International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 13, No. 4, December 2022, pp. 2432~2439
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v13.i4.pp2432-2439

An efficient MPPT based photovoltaic control model considering environmental parameters

Hossein Zeynal[1], Zuhaina Zakaria[2], Bahareh Pourveis[1]
[1]Department of Electrical and Computer Engineering, Buein Zahra Technical University, Buein Zahra, Iran
[2]Power System Planning and Operations Research Group (PoSPO), School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia

Article Info

Article history:

Received Mar 10, 2022
Revised Aug 15, 2022
Accepted Aug 30, 2022

Keywords:

Incremental conductance method
MATLAB/Simulink
Maximum power point tracking
Photovoltaic system
Radiation and temperature loop

ABSTRACT

This paper presents an efficient way for maximum power point tracking (MPPT) in photovoltaic (PV) system. MPPT is one of the crucial issues when working with PV system as well as the grid. To gain the highest efficiency for PV system the maximum power has to be generated continuously. The proposed MPPT method allows PV system to have real-time maximum power all the time with high accuracy and less fluctuations. As of the developed PV system control model presented in this work, an efficient MPP can be realized taking into account changes in irradiation level and temperature which are the thorny issues for other contender algorithms. To validate the model, results obtained from the proposed algorithm is compared with incremental conductance (IC) which is a universally accepted MPPT method. The simulation results exhibited that the developed model outperforms IC method in terms of accuracy of MPP and stability of the output in presence of variable irradiations and temperature. Based on the simulation results, the proposed algorithm is suitable for practical and real-time applications with promising results in terms of solution accuracy and execution. The model is implemented in MATLAB/Simulink.

Corresponding Author:

Zuhaina Zakaria
School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA
40450 Shah Alam, Selangor, Malaysia
Email: zyhainaz@uitm.edu.my

1. INTRODUCTION

One of the ways to utilize the solar energy source is to convert it into a new and usable form. That is photovoltaic system containing several components such as converters, solar arrays, and batteries [1]. It mainly works in two modes of grid-connected otherwise off the grid. Designing a photovoltaic system entail selecting the photovoltaic module, the number of modules required, the way that modules can be arranged to form the photovoltaic array, sizing the converter capacity, after that addressing the storage system specifications if required and specifying all other components of the system [2]. Therefore, to begin with the design of photovoltaic system one has to decide on network-independent and network-connected photovoltaic systems [3]. Factors such as the practical application of photovoltaic systems, environmental and climatic conditions, spatial and financial constraints can determine the design criteria.

The characteristics of photovoltaic systems require that in the design stages, the influence of various factors such as weather conditions, environmental pollution, solar radiation, the characteristics of electrical energy consumers, the efficiency of photovoltaic system components and their other characteristics. Therefore, to increase the utilization of these solar energy sources, we must use the maximum power point tracking under weather conditions [4]. These methods are known as maximum power point tracking or maximum power point tracking (MPPT). Referring to previous research, we find that the MPPT method has different functions in two separate categories. In the first category, which is affected by dynamic conditions, it has an effective performance, and in the other category, it is less compatible under environmental conditions. Therefore, in this paper, we try to provide valid models of simulation of integrated solar systems with microgrid, among the best classical method MPPT, which is the method of incremental conductivity under conditions of significant changes in environmental factors [5].

The MPPT control technique works by calculating power and voltage changes at any given time and achieving an instantaneous slope value. If the slope is positive, the operating point is found to be on the left-hand side of the maximum power point [5], [6]. Therefore, increasing the array voltage by changing the pulse width modulation (PWM) control signal is made to the extent that one can achieve a zero ratio of power and voltage changes. If the slope is negative, then, the operating point is located on the right-hand side of the maximum power point and the voltage reduction command must be performed to the point where it reaches the maximum power point of the MPPT [5]–[7].

Maximum power point tracking (MPPT) of photovoltaic arrays is paramount important issue in photovoltaic (PV) systems [6], [7]. Different MPPT methods are presented to date where efforts have been made to address the relevant disadvantages of PV modules and ways to prevail them. The MPPT methods can be divided into 19 models which are capable of tracking maximum power points in a specific way. Among them, few methods are more prevailing and found further universal acceptance [8].

The perturbation and observation (P&O) algorithm is one of the favorite method in MPPT by which increasing or decreasing the voltage or solar array terminal current at regular intervals and then comparison of current PV output power with pervious sampling output power, the MPPT can be realized [9]–[11]. The simplicity of this method made it quite suitable for wide application especially in new control systems [5]. However, the large fluctuations around the operating point in the steady state is a challenge when using this method in practice [12], [13], that is resulting in excessive energy loss [14]. To overcome the limitations of P&O, a fresh method so-called incremental conductance (IC) emerged. The IC method is performed by conducting a proportional comparison between the rate of increment between power and voltage (or current) for each subsequent two samples, so that the MPP can be found. As opposed to P&O method, the IC is more complex to be implemented. As an advantage, IC offers the ability to specify the proportional "distance" to reach the maximum power point (MPP). Moreover, this algorithm exhibited a precise MPP tracking capability in weather conditions with a number of fluctuations [14]. Nevertheless, the IC algorithm suffers from its instability due to the use of derivation operations in the body of algorithm [15].

The constant voltage (CV) algorithm as a simple alternative introduced to find MPP by considering a constant reference voltage and disregarding irradiation and temperature as insignificant parameters [5]. However, the proper application of this algorithm requires data gathering of the place the photovoltaic system is installed as well as voltage referencing which is a hinder. The CV can outperform the P&O and IC as long as the radiation is small [9], [16], that is not very real-world case.

Other techniques reported in this context including a MPPT approach based on temperature measurements which later discovered that this algorithm is not as efficient as the P&O and IC methods [9], [17], besides this method is data-dependent of the underworking PV system. Similarly, for open voltage method [9], because of interruption during the open voltage measurement, the energy loss becomes significant and therefore impractical for large cases. The feedback voltage (current) method [18], [19] which is based on comparison between PV voltage with constant voltage and duty cycle adjustment (D) of converter allowed the performance of the PV array resting nearby the MPP. This method is less complicated and make use of a single feedback loop which ends up an economical technique. However, it neglects the radiation level and temperature changes which is a defect for this method [15].

The fuzzy logic control-based methods is one of the technique used in MPP applications and recently it found great deal of attention due to the advances in microcontrollers and substantial reduction in implementation costs [20]. One of the major advantages of this method is on the controller model requiring no exact mathematical representations, which on the other hand results in minimum fluctuation in vicinity of MPP point. But there is no warranty on reliable operation when radiation level changes. Nonetheless, the efficiency of the fuzzy logic control method is related to the designer's experience and knowledge which limits a broad application of this method [21].

Furthermore, the neural network (NN) method is among those evolving techniques that smartly search for MPP in PV arrays [22], [23]. The NN method requires comprehensive training process and all data relevant to each individual PV array which varies by weather conditions and geographical location [24]. Thus the training process has to be repeated every time which is unfavorable.

2. MAXIMUM POWER POINT TRACKING

There are several models for solar cells, the most common of which is the two-diode model. The output power of PV array is always affected by environmental factors and represents discontinuous values. By installing MPPT in the PV system, one can always achieve the maximum output power of the system continuously. Incremental conductance method is used because of its easy and practical simulation and is also more compatible with environmental factors than other existing methods. The main technique of this method is based on the inclination of the array diagram in terms of voltage at the maximum power point [25], [26].

3. PROPOSED ALGORITHM

In most researchers reported to date, solar systems both in static and dynamic conditions, take up solar arrays with constant input of radiation level and the temperature. Since in practice the radiation levels are fluctuating throughout a day, as a result the input of the solar array is always under different temperature and radiation conditions. In another words, there is no fixed temperature and radiation for solar system. As a part of contribution, it is paramount important to study the solar system with dynamic changes in radiation levels.

It is pertinent to mention that as the radiation increases, the short-circuit current also spikes and the maximum power point shifts to high voltages. The maximum power amount is also updated. In the radiation loop, in addition to controlling the maximum power point, damage to the system against the negative impedance characteristic is somehow prevented.

Many maximum power tracking methods are not capable of adapting their controller following changes in the input parameters of solar system. Therefore, it is necessary to refine the controller parameters for the new inlet temperature. Such methods are dependent on the solar array, and methods that can track the very changes of the solar array input are independent of the solar array.

The temperature loop initiates when the radiation changes are small. Due to the fact that the characteristic of the solar array performance is a function of temperature variations, the maximum power point will be also renewed. As the temperature increases, the maximum power point shifts to the voltages with lower values. As a result, the maximum power value decreases slightly. Therefore, using this temperature loop allows following this point.

In short, the incremental conductance MPPT method is further rebuilt in this work so as to its accuracy is improved by adding few items. The two-part incremental conductance algorithm, the radiation and the temperature loops are incorporated in the solution. The proposed algorithm can then cater the maximum power point in more realistic fashion via the simulation.

4. SIMULATION RESULTS

To demonstrate a real-world solar cell modeling, and according to the datasheet values, the MSX-60 solar panel model is simulated at this work as shown in Table 1 and Figure 1. To model a solar array and all the practical associated parameters, as in Table 1, showed thee values of the simulation parameters based on the available datasheet.

Table 1. MSX-60 array parameters for standard test conditions

Item	Amount
Maximum Power	200 W
Open circuit Voltage	21 V
Short Circuit Current	3.75 A
Voltage in Maximum Power	17.1 V
Current in Maximum Power	3.5 A
Short circuit current temperature coefficient	0.0032 A/K
Open circuit voltage coefficient	-0.00123 V/K
The number of cells in each array	54
Number of Parallel Modules (NPPs)	125
Number of series modules (NSS)	4
Series Resistor	0.221 Ω
Parallel Resistor	414.405 Ω

In Figure 2, simulation model represents solar arrays, converters, controllers and monitoring devices are displayed. As a part of simulation, the solar array model that encompasses input parameters of radiation level and temperature value. The boost converter connected to the solar array is used to raise the voltage level and stabilize it at a reference voltage. This converter boosts the 300 Vdc of a photovoltaic array at a switching frequency of 5 kHz to a voltage level of 500 Vdc. The MPPT block is located at the bottom right. After the converter, a buffer capacitor is added which allows increasing the output power to the required level. Further, one can witness that the inductor similarly entered into the model to represent the effects of output filters, transformers and source impedance, which, on the other hand, is used to remove the harmonics produced by the inverter. Finally, as the model shows, the PV system with MPPT control is connected to the power grid. In Figure 2, simulations model which represents solar arrays, converters, controllers and monitoring.

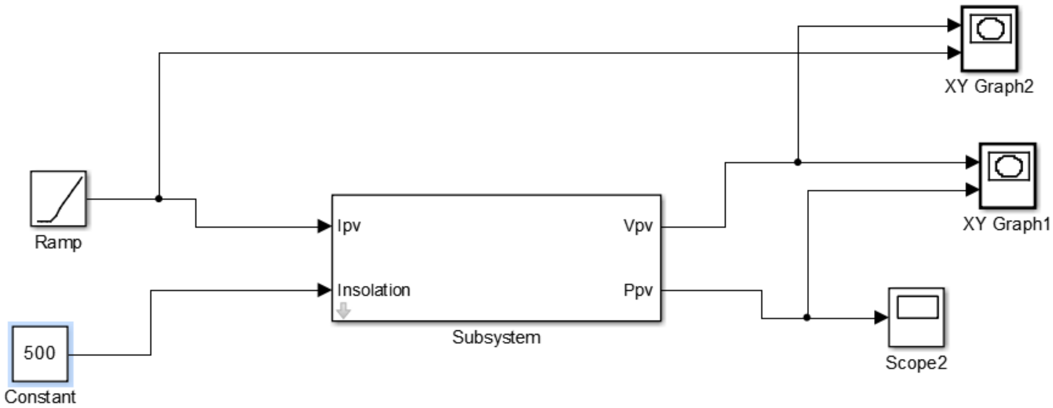


Figure 1. Solar cell simulation

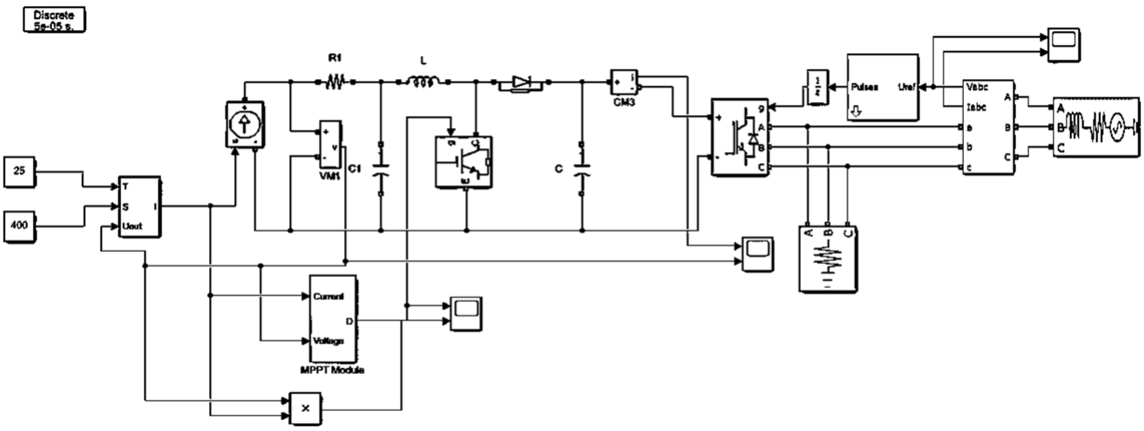


Figure 2. Developed model

When the proposed system circuit, as in Figure 3, is made available, the input radiation level can be set for 21000 W/m whereas the temperature maintained at 25 °C. After that, both the incremental conductance method of MPPT and the proposed method are simulated and outcomes will be studied in detail. Following the build-up process of voltage at the array, which takes 0.5 second, Figure 4 shows the output power of array in two methods of incremental conductance and the proposed method. As can be seen in Figure 4, the performance of the two model is almost the same, but the proposed method has reached the maximum power in a shorter time and has reached the value of about 10 kW sooner. The blue color indicates the incremental conductance and the purple color addresses the proposed MPPT method).

In order to accurately evaluate the performance of the MPPT based proposed method, following studies can be cast. For rapid changes in environmental conditions, the variable input radiation level of the array is considered as presented in Figure 5 exhibiting a number of fluctuations while the temperature is being kept constant. By incorporating radiation pattern shown in Figure 5, one can see the resultant PV output power of the incremental conductance method as well as the proposed MPPT method for variable radiation at fixed temperature.

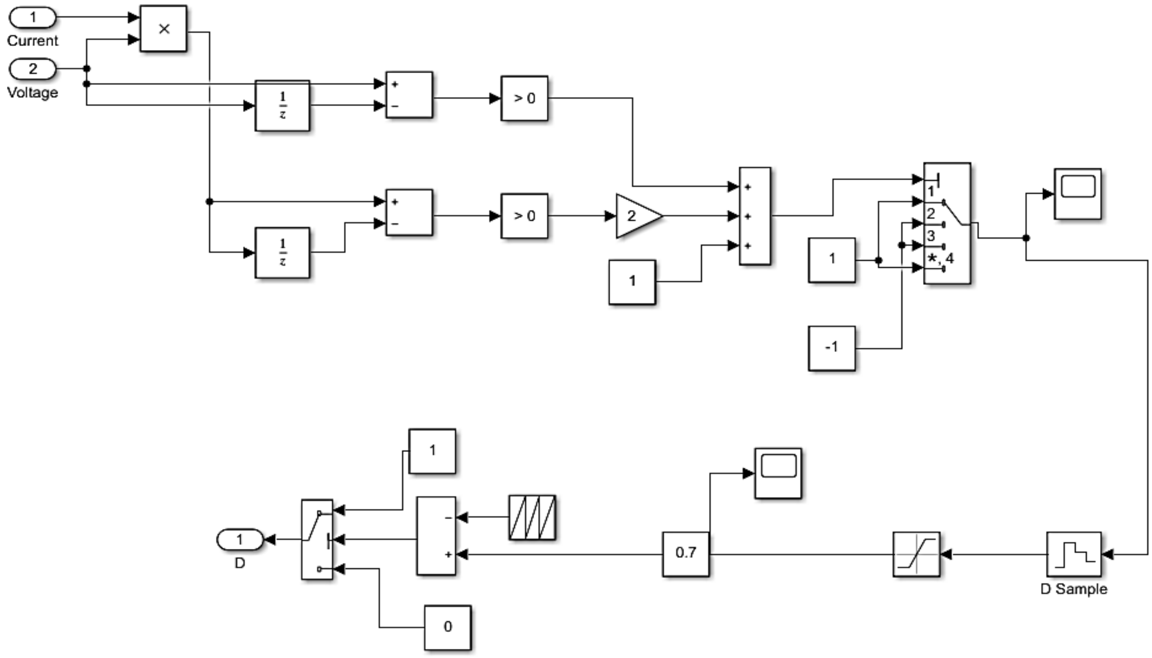


Figure 3. Proposed control system

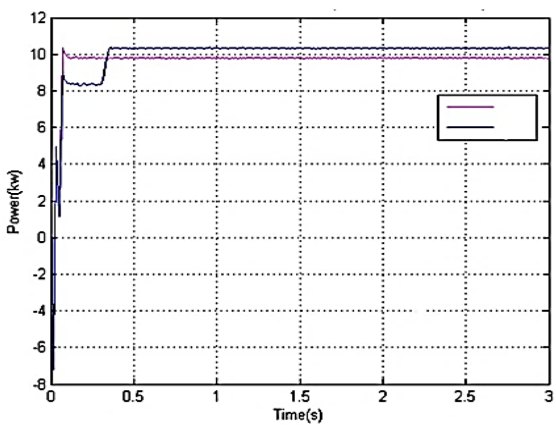


Figure 4. Output power representation of PV system

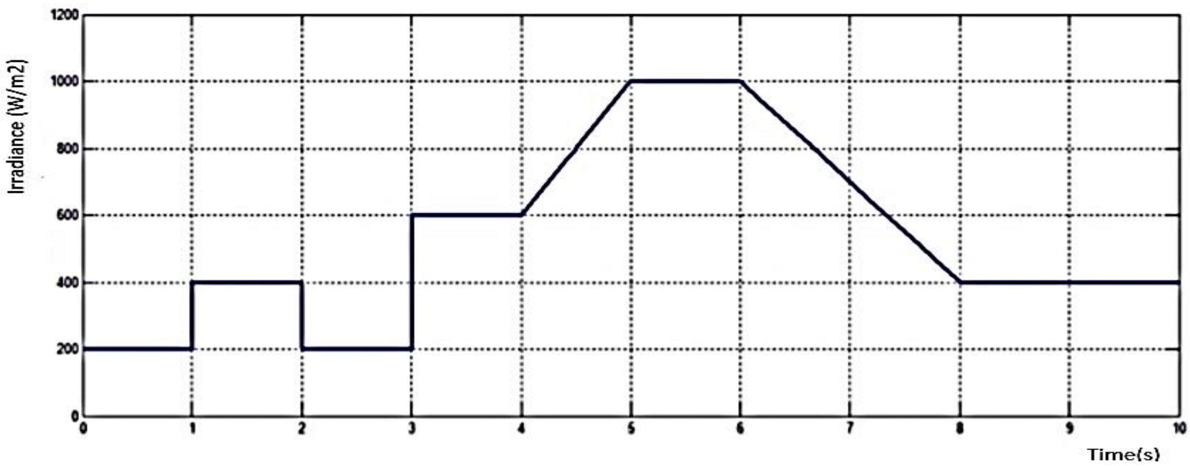


Figure 5. Radiation level changes over time

The simulation results in Figure 6, can reveal that the proposed method outperforms the incremental conductance method in presence of a changeable radiation input which ought to challenge the maximum power output tracking. As Figure 6 shows at the constant temperature and variable radiation level, the proposed method reaches the first MPP point earlier than the incremental conductance method. Further, to examine the performance of the proposed method, the radiation level shall be kept fixed at 1000 W/m2 whereas the temperature of the solar array is no longer constant and it shows changes as displayed in Figure 7.

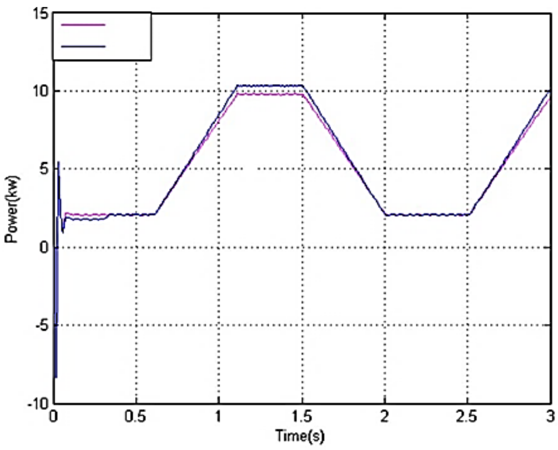


Figure 6. Output power in constant radiation and variable temperature

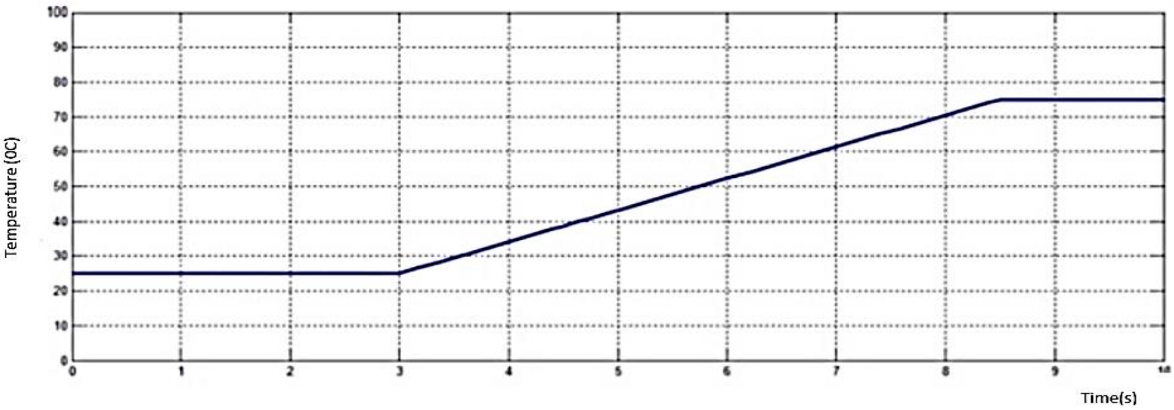


Figure 7. Temperature profile

As a result, Figure 8 presents the performance of tracking maximum power point for both methods. According to Figure 8, the proposed modified MPPT-based method outpaced the contender of incremental conductance method in terms of less computational time to reach the maximum power outputs of the PV array. Using numerical results shown in Table 2, under constant temperature and radiation conditions, the incremental conductance method and the proposed model can be compared. Under these conditions, the tracking performance by the proposed algorithm presents better than the other contender and it tracks the maximum power point faster and in an accurate way especially in the moments when there is a temperature change. Moreover, the incremental conductance method during the weather changes deviates from the maximum power point tracking and therefore, it is not suitable under this circumstance.

Table 2. Comparison of MPPT algorithms

MPPT	Output current	Output voltage	Output power	Accuracy
Incremental conductance	36.09A	250.34V	9.034 kW	low
Proposed Model	39.46A	250.37V	9.879 kW	high

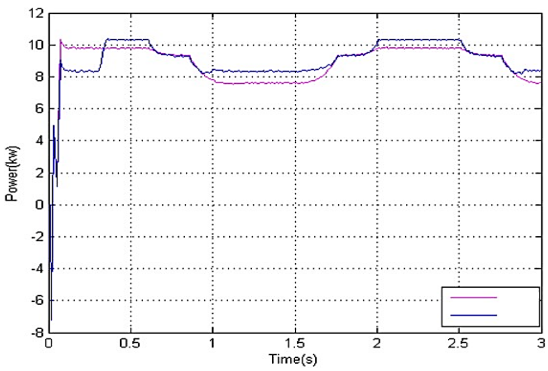


Figure 8. Array output power at constant temperature and variable radiation

5. CONCLUSION

At this work a grid-connected solar system using boost converter with MPPT was developed. The exact performance of the system components is studied and the effect of variable inputs of temperature and radiation level on the voltage and current of the solar array and their corresponding maximum power point were analyzed. Further, the array's voltage and current of the point of common coupling for the PV system to the grid can be realized. At this work, the focus was on MPPT methods such as incremental conductance and improve it through the proposed model. Thus, the proposed method caters better performance in tracking the maximum power point. When using the incremental conductance model, the output power contains losses and its value is less than the actual value of the system power. In this sense, the incremental conductance presents devastations in the amount of output power obtained from tracking as compared with the proposed method. Using the proposed method, the array output power is closer to the actual power value. This indicates that the algorithm is more accurate in tracking the maximum power point. More, after each sampling of the open circuit voltage and calculation of the relationship, the output voltage meets the maximum power point very quickly. The significant advantage of this method, in addition to high speed, is the absence of oscillation around the point of maximum power, which will prevent energy loss. It is simple to implement and is stable to changes in environmental conditions due to the nonlinear voltage-current characteristic. Due to the ease of measuring open circuit voltage in solar systems based on step-down converter, the developed method can be served properly for them.

REFERENCES

[1] M. Etezadinejad, B. Asaei, S. Farhangi and A. Anvari-Moghaddam, "An improved and fast MPPT algorithm for PV systems under partially shaded conditions," *IEEE Transactions on Sustainable Energy*, vol. 13, no. 2, pp. 732-742, 2022, doi: 10.1109/TSTE.2021.3130827.

[2] M. R. Patel, *Wind and solar power systems design, analysis and operations*, Boca Raton, United States: CRC Press Taylor & Francis, 2006

[3] M. A. A. Aziz, Z. M. Yasin, Z. Zakaria, "Prediction of photovoltaic system output using hybrid least square support vector machine," *IEEE International Conference on System Engineering and Technology (ICSET)*, 2017, pp. 151-156, doi: 10.1109/ICSEngT.2017.8123437.

[4] S. I. Sulaiman, T. K. A. Rahman, I. Musirin, S. Shaari, and K. Sopian, "An intelligent method for sizing optimization in grid-connected photovoltaic system," *Solar Energy*, vol. 86, no. 7, pp. 2067-2082, 2012, doi: 10.1016/j.solener.2012.04.009.

[5] S. E. Babaa, M. Armstrong, and V. Pickert, "Overview of maximum power point tracking control methods for PV systems," *Journal of Power and Energy Engineering*, vol. 2, no. 8, pp. 59-72, 2014, doi: 10.4236/jpee.2014.28006.

[6] N. Femia, G. Lisi, G. Petrone, G. Spagnuolo and M. Vitelli, "Distributed maximum power point tracking of photovoltaic arrays: Novel approach and system analysis," *IEEE Transactions on Industrial Electronics*, vol. 55, no. 7, pp. 2610-2621, 2008, doi: 10.1109/TIE.2008.924035.

[7] A. N. A. Ali, M. H. Saied, M. Z. Mostafa and T. M. Abdel- Moneim, "A survey of maximum PPT techniques of PV systems," *IEEE Energytech*, 2012, pp. 1-17, doi: 10.1109/EnergyTech.2012.6304652.

[8] T. Esram and P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," *IEEE Transactions on Energy Conversion*, vol. 22, no. 2, pp. 439-449, 2007, doi: 10.1109/TEC.2006.874230.

[9] R. Faranda and S. Leva, "Energy Comparison of MPPT Techniques for PV Systems." *WSEAS Trans. Power Systems*, vol. 3, no 6, pp.447-45, 2008.

[10] D. Sera, T. Kerekes, R. Teodorescu and F. Blaabjerg, "Improved MPPT method for rapidly changing environmental conditions," *IEEE International Symposium on Industrial Electronics*, 2006, pp. 1420-1425, doi: 10.1109/ISIE.2006.295680.

[11] S. Narendiran, "Grid tie inverter and MPPT—a review," *International Conference on Circuits, Power and Computing Technologies (ICCPCT)*, 2013, pp.564-567, doi: 10.1109/ICCPCT.2013.6529017.

[12] M. A. Elgendy, B. Zahawi, and D. J. Atkinson, "Assessment of perturb and observe MPPT algorithm implementation techniques for PV pumping applications," *IEEE Transactions on Sustainable Energy*, vol. 3, no. 1, pp. 21-33, 2012, doi: 10.1109/TSTE.2011.2168245.

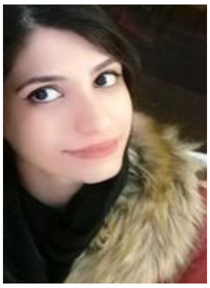
[13] N. Femia, G. Petrone, G. Spagnuolo and M. Vitelli, "Optimization of perturb and observe maximum power point tracking method," *IEEE Transactions on Power Electronics*, vol. 20, no. 4, pp. 963-973, 2005, doi: 10.1109/TPEL.2005.850975.

[14] A. Giustiniani, G. Petrone, G. Spagnuolo and M. Vitelli, "Low-frequency current oscillations and maximum power point tracking in grid-connected fuel-cell-based systems," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 6, pp. 2042-2053, 2010, doi: 10.1109/TIE.2009.2034175.
[15] V. Salas, E. Olias, A. Barrado, and A. Lazaro, "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems," *Solar Energy Materials and Solar Cells*, vol 90, no. 11, pp.1555- 578, 2006, doi: 10.1016/j.solmat.2005.10.023.
[16] K. K. Tse, H. S. H. Chung, S. Y. R. Hui and M. T. Ho, "A novel maximum power point tracking technique for PV panels," in *IEEE Annual Power Electronics Specialists Conference*, 2001, pp. 1970-1975 vol. 4, doi: 10.1109/PESC.2001.954410.
[17] R. F. Coelho, F. M. Concer and D. C. Martins, "A MPPT approach based on temperature measurements applied in PV systems," *IEEE International Conference on Sustainable Energy Technologies (ICSET)*, 2010, pp. 1-6, doi:10.1109/ICSET.2010.5684440.
[18] D. Maheshappa, J. Nagaraju, M.V. Khrishna Murthy, "An improved maximum power point tracker using a step- up converter with current locked loop," *Renewable Energy*, vol.13, 1998, pp.195-201, doi: 10.1016/S0960-1481(97)00071-2.
[19] C. Hua and C.Shen, "Comparative study of peak power tracking techniques for solar storage system," *Annual Applied Power Electronics Conference and Exposition*, 1998, pp. 679-685 vol.2, doi: 10.1109/APEC.1998.653972.
[20] R. M. Hilloowala and A. M. Sharaf, "A rule-based fuzzy logic controller for a PWM inverter in photo-voltaic energy conversion scheme," in *Conference Record IEEE Industry Applications Society Annual Meeting*, 1992, pp. 762-769 vol.1, doi: 10.1109/IAS.1992.244319.
[21] N. Patcharaprakiti and S. Premrudeepreechacharn, "Maximum power point tracking using adaptive fuzzy logic control for grid-connected photovoltaic system," in *IEEE Power Engineering Society Winter Meeting. Conference Proceedings*, 2002, pp. 372-377 vol. 1, doi: 10.1109/PESW.2002.985022.
[22] T. Hiyama, S. Kouzuma and T. Imakubo, "Identification of optimal operating point of PV modules using neural network for real time maximum power tracking control," in *IEEE Transactions on Energy Conversion*, vol. 10, no. 2, pp. 360-367, 1995, doi: 10.1109/60.391904.
[23] L. Zhang, Yunfei Bai, and A. Al-Amoudi, "GA-RBF neural network based maximum power point tracking for grid-connected photovoltaic systems," in *International Conference on Power Electronics, Machines and Drives*, 2002, pp. 18-23, doi: 10.1049/cp:20020083.
[24] A. Sayal, "MPPT techniques for photovoltaic system under uniform insolation and partial shading conditions," in *Students Conference on Engineering and Systems*, 2012, pp. 1-6, doi: 10.1109/SCES.2012.6199045.
[25] A. Raj, N. F. A. Aziz, Z. M. Yasin, and N. A. Salim, "Investigation of distributed generation units placement and sizing based on voltage stability condition indicator (VSCI)," *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 10, pp. 1317-1323, 2019, doi: 10.11591/ijpeds.v10.i3.pp1317-1323.
[26] N. F. N. Ismail, N. Hashim, and D. Johari, "A comparative study of cascade H-bridge multilevel voltage source inverter and parallel inductor multilevel current source inverter," *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 10, no. 3, pp. 1355-1363, 2019, doi: 10.11591/ijpeds.v10.i3.pp1355-1363.

BIOGRAPHIES OF AUTHORS

Hossein Zeynal received his MEng (2007) and Ph.D. (2013) degree from University Technology of Malaysia (UTM), Skudai, Malaysia in electrical power engineering. Presently He is an Assistant Professor at Department of Electrical and Computer Engineering, Buein Zahra Technical University, Qazvin, Iran. He can be contacted at email: hzeynal@gmail.com.

Zuhaina Zakaria received her Ph.D. degree in Power System from University of Strathclyde in Glasgow, UK in 2005. She is currently a Full Professor in the Faculty of Electrical Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia. She can be contacted at email: zuhainaz@uitm.edu.my.



Bahareh Pourveis received her BEng. degree in Electrical Engineering from Buein Zahra Technical University, Buein Zahra, Qazvin, Iran in 2019. She is currently pursuing her MEng degree in Electrical Engineering at University of Isfahan, Iran. She can be contacted at email: b.porvies@gmail.com.