Simulation Of A SEPIC DC-DC Converter Using Perturb And Observe And Fuzzy Logic Control

Goshwe, N.Y, Igwue G.A, Kureve, D.T.

Abstract: Perturb and observe (P & O) and fuzzy logic (FLC) controller based techniques for switching a single-ended primary-inductor (SEPIC) converter for harvesting power from a photo-voltaic (PV) panel is presented. The techniques are compared at varying irradiances of 1000, 900, 700 and 500 W/m^2 and varying temperatures of 30, 25, 20 and 18 degrees respectively. The results show that the SEPIC converter using P &O and FLC has a maximum voltage output of 58.76 V and 58.70 V; The Solar power output is maximum at 407.8 W and 400.7 W for irradiance of 1000 W/m^2 at 18^oC respectively. The converter output voltage using P & O has oscillations which are eliminated using the fuzzy logic controller.

Keywords: Perturb and Observe, Fuzzy Logic Controller, SEPIC, Photo-voltaic (PV) system, Irradiance and Temperature

1.0 INTRODUCTION

The sun emits energy that is the best option for renewable energy as it is available almost everywhere which can be harnessed freely. Radiation from the sun is converted to electrical energy by using PV solar cells which exhibit photo-voltaic effect [1]. Photo-voltaic (PV) solar panel is a very simple as well as reliable technology which directly converts energy from the sun into electricity for home and industrial utilization [2-5]. Maximum power can be obtained from photo-voltaic panels using controllers [6]. Various approaches can be used to implement MPPT such as perturb and observe (P&O), incremental conductance (INC), constant voltage and short-circuit current techniques [7-8]. These techniques are used to obtain the point at which maximum power is tracked for specified solar irradiation as well as temperature but they display oscillatory behavior around the maximum power point when operating under normal conditions. Moreover the system's response to rapid changes in temperature or irradiance is slow [10]. On the other hand the conventional PI controllers are fixed gain feedback controllers. Therefore they cannot compensate the parameter variations in the process and cannot adapt fast to changes that occur within the environment. PI-controlled system is less responsive to real and relatively fast alterations in state and so the system will be slower to reach the set point. Recently, intelligent based techniques have been introduced [9-11]. Amongst the methods which are intelligent-based, fuzzy logic has its own merit. The shape of the membership function of the fuzzy logic controllers can be adjusted such that the gap between the operation point and maximum power point is optimized. A SEPIC converter is used to provide a constant dc bus voltage [10-12]. The analysis of two MPPT techniques (P & O and FLC) of PV solar SEPIC converter that extracts maximum power from the module for varied solar irradiation and temperature is presented. Comparison and Modeling of the system is done using MATLAB/SIMULINK.

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2.0 METHODOLOGY

The system includes a PV panel, SEPIC converter, MPPT block, and the load. The PV panel block contains a single panel whose output is input into the SEPIC converter that boosts or bucks the input voltage to the required output voltage which is connected to the load as depicted in figure 1. MPPT controller senses the voltage and current and adjusts the converter such that the load receives the maximum power that is transferred from panel through the converter.

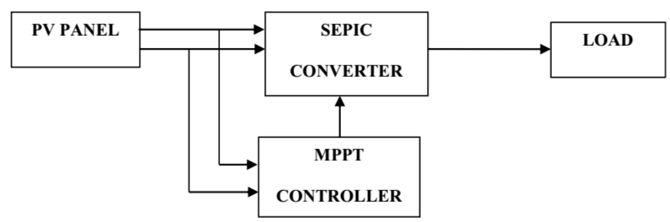

Figure 1: *Diagram of Solar SEPIC converter*

2.1 Photovoltaic Module

Whenever sunlight is exposed on a solar panel, a DC current varies linearly with the solar PV irradiance. The I-V characteristic of the module based on varying irradiances (1000, 900, 700 and 500 W/m^2) at 25 degrees is as presented in Figure 2.

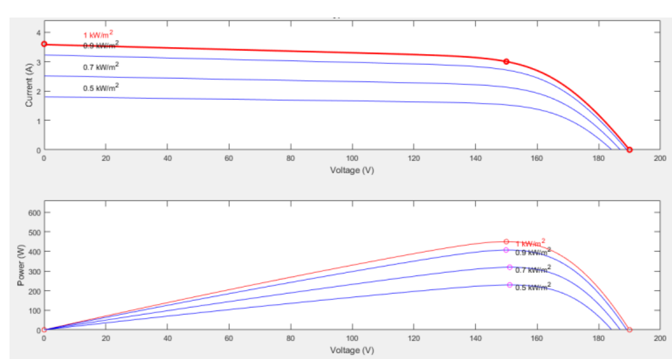

Figure 2: *PV characteristic curve for varying irradiance*

2.2 Perturb and Observe

The algorithm is based on the calculation of the PV power and the power change by sampling both the PV current and voltage. The tracker operates by periodically incrementing or decrementing the solar array voltage [12].

Table 1: *Summary of P&O*

Perturb	Change in power	Next perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

The algorithm works when instantaneous PV array voltage and current are used, as long as sampling occurs only once in each switching cycle. The process is repeated periodically until the MPP is reached there by inducing oscillation about the MPP. The oscillation can be minimized by reducing the perturbation step size. However, a smaller perturbation size slows down the MPPT. Figure 3 shows the flow chart of a P&O technique.

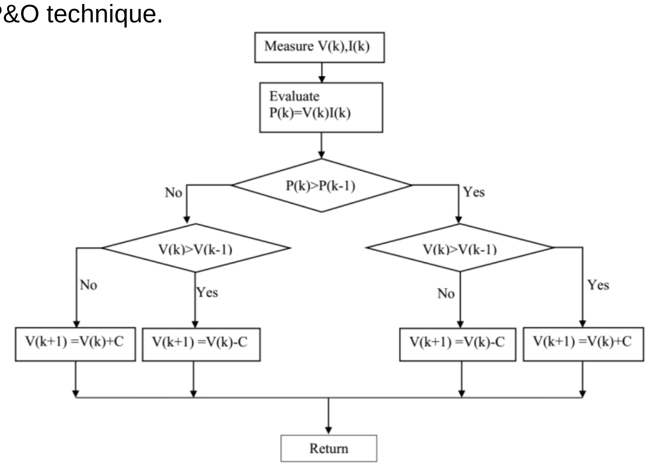

Figure 3: *The Perturb and Observe flow chart*

2.3 Fuzzy Logic Controller (FLC)

The input variables of the FLC are the slope of the power variation, E (k) and the change of the slope, CE (k) of the PV panel. The output of the FLC is the duty cycle of the PWM signal controls of the converter switching gate. The triangular membershipfunctions are used for the FLC for easier computation. The control system is generalized in a block diagram as presented in Figure 4.

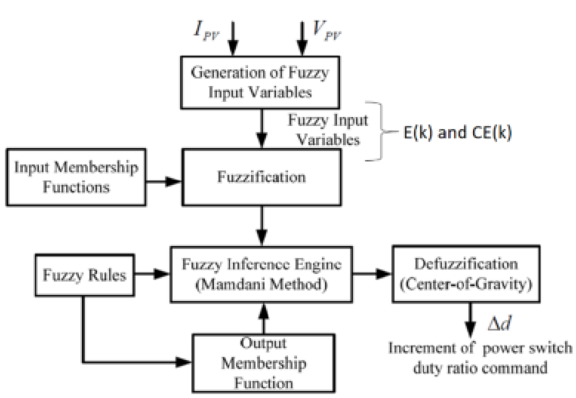

Figure 4: *The FLC MPPT diagram*

The input variables of the fuzzy logic controller are defined as in Equations (1) and (2).

$$E(k) = \left(\frac{P_{pv}(k)-P_{pv}(k-1)}{V_{pv}(k)-V_{pv}(k-1)}\right) \quad (1)$$

$$CE(k) = E(k) - E(k-1) \quad (2)$$

A seven-term fuzzy sets, Negative big (NB), Negativemedium (NM), Negative small (NS), zero (ZZ), Positive small (PS), Positive medium (PM), and Positive big (PB) define each linguistic variable. Each linguistic term associated with a linguistic variable set has a degree of membership that ranges from zero to one both inclusive as shown in table 2. A degree of membership one represents total membership in the linguistic variable set; a degree of membership of zero represents total exclusion from the linguistic variable set.

Table 2: *FLC Rule table*

CE/E	NB	NM	NS	ZZ	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZZ
NM	NB	NB	NB	NM	NS	ZZ	NS
NS	NB	NB	NM	NS	ZZ	PS	PM
ZZ	NB	NM	NS	ZZ	PS	PM	PB
PS	NM	NS	ZZ	PS	PM	PB	PB
PM	NS	ZZ	PS	PM	PB	PB	PB
PB	ZZ	PS	PM	PB	PB	PB	PB

2.4 SEPIC DC-DC Converter

The converter consist of two inductors (L_1 and L_2), three capacitors ($C_1$and C_o), a diode (D) and switch (Q) which is typically a transistor such as MOSFET.

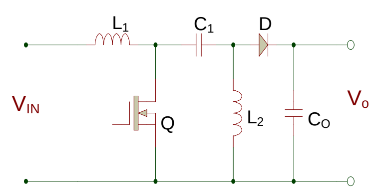

Figure 5: *The circuit diagram of the SMPS.*

The converter in Figure 5 is in Continuous Conduction Mode (CCM) therefore, current through the inductor L_1 never falls to zero.

3.0 Simulation Study

The simulation of the PV solar based SEPIC converter using FLC MPPT is carried out in MATLAB/Simulink using the parameters presented in table 3-4

Table 3: *Converter design specifications*

Description	Value
Minimum Input Voltage	50 V
Maximum Input Voltage	340 V
Switching frequency	200 kHz
Inductor	26.24 µH
Output Capacitor	220 µF
Output Voltage	60 V

Table 4: *solar panel specifications Sunpower E20 400 watt solar panel SPR-E*

Parameters	Specifications
Power Output	400 W
Open circuit Voltage (Voc)	85.3 V
Short circuit current (Isc)	6.43 A
Voltage at maximum power (Vmpp)	72.9 V
Current at maximum power (Impp)	5.97 A
Module size	36 cells

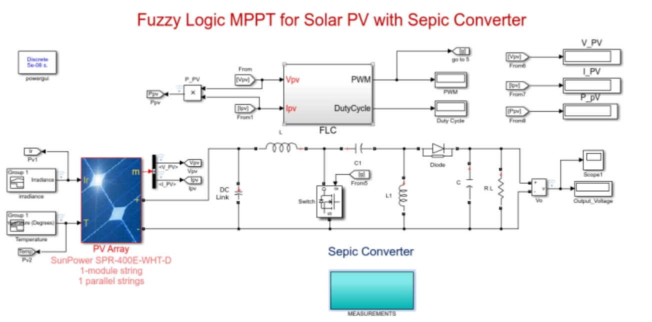

Figure 6: *Simulink model of the PV solar SEPIC Converter with Fuzzy logic controller MPPT*

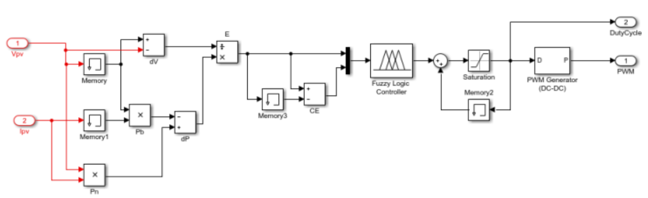

Figure 7: *Simulink model of the Fuzzy logic controller MPPT*

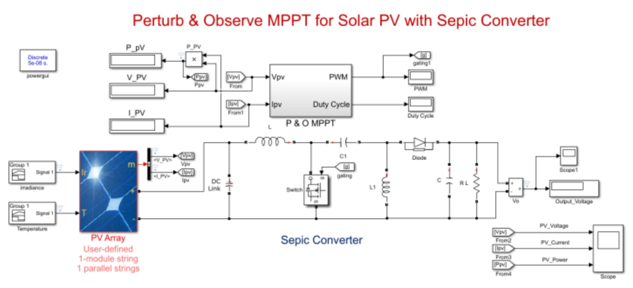

Figure 8: *Simulink model of the PV solar SEPIC with P and OMPPT*

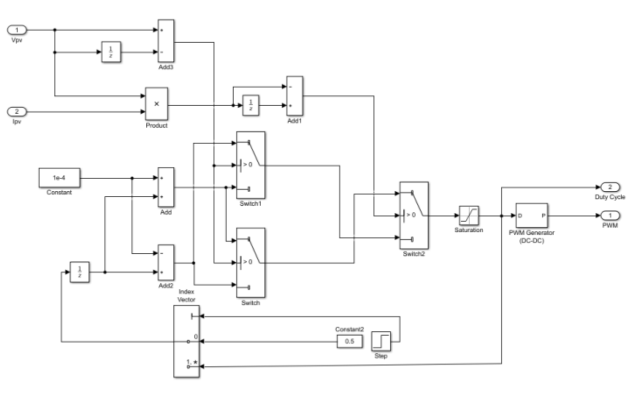

Figure 9: *Simulink model of the P and OMPPT*

4.0 RESULTS

This chapter presents the results obtained from the simulations of analysis done in chapter three.

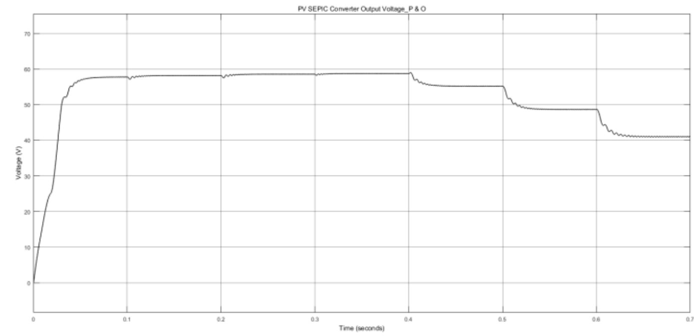

Figure 10: *SEPIC output voltage using P and O controller for different Irradiances and temperature*

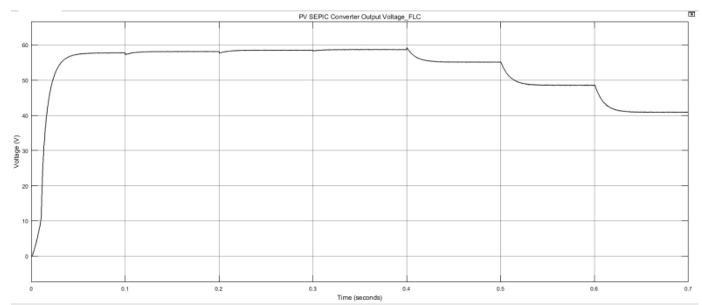

Figure11: *Output Voltage of SEPIC using FLC MPPT for different Irradiances and temperature*

The summary of Figure 10 and 11 is as presented in Table 5

Table 5: *SEPIC voltage under varying Irradiance and Temperature for P and O and FLC MPPT*

S/N	Voltage (V)		Irrad (W/m^2)	Temp (^{o}C)
	P&O	FLC		
1	57.74	57.74	1000	30
	58.19	58.15		25
	58.59	58.50		20
	58.76	58.70		18
2	55.17	55.18	900	25
3	48.63	48.60	700	25
4	40.95	40.94	500	25

Figure 10 presents the output voltage of the PV solar based SEPIC using P and O MPPT controller. The output voltage as it relates to varying irradiance and temperature is as presented in Table5. From the table5, it indicates that the output voltage of the converter for P and O MPPT is maximum at 57.74, 58.19 V, 58.58 and 58.76 V for 1000 W/m^2 and changes of 30^{o}C, 25^{o}C, 20^{o}C and 18^{o}C respectively. At 900 W/m^2 and 25^{o}C, the Voltage output drops to 55.17 V. For 700 W/m^2 and 500 W/m^2 both at 25^{o}C, the maximum voltage output is 48.63 V and 40.95 V respectively. Oscillations are observed in the output wave form which is high at 1000 W/m^2 and 30^{o}C between and low at 500 W/m^2 and 25^{o}C between. It is observed that at every change in temperature, there is a dip in the output voltage signal before it settles back through the action of the MPPT controller.

Figure 11 presents the output voltage of the SEPIC using FLC MPPT controller. The output voltage as it relates to varying irradiance and temperature is as presented in Table 5. From table 5, it indicates that the output voltage of the SEPIC for FLC MPPT peaks at 57.74 V, 58.15 V, 58.50 V and 58.70 V for 1000 W/m^2 and changes of 30^{o}C, 25^{o}C, 20^{o}C and 18^{o}C respectively. At 25^{o}C, and 900 W/m^2, the Voltage output drops to 55.18 V. For 700 W/m^2 and 500 W/m^2 both at 25^{o}C, the maximum voltage output is 48.60 V and 40.94 V respectively. Oscillations are not observed in the output wave form of the converter but it is observed that at every change in temperature, there is a dip in the output voltage signal before it settles back through the action of the FLC MPPT controller.

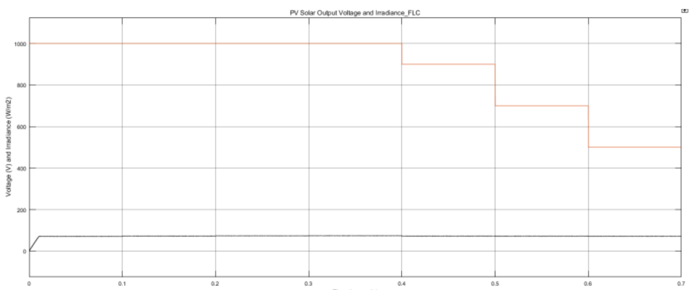

***Figure 12:** Output Voltage with varying Irradiance for FLC MPPT*

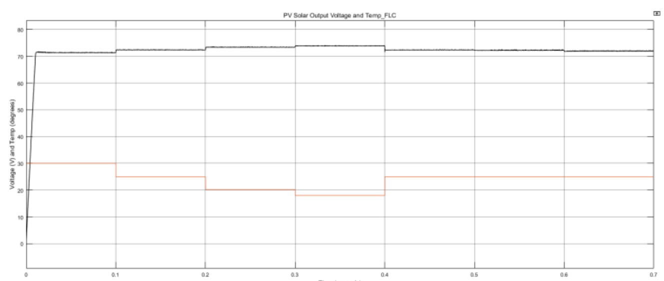

***Figure 13:** Output Voltage with varying Temperature for FLC MPPT*

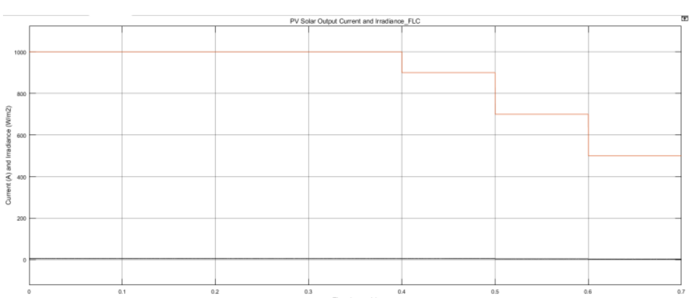

***Figure 14:** Output Current with varying Irradiance for FLC MPPT*

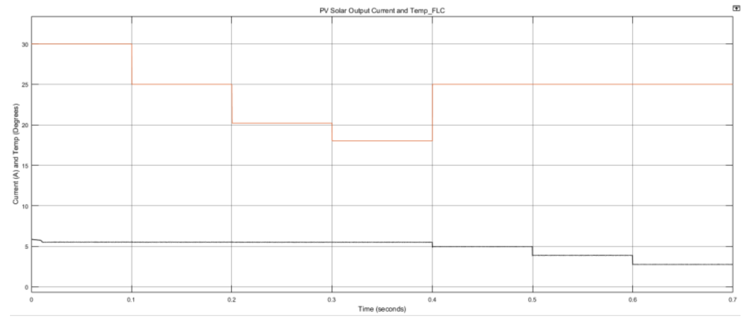

***Figure 15:** Output Current with varying Temperature for FLC MPPT*

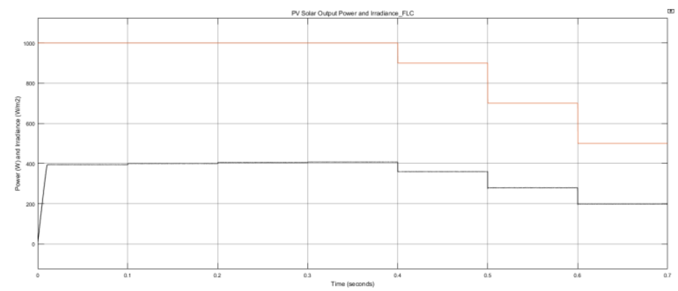

***Figure 16:** Output Power with varying Irradiance for FLC MPPT*

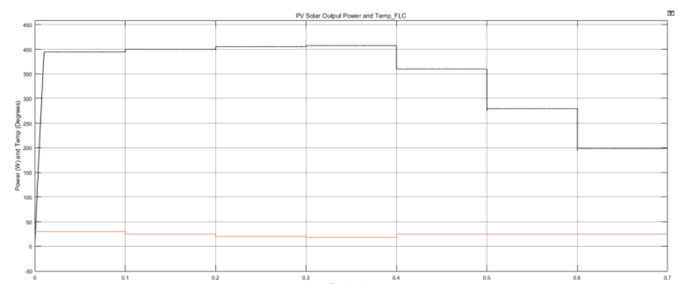

***Figure 17:** Output Power with varying Temperature for FLC MPPT*

Figure (s) 12 – 17 presents the voltage, current and power outputs all over varying irradiances and temperature for FLC MPPT. From table 5, and figures (s) 12 – 17, the voltage obtained at the output of the PV panel using FLC MPPT in figure 12 and 13 is 71.64 V, 72.49 V, 73.56 V and 74.04 V over 1000 W/m^2 and 30, 25, 20 and 18 degrees respectively, at 900, 700 and 500 W/m^2, the temperature remains constant at 25 degrees with the voltage at 72.54 V, 72.42 V and 72.16 V respectively. Figure (s) 14 and 15 presents the current output with varying irradiance and temperature. The Current constantly peaks at 5.51 A over at 1000 W/m^2 and 30, 25, 20 and 18 degrees. At 900, 700 and 500 W/m^2 and 25 degrees, the output current is 4.94 A, 3.86 A and 2.76 A respectively. Figure (s) 16 – 17 presents the output power of the PV panel at varying irradiances and temperatures. The power output had 394.7 W, 400.1 W, 405.3 W and 407.7 W at 1000 W/m^2 and 30, 25, 20 and 18 degrees respectively. At 900, 700 and 500 W/m^2 and 25 degrees, the output power is 360.1 W, 279.8 W and 199 W respectively.

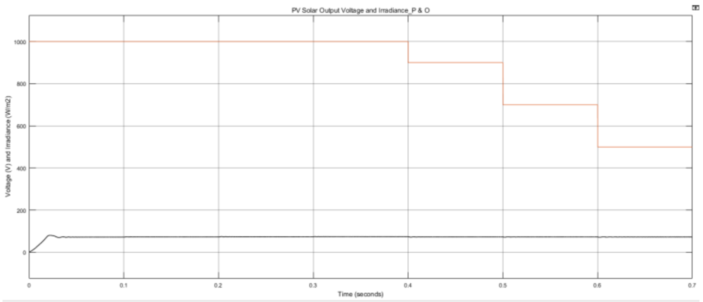

Figure 18: *Output Voltage with varying Irradiance for P and O MPPT*

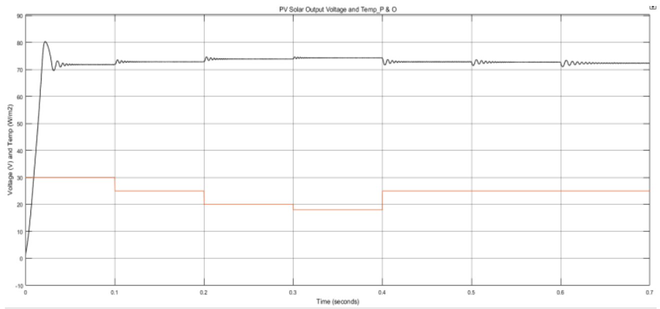

Figure 19: *Output Voltage with varying Temperature for P and O MPPT*

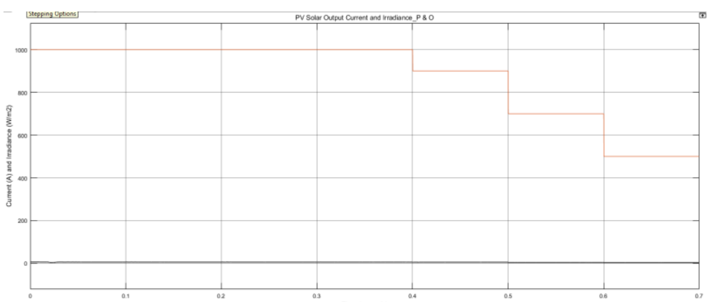

Figure 20: *Output Current with varying Irradiance for P and O MPPT*

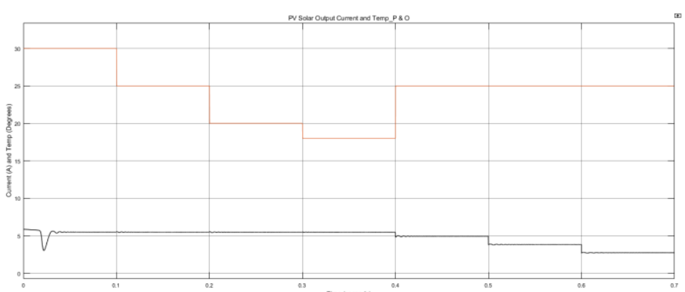

Figure 21: *Output Current with varying Temperature for P and O MPPT*

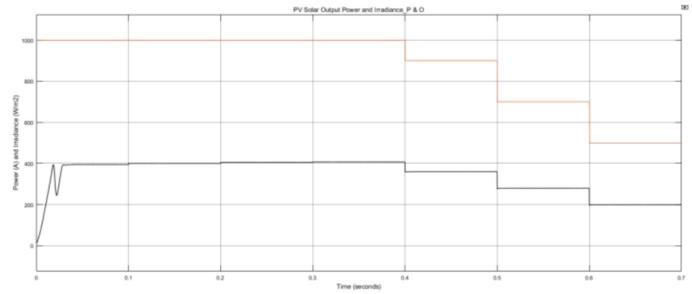

Figure 22: *Output Power with varying Irradiance for P and O MPPT*

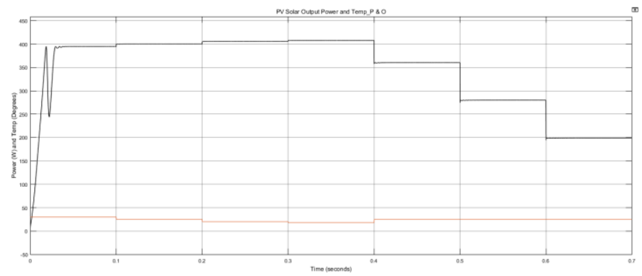

Figure 23: *Output Power with varying Temperature for P and O MPPT*

Figure 18 - 23 presents the PV Solar outputs for voltage, current and power over varying irradiances and temperature for P and O MPPT. From table 6, and figures (s) 18 – 23, the output voltage of the PV panel using P and O MPPT in figure 18 and 19 is 71.93 V, 73.05 V, 73.86 V and 74.56 V at 1000 W/m^2 and 30, 25, 20 and 18 degrees respectively, but at 900, 700 and 500 W/m^2 and 25 degrees, the voltage is at 72.95 V, 72.81 V and 72.35 V respectively. Figure 20 and 21 presents the current output with varying irradiance and temperature. The Current constantly peaks at 5.49 A at 1000 W/m^2 and 30, 25, 20 and 18 degrees. At 900, 700 and 500 W/m^2 and 25 degrees, the output current is 4.94 A, 3.84 A and 2.75 A respectively. Figure (s) 22 – 23 presents the output power of the PV panel at varying irradiances and temperatures. The power output had 394.8 W, 400.2 W, 405.4 W and 407.8 W at 1000 w/m^2 and 30, 25, 20 and 18 degrees respectively. At 900, 700 and 500 W/m^2 and 25 degrees, the output power is 360.2 W, 279.9 W and 199 W respectively. The summary of Figure (s) 18– 23 are as presented in Table 6

Table 6: *Voltage, Current and Power outputs under varying Irradiance and Temperature for P and O and FLC MPPT*

S/N	Voltage (V)		Current (A)		Power (W)		Irrad (W/m^2)	Temp (^{o}C)
	P&O	FLC	P&O	FLC	P&O	FLC		
1	71.93 73.05 73.86 74.56	71.64 72.49 73.56 74.04	5.49 5.49 5.49 5.49	5.51 5.52 5.51 5.51	394.8 400.2 405.4 407.8	394.7 400.1 405.3 407.7	1000	30 25 20 18
2	72.95	72.54	4.94	4.97	360.2	360.1	900	25
3	72.81	74.42	3.84	3.86	279.9	279.8	700	25
4	72.35	72.16	2.75	2.76	199.0	199.0	500	25

5.0 CONCLUSION

A Solar-PV SEPIC DC-DC converter for harvesting maximum power using different control techniques (perturb and Observe and fuzzy logic controller) has been simulated using varying solar irradiances and temperatures. The performance of the system presented ripples in the output voltage of the SEPIC converter at 1000 W/m^2 and 500 W/m^2 in the P and O MPPT controller with the maximum power of 400.8 W tracked at 1000 W/m^2 and 18 degrees while the FLC MPPT had no ripples or oscillations at the output voltage of the PV module with maximum tracked power at 400.7 W/m^2 at 18 degrees. The model shows that the FLC MPPT model eliminated the oscillations noticed in the P and O controller which makes it a better alternative to the P and O for MPPT in PV modules.

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