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Analysis and Optimization of Fuzzy Logic Based MPPT for Grid Connected Photovoltaic System

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Abstract— Solar is one of the most important renewable energy sources that consistently operates with clean, sustainable, and ecologically beneficial operations in the photovoltaic power producing station. Additionally, due to the nature of photovoltaic power, the fluctuating trend in PV system output energy reduces their dependability in terms of supplying consumers with uninterrupted energy. A significant benefit of photovoltaic (PV) structures is their capacity to harness the immense and unpredictable power of the sun. Strong sunlight environments have accelerated PV science, which is now present in high-efficiency regions and regions with frequent cloud cover. A modeling approach for renewable grid-connected microgrids is presented in this research. Under gloomy or foggy situations, the long rambling factor makes up the majority of solar insolation. This work simulates a PV system using MATLAB and uses a fuzzy method to monitor the component that consumes the most energy. The findings of the fuzzy Logic version were improved for validation, and they were also contrasted with those from other methods like perturb and observe (P&O) and proportional integral differential (PID).

Keywords: *PV, Grid connected PV, Fuzzy logic based MPPT, MATLAB simulation and Optimization.*

1. INTRODUCTION

After the energy crisis and environmental problems, including pollution and global warming, solar photovoltaic (PV) systems have attracted a lot of research attention. Regarding the effectiveness of solar photovoltaic systems, additional research is now being done on how to extract more electricity efficiently from PV cells. The output voltage of solar PV systems varies with sun irradiation and temperature variations, which is their primary flaw. One maximum power point (MPP) from the photovoltaic array input is tracked by the Maximum Power Point Tracking (MPPT) procedure. Automatically determining the voltage MPPT or current MPPT at which a PV array should run to attain the MPPT maximum output at the specified temperature and irradiance. It is noticed that the P-V characteristics of the PV array become more complicated and exhibit several peaks under partial shade situations [1]. Several MPPT tracking strategies are in use, and comparisons between the majority of these MPPT approaches and the quantity of energy harvested from the PV panel have been made in the literature [2–3]. Perturb and Observe (P&O) and the Incremental Conductance (IC) algorithm are the two most often used MPPT algorithms.

Different MPPT types have been created and introduced [4-5]. Fuzzy logic is an excellent approach for determining a solar panel's MPP and has strong stability and a high reaction rate. Since it has superior performance, accuracy, and stability, fuzzy-based MPPT [6-7] research papers have been published more recently. To improve the effectiveness and reliability of solar photovoltaic (PV) power generation, the author [8–9] suggests a fuzzy-based MPPT and constructs a dynamic model of a grid-connected PV system using the MATLAB/Simulink environment. The system with fuzzy-based MPPT boosts energy production efficiency, according to simulation data. A novel fuzzy-based method was suggested in Reference [10] and compared to the others to track the solar panel's most significant power.

Photovoltaic systems require installing power conversion equipment between the PV array and the Grid. With steady-state operation on the grid side, the control is intended to produce PV software quality with MPPT algorithm performance and high load current harmonics for generator PV applications. The PV array should operate over the estimated voltage and current at maximum power output in order to generate the most electricity, independent of the weather. The MPPT system does this. The power converter converts the PV array's DC to an electrical current. A DC-AC converter converts DC to AC with a unity power factor for grid-connected applications.

In contrast, a DC-DC converter often performs MPP and voltage boosting in a two-stage paradigm. A DC-AC converter is used in a single-stage structure to monitor the MPP, regulate the active and reactive power transferred to the Grid, and change the DC produced by the PV array into AC. The high-frequency components of the AC inverter current are filtered via the grid interface to deliver low total harmonic distortion AC to the Grid. For grid-connected PV systems, conventional linear control methods such as proportional-integral (PI), proportional resonant (PR), hysteresis, and predictive controllers have been made accessible by [11] and [12]. The control system performs two kinds of tasks: stabilization and tracking [13]. In a stabilization challenge, the control system's goal is to maintain the closed-loop system's state stable around its equilibrium point.

2. MODELING OF A GRID CONNECTED SOLAR SYSTEM WITH FUZZY LOGIC

Photovoltaic systems require installing power conversion equipment between the PV array and the Grid. These systems are built to function alongside both the Grid and other systems. An MPPT algorithm, an energy exchanger, a meter connection, and a management system make up energy endurance. With steady-state operation on the grid side and high load current harmonics for generator PV applications, the control is intended to produce good PV software quality [14]. The PV array should operate over the estimated voltage and current at maximum power output to generate the most electricity, independent of the weather. The MPPT system does this. The PV array's DC is converted via the power converter.

A DC-AC converter transforms DC to AC with a unity power factor for grid-connected systems, whereas a DC-DC converter often conducts MPP and voltage boosting in the two-stage idea. In a single-stage construction, a DC-AC converter controls the active and reactive power transmitted to the Grid, monitors the MPP, and converts the DC current generated by the PV array to AC current. In order to supply the Grid with AC with low total harmonic distortion, the high-frequency components of the AC inverter current are filtered via the grid interface. [15] and [13] have presented conventional linear control techniques for grid-connected PV systems, including PI controller, Proportional Resonant (PR) controller, and Hysteresis controller.

2.1 PV systems design

The data sheet supplied by the manufacturer is frequently the foundation for calculations that replicate the PV parameters. The I-V characteristics are most accurately predicted at a specific operating temperature and sun irradiation. Theoretical models are used to forecast how the PV cell will behave in terms of open circuit voltage, short circuit current, and MPPT algorithm voltage and current. The single diode model (SDM), the most used approximation model, is shown in Figure 1. This model successfully balances simplicity and accuracy (Chen, 2010). The SDM is depicted in a simplified manner in the ideal single diode model (ISDM). Series and shunt resistances are not taken into consideration by the ISDM in figure 1.

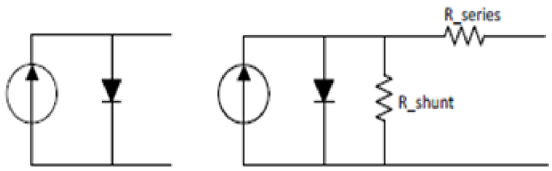

Figure 1: PV representation model

The ISDM model assumes Iph and Id. This thesis uses the SDM model, which is commonly used, simple, and accurate. The efficiency of the PV cell may be increased by first determining the (MPP). When the power change over the voltage changes equals zero, the MPP is attained. We must use one of the Maximum Power

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Point Tracking (MPPT) techniques to obtain the MPP. The most popular and often employed methods are "Hill Climbing" methods. The P&O and Incremental Conductance techniques are the two most used for ascending hills. Temperature and solar radiation are two elements that influence the amount of energy that current PV cells generate (temperature).

2.2 Maximum power point technology

A specific strategy was required to find significant solar power with stationary solar panels. To maximize the power point, various techniques have been developed, including, Voltage feedback, Perturbation and Observe (P&O), Incremental Conductance (IncCond), Power feedback, Parabola Prediction, Particle Swarm Optimization (PSO), Fuzzy Logic Control (FLC), Score Open Circuit Voltage, Neural Network (NN), Current Scanning and Adaptive Neuro-Fuzzy Inference System (ANFIS). In the next section, we'll discuss fuzzy logic technology and how it may help you get the highest MPPT output. The MPPT Fuzzy Controller (FLC) (PWM control) is a technique for managing a DC-to-DC converter's electrical output. To lessen the unpredictable nature of PV production, FLC was used.

2.2.1. Fuzzy logic controller design parameters

An example of a fuzzy logic-based maximum power point tracker is shown in Figure 2. The PV module's output voltage and output current (Vm) are the only two state variables the fuzzy controller interprets as inputs, as shown from the observation (Im). The fuzzy logic controller creates a signal proportionate to the converter duty cycle based on measurements and sends it to the converter via a pulse width modulator (D). Pulse width modulation (PWM), which is performed by this modulator, produces the control signals for the converter switch (s). It is known as a closed loop system when referring to fuzzy logic controller technology.

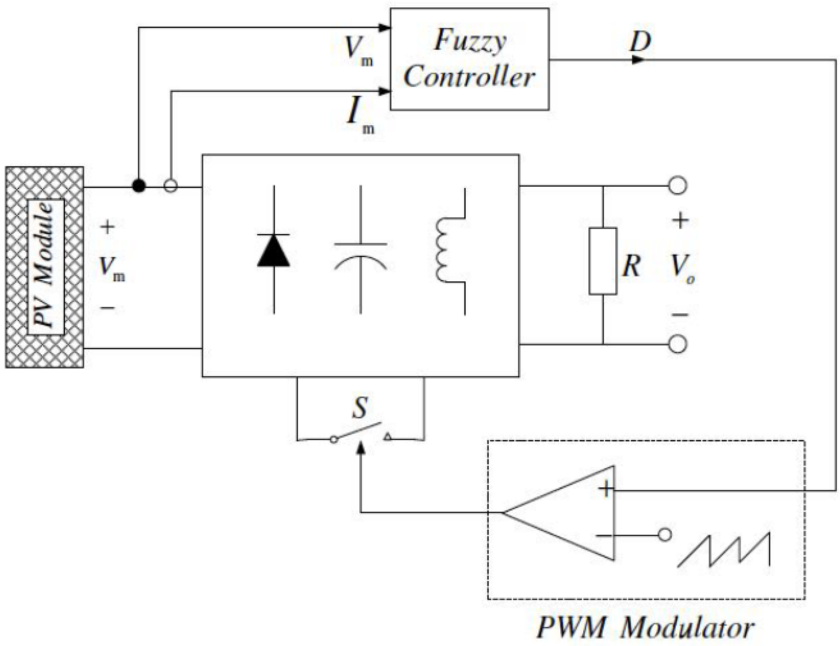

Figure 2: Schematic diagram of Fuzzy Logic Controller

When the fuzzy controller was modified in MATLAB, the FIS file was created so that it could be called in the Simulink system. Figure 3 displays the fuzzy controller's performance after looking at the output at various input values.

The many input and output readings that were taken are listed in Table1. Finally, this reading is used to optimize the fuzzy logic controller's duty cycle. The system was built using Simulink/MATLAB and tested for a variety of solar irradiation levels. The different irradiance fluctuations were simulated using the Simulink/MATLAB simulation model.

Table 5.1: Duty Cycle Optimization table for different values

Current	Voltage	Duty cycle
0.49	11	0.929
0.299	15	0.9169
5	17	0.7293
9.8	18	0.8354
9.9	25.01	0.6102
14.9	17.33	0.6229
15	17.3	0.6429

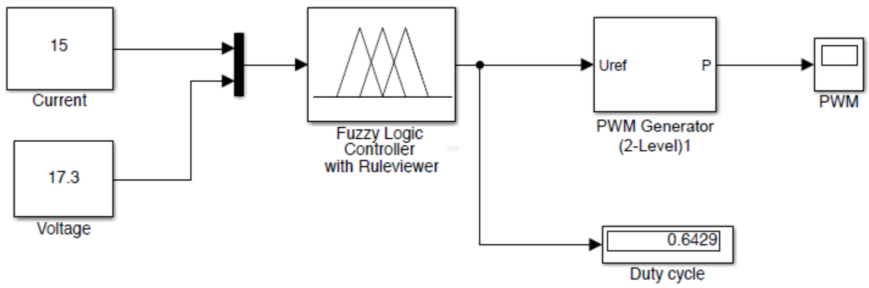

Figure 3: Optimum duty cycle controller in MATLAB

In order to verify the functionality of the fuzzy controller and the effectiveness of the converter, readings of the input power and output power of the MPPT were collected at solar irradiation (1000w/m2, 800w/m2, 600w/m2, 400w/m2, and more) and duty cycle were noted at the same radiation levels. Details regarding the simulation findings are provided in Table 2.

Table 5.2: FLC Simulation results

Irradiance value (W/m^2)	Power Input in watt	Power Output in Watt	Value of Duty Cycle	Efficiency
1000	251.7	253	0.65	0.99486166
850	219.7	221.9	0.65	0.99008562
700	170.9	172.7	0.59	0.9895773
550	118.98	120.5	0.49	0.98738589
400	78.86	79.4	0.35	0.99319899

2.3 Fuzzy based MPPT for Grid connected PV system

The Simple P&O technique creates and manages the fuzzy logic based MPPT Controller in uncertain situations. The building block indicates the device's uncertain condition for SIMULINK/signal in MATLAB. The evaluation is completed by comparing the data to determine the most precise and effective method for tracking maximum power in ambiguous situations. The MATLAB/SIMULINK program was utilized to build the model. The output of the PV Module is coupled to the DC-DC Buck-Boost converter, which houses the electric drive.

Fuzzy Logic Based MPPT Controller sends a gate signal pulse to the MOSFET. The controller is designed to keep track of the PV module's maximum power under rapidly changing circumstances. Unpredictable circumstances might be caused by temperature and irradiation level variations. Uncertainty is accepted by the PV Module using a signal block made up of many input signals. In order to make a more realistic comparison, the uncertainty for both strategies is equal. The fuzzy logic controller and MPPT algorithm are connected in this arrangement. The MPPT file, which contains the rules and membership functions for maximizing the output voltage from the solar PV module, is stored by the fuzzy logic controller. The output of the fuzzy logic controller is supplied to the output block, which modulates the signal with the suitable repeated sequencing signal. The input signal block sends the voltage and power change signal to the fuzzy logic controller. The gate drive, a buck-boost converter, receives the output after that. The membership function and rule evaluations define the output of the fuzzy logic controller. The fuzzy logic controller (FLC) can handle inhomogeneity, functions with assumed inputs, and is not dependent on a precise mathematical model.

Additionally, fuzzy is a lot stronger than a typical non-linear FLC system controller. The four major elements are the inference counting approach, system defuzzification, basis on the rule, and fuzzification [10]. E is the error, and alteration in error, namely CE, at the duty cycle denoted as D, where symbol V(t) along with P(t) is denoted as voltage as well as the power of a PV cell, respectively, are FLC's inputs in this study.

The following are the implied steps:

If dP/dV is greater than 0, the system controller modifies the system's duty cycle to change voltage rises until power is adjusted to the highest value.

If dP/dV is equal to 0, the controller remains with the same duty cycle, the power reaches the highest value

If dP/dV is smaller than 0, the change in the controller duty cycle is maintained the voltage value decreases until power is adjusted to the highest value.

Based on five fuzzy sets, negative small (NS), negative large (NB), positive small (PS), positive big (PB), and zero, membership function values are assigned to the linguistic variables (ZE). Figure 4 shows how fuzzy subsets are divided and how membership functions may take different forms depending on duty cycle implemented at the system, as demonstrated in Figures 5 to 6. The uncertainty for both strategies should be identical to allow for a more accurate comparison. The fuzzy logic controller and the MPPT algorithm are connected in this architecture. The MPPT file is kept in the fuzzy logic controller and contains the rules and membership functions for getting the most significant output voltage from the solar PV module.

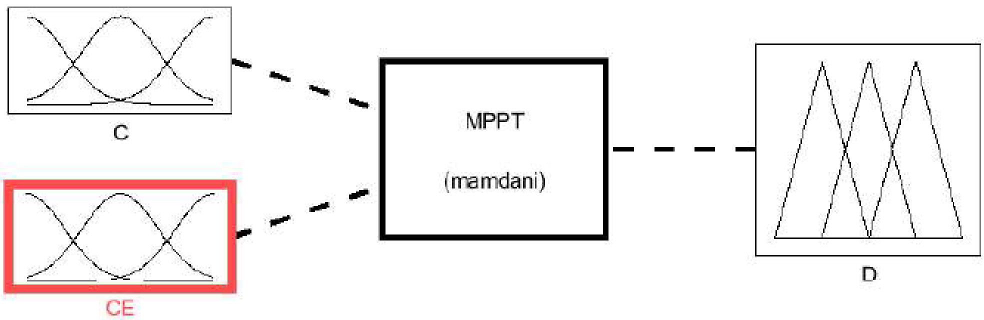

Figure 4: Fuzzy controller Model

For a more accurate comparison, the uncertainty for both techniques is equal. The fuzzy logic controller is linked to the MPPT algorithm in this architecture. The MPPT file, which contains the rules and membership functions for achieving the highest output voltage from the solar PV module, is stored in the fuzzy logic controller.

The fuzzy logic controller receives a voltage and power change signal from the input signal block, and the output of the fuzzy logic controller is supplied to the output block, which modulates the signal with the suitable repeated sequencing signal. The buck-boost converter's final output is then sent into the gate of an IGBT. The membership function and rule evaluations are used to determine the fuzzy logic controller's output.

At first, we use three membership functions to optimize the fuzzy logic controller and the output is stored in the table. For the next step, we use another fuzzy logic system table with five membership functions.

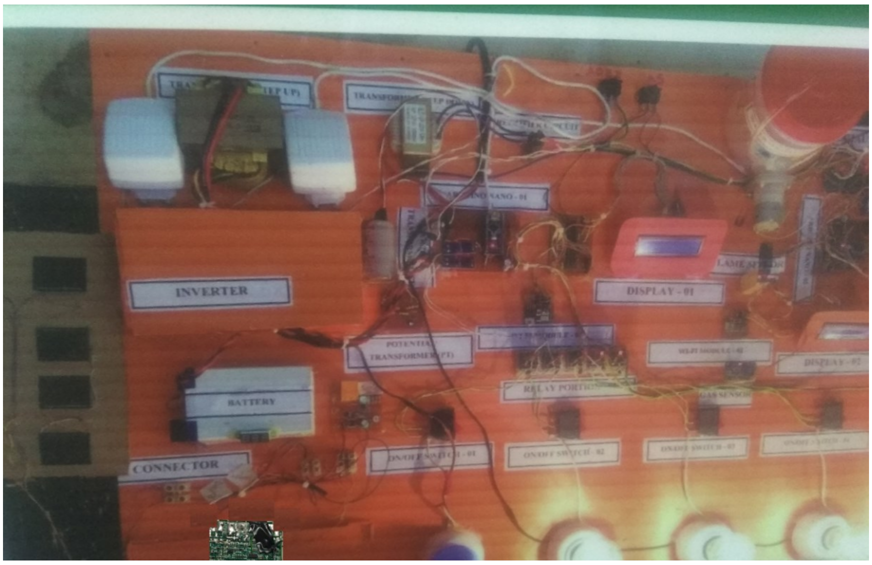

Figure 5: Setup for FLC run by Arduino

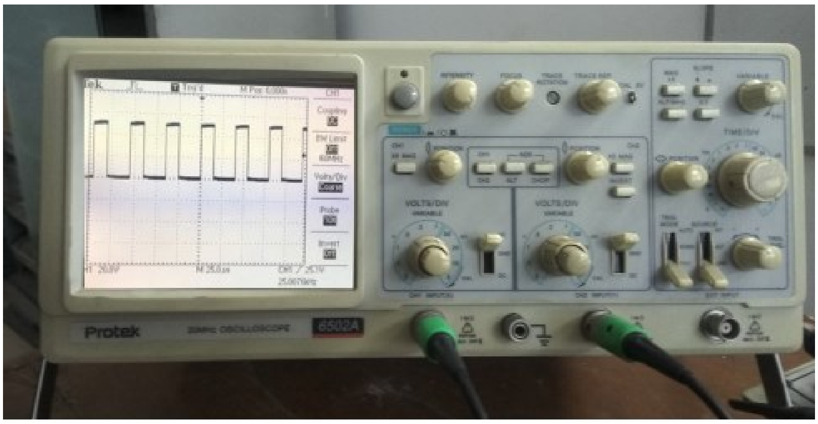

Figure 6: Experimental duty cycle output monitoring

By examining the system's behavior, fuzzy control rules may be derived. In order to enhance tracking performance in terms of dynamic responsiveness and resilience, the various operating circumstances are taken into account.

3. RESULT AND DISCUSSION

The tracking procedure begins with a default duty cycle of D=0. Then, based on projected values that have previously been entered into the fuzzy (1000w/m2, 800w/m2, 600w/m2, 400w/m2, 200w/m2) system, the converter input current Im and voltage Vm are monitored and sensed to determine the duty cycle that can deliver the converter's maximum power output at that moment. This process is repeated repeatedly until the power reaches its maximum and the system stabilizes.

During the simulation, solar irradiation of 1000 W/m2 and a temperature of 25 °C were used to test the two controllers. The outcomes for the power given to the battery with a simulation time of 0.03 s are shown in Figure 7. As can be observed, the two controllers achieve an excellent stability time of 0.005 s and a maximum power extraction of 65 W. Figure 7 shows that, in contrast to the fuzzy control, which is stabilized at a value of D = 0.693, the duty cycle of the P&O control exhibits modest fluctuations between 0.6926 and 0.7.

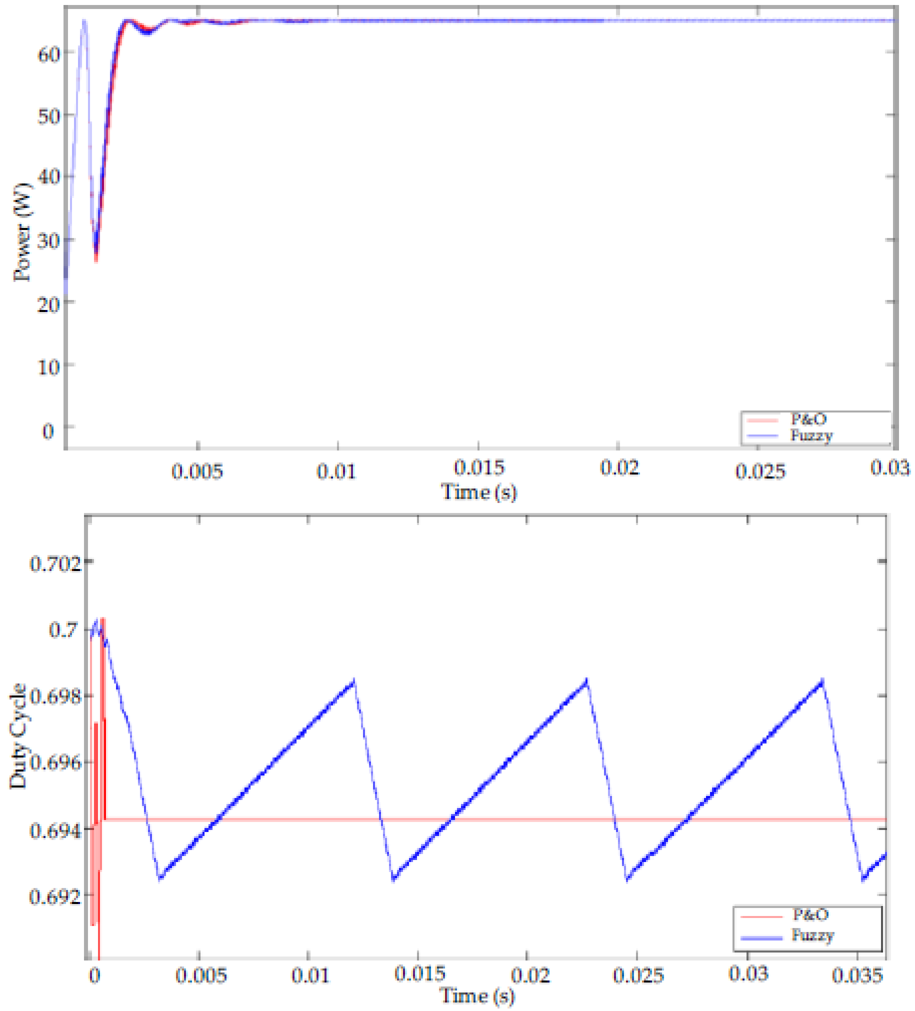

Figure 7: PV system output with the duty cycle

In the second scenario, a 25 °C working temperature and abrupt fluctuations in sun irradiation were used to assess the controllers' effectiveness. At first, an irradiance signal with 200 W/m2 increments between 200 W/m2 and 1000 W/m2 was employed. Irradiance changes occurred every 0.2 seconds during the course of a 1-second simulation.

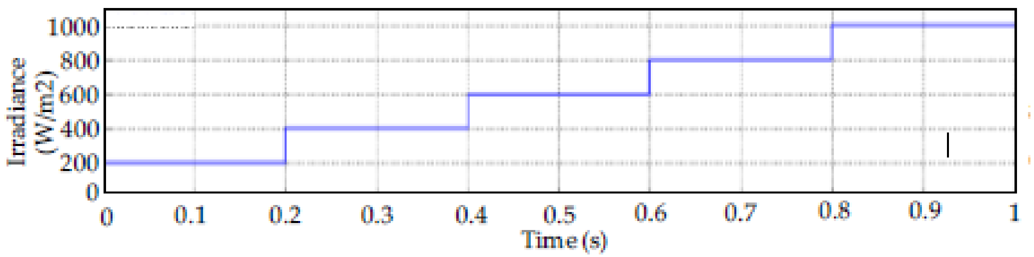

Figure 8: PV system input irradiance with an increment

The test signal used after that had solar irradiance drops between 1000 W/m2 and 200 W/m2 (Figure 8). The output power for irradiance signal increases is shown in Figure 9. Overall, it can be said that the two controllers exhibit satisfactory performance at various moments. The power obtained falls within the duty cycle range of 11.7 W to 64.9 W.

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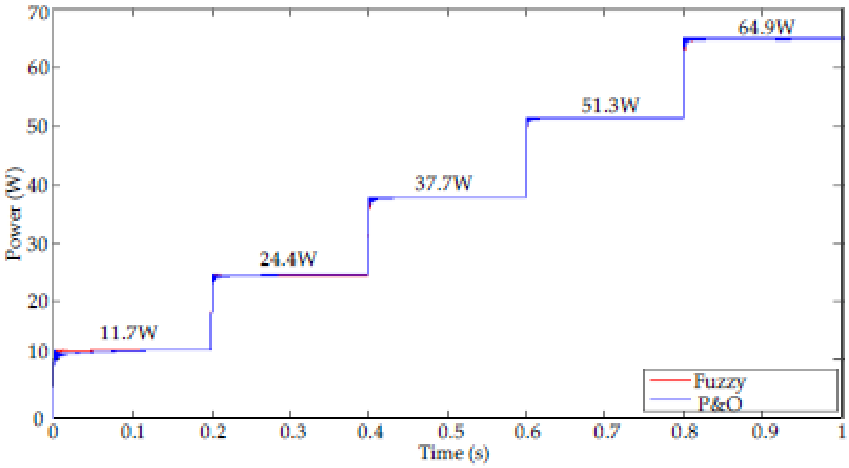

Figure 9: PV system input irradiance with an increment

At this time, constant solar irradiation of 1000 W/m2 was used to assess the system's performance for rapid temperature variations. The signal in Figure 10 was first employed with temperature rises occurring with a difference of 0.2 seconds between 0 to 100 C and the test duration of 1 s. All two controllers function well with an output system power between 63.9 W to 11.6 W, just like with the increased signal. It can be observed that while the P&O system controller exhibits the change that defines this methodology, the system's performance is not adversely impacted.

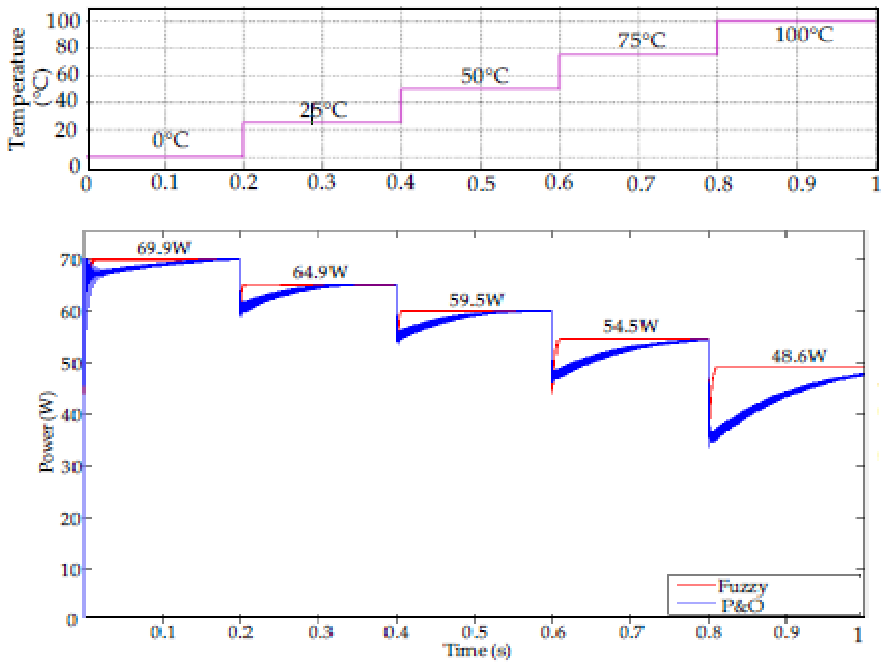

Figure 10: PV system input temperature/output power with an increment

Finally, as seen in Figure 11, the system's performance was assessed for rapid temperature changes and solar irradiation at different values of time ranging from zero to one sec. Figure 11 displays the power collected from Grid-connected PV modules adding fuzzy or P&O system controllers under the stated test conditions. The results show that the FL system controller adheres to the MPP tracking without oscillations or losses. On the other hand, the P&O system controller displays some power losses along with oscillations in reaction to solar irradiation and temperature change. The case studies for the P&O system control that is worst among 0.3 and 0.4 s, during which time the power changes in between 11.5 and 37.5 W when the temperature change counted from 50 to 75 C along with solar irradiation of near about 1000 W/m2.

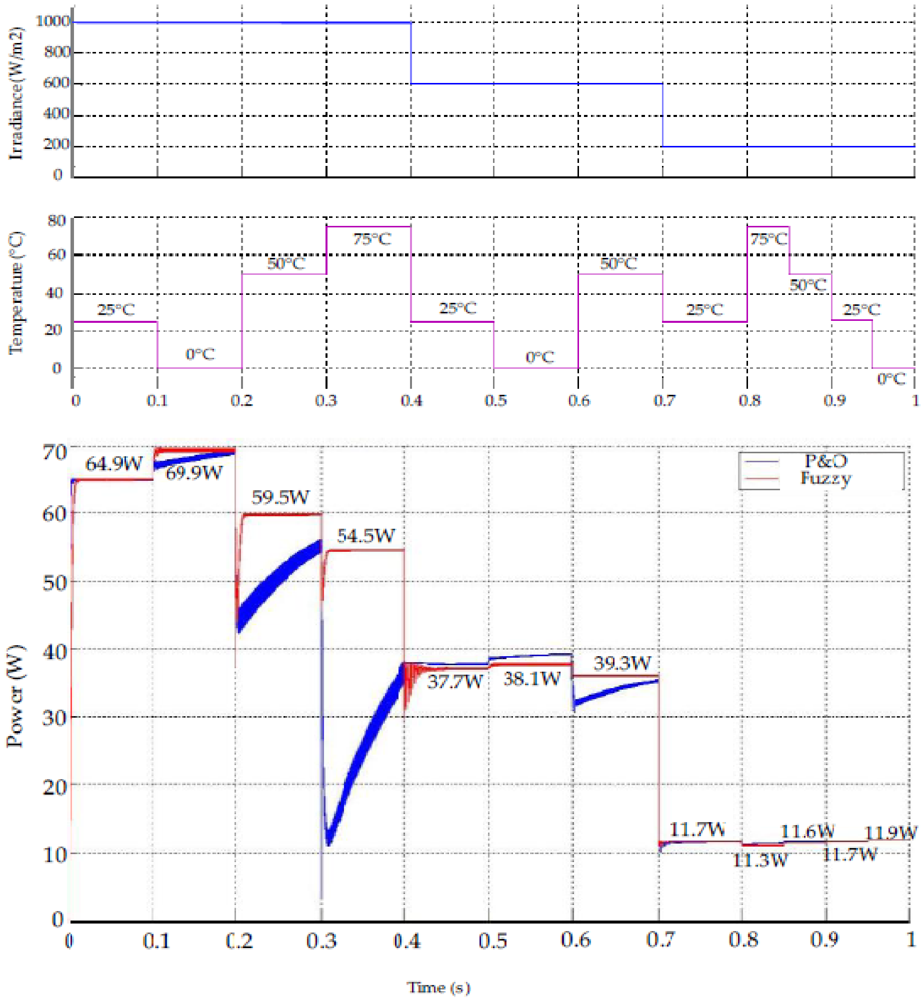

Figure 11: Power Output change due to temperature and irradiance change

The PV module with the highest power point tracking and the performance of the FLC controller and the P&O controller were evaluated. Each part of the Grid-connected PV system is modeled with a MATLAB/Simulink. Alternate test scenarios with changes in temperature along with solar irradiance were analyzed to measure the operation of the Grid connected PV system. It has been checked that the FLC controller functions superbly in these conditions, compared with P&O system control, which is greatly influenced by rapid alteration in the operational temperature of the Grid-connected PV module.

4. CONCLUSION

To conclude the article, a fuzzy logic algorithm is used to control the tracking of the maximum power point of a PV module cell. Finally, the simulated performance was compared with that of a controller run by the P&O algorithm. Here, the PV system with FLC was simulated in Simulink to analyze the performance of the Grid connected system, considering the various test conditions with fluctuation of signals for temperature change and change of irradiation variables of solar power. Compared to P&O logic control, if the system is severely harmed, the fuzzy controller shows excellent performance when the change in temperature for PV operation in the module abruptly. While it was demonstrated that the two controllers worked fine in the existence of differences in solar irradiance and collected the optimum power in accordance with the required electrical system characteristics of the PV module, in comparison, the P&O system controller still displayed regular oscillations. At the same time, there was a sudden change in irradiance. The final consideration for the article is the main contribution of this study, an assurance of fuzzy controller supplied grid-connected PV system power with the maximum amount of electricity possible. Additionally, the fuzzy logic controller is implemented on the inexpensive Arduino platform, demonstrating the advantage of fuzzy control's ease of programming with microcontrollers.

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