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# MODELING AND SIMULATION OF PHOTOVOLTAIC MODULE WITH ENHANCED PERTURB AND OBSERVE MPPT ALGORITHM USING MATLAB/SIMULINK

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## ABSTRACT

Modeling and analysis of photovoltaic (PV) system is substantial for designers of solar power plants to do a yield investigation that precisely predicts the expected output power under changing weather conditions. The model allows the prediction of PV module's behaviour and characteristics based on the mathematical model equivalent circuit using Matlab/Simulink platform under different temperature and solar radiation readings. The second part of this paper proposes an enhancement to the conventional perturb and observe (P&O) maximum power point tracking (MPPT) technique in order to overcome the disadvantages of this method such as oscillation and slow tracking under sudden change of atmospheric conditions. The proposed method suggested that utilizing a variable perturbation step size depending on power changes instead of constant step size which is used in conventional P&O algorithm in order to ensure that the solar energy is captured and converted as much as possible. The simulation results are compared with that of traditional P&O to demonstrate the effectiveness of the proposed method

**Keywords:** PV modelling, matlab / simulink, MPPT, perturb and observe MPPT, enhanced P&O.

## INTRODUCTION

Solar energy is available and clean source that has been used to generate electrical power. In the recent years, the total installed capacity of photovoltaic (PV) generation of electrical energy has increased dramatically from 40 to 177 GW in 2010 and 2014, respectively. The fast increasing usage and significance of PV energy is observed because it is uncontaminated, creates less impact to the environment, freely accessible, less maintenance requirement compared to other resources, creates less noise pollution, and easy to expand [1, 2].

The fundamental device of a solar system is the PV cell, which directly converts daylight into electricity. Typically, a PV cell produces voltage around 0.5 to 0.8 depending on the semiconductor type and the developed technology. This amount of voltage is insufficient and cannot be put to use. Therefore, the cells are linked together to consist a PV module which is the smallest unit that can be utilized to generate a useful amount of PV power. The modules can be connected in parallel and/or in series to form the PV array. In order to study electronics converters of the PV system that are used to regulate current and voltage of the load, to control the power flow of grid-connected photovoltaic power plant (PVPP) and primarily to track the maximum power point (MPP) of the module, one initially needs to know how to model the PV device that is attached to the converter. It is obvious that the output characteristics (I-V and P-V) of the PV modules rely on solar irradiation, temperature and the output voltage [3]. However, there is always a unique point on the V-P or V-I curve called the MPP. This point cannot be identified based on those characteristics, but it can be located by MPPT algorithms.

There are a lot of MPPT algorithms that have been utilized through the advancement of PV energy system. The issues of using MPPT to extract the maximum available power from the PV array has been studied and addressed using different algorithms in the literature. For instance, hill climbing (HC), incremental conductance (INC) method, perturb and observe (P&O) algorithm, look-up table method, constant voltage (CV) or constant current (CC). The aforementioned algorithms have been proposed and reported in [4, 5], In addition, there are high-efficiency algorithms such as particle swarm optimization (PSO) [6], fuzzy logic (FL) algorithm [7] and artificial neural network (ANN) algorithm [8]. These current methods have several advantages and drawbacks concerning to oscillations, complexity, speed, the cost and extra hardware.

A P&O MPPT technique is widely used in PV system due to its ease of implementation and small number of measured parameters required. They operate by increasing or decreasing the array voltage using fixed step value. In case PV array voltage perturbed at any direction and yield increases in terms of power value, this indicates that the operating voltage should be further perturbed in the same direction, otherwise the direction of the perturbation must be reversed. The disadvantage of this method is that it loses some amount of available power at steady state operation because of the oscillation at MPP, especially when the insulation and temperature constant or vary slowly [4, 5, 9]. For improving this method and solving its drawback, there are many adaptive techniques such as [1] considering the current instead of voltage perturbation in conventional P&O to operate the PV panel at MPP, [9] improving the P&O based on auto-tuning perturbation step and hysteresis band. In some methods,

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the variable steps are used instead of fixed step as proposed in [4, 10], in different ways.

In this paper, the focus will be divided into two parts. The first one aims to model and simulate the PV module, present the variation effects of solar radiation and investigate the influence of temperature on the module outputs. The second part proposes an enhancement for the P&O MPPT algorithm by using variable step size depending on the output power changes to improve the response speed of the algorithm in order to extract maximum available power of the array.

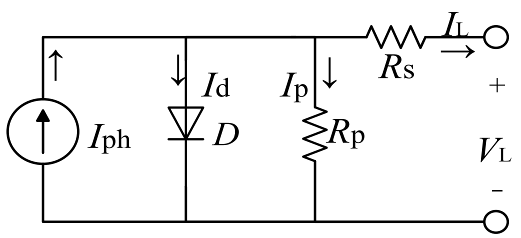


**Figure-1.** Equivalent circuit of a solar cell.

**MODELING OF THE PV MODULE**

Figure-1 shows equivalent circuit of the PV module which consists of several PV cells. It includes a current source generating photo current which depends on the irradiation, a big diode equivalent to the p-n transition area of the solar cell, the voltage losses represented by series resistance and parallel resistance indicating the leakage current. The output current and voltage relationship for PV module can be expressed by the following equation [3, 11, 12].
By using Kirchhoff's laws:

$$I_{\mathrm{Ph}} - I_{\mathrm{D}} - I_{\mathrm{P}} - I_{\mathrm{L}} = 0 \;\Rightarrow\; I_{\mathrm{L}} = I_{\mathrm{Ph}} - I_{\mathrm{D}} - I_{\mathrm{P}} \quad (1)$$

And $(V_{\mathrm{D}} = V_{\mathrm{P}}) = V_{\mathrm{S}} + V_{\mathrm{L}} \Rightarrow V_{\mathrm{D}} = R_{\mathrm{S}} I_{\mathrm{L}} + V_{\mathrm{L}}$ (2)

Where $I_{\mathrm{P}} = \dfrac{V_{\mathrm{P}}}{R_{\mathrm{P}}} = \dfrac{V_{\mathrm{D}}}{R_{\mathrm{P}}}$, substitute by $V_{\mathrm{D}}$ from Equation. (2):

$$I_{\mathrm{P}} = \frac{I_{\mathrm{L}} R_{\mathrm{S}} + V_{\mathrm{L}}}{R_{\mathrm{P}}} \quad (3)$$

The diode current can be expressed as follows [11, 13].

$$I_{\mathrm{D}} = I_{\mathrm{sat}} \left( e^{\left( V_{\mathrm{D}} / m N_{\mathrm{s}} V_T \right)} - 1 \right) \quad (4)$$

Where $\mathrm{V}_T = \dfrac{KT}{q}$, substitute by $V_T$ in Equation. (4), yield:

$$I_{\mathrm{D}} = I_{\mathrm{sat}} \left( e^{\left( q V_{\mathrm{D}} / m N_{\mathrm{s}} KT \right)} - 1 \right) \quad (5)$$

By substituting Equations. (3) and (5) in Equation. (1), the load current can be written as the flowing equation:

$$I_{\mathrm{L}} = I_{\mathrm{Ph}} - I_{\mathrm{sat}} \left( e^{\left( q V_{\mathrm{D}} / m N_{\mathrm{s}} KT \right)} - 1 \right) - \frac{I_{\mathrm{L}} R_{\mathrm{S}} + V_{\mathrm{L}}}{R_{\mathrm{P}}} \quad (6)$$

The $I_{\mathrm{Ph}}$ , $I_{\mathrm{D}}$ , $I_{\mathrm{P}}$ and $I_{\mathrm{sat}}$ are the photo current, the diode current of the PV cell, shunt current and the reverse saturation current of the solar module, respectively. $N$s is the number of cells connected in series, $V_T$ is the thermal voltage and equals to 25.7V at 25°C (298K) and $m$ is the ideal factor of the diode (1-5($V_T$)). $K$ is the Boltzmann constant ($1.381\times10^{-23}$ J/K) and $q$ is the charge of the electron ($1.6021\times10^{-19}$C). $R_{\mathrm{S}}$ and $R_{\mathrm{P}}$ are the equivalent series and parallel resistance of the solar module, respectively.

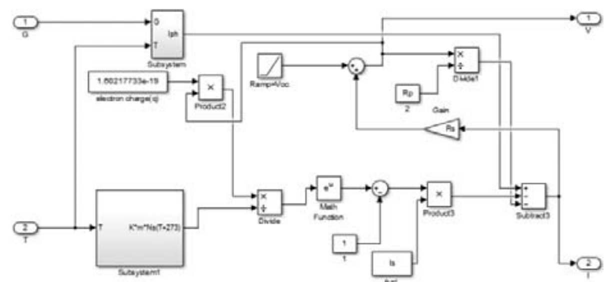

**Figure-2.** PV module Matlab/SIMULINK model.

$I_{\mathrm{Ph}}$ is affected by sun irradiance and temperature. The influence of these two factors can be shown by [12].

$$I_{\mathrm{ph}} = \left[ I_{\mathrm{sc}} + \alpha_i (T - 25) \right] \frac{G}{G_{\mathrm{ref}}} \quad (7)$$

Where $I_{\mathrm{Ph}}$ is the photo current at nominal PV standard tests condition (STC) (normally 25°C and 1000 W/m$^2$) for temperature and irradiation. $I_{\mathrm{sc}}$ is the nominal short circuit current of the module. $G$ and $G_{\mathrm{ref}}$ are the amount of actual and nominal irradiation, respectively. $T$ is the temperature degree in kelvin (K) and $\alpha_i$ is the current temperature coefficient. The $I_{\mathrm{sat}}$ and $I_{\mathrm{sc}}$ can be obtained according to the following equations [3].

$$I_{\mathrm{sc}} = I_{\mathrm{sc,ref}} \left( \frac{R_{\mathrm{P}} + R_{\mathrm{S}}}{R_{\mathrm{P}}} \right) \quad (8)$$

$$I_{\mathrm{sat}} = \frac{I_{\mathrm{sc,ref}} + \alpha_i (T - 25)}{e^{q\left( V_{\mathrm{oc,ref}} + \alpha_v (T-25) / N_{\mathrm{s}} mKT \right)} - 1} \quad (9)$$

The $I_{\mathrm{sc,ref}}$ and $V_{\mathrm{oc,ref}}$ are the short circuit current and open circuit voltage of the module at STC, whereas, $\alpha_v$ is the open circuit voltage temperature coefficient. Normally these values are evaluated by the manufacturer. The output voltage and current of the module will be as follow:

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$$I_L = [I_{sc} + \alpha_i (T-25)]\frac{G}{G_{ref}} - I_{sat}\left(e^{\left(qV_D/mN_sKT\right)}-1\right) - \frac{I_L R_S + V_L}{R_P} \quad (10)$$

Based on Equation. (10), the MATLAB/SIMULINK model of Figure-2 was developed. Most of the equation parameters could be obtained from the manufacturers' datasheet.

**Table-1.** STP270-24-Vb-1 PV module specifications.

| | |
|---|---|
| Maximum output power at STC ($P_{max}$) | 270W |
| Open circuit voltage (*Voc*) | 44.5V |
| Short circuit current (*Isc*) | 8.2A |
| Maximum power voltage (*Vmp*) | 35V |
| Maximum power current (*Imp*) | 7.71A |
| Temperature coefficient of Isc ($\alpha_i$) | 0.054/C° |
| Temperature coefficient of Voc ($\alpha_v$) | -0.313/C° |
| Parallel and series resistance (*Rp*,*Rs*) | 589.64Ω,0.567Ω |
| Numbers of series cells (*Ns*) | 72 cells |
| Ideally factor of the diode (*m*) | 0.93037 |

In this paper, as an example, PV Monocrystalline module Suntech Power STP270-24-Vb-1 with maximum power of 270W at STC is taken for case study and the model specification illustrated at Table 1. As a result, the *I-V* and *P-V* curves are generated as shown in Figure-3.

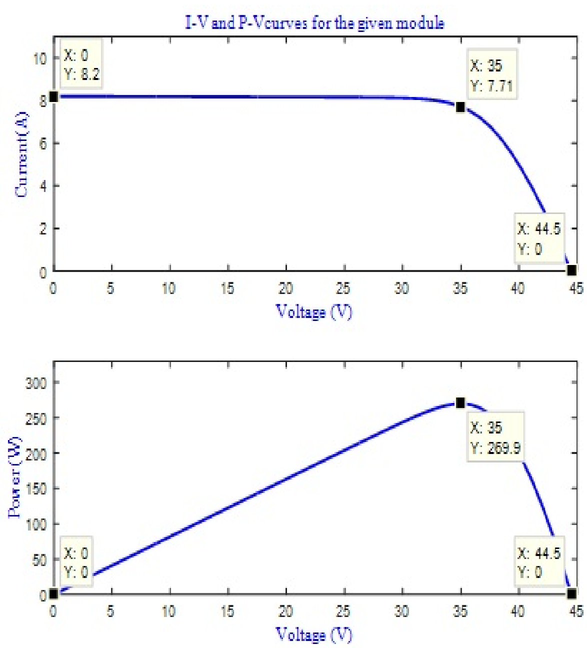


**Figure-3.** The *I-V* and *P-V* curves for the given module.

The model above in Figure-2 includes subsystems and one of them is used to calculate the photo current which depends on the radiation and temperature as described in Equation. (7). Based on that equation, the subsystem of Figure-4 is obtained and the results of the simulation explain the effects of these two factors in Figures 5 and 6, respectively.

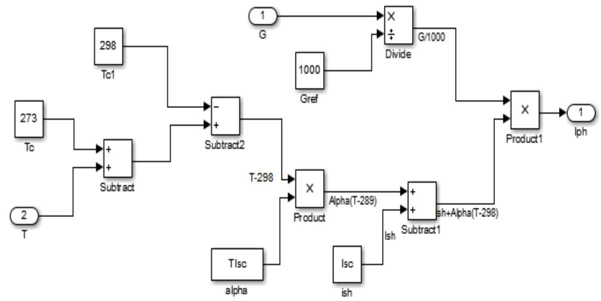


**Figure-4.** The simulation subsystem of $I_{Ph}$ for varying module temperature and insulation.

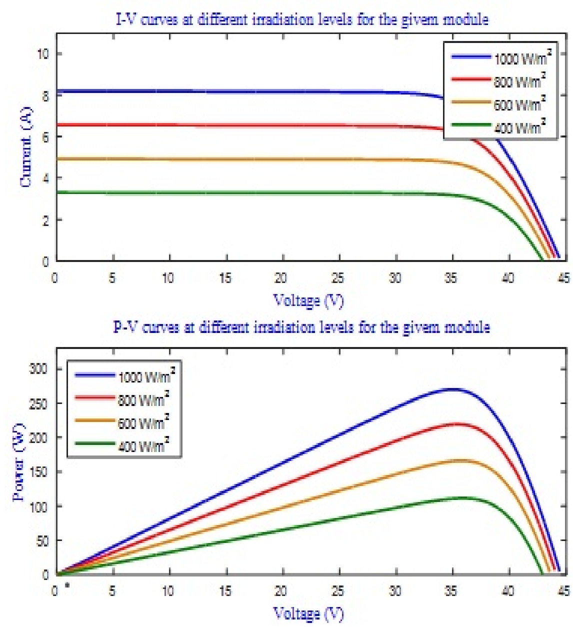


**Figure-5.** *I-V* and *P-V* curves at different levels of sun irradiance and constant temperature 25 °C.

Usually, the current of the PV module is strongly dependent on the sun irradiance. However, the power has an increment of 50W as solar irradiation increases. The power was 219W at 800W/m$^2$, then increased to 270W when the irradiation reaches 1000W/m$^2$. Additionally, the photovoltaic current generated decreases proportionally with irradiance as illustrated in Figure-5.

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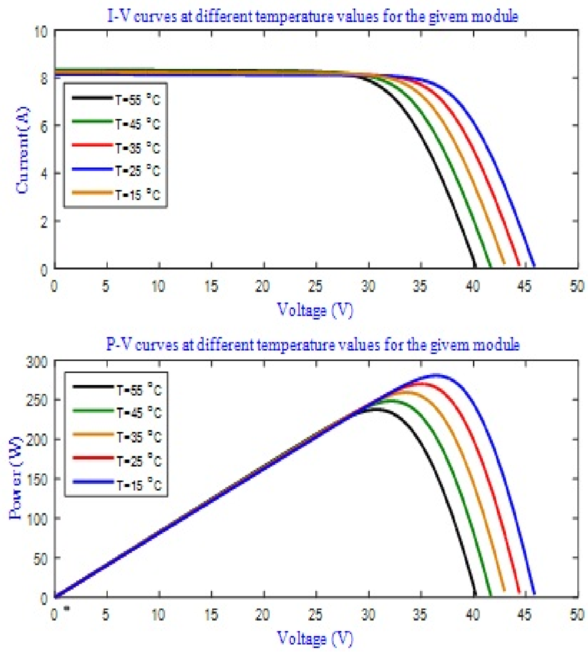


**Figure-6.** *I-V* and *P-V* curves at different values of temperature with constant sun irradiance 1000W/m$^2$.

Generally, at any specific solar radiation, in case the module temperature increases, the open circuit voltage ($V_{oc}$) will decrease slightly whereas short circuit current ($I_{sc}$) rises. This behaviour is accurately tested and presented as shown in Figure. 6.

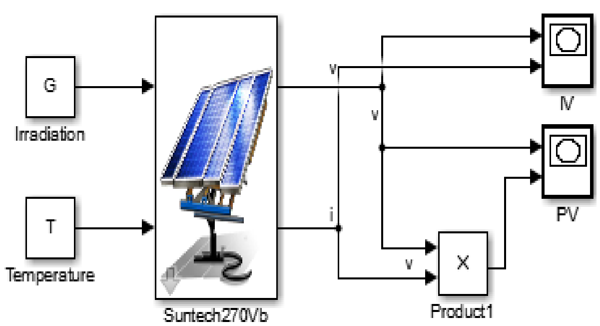


**Figure-7.** Simulation model of photovoltaic panel.

## CONVENTIONAL P&O MPPT ALGORITHM

The most common MPPT algorithm is P&O because of its simplicity and less number of sensors utilized. By periodically increasing or decreasing the PV array voltage, the P&O technique changes the operating voltage towards MPP. The process is carried out by comparing the amount of power observed between present and past cycle. If the power during this cycle exceeds the past cycle, the perturbation is proceeded in the same direction at the following perturb cycle. Otherwise the perturbation direction is reversed to the opposite direction. The summary of the conventional P&O algorithm technique is illustrated in table 2 [1, 14, 15].

**Table-2.** Summary of the conventional P&O algorithm.

| Perturbation | Power | Next perturbation |
|---|---|---|
| Increase | Increase | Increase |
| Increase | Decrease | Decrease |
| Decrease | Increase | Decrease |
| Decrease | Decrease | Increase |

## ENHANCED P&O MPPT ALGORITHM

The MPPT algorithm objective's is to track the maximum current (Imax) and maximum voltage (Vmax) of the photovoltaic array, where the maximum available output power (Pmax) is obtained. This paper proposes an enhancement to the P&O method to overcome the limitation of the conventional method such as failure under sudden changing in weather condition and oscillations at steady state condition, as mentioned in previously. In order to guarantee that MPPs are followed under sudden change of sun irradiance, the new proposed enhancement point of the P&O algorithm is to use variable perturbation depending on power change instead of fixed perturbation step size in conventional P&O and some of adaptive methods [4, 10] and [16] as well. It means that, the perturbation step size varies and adjusts consistently under changing weather condition. This proposed method can reduce the primary disadvantage usually related to P&O algorithm such as tracking efficiency and convergence speed. The variable perturbation step size that relies on power change can be obtained by the following equation and flowchart.

$$\Delta V_i = \Delta V_o \times \frac{dP_i}{dV_i} \tag{11}$$

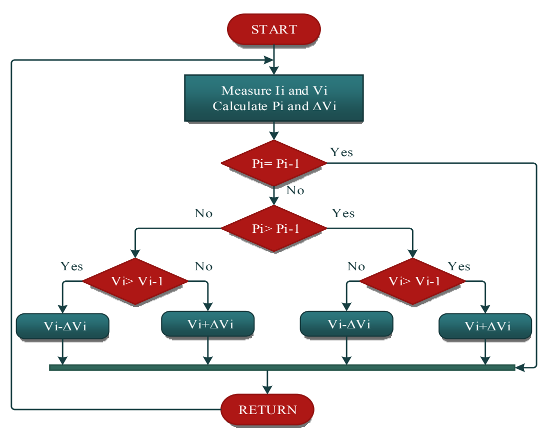


**Figure-8.** Flowchart diagram of enhanced P&O MPPT method.

## RESULTS AND DISCUSSION

The simulation results are obtained by utilizing Matlab/Simulink platform for the conventional P&O MMPT algorithm and the proposed enhanced method of solar PV system array. This system is designed by using 301 modules, each produces maximum of 270W at STC as

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illustrated in Table 1, the array distributed as 43 parallel strings and 7 series connected module per string. The peak output power of the PV array generators should be around 81kW at STC as per the following calculation 7×43×270W=81.2kW.

Figure-9 shows the output power of the PV system using conventional P&O technique at three different levels of radiation. It starts at 1000W/m$^2$, decreases to 400W/m$^2$, and then increases up to 800W/m$^2$ at a constant temperature of (25$^o$C). The power produced under STC is around 77.1kW whereas the maximum power is 30.7kW and 61.7kW when the radiation values are 400W/m$^2$ and 800W/m$^2$, respectively.

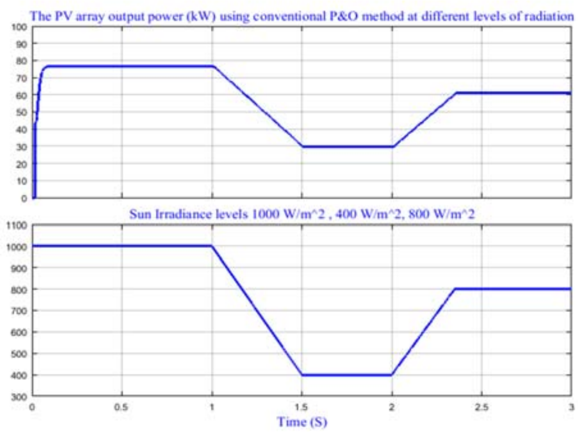


**Figure-9.** The output power of the PV array at different levels of radiation using conventional P&O MPPT method.

The same array is used to test the aforementioned enhanced method at the same radiation and temperature. MPPs are $P_{MPP1}$=80.3kW at $G_1$=1000W/m$^2$, $P_{MPP2}$=31kW at $G_2$=400W/m$^2$ and $P_{MPP3}$=64kW at $G_3$=800W/m$^2$. Figure-10 displays results of produced power by using enhanced P&O algorithm, which is proposed to get the MPPs under various solar irradiations. The power produced under STC is better than the conventional method and near to the calculated value of 81kW.

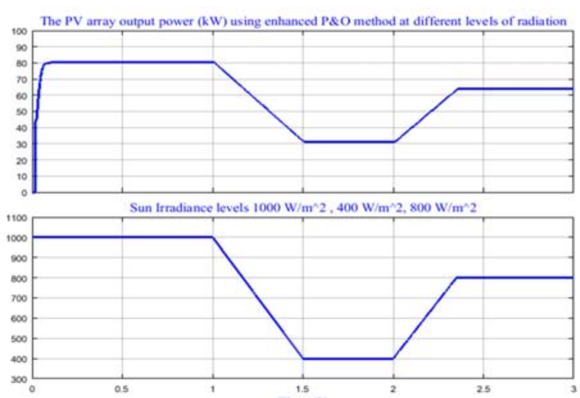


**Figure-10.** The output power of the PV array at different levels of radiation using enhanced P&O MPPT method.

The comparison between the power obtained by using conventional and enhanced P&O MPPT algorithm at the same weather conditions, temperature and irradiation illustrated in the following table as per the results shown in Figures 9 and 10, respectively.

**Table-3.** Comparison between Conven. & enhanced P&O.

| Sun Irradiation | Temp. | MPP using P&O | MPP using enhanced P&O |
|---|---|---|---|
| 1000W/m$^2$ | 25$^o$C | 77.1kW | 80.3kW |
| 800W/m$^2$ | 25$^o$C | 61.7kW | 64kW |
| 400W/m$^2$ | 25$^o$C | 30.7kW | 31kW |

It is clear that the proposed method enhances the maximum available power produced by the PV array through varying the radiation as compared to conventional method. The efficiency and the increasing rate of the change in speed shows the effectiveness of the proposed method. But, on the other side the oscillation problem still exists.

## CONCLUSIONS

In this paper, a MATLAB/SIMULINK model of solar module was developed and presented in the first part. The model is based on the fundamental circuit equation of PV module, taking into consideration the effects of physical and environmental conditions, such as temperature and solar radiation. This modelling aims to understand different characteristics of photovoltaic module and array under different atmospheric changes. MPPT techniques are utilized to extract the maximum available power from the solar PV array. The conventional P&O MPPT algorithm with fixed perturb size is not effective during oscillation and cannot track sudden change in atmospheric conditions. Therefore, in order to improve P&O MPPT technique's performance, an enhanced method has been used in the second part of this paper by using variable step size depending on power changes at different weather condition. The results of conventional and proposed method were compared in Table 3 and Figures. 9&10 respectively, which shows the effectiveness of the enhanced strategy as compared to the conventional method.

## ACKNOWLEDGEMENTS

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