

Research Article

DESIGN OF PERTURB AND OBSERVATION AND FUZZY LOGIC BASED MPPT CONTROLLERS OF PV ARRAY BY USING POSITIVE SUPER LIFT DC/DC BOOST CONVERTER**Ayşe KOCALMIŞ BİLHAN^{*1}**, **Serenay EMİKONEL²**¹ Nevşehir Hacı Bektaş Veli University, Faculty of Engineering, Department of Electrical Electronic Engineering, 50200, Nevşehir, Turkey² Nevşehir Hacı Bektaş Veli University, Faculty of Engineering, Department of Electrical Electronic Engineering, 50200, Nevşehir, Turkey

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Abstract: The electricity which is generated from the photovoltaic (PV) module needs a couple of requirements for utilizing. Firstly, the PV module should work in maximum power point, and secondly, it is needed a power conversion unit. To calculate to Maximum Power Point (MPP) of a PV module or array, solar radiation, ambient temperature, cloudiness ratio, and even wind speed have to be considered. In this paper, the duty cycle of the power conversion unit has been calculated by considering solar radiation. In these calculations, a conventional method which is perturb and observation (P&O), and another approach which is fuzzy logic control (FLC) were studied and compared by using MATLAB/Simulink.

Keywords: converter, fuzzy logic, perturb and observation, solar energy

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1. Introduction

With the increase in energy demand, electrical production from fossil-based energy sources brings with it many problems such as global warming, environmental pollution, air pollution, and health threats [1-4]. The fact that these energy sources which will be consumed away in the next century have led researchers to investigate renewable energy sources. In this respect, solar energy, wind energy, water energy, bioenergy and their applications have become more popular energy research topics [5-8]. Solar energy becomes one of the most popular energy sources of electrical power generation in renewable energy sources. However, today, the high initial installation costs of PV systems and the fact that only a small part of the rays from the sun can be converted into electrical energy is the most important problem of PV systems.

The DC output voltage which is directly obtained from the solar module is usually low. Therefore, it needs to be boosted a to higher DC voltage to meet the load or it can be converted to AC voltage. Also, because the energy production capacities of PV systems change at any time depending on temperature and radiation and it is desired to obtain high efficiency from PV systems, these systems must be operated at the maximum power point. Despite the changing environmental conditions, various MPPT algorithms such as perturb and observation (P&O), fuzzy logic, particle swarm optimization, etc. have been developed in the literature to keep the amount of energy produced from solar energy at a high level [9]. The perturb and observation algorithm (P&O) is a widely used method for tracking the maximum power point in both solar and wind energy, due to its simple feedback structure, and low cost and ease of implementation. Also, in recent years, fuzzy logic-based controllers became more popular for MPPT [10]. In many recent research, in order to increase the efficiency of PV systems, the fuzzy logic method has been integrated into the traditional P&O method [11].

In PV energy systems, various converter circuits such as buck, boost, or buck-boost are used to provide a constant voltage with the desired amplitude to the load or the inverter. The proposed system contains a control system, solar array, a DC/DC converter, and load. In Fig. 1, the output voltage of the PV module is regulated and increased by using DC/DC positive lift boost converter circuit [12, 13]. The super-lift technique is the popular method widely used for boosting the voltage. It can be obtained higher output voltage value than input voltage value by using a lift boost converter circuit. A solar array has two inputs irradiance (G) and temperature (T).

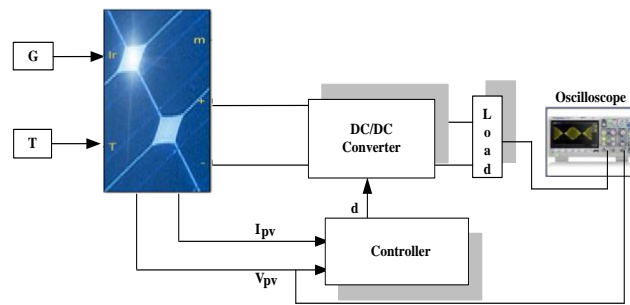


Figure 1. Block diagram of the whole system

The paper is arranged as follows: Section II covers the positive super lift DC/DC boost converter. In Section III, the studied system and both P&O and FLC-based MPPT techniques are detailed. The simulation results are presented and discussed in Section IV. Finally, conclusions are provided in section V.

2. Positive super lift boost converter

The positive super lift converters have very high efficiency among DC converters and it is aimed to raise the voltage without ripple by using these types of converters [14]. The output voltage increases in geometric progression stage-by-stage. This type of converter can be separated into two part such as the main circuit and the additional circuit. The circuit gain can be increased with each additional circuit. The proposed system consists of one switching component (S), 2 capacitors, one inductor, 2 fast recovery diodes, and R load. The equivalent circuit has been shown in Fig. 2.

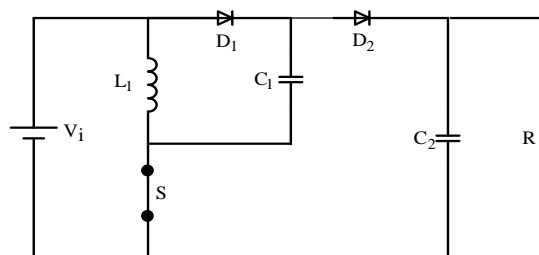


Figure 2. The positive super lift converter circuit

The switch-on (turn-on) & switch-off (turn-off) equivalent circuits are shown in Fig.3 (a) and (b), respectively.

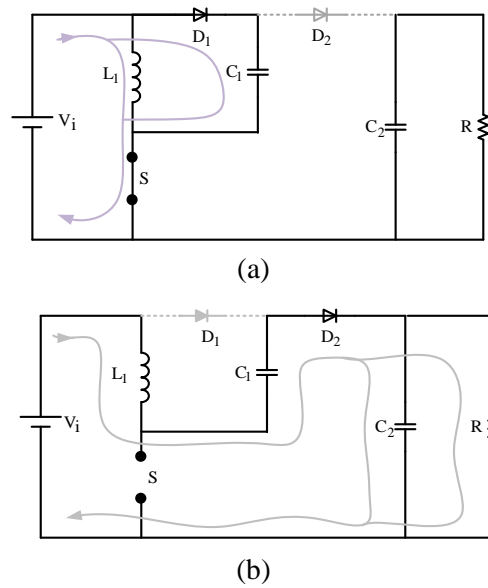


Figure 3. (a) Equivalent circuit diagram during the switch-on period; (b) Equivalent circuit diagram during the switch-off period.

The voltage across capacitor C_1 increase to V_i during the turn-on duration. The current flowing through the inductance L_1 increases with the current i_{L1} and the input voltage V_i during the conduction period dT . The input current i_i is equal to $i_{L1} + i_{C1}$. In the turn-off duration $((1-d)T)$, D_1 is reverse biased and turns off, and D_2 turns on. During the turn-off time of the switch (S), the input current is equal to i_{L1} ($i_{L1}=i_{C2}$). Therefore the ripple of the inductor current i_{L1} and output voltage (V_o) can be calculated as;

$$\Delta i_{L1} = \frac{V_i dT}{L_1} = \frac{V_o - 2V_i(1-d)T}{L_1} \tag{1}$$

$$V_o = \left(\frac{2-d}{1-d} \right) V_i \tag{2}$$

3. Mppt control methods

To increase the efficiency obtained from photovoltaic (PV) modules, these modules are required to operate at the maximum power point. Many theories such as perturb and observation (P&O), fuzzy logic (FL), pulsating conductivity (IC), and data mining are applied in the literature to determine the maximum power point by considering the radiation value. Figure 1 shows the block diagram of the system used during this study.

3.1. The perturb and observation algorithm (P&O)

Due to its ease of application, the perturb and observation algorithm (P&O) is one of the most preferred methods for Maximum Power Point Tracking (MPPT). The algorithm works iteratively until the maximum power point is determined [15, 16]. There are multiple possibilities for the P&O algorithm in the literature, but the classical flow chart of the P&O algorithm is given in Fig. 4.

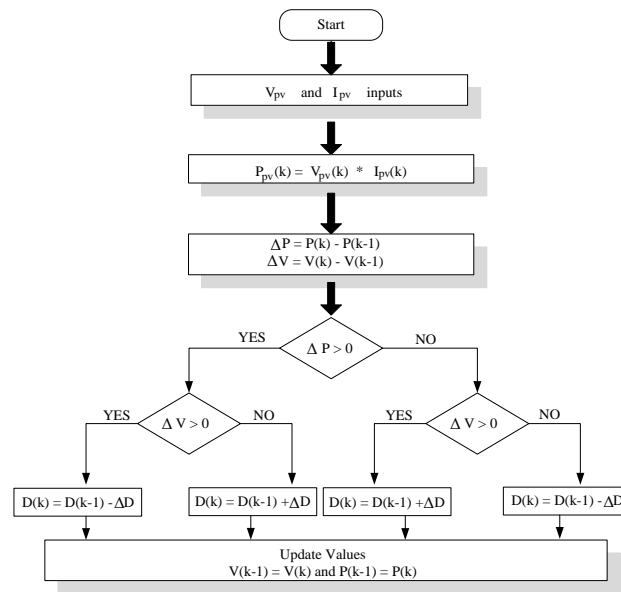


Figure 4. Flow Chart of P&O Algorithm

When the flow chart is examined, it can be observed that the voltage and current are selected as the initial value. The power of the PV module is calculated by using these values. During continuous operation, an instantaneous power value is calculated using the current (I) and voltage (V) information obtained with the help of sensors. By comparing this power value with the previous power value, the power change is calculated (ΔP). Also, when calculating the power change, the change in the voltage (ΔV) and the change in current (ΔI) are calculated. MPPT is performed with these calculated values. While making this determination; if the ratio is bigger than 0, the operating point is the left of the maximum power point, if the ratio of is lower than 0, the operation point is the right of the maximum power point, and if the ratio of is equal to 0, the operating point is at the maximum power point. This situation is illustrated in Fig. 5.

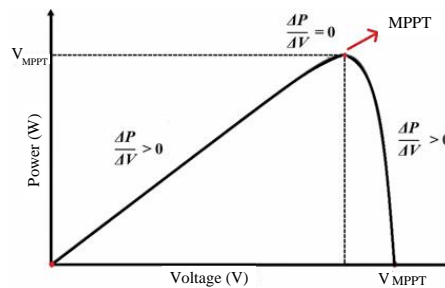


Figure 5. P&O Algorithm

The duty ratio of the positive super lift converter is controlled by the output of the P&O algorithm which has been shown in Fig. 6.

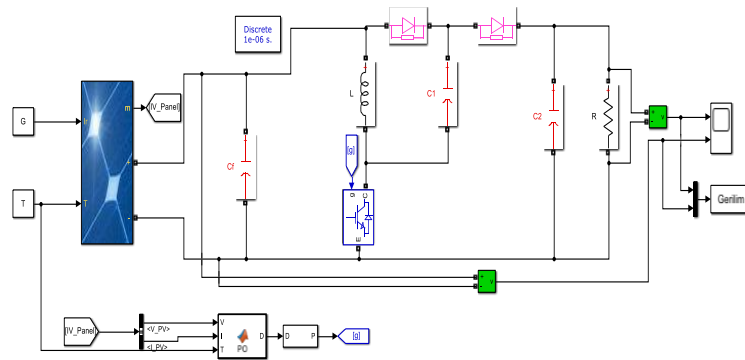


Figure 6. The MPPT tracking with P&O

3.2. The fuzzy logic control (FLC) algorithm

The use of fuzzy logic controllers in a PV system has significant increase year by year. In particular, FLC has become popular due to its superior ability to deal with the nonlinearity and uncertainties of any system and its easy design. Also, it has expanded its use in PV system applications because it is durable and does not require full knowledge of the system model compared to other control methods [17].

In this study, the power change was obtained by calculating the power with the current and voltage information coming from the PV panel and subtracting it from the previous power value, and the error (e) and error change (de) inputs produced by the panel, based on the voltage changes obtained by subtracting the current voltage from the previous voltage value, membership transforms it into linguistic variables with functions. The flow chart of FLC MPPT method has been shown in Fig. 7 [18,19].

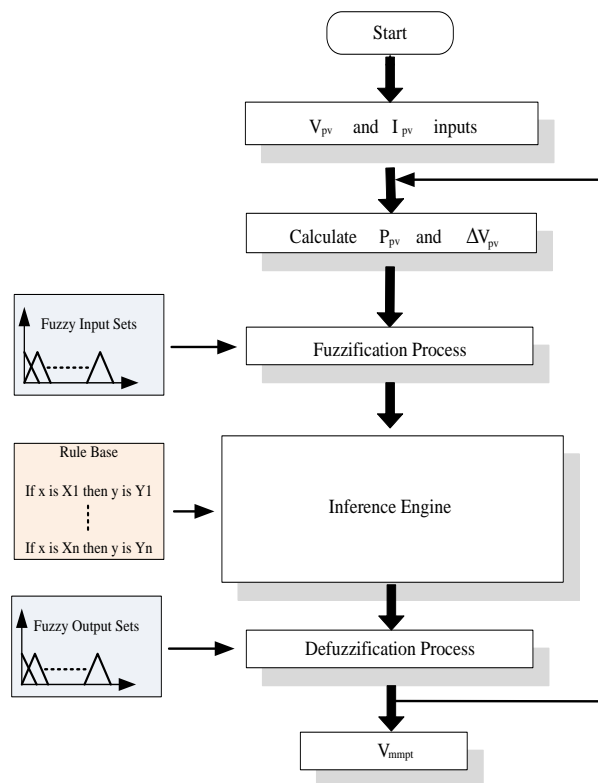


Figure 7. Flow chart of FLC Algorithm

To implement the MPPT algorithm, the fuzzy logic designer function from MATLAB has been used. The controller's inputs are error (e) and variations in error (de) are calculated by using Eq.(3) and (4) [20]:

$$e = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \tag{3}$$

$$de = e(k) - e(k-1) \tag{4}$$

In this study, Mamdani's approach has been used as the fuzzy inference technique. In this technique, it is based on the max-min conditions. Also, triangular curves as fuzzy membership functions (MFs) have been used. Five MFs are used for better accuracy; however, it takes more processing time and demands more memory. The linguistic variables which are shown in Fig. 8 are denoted as NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big). The developed 25 rules are given in Table I.

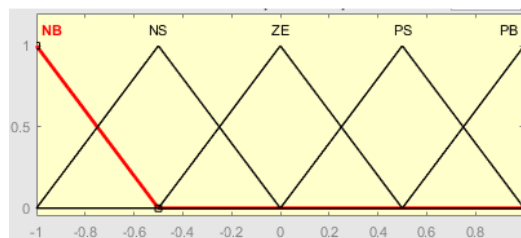


Figure 8. The FLC membership functions

Table 1. Fuzzy rules tables

e/de	NB	NS	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

The duty ratio of the converter is controlled by FLC. The maximum power point of solar array which is used fuzzy logic algorithm has been shown in Fig. 9.

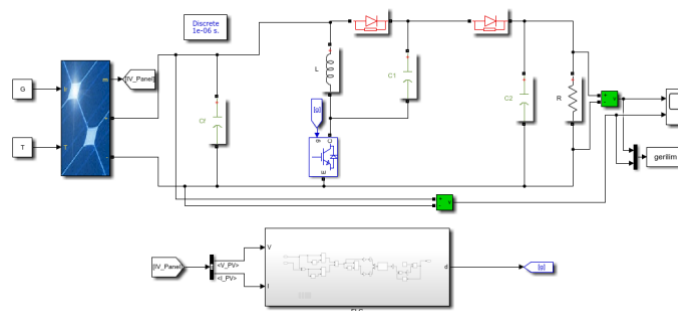


Figure 9. The MPPT tracking with FLC

4. Design and simulation results

The electrical characteristics of a PV module that have been used, given by the manufacture’s data sheet at the nominal temperature of 25°C and average solar spectrum at AM 1.5, are shown in Table II.

Table 2. Electrical Characteristics of LNSE-245P PV Module

Optimum Operating Voltage (V_{mp})	30V
Optimum Operating Current (I_{mp})	8.7A
Open Circuit Voltage (V_{oc})	37.1V
Short Circuit Current (I_{sc})	8.74A
Max. Power (P_{max})	245W

In the simulation, 5 series modules connecting 2 parallel strings have been used. In Fig. 10, Power-Voltage (P_{pv}/V_{pv}) and Current-Voltage (I_{pv}/V_{pv}) curves have been shown.

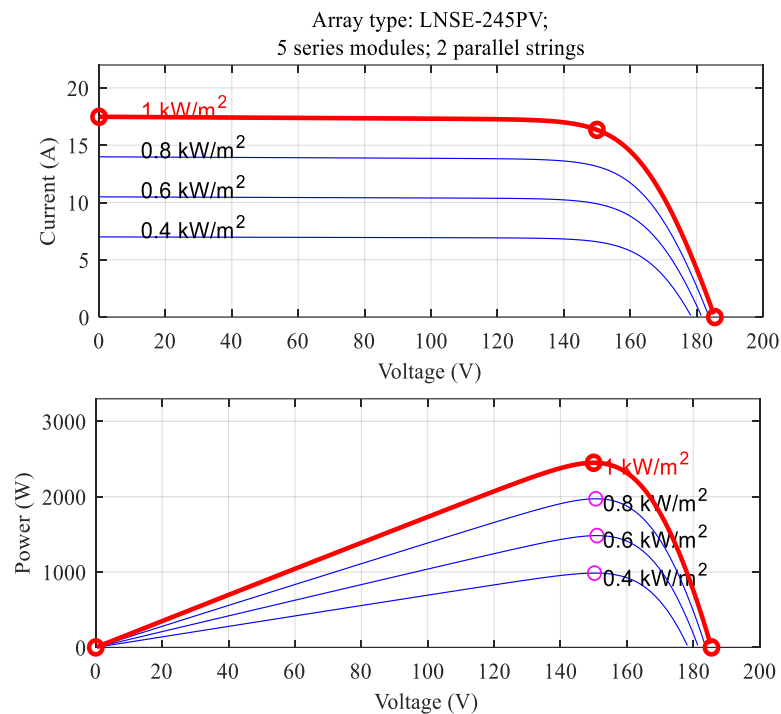


Figure 10. Characteristics of the PV array

Simulation results have been taken under various irradiance conditions such as 1000 W/m², 800 W/m², and 600 W/m². The parameters of the DC/DC converter are used as $C_f=4400\mu\text{F}$, $C_1=C_2=2200\mu\text{F}$, $L=10\text{mH}$, and $R=80\Omega$.

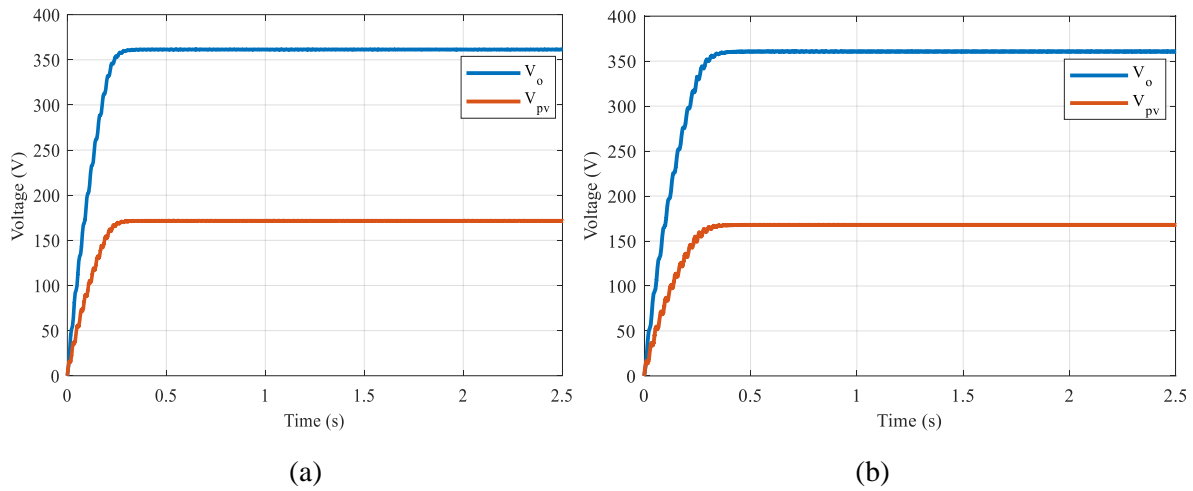


Figure 11. Simulation results for (a) P&O controller, (b) FLC for 1000 W/m² irradiance value

Fig. 11 (a) and (b) show the simulation results for both P&O and FL controllers with 1000 W/m² irradiance value, respectively. In the Figures, V_o represents the output voltage value of DC/DC converter and V_{pv} represents the output voltage value of PV array.

In Fig. 12, the simulation results were obtained with 800 W/m² irradiance value.

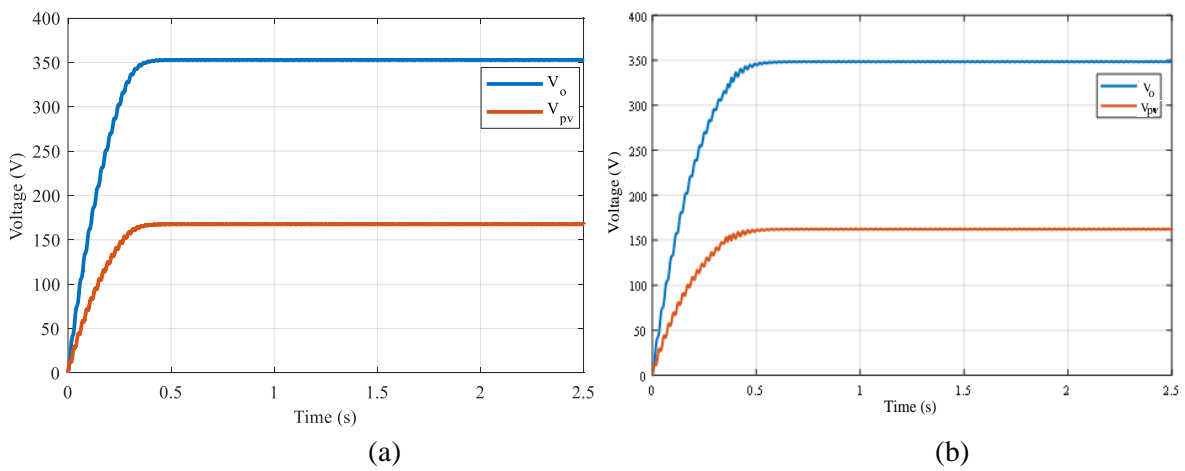


Figure 12. Simulation results for (a) P&O controller, (b) FLC for 800 W/m² irradiance value

The simulation results for 600 W/m² irradiance value for both P&O and FLC algorithms have been shown in Fig.13.

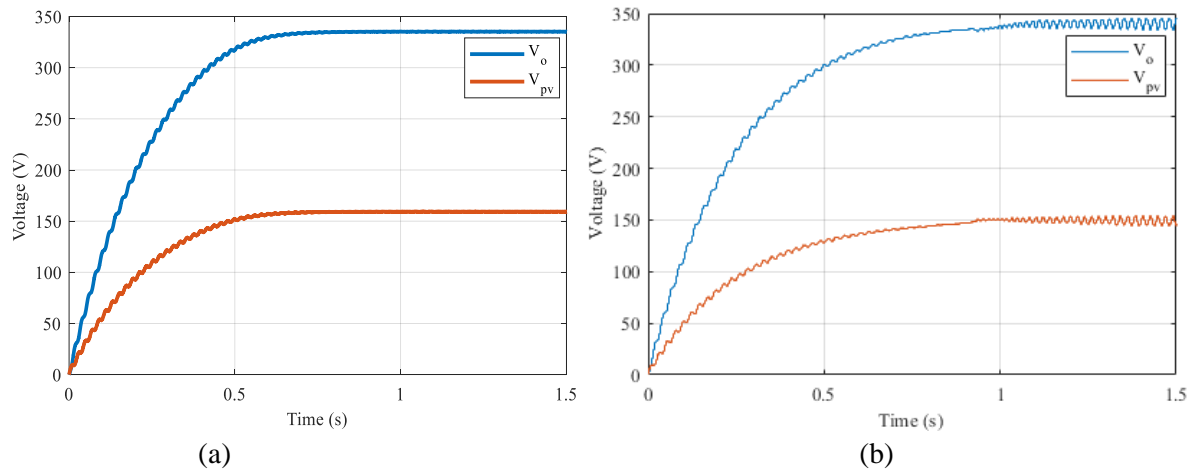


Figure 13. Simulation results for (a) P&O controller, (b) FLC for 600 W/m² irradiance value

In Fig. 14., the output voltage of PV, the output voltage of DC/DC converter with P&O controller, and the output voltage of DC/DC converter with FLC are given for 1000 W/m² irradiance value.

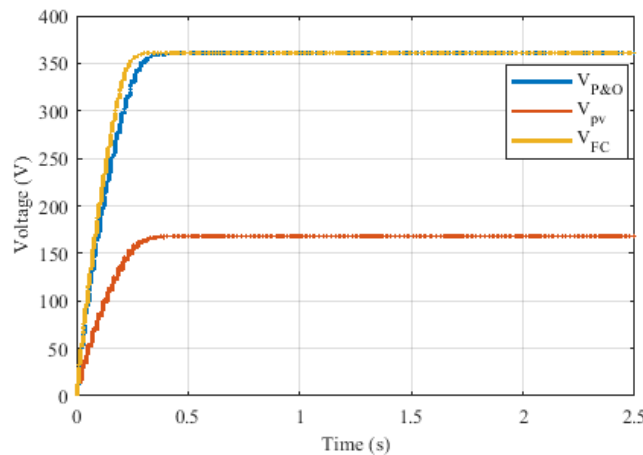


Figure 14. Simulation results of PV array and DC/DC converter for P&O controller and FL controller with 1000 W/m² irradiance value

5. Conclusion

The progressive decrease of fossil fuels and environmental concerns lead researchers to research other energy sources such as solar, wind, etc. In the literature, many various systems were designed to convert the irradiation coming from the sun into electrical energy. For this purpose, solar panels are highly preferred. In this work, the positive super lift converter and PV array has been modelled and designed by using MATLAB/Simulink simulation program. P&O and fuzzy logic methods were proposed and used to achieve to maximum power from photovoltaic array. It is aimed to achieve higher sensitivity and the fastest system responses to changes in irradiance and temperature levels by this work. Therefore, two different MPPT methods have been simulated and compared.

In the conventional DC/DC converter circuits, an increase of the voltage is carried out up to a certain limit, while in the positive super lift converter circuits, this situation enables higher values to be reached. For this reason, the positive super lift converter is used in this study. It is an advantageous situation for this circuit as it responds faster and reaches the desired maximum power point in a lower duty period. In this way, more energy can be transferred to the grid or higher voltage levels can be achieved for individual users.

As a result, it can be concluded that the FLC algorithm is very sensitive and consume significant computational resources. Also, it is seen that FLC based MPPT controller has better extraction of the maximum power from PV modules.

References

- [1] W. Nsengiyumva, S. G. Chen, L. Hu, X. Chen, "Recent advancements and challenges in Solar Tracking Systems (STS): A review", *Renewable and Sustainable Energy Reviews*, 81, 250-279, 2018.
- [2] Y. Zhu, J. Liu, X. Yang, "Design and performance analysis of a solar tracking system with a novel single-axis tracking structure to maximize energy collection", *Applied Energy*, 264 (114647), 2020.
- [3] F. Dinçer, "The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy", *Renewable and Sustainable Energy Reviews*, 15 (1), 713–720, 2011.
- [4] J. Yu, Y.M. Tang, K.Y. Chau, R.. Nazar, S. Ali, W. Iqbal, "Role of solar-based renewable energy in mitigating CO₂ emissions: Evidence from quantile-on-quantile estimation", *Renewable Energy*, 182, 216-226, 2022.
- [5] A. Rahman, O. Farrok, M.M. Haque, "Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic", *Renewable and Sustainable Energy Reviews*, 161, 2022.
- [6] Z. Gumus, M. Demirtas, "Comparison of the algorithms used in maximum power point tracking in photovoltaic systems under partial shading conditions", *Journal of Polytechnic*, 24(3), 853-865, 2021.
- [7] S.Adak, H.Cangi, B.Eid and A.S.Yilmaz, "Developed analytical expression for current harmonic distortion of the PV system's inverter in relation to the solar irradiance and temperature", *Electric. Eng.*, 1031, 103 (1), 697-704, Oct. 2020.
- [8] C. Haydaroglu, B. Gumus, "Examination of web-based pvgis and sunny design web photovoltaic system simulation programs and assessment of reliability of the results", *Journal of Engineering and Technology*, 32-38, 2017.
- [9] R.. Das, K.M. Rahman, "Effect of response time and starting point of duty cycle in maximum power point tracking operation of solar panel using PO algorithm," *2016 9th International Conference on Electrical and Computer Engineering (ICECE)*, 357-360, 2016.
- [10] L. P. N. Jyothy and M. R. Sindhu, "An artificial neural network based mppt algorithm for solar pv system," in *2018 4th International Conference on Electrical Energy Systems (ICEES)*, 375–380, 2018.

- [11] M. Zerouali, S. Zouirech, A.E. Ougli, B. Tidhaf, H. Zrouri, "Improvement of conventional mppt techniques P&O and INC by integration of fuzzy logic," *2019 7th International Renewable and Sustainable Energy Conference (IRSEC)*, 1-6, 2019.
- [12] A.S. Tekade, R. Juneja, M. Kurwale, P. Debre, "Design of positive output super-lift Luo boost converter for solar inverter," *2016 International Conference on Energy Efficient Technologies for Sustainability (ICEETS)*, 153-156, 2016.
- [13] N. Silpa, J. Chitra, "An improved Luo converter for high voltage applications," *International Journal of Emerging Technology and Advanced Engineering*, 4(5), May 2014.
- [14] S.S. Dheeban, N.B. Muthu Selvan, L. Krishnaveni, "Performance improvement of Photo-Voltaic panels by Super-Lift Luo converter in standalone application", *Materials Today: Proceedings*, 37, 1163-1171, 2021.
- [15] C.H. Basha, C. Rani, "Different conventional and soft computing mppt techniques for solar pv systems with high step-up boost converters: a comprehensive analysis", *Energies*, 13(1), 371, 2020.
- [16] M.A. Vildirim, M. Nowak-Ocłoń, "Maximum power point tracking algorithm under time-varying solar irradiation", *Energies*, 13, 6722, 2020.
- [17] M. İ. Ort, "PV sistemlerde güneşi takip eden sistem tasarımı ve mppt kontrolü ile enerjinin yuke maksimum olarak aktarılması", *İstanbul Technical Uni., Fen Bilimleri Enst., MSc*, s. 52, Istanbul, 2016.
- [18] T. L. Kottas, S. B. Yiannis, D. K. Athanassios "New maximum power point tracker for PV arrays using fuzzy controller in close cooperation with fuzzy cognitive networks" *IEEE Transactions on Energy Conversion*, 21(3), 793-803, 2016.
- [19] M.A.A. Mohd Zainuri, M.M. Mohd Radzi, A.C. Soh, N. Rahim, "Adaptive P&O-fuzzy control mppt for pv boost dc/dc converter." *2012 IEEE Int. Conf. on Power and Energy*, pp. 524-529, 2012.
- [20] D. Haji, N. Genc, "Fuzzy and P&O Based MPPT Controllers under Different Conditions", *7th Int. Conf. on Renewable Energy Research and Applications (ICRERA)*, 14-17 Oct., 649-655, 2018.