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# Tracking of Maximum Power Point in Solar PV (SPV) Systems using Perturb & Observe (PO) and Incremental Conductance (IC) Method

**Deepak Verma, Shilpa Kalambe, Nikhil Kumar**

***Abstract*: The solar energy being clean, green & commercially modest, have become one of the most prevalent choice amongst the renewable sources of electrical energy. Utilization of energy generated from Solar photovoltaic (SPV) system rest on the maximum extraction of the power generated. Ideal maximum power point (MPP) tracking (MPPT) is used to transfer 100% generated power from source and transfer it to load. In literature of recent years, a good number of publications found on SPV systems and MPPT. In this paper most popular MPPT techniques-Perturb & Observe (PO) and Incremental Conductance (IC) methods are simulated and implemented. The comparison is also presented on the ground of parameters like tracking time, tracking efficiency etc.**

***Keywords*— Solar Photovotaic (SPV); MPPT; Perturb and Observe (PO) method; Incremental Conductance method (IC); MATLAB/Simulink.**

## I. INTRODUCTION

The current output of a single solar cell can be given by (1) below:

$$I_{pv} = I_{ph} - I_s\left[\exp\left\{\frac{V_{pv}+I_{pv}R_s}{N\times V_T}\right\}-1\right] - I_{s_2}\left[\exp\left\{\frac{V_{pv}+I_{pv}R_s}{N_2\times V_T}\right\}-1\right] - \frac{V_{pv}+I_{pv}R_s}{R_{sh}} \quad (1)$$

where,

$I_{pv}$ output current of a cell

$I_{ph}$ photon generated current

$I_s$ saturation current of first diode

$I_{s2}$ saturation current of second diode

$V_{pv}$ output voltage of a cell

$R_s$ series resistance of a cell

$R_{sh}$ shunt resistance of a cell

$V_T$ thermal voltage

N diode emission coefficient or quality factor of first diode

$N_2$ diode emission coefficient or quality factor of second diode.

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Fig.1 depicts the "two diode model" of a solar cell Eq. (1) can be better understand by this model. Fig. 1 is also known as the equivalent circuit of a solar cell it also elaborates the losses associated in the solar cell. Current in diode D represents the losses due to recombination in P-region and N-region however diode D2 represents the losses due to recombination in depletion region.

The current–voltage (I-V curve) and power-voltage (P-V curve) characteristics as shown in Fig. 2 of SPV cell is non-linear in nature (Hill shape) and it indicates that there exists only one point of operation where the SPV cell delivers maximum power [1-4]. At this point of maximum power, the source impedance is matched with the impedance of load, though maximum power can be extracted [5-6]. Nevertheless, impedance matching is done by the DC-DC converter and the changing impedance of the source with environmental conditions can be track by the MPPT technique [7].

In literature most of the MPPT discussed required complex circuitry or expensive controllers

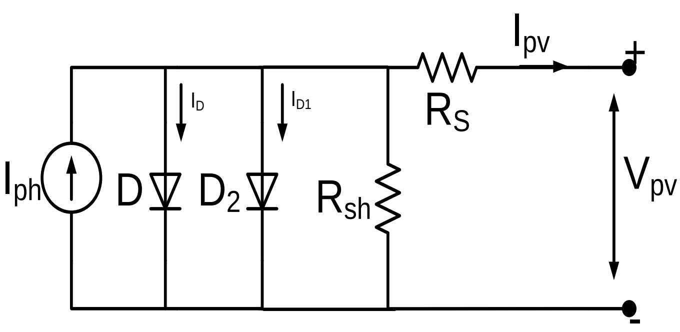


**Fig. 1. Electrical equivalent circuit or two diode model of a SPV cell**

The current-voltage I-V and power-voltage P-V characteristic of a solar cell is shown in Fig. 2.

From the Fig.2 it can be seen that there is only one point in the P-V curve, at which we get the maximum generated power. Nevertheless, for obtaining maximum power from the solar array, the operating voltage or operating current should be corresponding to the maximum power point i.e. $V_{mpp}$ or $I_{mpp}$.

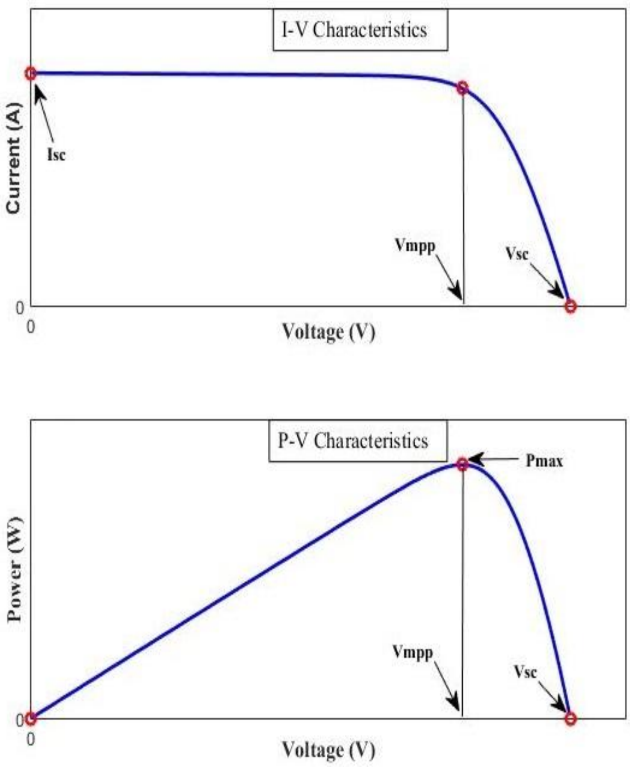


**Fig. 2. I-V and P-V Characteristics of a solar cell**

## II. MAXIMUM POWER POINT TRACKING

The process of tracking of an MPP is basically done to match the impedance between SPV source and the load. In this process a DC-DC converter is required for matching the impedance of SPV source, in accordance with the load by varying its duty ratio. The change in duty cycle turns out the change in impedance experienced by the SPV source; hence the impedance of load is altered. In addition, impedance of SPV source is changed with the states of environment such as that intensity of solar radiation and the temperature of surroundings.

The calculation of duty cycle of converter with respect to the matching condition of impedance is done by the MPPT algorithm. More than 35 schemes of MPPT have been reported in the literature [2], in addition to recent advances IC and PO MPPT algorithms are the most popular, which are easy to implement and common in use [4]. A discussion of this PO scheme is given below:

### *A. Perturb & Observe (PO) method of MPPT*

The circuitry and computation required by PO scheme is less complex, due to this it is one of the most popular among the other schemes. The approach employed to find MPP is 3-point iteration. This operating point of the SPV source has oscillations around the point of maximum power.

As shown in Fig. 2 *dP/dV* is positive prior to MPP, at MPP *dP/dV* is zero and past MPP *dP/dV* is negative. Which means to inspect *dP/dV*, the MPP is easy to track for any environmental conditions with duty cycle disturbances [7].

This technique is implemented by perturbing or changing the duty cycle at regular intervals, though looking at *dP/dV*, as a result of this scheme operating point swings around the point *dP/dV=0* i.e. MPP. This operation and methodology is described in Figure 3 and Table I respectively.

**TABLE I. METHODOLOGY OF PO METHOD**

| Perturbation | Change in power | Next perturbation |
|---|---|---|
| Positive | Positive | Positive (increment in duty ratio 'D') |
| Positive | Negative | Negative (decrease in duty ratio 'D') |
| Negative | Positive | Negative (decrease in duty ratio 'D') |
| Negative | Negative | Positive (increment in duty ratio 'D') |

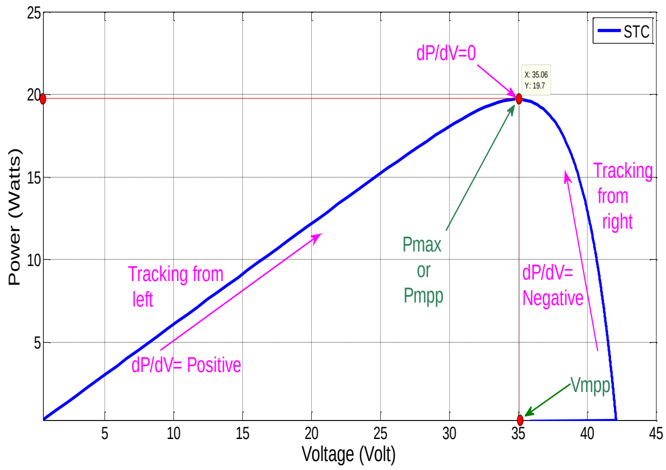


**Fig. 3. P-V characteristic of solar PV in context with PO MPPT.**

### *B. Incremental Conductance (IC) Method*

This method is based on the fact *dP/dV* is zero at the MPP ($P_{max}$) as shown in Fig 3, This can be expressed as follows:

Power: $P = V \times I$

$$\frac{dP}{dV} = I + V\frac{dI}{dV}$$

At true MPPT

$$\frac{dP}{dV} = 0$$

$$I + V\frac{dI}{dV} = 0$$

$$\frac{dI}{dV} = -\frac{I}{V} \qquad (2)$$

Where $dI/dV$ : *Incremental conductance*
$I/V$ : *Instantaneous conductance*

**TABLE II. METHODOLOGY OF IC METHOD**

| Before MPP | After MPP | At MPP |
|---|---|---|
| $\frac{dP}{dV} > 0$ or $\frac{dI}{dV} + \frac{I}{V} > 0$ | $\frac{dP}{dV} < 0$ or $\frac{dI}{dV} + \frac{I}{V} < 0$ | $\frac{dP}{dV} = 0$ or $\frac{dI}{dV} + \frac{I}{V} = 0$ |

Equation 2 presents that the maximum power can be reached by comparing instantaneous conduction with incremental conductance. The TABLE-II shows the course of action of this scheme, which is divided into three regions. The flow chart of the scheme is presented in Fig.4 [9].

The scheme is comparatively complex and computationally more demanding than PO [10–11].

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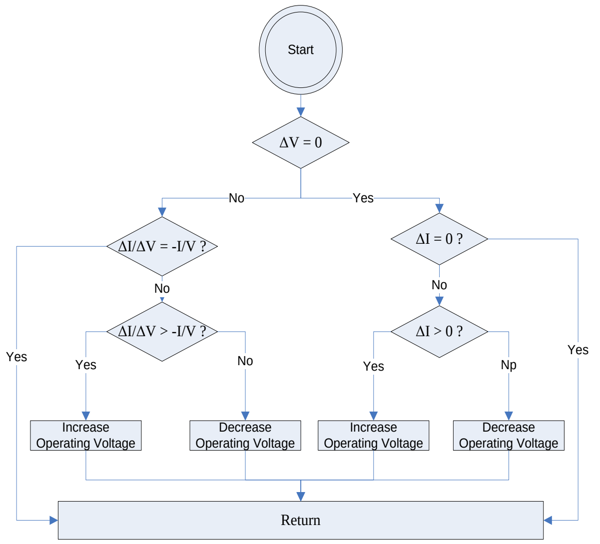



**Fig. 4. Flowchart of IC method**

## III. MATLAB/SIMSCAPE IMPLEMENTATION OF PO METHOD

The PO method is simulated/implemented in *MATLAB/Simulink* with DC-DC boost converter. The design calculation of boost converter is presented in [4,12]. Simulation of SPV array is done for modules *XR36-300* made by *Xunlight*. Solar array given in *MATLAB* library is used and analysis of behavior of SPV array with different environmental condition. Fig. 5 shows the SPV array available in *MATLAB* [13-19].

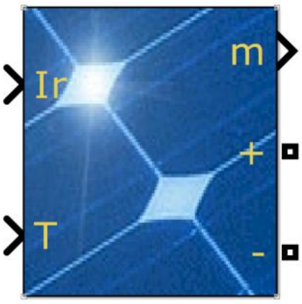



**Fig. 5. Solar module available in MATLAB.**

Parameters used for simulation are given in table III.

**TABLE III**
**SOLAR PANEL PARAMETERS USED IN SIMULATION.**

| Parameters | Value |
|---|---|
| Maximum Power (W) | 300 |
| Open circuit voltage Voc (V) | 81 |
| Voltage at maximum power point Vmp (V) | 60 |
| Cells per module (Ncell) | 36 |
| Short-circuit current Isc (A) | 6.35 |
| Current at maximum power point Imp (A) | 5 |
| Light-generated current (A) | 6.70 |
| Diode saturation current (A) | 1.9e-10 |
| Diode ideality factor | 3.6 |
| Shunt resistance Rsh (ohms) | 49.5 |
| Series resistance Rs (ohms) | 2.2 |

Next to these parameters, parameters depends on temperature for simulation are given in table IV.

**TABLE IV TEMPERATURE DEPENDENCE PARAMETERS USED IN SIMULATION**

| Parameters | Value |
|---|---|
| Temperature coefficient of Voc (%/deg.C) | -0.38 |
| Temperature coefficient of Isc (%/deg.C) | 0.12 |

To obtain different characteristic and testing of MPPT simulation model is given in Fig. 6.

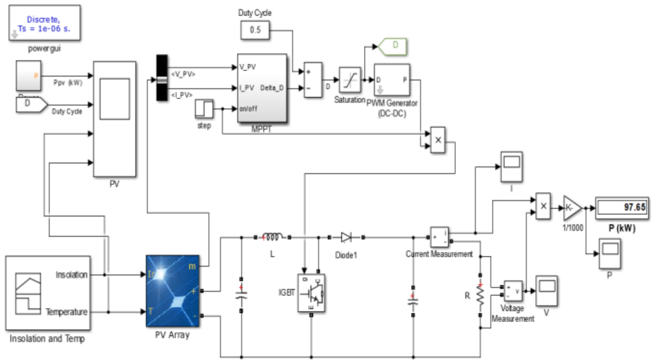



**Fig. 6. MATLAB simulation model of PO scheme of MPPT.**

The *MATLAB* results of solar array are shown in Fig. 7 for different environmental conditions.

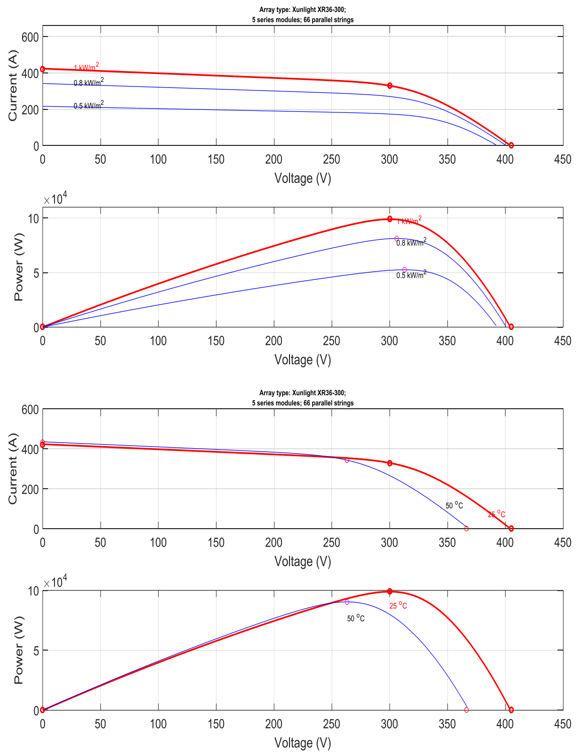
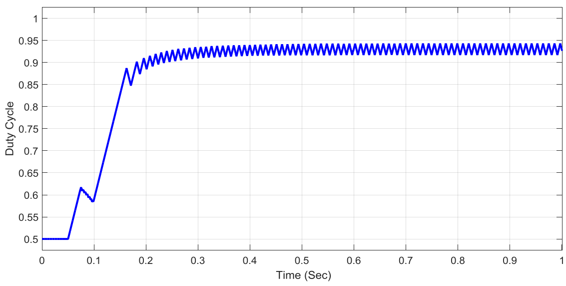



**Fig. 7. IV and PV characteristic of solar array for different environmental conditions.**

The operation of PO method is shown in Fig. 8. The maximum power is achieved and PO shows oscillations around this point which is point of maximum power. However, in case of IC less oscillations we around the MPP.

(a)




(b)

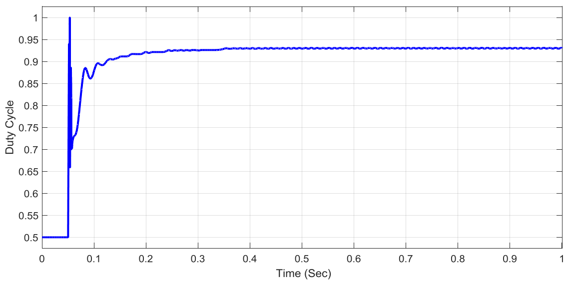
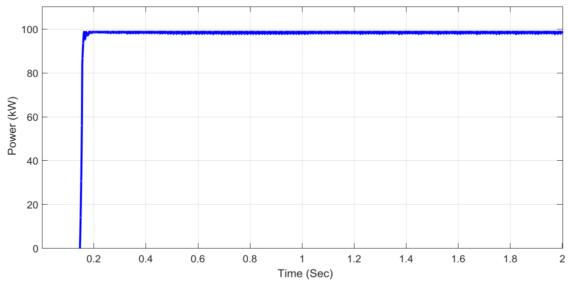



**Fig. 8. Duty cycle of the boost converter: (a) PO and (b) IC.**

Fig. 9 depicts the output power of solar with respect to time, the oscillation/fluctuation in power is present due to the converter tends to keeps on tracking (3 point of operation) the maximum power by changing the duty cycle continuously.

(a)




(b)

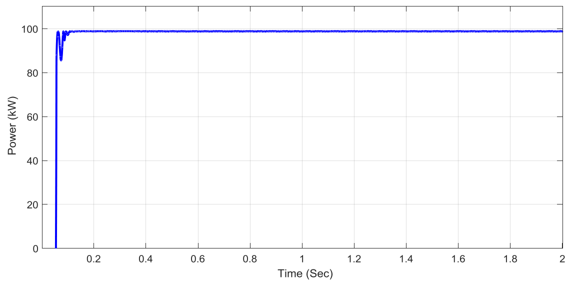


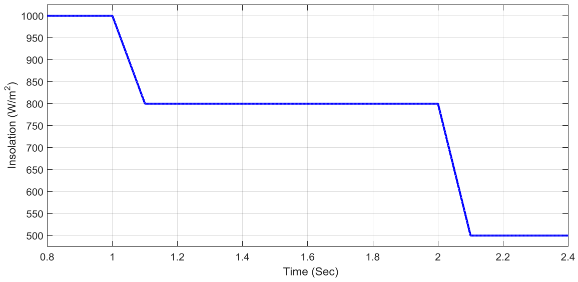

**Fig. 9. Output power from PV array: (a) PO and (b) IC.**

MPPT methods are tested for different insolation conditions such as 1000 W/m$^2$, 800 W/m$^2$ and 500 W/m$^2$. Fig. 10 (a) shows the insolation given to the PV array, (b) Duty cycle in PO and (c) duty cycle in IC.

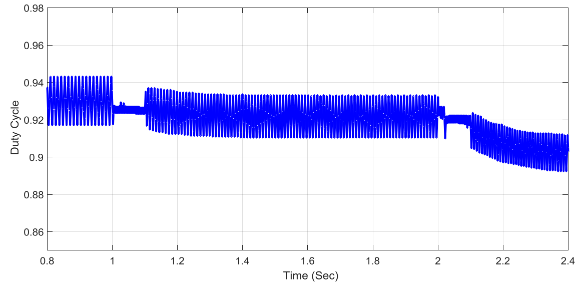
Fig. 11 (a) shows the output power from PV array in case of PO method and (b) in case of IC method. From results shown in Fig. 11 it is clear more oscillation are there in PO method but both methods are able to track maximum power.

MPPT methods are also tested for changing temperature conditions because in some locations temperature varies in the wide range. Fig. 12 (a) shows the temperature given to the PV array which varies from 25$^0$C to 50$^0$C, (b) shows the duty cycle in PO method and (c) shows duty cycle in IC method. Fig. 13 (a) shows the output power from PV array in case of PO method and (b) in case of IC method with variable temperature. From results shown in Fig. 11 it is clear more oscillation are there in PO method but both methods are able to track maximum power.

(a)




(b)




(c)

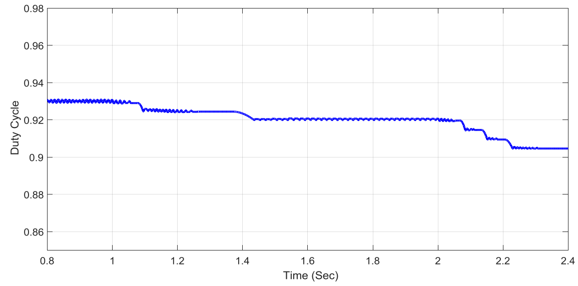
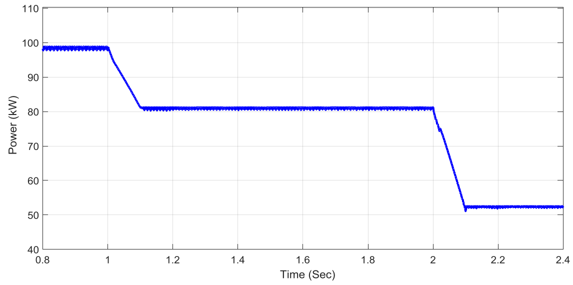



**Fig. 10. (a) insolation given to the PV array, (b) Duty cycle in PO and (c) duty cycle in IC with variation in insolation.**

(a)



(b)

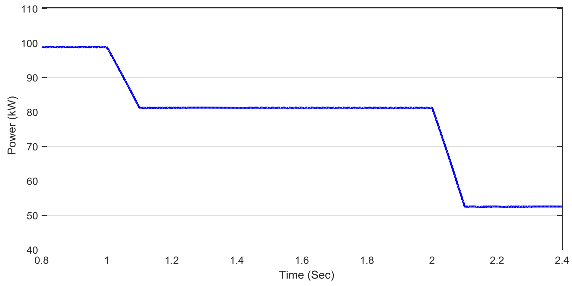
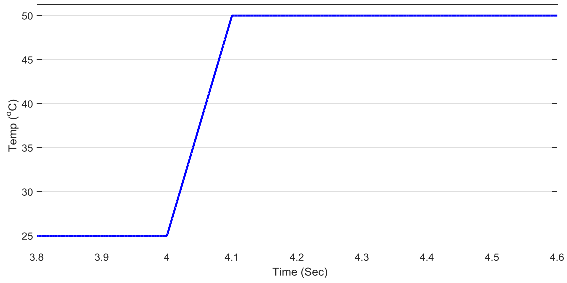
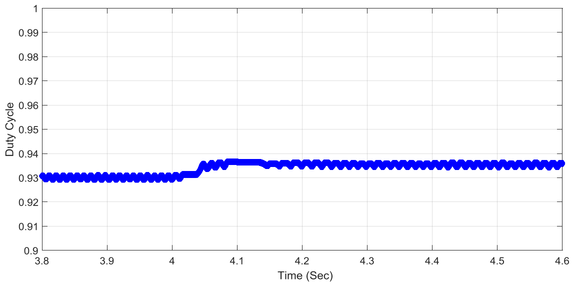



Fig. 11. Output power from PV array with changing insolation: (a) PO and (b) IC.

(a)




(b)




(c)

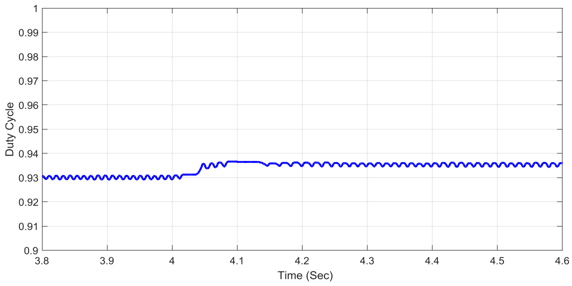
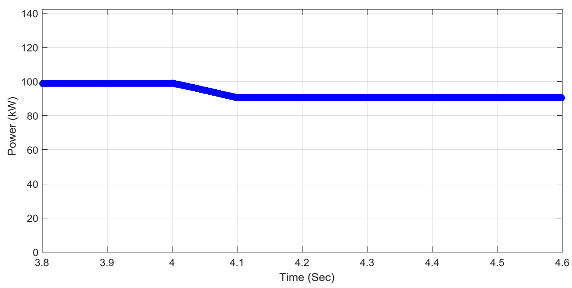



Fig. 12. (a) temperature given to the PV array, (b) Duty cycle in PO and (c) duty cycle in IC with variation in temperature.

(a)




(b)

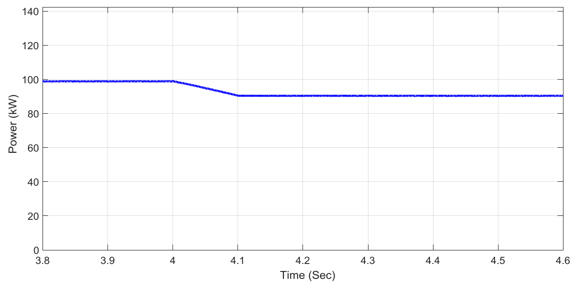



**Fig. 13. Output power from PV array with changing temperature: (a) PO and (b) IC.**

## IV. COMPARISION OF PO AND IC METHODS

The results obtained for different environmental conditions in comparison between the two schemes are presented in Table V based on the criteria given below:

*A. Degree of complexity*
This category explains the level of intricacy of circuitry requisite for realization of the scheme.

*B. Dependency of PV array*
This category describes the dependence (whether dependent or independent) of MPPT scheme on the nature and dimension of the SPV system.

*C. Tracking speed*
This category describes the monetary facilities of MPPT trackers compared to other trackers

*E. Sensor required*
The control or sensory parameters required to detect a point of maximum power, such as voltage (V), current (I), temperature (T), or a combination of all three.

**TABLE V COMPARISION OF PO AND IC METHODS.**

| Parameters | PO | IC |
|---|---|---|
| Dependency of PV array | No | No |
| Degree of complexity | Less | More |
| Sensor required | V and I | V and I |
| Tracking speed | Less | More |
| Cost | Less | More |

## V. CONCLUSION

MPPT stage is an important stage in SPV applications nonetheless an amount of power is not extracted from the solar array and energy-payback period becomes more. This paper presents a detailed analysis of PO and IC MPPT method. Results shows that the MPPT methods achieve the maximum power point. The IC method is fast but more complex as comparted to PO method.

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