# Modeling Solar Modules Performance Under Temperature and Solar Radiation of Western Iraq

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**Article Info**

***Article history:***

Received Jun 25, 2018
Revised Sep 11, 2018
Accepted Sep 25, 2018

***Keyword:***

BP solar
Math modeling
MPP
Photovoltaic modules
Synthesis power

**ABSTRACT**

This paper demonstrates a mathematical representation of Photovoltaic (PV) solar cells and hence panels performance. One-diode solar cell model is implemented to simulate the cell and extract the performance indications. The tested PV modules are BP Solar (60 Watt) and Synthesis Power (50 Watts), which are operating in a PV generation system in the University of Anbar - Iraq, College of Applied Sciences. The math model demonstrates Power versus Voltage (P-V) characteristic curves to depict and study various parameters with affecting variations in the PV array performance. The parameters include ambient and cell temperature degrees and solar irradiance (G) level which are the main elements to dictate the productivity of a solar system. G is represented by sun unit (1 sun=1 kW/m$^2$). The outcomes of the simulation model characteristics curves have been compared with curves provided by the tested modules data sheets. MATLAB software has been used to simulate the model and extract the results. This paper also investigated photovoltaic simulation with maximum power point tracking (MPPT) converter to evaluate hence predict the behaviors of the whole photovoltaic DC current generation using PSIM Power Electronics program. The model focuses on the basic components in PV systems; The panel and the DC-DC converter. The modeling outcome data will be used as a reference verifying the performance of the tested modules during the year seasons under the dominating dusty hot weather in western Iraq.



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## 1. INTRODUCTION

Nowadays, rising environmental pollution problems based on classic energy forms causes the planet to be hostile due to the climate changes and other geo and hydro contaminations. The problems are apprehended about the way of energy harnessing and utilization. In this point, fast pace revolutionary techniques are invented to solve these problems, renewable energy resources trans-form the passive energy to a clean active energy used to generate electricity with no emissions such as PV systems [1], wind energy generators, tidal generators, biomass systems, thermal panels, and geothermal systems. This paper will concentrate on the analysis of PV panels used in PV systems. The subject is gaining huge attention since PV panels are the most popular renewable energy resource. PV panel depends on the photo-radiation, weather, and the load's conditions. Thus, the output current, voltage, and wattage of PV panel can be fluctuating rapidly and sharply depending on the mentioned affecting condones. Therefore, power converters are used in the PV systems to provide a reliable useful energy to the customers stabilizing and improving the PV penal output energy. Thus, various control techniques have been proposed and invented one of them Clipped

Sinusoidal Pulse Width Modulation CSPWM technique [2] which proved to reduce the harmonic currents and provide best possible electrical energy. To prove any proposed method effectiveness, operation characteristics should be compared and tested under same affecting conditions. However, the design, control, monitor, and evaluation of PV system performance with experimental equipment, preparing multi specification parameters are experimentally necessary but difficult to be found to prove the performance. Thus, the economic burden will be very high. Therefore, from an economic perspective, the MATLAB simulation and mathematical analysis can be more effective and accurate. In this paper, a detailed simulation model of solar PV cell and hence PV panel has been coded with simulation analysis, creating actual and accurate simulation analysis technique, required to address the above economic and experimental setbacks.

This paper also investigated photovoltaic simulation with MPPT converter to evaluate hence predict the behaviors of the whole photovoltaic DC current generation using PSIM Power Electronics program. The model focuses on the basic components in PV systems; The panel and the DC-DC converter.

One diode model equivalent circuit is popular model used to evaluate the performance data which are represented by P-V characteristic curves of a typical BP Solar and Synthesis Power PV modules. The solar module model P-V characteristic compared with the field performance test data, in the area of Anbar irradiance conditions and temperature degrees. Afterward, PSIM model of a photovoltaic system with MPPT DC-DC buck converter, developed by the perturbation and observation P&O switching control method. The modeling simulation by MATLAB and modeled circuit by PSIM are useful for PV systems designers, due to the simplicity, accuracy, and easy-to-use simulation and modeling method. The data extraction and model assessment has been demonstrated to indicate the input/output data of the model such as; weather conditions, converters effectivity, control methods, and solar physical parameters.

## 2. MODELING & SIMULATION

The electrical modeling circuit shown in Figure 1 represents the PV cell. It is fed with the dependent current source to represents the intensity of solar irradiation. Thus, the amount of drawn current has a direct correlation to falling light intensity on the PV cell. Also, the source is connected in parallel with a diode which represents the behavior of solar cell of silicon p-n junction photodiode. Therefore, through light absence, darkness, the PV cell is inactive element works as load diode [3]. The shunt and series resistances represent the effect of the temperature since the resistance of the materials increases when the operation temperature becomes higher.

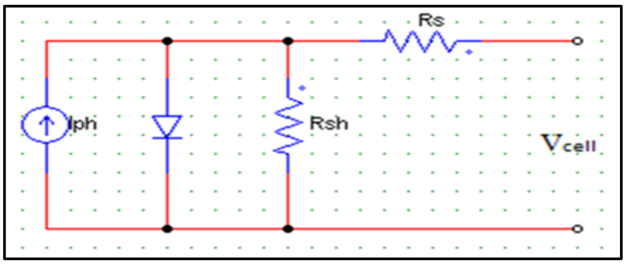


Figure 1. Model circuit of a solar cell

As previously mentioned, BP Solar PV and Synthesis Power PV modules have been tested under the conditions of radiation and temperature in the west of Iraq, these modules are suitable for traditional operations of photovoltaic systems. BP Solar PV and Synthesis Power PV modules provide 60W and 150W respectively. Both modules consist of 36 silicon cells connected in series. The data sheet main specifications are demonstrated in Table (1). The MATLAB math modeling is implemented using climate and physical parameters with modeling equations [4]. As a result, the operation current (I) can be calculated depending on typical panel specification mentioned in the table (1) [5]
(ISC, VOC), Irradiation (G), Series resistance (Rs), and Temperature (T). This modeling provides analytical simulation outcomes to evaluate the panels. The model has many constants and variable to cover the physical and electrical parameters, as shown below:

Va: Operation voltage
K: Boltzmann constant
q: Electron Charge
A: quality coefficient (=2 for Crystalline Silicon, <2 for Amorphous Silicon)

Vg: Diode Band Gap voltage (=1.12eV for Crystalline Silicon, <1.75 for Amorphous Silicon)
Ns: Number of panel PV cells
T1: Minimum operation temperature
Voc: Open Circuit voltage for each PV cell
1sc: Short Circuit Current for each PV cell
T2: Maximum operation temperature
Tak: Actual operation temperature
The parameters above are used in math modeling equations below:

$$I_{L\_T1}=Isc\_T1*G \quad (1)$$

$$I_L=I_{L\_T1}+K * (Tak-T1) \quad (2)$$

$$K=(Isc\_T2 – Isc\_T1)/(T2-T1) \quad (3)$$

$$I_{T1}=Isc\_T1/(exp (q * Voc\_T1)/(N * K * Ta-1) \quad (4)$$

$$I_0=I_{T1} * (Tak/Tac) (3/N) *exp (-q * Vg / (Ns * K) * ((1 / Tak) - (1/Tac)) \quad (5)$$

$$dV/dI\_Voc=- 1.15 / Ns /2 \quad (6)$$

$$X=Io\_T1 *q / (N * K * Tac) * exp( q * Voc\_T1 / (Ns* K*Tac)) \quad (7)$$

$$Vt\_Ta=A * K * Tak /q \quad (8)$$

$$Rs=dV\backslash dI\_Voc-(1/X)=Xv \quad (9)$$

Newton Raphson iteration numerical method has been applied to extract the value of current for every working voltage to find P-V curves under the effect of Temperature and irradiation of Anbar province west Iraq, as shown in equation (10) [6].

$$Ia=Ia-(I_L-I_a-I_0*(exp((V_{oc}+Ia*Rs)/Vt\_Ta)-1))/(-1-(I_0*(exp((Vc+Ia*Rs)/(Vt\_Ia)1))*Rs/Vt\_Ia \quad (10)$$

**MATLAB Code**

```
Va=[0:0.5:21.5];
G=1;
k=1.38e-23; % Boltzman constant
q=1.60e-19; % Electron charge
A=2; Vg=1.12; Ns=36 T=25;
Voc_T1=22.1 /Ns; Isc_T1=3.99;
T2=273 + 75; Voc_T2=17.05 /Ns;
Isc_T2=2.99; TaK(n)=T1;
Iph_T1=Isc_T1 * (G);
for n=1:4
a(n)=(Isc_T2 - Isc_T1)/Isc_T1*1 /(T2 - T1(n));end
for n=1:4
Iph(n)=Iph_T1* (1 + a(n)*(TaK(n) - T1(n)));end
for n=1:4
Vt_T1(n)=k*T1(n)/q;end %=A*kT/q
for n=1:4
    Ir_T1(n)=(exp(Voc_T1/(A* Vt_T1(n)))-1);end
 for n=1:4
    Ir_T2(n)=Isc_T2/(exp(Voc_T2/ (A*Vt_T1(n)))-1); End
b=Vg * q/(A*k);
for n=1:4
Ir(n)=Ir_T1(n)*(TaK(n)/T1(n)).*(3 /A) .* exp(-b.*(1./TaK(n) -(1/T1(n))));end
for n=1:4
X2v=Ir_T1(n)/(A*Vt_T1(n))*exp(Voc_T1/(A*Vt_T1(n)));end
dVdI_Voc=- 1.15/Ns / 2; % dV/dI at Voc per cell
```

```
Rs=- Dv/dI_Voc - 1/X2v; %series resistance per cell
for n=1:4
Vt_Ta(n)=A*1.38e-23 * TaK(n) / 1.60e-19; end %=A*k*T/q
Vc=Va/Ns;
Ia=zeros(size(Vc));
Ia=Iph - Ir.*(exp((Vc+ia.*Rs) ./Vt_Ta) -1); % Newton’s method
Ia=[iav;ia]; end % to observe convergence for debugging.
p=Va.*Ia; %power
plot(Va,p);
```

## 3. SIMULATION RESULTS

Typically, the electrical properties and specifications of PV panels is provided in its datasheet by the manufacturers. However, before purchasing any PV panel brand, it is highly recommended to make confirmation measurements to assure there is no deviation from nominal values. In some brands, the deviation from promised values is large and expected due to lack of efficiency and manufacturing malfunctions. The specifications of tested models are listed in Table 1.

Table 1. Specification of the Simulated Modules

| Parameter | BP Solar | Synthesis Power |
|---|---|---|
| Isc (Ampere) | 3.9 | 3.18 |
| Voc (Volt) | 22 | 20 |
| Pout (Watt) | 60 | 50 |

### 3.1. Irradiance

PV generation resource depends basically on the ability of silicon or other certain materials of transferring the photo-radiation energy from the sun or any other source into moving to charge hence electrical energy. Irradiance (G) is energy amount that applied energy on a given area (watts per square meter ($W/m^2$)). Thus, it is instantaneous value averaged over a defined period [7]. Therefore, commonly the irradiance is specified per hour, day, or even month. In this paper, after applying the simulation of the last section the P-V curves is plotted in different colors to differentiate them. Each curve explains the electrical behavior produced by a panel under different G which varies from (0.7 to 1.2) $W/m^2$ the amount of solar radiation during the year seasons in Anbar. The data of radiation is collected from solar maximum radiation tracker installed in the University of Anbar where G=1.2, 1, 1, 0.7 suns during the Summer, Spring, Autumn, and Winter respectively.

Figure 2 depicts the effect of different G on the power generation of BP Solar module when the temperature is fixed at the standard value 25 Celsius degree. Despite the given Maximum power of the panel which is 60 watts, the power obtained at winter (when G=0.7) is the minimum equal 41 watts, whereas the maximum power can be obtained at summer (G=1.2) is the maximum equal 73 watts. It should be noted, the power value in the Table 1 for BP Solar module is 60 which is the value power at the most of spring and Autumn (when G=1) which is standard used to test and determine the module electrical performance.

In Figure 3, the effect of G variation on Synthesis Power module performance. Despite the given Maximum power of the panel which is 60 watts, the power obtained at winter (when G=0.7) is the minimum equal 32 watts, whereas the maximum power can be obtained at summer (G=1.2) is the maximum equal 57.5 watts. It should be noted that power value in the table (1) for Synthesis Power module is 50 Watts which is the value power at the most of spring and Autumn (when G=1) which is standard G used to test the module electrical Performance [8].

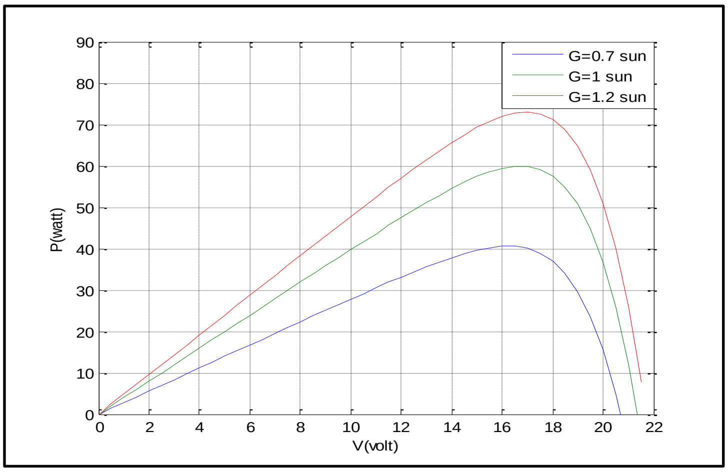


Figure 2. P-V curves under irradiance variation of BP Solar modul

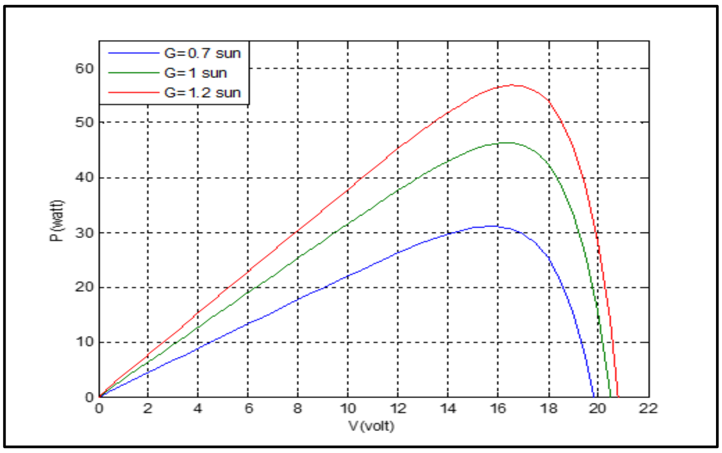


Figure 3. P-V curves of synthesis power under irradiance variation

### 3.2. Temperature Effect

When temperature increases the resistivity of the conductors and doped semiconductors becomes higher, thus the current decreases for PV modules. The shunt and series resistance represent the effect of the temperature. The temperature in Western Iraq is 25, 50 °C, in winter and Summer respectively. However, as temperature accumulating, the heat can rise to 75 °C especially in the deep areas in the western desert, which is the promising farm for such PV projects. In Figure 4, the effect of temperature on the PV generation is depicted. The maximum power is 61 watts extracted at 25 °C, whereas the minimum power is 75.5 watts at 75 °C. The P-V curves are plotted at the standard solar radiation G=1 [9]. As shown in Figure 5, the temperature effect on PV generation of Synthesis Power module is illustrated. The maximum power is 47 watts extracted at 25 °C, whereas the minimum power is **44** watts at 75 °C.

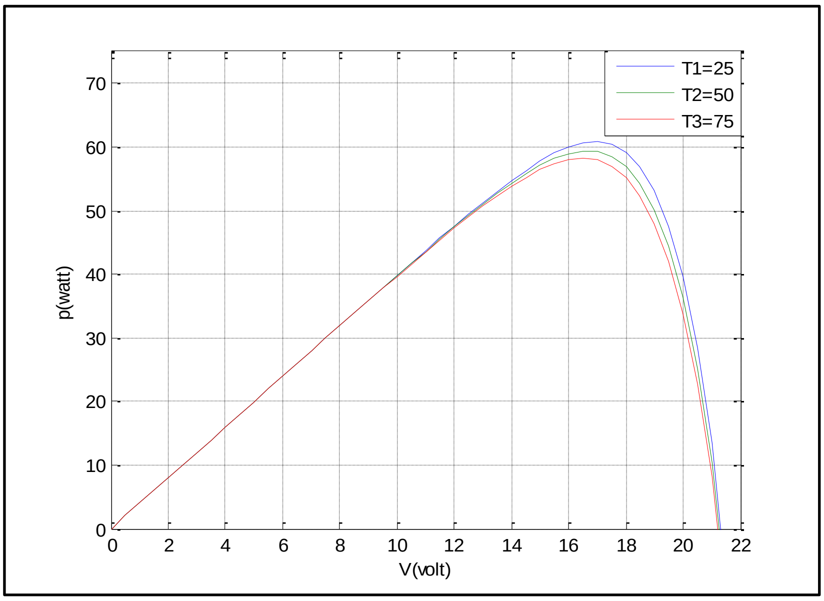


Figure 4. P-V curves of BP Solar module under temperature variation

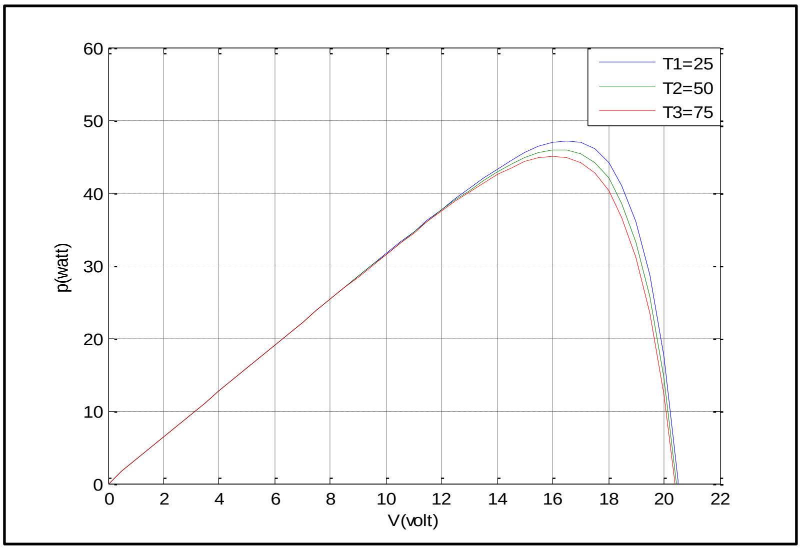


Figure 5. The P-V curve of synthesis power module under temperature variation

## 4. DC-DC CONVERTER SIMULATION

Provide a statement that what is expected, as stated in the "Introduction" chapter can ultimately result in "Results and Discussion" chapter, so there is compatibility. Moreover, it can also be added the prospect of the development of research results and application prospects of further studies into the next (based on result and discussion).

DC-DC Converter is used to track and harness Maximum Power Point (MPP) in the P-V curves of the PV panels. Therefore, High irradiation, efficient manufacturing, and low operation temperature are not the only cofactors to affect the PV panel performance and harness maximum possible electrical energy from the PV panel. An appropriate MPPT method increases the efficiency of energy harnessing and ensuring the maximum power in the P-V curve. Several MPPT algorithms are invented and used in the PV systems along with DC-DC converters [10]. They are:

a. Perturbation and Observation method (P&O)
b. Hill Climbing Algorithm method (HC)
c. Incremental Conductance method (INC)

In this section, a PV panel cascaded by a buck converter controlled by the P&O algorithm is simulated by PSIM. This simulation aims to extract the MPP in the P-V curves of the tested modules under the fixed value of G=1 Sun and T=25 °C. In the PV systems, the main functions of buck DC-DC converter are stepping down module generated DC voltage to connect it to the batteries and act as intermediate power processor to track MPP from the connected PV array [11]. The converters change output voltage and current to interface a fixed source to a variable load. The P&O algorithm is popular since it has a very fast response with the best result because it reaches steady state operating stage quickly it is implemented in Figure 6. In Figure 7, MPPT converter using P&O Method in its swiching gate is built and executed by PSIM. The temperature T=25 °C and G=1 sun are assumed and considered in PSIM simulation.

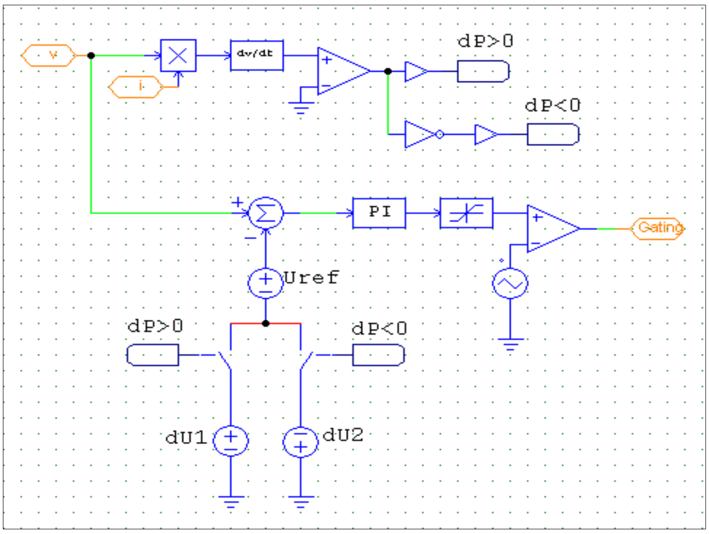


Figure 6. Perturb and observe method to observe the maximum power (when dP=0)

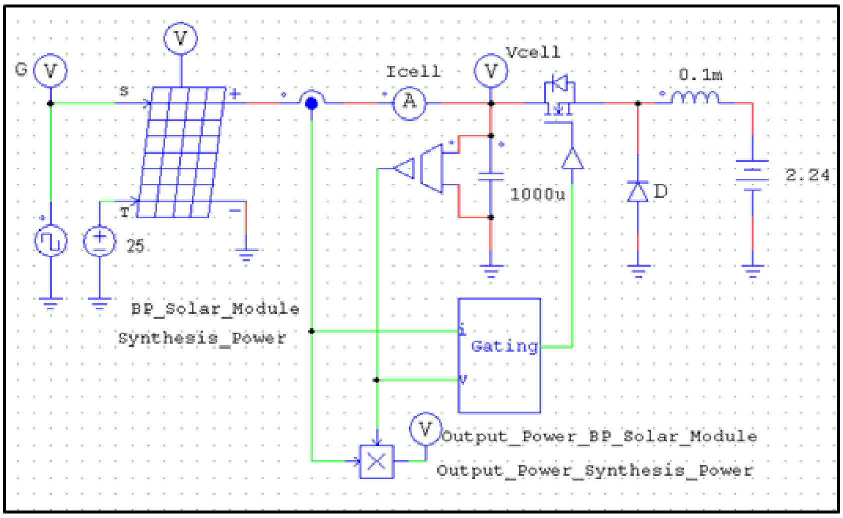


Figure 7. MPPT buck converter with P&O method

The voltage is perturbed and observe the change of output power. The gating sub-circuit is P&O method controlling the converter switching circuit to change the switch gate (transistor) achieving MPP from tested BP Solar and Synthesis Power panels [12]. Figure 7 depicts the output power from DC-DC buck converter shown above. The maximum power is 60 Watt for BP Solar and 47 which are identical to the maximum power in the P-V curve. Figure 8 shows the MPPT buck converter with P&O method output.

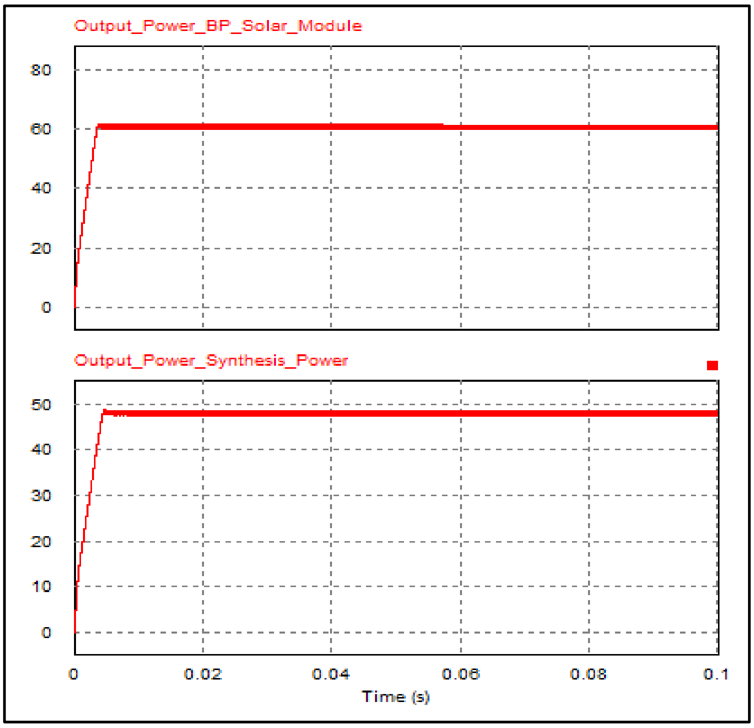


Figure 8. The MPPT buck converter with P&O method output

## 5. CONCLUSION

Mathematical modeling of two modules is presented by MATLAB coding and PSIM power electronics program to analyze the performance of BP Solar and Synthesis Power PV panels. This paper has introduced the effect of Temperature and sun Irradiation of the west of Iraq area. This simulation work will be employed as a reference to assess the performance of any PV module used in this area to compare their practical and actual results.

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