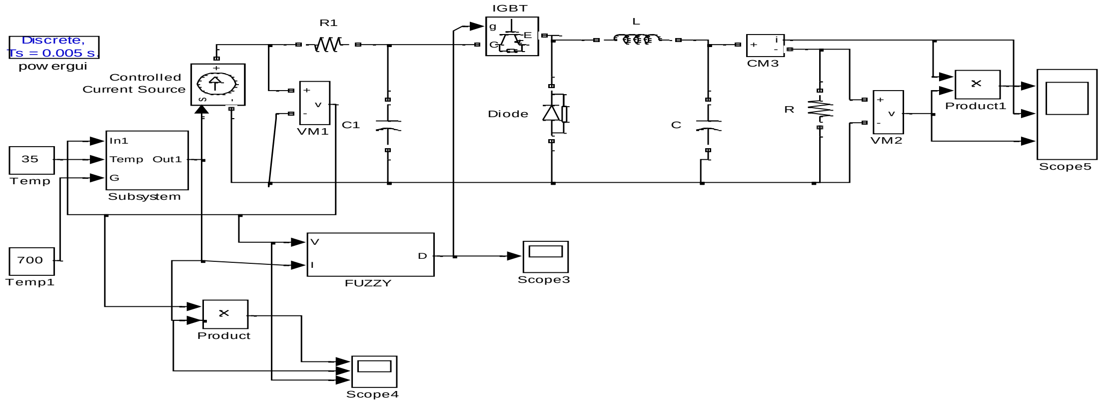

Figure 14.a : PV array with Fuzzy controller and Buck converter.

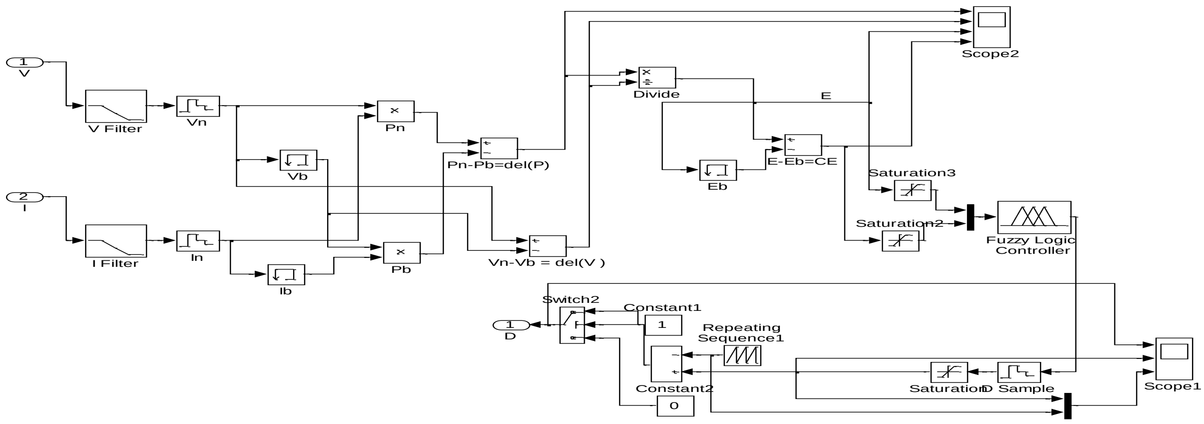

Figure 14 b: Internal model diagram of fuzzy controller subsystem.

Following the assembly of the PV array with a fuzzy controller to the buck converter, Figure 4.13a displays the model architecture in its entirety. The current model is run at a temperature of 35 C and an irradiation of 700 W/m2. The output of the PV array in terms of power, current, and voltage is represented in scope 4 in figures 15 and 16, while the output of the converter is shown in scope 5. As can be seen, the top plot in Fig. 15 represents the power input to the buck from the fuzzy regulated PV array. Iin and vin, in a similar manner, represent the PV array's output current and voltage inputs to the DC-DC converter. In order for the converter input condition to reach the maximum power point after several iterations of voltage changes, the fuzzy controller adjusts the duty cycle of the gate pulse in accordance with the value of voltage and current change, i.e. Vin and Pin. As a result, we can see fluctuations in Vin, Iin, and Pin near the beginning of the plot in Figure 15 After a while, as the maximum power point is reached, the perturbation is only needed to keep the duty cycle at the desired voltage Vin. We can observe that Vin is at 16V and Pin is at 26W in steady state (approx.).

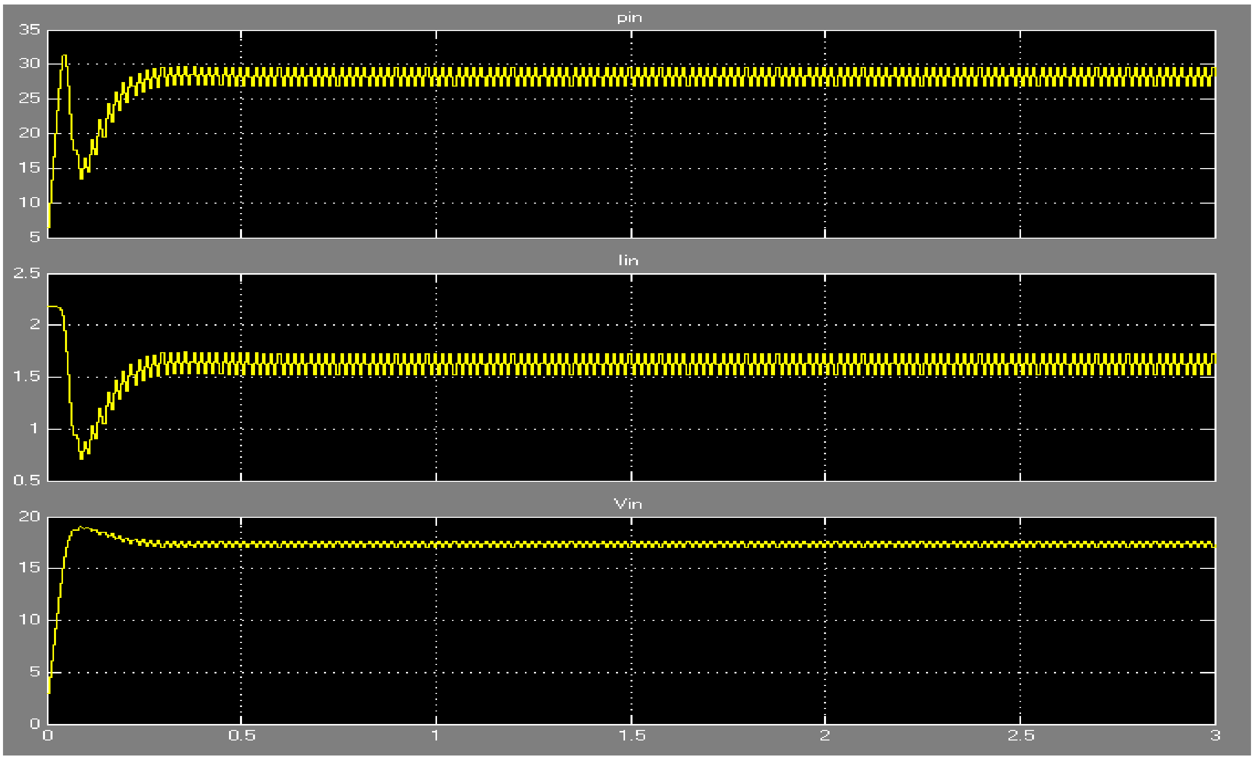

Figure 15: PV array with fuzzy controller and Buck converter input power, current and voltage.

The output power, current, and voltage of the converter, denoted as Pout, Iout, and Vout, are shown in Figure 16. The Vout is 11 volts, and the Pout is close to roughly 23 Watts.

We can see that the fuzzy controller helps to keep the PV array's power at the required maximum power point for each irradiance and temperature, but the Pout is lower than with an MPPT controller that doesn't use fuzzy than. The MPPT adjusts the duty cycle at a value where we can get V and I when the irradiance and temperature vary

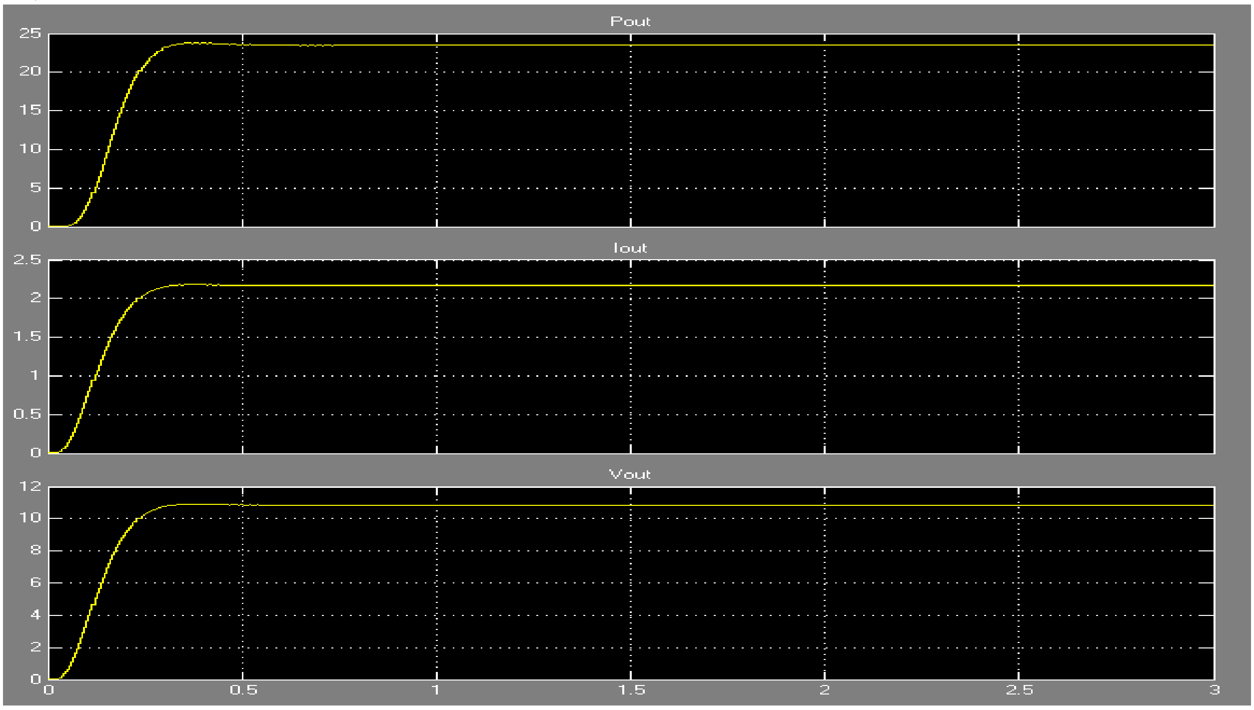

Figure 16: PV array with fuzzy controller and Buck converter input power, current and voltage.

Maximum power can be produced at a certain spot. However, a substantial amount of ripple is present at the PV array output as a result of frequent perturbations; these ripples are diminished by converter regulation and the employment of filters at the input and output ends of converters. In light of this, it can be said that the fuzzy controller and DC-DC converter can assist in operating the PV array at its peak power point with a notable reduction in voltage and current signal variations.

As a result, the fuzzy controller's created fuzzy rules for the MPPT algorithm replaced the MPPT P & O and provided quick and reliable management of the converter duty cycle with the least amount of time and signal jitter.

4. Conclusion

Due to its characteristic of having the fewest carbon emissions, solar power is the most ideal. The output of a PV system is influenced by the temperature of the surrounding air and the intensity of the sun's irradiation. In this study, the scenario of using an array of photovoltaic cells for power system consumption is taken into consideration. MPPT systems respond slowly to actual and swift changes in system status. This article proposes a technique that combines fuzzy logic and PSO. The advantage of adopting fuzzy logic systems control is that the MPPT may be quickly implemented using straightforward if-else rules. However, it is necessary to characterise the shape of the membership function of the fuzzy logic MPPT controllers in order to improve the compatibility between the point of operation and MPPT while taking into account the precise error range and change in error values. In this study, an MPPT controller is designed to increase the energy conversion efficiency of the solar arrays using a fuzzy logic control input and an intelligent optimum MF function seeking strategy. With the given solar irradiance, temperature, and load, the suggested PSO-based fuzzy logic controller achieves MPPT. The SIMULINK tool is used to model the PV system with converter system. To obtain the maximum power point, the duty cycle is estimated using the PSO fuzzy logic controller input MF. Different Simulink models of the proposed PSO-optimized Fuzzy MPPT scheme, non-optimized fuzzy based MPPT, and standard P&O-based MPPT have been developed, and the results are compared. To control fuzzy controlled simulink modelling, a MATLAB-based tool called PSO is utilised. This programme is ideal for analysing the I-V and P-Vcharacteristics of a PV array under various irradiation conditions and varying temperatures. The findings of the PSO optimised fuzzy logic controller are compared to those of conventional techniques like P&O and regular fuzzy controlling methods, which demonstrate that the PSO optimised fuzzy scheme produces more power than either of them.

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