MPPT Based on Fuzzy Logic Controller (FLC) for Photovoltaic (PV) System in Solar Car

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Abstract

This paper presents a control called Maximum Power Point Tracking (MPPT) for photovoltaic (PV) system in a solar car. The main purpose of this system is to extracts PV power maximally while keeping small losses using a simple design of converter. Working principle of MPPT based fuzzy logic controller (MPPT-FLC) is to get desirable values of reference current and voltage. MPPT-FLC compares them with the values of the PV's actual current and voltage to control duty cycle value. Then the duty cycle value is used to adjust the angle of ignition switch (MOSFET gate) on the Boost converter. The proposed method was shown through simulation performed using PSIM and MATLAB software. Simulation results show that the system is able to improve the PV power extraction efficiency significantly by approximately 98% of PV's power.

Keywords: maximum power point tracking (MPPT), photovoltaic (PV), boost converter, fuzzy logic controller, solar car.

I. INTRODUCTION

Consumption on fossil fuels as source of transportation energy has been predicted to increase along with population and economic growth in Indonesia. On the other hand, the depletion of fossil fuels, increasing emissions of pollutants and greenhouse gases become a serious problem in big cities. Nowadays, renewable energy becomes a solution to solve this problem in supplying the energy needs especially in the field of transportation. There are so many kinds of renewable energy that have been developed as sources of energy for transportation.

Indonesia is a tropical region and has availability of abundant solar energy. Among renewable energy sources, solar energy seems to be the most attractive energy source for electrical energy used by cars in Indonesia. The advantages of solar energy compared to fossil fuels are because it is clean, pollution-free, and quiet/without sound. Conversion of solar energy into electrical energy requires a device called a photovoltaic (PV). Lately, PV has been produced in different types. Some commercial PVs have average efficiency varying with the highest efficiency value of 20 % [1]. Electricity provided by PV is the result of voltage and current in the same time. PV voltage and current depends on temperature and solar irradiation changes. Maximum Power Point Tracking (MPPT) is a technique to extract possible maximum power from the PV modules under all conditions of temperature and solar irradiation. MPPT has to use a good algorithm to find the MPP condition in a short time and also has a high efficiency. MPPT simulations have been investigated over the last few years and are summarized in [2-4].

Many conventional methods have been used for MPPT such as Perturb and Observe (P&O), fractional open-circuit voltage and incremental conductance. Conventional methods have slow responds and unsatisfactory. To resolved this problem and overcome non linearity of PV, an intelligent MPPT algorithm based on fuzzy logic controller (FLC) will be discussed in this paper.

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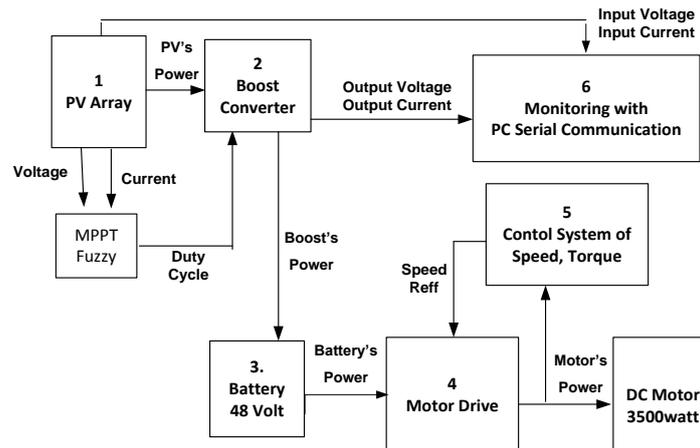
Figure 1. Electrical vehicle powered by PV [5]

II. MATERIAL AND METHOD

A. Electrical Car Powered by PV

Electric car (EC) powered by photovoltaic (PV) project is a joint research between the Institut Teknologi Sepuluh Nopember (ITS) Surabaya and SMK Muhammadiyah 7 Gondanglegi, Malang. This EC's name is Suryawangsa. It uses brushless DC motor as its main propulsion and lead-acid batteries as its source of electricity. There are four PVs on the top the EC. Total maximum output power of the PV is 200 Watts.

Battery in addition is being used as a source of electrical energy storage or as energy storage generated by photovoltaic (PV). The electric car powered by PV is able to perform self-charging from sun energy. This car's design and shape can be seen in Figure 1 [5].

In Figure 1, the whole car system consists of 6 blocks of diagram. The first block is photovoltaic array. The second block is boost converter. The third block is battery. The fourth block is DC motor's driver. The fifth block is speed/torque control system of DC motor and the last block is monitoring system using serial communication. This paper focus is on the battery charging powered by PV as shown by block 1-3.

Photovoltaic Model

PV model is described as a simple circuit consisting of a current source which is connected in parallel with a diode as shown in Figure 2. PV's output power depends on irradiation of sunlight and temperature received by PV cell's surface [6]. PV has various types and models. Each PV module has different characteristics and efficiency. In this work, the selected PV module is BELL 50WP whose specification is shown in Table 1.

This PV module was simulated using PSIM software in order to get the I-V (current-voltage) and P-V (power-voltage) curves. Simulation results are plotted in Figure 3 and Figure 4. Figure 3 is the simulation results with different temperature and constant irradiation conditions,
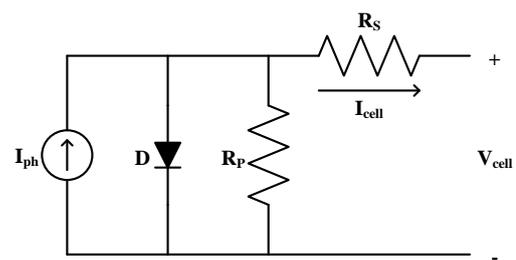
Figure 2. PV model

Table 1.
Specifications of solar panel

Spesifications	Value
Manufacture	BELL Electronics
Standart Irradiance and Temperature	1000 W/m2, 25°C
Maximum Power (Pmax)	50 W
Voltage @ Pmax (Vmp)	17.35 V
Current @ Pmax (Imp)	2.88 A
Open-circuit Voltage (Voc)	21.88 V
Short-circuit Current (Isc)	3.08 A
Number of Cell	24 cell
Tollerance Wattage	5%
Weight module	10 kg
Size module	670cm*620cm*35 cm

while Figure 4 is the simulation results with different irradiation and constant temperature conditions.

B. Boost Converter Design

DC-DC boost converter has an important role in the PV system. MPP conditions can be achieved by using boost converter as a power conditioner. References [7-8] offers boost converter topologies. In this paper the boost converter topology shown in Figure 5 is used [9]. It consists of a single MOSFET or IGBT switch, an inductor, a diode and a capacitor.

To design a good converter, it requires calculation of appropriate components since wrong values of the components may cause unfavorable outcomes. The results of equation (1 to 5) are parameters that required for the design of boost converter [5], as seen at Table 2. Where: P is power, V_{in} is input voltage, I_{in} is input current, V_{out} is output voltage, I_{out} is output current, f is frequency, D is duty cycle, R is resistance, I_L is inductor's current, L is inductor and C is capacitor.

Calculation of duty cycle (D):

$$D = 1 - (Vin/Vout) = 1 - (34/50) = 32 \quad (1)$$

Calculation of output current (I_{out}):

$$Iout = P/Vout = 200W/50V = 4A \quad (2)$$

Calculation of resistance (R):

$$R = Vout/Iout = 50V/4A = 2.5\Omega \quad (3)$$

Calculation of inductor's current (IL):

(a)

(b)
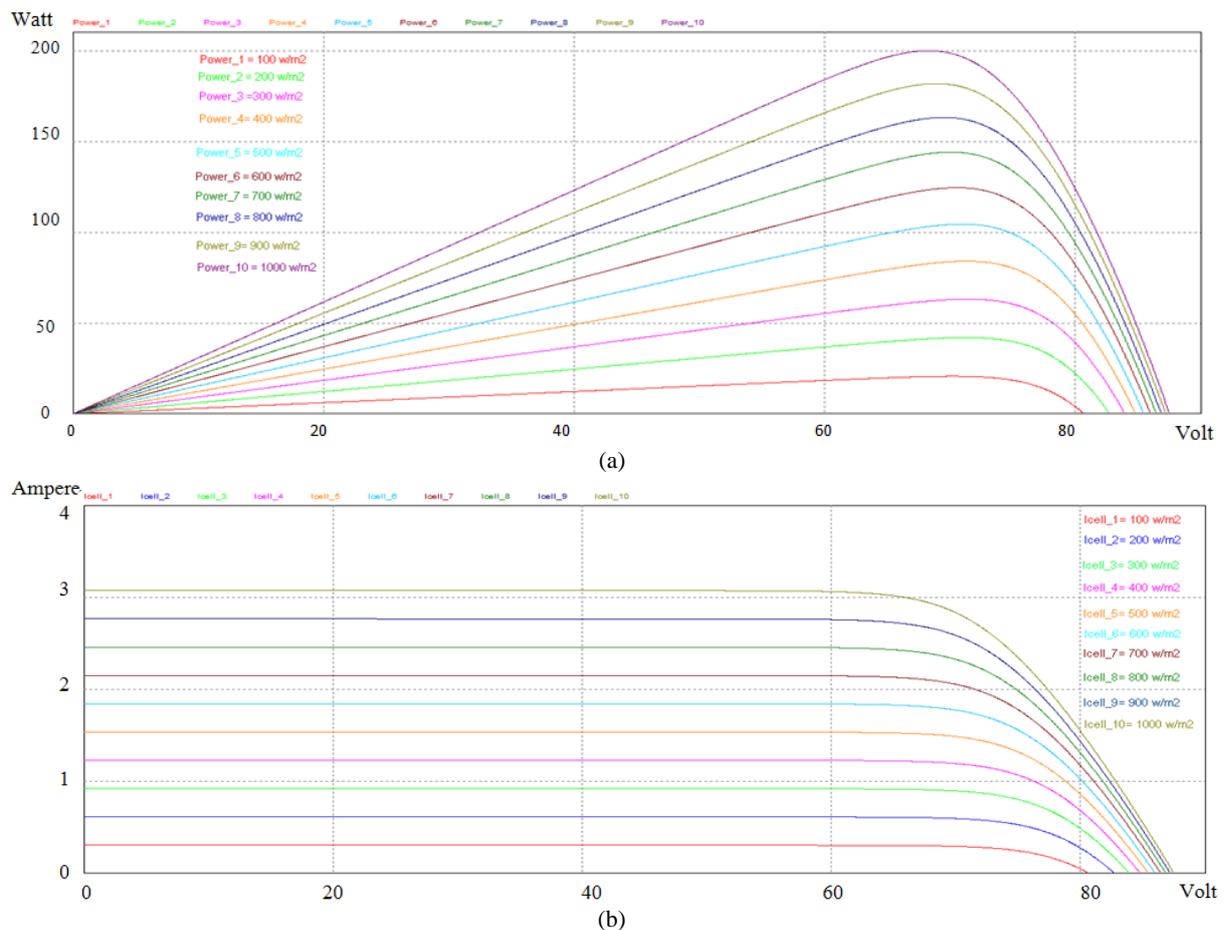
Figure 3. Simulation result of different irradiance from 100 W/m^2 until 1000 W/m^2 (step 100 W/m^2) and constant temperature at 25°C; (a) P-V Curve; (b) I-V e

(a)

(b)
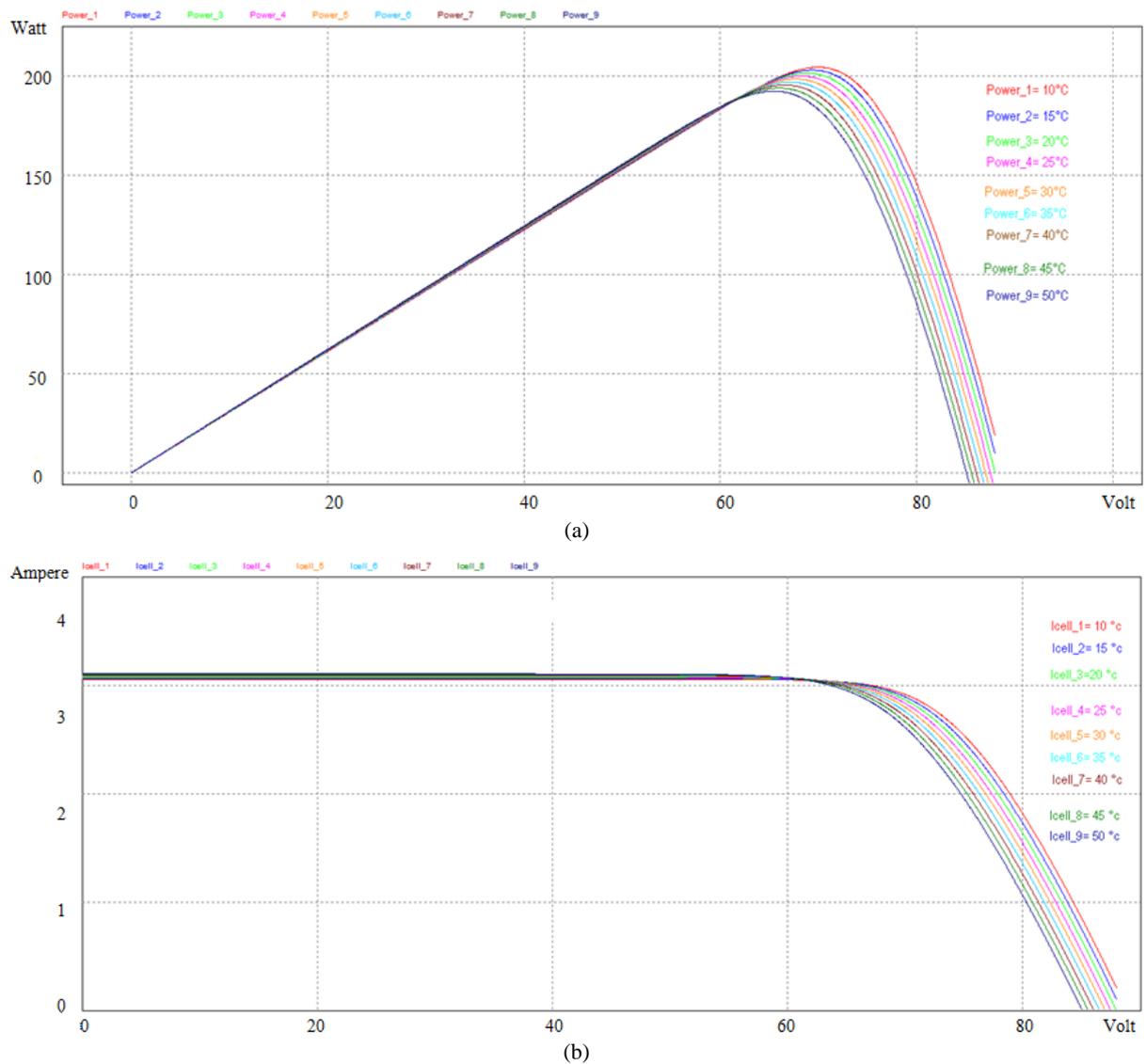
Figure 4. Simulation result of different temperature from 10°C until 50°C (step 5°C) and constant irradiance 1000 W/m$^{2;}$ (a) P-V Curve; (b) I-V Curve

$$IL = 0.2 \times Iin = 0.2 \times Iout \times Vout/Vin \quad (4)$$

$$= 0.2 \times 4A \times \frac{50V}{34V}$$

$$= 0.11A$$

Calculation of inductor (L):

$$L = (Vin \times (Vout - Vin))/(IL \times f \times Vout) \quad (5)$$

$$= \frac{34V \times (50V - 34V)}{0.11A \times 20\text{khz} \times 50V}$$

$$= 5.44 \; miliHenry$$

Calculation of capacitor (C):

Assumed: $\Delta Vout/Vr = 0.1V$

$$C = (Vout \times D)/((\Delta Vout/Vr) \times f \times R) \quad (6)$$

$$= \frac{50V \times 0.32}{0.1 \times 20khz \times 12.5\Omega}$$

$$= 640 \; uF$$

C. Maximum Power Point Tracking (MPPT)

The basic method of MPPT controller is to find voltage reference (VMPP) and current reference (IMPP) under different conditions of solar irradiation and temperature by changing the value of load (R). Figure 6 shows characteristics of I-V (current-voltage) and P-V (power-voltage) curves. Working point (OPR1) is the maximum power point (MPP) value in the condition insolation (λ1), temperature (T1) and load (R1). If irradiation changes from λ1 to λ2 and temperature change from T1 to T2, the I-V curve shift from the curve (λ1, T1) to the curve (λ2, T2). Load condition should be changed from R1 to R2 to get MPP conditions (OPR2).

D. Fuzzy Logic Controller (FLC)

A fuzzy logic controller (FLC) uses two inputs such as error (E) and changes in error (ΔE), while the output of FLC is the duty cycle
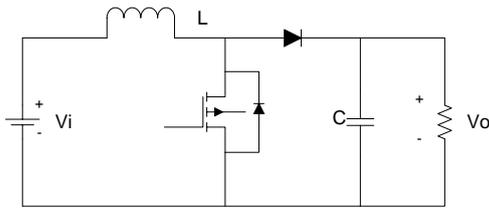
Figure 5. Boost converter.
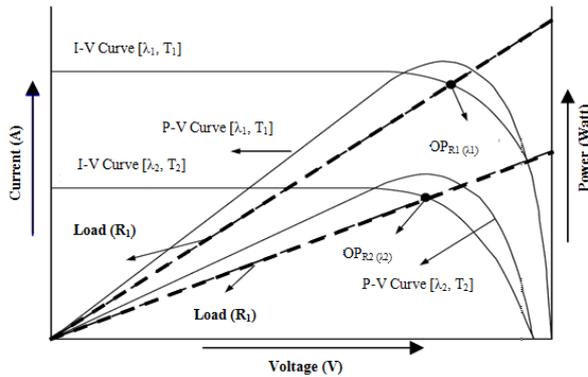
Figure 6. MPPT curve

Table 2.
Specification of boost converter

Parameter	Value
Power (P)	200 Watt
Input Voltage (V_{in})	34 Volt
Output Voltage (V_{out})	50 Volt
Frequency	20 kHz
Capacitor (C)	640 uF
Inductor (L)	5.44 mH
Load Resistor (R)	12.5 Ohm

Table 3.
Fuzzy rule

E ΔE	nbe	nse	ze	pse	pbe
nbDe	m	m	vb	vb	vb
nsDe	m	m	b	b	b
zeDe	b	m	m	m	s
psDe	s	s	s	m	m
pbDe	vs	vs	vs	m	m

D. Equation 7 is error's equation and equation 8 is change in error's equation.

$$E(k) = \frac{P_{(k)} - P_{(k-1)}}{V_{(k)} - V_{(k-1)}} \qquad (7)$$

$$\Delta E(k) = E_{(k)} - E_{(k-1)} \qquad (8)$$

Designing a FLC involves four steps: fuzzification, interference, rule based, and defuzzification. Numerical input variables are converted into linguistic variables based on the membership function during fuzzification [10]. In operation of MPPT control, after E and ΔE are calculated, these inputs are converted into linguistic variables and then the output D is generated by looking up a rule-base table. The FLC tracks the MPP based on master rule of "If A and B, Then C" [10]. To determine the output of the fuzzy logic, the inference is used. There are many methods for inference but the popular one is Mamdani [10]. In this paper, fuzzy
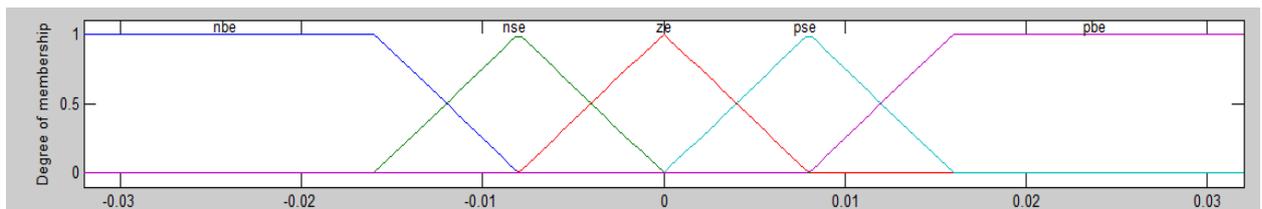
(a)
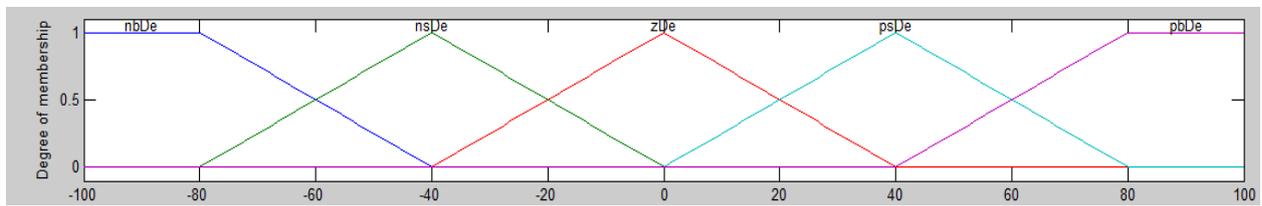
(b)
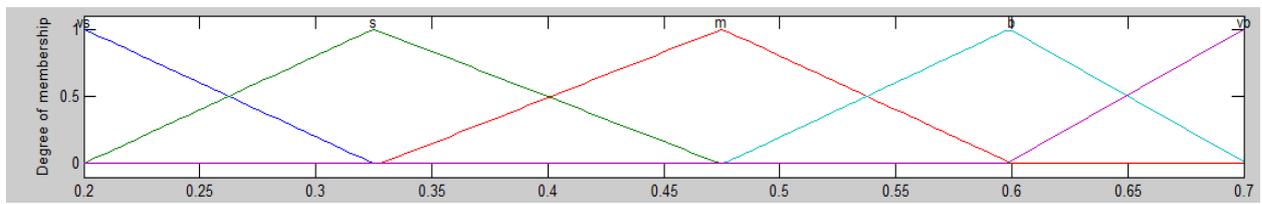
(c)

Figure 7. (a) membership $E_{(k)}$, (b) membership $\Delta E_{(k)}$, (c) membership duty cycle
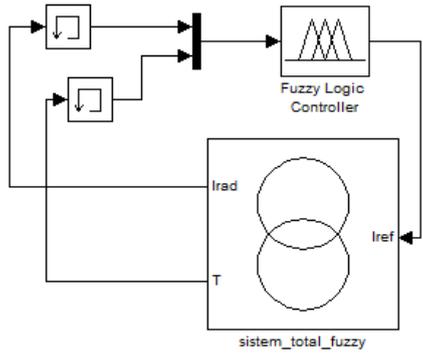
Figure 8. PSIM coupler in Matlab Simulink
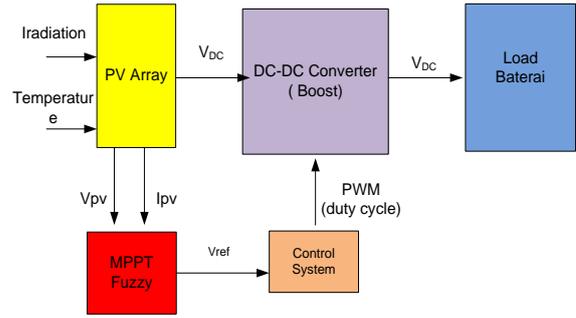
Figure 9. Block diagram of PV system

inference is carried using Mamdani's type and the defuzzification use the center of grafity (COG) to compute the output of this FLC [11].

The result of this process is membership function of MPPT control, as seen at Figure 7 and fuzzy rule, as seen in Table 3. Where: nbe is negative big error, nse is negative small error, ze is zero error, pbe is positive big error, pse is positive small error, nbDe is negative big delta error, nsDe is negative small delta error, zDe is zero delta error, pbDe is positive big delta error, psDe is positive small delta error, vs is very small, s is small, m is medium, b is big and vb is very big.

III. SIMULATION

Designing a PV model and a boost converter on PSIM is simpler than on MATLAB. The problem is that a fuzzy logic controller cannot be designed on PSIM. SIM Coupler in Figure 8 is a plug-in that could help to connect MATLAB Simulink with PSIM. Block diagram of PV system is shown in Figure 9. It consists of PV

array (yellow), boost converter (purple), MPPT based fuzzy logic controller/FLC algorithm (red) and the battery/load (blue). The MPPT algorithm (red) is explained in more detail in figure 10 and figure 11. Simulation results in Figure 3 and Figure 4 show that the effect of irradiation changes is more significant than the effect of temperature changes in PV's output power changes. Therefore, simulation was only done by changing the value of irradiation and keeping temperature constant.

Figure 12 shows simulation result of the PV system with MPPT. Figure 13 shows simulation result of the PV system without MPPT. The system was tested in irradiation 1000 W/m^2, 800 W/m^2, and 600 W/m^2. It shows that PV's power output almost reached the maximum power (P_{max}). From the results in Table 4 and Table 5, it is obvious that the system with MPPT gives higher efficiency than that without MPPT. It is concluded that the MPPT system could produce a maximum power output of PV eventhough under different (high/low) irradiation conditions.
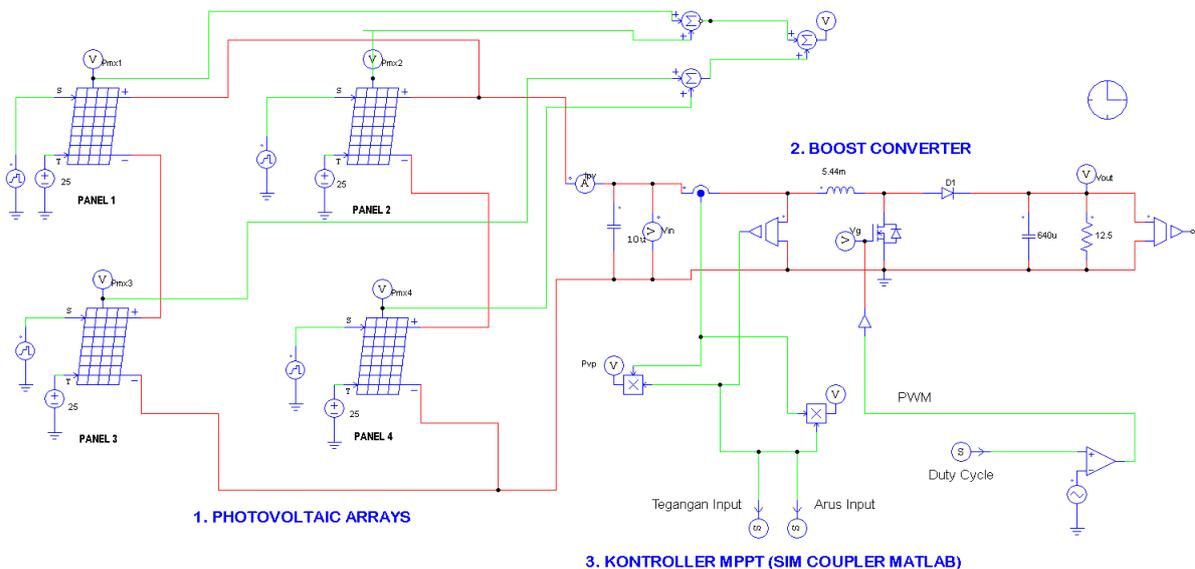
Figure 10. Schematic of MPPT system in PSIM

Figure 11. Schematic of MPPT in MATLAB

Figure 12. Simulation result with MPPT System

Figure 13. Simulation result without MPPT System

Table 4.
Power output with MPPT at irradiation 800-1000 W/m^2
and temperature 25°C

Parameters	P$_{max}$	Power out	Efficiency
1000 W/m^2	200	196	98%
800 W/m^2	163	160	98%
600 W/m^2	104	100	96%

Table 5.
Power output without MPPT at irradiation 800-1000 W/m^2
and temperature at 25°C

Parameters	P$_{max}$	Power out	Efficiency
1000 W/m^2	200	190	95%
800 W/m^2	163	139	85%
600 W/m^2	104	54	51%

IV. CONCLUSION

In this paper we have presented the design and simulation of Maximum Power Point Tracking (MPPT) for a photovoltaic system in the solar car using fuzzy logic. Based on simulation results we can conclude that: The effect of irradiation changes is more significant than the effect of temperature changes in PV's output power changes. The resulting efficiency value system with MPPT is 96 to 98% (almost reaches the maximum peak power), while the efficiency of the resulting system without MPPT is 51% to 90% (not producing maximum power).

ACKNOWLEDGEMENT

REFERENCES

[1] T. Esram and P.L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," *IEEE Transactions on Energy Conversion* vol. 22, pp. 439-449, June 2007.

[2] E. Bianconi, et al., "Perturb and observation MPPT algorithm with a current controller based on the sliding mode," *Science Direct: Electrical Power and Energy Systems* vol.44, pp. 346-356, July 2012.

[3] T. Esram and P.L. Chapman, "T-S fuzzy maximum power point tracking control of solar power generation systems," *IEEE Transactions on Energy Conversion* vol. 25, no. 4, December 2010.

[4] C. B. Salah and M. Ouali, "Comparison of fuzzy logic and neural network in maximum power point tracker for PV systems," *Science Direct: Electric Power Systems Research* vol. 81, pp. 43–50, July 2010.

[5] M. Veerachary, et al., "Neural network based maximum power point tracking of coupled inductor interleaved boost converter supplied PV system using fuzzy controller," *IEEE Trans. Ind. Electron.*, vol. 50, no. 4, pp. 749–758, August 2003.

[6] Hong Wang, "The stand-alone PV generation system with parallel battery charger", I*nternational Conference on Electrical and Control Engineering (ICECE),* pp. 4450-4453, June. 2010.

[7] M. A. A. Mohd Zainuri, et al., "Adaptive P&O fuzzy control MPPT for PV boost DC-DC converter," *IEEE International Conference on power and Energy (PECon),* 978-1-4673-5019-8, December 2012.

[8] L. Guo, et al., "Design of a fuzzy controller using variable structure approach for application to DC–DC converters," *Science direct: Electric Power system Research* vol. 83, pp.104-109, August 2012

[9] J.M. Enrique, et al., "A reliable, fast and low cost maximum power point tracker for photovoltaic applications," *Solar Energy* vol. 84, pp. 79-89, November 2009.

[10] Yeu Wu, et al, "Fuzzy logic and neuro-fuzzy system: a systemetic introduction", *International Journal of Artificial Intelligence and Expert System (IJAE)* vol. 2, issue 2, pp 47-80, 2011.

[11] A. M. A. Mahmoud, et al., "Fuzzy logic implementation for photovoltaic maximum power tracking," in *Proc. 9th IEEE Int. Workshop Robot Human Interactive Commun.*, pp. 155–160, 2000.