

Design and implementation maximum power point tracker flyback converter using fuzzy logic controller

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Article Info

Article history:

Received Dec 26, 2021

Revised Nov 25, 2022

Accepted Jan 9, 2023

Keywords:

Flyback converter

Fuzzy logic controller third

Maximum power point tracker

Photovoltaic

ABSTRACT

Photovoltaic (PV) system generally used as a distributed generating unit source, one of important factor to maximize the efficiency of PV system is maximum power point tracker (MPPT). MPPT is used to eliminate the weakness of PV that very dependent on the ability of the device to perform operation at the optimal point. MPPT also used to extract the maximum power from the PV array, maximum power can be achieved by tracking the maximum power point (MPP) using a control method such as fuzzy logic controller (FLC). FLC is also used to control flyback converter and stabilize the output voltage. FLC used power of PV as an input and duty cycle as an output, with 7 membership function input and 7 membership function output. This paper discusses about designing of MPPT using flyback converter with FLC. The simulation work (using MATLAB) exhibit and evaluate the method under different conditions (temperature and irradiance). Based on the simulation result, a PV system using MPPT can maintain the power efficiency more than 85% and stabilize the output voltage according to the setting point for battery charger.

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1. INTRODUCTION

The development of renewable electrical energy using photovoltaic (PV) has been widely used to substitute electrical energy with fossil fuels. Electricity from solar power is attractive because the availability of energy sources is guaranteed and the operating cost are low. PV modules are a component that can convert sunlight into electrical energy using semiconducting materials. In order to extract the maximum power form a PV module, a technique called maximum power point tracker (MPPT) is required. MPPT is used to eliminate the weakness of PV that very dependent on the ability of the device to perform operation at the optimal point. MPPT controller simply helps to track and achieve the maximum power point (MPP) under all operating condition [1]-[3].

For implementing the MPPT from PV and charging the battery, a converter with type buck boost is needed. A buck boost converter is needed because the output PV is very volatile and depend on some conditions like irradiation and temperature, a buck boost can increase and decrease the voltage. So in this research, it is proposed to use flyback converter as a controller in solar charger [4], [5].

A flyback converter has a working principle like a buck boost converter, which can increase or decrease the incoming DC voltage based on the amount of duty cycles that entered in PWM switching components. Flyback converter is the the simplest isolated DC-DC converter topology because of absence of inductor component , there is only one semiconductor switch and one magnetic component (transformator or

coupled inductor) [6]-[8]. To extract MPP from PV and maintain the output voltage. A method that called fuzzy logic controller (FLC) is used.

FLC is one of the system control methods that is currently widely used. FLC has the advantage of working with imprecise input and there is no need accurate for a mathematical model of the system, FLC also can handle the nonlinearity. This is one of the advantages of FLC so that the controller design is easier to do by relying only on logical rules [9]-[11]. The FLC consist of two input and one output. In this research, FLC is used to maximize the power generated by PV and maintain the converter output voltage in battery charging setting point.

In this research is simulated in Simulink of MATLAB by injecting several different condition like solar irradiation and temperature value at PV during simulation period. This paper is focusing on the design of MPPT algorithm using FLC method. The result of this research is known can maintain the efficiency more than 85% and stabilize the output voltage.

2. SYSTEM DESCRIPTION

A flyback converter is a type of converter that can be used to adjust the voltage and to obtain maximum power on the solar panels. A method called FLC is required to adjust the duty cycle, FLC uses input voltage and current voltage from PV to determine duty cycle value. The FLC also uses the output voltage and output current from converter to give the feedback about the system. Beside to regulate the output voltage to setting point, FLC also uses to Maximize the power from solar panel. The output from FLC is duty cycle. Duty cycle will make the output converter lower if the output PV voltage is higher than 14.4 V, and vice versa will make the output converter higher if the output PV is below 14.4 V.

The topology of the maximum power pint tracker flyback converter using FLC is shown in Figure 1. The system input is a PV with a maximum power capacity of 120 WP and the storage is a battery with capacity 34 Ah. During the simulation, the values of irradiance and temperature are changed to find out how the response generated by the flyback converter.

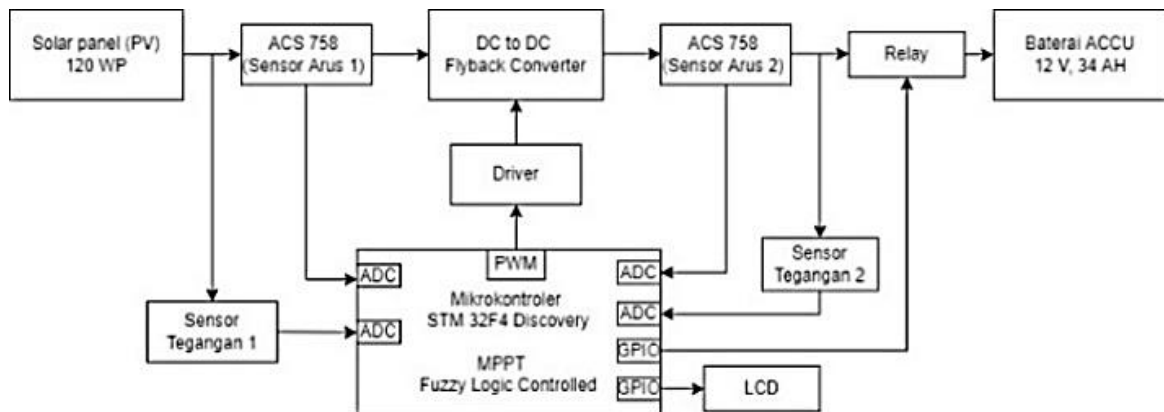


Figure 1. Design block diagram of the system

2.1. Solar Panel

Solar panels is a device that convert solar energy into electrical energy, especially in DC. The working process of solar panel begins when sunlight is captured by the PV and absorbed by p and n type semiconductor materials (p-n junction semiconductor) resulting in the release of electrons. Things that affect the amount of power produced by PV are light intensity (irradiation) and temperature of the PV module. This semiconductor consists of atomic bonds in which there are electrons as the basic constituent. Large power of PV is expressed in Watt peak (WP). The equivalent circuit of PV can be shown in Figure 2. The mathematical equation for the PV module can be expressed as (1). The parameters of PV used in this system are presented in Table 1.

$$I = I_{ph} - I_s \left(\exp \frac{q \cdot (V + I \cdot R_s)}{N \cdot k \cdot T} - 1 \right) - \frac{(V + I \cdot R_s)}{R_{sh}} \quad (1)$$

where:

I_{pv} = output power pv module (A)
 I_{ph} = generated current (A)
 I_s = saturation reverse current (A)
 q = electron charge ($1.6 \times 10^{-9}C$)
 V = output voltage PV (V)
 R_s = series resistance (Ω)
 R_{sh} = shunt resistance (Ω)
 K = constant voltman ($1.38 \times 10^{-23}/K$)
 T = junction temperature in kelvin (K)
 N = ideality factor of diode

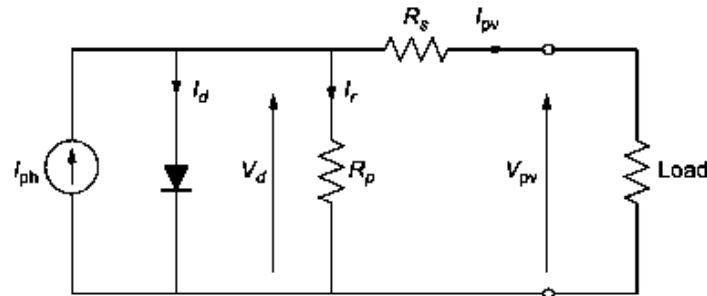


Figure 2. Equivalent circuit of PV module

Table 1. Parameters of solar panel

Parameter	Value
Maximum Power (P_{max})	120 W
Open Circuit Voltage (V_{oc})	21.51 V
Short Circuit Current (I_{sc})	7.19 A
Maximum Power Voltage (V_{mp})	18.2 V
Maximum Power Current (I_{max})	6.67 A
Maximum System Voltage	1000 V
Dimensi	102×68×3

2.2. Flyback Converter

Flyback converter is a type of high frequency power electronic circuit. This flyback converter has characteristic such as a buck-boost converter, which can increase or decrease the incoming DC voltage. Flyback converter circuit is consisting form switching component such as MOSFETs, thyristors, and IGBTs to adjust the duty cycle. Flyback converter has advantages compared to other converters, that is isolation between the input side and the output side. The equivalent circuit using a transformer model that includes the magnetizing inductance can be seen in Figure 3. It is having two operating modes with respect to ON and OFF condition of switch flyback converter. In mode 1 switch closed condition is shown in Figure 4.

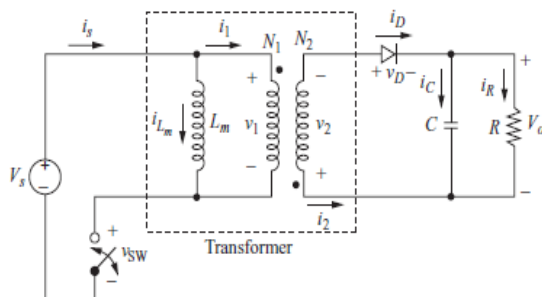


Figure 3. Equivalent circuit of flyback converter

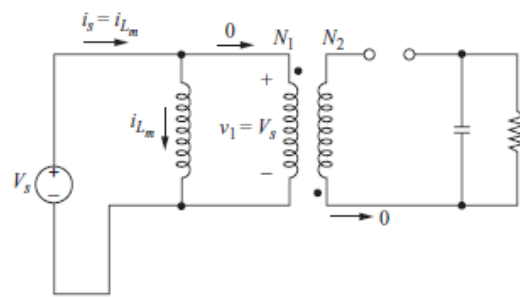


Figure 4. Mode 1

Analysis when switch closed, on the source side of the transformer, The mathematical equation for a current in transformer can be expressed as:

$$v_1 = V_s = L_m \frac{di_{Lm}}{dt} \quad (2)$$

$$\frac{di_{Lm}}{dt} = \frac{\Delta i_{Lm}}{\Delta t} = \frac{\Delta i_{Lm}}{DT} = \frac{V_s}{L_m}$$

Solving for the change in current in the transformer magnetizing inductance:

$$(\Delta i_{Lm})_{closed} = \frac{V_s DT}{L_m} \quad (4)$$

$$v_2 = v_1 \left(\frac{N_2}{N_1} \right) = V_s \left(\frac{N_2}{N_1} \right)$$

$$v_D = -V_o - V_s \left(\frac{N_2}{N_1} \right) < 0$$

$$i_2 = 0$$

$$i_1 = 0$$

Since the diode is off, $i_2 = 0$, which meant that $i_1 = 0$. So while the switch is closed, current is increasing linierly in the magnetizing inductance L_m , and there is no current in the windings of the ideal transformer in the model.

Then further condition is in mode 2 switch open is shown in Figure 5. Analysis when switch open, when the switch opens the current cannot change instantaneously in the inductance L_m , so the conduction path must be through the primary turns of the ideal transformer. Voltages and currents for an open switch are:

$$v_2 = -V_o$$

$$v_1 = V_2 \left(\frac{N_1}{N_2} \right) = -V_o \left(\frac{N_1}{N_2} \right)$$

$$L_m \frac{di_{Lm}}{dt} = v_1 = -V_o \left(\frac{N_1}{N_2} \right)$$

$$\frac{di_{Lm}}{dt} = \frac{\Delta i_{Lm}}{\Delta t} = \frac{\Delta i_{Lm}}{(1-D)T} = \frac{-V_o}{L_m} \left(\frac{N_1}{N_2} \right) \quad (4)$$

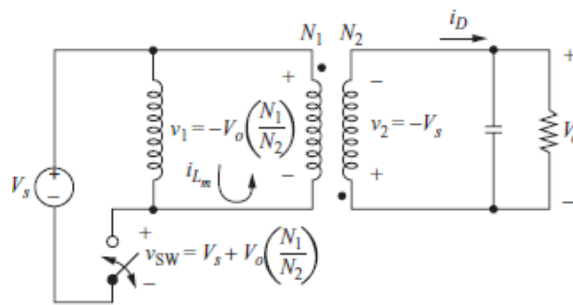


Figure 5. Mode 2

Solving for the change in the transformer magnetizing inductance with the switch open are:

$$(\Delta i_{Lm})_{open} = \frac{-V_o (1-D)T}{L_m} \left(\frac{N_1}{N_2} \right) \quad (5)$$

Since the net change in inductor must be zero over period for steady-state operation, in (6) show:

$$(\Delta i_{Lm})_{closed} + (\Delta i_{Lm})_{open} = 0 \quad (6)$$

$$\frac{V_s D T}{L_m} - \frac{V_o (1-D) T}{L_m} \left(\frac{N_1}{N_2} \right) = 0$$

Solving for V_o :

$$V_o = V_s \left(\frac{D}{1-D} \right) \left(\frac{N_1}{N_2} \right) \quad (7)$$

where:

- V_o = Output voltage (V)
- V_s = Input voltage (V)
- D = Duty cycle (%)
- N_1 = Primary winding (Turn)
- N_2 = Secondary winding (Turn)

The parameter selection for designing Flyback converter is given in Table 2. The waveforms for voltage and current flowing through the components of the flyback topology are shown in Figure 6.

Table 2. Parameter of flyback converter

No	Parameter	Value
1	Input Voltage	18.2 V
2	Output Voltage	14.4 V
3	Input Current	6.67 A
4	Output Current	4 A
5	Duty Cycle	50 %
6	Capacitor	5792 uF
7	Primary Winding	6.5 Turn
8	Secondary Winding	11 Turn
11	Load Resistance	2.15 Ω
12	Switching Frequency	40 kHz

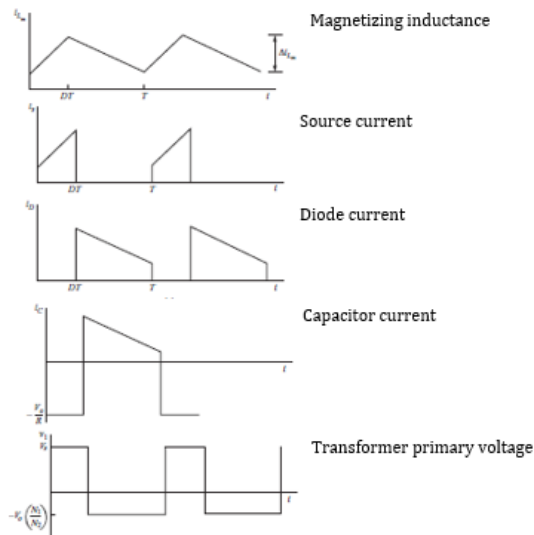


Figure 6. Flyback converter current and voltage waveforms

2.3. FLC

FLC generally consist of three stages: fuzzification, inference machine with rule base, and defuzzification. Fuzzyfication is a process that convert numerical input variable into linguistic variable based on membership function. The input of a MPPT FLC is usually an error (E) and a changing in error / delta-error

(DE). In the defuzzification process, the FLC output is converted from a linguistic fuzzy based MPPT controller to numerical variable (duty cycle) that declared in FLC output.

A fuzzy controller design can be performed in 3 steps.

- Step1: Choose fuzzy input and output variables and their membership functions.
- Step2: Express the inference rules linking input and output variables.
- Step3: Defuzzification of the output parameter.

As the fuzzyfication process there are two inputs variables, input error and delta-error. The membership function input error variable is shown in Figure 7. There is also the membership function input delta-error variable show in Figure 8.

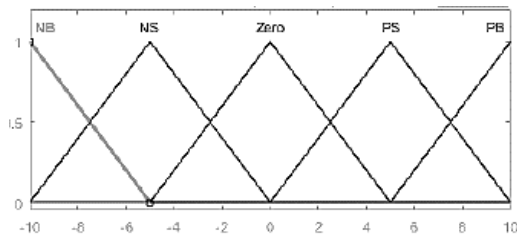


Figure 7. Membership function input (error)

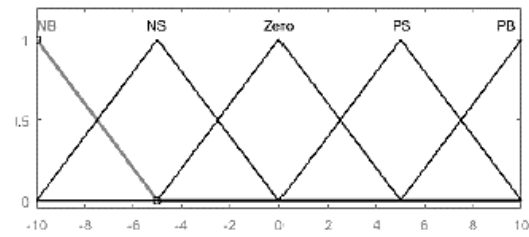


Figure 8. Membership function input (delta-error)

The error and delta-error of the output voltage will be the inputs of FLC. These two inputs are divided into five groups; NB (Negative Big), NS (Negative Small), Z (Zero), PS (Positive Small), and PB (Positive Big). These fuzzy control rule base for error and delta-error can be referred in the table that is shown in Table 3.

Table 3. Rule base of fuzzy logic

$e/\Delta e$	NB	NS	Zero	PS	PB
NB	D9	D8	D7	D6	D5
NS	D8	D7	D6	D5	D4
Zero	D7	D6	D5	D4	D3
PS	D6	D5	D4	D3	D2
PB	D5	D4	D3	D2	D1

The last process is defuzzification process. The output of the rule base is in the form of fuzzy values. The defuzzification process is needed to convert a fuzzy value (linguistic variable) into a value in the form of a duty cycle which is used to adjust the switching in converter. The membership function output variable is shown in Figure 9.

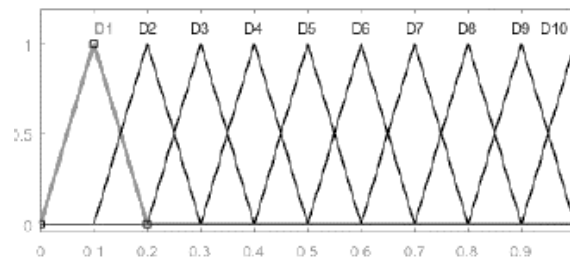


Figure 9. Membership function output

2.4. MPPT

The solar intensity factor and the module surface temperature that change everytime resulting the MPP of the solar panel changing, this point will not always be in the same position every time. However, the

MPP point can be determined by conducting an assessment using the appropriate algorithm. It is desirable to operate the PV cell to produce maximum power. To keep the module working in its operating area, an algorithm called the MPPT is needed. In this research, the method that used is FLC.

3. SIMULATION RESULT

The topology is investigated in MATLAB environment in order to check their behaviour and performance. This investigation is checked in close loop configurations. Beside simulation, this research is also being developed in real time using hardware.

3.1. Simulation Model of MPPT Flyback Converter

One of the objectives of testing in this research is to be able to achieve MPP based on irradiation input and temperature on the PV module. In this simulation, there are two condition that changing during simulation, these are irradiance and temperature. The irradiance values that given to the solar panel are 200 W/m², 400 W/m², 600 W/m², 800 W/m², and 1000 W/m². The temperature value that given are 25°C, 30°C, and 33°C. The MPPT flyback converter simulation circuit with FLC is shown in Figure 10 and the output voltage closed loop simulation of flyback converter is shown in Figure 11.

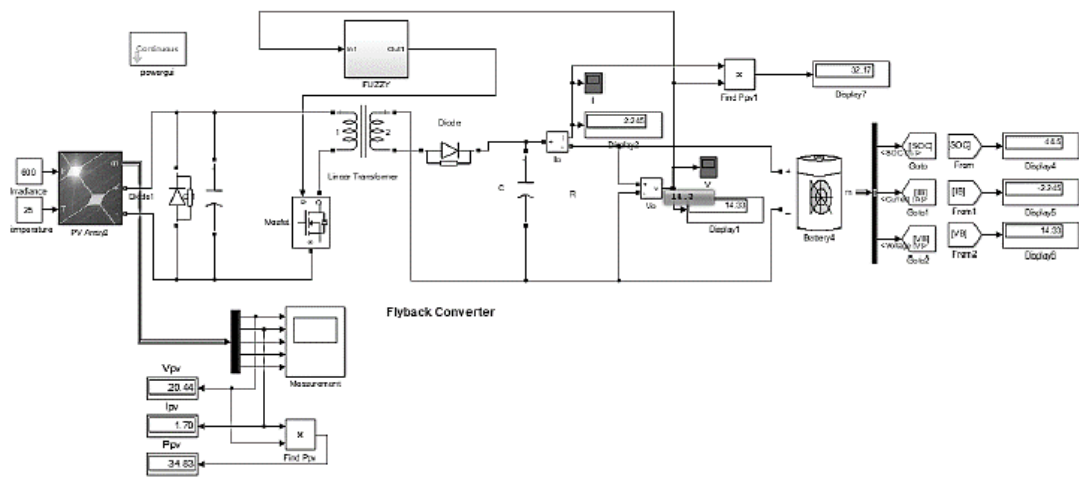


Figure 10. Flyback converter closed loop simulation circuit with FLC

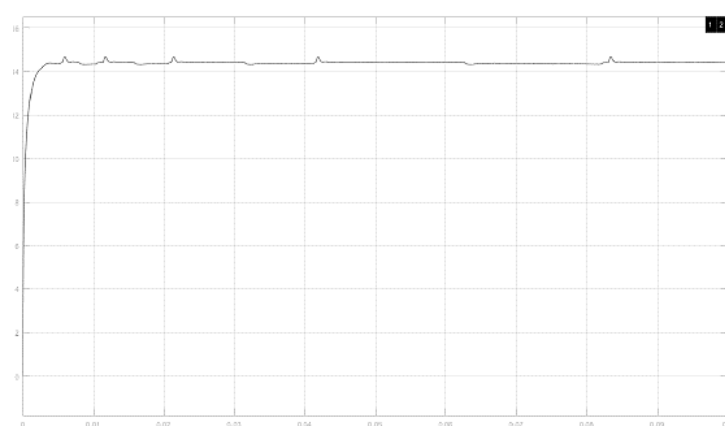


Figure 11. Output voltage closed loop simulation of flyback converter with FLC

In this simulation, the input source is a PV with power of 120 WP. A load used is a resistor with a value according to the converter calculation which is assumed to be a lead acid battery. The voltage closed

loop of flyback converter is in Figure 11. The results from a closed loop with an irradiance value is 1000 W/m². The output voltage that produced by converter is around 14.4 volt and the wave results are able to steady state at set point. The simulation result of MPPT flyback converter closed loop system is shown in Table 4, Table 5, and Table 6.

Table 4. Closed loop simulation results in 25°C

Irradiance (W/m ²)	V _{in} (V)	I _{in} (V)	V _o Setpoint (V)	V _o (V)	I _{out} (A)	Error V _o (%)	Eff (%)
200	14.93	1.4	14.4	14.26	0.93	0.97	63.4
400	19.85	1.53	14.4	14.32	1.92	0.55	90.5
600	20.44	1.7	14.4	14.33	2.24	0.48	92.3
800	15.22	5.62	14.4	14.51	5.33	0.76	90.4
1000	15.55	7.01	14.4	14.59	6.65	1.31	89

Table 5. Closed loop simulation results in 30°C

Irradiance (W/m ²)	V _{in} (V)	I _{in} (V)	V _o Setpoint (V)	V _o (V)	I _{out} (A)	Error V _o (%)	Eff (%)
200	15	1.41	14.4	14.26	0.94	0.97	63.4
400	19.51	1.45	14.4	14.31	1.78	0.62	90.1
600	20.06	1.68	14.4	14.33	2.1	0.48	89.3
800	15.14	5.64	14.4	14.51	5.32	0.76	90.4
1000	15.57	7.04	14.4	14.59	6.67	1.31	88.8

Table 6. Closed loop simulation results in 33°C

Irradiance (W/m ²)	V _{in} (V)	I _{in} (V)	V _o Setpoint (V)	V _o (V)	I _{out} (A)	Error V _o (%)	Eff (%)
200	15.03	1.41	14.4	14.26	0.95	0.97	63.9
400	19.29	1.41	14.4	14.31	1.72	0.62	90.5
600	19.87	1.54	14.4	14.32	1.94	0.55	90.8
800	15.3	5.65	14.4	14.51	5.36	0.76	90
1000	15.52	7.05	14.4	14.59	6.68	1.31	89

From closed loop simulation testing using a 5×5 fuzzy membership function input and varying temperatures, it can be seen that at a temperature of 25°C the highest efficiency value is found at 600 W/m² irradiation, which is 92.3% and the smallest at irradiation 200 W/m², which is 63.4% with an average efficiency of 85.12%. While the test at a temperature of 30°C obtained an average efficiency value of 84.37% and at a temperature of 33°C an average efficiency value of 84.84% was obtained. The best value is obtained when using a temperature of 25°C when the solar panel works on the best conditions. So that we can recognize the effect of high temperature on the PV system. The use of FLC in MPPT technique can produce average efficiency more than 84%.

4. CONCLUSION

Renewable electrical energy, such as photovoltaic (PV) modules, is increasingly used to replace fossil fuels. The maximum power point tracker (MPPT) is used to extract maximum power from PV modules. This paper presents design and implementation of MPPT flyback converter using FLC. This research investigated topology in MATLAB to check performance and behavior of PV modules. The performance of flyback converter system is able to produce a stable output voltage of 14.4 volt and average efficiency more than 84% in three different temperature. Simulations showed that the highest efficiency value is found at 25°C with 600 W/m² irradiation, while the lowest is at 200 W/m². The results of simulation experiments show that FLC is feasible to applied in the MPPT control system.

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