Comparative Analysis of the Modified Perturb & Observe with Different MPPT Techniques for PV Grid Connected Systems

Saad A. Mohamed Abdelwahab*, ***‡, Abdallah Mohamed Hamada **, Walid S.E. Abdellatif *, ****

* Electrical Department, Faculty of Industrial Education, Suez University, Suez, Egypt.

** Electrical Department, Alex. Technological Collage, Min. of Higher Education, Alex., Egypt.

*** High Institute of Electronic Engineering, Ministry of Higher Education, Bilbis- Sharqiya, Egypt.

****Department of Electronics and Electrical Communications Engineering, Higher Institute of Engineering and Technology, Ministry of Higher Education – Kafr Elsheikh, Egypt.

(saad.abdelwahab@suezuniv.edu.eg, abdallahmhe@yahoo.com, walid.abdellatif@suezuniv.edu.eg)

‡ Saad A. Mohamed Abdelwahab; Electrical Department, Faculty of Industrial Education, Suez University, 43527 Suez, Egypt, Tel: +201096250375, Fax: +20629203469, saad.abdelwahab@suezuniv.edu.eg

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Abstract- The maximum power point tracking (MPPT) techniques are used in photovoltaic (PV) systems to fully utilize the PV array output power that depends on the change in PV radiation and ambient temperature. In this paper, modified perturb and observe (MP&O) algorithm is proposed to be more efficient for MPPT of grid-connected PV system. The results of this MP&O algorithm are shown to track the maximum energy under fast-changing weather conditions at two cases of solar radiation changes, the first case is the solar radiation change in ramp mode, and the second case is the displaying under random change of solar radiation. The maximum power point (MPP) can be obtained by controlling the operating period that is fed on the MOSFET gate within the boost converter. In addition, the control technique used with the three-phase inverter is a dynamic-based PI controller. The MP&O algorithm is built on the determination of the maximum effective point on the property curve and is similar to the traditional scheme. The idea of this comparison is to use the change in solar radiation to determine the difference between the working point of the PV solar array and the number of sectors. The performance is estimated and compared by mathematical investigation and simulation analysis. The proposed method offers high performance and accurate tracking in rapidly varying weather environments.

Keywords Maximum power point tracking, perturb and observe algorithm, MP&O and grid connected PV system.

1. Introduction

Photovoltaic (PV) energy depends on converting sunlight into electricity. In recent years, the price of PV array has decreased dramatically until, which led to an increase in PV generation in recent years. Many studies rely on PV systems to simulate the development of PV algorithms, maximum power point (MPP) tracking, and control strategies. Standalone PV systems must be connected to the solar energy storage system, while in the PV grid connected system does not need energy storage systems and this is what distinguishes it from stand-alone PV systems. Researchers in the PV system need to be easy and reliable ways to track the maximum power of the PV power generated under different conditions of solar radiation and temperature [1].

The increasing demand for electric energy around the world is a result of the increased use of new and renewable energy sources. One of the best renewables that have been studied extensively in recent times is PV energy. PV energy has many obvious advantages, among which it is a clean energy source that has no polluting effect, very reliable and flexible in size, and requires minimal maintenance [1-2].

The low efficiency of the PV system is a driving force for tracking the maximum power generated by PV systems. Many papers are classified as a development of the PV system with MPPT methods in the last few years. MPPT of direct methods to find MPP such as perturb and observe (P&O) [1-5], incremental conductance (IC) technique [6-10], sliding mode control, fuzzy logic control [11-13] and modified perturb and observe (MP&O) technique [14-20]. The MP&O technique has been considered as the most preferred option. In [14], the P&O method (MPPT) to reduce volatility and reduce the possibility of a direction loss system when radiation changes slowly to about 12% under rapid change of radiation. In [15], track MP&O for MPPT at four sectors of operation of the solar system under different operating conditions with the help of the four sectors, change the size of the step is to get the maximum capability of the system connected to the grid.

Most of the researchers present MPPT methods through the number of specific characteristic sectors to PV array. In this research, multiple sectors are dealt with through which the system response to the rapid changes of solar radiation is increased. This paper introduced a MP&O algorithm as a more effective solution in MPPT for the PV system connected to the grid. The results of the proposed method for tracing the maximum energy under fast varying climatic environments are shown in two cases of solar radiation change, the first in solar radiation change in the slope mode, and the second shown under random change of solar radiation. The modified procedures are able to achieve the MPPT under fast varying distinctive environments with advanced accuracy than their conventional schemes.

The research will be presented in the following terms: Section II describes the construction and modelling of the proposed system. The MPPT techniques; P&O, IC and MP&O algorithm are given in Section III. Section IV depicts the results and discussion of MPPT operation under ramp and random changes of solar radiation for the aforementioned techniques. Lastly, the conclusions are obtainable in section.

2. Structure and Modelling of The Proposed System

The circuit diagram in Fig. 1, illustrates the three-phase grid connected PV generation system. The proposed system consists of two main categories, the first scheme is power diagram which includes: a PV array supply, DC link capacitor, boost converter, three phase inverter, RL filter, step-up transformer and three phase utility grid. The second category is the control scheme MPPT by using different MPPT techniques and the inverter controller with three phase PV grid connected system.

The proposed controller depends on the variable step sizes by comparing the P-V curve and an afresh created one, particularly producing it to improve system reaction. In this work, we can locate the working point on a distant P-V curve or near MPPT. After the working point is far away from MPP, the magnitude of the step voltage is applied to a large voltage reference voltage. In addition, the application of small step size will get to near the MPP operating point location.

2.1 PV Modeling

Figure 2 shows the MATLAB/SIMULINK of PV model based on 1-diode equivalent circuit. The MATLAB program for PV panel includes the following parameters and variables as inputs, the current source I_L act as solar radiation created current, diode saturation current I_0, shunt resistance R_{sh}, and series resistance R_S, to represent the temperature and radiation dependent I-V characteristics of a PV module as shown in Fig. 3.

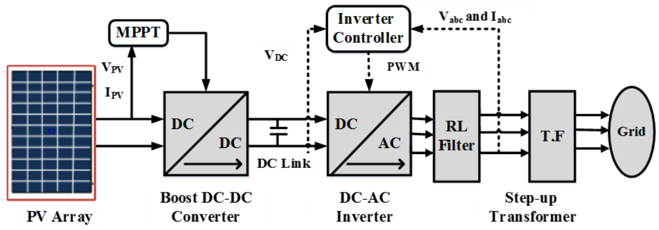


Fig. 1. Simplified diagram of grid connected of PV system.

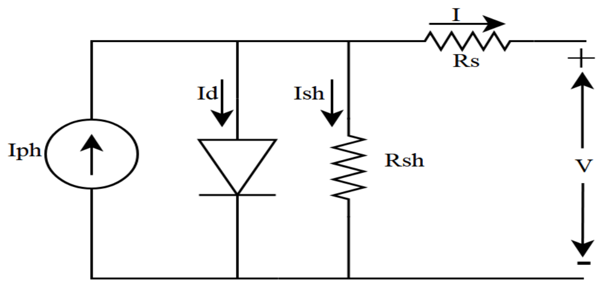


Fig. 2. Single-diode equivalent circuit of a PV cell.

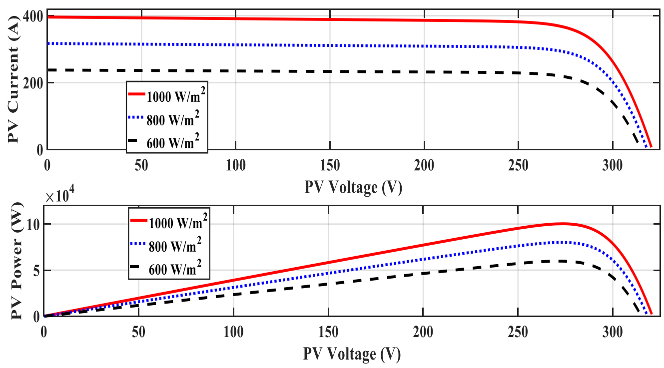


Fig. 3. I-V and P-V characteristics curves under variable irradiation.

The model is given by the following equations [6, 21]:

$$I_d = I_0\left[\exp\left(\frac{V_d}{V_T}\right) - 1\right] \tag{1}$$

$$V_T = \frac{K * T}{q} * n_1 * N_{cell} \tag{2}$$

$$I = I_{ph} - I_s\left\{\exp\left[\frac{q(V + IR_s)}{A \cdot K \cdot T}\right] - 1\right\} - \left(\frac{V + IR_s}{R_{sh}}\right) \tag{3}$$

$$I_{ph} = [I_{sc} + K_i(T - T_{ref})].\left(\frac{G}{1000}\right) \tag{4}$$

Where, V_T is output voltage (V), I_d is diode current (A), I_0 is diode saturation current (A), V_d is diode voltage (V), K is constant of boltzmann = $1.3806*10^{-23}$ $J.K^{-1}$, n_1 is diode factor of ideality up to 1.0, q is charge of electron = $1.6022*10^{-19}$ C, N_{cell} is the No of series cells, G is solar radiation and T is cell temperature (C°).

2.2 Modelling of The Boost Converter

The output voltage of the PV array is a small value that will boost the voltage required in the system. Therefore, the DC/DC boost converter is employed to step up the PV output voltage in order to investigation the required voltage level and the synchronized with the electrical grid by DC/AC inverter as seen in Fig. 4. It contains two nearly-ideal semiconductor switches (diode and MOSFET) and energy storage elements (inductor and capacitor).

Reducing the ripple of the network feeder voltage in the boost converter by the low pass filter resulting from the variable input current of the converter due to the switching of the transformer and using the capacitor (C_a) for the terminal voltage stability of the PV array while an output capacitor (C_1) acts as a low-pass filter to reduce the output voltage ripple [5, 20].

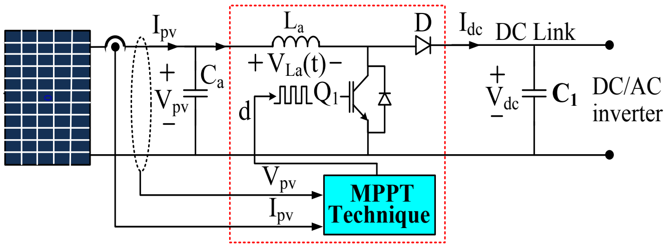


Fig. 4. Basic configuration of the DC/DC boost converter.

In the current source PV cell, the capacitor (C_a) is evaluated by using Eq. (5) and the standards of its elements are specified as follows [21]:

$$C_a = \frac{D * V_{PV}}{4 * \Delta V_{PV} * f_s^2 * L_{dc}} \tag{5}$$

$$D = 1 - \frac{V_{PV}}{V_{dc}} \tag{6}$$

$$L_a = \frac{V_{PV} * (V_{dc} - V_{PV})}{\Delta I_{La} * f_s * V_{dc}} \tag{7}$$

$$\Delta I_{La} = 0.13 * I_{PV} * \frac{V_{dc}}{V_{PV}} \tag{8}$$

$$C_1 \geq \frac{P_{PV}}{\Delta V_0 * f_s * V_{dc}} \tag{9}$$

Where, V_{PV} is converter input voltage (V), I_{PV} is array maximum current (A), P_{PV} is a nominal power of PV (W), f_s is converting frequency (Hz), C_a is the link capacitance of PV (F), C_1 is the capacitance of DC-link (F), L_a is the inductor of boost converter (H), L_{dc} inductor of boost converter output converter, V_{dc} is boost converter output voltage (V), D is duty cycle of the boost converter, ΔV_{PV} is the voltage variation (V), ΔI_{La} is Current ripple of boost inductor and ΔV_0 is the ripple of output voltage (V).

2.3 Interface of the grid inverter controller

The grid inverter is used for the purpose of connecting the photoelectric energy to the electrical grid. DC voltage is controlled as well as control of active and reactive power that is linked to the network by the converter under changed climatic environments. To achieve the unit power factor procedure, the utility grid is injected zero reactive currents by applied the vector control. Figure 5 illustrates the controller block diagram where the internal controller loops operate double controllers of PI to order the quadrature-current Iq, and the direct - current Id. Overall connotation of the voltages of network inverter and currents of line can be expressed in these equation [15].

$$\begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} = R_f . \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L_f . {}^{d}/_{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{10}$$

Where, E_a, E_b and E_c are the voltages of inverter output, v_a, v_b and v_c are the voltages of grid, i_a, i_b and i_c are the line currents of grid and R_f, L_f are the filter resistance and inductance respectively.

$$V_d = e_d - i_d . R_f - L_f . {}^{di_d}/_{dt} - \omega . i_q . L_f \tag{11}$$

$$V_q = e_q - i_q . R_f - L_f . {}^{di_q}/_{dt} - \omega . i_d . L_f \tag{12}$$

Where, v_q, v_d are voltage of the grid q-axis and d-axis, e_d and e_q are the inverter-voltage of d-axis and q-axis, id and i_q are the injected grid currents of d-axis and q-axis and ω is the angular frequency of grid.

Simultaneously, powers of output active and reactive are valued as tracks [15]:

$$P = \frac{3}{2}[i_d . V_d \; - i_q . V_q \;] \tag{13}$$

$$Q = \frac{3}{2}[i_q . V_d \; - \; i_d . V_q \;] \tag{14}$$

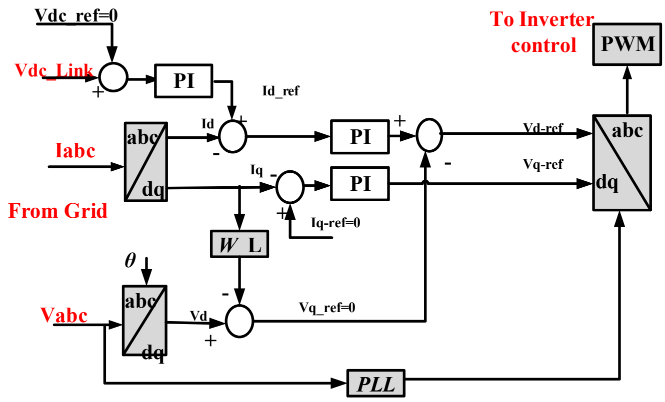


Fig. 5. Block diagram of Inverter control.

3. MPPT Techniques

3.1 IC Technique

The IC method is built on the power-voltage slope as exposed in Fig. 6. The IC MPPT flow chart is shown in Fig. 7. The slope of the P-V characteristic is calculated, if the action point on the left side of the MPPT is positive, therefore it is stimulated to the truth by increasing the PV voltage. But if the slope of the typical curve is negative, the procedure assumes that the point of operating is located on the side of the MPP right and therefore it must be encouraged to the left by reducing the PV voltage. The effective point is at MPP when the P-V curve slope is zero and the voltage adjustment algorithm will stop as in the following equation [6]:

$$\frac{dI_{PV}}{dV_{PV}} = -\frac{I_{PV}}{V_{PV}} \quad \text{At MPPT} \tag{15}$$

$$\frac{dI_{PV}}{dV_{PV}} > -\frac{I_{PV}}{V_{PV}} \quad \text{Left of MPPT} \tag{16}$$

$$\frac{dI_{PV}}{dV_{PV}} < -\frac{I_{PV}}{V_{PV}} \quad \text{Right of MPPT} \tag{17}$$

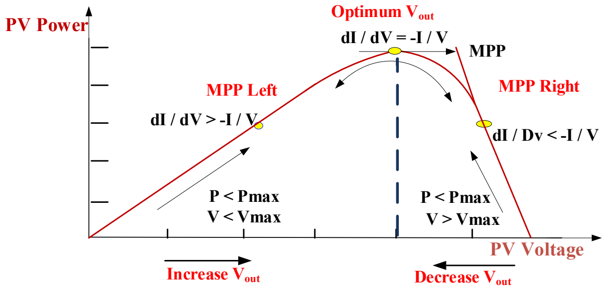


Fig. 6. ICalgorithm power - voltage curve.

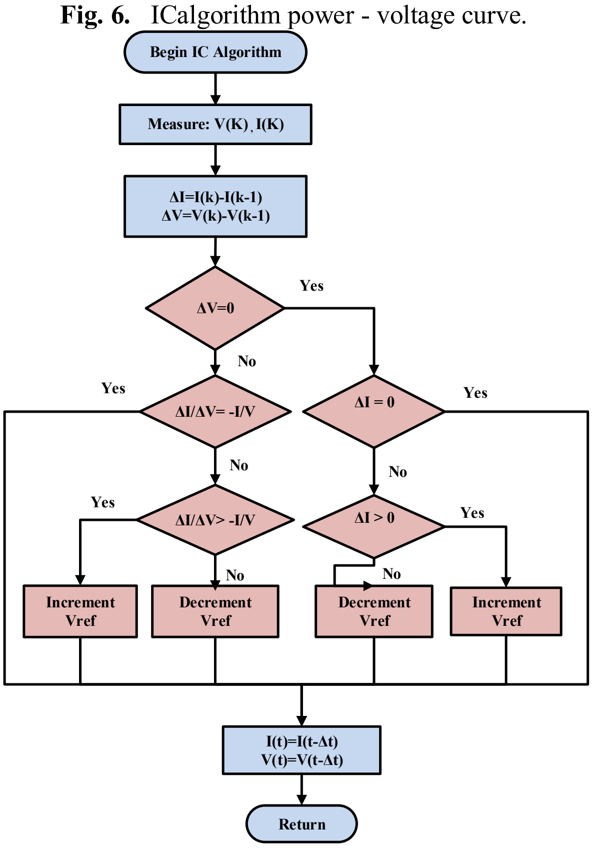


Fig. 7. The IC algorithm flowchart.

3.2. P&O Technique

Traditional P&O technique [1-5] works sometimes through photovoltaic voltage or current disturbances and compares the power of photoelectric output with the previous turbulence cycle. The traditional P&O technology is built on the variation in PV power produced by changes of voltages. Figure 8 illustrates the photovoltaic output power versus the plate voltage at a specific radiation. There are two locations to run as a point A ($d_P / dv > 0$) and point B ($d_P / dv < 0$). When the small step size of the voltage is used, it reaches the small steady state oscillations with a slow MPPT response result and increases the power loss. At the bottom line, there are three constraints connected with the typical MPPT controller. The primary one is answerable for huge fluctuations round the MPPT, the next constraint is the controller short speediness reply and the third one can drop the MPP drive below fast varying radiation. The Flowchart in Fig. 9 shows the implementation steps for the traditional P&O algorithm.

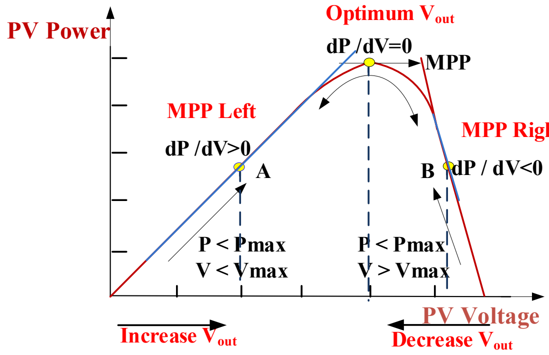


Fig. 8. P&O three modes of operation.

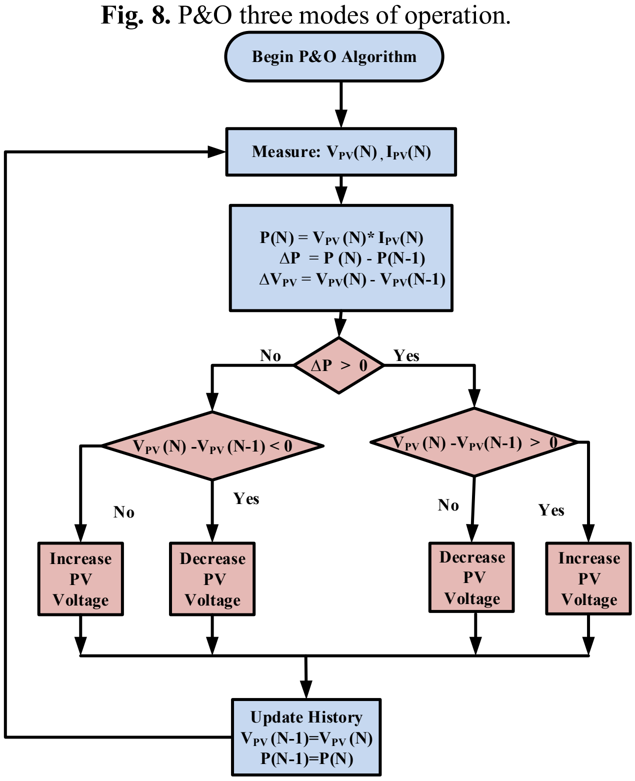


Fig. 9. The P&O algorithm flowchart.

3.3. MP&O Technique

Previous research has indicated that the most effective means of P&O MPPT in PV array system [14-20], however, this can be inaccurate to control of the working point at P-V characteristic. Our research here is expected to tackle a new significantly improved and simplified MP&O approach that will enhance the performance of traditional P&O algorithm by using reduce the fixed state fluctuation depend on change step scope of P-V curve. The step size will be great when the turbulence moves near the MPP, as soon as the MPP passes, the step size develops reduced.

The power curve is compared with an appropriate generation curve (G.dP/dV). The main difference between modified approach and other articles can be calculated in two ways. The first is the application of this approach to the PV power systems connected to the grid. The second is the PV operation area for a number of sectors, as shown in Fig. 10. Through this proposal, it can be used for a step size variable voltage the operating point segment is located. When the playback point is near from the mode of MPP, a small step size is applied to reduce the fluctuations in stable condition. Figure 11 illustrates the flowchart of the proposed different-sector algorithm.

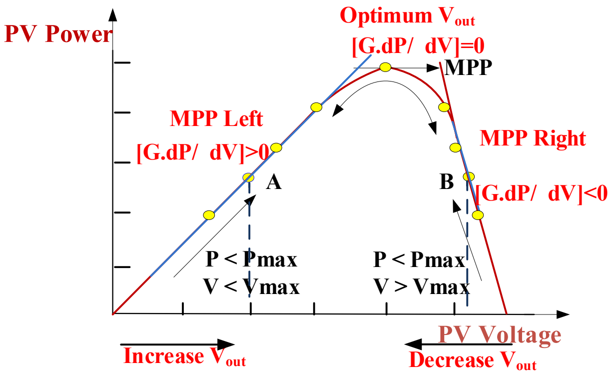


Fig. 10. MP&O modes of operation.

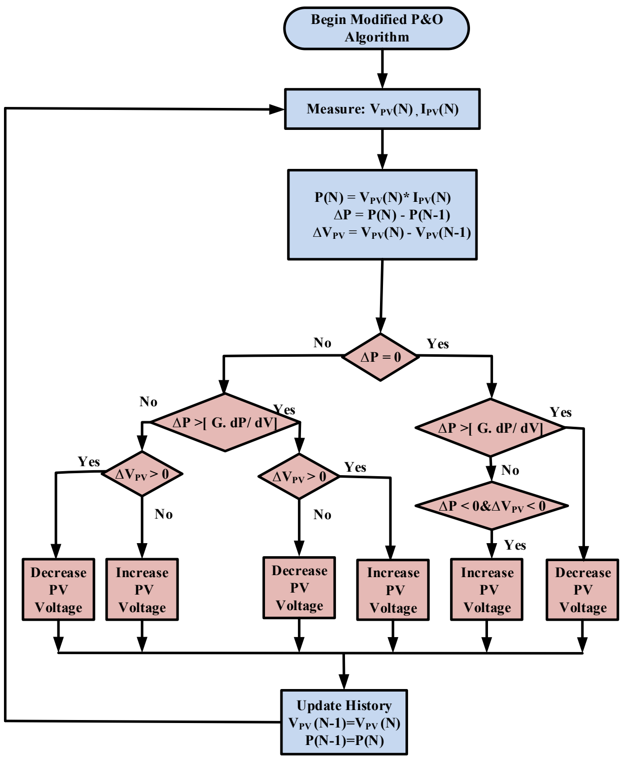


Fig. 11. The MP&O algorithm flowchart.

4. Results and Discussion

4.1. Results under ramp changes of solar radiation

MATLAB computing environment is used for display the proposed technique validity on the PV grid connected system. The system details are specified in Table 1. Figure 12, shows the change of solar radiation under the ramp profile with constant ambient temperature, in the form of solar radiation starting from 600 W/m^2 was gradually rising to 1000 W/m^2 and then less radiation until 800 W/m^2.

Figure 13 shows, PV output system performance comparison to IC, P&O and MP&O method under ramp changes of solar radiation. The output of PV power in the three different techniques shows that the best output energy using MP&O technique compared to another methods IC and P&O technique. Also, by comparing the MP&O algorithm performance with traditional P&O in the fast-varying weather environments of solar radiation, the MP&O is more accurate than the traditional method and under the high efficiency fast-varying weather solar radiation environments. The MP&O follows best MPPT. The proposed MP&O algorithm for tracking the system increases efficiency from 94% to 98% than traditional technology. This improvement in efficiency is better than [15].

Table 1. System parameters

Parameters	Values
PV maximum power of module	305.2 W
PV short circuit current of module	5.96 A
PV open circuit voltage of module	64.2 V
PV maximum current of module	5.58 A
PV maximum voltage of module	54.7 V
Parallel strings of PV array	66
Series-connected modules per string	5
Inductance of boost converter	5 mH
Resistance of boost converter	0.005 Ω
Capacitance of boost converter	100 µF
Converter switching frequency	10 kHz
Reference voltage of DC link	500 V
Inductance of filter	0.25 mH
Resistance of filter	0.015 Ω
Grid voltage	25 kV
Grid frequency	60 Hz
Step up transformer	260V / 25 kV

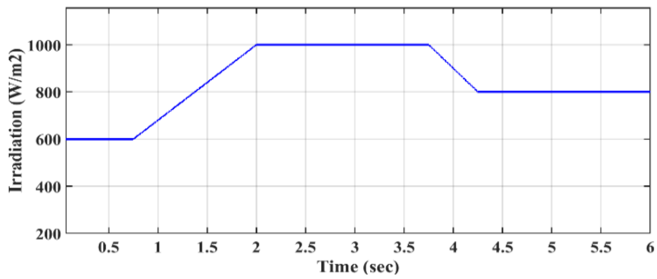
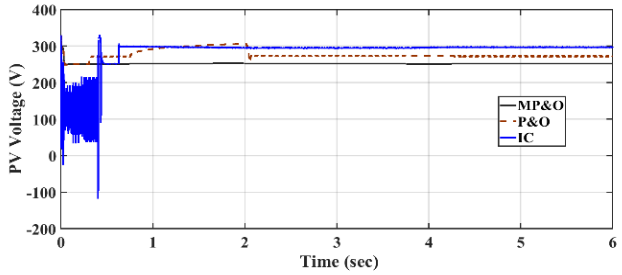


Fig. 12. Irradiance in a ramp changed profile.

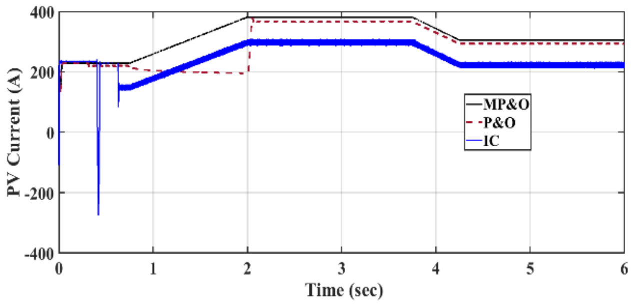
It is important to mention that, the oscillation is high during the high change in radiation, where the large voltage fluctuation occurrence from 0 to 0.5 second during applying IC algorithm, which has led to delaying the stability of the system at MPPT. This is clear evident that the suggested technique successfully minimizes the voltage oscillation as show in Fig. 13(a). Also, voltage fluctuation with the proposed method compared to the IC algorithm, which we find from 0 to 0.5 seconds large voltage fluctuation, delaying the stability of tracking the maximum value of the power of the system.

By comparing of output the PV current of the three techniques as cleared in Fig. 13(b), MP&O algorithm is the best performance to track the maximum possible of PV current. It is also noted that the maximum current value is not followed by the moment of change in solar radiation from 1 to 2 seconds for the P&O. The IC algorithm, there is a significant reduction in the signal value from the start time at 0.5 seconds with high output current fluctuation.

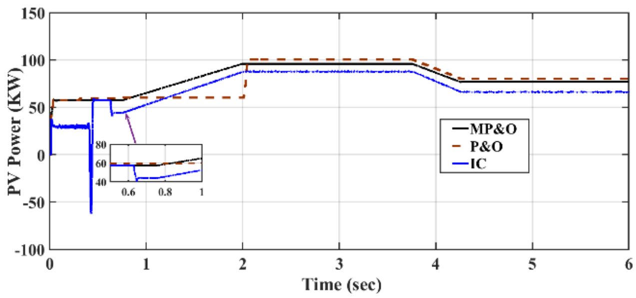
Figure 13 (c) shows the PV output power in the three different techniques, showing that the best output energy using MP&O compared to another methods IC algorithm and P&O. The system oscillations are reduced about the MPP and the system response is less than the IC and P&O algorithm. Table 2 shows the PV output power under different radiation between three different techniques.



(a)



(b)



(c)

Fig. 13. Performance comparison of PV system under ramp change irradiance; (a) output of PV voltage (b) output of PV current, and (c) output of PV power.

Figure 14, shows the great similarities between MP&O output boost converter and reference voltage. This indicates a high response to the proposed control.

Table 2. PV output power under different radiation

Time (sec)	Solar Radiation (W/m^2)	PV Output power (KW)		
		P&O MPPT	IC MPPT	MP&O MPPT
0 to 1	600	63	45	65
1 to 2	600 to before 1000	63 to 64	45 to 90	65 to 99
3.7 to 4.3	1000 to 800	99 to 80	90 to 75	99 to 80

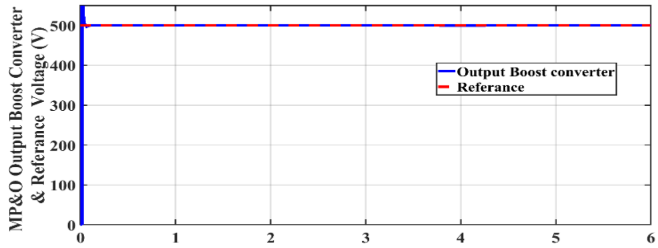
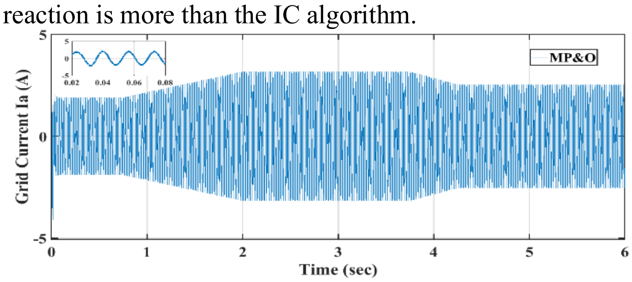


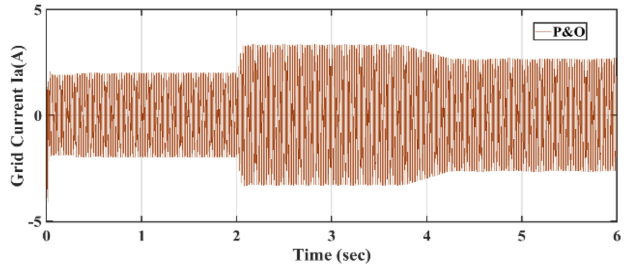
Fig. 14. MP&O output boost converter and reference voltage.

The system presents some of the main results of the utility grid currents, voltages and powers and that the system is synchronized with the utilities grid. The grid current and voltage at single phase using MP&O, P&O and IC algorithms under ramp changes of radiation as shown in Fig. 15 and Fig. 16. The results show that the current of the grid is changed to follow the maximum current; also, the voltage is stable to maintain the synchronization of the utility grid.

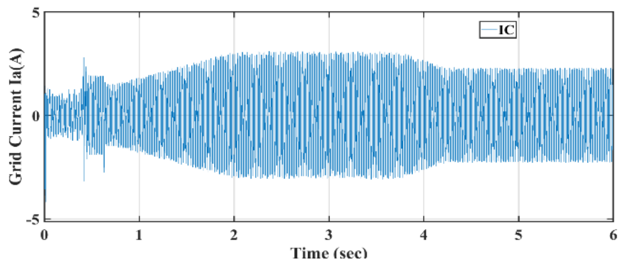
To ensure the operation of the unit power factor, the reactive power value must be zero. Figure 17 illustrate tracking the active power of the radiation form under different radiation levels. The d-axis component, active current change with solar radiation change from 0 to 1 pu where the q-axis current component of reactive is zero as shown in Fig. 18. It is reduced fluctuations in the system, in addition the system reaction is more than the IC algorithm.



(a)



(b)



(c)

Fig. 15. Grid current under different algorithms.

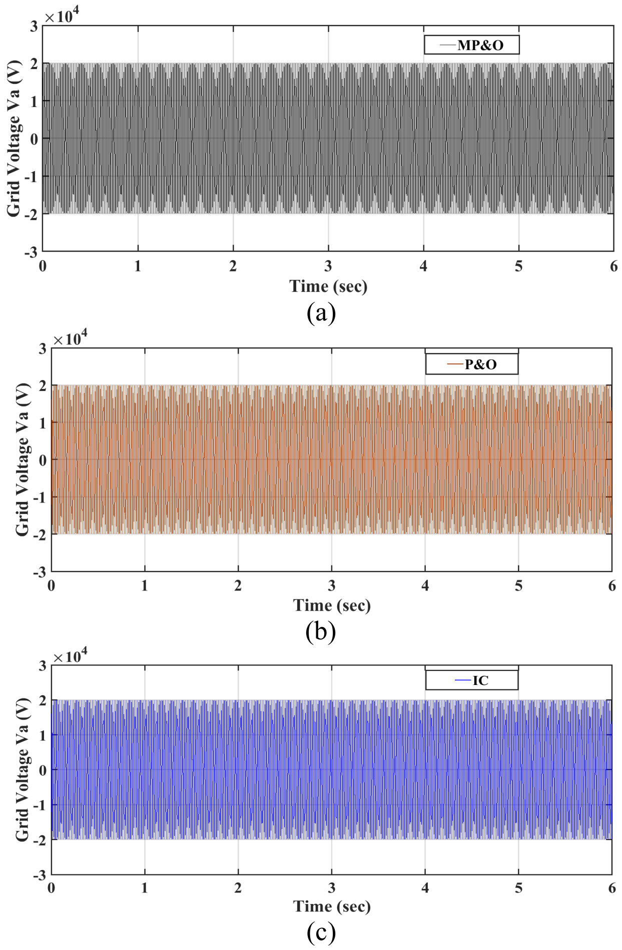


Fig. 16. Grid voltage under different algorithms.

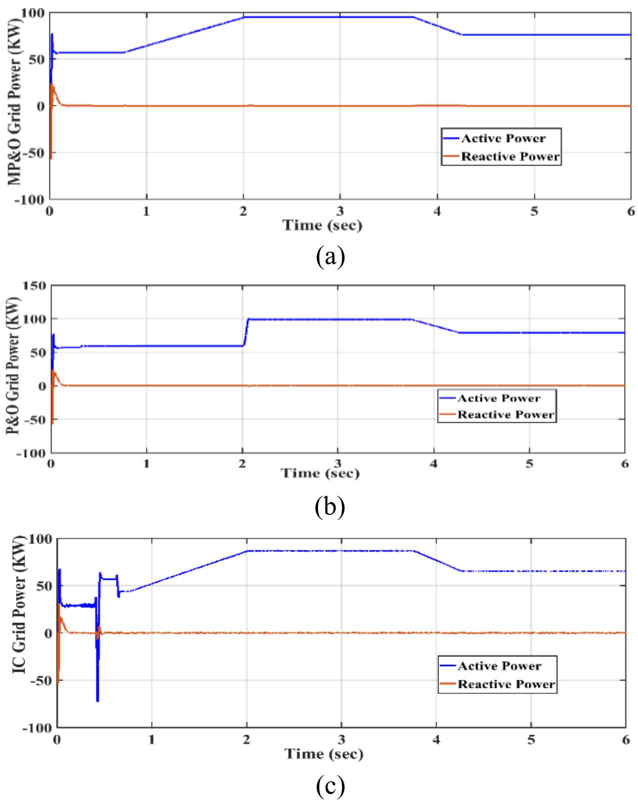


Fig. 17. Grid active and reactive power under different algorithms.

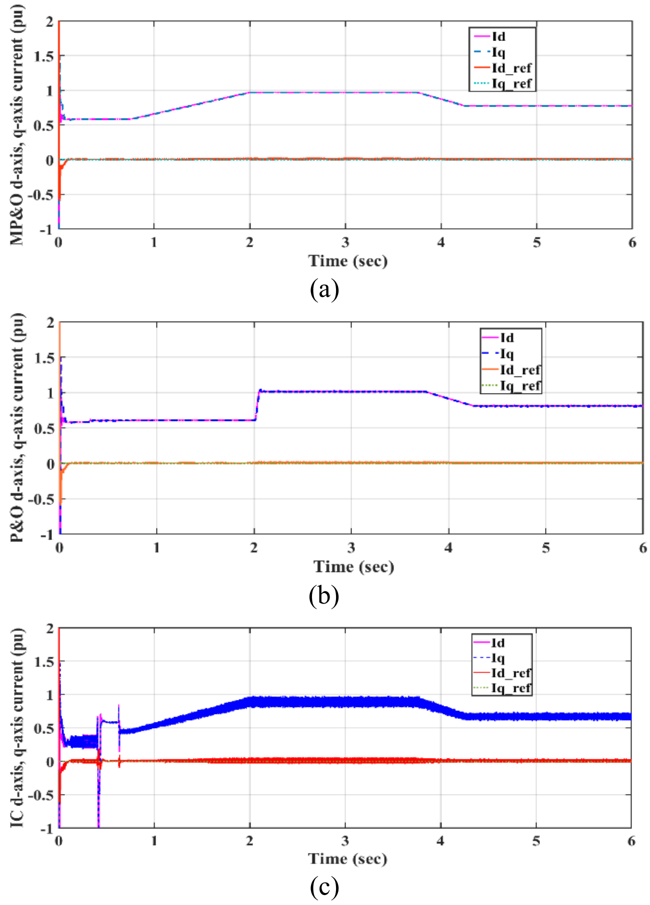


Fig.18. d-axis and q-axis current under different algorithms.

4.2. Results under random changes of solar radiation

The change of solar radiation under the random profile with constant ambient temperature are the varies randomly with an average value of 675 W/m^2 as showing in Fig. 19. Random change of radiation has a rainy day and it has clouds and this is one of the most difficult cases on the system of the MPPT for ensure the effectiveness of the proposed scheme.

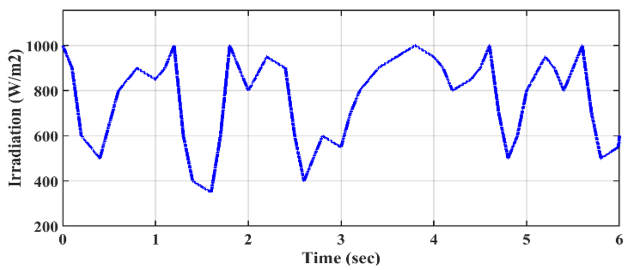


Fig. 19. Irradiance in a random changed profile.

Figure 20 shows, the performance comparison of the solar output system by using IC, P&O and MP&O technique under random changes of solar radiation. Figure 20(a) shows PV output voltage with three different algorithms. Consequently, the MP&O algorithm is the best performance of voltage output compared with the traditional P&O and IC algorithm as illustrated in Fig. 20 (a). By comparing the current of the PV system in the three techniques under random changes solar radiation as shown in Fig. 20 (b), it is clear that the method proposed by MP&O is better than IC and P&O in tracking the maximum possible of PV current. Also, the maximum value of the current is not followed by the moment of change in solar radiation. As for IC algorithm, a significant decrease in the value of signal at the moment of beginning at 0.5 seconds with a large fluctuation in the output of the current.

Figure 20 (c) displays the PV output power in the three different methods under random changes solar radiation, showing that the best output power using MP&O algorithm compared to another two methods IC and P&O. Also, by comparing the presentation of the MP&O and the traditional P&O in the fast-changing weather conditions of solar radiation, the MP&O algorithm is better than the traditional system. The system fluctuations are reduced about the MPP and the system response is faster than the IC and P&O controllers. The proposed MP&O algorithm for tracking the system improvement in efficiency.

The system presents some of the main results of the utility grid output currents, voltages and powers with the grid of utilities. Figure 21 shows the network current at single phase by using MP&O, P&O and IC algorithms under random changes solar radiation. To approve the process of the unity power factor, the reactive power value must be zero. This is illustrated by Fig. 22 tracking the active power of the radiation form under random changes solar radiation.

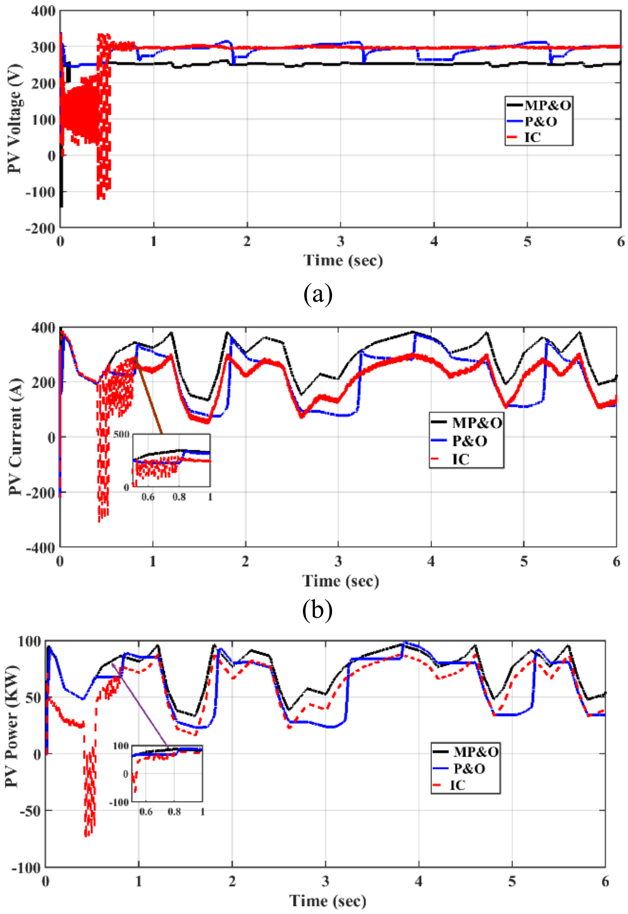


Fig.20. Performance analysis comparison of PV system under random change irradiance; (a) PV output voltage (b) PV output current, and (c) PV output power.

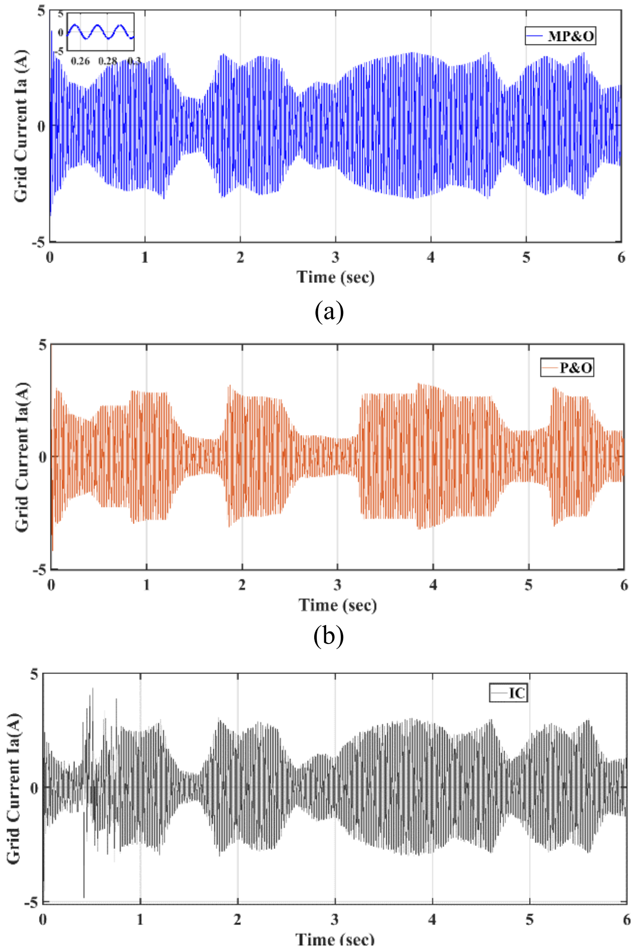
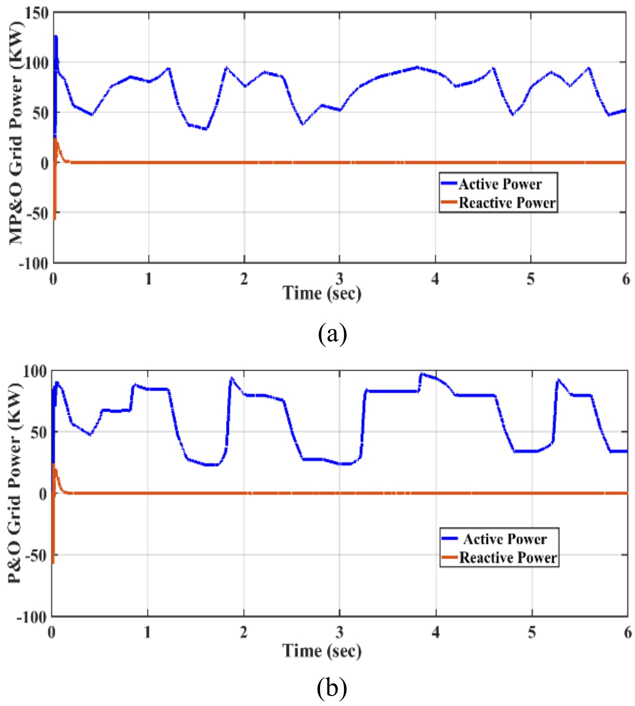
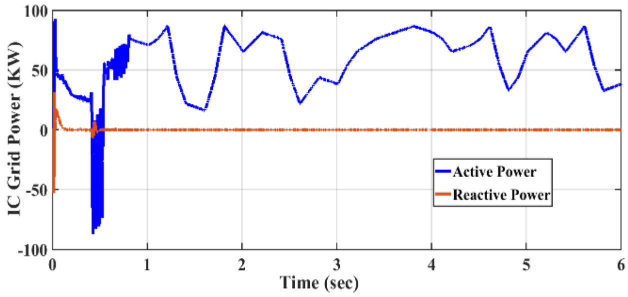


Fig. 21. Grid current under different algorithms.

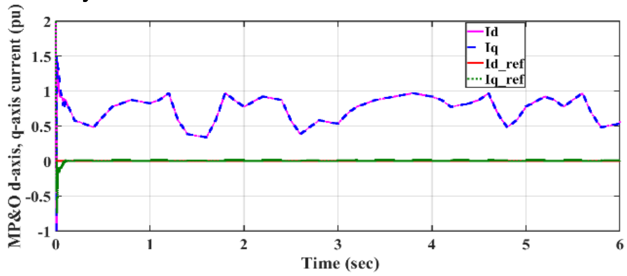




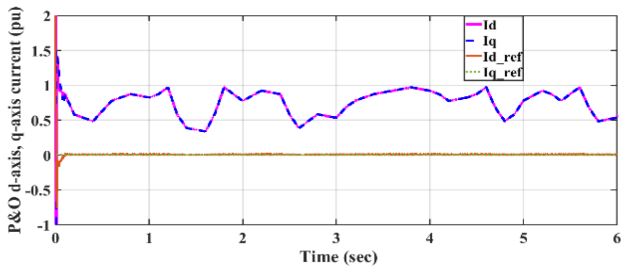
(c)

Fig. 22. Grid active and reactive power under different algorithms.

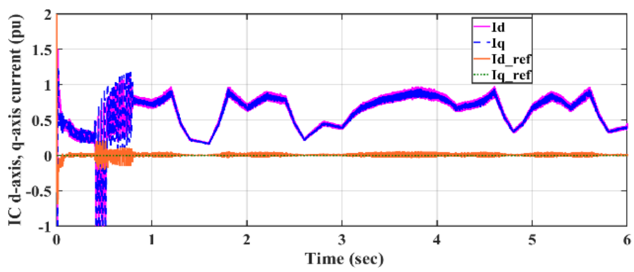
The d-axis component of active current change from 0 to 1 pu under random changes solar radiation where the q-axis component reactive current is zero as shown in Fig. 23. The MP&O system oscillations are less than the IC controllers.



(a)



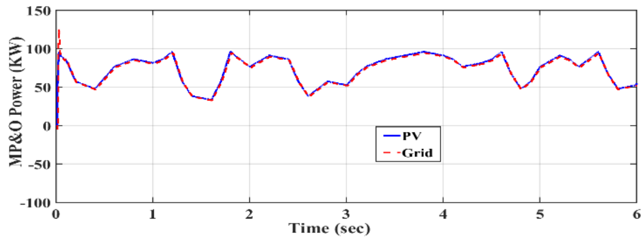
(b)



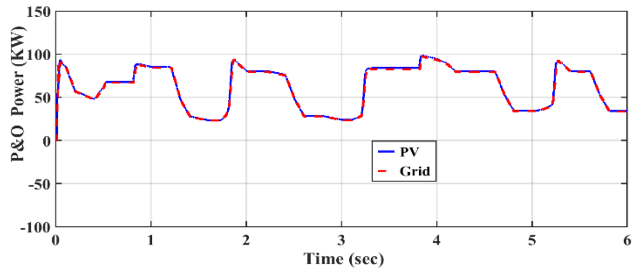
(c)

Fig. 23. d-axis and q-axis current under different algorithms.

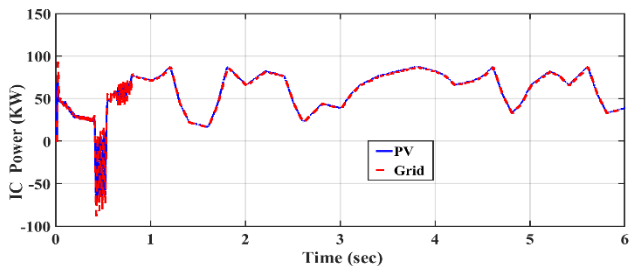
Figure 24, show the matching of PV output power with the grid power under random changes solar radiation, it is found to be 99%. This indicates the fast response, good tracking efficiency and good inverter control for the extracted power under different operation conditions.



(a)



(b)



(c)

Fig. 24. Performance comparison of PV and grid power under different algorithms.

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5. Conclusions

This paper presents a complete exhibiting of PV system with the control structures in the MATLAB/SIMULINK environment. The proposed control scheme based on the MP&O algorithm is presented to improve the performance of MPPT of grid-connected PV system. The proposed MP&O algorithm is used to improve the system response and reduce the constant oscillations of the voltages, current and power, which improves the efficiency of the system. By comparing the MP&O method and the P&O and IC method under different weather conditions the MP&O was better for an average rate of maximum electric energy. The current-voltage curve method is used to separate environmental effects from affecting the working point to MPP in the case of continuous irradiation, most of the time. The proposed system works under different sectors with different steps to obtain the maximum capacity of the solar energy and connected it with the grid. Finally, simulation results show the robustness and feasibility of the control scheme built on the proposed MP&O algorithm for MPPT and increases efficiency from 94 % traditional technology to 98%.

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