Bulletin of Electrical Engineering and Informatics
Vol. 11, No. 5, October 2022, pp. 2491~2499
ISSN: 2302-9285, DOI: 10.11591/eei.v11i5.3782

Modeling and parameter estimation of solar photovoltaic based MPPT control using EKF to maximize efficiency

Rachid Kerid[1,3], Younes Bounnah[2]
[1]MVRE Laboratory, Department of Electronics, Faculty of technology, University of Blida 1, Blida, Algeria
[2]MVRE Laboratory, Department of H. U., High School of Hydraulics, Blida, Algeria
[3]MVRE Laboratory, ENSH of Blida, Blida, Algeria

Article Info

Article history:

Received Mar 10, 2022
Revised Jun 28, 2022
Accepted Jul 30, 2022

Keywords:

Efficiency
EKF
Incremental conductance
MPPT
Photovoltaic
Sensor less control

ABSTRACT

In this paper, we focus on the design, modeling and implementation of a MPPT controller based maximum power tracking of photovoltaic system. The electrical characteristic of The PV system is non-linear and changes with the solar irradiation and the ambient temperature. Therefore, the incremental conductance (IC) method control is known for its stability and robustness, and is used to extract the maximum energy from the PV source using a boost converter topology. It provides a strong basis for the improvement and optimization of control parameters of a photovoltaic system. Implementing MPPT algorithm usually need the use of a lot of sensors if accuracy of the system has to be increased. However, IC method with an extended Kalman filter (EKF) can be utilized in order to estimate some parameters to reduce the number of Sensors. The EKF is deployed in the optimal position to estimate both current and the capacitor voltage, thus allowing to eliminate two sensors devise from the entire PV system, which increases the system efficiency and reliability, simplifies the control method and decreases the system cost. The performance of the proposed technique is validated by experimental and simulation results under different operating conditions and load changes.

Corresponding Author:

Rachid Kerid
MVRE Laboratory, Department of Electronics, Faculty of Technology, University of Blida 1
GV3G+W95, Ouled Yaïch, Algeria
Email: r.kerid@ensh.dz

1. INTRODUCTION

Recently, the demand in electricity is increasing and the constraints related to its production, such as the effects of pollution and climatic warming. In this context, intensive researches toward the development of renewable and sustainable energy sources, especially, photovoltaic (PV) systems, which is able to fulfill the power demand in the standalone condition or in isolated location, and offer a competitive solution and free solar energy [1]-[5]. Photovoltaic energy is considered in several countries and regions with a high solar power density such as, Mediterranean countries and other regions as a potential candidate of energy. Therefore, Stand-alone and grid-connected systems of solar energy have developed greatly in recent years.

Several researches have focused on these applications include PV grid-connected systems [6], optimal control of hybrid systems, electric vehicles [7], air conditioning, traffic light application, refrigeration, water pumping [8]. Nevertheless, there are some inconvenient for the PV systems, such as, high manufacture cost, low energy conversion efficiency in PV modules and deterioration of the maximum power with varying resistance values. In addition, PV system gives naturally a nonlinear characteristic (V-I) which vary with the temperature and radiant intensity. Their maximum power point varies nonlinearly with environmental conditions (e.g., solar irradiation, temperature, load and degradation level) [9]-[12]. In addition, the aging of solar cells of PV module and load current are the main reasons for the low electrical efficiency of photovoltaic systems. However, until now, very little study has been conducted on finding the factors of low performance of PV system.

Nowadays, to overcome these barriers, the maximum power point of the PV system under real operating condition is studied in [13]-[15], and implemented [16], an intensive literature review on online and offline tracking of the MPP algorithm or technique is presented in refs. [10]-[20]. The use of MPPT technique to extract the maximum power produced by an array of PV cells is primordial; the operating point of the system is forced toward this optimal condition.

A lot of literature is available on MPPT techniques to increase global system efficiency is proposed, these techniques include the incremental conductance (IC) used in this work, which have proved good performances under different irradiation and temperature, and others methods. Another kind of algorithm is proposed, such as MPPT technique by using artificial neural networks (ANN) and fuzzy logic control [15].

In this work, IC method is combined with an extended Kalman filter algorithm (EKFA) to extract the maximum power using a DC-DC converter (boost) from the PV source. The EKF can be used to estimate some parameters to reduce the number of sensors, where the capacitor voltage and the PV current are estimated by EKF, which increases the system efficiency and reliability, simplifies the control method and decreases the system cost [3], [4].

The paper is organized as follows: in section 2, the model of PV system based on single diode is presented. In section 3, the proposed MPPT based IC with EKF algorithm is described. The proposed MPPT technique is analyzed with numerical calculations and detailed discussions in section 4. Concluding remarks of work are given in section 5.

2. MODELING OF THE PV SYSTEM

In this study, a single diode model of PV solar cell has been proposed, as illustrated in Figure 1 [6]-[10]. In this model, the relationship between the output voltage (V) and output current (I) of PV cell can be given as

$$I = I_{ph} - I_{sat}\left\{exp\left[\frac{q(V+IR_s)}{AkT}\right] - 1\right\} - \frac{V+IR_s}{R_{sh}} \quad (1)$$

where I_{ph} and I_{sat} are the PV photo current and reverse saturation current when there is no light on the PV cell, respectively. The R_s and R_{sh} are the equivalent series resistance and equivalent parallel resistance, respectively. A, K and T are coefficient of diode ideality, Boltzmann constant and absolute temperature of PV cell.

The maximum power output of the PV cell is formulated as:

$$P_m = I_{sc}V_{oc}F_f \quad (2)$$

where V_{oc}, I_{sc} are the open-circuit voltage and short-circuit current respectively, and F_f is fill factor (0.75 to 0.8). Therefore, the photo-electric conversion efficiency of PV cell expressed by:

$$\eta = \frac{V_{oc}I_{sc}F_f}{P_{in}} \times 100 \quad (3)$$

where P_{in} is the input power of PV cell.

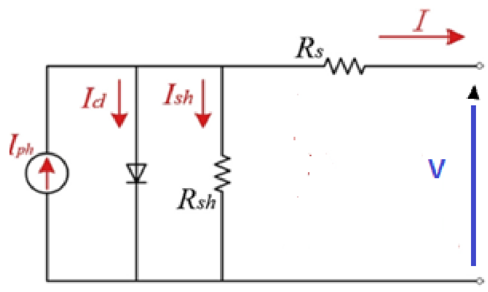


Figure 1. Equivalent circuit of PV solar cell

3. MPPT BASED INCREMENTAL CONDUCTANCE WITH EKF

The IC method has been introduced to track the maximum power point (MPP) in photovoltaic systems where IC control has several advantages of better performance, simple and robust design. Among all, the IC method is widely used, because this method is less expensive, easier to implement than other algorithm, and having good tracking accuracy [3]. Nevertheless, the current-voltage (I-V) and power voltage (P-V) characteristics of the PV module at different solar irradiation and constant temperature are shown in Figures 2(a) and 2(b). The details of the entire system design, which includes the PV generator, boost converter, and resistive output load is shown in Figure 3.

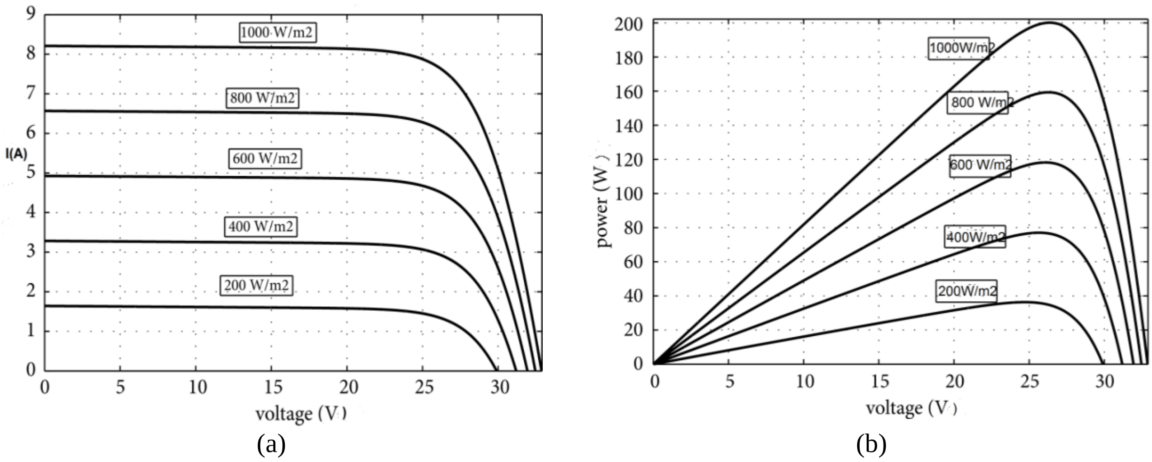


Figure 2. Influence of the solar radiation for constant temperature (25 °C), (a) (I-V) characteristics of PV, and (b) (P-V) characteristics of PV

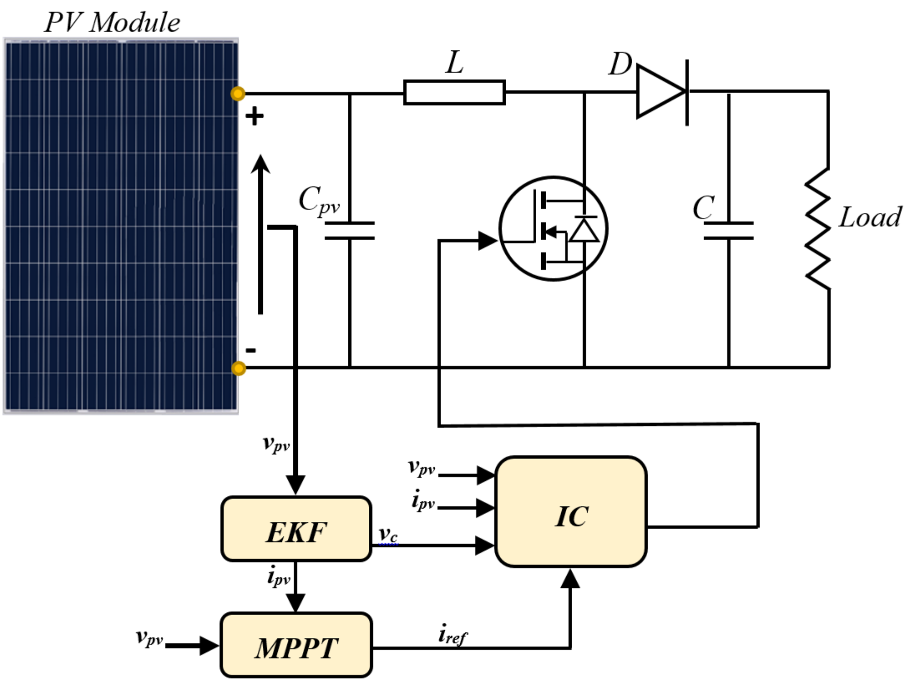
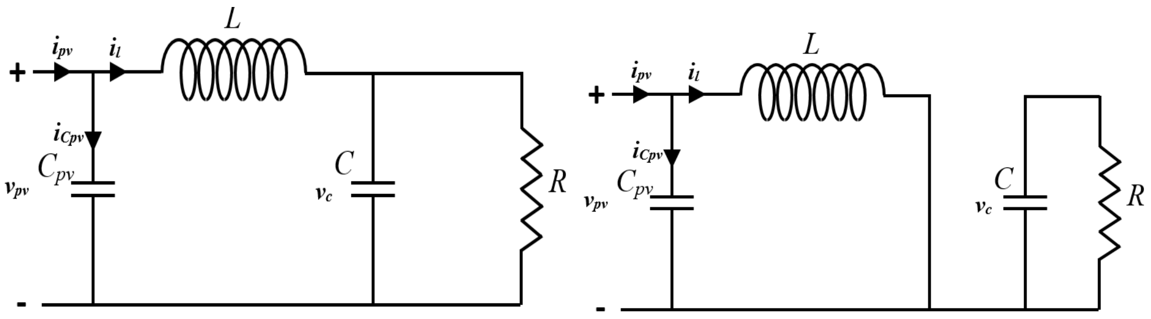


Figure 3. Schematic diagram of MPPT in PV system

3.1. Boost converter model

The boost converter has become a topic of great interest in this field topology. Further, its voltage increasing, its high efficiency, the possibility of implementing a MPPT, its reliability and its low cost are decisive advantages [11]-[14]. Figure 4 shows the boost chopper structure. The two states ON and OFF of the (DC-DC) converter (boost) is described in Figures 4(a) and 4(b).



(a) (b)

Figure 4. Equivalent circuit of the (DC-DC) converter (a) switch is off and (b) switch is on

Applying Kirchhoff's laws, the ideal mathematical model of the circuit in Figure 4 is done by:

$$\begin{aligned} L\frac{di_l}{dt} &= U_{PV} - V_C(1 - S_{s1}) - R.I_{PV} \\ C\frac{dV_C}{dt} &= I_{PV}(1 - S_{s1}) - \frac{V_C}{R} \\ S_{s2} &= \overline{S_{s1}} \end{aligned} \tag{4}$$

$S_{s1:}$ switch position [0 1]

3.2. Parameter identification of PV system using EKF

The model of the PV system including disturbance can be given as [21]-[25]:

$$\begin{aligned} \dot{X} &= AX + BU + W, \\ Y &= CX + DU + V \end{aligned} \tag{5}$$

$$A = \begin{bmatrix} 0 & -\frac{1-S}{L} & 0 \\ \frac{1-S}{C} & -\frac{1}{R.C} & 0 \\ 0 & 0 & 0 \end{bmatrix} B = \begin{bmatrix} \frac{1}{L} \\ 0 \\ 0 \end{bmatrix} C = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}, D = 0, \tag{6}$$

where *S* is the switching state, *W* and *V* are the zero-mean white Gaussian noises with covariance Q and R which represent the model error and measurement noise, respectively. The values of PV specification parameters at 1000 W/$m^2$are given in Table 1.

Table 1. PV specification at 1000 W/m^2 and temperature of 25°C

Parameters	Specification
Peak power	200 W
Open circuit voltage	32.5 V
Max power voltage	26.4 V
Short circuit current	8 A
Max power current	7.5 A

3.3. Incremental conductance-method based MPPT

The MPP tracking technique depends on the differential of the power of PV system with respect to PV voltage is zero at the MPP as done by [3]:

$$\begin{Bmatrix} \frac{\Delta I}{\Delta V} = 0, atMPP, \\ \frac{\Delta I}{\Delta V} > 0, Left \cdot \\ \frac{\Delta I}{\Delta V} < 0, Right. \end{Bmatrix} \tag{7}$$

Differentiating the PV power with respect to voltage

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \quad (8)$$

$$\begin{cases} \frac{\Delta I}{\Delta V} = -\frac{I}{V}, atMPP, \\ \frac{\Delta I}{\Delta V} > -\frac{I}{V} 0, Left. \\ \frac{\Delta I}{\Delta V} < -\frac{I}{V} 0, Right. \end{cases} \quad (9)$$

By using the values of V_{pv} and I_{pv} at different points and comparing the conductance (I/V) to the (IC) ($\Delta I/\Delta V$). Assuming the ripple components in the currents is low and using the forward Euler method for discretization [20], the MPP can be described as shown in Figure 5.

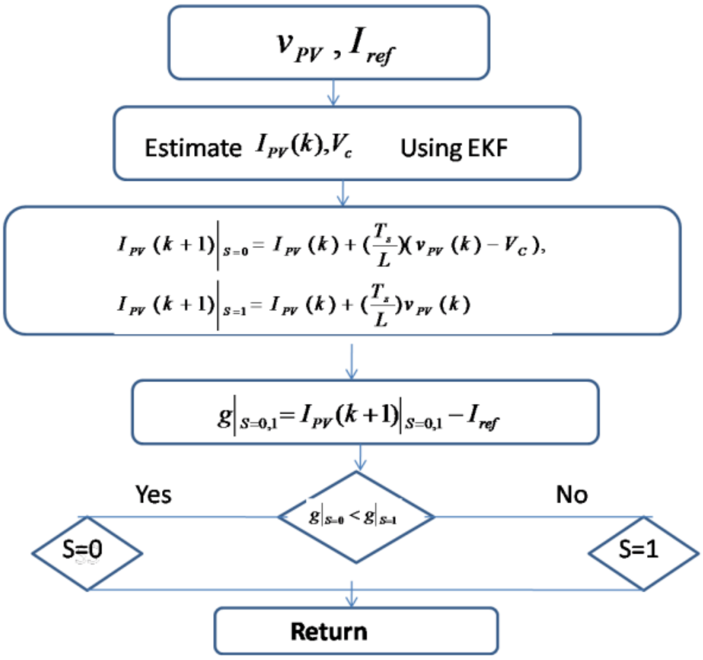
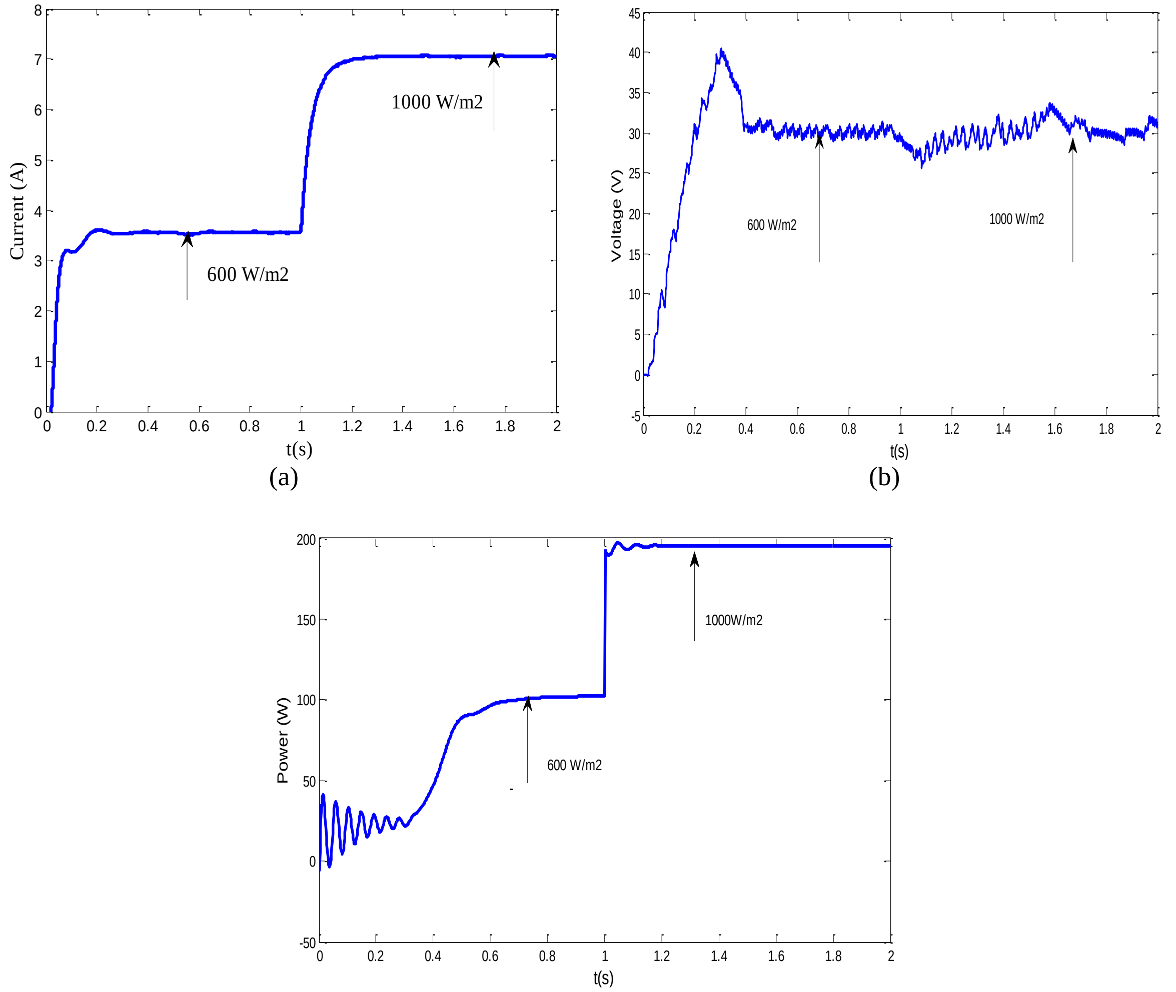


Figure 5. Flowchart of IC algorithm with EKF to generate the switch state

4. RESULTS AND DISCUSSION

In order to evaluate the performance of our PV system and to examine changes in the efficiency, we investigated the influence of the temperature and radiant intensity. In literature, conventional algorithms use three sensors for the MPPT operation. Two sensors are used for IC method and third one for the capacitor voltage. In this study, to reduce the total number of sensors, only one sensor is needed to collect the data at every time step, where the EKF algorithm used to estimate the other two states. The optimal switching state is generating by the MPC algorithm, where the switching state is based on a current optimization function. To validate the performance of the entire system, the proposed IC control based MPPT has been modeled, simulated using MATLAB/Simulink under different radiation conditions, and compared with the conventional algorithm [2]-[10].

In order to maximize as possible, the performance of PV system, first, the power, voltage and current are plotted separately as a function of time with the specifications presented in Table 1. Figures 6(a), 6(b) and 6(c) show the evolution of power, voltage and current respectively, using IC algorithm under MPP operation during a variation transient in solar radiation, the irradiation step varies from 600 W/m² to 1000w/m² assuming constant temperature 25°C. We observed that the PV performance is sensitively affected by the temperature and radiant intensity. The results show that, despite the use of only one sensor, the proposed algorithm shows an equivalent performance of the conventional system.



(c)

Figure 6. Evolution of the PV (a) current (b) voltage and (c) power, under different solar irradiation and constant temperature (25 °C)

In order to demonstrate the performance of EKF applied to PV system to estimate voltage, current and capacitor voltage, the simulations are realized using MATLAB/Simulink. The fitness function is optimized by EKF to search a good result for estimation of PV electrical parameters. The values of nominal and estimated parameters are given in Table 1. In Figures 7(a), 7(b), and 7(c) the estimated is quite close to the actual values.

From the simulations performed, it can be observed that the EKF proposed for estimation parameters of PV system is more consistent and convergent as well as another algorithm, such as the Monte Carlo algorithm [19]. And the results obtained were also compared with Newton Raphson and least square methods showing more accurate performance [15]-[17]. Further, the dynamic behavior of PV system is tested under different operating conditions and load changes. In addition, we shown that our results, in terms of precision and accuracy were remarkably similar those predicted in [10].

In Figure 8, we plot the photo-electric conversion efficiency of PV cell at different solar radiation, it has shown an enhanced efficiency of 40 % in comparison for the conventional system between 12 and 35% as indicated in [7], [8]. Therefore, the results demonstrate that IC algorithm has a better performance and it can track MPP under rapidly changing environmental conditions.

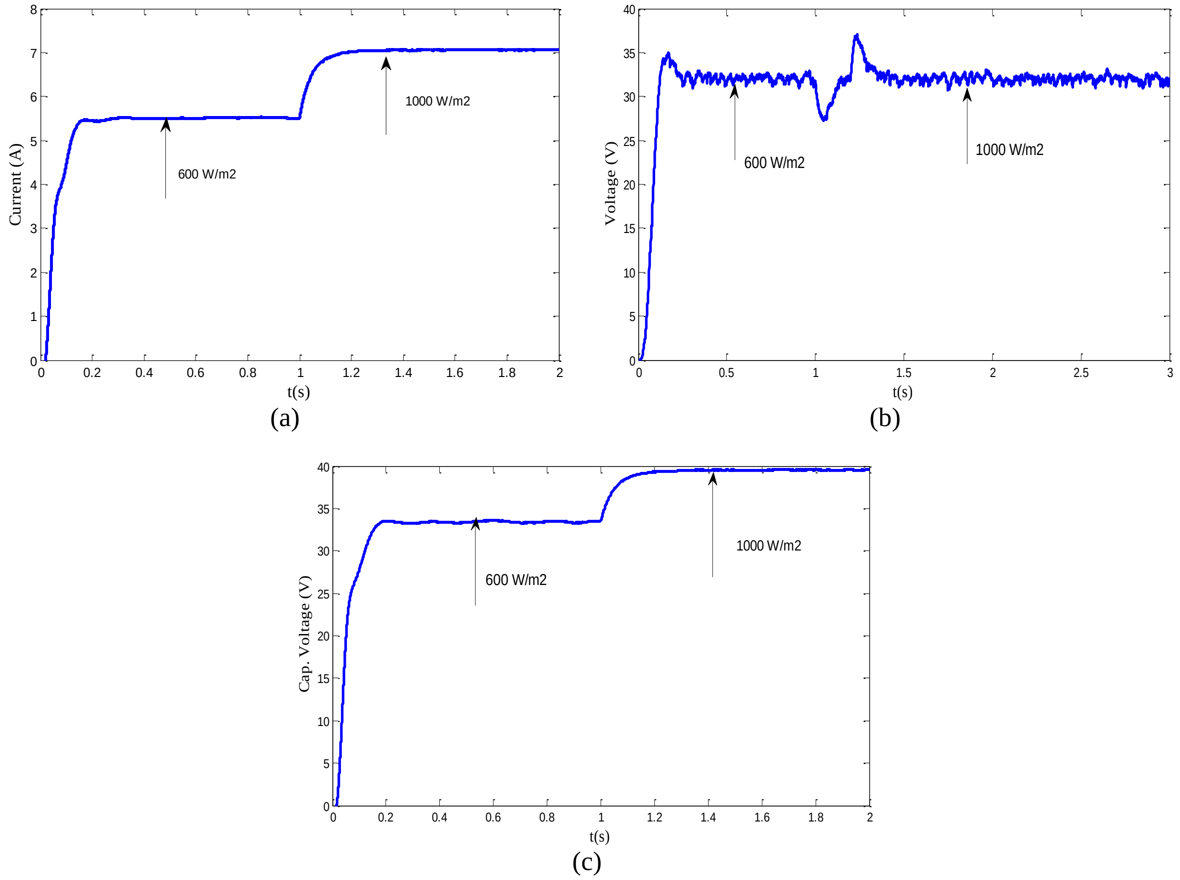


Figure 7. Estimated states with EKF, (a) current, (b) voltage, and (c) capacitor voltage

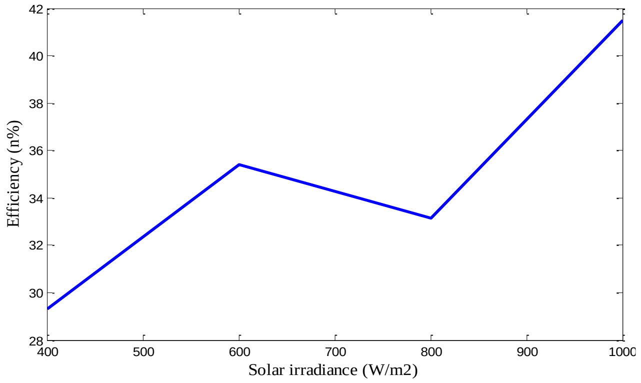


Figure 8. Efficiency of PV cell at different solar radiation

5. CONCLUSION

This paper proposed a simple MPPT scheme with an EKF which facilitates reduction number of sensor requirement as compared to the classical algorithm. The simulation results under different variations of irradiation show that the proposed algorithm can follow the MPP fast compared to the conventional method. Some advantages of the proposed IC MPP tracker are: a) better tracking accuracy, b) robustness under atmospheric conditions, c) reduces the sensor number of PV system.

To conclude, the proposed MPPT using IC with EKF algorithm can enhance the performance of any nonlinear system as the PV system. By comparison with other different algorithms, we have shown that the EKF provides similar performance, better optimization capability and has good convergence in simultaneously estimating PV electrical parameters such as capacitor voltage. At last, the proposed MPPT with EKF algorithm can be preferred for commercial application.

ACKNOWLEDGEMENT

This work was supported by the Algerian MVRE Laboratory, ENSH of Blida (Algeria).

REFERENCES

[1] G. Spagnuolo, G. Petrone, B. Lehman, C. A. Ramos Paja, Y. Zhao and M. L. O. Gutierrez, "Control of Photovoltaic Arrays: Dynamical Reconfiguration for Fighting Mismatched Conditions and Meeting Load Requests," in *IEEE Industrial Electronics Magazine*, vol. 9, no. 1, pp. 62-76, March 2015, doi: 10.1109/MIE.2014.2360721.
[2] M. H. Shahbaz*et al.*, "A streamlined 17-level cascaded H-bridge multilevel converter with solar PV integration," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 2, pp. 598-608, 2021, doi: 10.11591/eei.v10i2.2764.
[3] A. M. O. Anwer, F. A. Omar, H. Bakir, and A. A. Kulaksiz, "Sensorless Control of a PMSM Drive Using EKF for Wide Speed Range Supplied by MPPT Based Solar PV System," *Elektronika ir Elektrotechnika*, vol. 26, no.1, pp. 32-39, 2020, doi: 10.5755/j01.eie.26.1.25308.
[4] R. Kerid, H. Bourouina, and R. Yahiaoui, "Parameter identification of PMSM using EKF with temperature variation tracking in automotive application," *Periodicals of Engineering and Natural Sciences (PEN)*, vol. 6, no. 2, pp. 109-119, 2018, doi: 10.21533/pen.v6i2.168.
[5] T. Prakash, S. R. Mohanty and V. P. Singh, "PMU-Assisted Zone-3 Protection Scheme for PV Integrated Power Systems Immune to Interharmonics," in *IEEE Systems Journal*, vol. 14, no. 3, pp. 3267-3276, Sept. 2020, doi: 10.1109/JSYST.2020.2964742.
[6] D. H. Li, K. L. Cheung, T. N. Lam, and W. W. Chan, "A study of grid-connected photovoltaic (PV) system in Hong Kong," *Applied Energy*, vol. 90, no.1, pp. 122-127, 2012, doi: 10.1109/JSYST.2020.2964742.
[7] H. Pan *et al*., "A portable renewable solar energy-powered cooling system based on wireless power transfer for a vehicle cabin," *Applied energy*, vol. 195, pp. 334-343, 2017, doi: 10.1016/j.apenergy.2017.03.069.
[8] V. Badescu, "Dynamic model of a complex system including PV cells, electric battery, electrical motor and water pump," *Energy*, vol. 28, no. 12, pp. 1165-1181, 2003, doi: 10.1016/S0360-5442(03)00115-4.
[9] H. Rezk, I. Tyukhov, M. Al-Dhaifallah, and A. Tikhonov, "Performance of data acquisition system for monitoring PV system parameters," *Measurement*, vol. 104, pp. 204-211, 2017, doi: 10.1016/j.measurement.2017.02.050.
[10] T. Ikegami, T. Maezono, F. Nakanishi, Y. Yamagata, and K. Ebihara, "Estimation of equivalent circuit parameters of PV module and its application to optimal operation of PV system," *Solar energy materials and solar cells*, vol. 67, no. 1-4, pp. 389-395, 2001, doi: 10.1016/S0927-0248(00)00307-X.
[11] G. Notton, V. Lazarov, and L. Stoyanov, "Optimal sizing of a grid-connected PV system for various PV module technologies and inclinations, inverter efficiency characteristics and locations," *Renewable Energy*, vol. 35, no.2, pp. 541-554, 2010, doi: 10.1016/j.renene.2009.07.013.
[12] Y. K. Choi, "A study on power generation analysis of floating PV system considering environmental impact," *International journal of software engineering and its applications*, vol. 8, no.1, pp. 75-84, 2014, doi: 10.14257/IJSEIA.2014.8.1.07.
[13] P. P. Zarina, S. Mishra, and P. C. Sekhar, "Exploring frequency control capability of a PV system in a hybrid PV-rotating machine-without storage system," *International Journal of Electrical Power & Energy Systems*, vol.60, pp. 258-267, 2014, doi: 10.1016/j.ijepes.2014.02.033.
[14] N. O. Cherchali, A. Morsli, M. S. Boucherit, and L. Barazane, "Robust Controller to Extract the Maximum Power of a Photovoltaic System," *Journal of Electrical and Electronics Engineering*, vol. 7, no. 1, pp. 117-122, 2014.
[15] N. Khaldi, H. Mahmoudi, M. Zazi and Y. Barradi, "The MPPT control of PV system by using neural networks based on Newton Raphson method," *2014 International Renewable and Sustainable Energy Conference (IRSEC)*, 2014, pp. 19-24, doi: 10.1109/IRSEC.2014.7059894.
[16] Z. Massaq, A. Abounada, and M. Ramzi. "Fuzzy and predictive control of a photovoltaic pumping system based on three-level boost converter," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 3, pp. 1183-1192, 2021, doi: 10.11591/eei.v10i3.2605.
[17] R. Keridand and H. Bourouina, "Analysis of Wireless Power Transfer System with New Resonant Circuit for High Efficiency Using Perforated Capacitors," *Arabian Journal for Science and Engineering*, vol. 44, no. 3, pp. 2445-2451, 2019, doi: 10.1007/s13369-018-3579-2.
[18] M. Rasheed, O. Y. Mohammed, S. Shihab, and A. Al-Adili, "A comparative Analysis of PV Cell Mathematical Model," In *Journal of Physics: Conference Series*,vol. 1795, no. 1, p. 012042, March 2021, doi: 10.1088/1742-6596/1795/1/012042.
[19] C. P. Cameron, W. E. Boyson and D. M. Riley, "Comparison of PV system performance-model predictions with measured PV system performance," *2008 33rd IEEE Photovoltaic Specialists Conference*, 2008, pp. 1-6, doi: 10.1109/PVSC.2008.4922865.
[20] N. Shahidirad, M. Niroomand and R. Hooshmand, "Investigation of PV Power Plant Structures Based on Monte Carlo Reliability and Economic Analysis," in *IEEE Journal of Photovoltaics*, vol. 8, no. 3, pp. 825-833, May 2018, doi: 10.1109/JPHOTOV.2018.2814922.
[21] M. Ahmed, M. Abdelrahem, R. Kennel and C. M. Hackl, "Maximum Power Point Tracking Based Model Predictive Control and Extended Kalman Filter Using Single Voltage Sensor for PV Systems," *2020 IEEE 29th International Symposium on Industrial Electronics (ISIE)*, 2020, pp. 1039-1044, doi: 10.1109/ISIE45063.2020.9152256.
[22] J. Hu, Y. Xu, K. W. Cheng, and J. M. A. Guerrero, "Model predictive control strategy of PV-Battery microgrid under variable power generations and load conditions," *Applied Energy*, vol. 221, pp. 195-203, 2018, doi: 10.1016/j.apenergy.2018.03.085.
[23] B. Setiawan, E. S. Putra, and I. Siradjuddin, "Hybrid renewable energy photovoltaic and darrieus VAWT as propulsion fuel of prototype catamaran ship," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 4, pp. 1846-1855, 2021, doi: 10.11591/eei.v10i4.3113.
[24] M. J. Khan, A. K. Yadav, and L. Mathew, "Techno economic feasibility analysis of different combinations of PV-Wind-Diesel-Battery hybrid system for telecommunication applications in different cities of Punjab, India," *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 577-607,2017, doi: 10.1016/j.rser.2017.03.076.
[25] H. Haider, S. Masri, A. M. H. Saad, A. B. Ahmad, and T. Sutikno, "Development of fast and accurate algorithm to extract the five parameters of photovoltaic modules," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 1, pp. 379-386, 2020, doi: 10.11591/eei.v9i1.1707.

BIOGRAPHIES OF AUTHORS

Rachid Kerid obtained his M.Sc. degree in electrical engineering from the High polytechnic school of Algiers (Algeria) and doctorate degree in electronics from university of Blida 1 (Algeria) in May 2020; he becomes a temporary researcher at the University of Blida in Algeria where he worked on the development of switch, sensor and electrical machine in faculty of electronics of Blida University. He had been working as Professor at high school of hydraulics; his research interests include nanotechnology, electrical machines, wireless power transfer (WPT) and renewable energy. He can be contacted at email: r.kerid@ensh.dz.

Younes Bounnah Holder of a M.Sc. degree in Mechanical Engineering from the University of M'sila (Algeria), he is a doctoral student in science assigned to the Mobilization and development of water resources laboratory at the National High School of Hydraulics where he, currently, performs the function of a teacher-researcher. The main areas of research that interest him are: tribology, thermal transfers, CFD, renewable energies, electrical machines, software development, embedded systems and artificial intelligence. He can be contacted at: y.bounnah@ensh.dz.