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Efficiency improvement of photovoltaic by using maximum power point tracking based on a new fuzzy logic controller

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Abstract

Maximum power point tracking (MPPT) is a technique to maximize the power output of a photovoltaic (PV). Therefore, to achieve higher PV efficiency, the development of MPPT control algorithm is necessary. Recently, it was revealed that, in certain conditions, fuzzy logic controller (FLC) is better than other control algorithms and is possible to be developed. This study fabricated and implemented MPPT based on the proposed a new FLC. Input Calculator (IC) via sensors reads current and voltage of PV and generates the comparison of voltage and current of PV, then IC output becomes fuzzy algorithm input. Fuzzy algorithm produces duty cycle that drives synchronous buck converter. The result showed that MPPT system with the proposed FLC method has 99.1% efficiency while MPPT system with P&O method has 95.5% efficiency. From the obtained result, it can be concluded that the MPPT based on the proposed FLC can increase the overall efficiency of the system to 99.3%.

Keywords: maximum power point tracking; fuzzy logic controller; photovoltaic efficiency; synchronous buck converter.

I. Introduction

Photovoltaic systems have been widely used in power systems technology providing safer and pollution-free electricity sources. Unfortunately, solar panel fabrication requires high costs and low energy efficiency. Therefore, PV energy efficiency can be increased by operating PV at its maximum output power [1]. PV efficiency may be increased and operated at the maximum power point (MPP). A device that forces PV to operate at the MPP is called maximum power point tracking (MPPT) which typically employs a DC to DC converter that connects the PV system to the load [2]. To obtain maximum power from solar panel array, photovoltaic power system usually requires a MPPT controller [3].

There are several control algorithms of MPPT that can be used to maintain PV working at the MPP. Examples are Perturb & Observe (P&O) and incremental conductance. Compared with the incremental conductance algorithm, the P & O algorithm gains faster convergence to achieve the maximum power point [4]. However, the algorithm will potentially generate steady state oscillations with a large enough voltage variations which will result in failing to determine the MPP especially in areas with rapid variation in solar irradiation [5]. The use of incremental conductance method reduces oscillation in the time it reaches the point of maximum power, but it requires longer convergence time [6].

The other alternative of MPPT controller- is Fuzzy Control [7][8][9]. The use of fuzzy logic controller is better than conventional controllers [10]. A DC to DC converter is needed for implementing MPPT. The DC to DC converter delivers the maximum power from PV module to the load by adjusting the duty cycle and being able to distribute a maximum power when the load changes [11]. Some DC to DC converter topologies are implemented for MPPT including buck converter, boost converter, cuk converter, full bridge converter and buck boost converter [12].

This study deals with MPPT using Fuzzy Logic Controller (FLC) with two new fuzzy input variables

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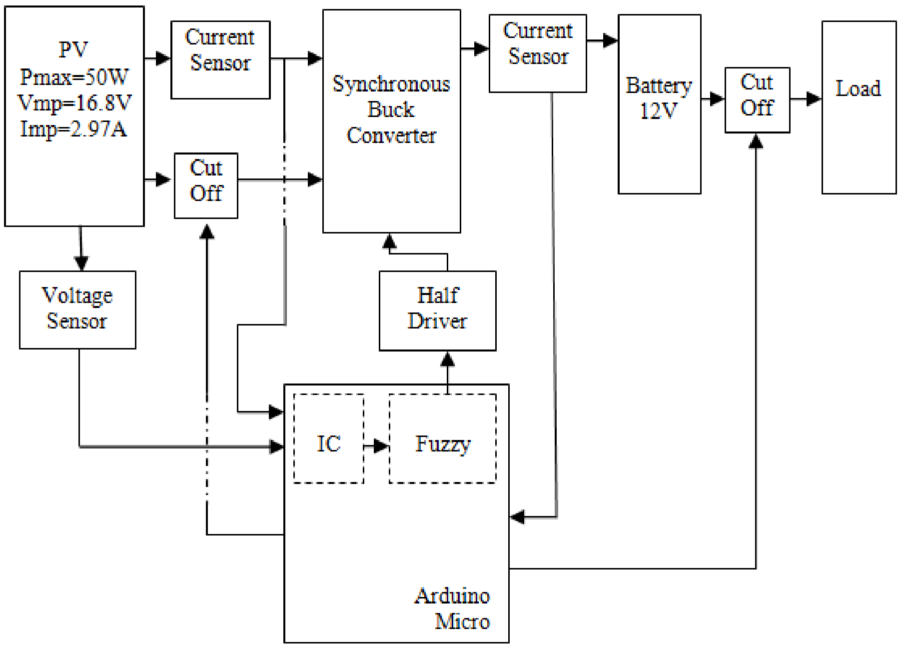

Figure 1. Photovoltaic with MPPT system

that is I/V and dI/dV where I and V represent current and voltage of the PV panel. The FLC adjusts the duty cycle of buck converter.

II. Materials and methods

Figure 1 shows a block diagram of the whole system of MPPT which will be examined in this study. MPPT system consists of solar panels (photovoltaic), synchronous buck converters, battery, resistance, and Arduino Micro as a controller. Circuit cut-off is also added to the MPPT system, which is useful for preventing reverse flow from the battery to solar panels in the solar panel voltage below the battery voltage. IC stands for input calculator which calculates fuzzy input variables.

A. Photovoltaic

The mathematical model was developed to simulate the characteristic of PV panels. Figure 2 shows a series of PV circuit panels below [13]. The basic equation of the PV panels is shown by equation (1) below:

$$I = I_{pv,cell} - I_d = I_{pv,cell} - I_{0,cell}\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \quad (1)$$

where $I_{pv,cell}$ is the current generated by the incident light, I_d is the Shockley diode equation, $I_{0,cell}$ is the reverse saturation or leakage current of the diode, q is the electron charge [1.60217646×10^{-19} C], k is the Boltzmann constant [1.3806503×10^{-23} J.K^{-1}], T [K] is the temperature of the p-n junction, and a is the diode ideality constant. A shunt resistance (R_p) and a series resistance (R_s) component are added to the model since no solar cell is ideal in practice. A typical characteristic of PV power model curve and voltage curve is shown in Figure 3. In this study, it is only used a single PV panel with the parameters shown in Table 1.

Table 1.
Specifications of PV

Specifications	Values
Irradiance	1000 W/m^2,
Temperature	25°C
P_{max}	50 W
V_{mp}	16.8 V
I_{mp}	2.97 A
V_{oc}	21 V
I_{sc}	3.23 A
Weight	10 kg
Size	6.7 m × 6.2 m × 0.35 m

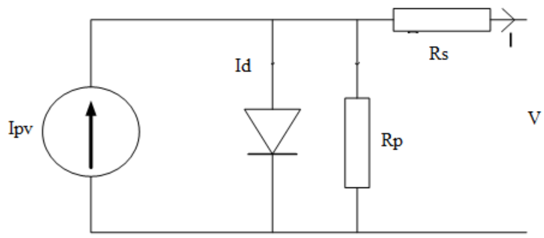

Figure 2. Equivalent circuit of solar cell

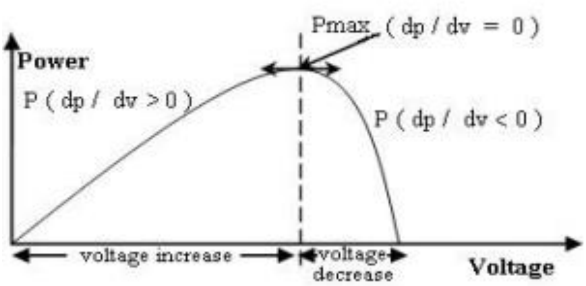

Figure 3. Power-voltage characteristic of a PV module

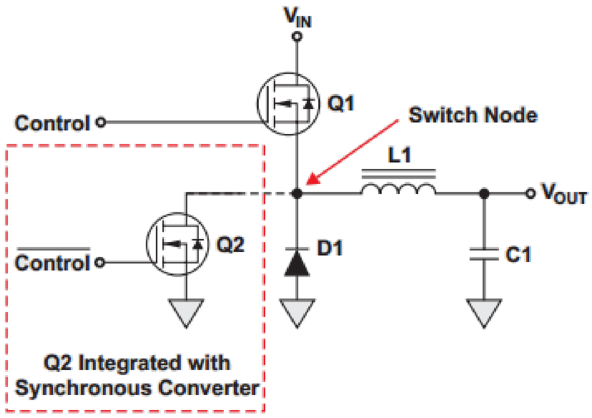

Figure 4. Synchronous and nonsynchronous buck circuits

B. Design of synchronous buck converter

A buck converter is a step-down DC to DC converter, the average input voltage V_{in} is greater than the output voltage V_{out}. A basic circuit of buck converter is illustrated in Figure 4. The main components are Q1, which is the high-side power MOSFET, L1 and C1. N-channel MOSFET (Q2) is used for a synchronous-buck topology. In a nonsynchronous-buck topology, a power diode (D1) is used. In a synchronous converter, the N-channel MOSFET (Metal Oxyde Semiconductor Field Effect Transistor) is integrated in the device.

The main advantage of a synchronous rectifier is that the voltage drop across the power diode low-side MOSFET can be higher than the voltage drop across the low-side MOSFET of a nonsynchronous converter. If there is no change in current level, a lower voltage drop translates into less power dissipation and higher efficiency [14]. In this work, MOSFET IRF540N type N-channel was selected [15].

If the converter is designed with an efficiency of 90%, the output power of the converter can be determined from

$$\text{Efficiency} \ (\eta) = \frac{P_{out}}{P_{input}}$$
$$90\% = \frac{P_{out}}{50W} \Rightarrow P_{out} = 45W \quad (2)$$

The synchronous buck converter will be designed to generate output voltage 14 V since it will be used to charge a 12 V battery. Its output current is calculated by current outpurt on equation (3).

$$\text{Current ouput} \ (I_o) = \frac{P_{out}}{V_{out}}$$
$$\frac{45W}{14V} = 3.21A \quad (3)$$

The minimum value for inductor can be determined by using a duty cycle of 0.5 applied to the following equation:

$$L_{\min} = \frac{(1-D)*R}{2*f}$$
$$= \frac{(1-0.5)*3.2}{2*50kHz} = 16\mu H \quad (4)$$

The minimum value for capacitor can be determined by using a ripple of 2% applied to the following equation:

$$C_{\min} = \frac{1-D}{8*L*\frac{\Delta V_o}{V_o}*f^2}$$
$$= \frac{(1-0.5)}{8*16\mu H*2\%*50^2 kHz} = 78\mu F \quad (5)$$

C. Design of a new fuzzy logic controller

A fuzzy logic controller is utilized to generate duty ratio to achieve faster tracking speed and better dynamic performance. The FLC uses dI/dV as fuzzy input variables. The block diagram of MPPT for PV system with the proposed FLC is shown in Figure 5.

The MPP can be determined based on the rate of slope on the PV curve as illustrated in Figure 3, if dP/dV is negative then MPPT is on the right side of

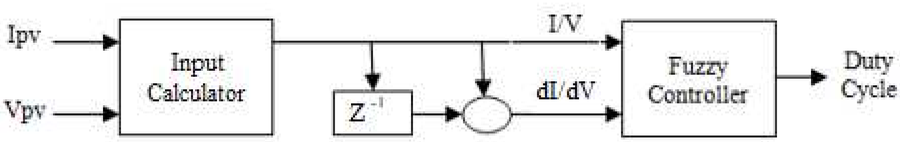

Figure 5. Control diagram of the proposed FLC

recent position and if the MPP is positive the MPPT is on the left side [9]. dP/dV can be calculated by using equation (6) where dI/dV represents conductance increment.

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = I.\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \tag{6}$$

MPP is reached when $dP/dV = 0$ and

$$\frac{dI}{dV} = -\frac{I}{V} \tag{7}$$

$$\frac{dP}{dV} > 0 \; then \, V_P < V_{mpp} \tag{8}$$

$$\frac{dP}{dV} = 0 \; then \, V_P = V_{mpp} \tag{9}$$

$$\frac{dP}{dV} < 0 \; then \, V_P > V_{mpp} \tag{10}$$

To determine the output power of the PV, it is necessary to perform power calculation based on the output voltage and current of PV before it is further processed in the fuzzy controller.

The fuzzy controller has two inputs which are dI/dV and I/V, and duty cycle as the output for controlling the MOSFET in the synchronous buck converter. Fuzzy controller contains three basic parts: Fuzzification, Base Rule, and Defuzzification.

1) Fuzzification

Figure 6 shows the fuzzy set of the dI/dV input which contains five triangular membership functions. Figure 7 shows the fuzzy set of the I/V input which contains five triangular membership functions. Figure 8 shows the fuzzy set of the duty cycle output which contains five triangular membership functions.

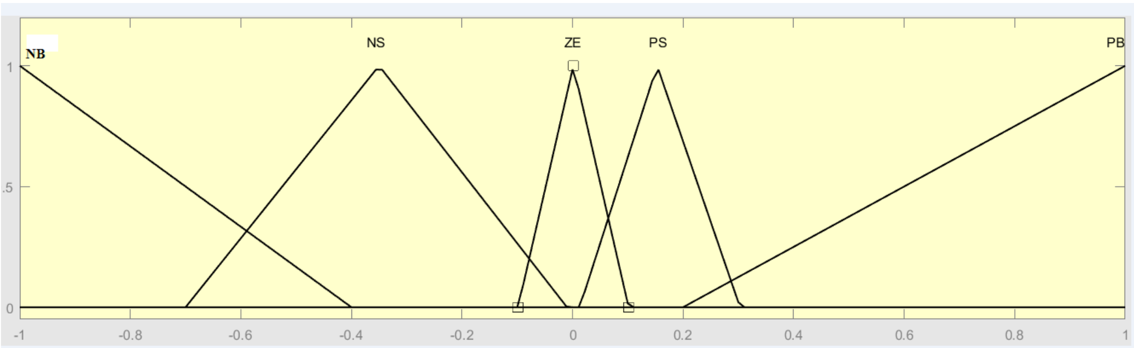

Figure 6. Membership functions of dI/dV

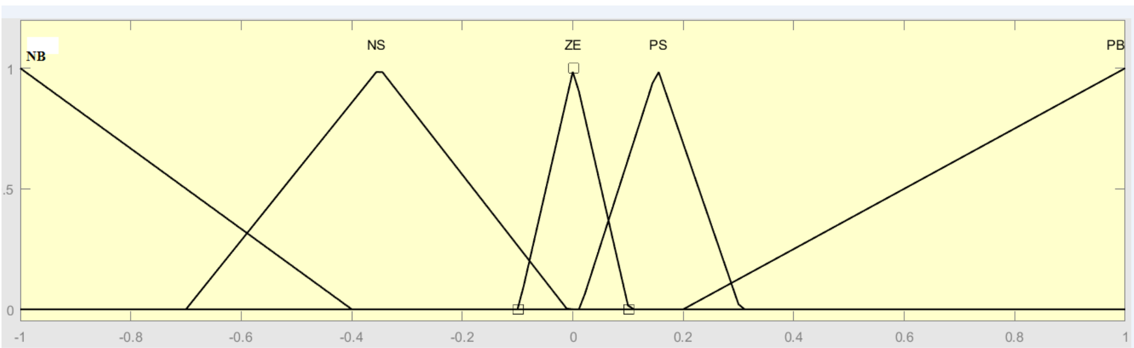

Figure 7. Member function of I/V

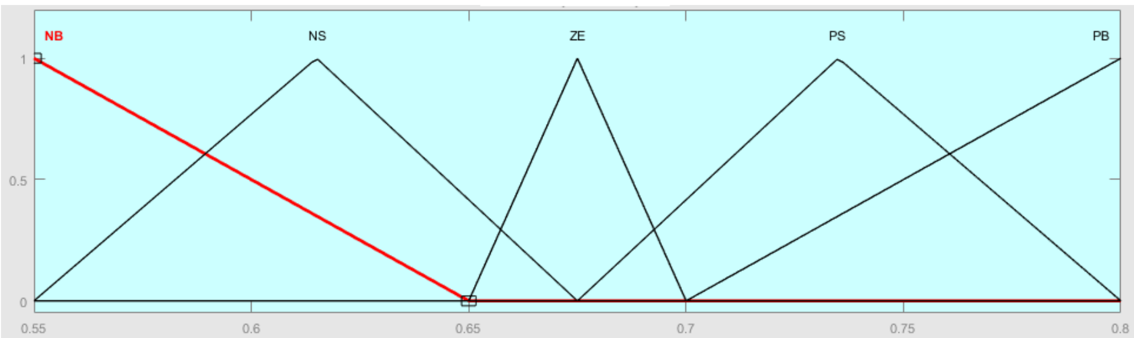

Figure 8. Member function of duty cycle

Table 2.
Fuzzy rules

dI/dV / I/V	NB	NS	ZE	PS	PB
NB	NS	NS	ZE	PS	PB
NS	ZE	NS	ZE	PS	PS
ZE	PS	ZE	ZE	ZE	ZE
PS	PS	PS	ZE	NS	NS
PB	PB	PS	ZE	NS	NB

Table 3.
Testing voltage sensor

Voltage of multimeter (V)	Voltage of sensor (V)	Error (%)
12	12.1	0.83
12.99	13	0.08
14	14.1	0.71
15.23	15.3	0.46
16.07	16.1	0.19
17.11	17.1	0.06
18.28	18.1	0.98

Table 4.
Testing current sensor

Current of multimeter (A)	Current of sensor (A)	Error (%)
0.49	0.51	3.92
1.04	1.06	1.89
1.5	1.5	1.32
2.06	2.04	0.98
2.53	2.54	0.39
3.06	3.05	0.33

Table 5.
Testing of synchronous buck converter

Duty cycle (%)	Vi (V)	Ii (A)	Vo (V)	Io (A)	Pi (W)	Po (W)	Eff. (%)
50	18.4	1.0	8.3	1.8	18.7	14.6	78.1
60	18.3	1.3	10.1	2.1	24.7	20.9	84.6
70	18.3	1.7	11.9	2.4	31.2	28.4	91.0
80	18.1	2.1	13.6	2.7	38.3	36.4	95.0
90	17.7	2.6	15.1	3.0	45.7	45.0	98.5
95	17.3	2.8	15.7	3.0	48.3	47.7	98.8

2) Control rule base

Determination of the rule-base of IF-THEN in the controller contains all the information to control the parameters and is based on conductance increment, as shown in Table 2. The control rules are evaluated by an inference mechanism, and represented as a set of:

```
Rule 1. IF (I/V) is NB and (dI/dV)
  is NB THEN the Duty
  cycle is NB.
Rule 2. IF (I/V) is NS and (dI/dV)
  is NB THEN the Duty
  cycle is NS.
...
Rule 25. IF (I/V) is PB and (dI/dV)
  is PB THEN the Duty
  cycle is NB.
```

3) Defuzzification

Defuzzification uses centre of gravity method to calculate output of this fuzzy controller which is the duty cycle (D).

$$D = \frac{\sum_{j=1}^{n} \mu(d_j) - d_j}{\sum_{j=1}^{n} \mu(d_j)} \quad (11)$$

III. Results and discussions

A. Assessment of voltage and current sensors

Voltage and current sensor testing was conducted to determine performance of each sensor. Comparative measuring instrument is a digital multimeter. A voltage sensor used voltage divider circuit, while ACS712 was used in the current sensor, which has the sensitivity of 185 mV/A. Results of voltage and current sensors tests are shown in Table 3 and Table 4 respectively. The average error on the voltage sensor is 0.47% and the average error in the current sensor was 1.41%

B. Assessment of synchronous buck converter

Testing of synchronous buck converter is used to find the value of the efficiency of the converter to alter the duty-cycle and with a fixed resistive load of 3.9 Ohm. Table 5 shows that the efficiency of synchronous buck converter is very well when the duty-cycle approaches 100%. This test does not include the circuit cut-off on the solar panels and the load.

C. Assessment of MPPT system

The input of the MPPT system is the voltage and current output from PV, while the output of the MPPT system is a varying duty cycle to drive the synchronous buck converter circuit.

Firstly, a 50 W PV is used to generate power and placed in the shade so that the temperature of the PV is not too high hence MPP can be obtained as much as possible. Several tests using computer simulation were performed at irradiation 1000 W/m^2 and temperature 25°C. Then, an experiment was implemented for verifying the proposed MPPT algorithm. PV connected to MPPT device with a load at 12 V / 45 Ah battery. The test was conducted at 12:00 AM. The solar irradiation was measured using a pyranometer at 1000 W/m^2 with a temperature of 25°C. Onsite setting can be seen in Figure 9.

In order to compare performance between conventional P&O (Perturb and Observe), fuzzy and proposed Fuzzy Logic Controller, and the output power of PV module that is controlled by the aforementioned three algorithms is focused, as shown in Figure 10 and Table 6.

Figure 9. Implementation of MPPT on location

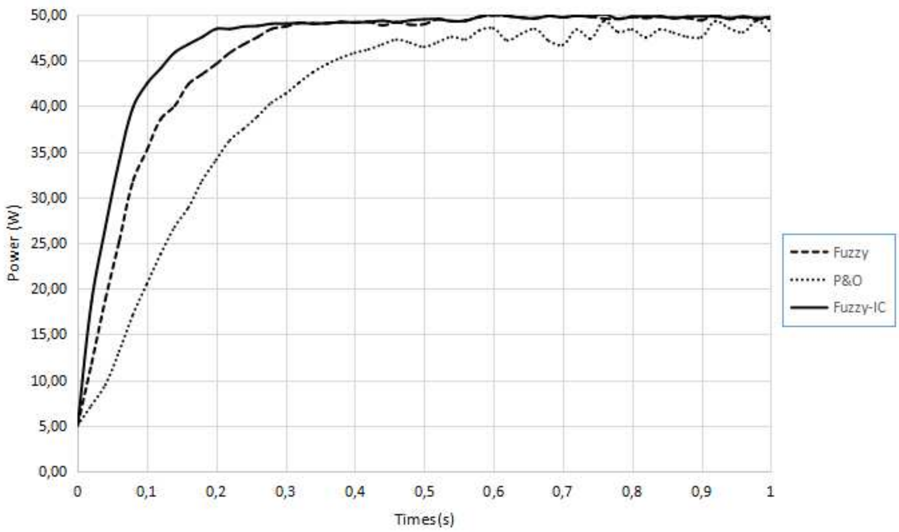

Figure 10. Result of MPPT implementation with various algorithms

Table 6.
Output power of MPPT with various algorithms

Algorithm	Pmax (W)	Pout (W)	Efficiency (%)	Rise time (s)	Settling Time (s)
P&O	50	47.7	95.5	0.35	1.0
Fuzzy	50	49.54	99.1	0.20	0.5
New FLC	50	49.65	99.3	0.15	0.3

IV. Conclusion

Maximum power point tracking with a new FLC method is proposed in this paper. The proposed method is the implementation of a MPPT controlled by proposed FLC and the use of synchronous buck converter to keep the PV output power at the maximum point. From the result obtained it can be concluded that the MPPT based on a new FLC can increase the overall efficiency of the system to 99.3%, MPPT system with fuzzy method has 99.1% efficiency while MPPT system with P&O method has 95.5% efficiency.

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References

[1] Z. Salameh and D. Taylor, “Step-up maximum power point tracker for photovoltaic arrays,” *Solar Energy*, vol. 44, no. 1, pp. 57–61, 1990.
[2] V. C. Kotak and P. Tyagi, “DC to DC Converter in maximum power point tracker,” *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering,* vol.2, no. 12, pp 6115-6125, Dec 2013.
[3] F. Qiang and T. Nan, “A Strategy research on MPPT technique in photovoltaic power generation system,” *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 11, no. 12, Dec. 2013.
[4] V. R. Bharambe and K. M. Mahajari, “Implementation of P&O MPPT for PV System with using buck dan buck-boost converters,” *International Journal of Research in Electrical Engineering*, vol. 2, no. 3, pp.5-10, March 2015.
[5] R. S. Ponuguti, “Comparative study of P&O and Incremental Conductance MPPT algorithms for Photovoltaic System,” *International Journal of Innovations in Engineering and Technology*, vol. 5. Jan 2016 pp.200-206.
[6] R. I. Putri, S. Wibowo, and M. Rifa’i, “Maximum power point tracking for photovoltaic using incremental conductance method,” *Energy Procedia*, vol. 68, pp. 22–30, Apr. 2015.
[7] S. Aji, D. Ajiatmo, I. Robandi, and H. Suryoatmojo, “MPPT based on fuzzy logic controller (FLC) for photovoltaic (PV) system in solar car,” *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, vol. 4, no. 2, p. 127, Dec. 2013.
[8] B. M. Hamed and M. S. El-Moghany, “Fuzzy controller design using FPGA for photovoltaic maximum power point tracking,” *International Journal of Advanced Research in Artificial Intelligence*, vol. 1, no. 3, 2012.
[9] T. Balamurugan and S. Manoharan, "Fuzzy controller design using soft switching boost converter for MPPT in hybrid system,” *International Journal of Soft Computing and Engineering*, vol. 2, no. 5, pp. 87-94, May 2012.
[10] G. Y. Ayvazyan, G. H. Kirakosyan, and A. H. Vardanyan, “Maximum power operation of PV system using fuzzy logic control,” *Armenian Journal of Physics*, vol. 1, pp. 155-159, 2008.
[11] R. I. Putri and M. Rifa’i, “Maximum power point tracking control for photovoltaic system using neural fuzzy,” *International Journal of Computer and Electrical Engineering*, vol. 4, no. 1, pp. 75–81, 2012.
[12] K. Manickavasagam, "Fuzzy logic controller based single buck boost converter for solar PV cell," *International Journal of Applied Power Engineering*, vol. 3, No. 1, pages 1-8, 2014
[13] H. S. Rauschenbach, *Solar Cell Array Design Handbook*. Jet Propulsion Laboratory, National Aeronautics and Space Administration, (NASA-CR-149364), vol. 1, October 1976.
[14] R Nowakowski and N. Tang, *Efficiency of synchronous versus nonsynchronous buck converter*, Analog Aplication Journal Texas Instrument Corporated, 2009
[15] Infineon Corp, *100V Single N-Channel HEXFET Power MOSFET in a TO-220AB package IRF54ON*, [Online], Available: https://www.infineon.com/cms/en/product/power/mosfet/20v-300v-n-channel-power-mosfet/80v-100v-n-channel-power-mosfet/irf540n

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