Journal of Electrical Engineering and Computer (JEECOM)
Vol. 7, No. 2 (2025), DOI: 10.33650/jeecom.v4i2
p-ISSN: 2715-0410; e-ISSN: 2715-6427

Solar Cell Energy Utilization Using SEPIC Converter with Fuzzy Logic Control for Electric Stove

Indhana Sudiharto[1], Suryono[2], Ahmad Firyal Adila[3], Anang Budikarso[4]
[1,2,3,4]Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia

Article Info

Article history:

Received Okt 09, 2025
Revised Okt 27, 2025
Accepted Okt 28, 2025

Keywords:

Solar cell
SEPIC converter
Electric stove
Fuzzy Logic Control

ABSTRACT

In this modern era, most household appliances require electrical energy as an energy source. The use of energy in large and sustainable amounts will cause an energy crisis. Where fossil fuels will run out and cannot be renewed. Therefore, renewable alternative energy is needed that can be used as an energy substitute for one of the solutions. One of the alternative energies is solar cell energy that to supply the energy needs of electric stoves. This study discusses photovoltaic system that use 10 solar cells each with a power of 100 WP and 90 VDC. The electrical energy generated from the solar cell is 1000 WP. From the solar cell, the voltage is increased using a Single-Ended Primary-Inductor Converter (SEPIC) converter and controlled using Fuzzy Logic Control (FLC). The output voltage is used to meet the power needs of an electric stove with a maximum power of 650 W which has an average efficiency of 93%.

Corresponding Author:
Ahmad Firyal Adila,
Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia
Email: firyal@pens.ac.id

1. INTRODUCTION

Electric energy is now a basic necessity for humans. Almost all the needs of human life can't be separated from electrical energy [1]. But the resources to produce electricity still use non-renewable energy such as petroleum, gas and coal so as to produce air pollution that is not good for the environment [2]. Renewable energy is the right solution to overcome the problems that have been presented above, namely by using solar cells. Solar cells can convert solar energy into electrical energy that will be used as an alternative energy source [3]. Solar cells are very potential to be utilized because of their unlimited availability, zero noise, and also does not produce air pollution so as to prevent global warming. Indonesia has a high potential for solar energy because Indonesia is a tropical country [4] and the geography of Indonesia is located in the equator with sun exposure 12 months a year [5].

Solar cell can't be directly connected to a load caused by an unstable energy conversion due to weather conditions, temperature and sudden solar illumination [6-7]. Therefore, a DC-DC converter is needed that can maintain voltage stability, i.e. by using SEPIC converter [8]. Sepic converter can produce smaller voltage and greater voltage than input voltage depending on the duty cycle value used [9]. To solve problems in the system, the design of this tool is also equipped with intelligent control to control the output voltage of SEPIC converter that is to use FLC system so that the power produced according to the desired [10].

From this research, it is have provided able to design and implemented the use of a SEPIC converter to stabilize the output voltage of solar cells in order to be able to meet the energy needs of electric stove loads whose output power can be adjusted using FLC.

2. METHOD

2.1. System Design

Figure 1 is the process of the system used in research. This system uses 10 solar cells with a power value of 100 WP installed 5 series and 2 parallel as the main energy source which is then connected with DC-DC SEPIC converter.

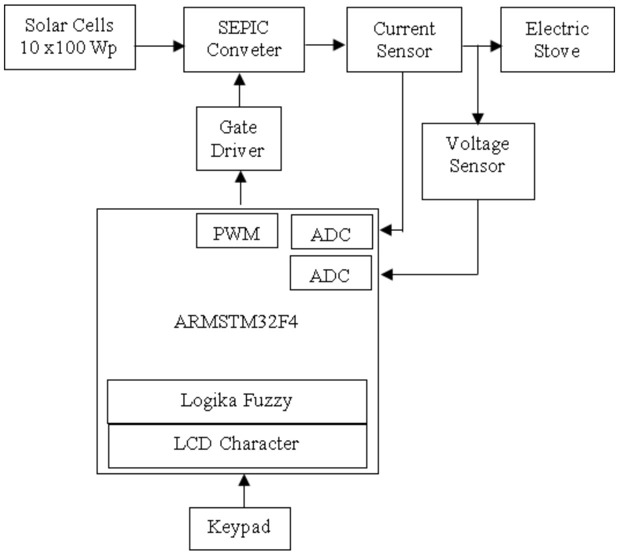

Figure 1. Electric stove system design

This system controls the power of the electric stove to fit the set point that has been determined and set by the keypad. This system uses SEPIC converter which has a PWM control on the source to regulate the input voltage of the PV, so that the source can work then set the duty cycle of the source so that it gets power according to the set point by using logic-fuzzy control. Furthermore, the output voltage is kept constant and used for the load of electric stoves. The sensors used will then transmit data to ARMSTM32F4. The data results will be continued to Analog to Digital Converter (ADC) and displayed on the Liquid Crystal Display (LCD).

2.2. System Modelling

A. Solar Cell Module

Solar cells are a component that can convert solar energy into DC electrical energy using the principle of the Photovoltaic effect [11]. Solar cells can produce electric current and voltage at different load and light conditions [12]. Solar cell equivalents can be seen in Figure 2.

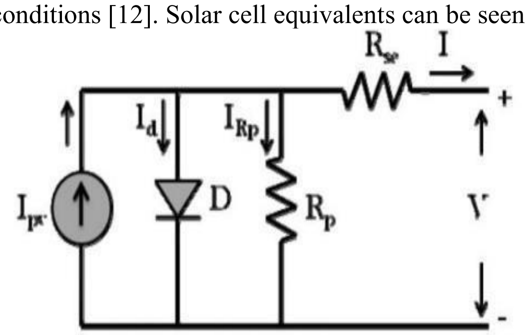

Figure 2. Solar cell equivalent circuit

The way solar cells work is actually identical to semiconductor diode devices [14]. If the solar cell is exposed to sunlight, then arises called electrons and holes around the P-N junction that move consecutively towards the n layer and towards the P layer. This capability is represented in the current-voltage curve (I-V). The basic principle for measuring the I-V curve of PV on current control is provided between short circuit points and open voltage points [13]. Figure. 3 is characteristic of the I-V and P-V curves in solar cells.

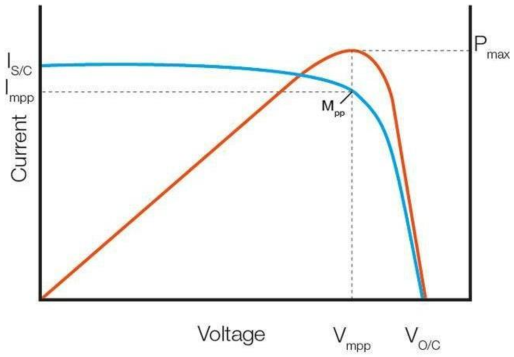

Figure 3. Characteristics of I-V and P-V curves in solar panels

Table 1. Solar cell specifications

ELECTRICAL DATA	SYMBOL	NAMEPLATE VALUE
Model Type		Mixenoct 100P-12
Rated Power	Pmax	100 W
Rated Current	Impp	5.72 A
Rated Voltage	Vmpp	17.5 V
Short Circuit Current	Isc	6.35 A
Open Circuit Voltage	Voc	22 V
Module Dimensions		1085x675x25mm
Weight		8.7 kg

B. SEPIC Converter

SEPIC converter is basically a topology type buck-boost converter. This converter is unlike the Cuk converter which provides non-reversing output and has low input current ripples. SEPIC converter has higher efficiency than most other DC-DC converters [15]. Figure. 4 is a SEPIC converter serial image. The structure of the SEPIC converter is shown in Figure. 4. Where SEPIC converter consists of two inductors with two capacitors and a diode.

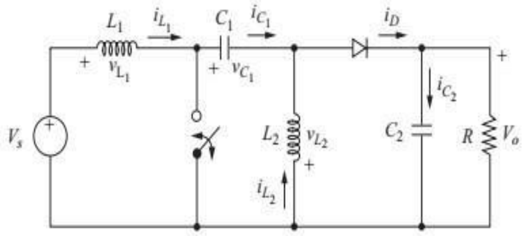

Figure 4. SEPIC circuit

To determine the component value of the SEPIC converter using the equation, Where D is the duty cycle ratio of the switch which can be expressed as

$$Vo = Vs\left(\frac{D}{1-D}\right) \tag{1}$$

$$D = \frac{Vo}{Vo + Vs} \tag{2}$$

$$L1 = L2 = \frac{Vin \times D}{\Delta I_L \times fs} \tag{3}$$

$$C1 = C2 = \frac{Vo \times D}{R \times \Delta Vo \times fs} \tag{4}$$

SEPIC converter has the ability to produce output voltages smaller or greater than input voltages with uninverted polarity. Table 2 shows the proposed SEPIC parameters.

ISSN: 2715-6427

Table 2. Parameters of SEPIC converter design

Parameter	Value	Unit
Vin	90	V
Fs	100	kHz
Vout	220	V
ΔIL	20%	A
ΔVo	0.2%	V
L1	0.36	mH
L2	0.36	mH
C1	48	μF
C2	48	μF

Where:
Vin = Input Voltage(V)
Fs = frequency (Hz)
Vout = Output voltage(V)
ΔIL = Current Ripple (A)
ΔVo = Voltage Ripple (V)
L1 = Inductor1 (mH)
L2 = Inductor2 (mH)
C1 = Capacitor1(μF)
C2 = Capacitor2 (μF)

The above parameters are needed to design the SEPIC converter which is used to increase the voltage output of the solar panels which are all 90 VDC to 220 VDC.

C. Fuzzy Control System

FLC is a problem-solving method that contains elements of uncertainty and is the result of improvements from Boolean algebra regarding the concept of partial truth. In SEPIC converter, fuzzy algorithm is used to control and stabilize power at the setting of power points that have been determined by the load used is the electric stove. Fuzzy logic control design needs to observe the open loop curve so that it can determine errors and delta errors [16]. Controllers that use fuzzy logic have been widely used in the last decade because fuzzy logic can handle imperious input problems, does not use accurate mathematical modeling and is capable of handling impatience. Figure 5 is the membership function used. To process the value information of each linguistic variable, the number of membership functions depends on the level of accuracy of the controller, but usually varies from 5 to 7. This study used 7 levels of fuzzy membership and obtained the rules as in table 3.

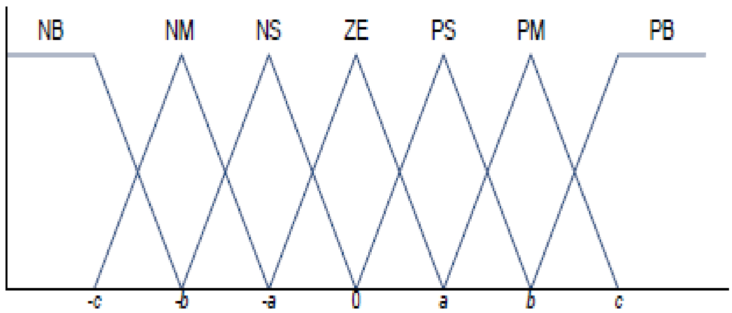

Figure 5. Fuzzy membership function

Table 3. Rule base

DE \ E	NB	NM	NS	ZE	PS	PM	PB

NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The following surface appearance of the FLC design that has been made for this system can be seen in Figure 6.

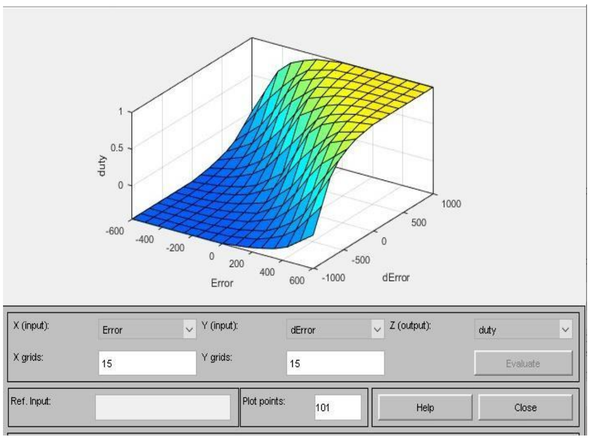

Figure 6. Surface of FLC

3. RESULTS AND DISCUSSION

In this research, design and control of the SEPIC converter using fuzzy algorithm modeling can be implemented using MATLAB simulation. Previously, an integration circuit without control and an open loop power response was required so that the results could be compared with an integration circuit using FLC and a closed loop responses. Figure 7 is a SEPIC converter simulation circuit without control.

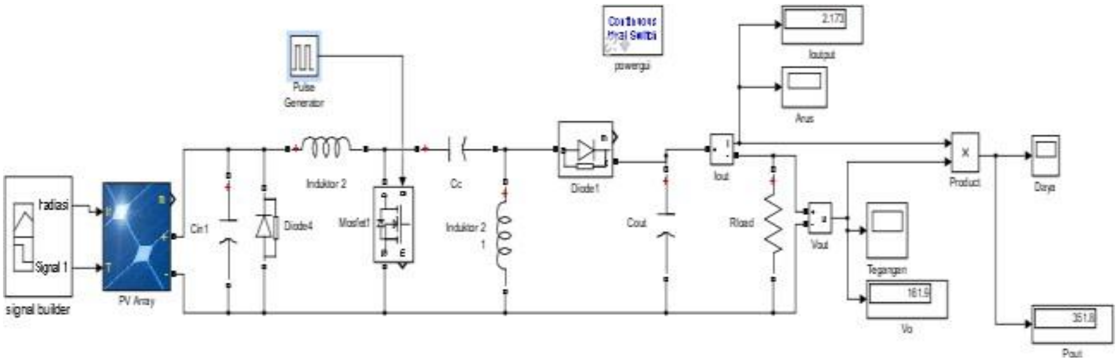

Figure 7. SEPIC converter simulation circuit without control

The simulation results of the first experiment are the SEPIC converter circuit without using FLC where in this experiment there are three set points of power output, namely 300W, 400W, and 500W.

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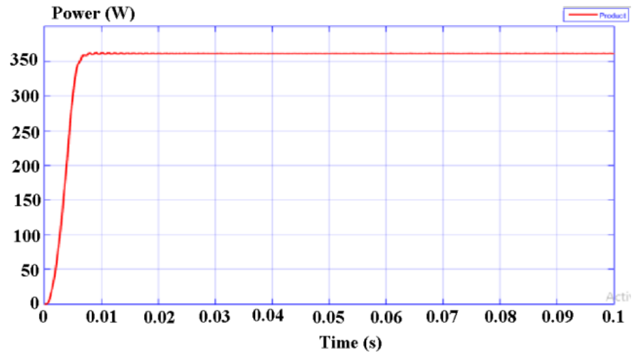

Figure 8. Results of SEPIC converter without control for power output 300W setpoint

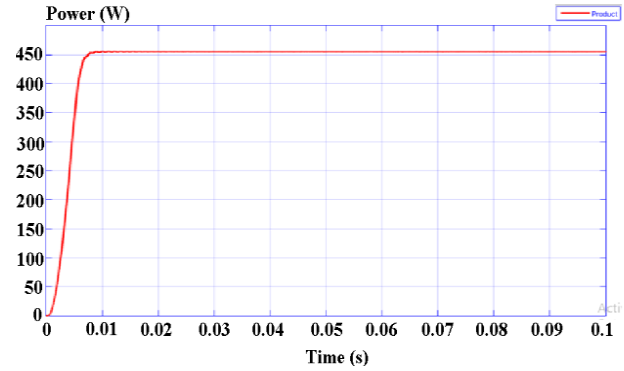

Figure 9. Results of SEPIC converter without control for power output 400W setpoint

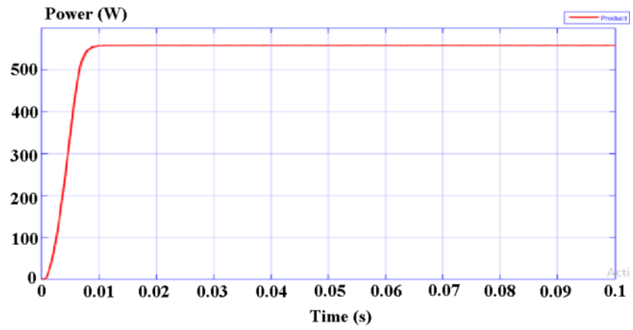

Figure 10. Results of SEPIC converter without control for power output 500W setpoint

From the simulation results, the output power value is 370W for the 300W set point, 460W for the 400W set point and 570W for the 500W setpoint where the output power value does not match the set point value. To find out how much the error can be calculated using the formula:

$$Error = \frac{[Pin - Pout]}{Pin} \times 100\% \quad (5)$$

So that the error value is known as follows:

$$\frac{300 - 370}{300} \times 100\%$$

$$\frac{400 - 460}{400} \times 100\%$$

$$\frac{500 - 570}{500} \times 100\%$$

Error of setpoint 300W = 23.3%
Error of setpoint 400W = 15%
Error of setpoint 500W = 14%

For the SEPIC converter simulation experiment circuit using FLC as follows:

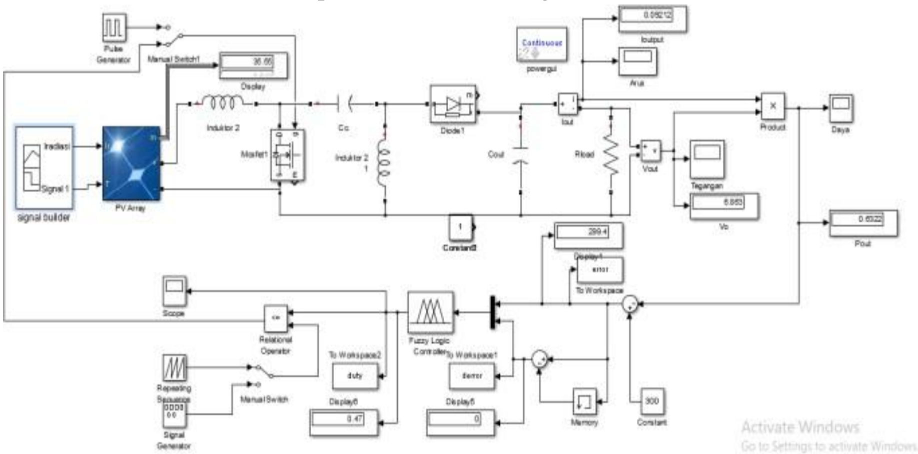

Figure 11. SEPIC converter simulation circuit with FLC

In the SEPIC converter simulation experiment using FLC control, no calculation is needed to determine the duty cycle, where the FLC control here functions to control the output power of the SEPIC converter to match the specified output power setpoint.

The simulation results of the second experiment are the SEPIC converter circuit using FLC control, the same thing as the first experiment using three set points, namely 300W, 400W, and 500W. The results are as follows:

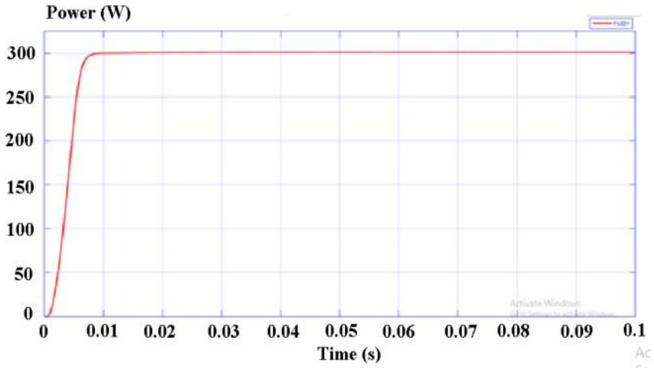

Figure 12 . Results of SEPIC converter using FLC at 300W setpoint

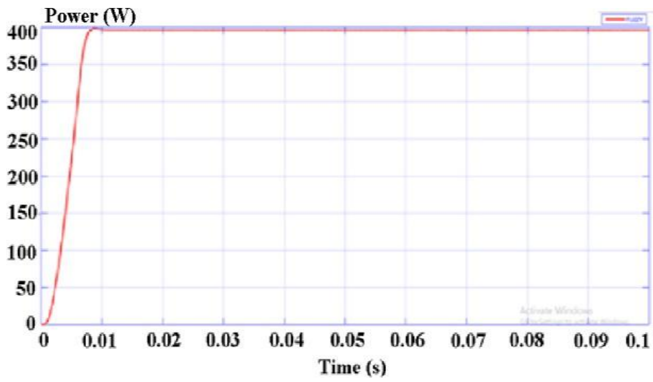

Figure 13. Results of SEPIC converter using FLC at 400W setpoint

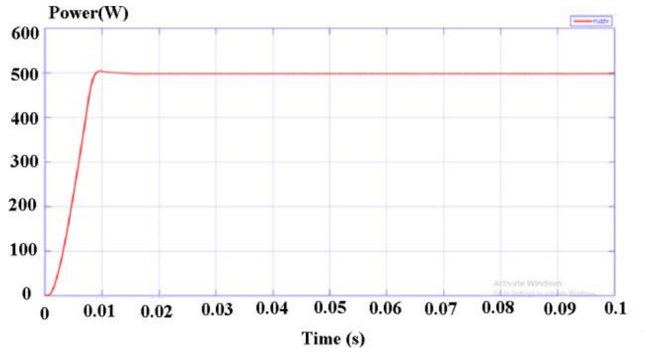

Figure 14. Results of SEPIC converter using FLC at 500W setpoint

From the simulation results, the output power value is obtained where the output power value does not match the set point value. to find out how errors can be calculated using the same formula in the first experiment and obtained error setpoint 300W is 1.67%, error setpoint 400W = 1.5%, and error setpoint 500W is 1.8% respectively.

In order to find out the system can work according to what is desired, integration is carried out by changing the irradiation value and temperature, for the irradiation value from 1000 W/m², 850 W/m² and 650W/m² while for the temperature value from 25°C, 30°C and 35°C. Table 4 is the result of integration.

Table 4. Data Integration Results

Set point (W)	Irradia-tion (W/m2)	Tempe-rature (°C)	Vout (V)	Iout (A)	Pout (W)	Error Pout (%)
300	1000	25	149	1,98	305	1,67
	850		153	2,05	305	1,67
	650		150	1,99	305	1,67
400	1000		172	2,34	406	1,5
	850		172	2,33	406	1,5
	650		174	2,32	406	1,5
500	1000		191	2,61	509	1,8
	850		189	2,57	509	1,8
	650		190	2,59	509	1,8
300	1000	30	147	1,97	305	1,67
	850		150	2,00	305	1,67
	650		149	1,97	305	1,67
400	1000		171	2,32	406	1,5
	850		170	2,32	406	1,5
	650		173	2,31	406	1,5
500	1000		190	2,61	509	1,8
	850		188	2,57	509	1,8
	650		188	2,58	509	1,8
300	1000	35	148	1,99	305	1,67
	850		150	2,03	305	1,67
	650		149	1,99	305	1,67
400	1000		178	2,31	406	1,5
	850		175	2,32	406	1,5
	650		178	2,32	406	1,5
500	1000		195	2,60	509	1,8
	850		190	2,57	509	1,8
	650		191	2,59	509	1,8

The results of the output power of the simulation integration test carried out by changing the irradiation and temperature values for 3 set points 300 W, 400 W, and 500W as follows:

$$\frac{300-305}{300}\times 100\%$$

$$\frac{400-406}{400}\times 100\%$$

$$\frac{500-509}{500}\times 100\%$$

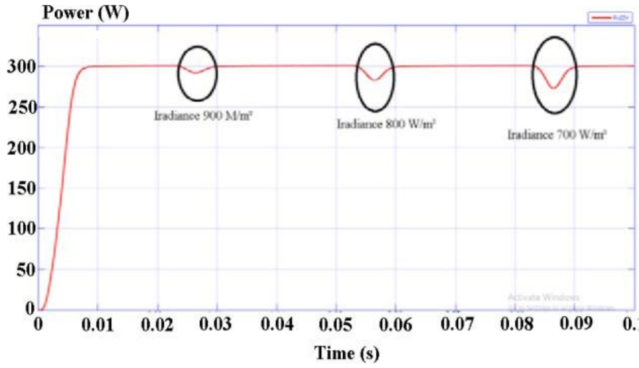

Figure 15. Result of simulation integration with FLC for 900 W/m², 800 W/m² and 700 W/m² irradiation and 25C° temperature at 300 W power point setting

From the output power signal from the integration in the simulation at the set point of 300W with irradiation and changing temperature, it can produce a constant output power as shown in the picture, which is 305W so that it has a %error of 1.67% and an efficiency of 98.4%.

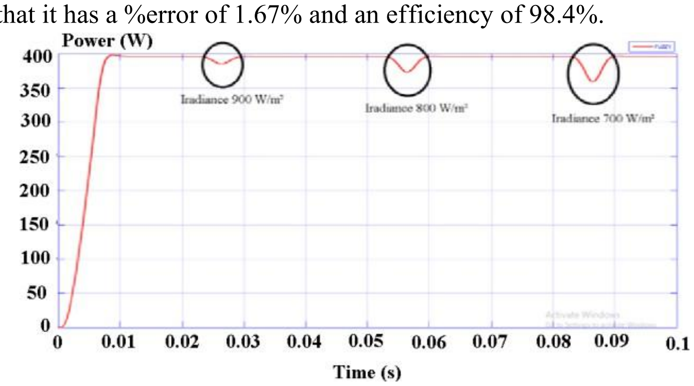

Figure 16. Result of simulation integration with FLC for 900 W/m², 800 W/m² and 700 W/m² irradiation and 25C° temperature at 400 W power point setting

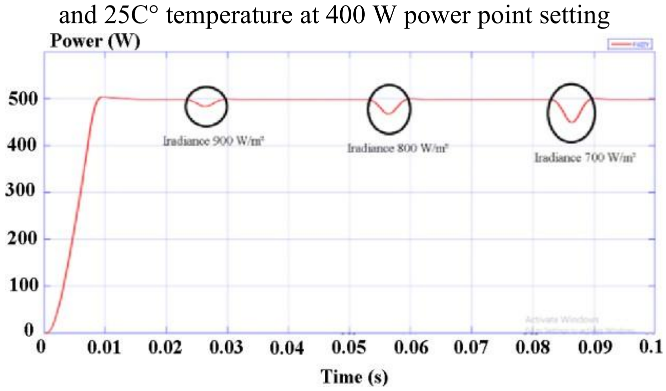

Figure 17. Result of Simulation Integration with FLC Control for 900 W/m², 800 W/m² and 700 W/m² irradiation and 25C° temperature using 500 W power point setting

From the results of the integration the system can work even though the irradiation value is changed because the system is designed with a solar panel capacity with a load of 60% so that when the irradiation drops the system can still supply a load of 500W.

4. CONCLUSION

From the experimental simulation results obtained, it can be concluded that the implementation of FLC significantly improves the accuracy and stability of the system compared to the conventional (non-FLC) configuration. When the circuit operates without Fuzzy Logic Control, the system exhibits a considerable deviation from the desired set power point, with an error magnitude of approximately 23.3%. This relatively high error indicates that the conventional control approach is less effective in maintaining the desired output power under varying operating conditions.

In contrast, when the FLC system is applied, the resulting error decreases dramatically to only 1.8%. This demonstrates that the Fuzzy Logic Controller is capable of adapting to changes in system parameters and external disturbances more efficiently, resulting in a much more precise tracking of the set power point. The reduction in error also implies that FLC provides a smoother and more stable response, improving both the transient and steady-state performance of the circuit. Therefore, it can be concluded that FLC offers superior control accuracy, adaptability, and robustness. This makes it a suitable method for applications that require precise regulation of output power or other nonlinear system parameters.

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