



## Design of PV Solar Energy Generator using MPPT Technique to Control Single Input/Multiple Outputs (DC-DC) Converter

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### Abstract

The paper presents the design of a system consisting of a solar panel with Single Input/Multiple Outputs (DC-DC) Buck Converter by using Simulink dialogue box tools in MATLAB software package for simulation the system. Maximum Power Point Tracking (MPPT) technique depending on Perturb and Observe (P&O) algorithm is used to control the output power of the converter and increase the efficiency of the system. The characteristics of the MSX-60 PV module is chosen in design of the system, whereas the electrical characteristics (P-V, I-V and P-I curves) for the module are achieved, that is affected by the solar radiation and temperature variations. The proposed design module has been found to be stable for any change in atmospheric temperature and solar radiation. The maximum power is achieved at voltage 17V and current 3.5A when using MPPT controller, and approximate results for multiple outputs voltages and current (9V:2A, 5V:1A, 2.2V:0.5A) are obtained. The proposed model is very useful for engineers, researchers and experts to design their systems which require a simple and accurate PV cells model.

**Keywords:** Buck DC-DC Converter, Mathematical Modeling, Matlab/ Simulink, MPPT, PV cell/panel.

### 1. Introduction

The photovoltaic energy is one of the renewable sources in the past decade. It is a clean energy and a high reliability. So, it can be considered as one of the most sustainable renewable energy. Solar energy is one of the most important renewable sources of energy. The most important factors affected on the performance of solar cell are temperature, solar irradiation and PV technology type [1].

B. V. Chikate and Y. A. Sadawarte [1] studied the effects of ambient conditions and PV technology type on the efficiency of solar module. The performance of solar cell is depending on converting incident solar radiation into electricity which pointing to conversion efficiency. The design is used to obtain the current–voltage (I–V) characteristics with defined the maximum power point(MPP) [2]. The PV and I-V characteristic of the cell are nonlinear due to complex relationship

between current and voltage , and vary with change in cell temperature or solar radiation. There is single point on P-V or I-V characteristics curve where PV module produces highest output power at MPP [1].

M. A. Ozcelik and A. S. Yilmaz [3] presented the design of PV generator by using Matlab/Simulink software, and studying the effect of MPPT in PV system.

S. Rout [4] presented the implementation of a PV Model using Matlab/Simulink software. The mathematical equations of Photo current and voltage are used for design a PV system. Matlab dialogue box from simulink block Libraries is used for simulation.

P. Srivastava [5] examined the factors which affect the efficiency of solar cells. These factors are energy conversion, cell temperature, Maximum Power Point Tracking for solar cell.

Dominique Bonkoungou et al [6] presented an improved numerical approach modeling for I-V

characteristics of PV modules. The thermal performance of the proposed approach is improved by a coefficient computed by using the maximum power temperature coefficient provided by manufacturers.

R. R. Patel and T. A. Trivedi [7] presented a mathematical equation for design the module and simulation of PV cell panel by using Matlab/Simulink software. They show the variation in PV cell behavior under different environmental conditions.

In many applications, the PV cell panel must be connected to power converter system are used. Matlab/Simulink helps for studying the operation the converters by selecting the matrix manipulations in it, plotting of functions, implementation of MPPT algorithms and acts as user interfaces with the Solar PV modules for monitoring the performance of the system [8]. Among the researches that deals with the design of these converters as follows:

Kavitha H.S. [9] proposed converter uses one power switch which is high efficiency power conversion, multiple outputs. To reduce the switching and conduction losses, the techniques of soft switching and voltage clamping are used.

Mahesh G. N. M. et al [10] provided the operation and mathematical model of a Buck DC-DC converter for simulation using Simulink dialogue blocks. They discussed the transfer function of the system in order to use the Matlab Tuning tools to obtain better settling time, rise time and peak overshoot.

S. P. Singh et al [11] presented a soft switching technique for studying high efficiency buck DC-DC converter. They will focus on design, analysis and simulation buck converter modeling. The converter is designed in Continuous Conduction Mode.

In this paper, a modeling of Solar PV Emulator utilizing Single Input/Multiple Output (SIMO) Buck DC-DC converter is design and carried in Matlab software by using dialogue box from Simulink block Libraries for simulation. Maximum Power Point Tracking (MPPT) technique depending on Perturb and Observe (P&O) algorithm is used to regulate the output power of the converter. The characteristic of a PV cell has been tested when taking the effect of changing the temperature and solar radiation. The Simulink design of DC-DC buck converter circuit and MPPT controller is presented. The MPPT controller is used for increasing the efficiency of the system.

## 2. PV cell Mathematical Modeling

A photovoltaic (PV) module is formed by connecting many solar cells in parallel and series. A single diode model of solar cell is shown in fig.1. The equivalent electric circuit consists of a photocurrent source ( $I_{ph}$ ), a diode ( $D$ ), a parallel resistor ( $R_{sh}$ ) and a series resistor ( $R_s$ ) [12].

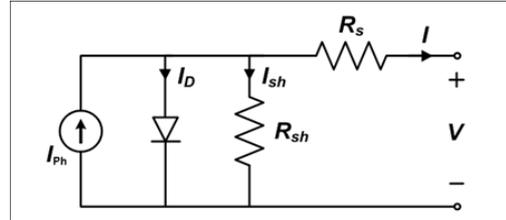


Fig. 1. Solar cell model.

The electrical characteristics of the PV cell module can be describing by the following sets of equations [12]:

$$I = I_{ph} - I_d - I_{sh} \quad \dots(1)$$

here:  $I_d$ : Diode current (A);  $I_{sh}$ : Current through the shunt resistance (A)

$$I_{ph} = [I_{sc} + K_i(T - T_r)] \left(\frac{S}{S_r}\right) \quad \dots(2)$$

here:  $I_{sc}$ : Short circuit current;  $K_i$ : Temperature coefficient of short-circuit current (A/K) at 25 °C and 1000W/m<sup>2</sup>;  $T$ : Cell operating temperature (K);  $T_r$ : Cell's reference temperature (298K);  $S$ : Solar irradiance (W/m<sup>2</sup>);  $S_r$ : Reference solar radiation (1000W/m<sup>2</sup>).

$$I_d = I_o \left[ \exp\left(\frac{V_d}{\frac{nkT}{q}}\right) - 1 \right] \quad \dots(3)$$

here:  $I_o$ : Diode saturation current(A);  $V_d$ : Diode voltage (V);  $k$ : Boltzmann's constant (1.38x10<sup>-23</sup>J/K);  $n$ : Diode ideality factor;  $q$ : Electron charge (1.602x10<sup>-19</sup>C)

$$I_o = I_{o,n} \left(\frac{T}{T_r}\right)^3 \exp\left[\frac{qE_g}{nk} \left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \quad \dots(4)$$

here:  $E_g$ : the band-gap energy of the semiconductor ( $E_g = 1.12$  eV for the polycrystalline Silicon at 25°C);  $I_{o,n}$ : the nominal saturation current.

$$V_{sh} = V_d \quad \dots(5)$$

$$V_d = V + IR_s \quad \dots(5)$$

$$I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{V + IR_s}{R_{sh}} \quad \dots(6)$$

The thermal voltage ( $V_T$ ) of the cell can be set by the equation:

$$V_T = \frac{KT}{q} \quad \dots(7)$$

then equation [1] become :

$$I = I_{ph} - I_o \left[ \exp \left\{ \frac{V+IR_s}{nV_T} \right\} - 1 \right] - \left[ \frac{V+IR_s}{R_{sh}} \right] \dots (8)$$

The equation (8) describes P-V and I-V characteristics of the solar cell. The characteristics vary with cell temperature and solar irradiation as shown in fig.2 [13]. Maximum power ( $P_m$ ) point is the operating point  $A(V_m, I_m)$  at which the power dissipated in the resistive load is maximum [14]:

$$P_m = V_m I_m \dots (9)$$

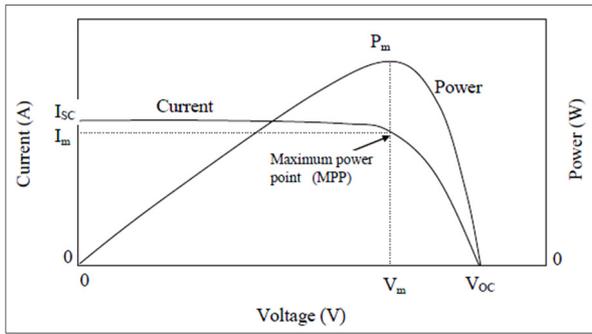


Fig. 2. Characteristics of solar cell

The performance of solar cell is tested under the Standard Test Condition (STC), where an average solar spectrum at Air-Mass (AM 1.5) is used, the cell temperature is defined as 25 °C, and the global irradiance is 1000W/m<sup>2</sup> [2].

### 3. PV Array Mathematical Module

The output power produced from single solar cell is not enough for any application. Therefore, to generate enough power, the PV modules are connected in parallel or series to form PV arrays which are used to increase the efficiency. The equivalent circuit for the solar module is shown in fig.3 [10], where  $N_s$  the number of cells connected in series and  $N_p$  the number of cells connected in parallel.

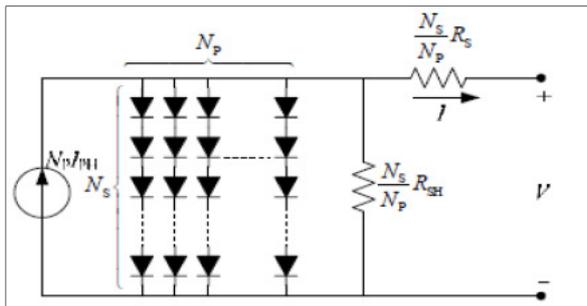


Fig. 3. General PV equivalent circuit model.

Based on the equivalent circuit of a PV module, its characteristic equation is given as follows [12]:

$$I_{ph,final} = N_p I_{ph} \dots (10)$$

$$I_{o,final} = N_p I_o \dots (11)$$

$$n_{,final} = N_s n \dots (12)$$

$$R_{s,final} = \frac{N_s}{N_p} R_s \dots (13)$$

$$I = N_p I_{ph} - N_p I_o \left[ \exp \left\{ \frac{\left( V + I \frac{N_s R_s}{N_p} \right)}{N_s \left( \frac{n k T}{q} \right)} \right\} - 1 \right] \dots (14)$$

$$I = N_p I_{ph} - N_p I_o \left[ \exp \left\{ \frac{\left( \frac{V}{N_s} + \frac{I R_s}{N_p} \right)}{\left( \frac{n k T}{q} \right)} \right\} - 1 \right] - \frac{\frac{N_p V + I R_s}{N_s}}{R_{sh}} \dots (15)$$

The electrical characteristic of the system is describing by equation (15) which is a non-linear mathematical equation and define the relationship between current and voltage generated by a PV module [12].

### 4. Simulink of PV Cell Array Module

Matlab/Simulink software package was used to implement the model of the Solar PV Emulator. The MSX-60 PV module is chosen as a reference for this simulink, that provides 60W nominal maximum power. Parameter specification of the MSX-60 module is shown in table (1) [7]. The PV cell characteristics affected by these parameters.

Table 1, Parameter specification of MSX-60 module ( $S = 1Kw/m^2, T = 25C$ )

Parameters	Values
$P_m$	60W
$V_m$	17.1V
$I_m$	3.5A
$I_{sc}$	3.8A
$V_{oc}$	21.1V
$k_i$	3mA/C
NOCT	40C
$n$	1.35
$R_s$	0.180Ω
$R_{sh}$	360Ω
$N_p$	1
$N_s$	36
$I_{o,n}$	0.000021A

Mathematical equations from equations (1) to (8) are used to carry out the PV model as shown in Fig.4 with input parameters temperature and

irradiance. The contents of the block PV-Module in fig. 4 are shown in fig. 5. Mathematical

equation (15) is used to implement the behavior of the PV model by using Matlab/Simulink program.

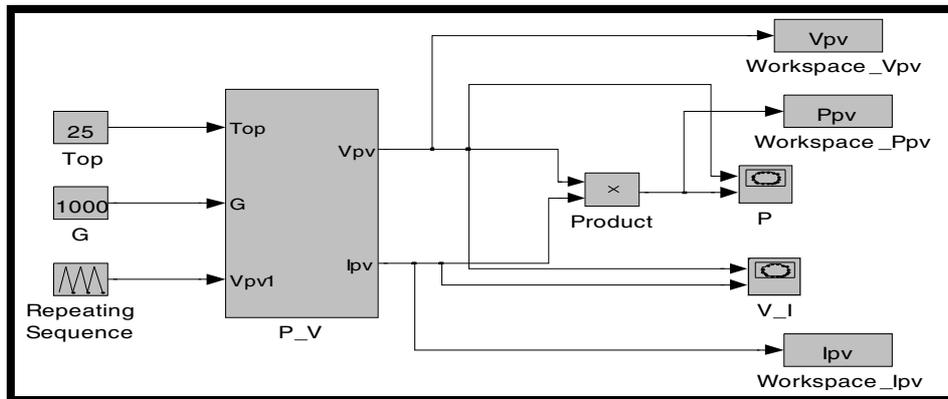


Fig. 4. Simulink of solar PV model.

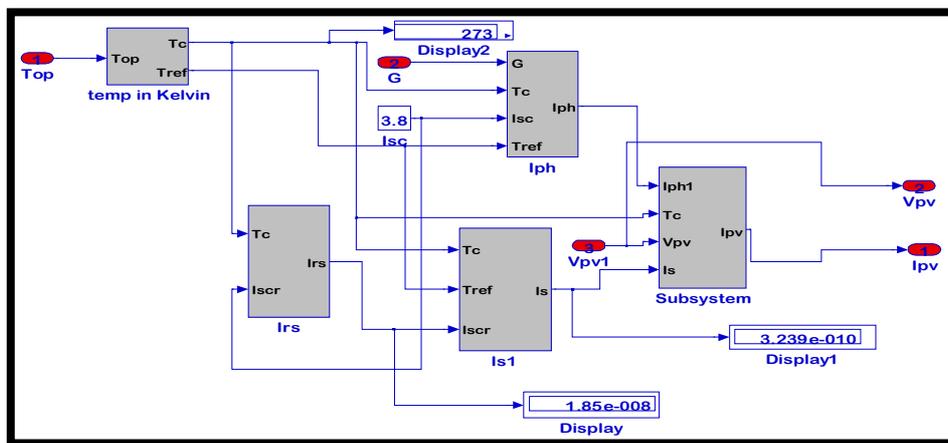


Fig. 5. Block PV-Module Simulink

### 5. Maximum Power Point Tracking

The Maximum Power Point (MPP) is an particular operating point where the power supplied to the load is at maximum and noted by ( $P_m$ ) as shown in fig.2. To increase the efficiency of PV module, it is important to operate PV energy generate system close to MPP. The output power is always variations according to atmospheric temperature and solar radiation, then, the MPPT controller with DC-DC Converter is used for transferring maximum power from the solar PV module to the load [5]. The maximum output power can be calculated as [15]:

$$P_m = V_m I_m \quad \dots (16)$$

The perturb and observe (P&O) algorithm is used for achieve the maximum output power. The most basic form of the algorithm (fig.6) operates as follows[16]: The output power is achieved by

multiplying  $V_{pv}$  and  $I_{pv}$  signals, then the change of power determined the direction of the MPP. Assume the operating point of PV module is away from the MPP, the operating voltage of PV module is perturbed by a small increment, and the resulting change of power  $\Delta P$  is observed. If the  $\Delta P$  is positive, then the operating point is moved closer to the MPP. Thus, the operating point moved in the same direction, and the further voltage perturbations should move toward the MPP. If the  $\Delta P$  is negative, the operating point has moved away from the MPP, and the voltage perturbation should be reversed to move back toward the MPP. In fig. 6, ( $k$ ) indicates to current values and ( $k - 1$ ) indicates to previous values for current, voltages and power.

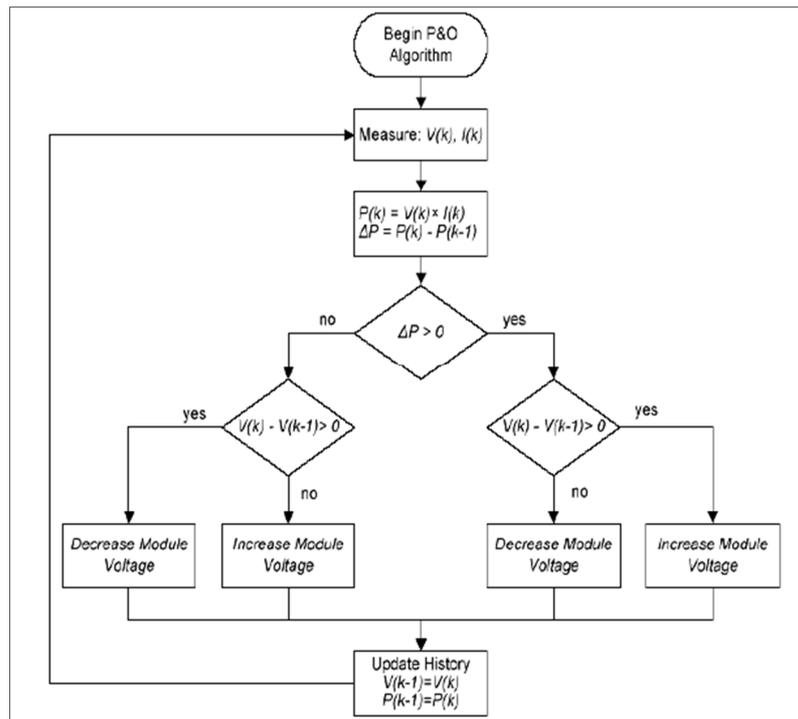


Fig. 6 Flow Chart of (P&O) algorithm used in our MPPT charge controller

### 6. MPPT Simulink

The Matlab/Simulink design for (P&O) algorithm is implemented as shown in fig.7.

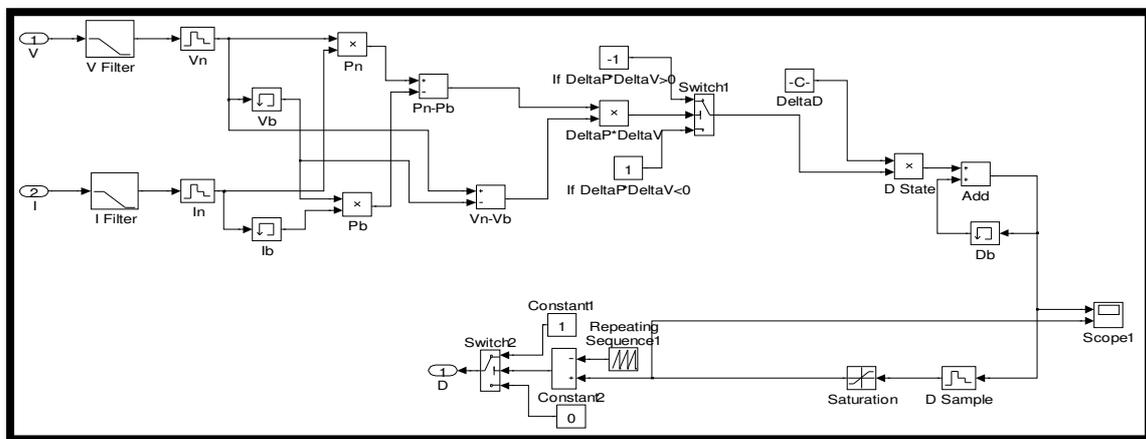


Fig. 7. MPPT Simulink.

### 7. Design of DC-DC Buck Converter

Switch mode DC-DC converters are used to describe a circuit which convert unregulated DC input voltage to provide single or multiple output DC voltages by a switching action. Fig.8 shows the DC-DC buck converter circuit of step down dc voltage [8]. Sometimes, an active power switch is used instead of freewheeling diode to operate at

low output voltage and high efficiency, this converter is called as synchronous dc-dc buck converter [17].

The buck converter circuit is operating in continuous current mode (CCM), and the MOSFET transistor acts as switch and turned (ON) and (OFF) depending on the signal applied to its gate from Pulse Width Modulation circuit

which is used to control the power transmitted from input to the load [8].

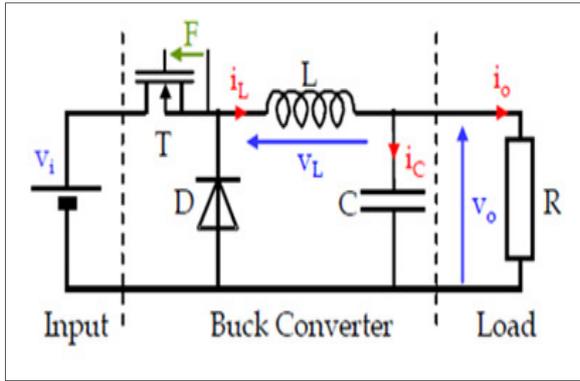


Fig. 8. Buck converter circuit

The differential equation at ON condition is given by[18]:

$$V_i = LC \frac{d^2V_c}{dt^2} + \frac{L}{R} \frac{dV_c}{dt} + V_c(t) \quad \dots (17)$$

If  $V_c(t)$  is constant, so equation (17) can be written as:

$$V_i - V_o = L \frac{di_L(t)}{dt} \quad \dots (18)$$

The Inductor and Capacitor currents waveforms are shown in fig. 9[18].

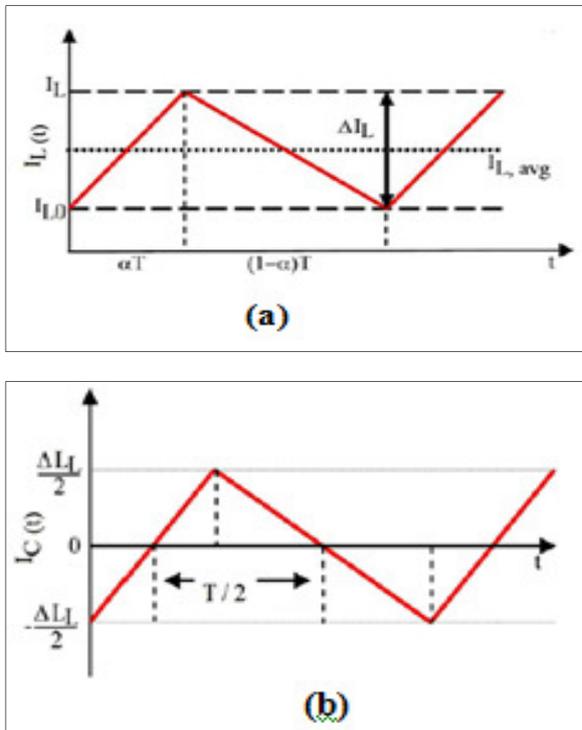


Fig. 9. A. Inductor current waveform, (b) Capacitor current waveform.

In a steady state condition, when  $t \rightarrow T_{ON} = \alpha T$ , the inductor current  $I_L$  is:

$$I_L = \frac{V_i - V_o}{L} \alpha T + I_{L_0} \quad \dots (19)$$

here  $I_{L_0}$  is the initial value of the inductor current and  $\alpha$  is the duty cycle.

The current ripple  $\Delta I_L$  is given by:

$$\Delta I_L = I_L - I_{L_0} = \frac{V_i - V_o}{L} \alpha T \quad \dots (20)$$

In OFF condition, the first differential equation is:

$$L \frac{di_L(t)}{dt} = -V_o \quad \dots (21)$$

The solution of equation (21) yields:

$$I_L(t) = \frac{-V_{out}}{L} t + I_L \quad \dots (22)$$

For  $t \rightarrow T_{OFF} = (1 - \alpha)T$ , the  $I_L$  decreases to  $I_{L_0}$  which is minimum value as:

$$I_{L_0} = \frac{-V_o}{L} (1 - \alpha)t + I_L \quad \dots (23)$$

Then the current ripple can be expressed as:

$$\Delta I_L = \frac{V_{on}}{L} (1 - \alpha)T \quad \dots (24)$$

By comparison between equations (20) and (24), it is obvious that:

$$V_o = \alpha V_i \quad \dots (25)$$

From fig. 9, the average current flow through the capacitor is zero, but the capacitor will be charged in one-half cycle, and the equation described the increasing in charge is :

$$\Delta Q = \frac{1}{2} \frac{\Delta I_L}{2} \frac{T}{2} = \frac{1}{8} \Delta I_L T \quad \dots (26)$$

and because  $V_c = V_o$ , then:

$$\Delta V_o = \frac{\Delta Q}{C} \quad \dots (27)$$

Then from (24) and (26):

$$\Delta V_o = \frac{1}{8LCf^2V_o} \quad \dots (28)$$

From fig.8, the value of the inductor L is:

$$L = (V_i - V_o) \frac{\alpha / f_{sw}}{I_r} \quad \dots (29)$$

From equation (28):

$$C = \frac{1}{8Lf^2\Delta V_o} V_o \quad \dots (30)$$

## 8. Single Input/ Multiple Outputs DC-DC Buck Converter

For Single Input/ Multiple Outputs (SIMO) circuit, one inductor and three power switches are used and must be properly driven. For dc-dc buck converter with three outputs, the three standard DC-DC buck converters are used to control independently the three output voltages. Fig.10 shows a electrical circuit with single input and three outputs [17].

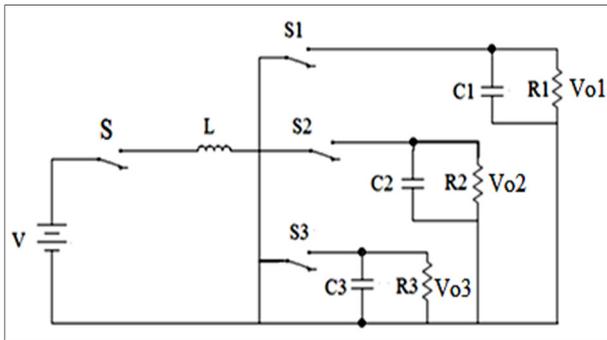


Fig. 10. Single input/multiple outputs circuit diagram.

### 9. Simulink of Multiple Output Buck DC-DC Converter

The simulink of the SIMO DC-DC buck converter in continuous conduction mode are carried by using the values of capacitance( $C$ ) = 1000 $\mu$ F, inductance( $L$ ) = 0.11H, resistance( $R$ )= 5 $\Omega$ . Fig.11 shows the simulink model for buck converter.

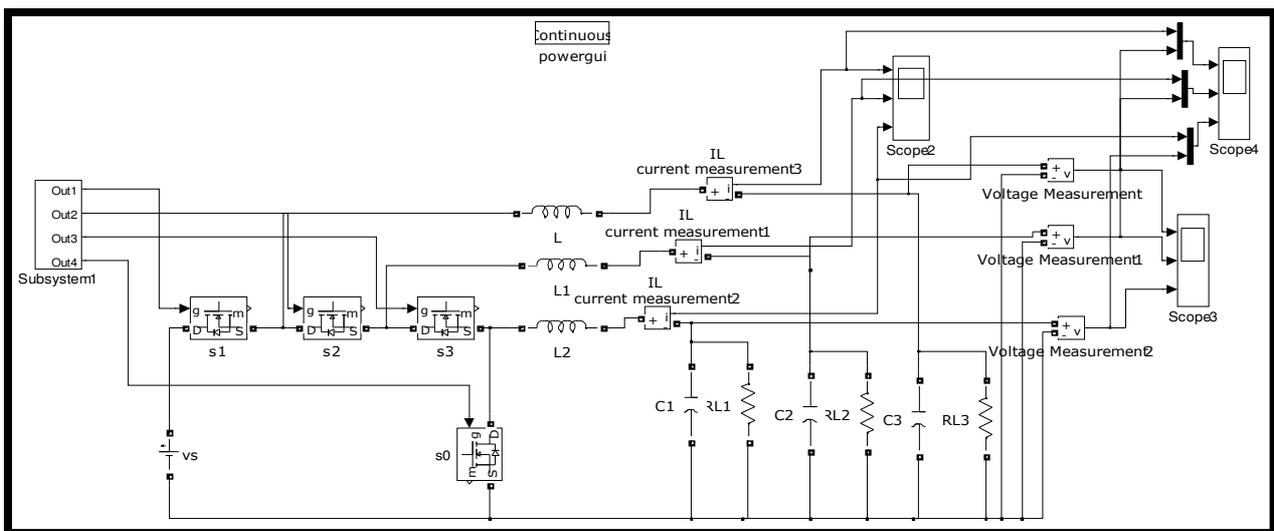


Fig. 11. Buck Converter Simulink (Multiple Outputs).

### 10. System Design

Fig.12 shows the block diagram of the proposed system design. The inputs of the MPPT controller are  $I_{pv}$  and  $V_{pv}$  from the PV panel. The output ( $D$ ) of the controller is fed to Buck DC-DC converter which produce three output voltages for using in different applications.

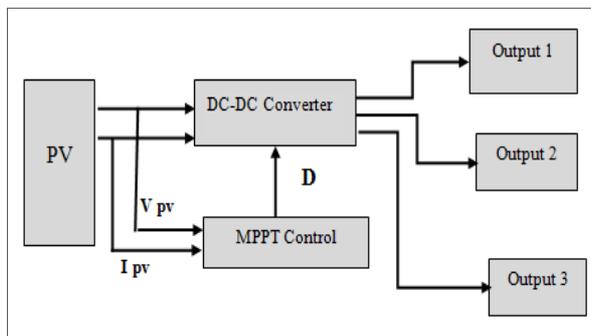


Fig. 12. Proposed system design.

### 11. Simulink Modeling of the Proposed System

Fig.13 shows the simulink circuit of the proposed system design employing solar cell panel and DC-DC buck converter controlling by MPPT controller. The system is used to produce three outputs voltages and currents. The approximate results of the system module are (9V:2A, 5V:1A, 2.2V:0.5A).

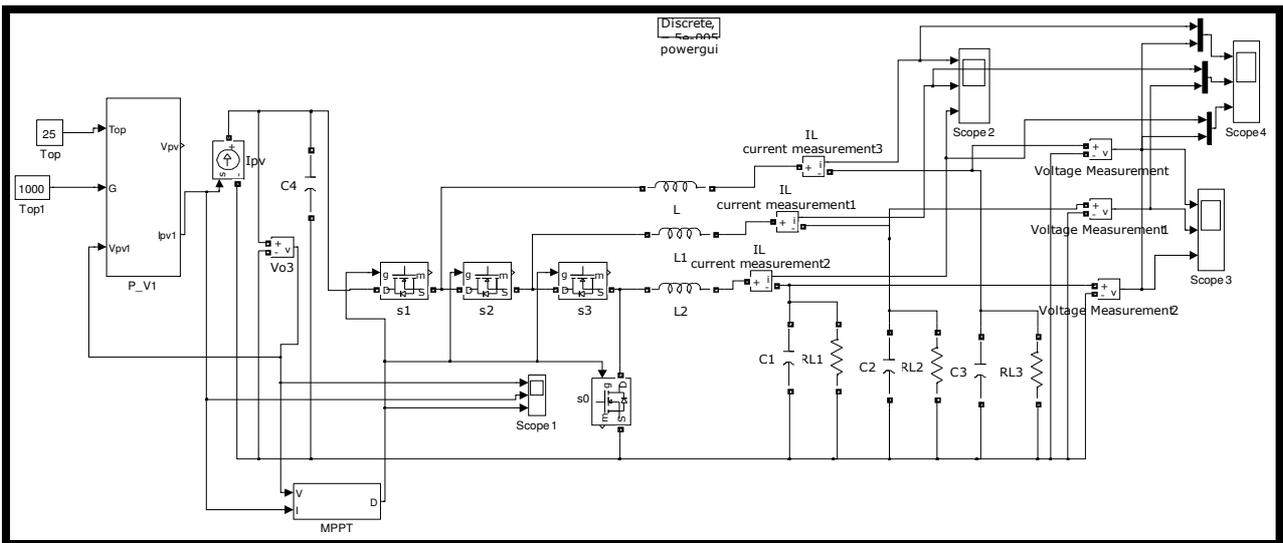


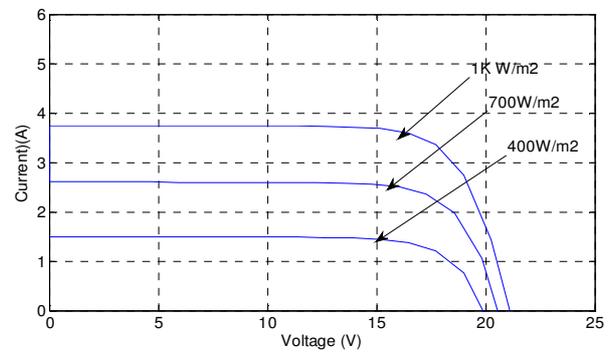
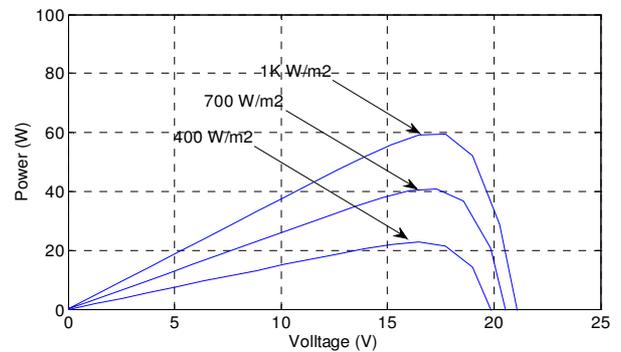
Fig. 13. Model of solar PV emulator utilizing buck converter.

### 12. Results and Discussion

The proposed PV module was simulated by using dialogue box from block Libraries in MATLAB. The results are as follows:

- Fig.14 shows the I–V, P–V and P-I characteristics for different values of solar irradiation (400, 700 and 1000  $W/m^2$ ) at constant temperature (25 °C). When the irradiation increases, the power and current increases as shown in fig. 14(a,b) respectively. The variation of voltage is very small in both conditions. The relationship between the power and current is shown in fig.14c. The value of the power is approximately 60W which is the maximum power of system operation, and the maximum value of the current is 3.8A. These operating conditions lead to increase the output power.
- Fig.15 shows the I–V, P–V and P-I characteristics for different values of temperature (25, 35 and 45 °C) at constant irradiation (1000 $W/m^2$ ) Here, when the operating temperature increases, the power and output voltage decrease as shown in fig.15(a,b). The value of power is 60W at temperature 25 °C, and decreases when the temperature increases. The variation of current is very small as shown in fig.15c. This operating condition leads to reduce the output power.
- From the PV characteristics we can observe that, there is a point at which the power output is maximum which gives the maximum efficiency. In the Standard Test Conditions, it was found that the proposed PV Emulator

produces the maximum power at 60W with voltage 17V and current 3.8A with increasing irradiation at constant temperature. For comparison, according to the datasheet, at Standard Test Conditions, the MSX-60 solar module produces the maximum power 60W with voltage at the maximum power of 17.1V and current of 3.5A.



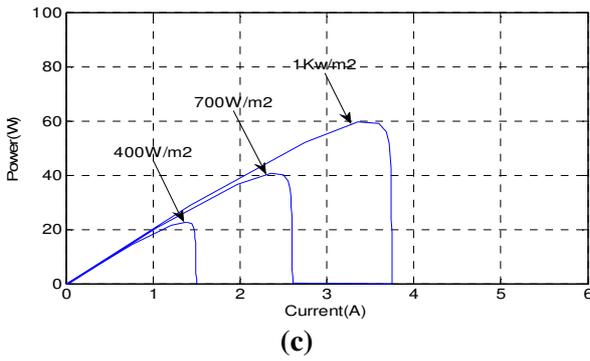


Fig. 14. (a) P-V, (b) I-V and (c) P-I characteristics at T=25C

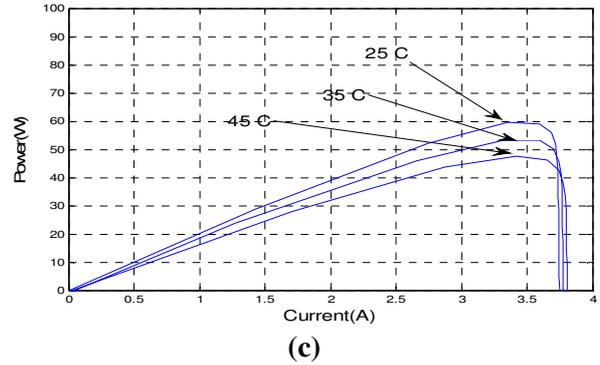
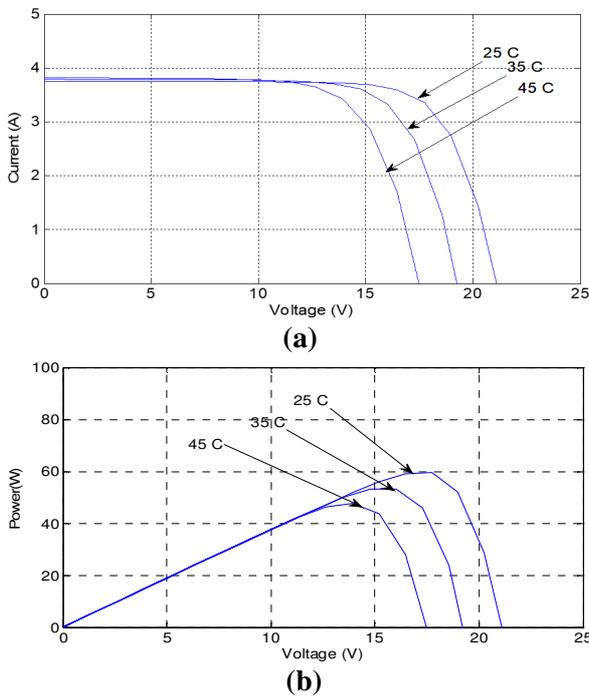


Fig. 15. (a) P-V, (b) I-V and (c) P-I characteristics at S=1000W/m2.



4. Fig.16 (a,b) shows the continuous level of the  $V_{pv}$  and  $I_{pv}$  values respectively, that is fed to MPPT controller to produce switching signal of the required duty cycle as shown in fig. 16c to control the DC-DC buck converter for achieve maximum efficiency according on the (P & O) algorithm. The output of MPPT is signal for two operating conditions, the duty Interval ( $T_{on}$ ) and the freewheeling mode ( $T_{off}$ ). However, these MPPT pulses more convenient for regulating the output voltages of the Buck DC-DC converter.

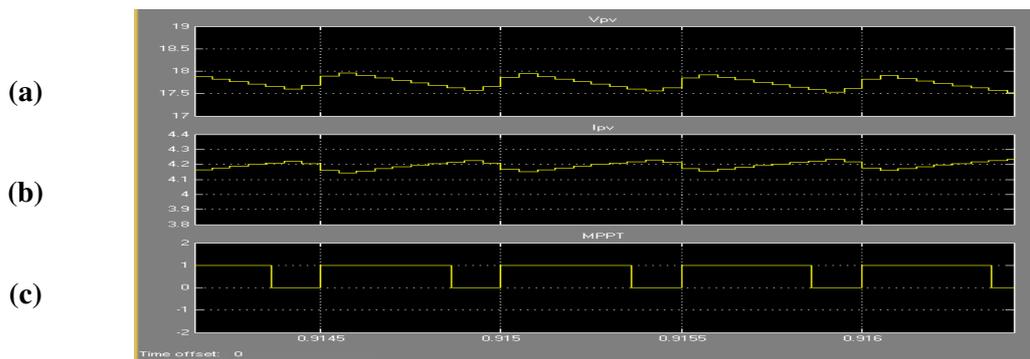


Fig.16.  $V_{pv}$  ,  $I_{pv}$  and MPPT switching waveforms.

5. For this proposed design, the module formed by connecting 36 PV cells in series. The output voltage can be calculated by multiplying the cell voltage by the number of the cells, while

the total current is equal to the cell current. Fig.17 shows the simulated waveforms of three output voltages and currents, here approximate values of the first output voltage of circuit is

9V and current is 2A, the second output voltage is about 5V and current is about 1A,

and the third output voltage is about 2.2V and current is about 0.5A.

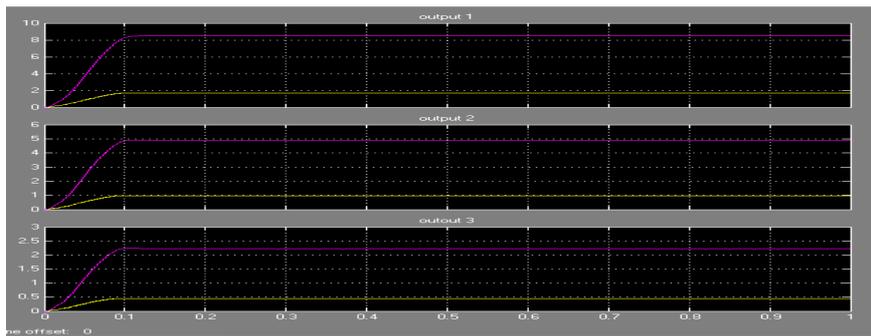


Fig. 17. Simulink results for output voltages and currents.

### 13. Conclusion

A Matlab/Simulink model for the PV solar panel with Multiple Outputs DC-DC Converter controlling by MPPT Technique was developed and presented in this paper. The PV system module is design depending on the circuit equations of solar cell model. The electrical characteristics (P-V, I-V and P-I curves) are achieved for MSX-60 solar module that explains its dependence on the solar radiation and atmospheric temperature. When temperature remains constant at 25°C, and the radiation increases, the current and voltage of the cell model increase, this leads to an increase in the output power. And when the radiation level keeps constant at 1000W/m<sup>2</sup> and the cell temperature increases, the current increases, but the voltage decreases, this leads to reduce in output power. The maximum power is achieved at voltage 17V and current 3.5A with MPPT technique. The Perturb and Observe algorithm is used for achieve Maximum Power Point. The regulator outputs of buck converter controlling by the signal feds from MPPT controller are successively achieved. Approximate results for multiple output voltages and current (9V:2A, 5V:1A, 2.2V:0.5A) are obtained.

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## تصميم مولد طاقة شمسية يستخدم تقنية MPPT للسيطرة على محول (تيار مستمر - تيار مستمر) ذي مدخل مفرد/ مخرج متعدد

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### الخلاصة

يتطرق البحث الى لتصميم منظومة مكونة من لوح ضوئي شمسي مع محول (تيار مستمر - تيار مستمر) ذي مدخل واحد / متعدد المخارج نوع Buck باستخدام ادوات صندوق حوار (Simulink) في الحقيبة البرمجية MATLAB لمحاكاة المنظومة. تم استخدام تقنية تتبع نقطة اعلى قدرة (MPPT) التي تعتمد على خوارزمية (P&O) للسيطرة على القدرة الخارجة للمحول وزيادة كفاءة المنظومة. تم اختيار خصائص النموذج الضوئي MSX-60 في تصميم المنظومة، حيث تم الحصول على الخصائص الكهربائية (المنحنيات P-V, I-V, P-I) للنموذج والتي تتأثر بتغيرات الإشعاع الشمسي ودرجة الحرارة للخلية الضوئية. وجد النموذج المقترح مستقراً لأي تغير في درجة حرارة المحيط والإشعاع الشمسي. ان اعظم قدرة تم الحصول عليها هي عند الفولتية 17V والتيار 3.5A عند استخدام المسيطر MPPT، وان النتائج التقريبية التي تم الحصول عليها للفولتيات والتيارات للمخارج المتعددة هي (9V:2A, 5V:1A, 2.2V:0.5A). أن النموذج المقترح مفيد جداً للمهندسين والباحثين والخبراء في تصميم انظمتهم التي تتطلب نموذجاً بسيطاً ودقيقاً للخلايا الشمسية.