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Performance Evaluation of P&O, IC and FL Algorithms used in Maximum Power Point Tracking Systems.

F. ALHAJ OMAR[1], G. GOKKUS[2] and A. AFSIN KULAKSIZ[3]

[1] Selcuk University, Konya/Turkey, fuad.omar@selcuk.edu.tr
[2] Nevsehir Haci Bektas Veli University, Nevsehir/Turkey, gokselgokkus@nevsehir.edu.tr
[3] Konya Technique University, Konya/Turkey, afsin@selcuk.edu.tr

Abstract **- Solar energy is the most viable alternative source; furthermore, the implementation of solar energy technologies can reduce the problems of environmental pollution and electricity production costs besides securing the demands of electrical power. This research addresses the evaluation of three algorithms used in maximum power point tracking systems (MPPT). These algorithms are Perturbation & Observation (P&O), Incremental Conductance (IC) and Fuzzy Logic (FL). They are considered as the most used in MPPT due to their simplicity and ease of realization. Based on Matlab/Simulink environment, the mathematical models of the three algorithms are designed and tested under various weather conditions. Collected simulation results illustrated the effectiveness of Fuzzy logic algorithm to draw more energy, decrease oscillation and provide a fast response under variable weather condition. The final simulation results show the fuzzy logic algorithm exhibits a better performance compared to both perturbation & observation and Incremental conductance algorithms.**

Keywords **– Photovoltaic, MPPT, Incremental Conductance, Perturbation & Observation, Fuzzy Logic.**

I. INTRODUCTION

The continued dependency on fossil fuels for energy production is leading to the continued rise in carbon emissions giving rise to atmospheric changes. Furthermore, continual daily increases in global energy use are depleting the supplies of oil and gas.

However, renewable energy sources are more viable alternatives since they are clean, pollution-free and non-exhaustible. Among all renewable energy systems, the solar energy system has received the most attention due to its ease of implementation and cost reduction. Despite all the advances in PV technology, the solar cells have some drawbacks such as the energy conversion efficiency is low and the characteristic curve of a solar cell is nonlinear and depends on the irradiance level and ambient temperature (Fig. 1) [1]. To increase the efficiency of the solar cell and optimize the power obtained from PV system, many maximum power point tracking techniques (MPPT) have been proposed, amongst these techniques, perturbation & observation, Incremental conductance and Fuzzy logic. The Maximum Power Point (MPP) is the point on the current-voltage (I-V) curve (Fig. 1) which corresponds to the maximum possible power output for the given PV panel (Pmax), and the Maximum Power Point Tracker (MPPT): A device that continually finds the MPP under variable weather conditions [2]. A typical diagram of the MPPT in a PV system is shown in (Fig. 2).

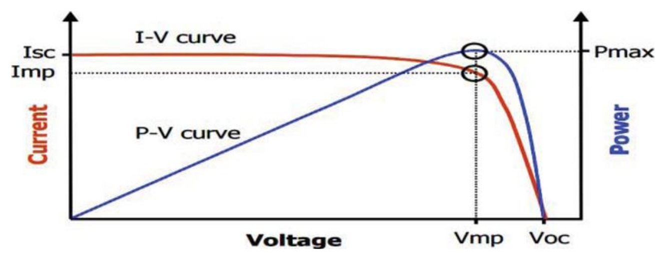

Figure 1: P-V & I-V characteristics of a solar panel.

In this study, a simulation test set up to evaluate the performance of the three mentioned MPPT algorithms. For performance evaluation, the mathematical models of the P&O, IC and FL algorithms are designed in Matlab/Simulink, and simulation results are obtained under different irradiation.

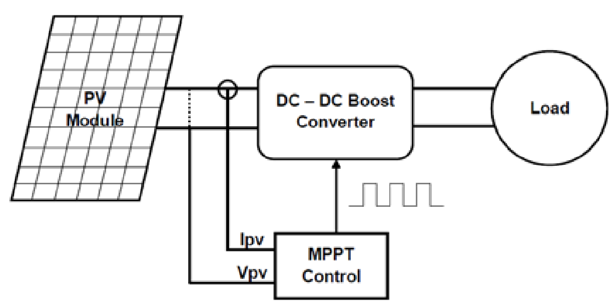

Figure 2: Typical diagram of MPPT in a PV System.

II. MAXIMUM POWER POINT TRACKING TECHNIQUES

A. Perturbation & observation (P&O):

This technique depends on changing duty cycle (perturbation) and measuring the output power (observation). First, if the change in duty cycle is positive and change in power is positive, this means the operating point would be on the left of the MPP and the next perturbation would be positive. On the other hand, if the change in power is negative, this means the operating point would be on the right of the MPP and the next perturbation would be negative. If the change in the duty cycle is negative and the change in power is positive, that means the operating point would be on the right of the MPP and the next perturbation would be negative. On the other hand, if the change in the duty cycle is negative and the change in power is negative, that means the operating point would be on the left of the MPP and the next perturbation would be positive [3]. The basic principle of the P & O algorithm is summarized in Table 1.

Table 1: The basic principle of the P & O algorithm.

Perturbation	Change in power	Next perturbation
positive	positive	positive
positive	negative	negative
negative	positive	negative
negative	negative	positive

B. Incremental conductance (IC):

This technique depends on the fact that the differential of the PV power with respect to PV voltage is zero at the MPP, positive on the left of the MPP, and negative on the right of the MPP [4], as given by:

$$\frac{dP_{PV}}{dV_{PV}} = 0, at\ MPP.$$
$$\frac{dP_{PV}}{dV_{PV}} > 0, left\ of\ MPP.$$
$$\frac{dP_{PV}}{dV_{PV}} < 0, right\ of\ MPP.$$

By using the measured values of V_{pv} and I_{pv} at different instants, the MPP can be reached as shown in (Fig. 3).

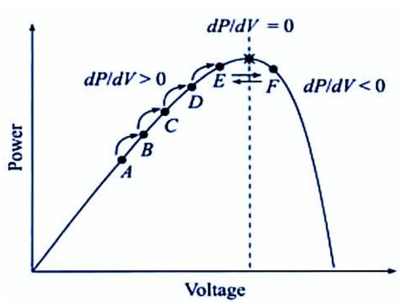

Figure 3: The principle of the IC algorithm.

C. Fuzzy Logic (FL):

Generally fuzzy logic control consists of three stages: fuzzification, rule base table lookup, and defuzzification [5]. In the fuzzification stage and based on a membership function, shown in (Fig. 4), numerical input variables are converted into linguistic variables. Where five fuzzy levels are used: NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small), and PB (Positive Big).

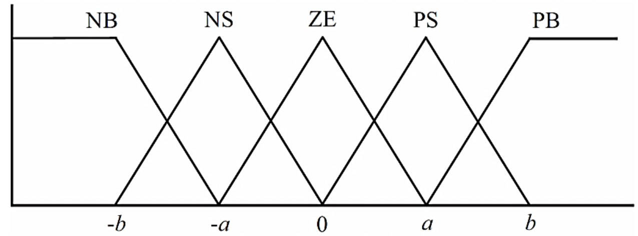

Figure 4: The proposed membership function for inputs and output of fuzzy logic algorithm.

For more accuracy seven fuzzy levels can be used. In (Fig. 4), *a* & *b* represent the range of the numerical variable values. Usually, the inputs to a MPPT fuzzy logic controller are an error *E* and a change in error *ΔE*. The user has the flexibility of choosing how to compute *E* and *ΔE*.

$$E(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)}$$

And

$$\Delta E = E(n) - E(n-1)$$

After calculating *E* and *ΔE* they will be converted to the linguistic variables, the fuzzy logic controller output, which is a change in duty cycle *ΔD* of power converter, can be found in the proposed rule base which is shown in Table 2.

Table 2: The proposed fuzzy logic rule base.

E \ ΔE	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

The change in duty cycle *ΔD* for the different combinations of *E* and *ΔE* is determined according to the power converter being used and the knowledge of the user.

During the defuzzification stage, the linguistic variables, namely the output of the fuzzy logic controller, are converted to numerical variables depending on the proposed membership function which is shown in (Fig. 4). This generates an analog signal that will control the power converter to the MPP.

III. MODEL OF THE SYSTEM

Based on the general mathematical equation of the PV cell, the model of the PV panel was built in Matlab/Simulink. The maximum output power of the modeled PV panel according to the Irradiance level are shown in Table 3.

I-V and P-V characteristics of the PV panel are obtained in several irradiance levels and constant temperature which are shown in (Fig. 5, Fig. 6). It is obvious that there is a maximum power point in every P-V curve in a specific irradiance.

Table 3: The MPP value according to the Irradiance level.

Irradiance level	Maximum power
700 w/m^2	28 Watt
900 w/m^2	38 Watt
1100 w/m^2	46 Watt

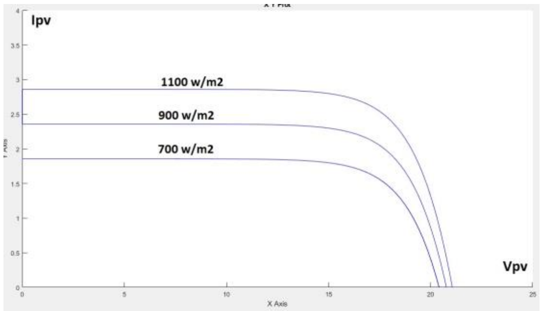

Figure 5: I-V characteristic of modeled PV panel.

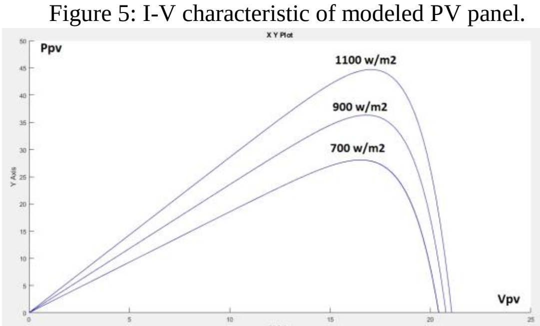

Figure 6: P-V characteristic of modeled PV panel.

A DC-DC boost convertor is utilized in the simulation. By controlling the duty cycle of the switching elements, the PV terminal voltage will be kept at the point that maximum power is obtained, and also the output voltage of PV panel will be matched with the desired load voltage. Input-output DC-DC boost converter equation is:

$$V_{PV} = V_O(1 - D)$$

Where V_{pv} is PV panel output voltage, V_O is DC-DC boost converter output voltage, and D is duty cycle [6].

The proposed system has been modeled and simulated using MATLAB/Simulink. (Fig. 7) shows our proposed Simulink model. In the simulation study, the three mentioned MPPT techniques are simulated and evaluated under the operating condition assuming the constant temperature and variable irradiance.

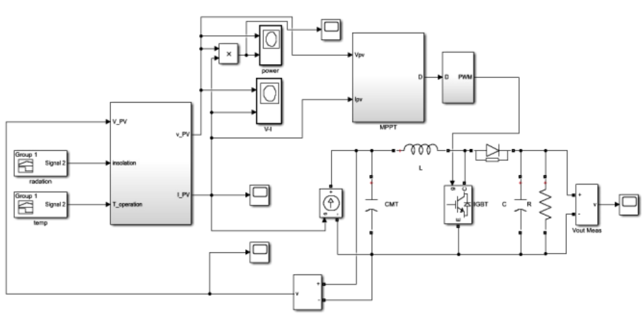
Figure 7: Diagram of the proposed system.

IV. SIMULATION RESULTS AND VALIDATION DISCUSSIONS

With a view to evaluate and analyze the maximum power point tracking techniques, an offline simulation has been tested in Matlab/Simulink for every algorithm.

Different levels of solar irradiance 700W/m^2, 900W/m^2 and 1100W/m^2 were applied as shown in (Fig. 8), while the temperature was constant at 25 degree Celsius.

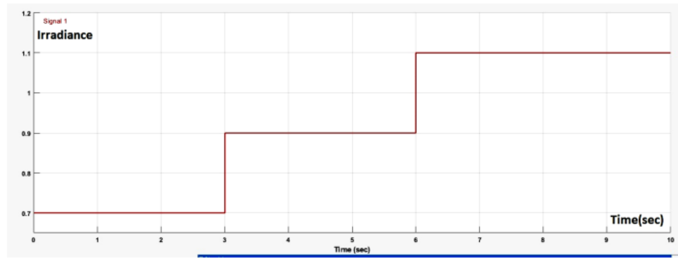

Figure 8: Solar irradiance: 700 W/m^2, 900 W/m^2 and 1100 W/m^2.

The withdrawn power from the PV panel was plotted with respect to time, refer to (Fig. 9, Fig. 10 and Fig. 11). Also the output voltage of the DC-DC boost converter for every algorithm was plotted, as illustrated in (Fig. 12, Fig. 13 and Fig. 14)

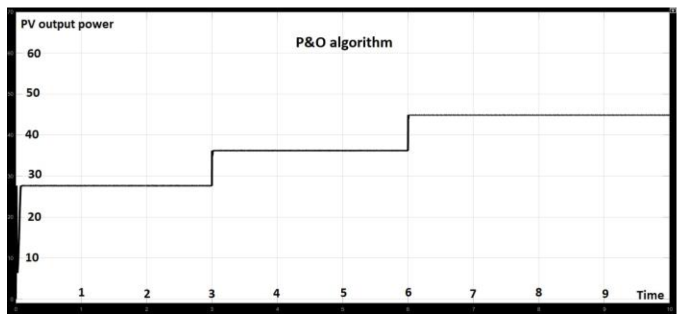

Figure 9: output power of solar panel with P&O algorithm.

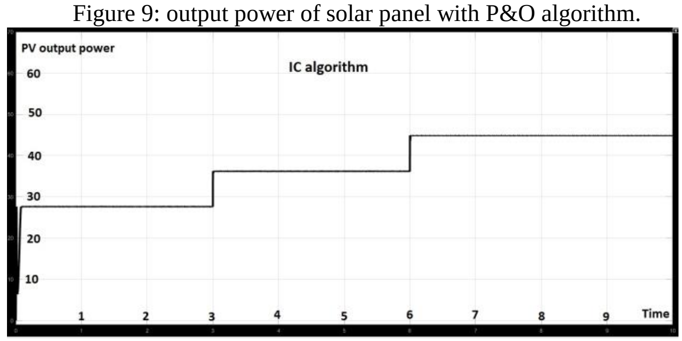

Figure 10: output power of solar panel with IC algorithm.

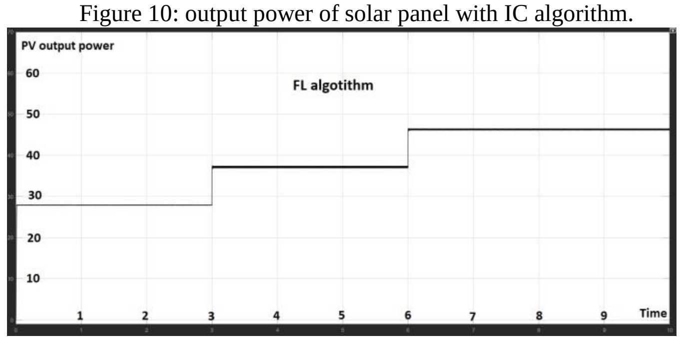

Figure 11: output power of solar panel with FL algorithm.

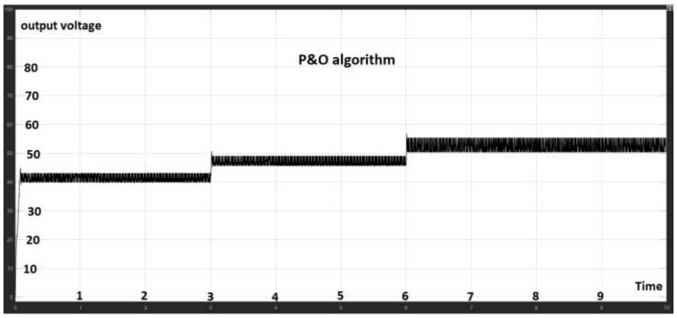

Figure 12: output voltage of boost converter with P&O algorithm.

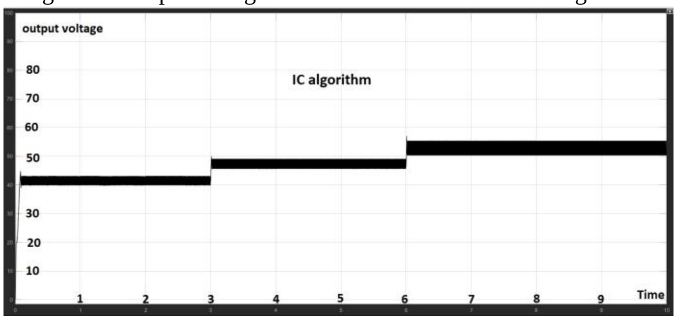

Figure 13: output voltage of boost converter with IC algorithm.

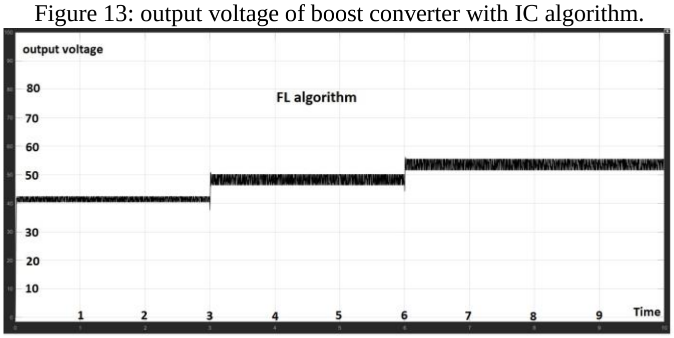

Figure 14: output voltage of boost converter with FL algorithm.

Through the collected simulation results, we can notice that all the tested algorithms were able to find and track the maximum power point despite the instantaneous change in the irradiance. It is also obvious that both algorithms, P&O and IC, were able to make the operating point of the system near the MPP, while FL algorithm made the operating point exactly at the MPP. Thus, the withdrawn energy from the solar panel using the FL algorithm was greater than the produced energy using the other algorithms, as shown in the Table 4.

Table 4: The withdrawn energy by using each algorithm.

Irradiance level	Withdrawn energy by P&O	Withdrawn energy by IC	Withdrawn energy by FL
700 W/m^2	27 watt	28 watt	28 watt
900 W/m^2	36 watt	36 watt	37 watt
1100 W/m^2	44 watt	44 watt	46 watt

Observing (Fig. 9 and Fig. 10), the P&O and IC algorithms show good dynamic performance, but larger steady state oscillations at the MPP, which makes the MPPT accuracy low.

The simulation results indicate that the steady state oscillation at the maximum power point is less when using the FL algorithm, (Fig. 11), resulting in lower energy loss and increased system efficiency.

Finally, with the view to optimizing the power production from solar panels, the results have showed that Fuzzy Logic technique has proven to exhibit superior performance in terms of efficiency than conventional techniques, (P&O and IC).

V. Conclusion

In this paper, a performance evaluation of Perturbation & Observation, Incremental conductance and Fuzzy logic used in maximum power point tracking system is presented. In order to verify the performance of the three maximum power point tracking techniques, the algorithms models were built in Matlab/Simulink and simulation results were collected. It is shown that the Fuzzy logic technique has better tracking achievement, is able to obtain maximum power in terms of variable irradiance, and is preferable in comparison with the conventional techniques. A fuzzy logic algorithm also reduces the steady state oscillation at the MPP resulting in decreased power losses.

Future efforts will be directed towards implementing of fuzzy logic algorithm by using STMicroelectronics-32 bit ARM and will be tested in the real PV system. Experimental results will be obtained to demonstrate the accuracy and effectiveness of the Fuzzy logic algorithm to increase the efficiency and yield of the solar generation system.

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