Application of a Combined System Between Perturb and Observe Method and Incremental Conductance Technique for MPPT in PV Systems

Ahmed Abd El Baset Abd El Halim, Naggar H. Saad and Ahmed Abd El Sattar

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Ahmed A. El Baset A. El Halim
Renewable energy Department
Faculty of Engineering
Egyptian Chinese University
Cairo, Egypt
ahmedabdelbaset2016@gmail.com

Naggar H. Saad
Electrical power and Machines Dep.
Faculty of Engineering
Ain Shams University
Cairo, Egypt
naggar_hassan@yahoo.com

Ahmed A. El Sattar
Electrical power and Machines Dep.
Faculty of Engineering
Ain Shams University
Cairo, Egypt
aasattar2@yahoo.com

***Abstract*—The fundamental issue of the Photovoltaic is the output proficiency; as the output relies upon solar irradiance and temperature. To progress its productivity, it should work at the Maximum Power Point constantly. Using power electronics, Maximum Power Point Tracking can be executed giving an interface among PV and load. The inspiration driving this paper is to propose a combine system that contains of Perturb and Observe and Incremental Conductance Method for Maximum Power Point Tracking for the Photovoltaic system. This combined structure is compared with other Maximum Power Point Tracking methodologies, which help in increasing the output proficiency, and decrease the output oscillations. The combined system between Perturb and Observe and Incremental Conductance Method was intended to adjust the duty ratio of the DC-DC converter and assurance that the track of Maximum Power Point works at its most extreme productivity. A simulation is performed to affirm the validity of the proposed controllers under different conditions. Finally, a comparative study between the methodologies is directed to favor the transcendence of the proposed controller for improving the PV effectiveness.**

Keywords—Maximum Power Point Tracking (MPPT), Perturb and Observe (P&O), Incremental Conductance Method (ICM), combined system of ICM and P&O.

I. Introduction

Maximum Power Point Tracking (MPPT) is a strategy that is commonly utilized with photovoltaic systems to increase the yield of it. The principle issue that influences the MPPT is the efficiency of transferring power from the PV to the customer's loads or the electric network. This proficiency relies upon two factors: the amount of sunlight that falls on the solar panels and the characteristics of the electrical load. As the amount of sunlight changes by time, the qualities of the load which gives the most extreme proficiency of power transfer change [1].

The scientific analysts applied a great deal of endeavors to optimize the yield of PV by utilizing several strategies for MPPT including Perturb and Observe (P&O) which usually utilized in practically; due to the enforcement of it is so easy. This strategy includes the operating point of PV, until it achieves the Maximum Power Point (MPP) [2]. For the most part, the P&O methodologies compare recent PV power with the past one [3]. The Incremental Conductance Method (ICM) is structured based on the observation of a distinctive P-V curve and the distinction of power with respect to voltage [3]. Because of this actuality, the MPP happens when the esteem of this operation is equivalent to zero [4]. This technique can follow the quick change in Irradiation more proficiently than P&O strategy [5]. But P&O technique is broadly utilized as its implementation is simple. P&O and ICM are characterized by simplicity and great execution; nonetheless, these methods are also marked by slow convergence and oscillations in produced power; thus, these methods are not reasonable to be implemented at a domain that experience the ill effects of quick changes either by irradiance and temperature [1].

Variable Step Size ICM (VSSICM) is for the most part like the ICM and the main distinction is the step size calculation [6]. The comparison made between variable step size and ICM MPPT techniques demonstrated that the VSSICM is increasingly viable with respect to the reaction time. The energy lost can be decreased with VSSICM MPPT technique. It very well may be seen that the response time with VSSICM MPPT technique is obviously better compared to that with ICM MPPT.

Another created strategy for MPPT utilizing Genetic Algorithm (GA) is presented in [7]. This procedure followed MPP quicker than conventional strategies; as it is utilized to realize the maximum proficiency of the PV systems. GA MPPT strategy is executed to search the MPP utilizing fuzzy control [8]. This technique isn't autonomous of the accurate mathematical of the PV. Tracking dependent on fuzzy computation is viewed as smart, as it tracks the MPP regardless of whether the inputs of the system are not precise. Binary Search (BS) technique is the MPPT dependent on GA [9]. In this technique, the controller recognizes all the changes in the PV system while searching the database for the ideal point utilizing GA.

Particle Swarm Optimization (PSO) is favored for MPPT as it is simple and characterized by its quick computation capacity [10]. The PSO methodology lessens steady state fluctuations and needs lower memory or computations. Moreover, this technique has the significant advantage of accessing MPP without pause. However, the initialization of duty ratio is tedious in the process of reaching the MPPT [11]. The improved PSO (IPSO) method has been applied to MPPT in PV arrays that are linked with the grid using the power electronics interface.

The modulation index for the converter can be generated by utilizing IPSO MPPT. Its tracking speed is higher compared to that of the conventional PSO; so it reduces the losses in energy during the MPPT process, and enhances the output efficiency [12]. In [13], the IPSO is presented as a master controller that controls the power of the sources relying upon IC control.

Concerning the fast PV MPPT strategy utilizing Cuckoo Search Algorithm (CSA), it is presented in [14]. This technique has the capacity of seeking under partial shading conditions. This strategy has less transient vacillations and small error in steady state compared to P&O and PSO technique. CSA technique is more robust, has better convergence and exhibits higher efficiency [15, 16]. In [17], the CSA is presented; it is exceptionally efficient, as it shows zero swaying at steady state; and thus, spares a lot of power. Additionally, this algorithm can track the MPP successfully when the atmospheric condition changes so rapidly.

Motivation behind this paper is to present the P&O dependent on ICM technique which is hybrid algorithm comprises of P&O and ICM for MPPT of the PV system. This technique is compared with other MPPT methods. The proposed technique provides high efficiency and less oscillation in MPPT operation. Table I, demonstrates the required sensors, speed, stability and proficiency for various MPPT strategies, compared to the technique for this paper.

II. Description and Operation of the Whole System

The connection diagram in Fig. 1, shows the connection of the PV system which comprises of PV array with maximum power 100 kW (model type: Sun Power SPR-305), switching duty ratio is enhanced by the MPPT controller, 5 kHz DC-DC boost converter utilized in rising the voltage of PV from 272 V_{DC} at the maximum power to 500 V_{DC}, 3-level 3-stage V_{SC}, which is utilized to change the 500 V_{DC} to 260 V_{AC} and advance the power factor to be unity, 10 $kVar$ capacitor bank to filter the harmonics generated by VSC, 100 kVA – 260 V / 25 kV three-phase transformer and grid.

III. Mathmatical Modeling of Solar PV

A. Mathmatical modeling of PV

Fig. 2, demonstrates the solar cell equivalent circuit using one diode model. The two equivalent resistors series resistor (R_s) and parallel resistor (R_p) represent the losses in the circuit.

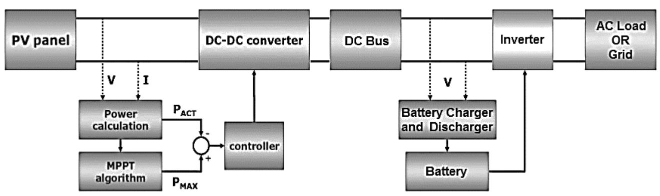

Fig. 1. Connection of whole PV system

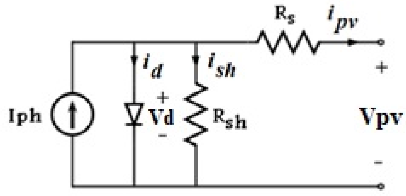

Fig. 2. Equivalent circuit of PV cell

The cell output current is affected by the losses caused to the circuit, which is expressed by Eq. (1). [6]

$$i_{pv} = I_{ph} - i_d - i_{sh} \quad (1)$$

Where i_{pv} is the PV output current (A), I_{ph} is photo generated current (A), i_d is diode current (A) and $i_{sh} = (v_{pv} + i_{pv}.R_s)/R_p$ is leakage current (A). Diode current is expressed based on I-V characteristics of a Shockley diode by Eq. (2).

$$i_d = I_{sat}(e^{\frac{v_d}{a.V_T}} - 1) \quad (2)$$

Where I_{sat} is diode saturation current (A), $v_d = v_{pv} + i_{pv} \times R_s$ is diode voltage (V), v_{pv} is the PV output voltage (V), a is ideality diode factor, $V_T = (N_s\, K_B/e)T$ is temperature voltage (V), N_s is number of cells that connected in series, K_B is Boltzmann's constant which equals to 1.3806×10^{-23} (J/K), e is absolute value of electron charge which equals 1.6022×10^{-19} (C) and T is cell temperature (K). The photo generated current (I_{ph}) value is represented by Eq. (3).

$$I_{ph} = \left[I_{ph.ref} + K_o\left(T - T_{ref}\right)\right]\frac{G}{G_{ref}} \quad (3)$$

Where $I_{ph.ref}$ is photo generated current at std. in (A), K_o is short-circuit coefficient of temperature at std., T_{ref} is reference temperature at ($25\,°C + 273 = 298\,K$), G is solar radiation in (W/m^2) and G_{ref} is reference solar radiation that estimated at 1000 W/m^2. The value of dark saturation current (I_{sat}) is represented by (4).

$$I_{sat} = I_{sat.ref}\left(\frac{T}{T_{ref}}\right)^3 e^{\frac{e.E_g}{K_B.a.V_T}}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right) \quad (4)$$

Where band gap energy is equal to $E_g = 1.121\left[1 - 0.0002677\left(T - T_{ref}\right)\right]$ of the silicon is based on electron volts and dark saturation current $I_{sat.ref}$ at std.. By substitution with Eqs. (2), (3) and (4) in Eq. (1), i_{pv} can be obtained.

TABLE I. MPPT COMPARATIVE TABLE [6]

#	Tracking methods	A/D	Sensors	Speed	Stability	Efficiency
1	Perturb and observe (P&O)	A/D	V&C	Slow	Not stable	Low
2	Incremental Conductance (IC)	D	V&C	Slow	Stable	Low
4	Fuzzy Logic Control	D	V&C	Very fast	Stable	High
5	Neural Network	D	V&C	Very fast	Stable	High
6	Practical Swarm Optimizer (PSO)	D	V&C	Very fast	Very stable	Very high
7	Cuckoo Search Algorithm (CSA)	D	V&C	Fast	Stable	High
9	Proposed technique	A/D	V&C	Very fast	Very Stable	Very high

(A/D: Analog/Digital – V&C: Voltage and Current)

B. I-V characteristics of PV

Table II. shows all the parameters of the PV module that will be used to Implement I-V characteristics of the PV system.

TABLE II. ELECTRICAL PERFORMANCE OF SUN POWER SPR-305 MODULE [16]

Parameters	Value
Voltage at MPP, V_{mp}	54.7 V
Current at MPP, I_{mp}	5.58 A
Power at MPP, P_{mp}	305.226 W
Open circuit voltage, V_{OC}	64.2 V
Short circuit current, I_{SC}	5.96 A
Series Equivalent Resistor, R_s	0.037998 Ω
Parallel Equivalent Resistor, R_p	993.51 Ω
Saturation Current, I_{sat}	$1.1753\text{x}10^{-8}$ A
Photo Generated Current, I_{ph}	5.9602 A
Q_d	1.3

Fig. 3 and Fig. 4 represent the $(I - V)$ attributes of the module given in table I. The characteristics are observed under std., irradiance 1000 W/m^2 and module temperature 25 $°C$.

IV. MPPT ALGORITHMS

Numerous techniques for MPPT had been suggested in [18,19, 20]. Two of them are frequently used to accomplish the MPPT: P&O and IC techniques. As of late, these methodologies are utilized in the commercial MPPT.

The motivation behind the MPPT, is to extract the maximum yield of power from the PV module, through its operation at the most efficient current and voltage. Mainly, the MPPT tests the output of PV module; then determines the best power point the PV module can generate to DC – to – DC converter as shown in Fig. 5.

A. Perturb and observe method

The P&O methodology is widely used in trade products and is the basis for the bulk of the more advanced algorithms in the literature [21]. It is widely used in practice, because of the minimum cost it has, the clarity of implementation. [21-23].

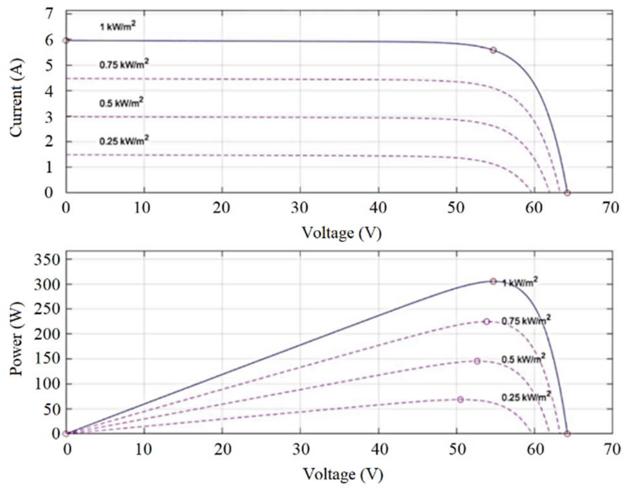

Fig. 3. I-V and P-V curves of one module at 25 deg.C

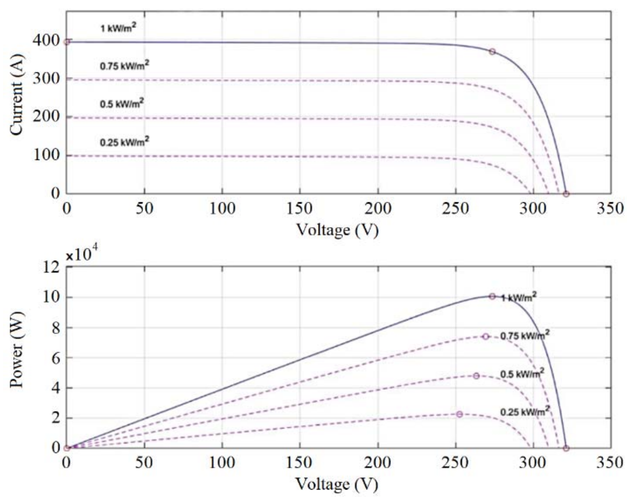

Fig. 4. I-V and P-V curves of the array at 25 deg. C

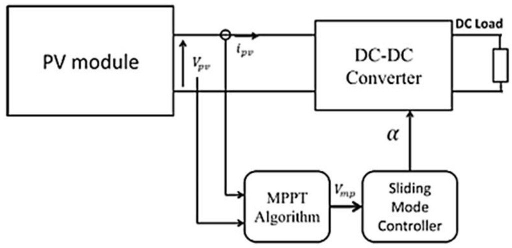

Fig. 5. Connection diagram of full PV system using MPPT control

P&O works by perturbing the operating voltage point (V) and monitoring the power deviation in order to deduce the next progression direction to obtain the reference voltage (V_{ref}) [24].

Consequently, if the working voltage (V) of the PV is perturbed in a forward direction and the power that is drawn from it increased, this infers the working point has advanced toward the MPP and, thusly, the working voltage must be likewise perturbed in that direction also. Another something, if the power drawn from the PV reduces, the working point has moved away from the MPP and so, the course of the working voltage perturbation must be turned around [25]. Fig. 6, demonstrates the P&O flowchart [25].

The real disadvantages of the P&O strategy are deviation from the MPP if there any occurrence of quickly changing atmospheric conditions, for example, mists [25].

A few enhancements in the P&O methodology have been proposed in order to diminish the amount of fluctuations around the MPP in a stable state, however, they hinder the method when environmental conditions change and decline efficiency among the shady days [26].

B. Incremental conductance method (ICM)

ICM relies on the idea that the inclination of the PV power versus voltage (P-V) curve is zero at the MP point. It was suggested to improve tracking precision and dynamic execution under quickly varying conditions [27-29]. The yield current and PV output voltage are then monitored. The MPPT controller relies on behavior identification and IC, and decides on the selection decision (increase or decrease the percentage of duty ratio). The productive power of PV can be calculated using P = V × I. Therefore, the power derivative generated by the system:

$$\frac{dP}{dV} = \frac{d(V \times I)}{dV} = I + V\frac{dI}{dV} \tag{5}$$

$$\frac{1}{V} \times \frac{dP}{dV} = \frac{1}{V} + \frac{dI}{dV} \tag{6}$$

The point of this strategy is to find the voltage working moment that the PV momentary conductance (I/V) is equivalent to (dI/dV). The slope of the PV power curve equals to zero at the MPP, mounting on the left of MPP and diminishing on the right-hand side (RHS) of MPP, as appeared in Fig. 7. The next equations are used to express what is done:

$$\frac{dP}{dV} = 0 \ if \ \frac{dI}{dV} = -\frac{I}{V}, (at\ MPP) \tag{7}$$

$$\frac{dP}{dV} > 0 \ if \ \frac{dI}{dV} > -\frac{I}{V}, (left\ of\ MPP) \tag{8}$$

$$\frac{dP}{dV} < 0 \ if \ \frac{dI}{dV} < -\frac{I}{V}, (right\ of\ MPP) \tag{9}$$

ICM flowchart is shown up in Fig. 8. In this method, two sensors are used to measure (I) and (V). The changes of (dV) and (dI) can be known carefully by examining the yield of the PV (I) and (V) at consecutive time interims $(n-1)$ and (n) as pursues [30]:

$$dV_n = V_n - V_{n-1} \tag{10}$$

$$dI_n = I_n - I_{n-1} \tag{11}$$

ICM can confirm the direction in which the operating point is perturb to achieve MPP. Hence, when the radiation is rapidly increased, it ought not have in the incorrect trend, as P&O can.

C. Proposed ICM based on P&O

This technique is the subject of this paper as it is a mix of two techniques, ICM and P&O; where the P&O technique principally decides the initial conditions of ICM then fed them to it. These initial conditions help the system to discover the MPPT quick with high proficiency with no event of any oscillations.

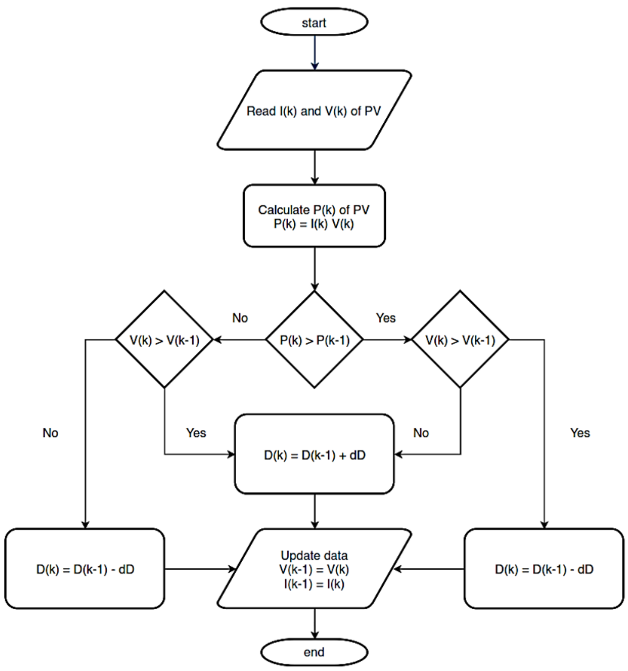

Fig. 6. Flowchart of P&O method

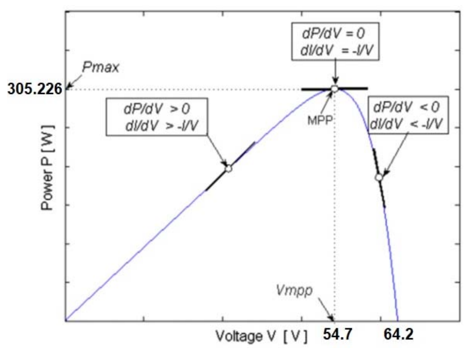

Fig. 7. Principle of ICM

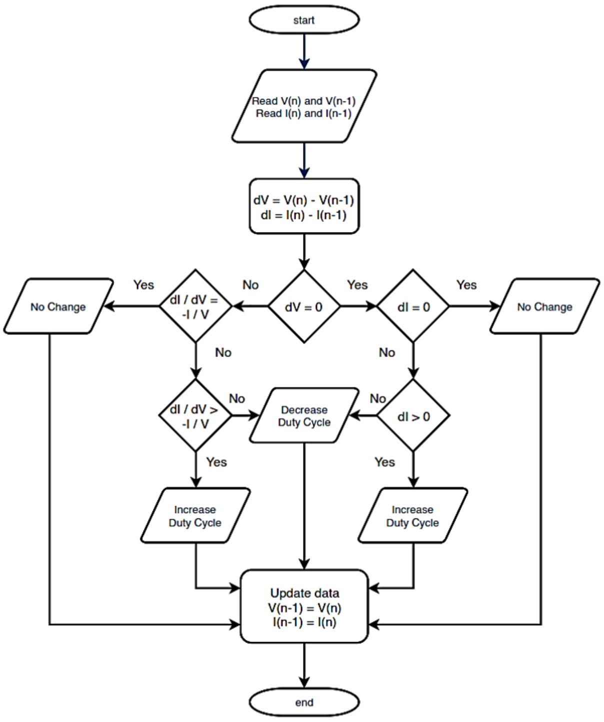

Fig. 8. Flowchart of ICM

In this technique, the P&O is working directly while ICM is stand by, until the initial condition is set up through the P&O. By and large, P&O technique is utilized to find out the initial duty cycle (D) for ICM. This procedure uses current and voltage sensors to verify and measure the productivity of the PV system. Also P&O is the least expensive to carry. Moreover, they are less complex to achieve because they rely on the passive circuitry to measure current and voltage. These measured values should be specified to show whether the duty cycle has increased or diminished. By contrasting the present input power with the previously input power, it can be decided if the (D) diminished or increased to keep following the MPP.

ICM is another methodology for MPPT. This strategy uses gradual measurements on the modification in the PV connection. Using these measurements, it can calculate whether there has been an increase or diminish in power since the last measurement. The IC is defined as $(d\, I_{PV}/d\, V_{PV}\ )$. By contrasting this measurement to the actual conductance of the PV array, one can figure out which side of the MPP the current operating point is located.

This duty cycle generated by P&O algorithm is fed to the ICM MPPT method as an initial condition, helping ICM to search effectively about MPPT. At long last, the entire system produces its duty ratio, which feeding the DC-DC converter which influences the yield control either by an increase or decline. The composited system flowchart is clarified in Fig. 9. By changing D after a specified period of time, the built-in system verifies the recently estimated input power. If the newly entered value of the input power is the largest compared to the old value, and for the voltage as well, D decreases in order to approach the greatest power. If the newly measured value of the input voltage is smaller than the old value and at the same time it has more input power, then D is increased at that time. On the other hand, when the current power is less than its predecessor and the current voltage is greater than its predecessor, so the D is diminished in order to converge to MPP. D also diminishes, when current power and voltage are lower than the old measured values.

At long last, the ICM combination and the precision of P&O technology help to reach MPP at high speed without any fluctuations or distortions.

V. Simulation Results

A. MPPT based on P&O

The output waveforms, shown in Fig. 10 and Fig. 11, indicate the power of PV, duty cycle, output voltage of PV and output power to the grid via time, due to sudden step changes in irradiance.

Fig. 10, shows the output power of the PV due to the change in irradiance; the overall efficiency of the output power is 97.869%. Meanwhile, it shows the output power, voltage and duty cycle for sudden step change in irradiance of PV. While Fig. 11, shows the output power of the system that feeds the grid, with overall efficiency 95.943%, and also indicates the high overshooting in the output power that reach 21.92% over the steady state.

B. MPPT based on ICM

The output waveforms, shown in Fig. 12 and Fig. 13, show the output voltage and power of PV, duty cycle and output power to the grid due to sudden changes in irradiance.

Fig. 12, illustrates the yield power of the PV due to the change in irradiance; the overall efficiency of the yield power is 94.99%. Meanwhile, it indicates the output voltage and duty cycle for sudden step change in irradiance of the PV. Whereas Fig. 13, indicates the output power of the system that feeds the grid, with overall efficiency 93.08%.

C. MPPT based on hybrid system between ICM and P&O

The output waveforms, shown in Fig. 14 and Fig. 15, indicate the output power of PV, duty cycle, output voltage of PV and output power to the grid due to sudden changes in irradiance.

Fig. 14, shows the yield power of the PV due to the change in irradiance; the overall efficiency of the output power is 97.868%. In same time, it shows the output power, voltage and duty cycle for sudden step changes in irradiance of PV. Finally, Fig. 15, illustrates the yield power of the system that feeds the grid, with overall efficiency 95.966%, which is the largest efficiency, compared to other methods in that paper.

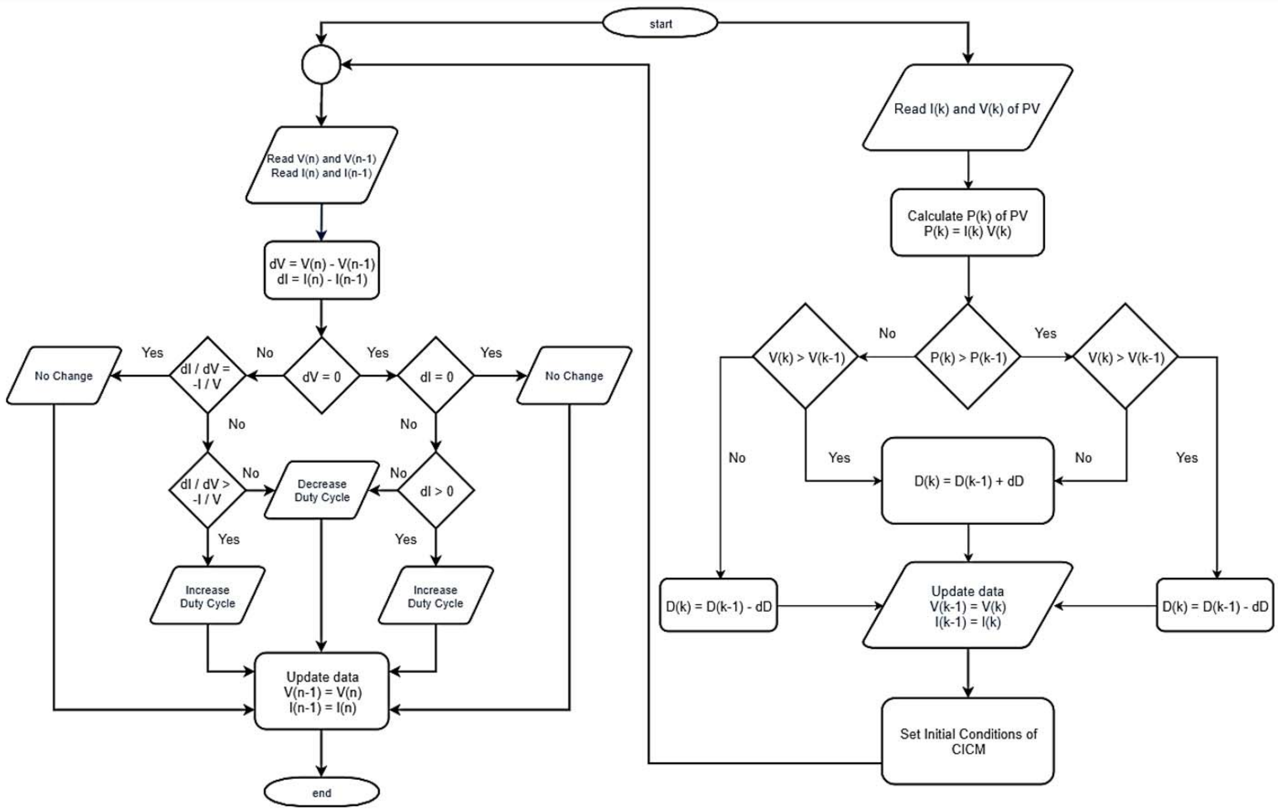

Fig. 9. Flowchart of a combined system ICM and P&O algorithm

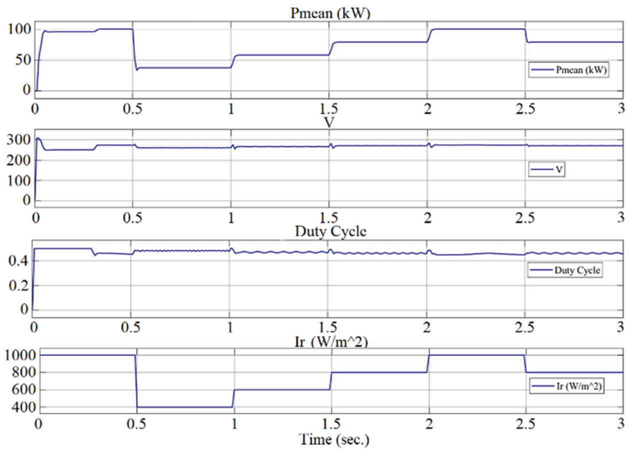

Fig. 10. Output power, voltage due to duty cycle via time for sudden step change in irradiance of PV using P&O MPPT

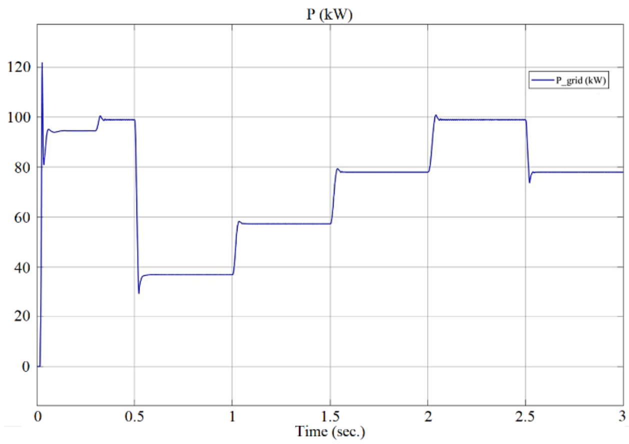

Fig. 11. Output power of grid using P&O MPPT

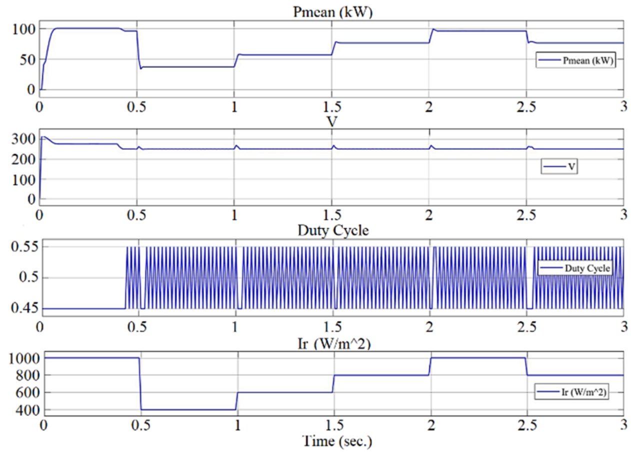

Fig. 12. Output power, voltage due to duty cycle via time for sudden step change in irradiance of PV using ICM MPPT

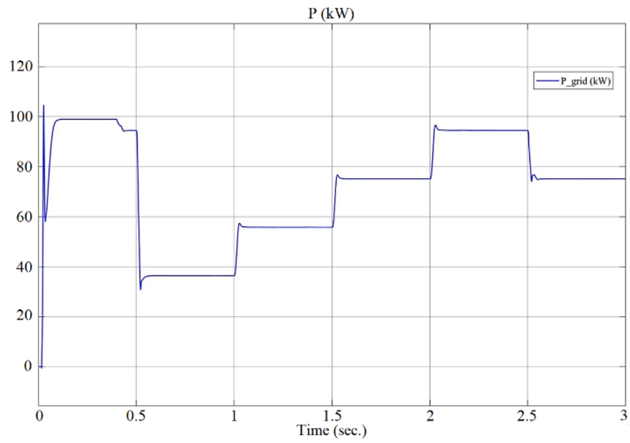

Fig. 13. Output power of grid using ICM MPPT

Table III. shows the output power of the PV for each case, output power to the grid, the losses of power in the system, the efficiency at every step change for PV power and grid power, overall efficiency and maximum overshoot for output power of the PV and grid.

Table III. indicates a comparison between the output efficiency of each case, the overall efficiency and maximum overshoot in the yield power of PV and grid.

The output power of PV at 1000 W/m^2 (1 sun) irradiance for the combination between P&O and ICM MPPT, subject of this study, is the highest one and has the efficiency of 99% compared to other MPPT methods, and it is higher than the second largest one (P&O technique) by 0.05%, and the ICM by 4.48%. Besides, the output power and voltage waveform do not have oscillations.

For 800 W/m^2 irradiance, the efficiency of the output power of the grid of the method subject of this paper increases by 0.0025% compared to the P&O method and 3.5625% compared to ICM. As for the 600 W/m^2 irradiance, the efficiency increases by 0.03667% compared to the P&O method and 2.3416% compared to ICM.

For 400 W/m^2 irradiance, the efficiency of output power of grid for the method of this paper is as P&O technique which is the highest output for the shown methods at these irradiances and increases 1.07% compared to ICM.

The combination between the P&O and ICM MPPT has high overall efficiency compared to other MPPT techniques, and low overshoot compared to the P&O or ICM standalone; so it does not need high power electronics components range.

VI. Conclusion

It turns out to be evident that the above outcomes demonstrate the validity of the proposed strategy as it has high productivity at all sudden change steps of irradiance compared with different techniques as appeared in table III, alongside its speed in tracking the MPP; as it achieves the steady state by a very high speed rapid with no disturbance or oscillations.

As seen from the above outcomes, the overshoot due to the abrupt irradiance changes has been limited, where a combination of the P&O and ICM has been used to improve the MPPT response, and accomplish high generally effectiveness compared to other MPPT; and thus, it doesn't need high power electronics components range. In other side, the rising time has been considerably decreased, as the system can achieve 0.9 from the most extreme estimation of the steady state in less than 62.5 msec. compared with other methods.

The conventional methods fluctuate at the MPP, which remains a problem in tracking precise MPP. For that, the proposed technique for this paper has been exploited to address this issue. The system offers a convincing demonstration at both the transient and steady state stage compared with the other MPPT, which lack of ideal execution at either the transient or the steady state operating point.

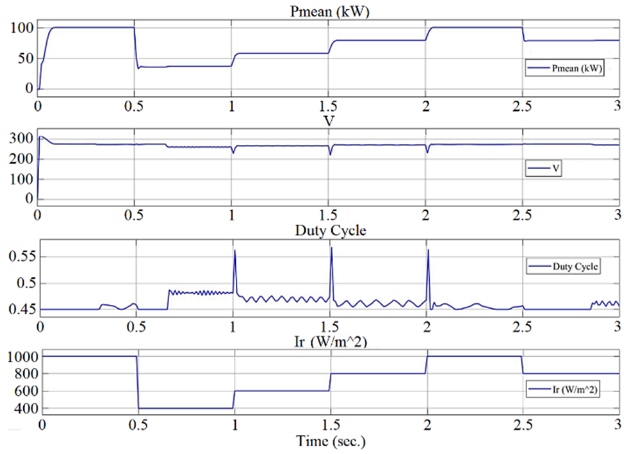

Fig. 14. Output power, voltage due to duty cycle via time for sudden step change in irradiance of PV using ICM based on P&O MPPT

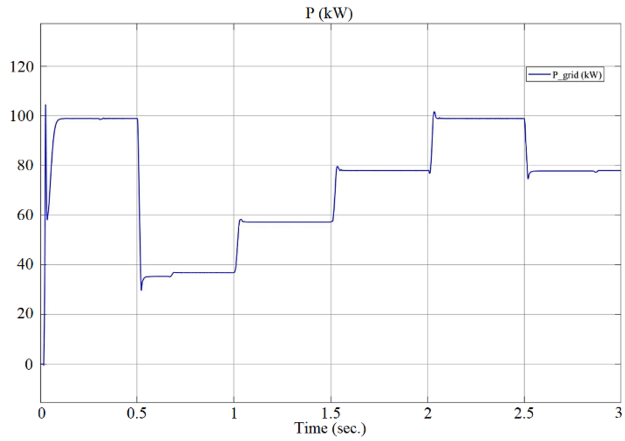

Fig. 15. Output power of grid using ICM based on P&O MPPT

TABLE III. EFFICIENCY OF OUTPUT POWER AND MAXIMUM OVERSHOOT DUE TO EACH MPPT METHOD

MPPT Method	Reference Power (kW)	Out Power of PV (kW)	Output Power on Grid (kW)	Power loss in the system (kW)	Efficiency		Overall Efficiency		Maximum overshoot	
					PV Power (%)	Grid Power (%)	PV Power (%)	Grid Power (%)	PV Power (kW)	Grid Power (kW)
P&O	100	100.714	98.95	1.764	100.714	98.95	97.8693	95.9437	100.724	121.922
	80	79.4	77.98	1.42	99.25	97.475				
	60	58.358	57.21	1.148	97.2633	95.35				
	40	37.7	36.8	0.9	94.25	92				
ICM	100	96.3	94.52	1.78	96.3	94.52	94.9927	93.08	100.709	104.624
	80	76.55	75.132	1.418	95.6875	93.915				
	60	56.9	55.773	1.127	94.833	92.955				
	40	37.26	36.372	0.888	93.15	90.93				
P&O with ICM	100	100.722	99	1.722	100.722	99	97.8688	95.96604	100.724	104.6242
	80	79.4	77.982	1.418	99.25	97.4775				
	60	58.352	57.232	1.12	97.253	95.3866				
	40	37.7	36.8	0.9	94.25	92				

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