Mugla Journal of Science and Technology

COMPARISON OF FUZZY LOGIC AND PERTURB&OBSERVE CONTROL IN MAXIMUM POWER POINT TRACKING FOR PHOTOVOLTAIC SYSTEM USING BUCK CONVERTER

Okan Bingöl[1], *Burçin Özkaya* [2*], *Serdar Paçacı*[3]

[1,2]Electrical and Electronics Engineering Department, Suleyman Demirel University, 32000, Isparta, TURKEY
okanbingol@sdu.edu.tr, burcinozkaya@sdu.edu.tr
[3]Information Technologies Department, Suleyman Demirel University, 32000, Isparta, TURKEY
serdarpacaci@sdu.edu.tr

Received: 06.12.2016, Accepted: 18.04.2017 doi: 10.22531/muglajsci.273181
*Corresponding author

Abstract

Recently, interest in solar energy has been increasing due to the decrease of traditional energy sources and the increase of energy demand. Solar energy has been preferred because it is environment friendly, pollution-free, unlimited and cost-effective. Electricity from solar energy is obtained by using photovoltaic (PV) systems. The efficiency of photovoltaic systems changes depending on the changing environmental conditions. The two most important factors affecting the operation of photovoltaic systems are solar irradiance and temperature. Under fast changing environmental conditions, maximum power point tracking (MPPT) should be done in order to work at the maximum power point of PV system. Maximum power point tracking tracks the operating point corresponding to the maximum power point. Thus, maximum power can be obtained from PV system.

In this study, simulation of the maximum power point tracking was carried out using Perturb &Observe and Fuzzy Logic Control methods and the results of these methods were compared. According to the simulation results, it was seen that fuzzy logic control method was better than perturb&observe method for following the maximum power point (MPP).

Keywords: Photovoltaic system, Maximum power point tracking, Perturb&Observe method, Fuzzy logic.

DEĞİŞTİR&GÖZLEMLE VE BULANIK MANTIK YÖNTEMLERİ İLE FOTOVOLTAİK SİSTEMLERDE MAKSİMUM GÜÇ NOKTASI TAKİBİNİN KARŞILAŞTIRILMASI

Öz

Son zamanlarda, geleneksel enerji kaynaklarının azalması ve buna karşılık enerji talebinin artmasından dolayı güneş enerjisine olan ilgi artmaktadır. Güneş enerjisi, atmosfer dostu olması, kirliliğe yol açmaması, sınırsız olması ve masrafsız olması nedeniyle tercih edilmektedir. Güneş enerjisinden elektrik, fotovoltaik sistemler kullanılarak elde edilmektedir. Fotovoltaik sistemlerin verimi değişen ortam koşullarına bağlı olarak değişmektedir. Fotovoltaik sistemlerin çalışmasını etkileyen en önemli iki faktör, güneş ışınım miktarı ve sıcaklıktır. Değişen ortam koşulları altında PV sistemin maksimum verimde çalışmasını sağlamak için maksimum güç noktası takibi yapılmalıdır. Maksimum güç noktası takibi(MGNI), maksimum güç noktasına karşılık gelen çalışma noktasını izler ve PV sistemden maksimum güç elde edilmesini sağlar.

Bu çalışmada, Değiştir&Gözlemle ve Bulanık Mantık yöntemleri ile değişen ortam koşulları altında maksimum güç noktası takibi yapılmıştır ve iki yönteme ait sonuçlar karşılaştırılmıştır. Simülasyon sonuçlarına göre, bulanık mantık kontrol metodunun maksimum güç noktasını takip etmede değiştir & gözlemle metoduna göre daha iyi olduğu görülmüştür.

Anahtar Kelimeler: Fotovoltaik sistem, Maksimum güç noktası takibi, Değiştir & Gözlemle metodu, Bulanık mantık

1 Introduction

Today, interest in the use of renewable energy sources has increased because of the limited stock of the traditional energy sources and the increase in energy demand. Among renewable energy sources, solar energy has received a great attention because it appears to be one of the most promising renewable energy source with features which are low maintenance cost, no fuel cost and environment friendly[1-4].

A PV system has a non-linear I–V characteristic and output power depends on atmospheric conditions. In P-V characteristics, there is one point where power is maximum. This point is the maximum power point (MPP) and change rate of power is zero at this point. Since the MPP changes with temperature and solar irradiance, it is difficult for PV system to operate continuously at the maximum power point without changing the system parameters. Therefore, an efficient maximum power point tracking (MPPT) technique is necessary that is expected to track the MPP at changing environmental conditions. MPPT methods are generally applied to DC-DC converter circuits [1, 2, 4-7]. In PV systems, DC-DC converters are used to change the output voltage. Generally, they are connected between the PV system and the load [8].

From past to present, many different MPPT techniques have been used. These techniques can be divided into conventional techniques and stochastic techniques. Conventional MPPT techniques have proven the ability to track the maximum power point (MPP) under uniform solar irradiance. On the other hand, conventional techniques have failed to track the true MPP under fast changing environmental conditions. Therefore, stochastic based methods and artificial intelligence have been developed to obtain maximum power under fast changing environmental conditions[2].

In this study, the maximum power point was carried out using perturb&observe and fuzzy logic control methods for a DC-DC buck converter. A PV model was developed in simulation environment. Then, perturb&observe and fuzzy logic control which are maximum power point tracking methods was applied separately to the PV model for a buck converter. In perturb&observe method, oscillation around the maximum power point was occurred and this was reduced the efficiency of the PV panel. On the other hand, the energy conversion efficiency of the PV system was increased using the Fuzzy Logic Control. In Figure1, block diagram of maximum power point tracking in PV systems is shown.

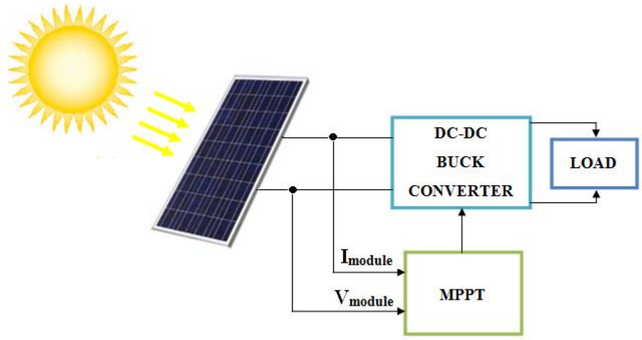


Figure1. Block diagram of maximum power point tracking in PV systems

2 Modeling of Photovoltaic Cell and Module

Photovoltaic systems are used to convert sunlight into electrical energy. The equivalent circuit of PV model which consists of a photo current (I_{PH}), a diode (D_1), a parallel resistor(R_{SH}) expressing a leakage current and a series resistor(R_S) describing an internal resistance to the current flow of the PV cell is shown in Figure 2 [9]-[13].

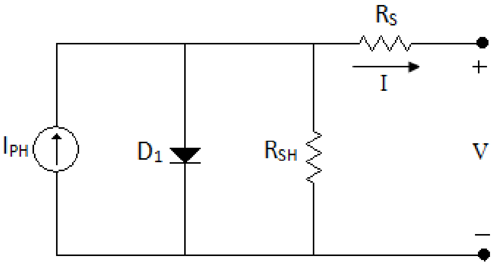


Figure2. The equivalent electrical circuit model of a PV cell

The output current of the PV cell obtained by Kirchhoff law is expressed as in equation (1).

$$I = I_{PH} - I_D - I_{SH} \qquad (1)$$

I_{PH} is generated by the incident light. I_D is the diode current which is proportional to the saturation current and is given in equation (2).

$$I_D = \mathrm{I_o}(\exp\left(\frac{\mathrm{q(V+IR_S)}}{\mathrm{kTAN_h}}\right) - 1) \qquad (2)$$

The I_{SH} represents the current passing through the parallel resistance (R_{SH}) and is given in equation (3).

$$I_{SH} = (\mathrm{V} + \mathrm{IR_S})/\mathrm{R_{SH}} \qquad (3)$$

The power obtained from a typical PV cell is less than 2W at 0.5V approximately. For this reason, PV cells must be connected in series-parallel configuration on module to increase the output power and voltage. A PV module has N_P parallel cell and N_S series cell. The equivalent circuit of PV module is shown in Figure 3. The output current of PV module is given in equation (4) [13].

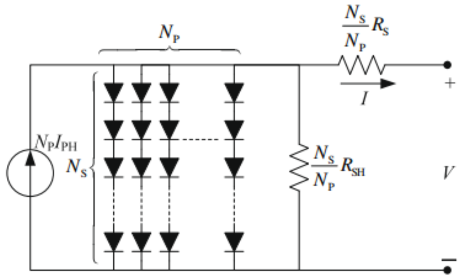


Figure3. The equivalent circuit of PV module

$$I = N_P I_{PH} - N_P I_o \left(e^{\frac{q(\frac{V}{N_S} + \frac{IR_S}{N_p})}{kTAN_h}} - 1 \right) - \frac{\frac{N_p}{N_s} V + IR_S}{R_{SH}} \qquad (4)$$

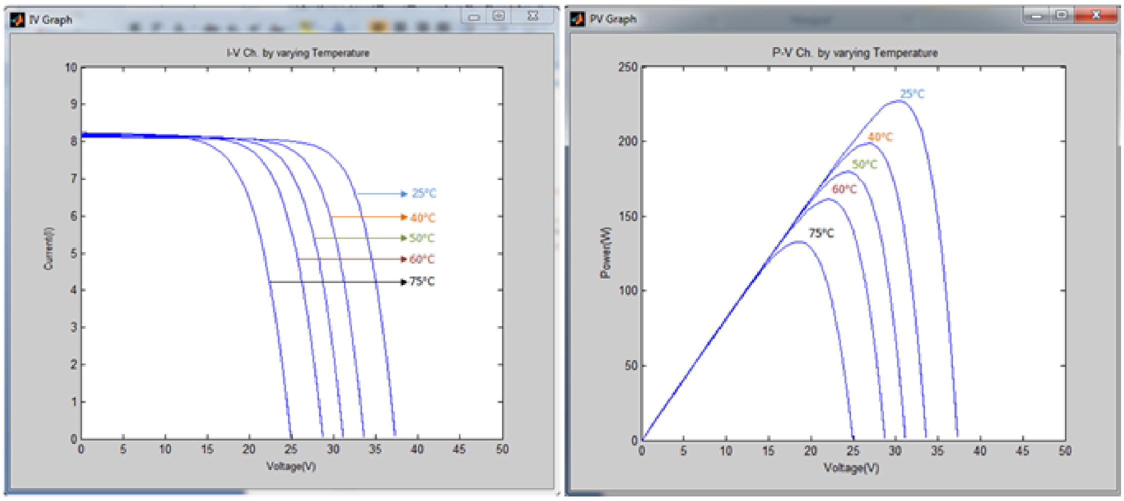
where
I_O is cell reverse saturation current;
T is the cell’s reference temperature;
k is a Boltzmann constant (1.381x10^{-23} J/K);
q is an electron charge (1.602x10^{-19} C);
A is an ideality factor of diode;
N_P is the number of PV cells connected in parallel;
N_S is the number of PV cells connected in series.

PV module parameters are given in Table 1.

Table1. PV module parameters [15]

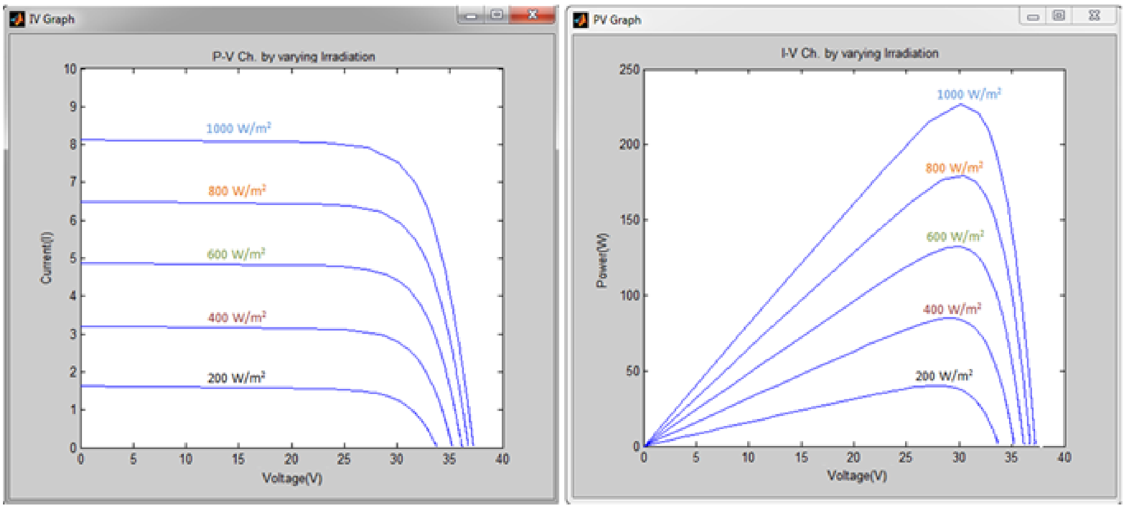
Parameter	Variable	Value
Maximum power	Pmax	225 W
Maximum power point voltage	Vmpp	29.7 V
Maximum power point current	Impp	7.59 A
Open circuit voltage	$\mathrm{V_{OC}}$	37.3 V
Short circuit current	$\mathrm{I_{SC}}$	8.13 A
Number of cell	$\mathrm{N_h}$	60

The I-V (current-voltage) and P-V (power-voltage) characteristics of the PV module vary depending on solar irradiance and temperature. When the solar irradiance is increased, the short-circuit current of the PV module increases and the maximum output power increases as well. When temperature is increased, the short-circuit current of the PV cell increases, but the maximum output power decreases. Since the increase in the output current is much less than the decrease in the voltage, the net power decreases at high temperatures. The I-V and P-V characteristics of PV module under varying temperature are shown in Figure 4 and The I-V and P-V characteristics of PV module under varying solar irradiance are shown in Figure 5.



(a) (b)

Figure4. The (a) I-V and (b) P-V characteristics of PV module under varying temperature

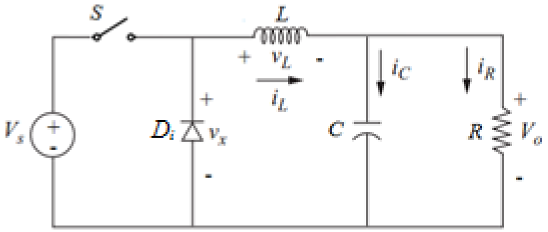


(a) (b)

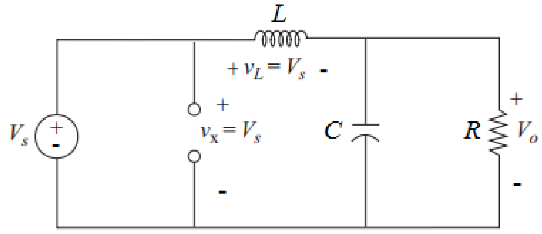
Figure5. (a) I-V and (b) P-V characteristics of PV module under varying solar irradiance

3 DC-DC Buck Converter

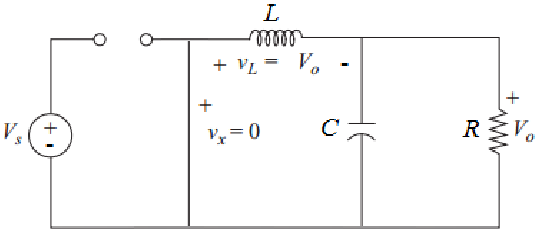
A buck converter (step-down converter) is a DC-DC power converter and its output voltage is lower than the input voltage. The circuit diagram of buck converter is shown in Figure 6(a) and it consists of a controlled switch *S*, a diode D_i a filter inductor *L*, a filter capacitor *C* and a load resistance *R*. In the circuit, V_O is output voltage and V_S is input voltage [8], [14], [16]. In Figure 6, (b) and (c) equivalent circuit for the switch closed and equivalent circuit for the switch open, respectively.



(a)



(b)



(c)

Figure6. (a) The circuit diagram of buck converter, (b) Equivalent circuit for the switch closed, (c) Equivalent circuit for the switch open

Analysis for determining the output voltage is to examine the inductor current and inductor voltage first for the switch closed and then for the switch open. The switch is closed between

$0<t<DT$ and is opened between $DT<t<T$ where T is period and D is duty ratio [16].

When the switch is closed in the buck converter circuit, the diode is reverse-biased. The voltage across the inductor is

$$v_L = V_S - V_o = L\frac{di_L}{dt} \tag{5}$$

The change in inductor current,

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_S - V_o}{L} \tag{6}$$

$$(\Delta i_L)_{closed} = \left(\frac{V_S - V_o}{L}\right) DT \tag{7}$$

When the switch is open, the diode becomes forward-biased to carry the inductor current. The voltage across the inductor is

$$v_L = -V_o = L\frac{di_L}{dt} \tag{8}$$

The change in inductor current,

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{-V_o}{L} \tag{9}$$

$$(\Delta i_L)_{open} = -\left(\frac{V_o}{L}\right)(1-D)T \tag{10}$$

Steady-state operation requires that the net change in inductor current over one period must be zero. The average inductor voltage is zero. This requires

$$(\Delta i_L)_{open} + (\Delta i_L)_{closed} = 0 \tag{11}$$

As a result, the relationship between the output voltage, the input voltage and the duty ratio (D) is given in Eq. (12).

$$V_o = V_s D \tag{12}$$

The parameters of the buck converter are given in Table 2.

Table2.The parameters of the buck converter

Parameter	Value
L	66 µH
C	75 µF
R	4.5 Ω

4 Perturb & Observe Method

The Perturb&Observe method is one of the widely used method to track the maximum power point in photovoltaic systems because its applicability is easy. In this method, MPPT is made by perturbing PV panel voltage or current. In this method, the operating voltage and current of the PV panel are measured periodically and the power is calculated according to voltage and current values. Then, power and voltage values are compared to the their previous values. The disruptive effect is made by directly affecting the duty ratio of the DC-DC converter, or by increasing the reference voltage, or by decreasing the reference voltage and the effect of output power of the PV system is observed. Since the dP/dV ratio at the maximum power point is equal to zero, this process continues until $dP/dV= 0$ [5, 17-19]. Figure 7 and Figure 8 show the perturb&observe method in the simulation environment and the flow chart of perturb&observe method, respectively.

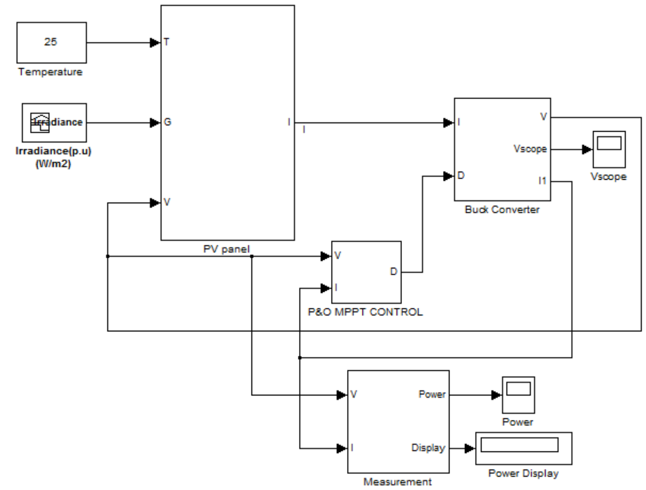


Figure7. The perturb&observe method in the simulation environment

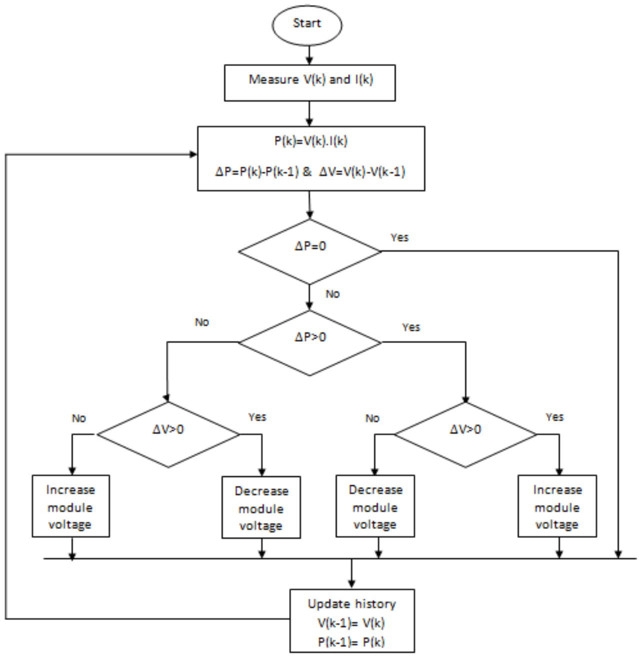


Figure8. The flow chart of perturb&observe method

5 Fuzzy Logic Control

Recently, the fuzzy logic control (FLC) has been used to eliminate the negative effects of conventional maximum power point tracking methods under fast changing environmental conditions. The application of fuzzy logic control is easy since it does not require knowledge of the exact model of the system [7, 8, 20].

In this study, there are two input variables and one output variable. The inputs of FLC are error *(e)* and change of error *(de)*, at sample time *k*, which are defined by (13) and (14), while the output of FLC is the duty cycle, *D*. The two input variables are described by:

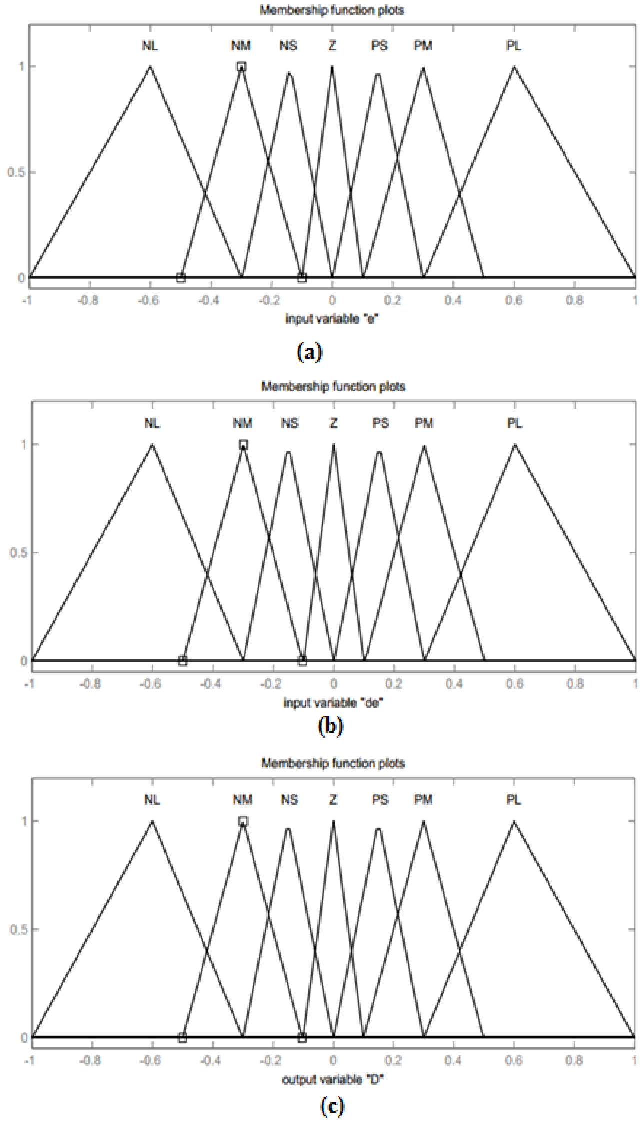
$$e(k) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \tag{13}$$

$$de(k) = e(k) - e(k-1) \tag{14}$$

In the equation (13), *P(k)* is the output power of the PV panel, *P(k-1)* is the previous output power of the PV panel, *V(k)* is the voltage of the PV panel and *V(k-1)* is the previous voltage of the PV panel. In Equation 14, *e(k)* represents the error value at present and *e(k-1)* represents the previous error value. The *e(k)* value indicates the location of the operating point where it is at MPP or left of the MPP or right of the MPP. The *de(k)* value indicates the direction of movement of the operating point [2, 6, 7].

Fuzzification

The linguistic variables used to create membership functions are NL (Negative Large), NM (Negative Medium), NS (Negative Small, Z (Zero), PL (Positive Large), PM (Positive Medium), and PS (Positive Small). Figure 9 shows the membership functions of the fuzzy logic controller.



(a)

(b)

(c)

Figure9. The membership functions (a) error (e), (b) change of error (de), (c) duty ratio(D)

Inference Method

Fuzzy inference was performed using Mamdani method and the fuzzy rules are shown in Table 3. The fuzzy rule table was created by trial and error and 49 rules gave better results in this system.

Table3. Fuzzy rules

e/de	**NL**	**NM**	**NS**	**Z**	**PS**	**PM**	**PL**
NL	PL	PL	PL	PL	NM	Z	Z
NM	PL	PL	PM	PM	PS	Z	Z
NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL
PS	Z	Z	NM	NS	NS	NM	NL
PM	Z	Z	NS	NM	NL	NL	NL
PL	Z	Z	NM	NL	NL	NL	NL

Defuzzification

In this system, the centre of gravity was used compute the output of this FLC which is the duty ratio. The equation of the center of gravity method is given in (15).

$$D = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)} \qquad (15)$$

The FLC in the simulation environment is shown in Figure 10.

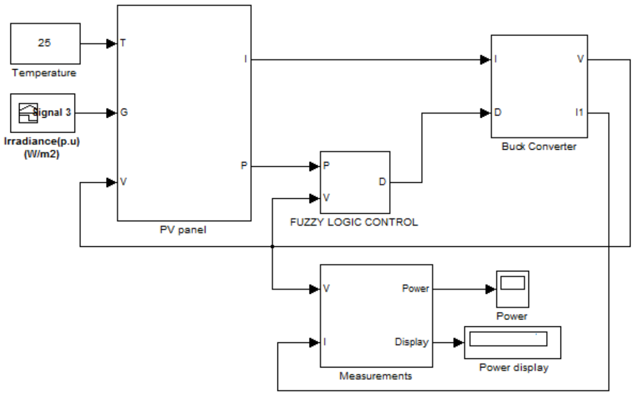


Figure10. The FLC in the simulation environment

6 Simulation Results

In this study, the output power of the PV system for the following test conditions was applied to Perturb&Observe and FLC method, separately.

- Constant temperature (25°C) and constant solar irradiance (1000W/m^2).
- Constant temperature (25°C) and varying solar irradiance values (200W/m^2, 400W/m^2, 600W/m^2, 800W/m^2 and 1000 W/m^2).

Figure 11 and 12 show the PV power curves under constant temperature and solar irradiance and PV power curves under constant temperature and varying solar radiation, respectively.

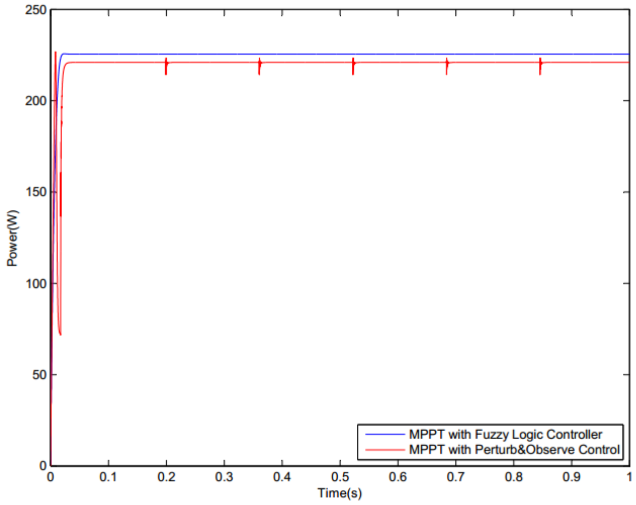


Figure11. PV power curves under constant temperature and solar irradiance

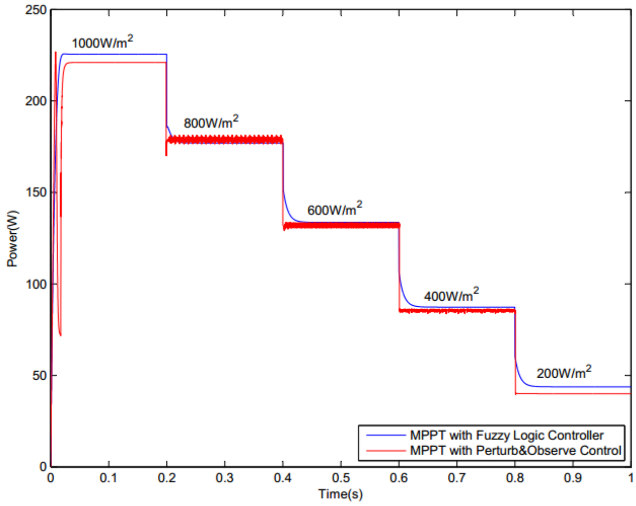


Figure12. PV power curves under constant temperature and varying solar radiation

When the Figure 11 is examined, under constant temperature and solar irradiance, the fuzzy logic control method has a shorter time response and less oscillation than perturb&observe method. When the Figure 12 is examined, under constant temperature and varying solar irradiance, the fuzzy logic control method follows the maximum power point more accurately than perturb&observe method at each step.

7 Conclusion

In this study, the maximum power point was carried out using perturb&observe and fuzzy logic control method for a buck converter. The aim of the work is to control the duty ratio of the buck converter in order to obtain maximum power from a PV module under fast changing environmental conditions. As a result, it is seen that the fuzzy logic control method is better than the perturb&observe method to track the maximum power point.

8 Acknowledgment

This article was presented as a paper on Innovations and Applications in Intelligent Systems - ASYU2016.

9 References

[1] Li, J. and Wang, H., “Maximum power point tracking of photovoltaic generation based on the fuzzy control method”, International Conference on Sustainable Power Generation and Supply, IEEE, 2009, pp. 1-6,

[2] Kamarzaman, N. A. and Tan, C. W., “A comprehensive review of maximum power point tracking algorithms for photovoltaic systems”, Renewable and Sustainable Energy Reviews, 2014, 585-598.

[3] Reisi, A. R., Moradi, M. H., and Jamasb, S., “Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review”, Renewable and Sustainable Energy Reviews, 2013, 433-443.

[4] Takun, P., Kaitwanidvilai, S., and Jettanasen, C., “Maximum power point tracking using fuzzy logic control for photovoltaic systems”, In Proceedings of International MultiConference of Engineers and Computer Scientists, Hongkong, 2011.

[5] Bounechba, H., Bouzid, A., Nabti, K., and Benalla, H., “Comparison of perturb & observe and fuzzy logic in maximum power point tracker for PV systems”, Energy Procedia, 2014, 677-684.

[6] Bouchafaa, F., Hamzaoui, I., and Hadjammar, A., “Fuzzy Logic Control for the tracking of maximum power point of a PV system”, Energy Procedia, 2011, 633-642.

[7] Cheikh, M. A., Larbes, C., Kebir, G. T., and Zerguerras, A., “Maximum power point tracking using a fuzzy logic control scheme”, Revue des energies Renouvelables, 2007, 387-395.

[8] Atallah, A. M., Abdelaziz, A. Y., ve Jumaah, R. S., “Implementation of perturb and observe MPPT of PV system with direct control method using buck and buck-boost converters”, Emerging Trends in Electrical, Electronics & Instrumentation Engineering: an International Journal (EEIEJ), 2014, 31-44.

[9] Chenni, R., Makhlouf, M., Kerbache, T., and Bouzid, A., “A detailed modeling method for photovoltaic cells”, Energy, 2007, 1724-1730.

[10] Villalva, M. G., Gazoli, J. R., and Ruppert Filho, E., “Modeling and circuit-based simulation of photovoltaic arrays”, In 2009 Brazilian Power Electronics Conference IEEE, 2009, 1244-1254.

[11] Villalva, M. G., Gazoli, J. R., and Ruppert Filho, E., “Comprehensive approach to modeling and simulation of photovoltaic arrays”, IEEE Transactions on power electronics, 2009, 1198-1208.

[12] Tsai, H. L., “Insolation-oriented model of photovoltaic module using Matlab/Simulink”, Solar energy, 2010, 1318-1326.

[13] Tsai, H. L., Tu, C. S., and Su, Y. J., “Development of generalized photovoltaic model using MATLAB/SIMULINK”, In Proceedings of the world congress on Engineering and computer science, Citeseer, 2008, 1-6.

[14] Ürgün, S., Erfidan, T., and Çoruh, N., “Design and Implementation of DC-DC Buck Converter”, EMO.

[15] https://www.solarworld-usa.com/~/media/ www/files/datasheets/sunmodule-plus/ sunmodule-solar-panel-225-mono-ds.pdf

[16] Hart, D. W., *Power electronics*, Tata McGraw-Hill Education, 2011.

[17] Rajesh, R., and Mabel, M. C., “A comprehensive review of photovoltaic systems”, Renewable and Sustainable Energy Reviews, 2015, 231-248.

[18] Bhatnagar, P., and Nema, R. K., “Maximum power point tracking control techniques: State-of-the-art in photovoltaic applications”, Renewable and Sustainable Energy Reviews, 2013, 224-241.

[19] Hua, C. and Shen, C., “Study of maximum power tracking techniques and control of DC/DC converters for photovoltaic power system”, In: Power Electronics Specialists Conference IEEE, 1998, 86-93.

[20] Algazar, M. M., EL-halim, H. A., and Salem, M. E. E. K. , “Maximum power point tracking using fuzzy logic control”, International Journal of Electrical Power & Energy Systems, 2012, 21-28.