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Comparative Study of Perturb & Observe, Modified Perturb & Observe and Modified Incremental Conductance MPPT Techniques for PV Systems

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K E Y W O R D S

Boost Converter, Impedance matching, Maximum Power Point Tracking (MPPT), Modified Perturb and Observation (Modified P&O).

A B S T R A C T

This paper presents a modified maximum power point tracking algorithm (Modified MPPT) for PV systems based on incremental conductance (IC) algorithm. This method verified with the dynamic irradiance and sudden change of irradiance, the comparisons with conventional methods, for example, the perturbation and observation (P&O) and Modified perturbation and observation (Modified P&O) were performed. A photovoltaic (PV) panel was simulated and tested using MATLAB/Simulink based on PV panel at Power Electronics Laboratory. The results show that this method capable to find the maximum power point (MPP) under dynamic behavior faster than (P&O) and Modified P&O). Reduced oscillation of MPP indicates enhanced efficiency, providing maximum power transfer to load.

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1. Introduction

Global energy attention has recently expanded significantly, due to population growth. Also, global warming is increasing due to carbon dioxide emissions from fossil fuels. Therefore, these complex challenges must be resolved. Several studies have suggested using sustainable energies to stand up to the issue of the absence of energy in the forthcoming years and to minimize the impacts of consuming fossil energizes. Solar energy has many advantages over conventional energy sources, because of its, clean, sustainable and safe energy.[1] However, the PV system is considered to be of low efficiency, due to the dependence on the power of PV panel on several factors such as the intensity of radiation and the temperature, i.e. weather conditions, resulting in energy loss and lower efficiency [1,2].

To enhance the efficiency of the photoelectric system, MPPT techniques are combined with the converter circuit to derive maximum power from the PV panel [1]. The main objective of MPPT is to extract maximum power from the PV array in every circumstance [3]. There are several considerations when designing MPPT, such as the number of sensors required [4], the level of complexity, the convergence speed, cost, and hardware required [5,6].

MPPT algorithms for PV systems are organized into three kinds: offline, online and hybrid algorithms [7]. The offline algorithms depend on system parameters, including open-circuit voltage (Voc) and short circuit current (Isc), this type includes fractional short circuit current (SCC) algorithm and fractional open-circuit voltage (OCV) algorithm [8]. the online methods do not depend on the PV model parameters, such (P&O) [6], and incremental conductance (IC) [4,9]. The combination of the two previous methods produces a hybrid method [1,10]. The (P&O) and (IC) Algorithms are commonly used due to operation simplicity and the low number of sensors required [4-11]. MPPT techniques have been widely described in the literature [4,12,13-14]. In [15] the short circuit current (SCC)-based adaptive P&O algorithm is suggested; this method involves two algorithms, that is (Current-perturbation-algorithm) and (Adaptive-control-algorithm). These methods were developed from P&O algorithm and the fraction short circuit current (FSCC) algorithm. The main drawback of this method is that in a large variation in radiation, the initial operating point should be determined, and the current short circuit should be estimated. In [16], Bata method was proposed to address the problem that facing MPPT methods, namely the tradeoff between the steady-state oscillations and dynamic behavior, and then the tradeoff between high computational load and accuracy. In [17], the author proposes a perturb and observe maximum power point tracking (MPPT) algorithm, the main difference of the proposed system includes the addition of PI control loop along with the MPPT control circuit. The author in [18], propose simulation of incremental conductance (IC) maximum power point tracking (MPPT) with a direct control method. The main difference of the proposed system to existing includes the elimination of the proportional-integral control loop and the investigation of the effect of simplifying the control circuit. The adaptive P&O algorithm proposed in [19], by estimating the short circuit current, in this proposed method, current perturbation is considered to improve the tracking speed.

In this proposes work, a modified incremental conductance (Modified IC) based variable step size for MPPT is introduced. This method can overcome the drawback of the conventional algorithms when a sudden and gradual change in irradiance has occurred. This algorithm (Modified IC) is applied to a step-up DC to DC converter that acts as impedance matching between panel and load resistance to extract maximum power possible from PV panel as will show in section (3). This method is implemented using MATLAB/Simulink and tested by applied sudden change irradiance and dynamic profile irradiance.

2. Equivalent Circuit and Mathematical Model of PV Cell

The photovoltaic cell is the smallest part of the photovoltaic model that can convert sunlight into direct electricity. To form a photovoltaic model, the number of photovoltaic cells can be connected into a series; a combination of a parallel chain unit forms a PV array [20,21].

By applying Kirchhoff's law:

$$I = I_{PH} - I_d - I_P \qquad (1)$$

I_{PH} is photocurrent, I_d is forward current of the diode, when Rs and Rp are taken into consideration; The Eq. will be as follow:

$$I = I_{PH} - I_O\left[\exp\left(\frac{V+IR_S}{Ns.A.VT}\right) - 1\right] - \frac{V+I.R_S}{R_P} \qquad (2)$$

Where: V is the diode voltage in volt (V). I_o the diode reverse saturation current in ampere (A). V_T the thermal voltage in volt (V). A Is ideality factor constant. Ns Is the number of PV cells in series. The photocurrent I_{PH} a function of solar irradiance and temperature as follows:

$$I_{PH} = \frac{G}{G_{ref}}\left(I_{PH,ref} + \mu_{sc}.\Delta_T\right) \qquad (3)$$

μ_{sc} Represent the temperature Coefficient of short circuit current (A/K). G_{ref} is irradiance at standard test conditions(STC)= 1000 W/m^2 at 25^{o}C. G is Irradiance (W/m^2). Δ_T=(T_c - $T_{c \cdot ref}$)(K), where $Tc._{ref}$ is temperature of cell at STC = 298 K. $I_{PH,ref}$ is Photo-current (A) at STC. Figure 1 represents the equivalent circuit of the PV cell.

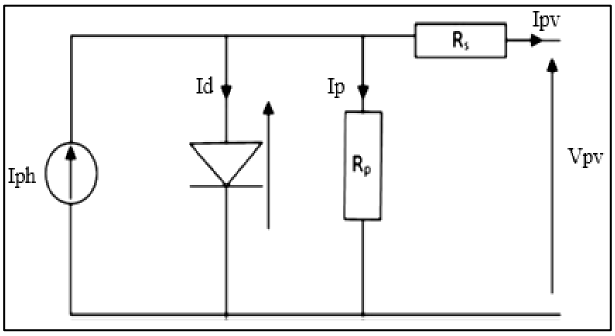


Figure 1: Solar model equivalent circuit [21]

In this work, the module was modeled using parameters listed in Table 1, MATLAB/Simulink was used to simulate the characteristics of this module as shown in Figures 2-4 which represent PV module, (P-V) and (I-V) characteristics.

Table 1: PV Panel datasheet 1

Parameters	Values	parameters	Values
P_{max}(W)	60.53	**Rs(Ω)**	0.514
V_{mpp}(V)	17.1	**Rp(Ω)**	124.86
Impp(A)	3.5	**Diode ideality factor**	0.76
Voc(V)	21.1	**Temp.coefficint of Voc(%/°C)**	-0.229
Isc(A)	3.8	**Temp.coefficint of Isc(%/°C)**	0.0307
Ns	36		

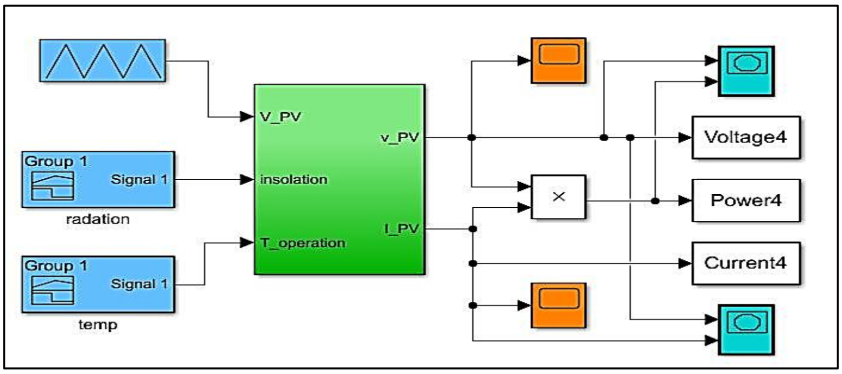


Figure 2: Simulink model of PV

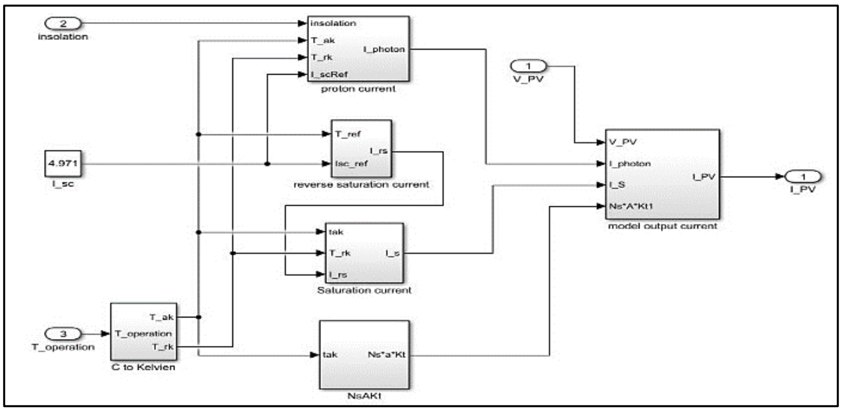


Figure 3: Detailed Simulink model of PV

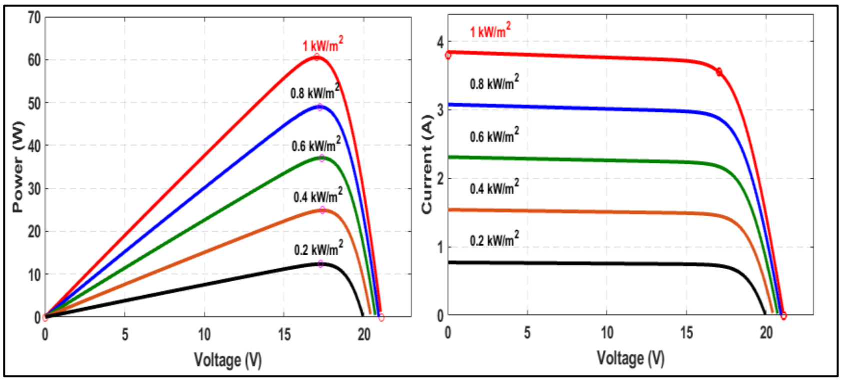


Figure 4: Photovoltaic Characteristics at 25 ℃ and variable irradiance

3. Step-up DC-DC Converter Modeling

In this work, a step-up DC-DC converter is selected so that tracking of maximum power point achieved using a variable duty cycle, it's also boosting the voltage of the PV panel to the desired level required for load or grid. Figure 5 illustrates the diagram for the overall system, consisting of the PV part, the converter circuit part, the load, and the MPPT control part.

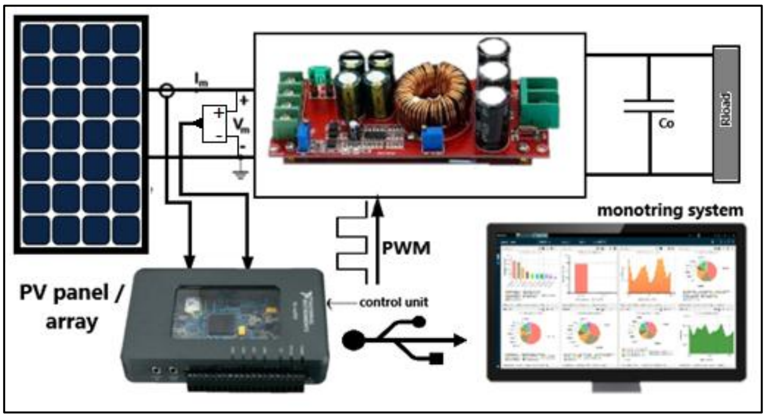


Figure 5: Schematic diagram of PV system

Figure 6 illustrates the DC-DC boost converter. output voltage Vo is always higher than input voltage VI in steady operation. It "step up" the voltage to a higher level. The converter includes an inductor (L), power (MOSFET) or (IGBT), a diode (D), filter capacitor (C), and load resistor (RL). The switch S is switched ON and OFF at the frequency fs = 1 / T with ON duty ratio = D / ton, where ton is the interval when the switch S is on.

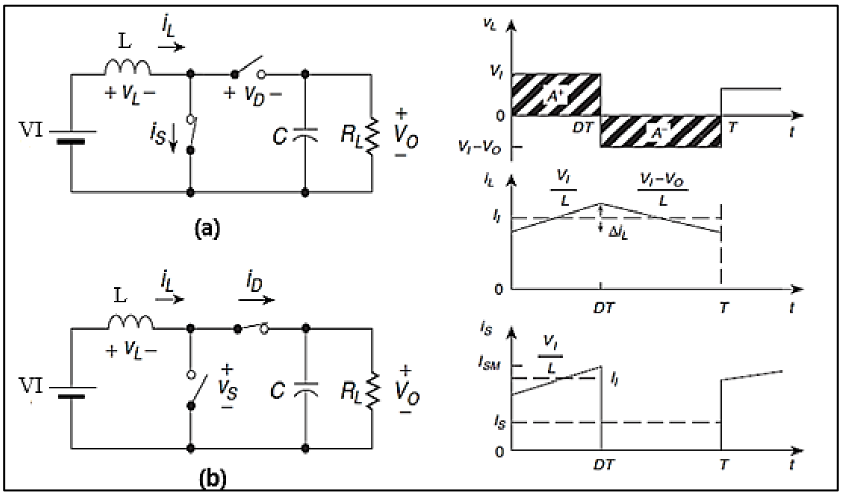


Figure 6: (a) closed switch mode, (b) open switch mode, (c) the waveform of ON-OFF switch modes. [22]

I. Analysis for the switch closed

When a switch is closed in figure 6(a), the diode will be reverse biased and voltage around closed-loop contain source, inductor, and switch is [22,23]:

$$V_L = V_I = L\frac{diL}{dt} \qquad (4)$$

The current increases linearly while the switch is closed as shown in the figure, because the rate of change of current is constant, and the change in inductor current is calculated from:

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{DT} = \frac{V_I}{L} \qquad (5)$$

Solving for ΔiL for the switch closed

$$(\Delta i_L)_{Closed} = \frac{V_I.DT}{L} \qquad (6)$$

II. Analysis for the switch open

The current increases linearly while the switch is open, because the rate of change of current is constant, and the change in inductor current is calculated from [23]:

$$V_L = V_I - V_O = L\frac{diL}{dt} \qquad (7)$$

$$\frac{\Delta iL}{\Delta t} = \frac{\Delta iL}{(1-D)T} = \frac{V_I - Vo}{L} \qquad (8)$$

Solving for ΔiL

$$(\Delta i_L)_{Open} = \frac{(V_I - Vo)(1-D)T}{L} \qquad (9)$$

The average value of the voltage across the inductor in the steady-state is zero, and from Eqs. (4) and (6) by expressing over one switching period

$$V_L = V_I D + (V_I - V_O)(1-D) = 0 \qquad (10)$$

$$V_I(D + 1 - D) - Vo(1-D) = 0 \qquad (11)$$

Solving for Vo

$$V_O = \frac{V_I}{(1-D)} \qquad (12)$$

$$I_o = (1-D)I_{In} \qquad (13)$$

In the same way, for steady-state operation, the net change in inductor current must be zero. Using Eqs. (6) and (9), yields the same result of Eq. (12).

4. Tracking Maximum Power PointAlgorithms

MPPT is an algorithm that produces the appropriate duty cycle (D) using an electronic circuit and feeds it to the power adapter circuit that adapts between the PV panel and loads, to continuously track maximum power as follows.

I. Impedance matching using a DC-DC Boost converter

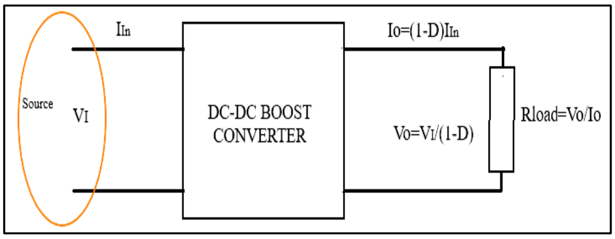


Figure 7: Boost converter schematic diagram

The schematic diagram of the DC-DC boost converter is shown in Figure 7, from the figure:

$$R_{load} = \frac{Vo}{Io} \qquad (14)$$

Insert Eqs. (12) and (13) in Eq. (14).

$$R_{load} = \frac{V_I/(1-D)}{I_{In}(1-D)} \qquad (15)$$

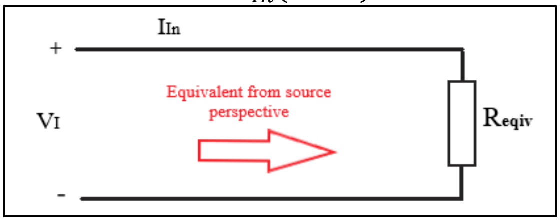


Figure 8: boost converter equivalent circuit

From Figure 8

$$R_{eqiv} = \frac{V_I}{I_{In}} \qquad (16)$$

$$V_I = (1-D)V_O \qquad (17)$$

$$I_{In} = \frac{I_O}{(1-D)} \qquad (18)$$

$$\therefore R_{eqiv} = \frac{(1-D)V_O}{\frac{Io}{(1-D)}} \qquad (19)$$

But Vo/Io=Rload

$$\therefore R_{eqiv} = (1-D)^2 R_{load} \qquad (20)$$

According to the power transfer theory, the power delivered to the load is maximized when the equivalent resistance Reqiv equals the output resistance. therefore, to extract maximum power from the PV panel, connect a boost converter between the panel and the load resistor, and use D to modify the equivalent load resistance seen by the source so that maximum power is transferred.

II. Conventional P&O algorithm

The conventional P&O MPPT method is usually used, because of its simple implementation and reduced cost [6]. P&O is considered as the standard for new MPPT algorithms for comparison. The principle of P&O method depends on the change in the output power and voltage of the PV panel. If dp/dv>0 the adjustment voltage perturbs in the same direction, else the voltage adjustment reversed [10], as shown the flowchart of P&O method in Figure 9.

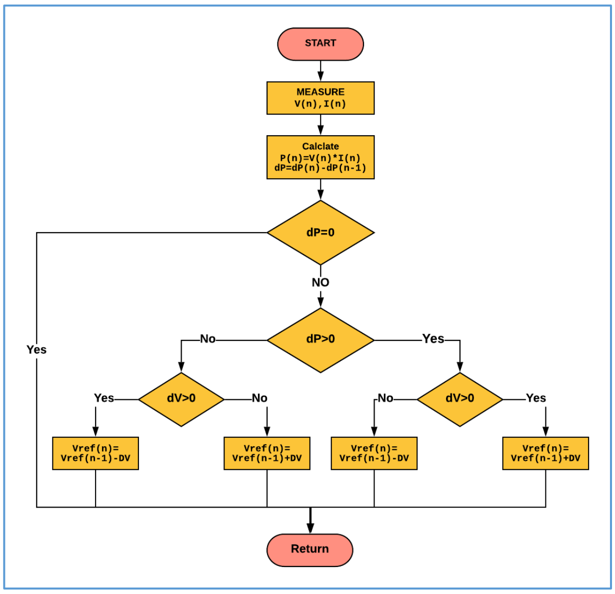


Figure 9: Conventional P&O Flowchart.

III.Modified P&O algorithm

Several disadvantages can be observed in the conventional P&O, for example, high oscillation about MPP and confusion when the dynamic change in irradiance and temperature occurs that may cause loss of tracking [13].

This drawback is due to perturbation step size; as oscillation is high about MPP the power is lost and efficiency will decrease. To minimize this drawback, the modified P&O is proposed. Figure 10 shows the flowchart of modified P&O.

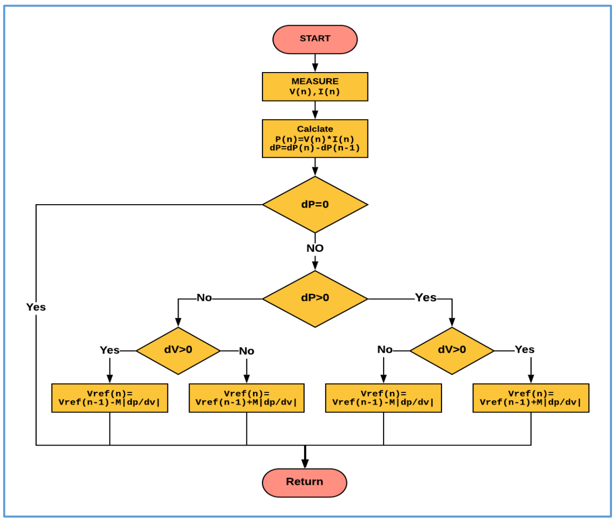


Figure 10: Modified P&O Flowchart

Several ways exist to vary perturbation size, such as [12]:

$$\Delta V_{n+1} = M\frac{\Delta P_n}{\Delta V_n} \qquad (21)$$

Where M is the constant requiring adjusting, and ΔP_n and ΔV_n represent the changing power and voltage respectively. As the radiation increases, the ΔP will increase and the ΔV will change slightly. When the radiation is reduced, the ΔP will decrease and result in a change in the ΔP / ΔV ratio each time the radiation changes. The perturbation size can be found in Another way, as follows [12]:

$$\Delta V_{n+1} = Mlog_{10}(\frac{\Delta P_n}{\Delta V_n}) \qquad (22)$$

As in the first method above, when the radiation increases, the ΔPn will increase and the ΔV will change slightly. When the radiation is reduced, the ΔPn will decrease and result in a change in the ΔPn/ΔVn ratio each time the radiation changes. The logarithm keeps the perturbation size small even if the ratio of ΔPn to ΔVn gets large this reduces the possibility of losing track due to large perturbation.

IV. Proposed MPPT algorithm

The problem with conventional methods is that it can fail in some cases when irradiance changes rapidly, these methods are unable to distinguish between the change caused by the change in radiation or by voltage disturbance. The fast tracking of the MPP is determined by the step size used in the algorithm. The larger step size results in fast tracking, but the system oscillates around the MPP and may result in a lack of efficiency. Whereas, if MPPT operating in reduced step size, the oscillation will be reduced and efficiency may be better, thus fixed step size MPPT should achieve a balance between the oscillations and dynamics. The variable step size is used to resolve this problem, rather than a fixed step size.
Figure 11 shows the flowchart of the introduced method based on the conventional incremental conductance (IC) algorithm with a variable step size. This MPPT algorithm is based on the truth that a PV generator's power-voltage curve usually has only one MPP at constant solar irradiance and cell temperature levels. At this MPP point, the power derivative concerning voltage is equal to zero,

meaning that the sum of instant conductance (Ipv/Vpv) and incremental conductance (dIpv/dVpv) is equal to zero. The sum of the instantaneous and incremental conductance is negative on the right side of the MPP, while the sum is positive on the left side of the MPP. The IC algorithm compares a PV generator's instantaneous conductance with its incremental performance and decides whether to increase or decrease a control parameter accordingly.

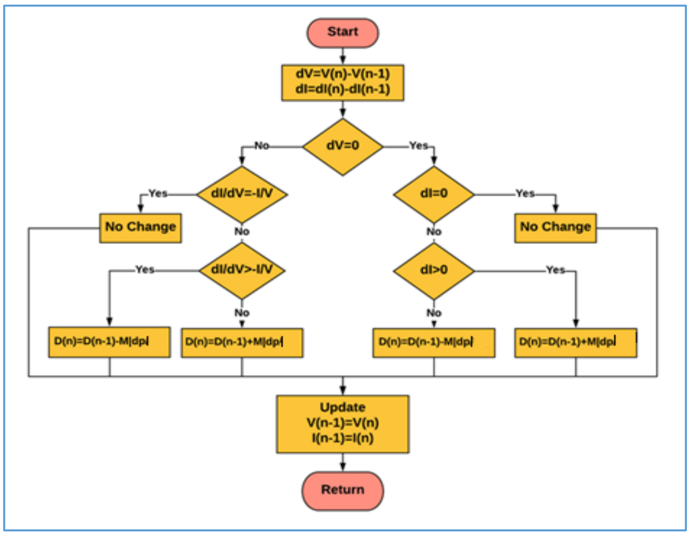


Figure 11: proposed algorithm flowchart

As mentioned in section III, the photoelectric power derivative of the PV array (dP/dV) may vary smoothly and is usually used as an appropriate parameter to determine the variable step size of the P&O algorithm. Therefore, it can also be used to specify a step size variable for the MPPT IC algorithm. [24]:

$$\Delta D = N\left|\frac{\Delta P}{\Delta V}\right| \qquad (23)$$

N: The scaling factor used to adjust the step size automatically.

when the irradiance changes the ΔP will change dramatically, whereas the change in ΔV will remain small, thus the ratio of ΔP/ΔV will be large in momentarily, maybe resulting to lose of tracking for a certain time.

In Figure 12 we note that if the step size change is based on the ΔP ratio only, the probability of losing the trace due to the small change in ΔV will be significantly reduced. When the irradiance increases, the ΔP increases in proportion to the increase in radiation. Conversely, when the irradiance decreases, the value of the ΔP decreases. Thus, the step-size, which depends on ΔP, as follows:

$$\Delta D = N|\Delta P| \qquad (24)$$

It’s clear from the P-V characteristics, that (ΔP) increased as we move far from MPP and reduced when we move toward it. Therefore, if the step size depends on (ΔP), then the step size is small near MPP and large as it far from it. To achieve equalization between the speed of tracking and the oscillations around MPP; this makes the accuracy and efficiency of the tracking are better. Also, the probability of movement of the operating point far from the MPP is reduced if the sudden changes occur of the irradiance, leading to improved transient performance, high dynamic response and low loss of transient power. Figure 12 shows an example of an illustration. If the radiation drops from S1 to S2, the operating point moves from point (a) to point (b), causing a too small change in voltage and significant change in power. So to access the new MPP (K), the algorithm should be reducing the duty cycle. We conclude from the previous, that the variable step affected the accuracy and performance of the algorithm to reduce this decline.

The big step size is avoided in the proposed method, and the duty cycle is reduced to driving the operating point to (C), which is near to the MPP (K). So the speed of tracking will be faster and the loss of transient power will be reduced.

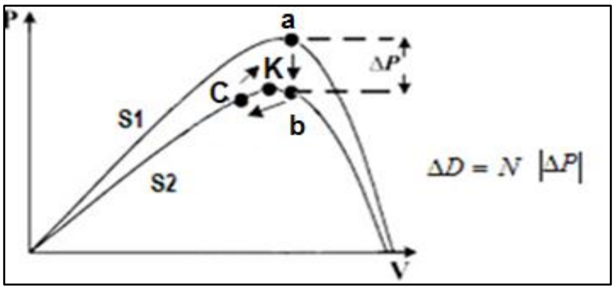


Figure 12: MPPT performance under variable irradiance

5. Simulation and Experimental Results

The MPPT for PV system shown in Figure 13, has been designed and simulated in MATLAB Simulink software, as well as to test the validity and feasibility of the improved method, following by comparing it with P&O and modified P&O algorithms. Table 1 shows the datasheet of the PV panel that simulated and used in this work. Moreover, DC-DC boost converter used as an adapter circuit between the PV panel and load. Comparison between a proposed algorithm and P&O and modified P&O algorithms achieved using a Simulink, the simulation carried out with the similar arrangements and situations, to achieve this aim a strict profile was selected to change the solar irradiance with a fixed temperature at a value of 25 ℃. And the tests were done for the duration of 1s. There are two scenarios for testing performance, the first scenario with a sudden change in irradiance from 500W/m^2 during 0-0.2s, to 800W/m^2 during 0.2-0.4s, and increased to 1000W/m^2 during 0.4-0.6, then decreased to 800W/m^2 during 0.6-0.8s, and finally increased to 900W/m2 during 0.8-1s. as shown in figure (14-16). The irradiance form, output power, output voltage, and efficiency for P&O, modified P&O and proposed algorithm is illustrated on one graph. From figures 14 and 15, it can be noticed that a proposed algorithm with proposed variable step size produces better performance than the other two algorithms, and have low steady-state oscillation and fast response at the sudden change in irradiance. Figure 16 shows the system efficiency of the three methods; from the figure, it is noticed that the Proposed MIC has better efficiency, minimized oscillation and fast speed response.

For the second scenario, the proposed technique was tested with a profile change of irradiance and compared with conventional P&O and Modified P&O under the same conditions. Figures 17-19 show, the profile change of irradiance, and results of three algorithms, the results confirm that, the suggested algorithm has a better speed of tracking and reduced oscillations at transient and steady-state concerning Modified P&O and P&O algorithms, in this way the efficiency for system increased effectively.

The tracking efficiency of the MPPT algorithm can be evaluated as [2,21].

$$T_{Eff}(\eta\%) = \frac{\int_0^t P_{MPP}}{\int_0^t P_{pv}} \times 100\% \qquad (25)$$

Where P_{MPP} is the power obtained by a given MPPT method and P_{pv} is the theoretical available power. The overall system efficiency can be summarized as in Table 2. It shows that the proposed algorithm has better efficiency in compression with Modified P&O and P&O.

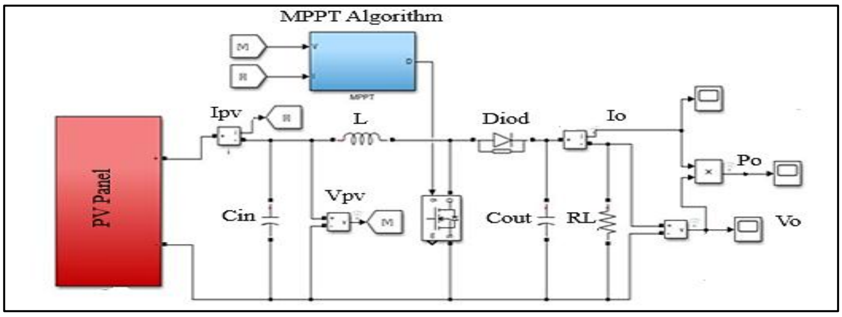
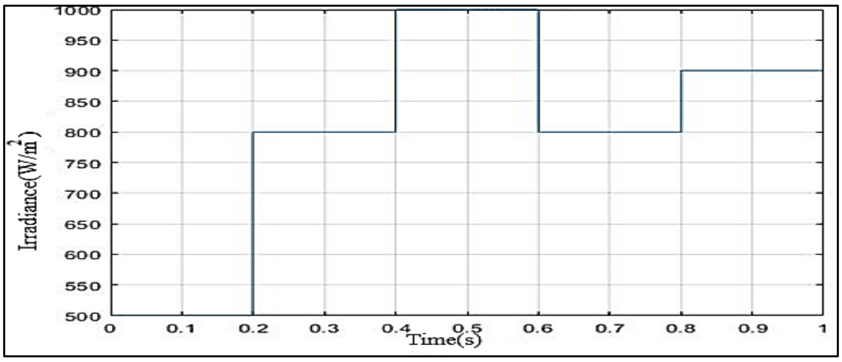
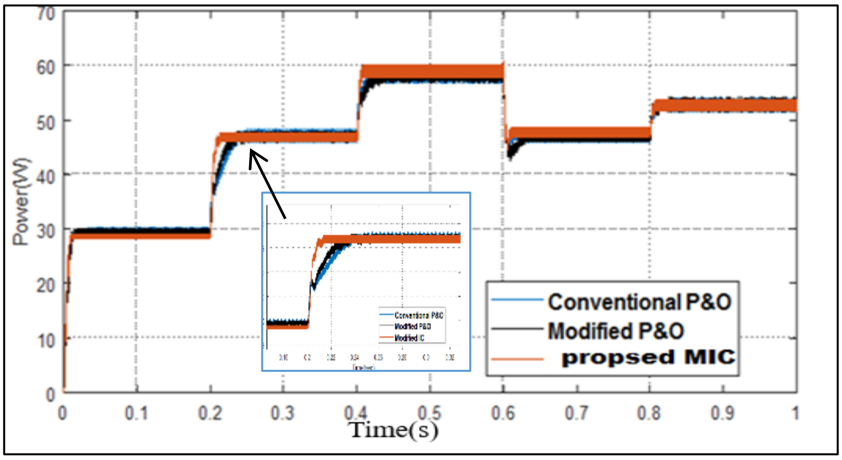


Figure 13: Complete system designed in Simulink



(a)



(b)

Figure 14: Results performance of P&O, MP&O and proposed MIC, (a) irradiance (b) Output power

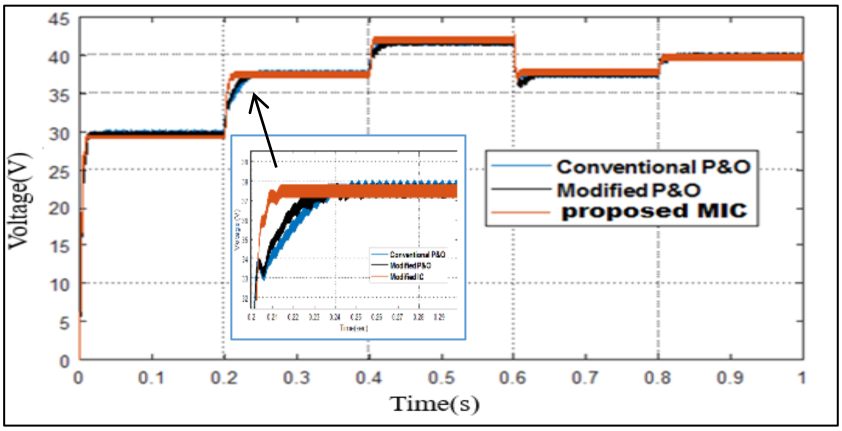


Figure 15: Output voltage of P&O, MP&O, and proposed MIC

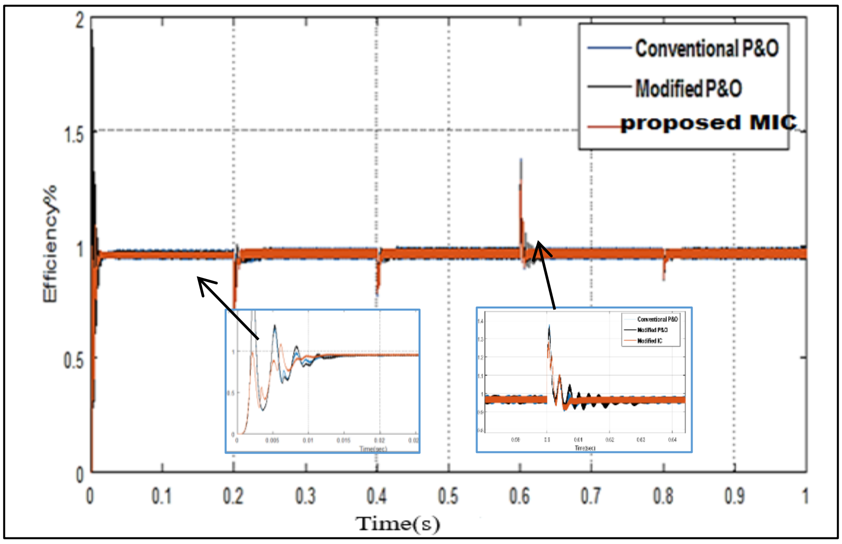
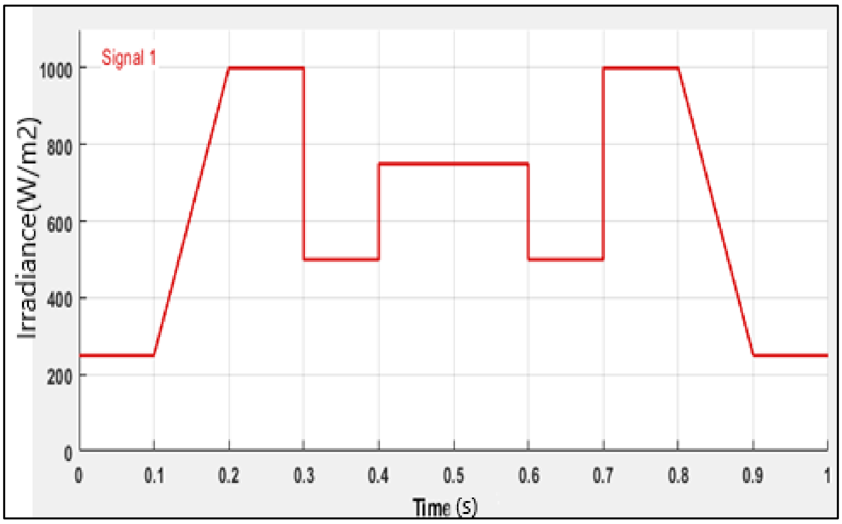
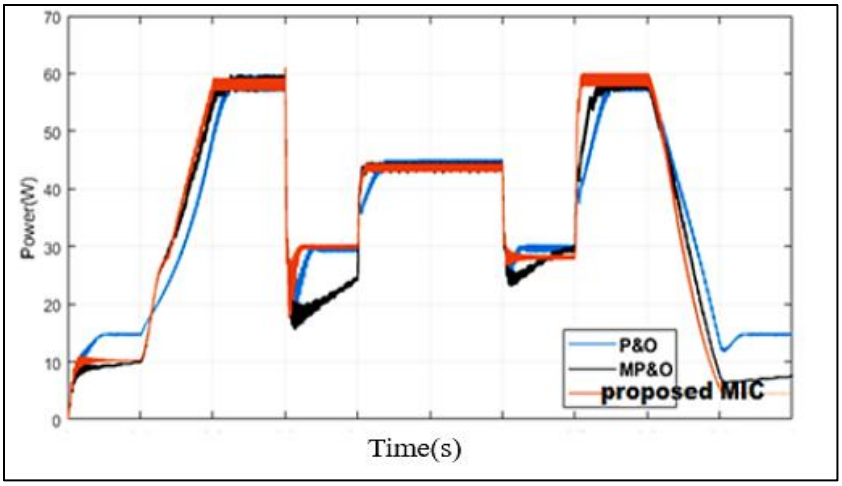


Figure 16: System efficiency under sudden irradiance change of P&O, MP&O, and proposed MIC



(a)



(b)

Figure 17: Results. Of P&O, MP&O, and proposed MIC, (a) irradiance profile (b) output power

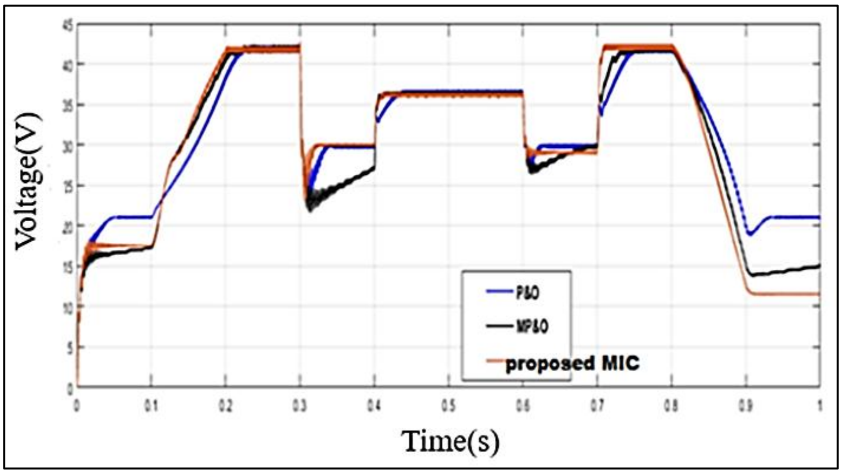


Figure 18: Output voltages of P&O, MP&O, and proposed MIC

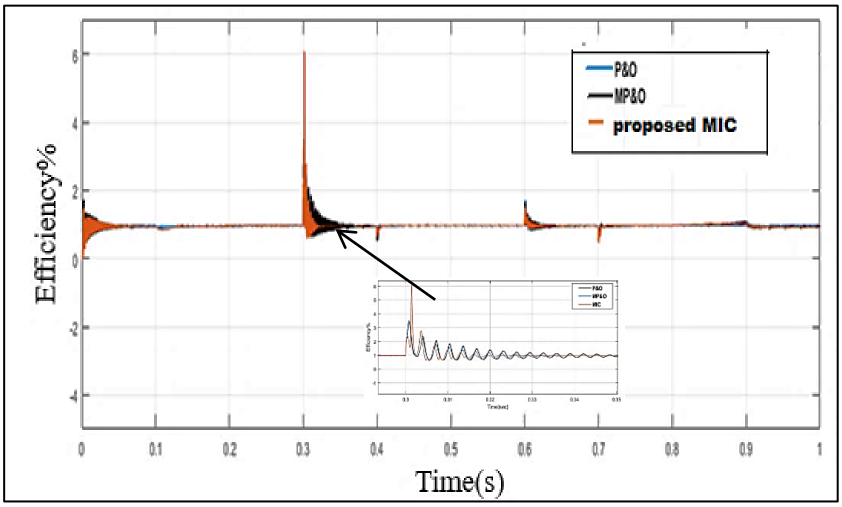


Figure 19: System efficiency under irradiance profile of P&O, MP&O, and proposed MIC

Table 2 Summary of efficiency

Algorithm	P&O	MP&O	MIC
Efficiency(%)	95.12	97.33	98.50

6. Conclusion

The proposed modified incremental conductance (Modified IC) MPPT algorithm depends only on the change of PV power instead of a PV power and PV voltage. Two scenarios were applied to test the performance of the algorithm and comparison done with respect to conventional P&O and Modified P&O. The first scenario is the sudden change of irradiance, while the dynamic change is applied in the second scenario. In the two scenarios, the results show that the proposed algorithm outperforms the conventional P&O and modified P&O due to reduced oscillation at the steady-state. The proposed MIC can increase of convergence speed and reduces oscillation about MPP, because of this, the system efficiency was enhanced to 1.1% and 3.3% concerning Modified P&O and P&O algorithms respectively, and hence the probability of divergence from MPP is eliminated.

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