

Original Research Article

A general review on Photovoltaic, modeling, simulation and economic study to build 100MW power plant in Lebanon

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ABSTRACT

The goal of this paper is to study the possibility to build a 100MW Photovoltaic Plant in small countries like Lebanon, it gives a general review about the basis of photovoltaics. Different electronic models of photovoltaic cells are presented. This paper presents also the functioning of a photovoltaic cell, its model using MATLAB/Simulink, and discuss some algorithms used to extract the maximum power from a PV panel. Simulated results are presented. Economic study to build a 100 MW photovoltaic farm in Lebanon is discussed, with a comparative table between its tariff and existing tariffs such as from Power Authority, Private Generators, and Regional Distributors. Some other solutions are proposed to build PV panels and plant above unused surfaces such as above lakes and rivers are also proposed for the Lebanese case.

Aims: The aim of this study is to help the reader to acquire sufficient information about Photovoltaic System and its function, MATLAB/Simulink Model, used Algorithms, and the most important thing is to compare its economic study for the Lebanese case to see if it is possible to build 100MW in Lebanon or not. The same study can be used for other countries, but of course the values might change.

Study design: This study used the software MATLAB/Simulink to model the Photovoltaic module, The economic study is based on other studies but it is developed for the Lebanese case.

Place and Duration of Study: This study was made by the authors during the year 2014 in Lebanon.

Methodology: The economic study is studied based on other studies in the world, but for this time, it is made for the Lebanese case, and the Farm used produces 100MW which is not done before in Lebanon. The tariffs of the existing sources are compared with the tariff of the proposed study, and based on it, one can choose if it is profitable to build such project in Lebanon or not.

Author's contribution: The authors' contribution is that this is the first study made for Lebanon to build 100MW Photovoltaic Farm, and it compares different tariffs in Lebanon such as from PV Farm, Power Authority (EDL), Private Generators, and Regional Distributors. And it shows clearly that the PV Farm is possible to be built in Lebanon only for certain conditions. Some other solutions to integrate PV system when there is lack of large

surfaces are proposed, one of the solutions is to construct PV systems on the surface of lakes and rivers which will produce a large amount of energy, and this method is sufficient to supply approximately the half needed energy in Lebanon, we have also studied the possibility of integration of PV panels on rooftops of residential buildings, and we have found that if the government uses only 12.5% of the total rooftop surface of residential buildings, it will be able to supply the needed power to the whole country without using any other power plant.

Results: The main interesting results in this paper are that the construction of PV Farm in Lebanon is possible if it is encouraged by the Government, its tariff is less than other sources of energy such as the Private Generator and Regional Distributor, but it can't be competitive with the power authority for several reasons, the authors also propose to use the surfaces of rivers and lakes in order to build PV Farms, for instance if one uses the lake Qaraoun in Bekaa, it is possible to produce between 600MW and 1200MW which is approximately equal to 26.5% to 53% of the total produced power in Lebanon. Thus the production of such power can resolve big problems in Lebanon such as the cut off of the electricity every day for about 12 hours.

Conclusion: The photovoltaic system is preferred with respect to other sources of energy. The future of photovoltaics is promising, the efficiency increase each year and it is expected to over pass 50% in the next decades, the price of photovoltaic system is decreasing which will give it advantages with respect to other renewable energy systems.

In conclusion, this paper presents a general review on photovoltaic system. The models and mathematical expressions of photovoltaic cells are presented. The MATLAB model of the standard expression of photovoltaic module is designed. The results are discussed, many characteristics such as I-V curves and P-V curves are simulated using different parameters. An economic study of building 100MW photovoltaic farm is presented and discussed. Some advantages and disadvantages of the PV system are discussed. Finally, the usage of unused surfaces such as above lakes and rivers may be very efficient for small countries like Lebanon, and the produced power using these surfaces is approximately the half produced power in Lebanon, therefore this paper may be very helpful to resolve the problem of electricity in Lebanon and any other country which has the same characteristics and problems as for Lebanon.

Keywords: Photovoltaic, MATLAB Model, PV Farm, Power plant, economic study, Lebanon.

1. INTRODUCTION

The photovoltaic is considered as a generator of electricity from solar radiation using semiconductors, it converts the solar energy into electrical energy using the photovoltaic effect. The photovoltaic panel is composed of many modules and each module contains many photovoltaic cells arranged in series and parallel in a way to give a certain voltage and a certain current at the output [1-6]. Many papers present the mathematical equations, the MATLAB/Simulink model and simulation of the photovoltaic system [7-17]. Other papers present the simulation using LABVIEW [18-19].

This paper shows a brief review about photovoltaic. In the second Section, a general description and form of Photovoltaic cells, their functions and equivalent circuits are presented. Mathematical Modeling of Photovoltaic Panel is discussed in section 3. In the fourth Section, some Maximum Power Point Algorithms are presented, and only two are developed. They serve to extract the maximum power from a PV panels. In the fifth Section,

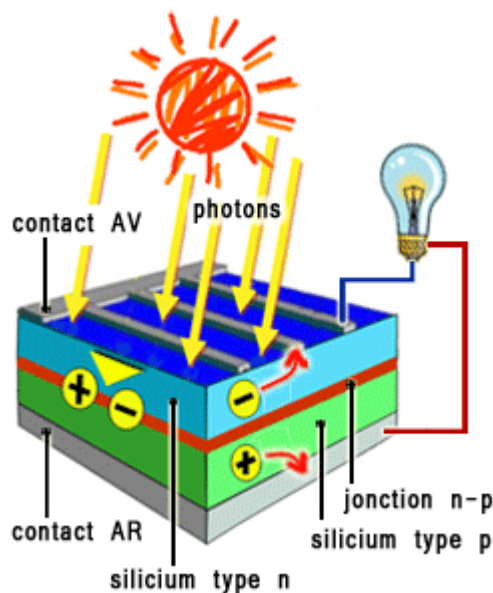
33 a MATLAB model of photovoltaic panel is presented. The section 6 treats and discusses the
34 results obtain from section 3. The Section 7 studies the economic study to build a 100MW
35 photovoltaic farm in Lebanon. The Section 8 presents some possible implementation of PV
36 in small countries like Lebanon. Section 9 presents conclusions. And finally section 10
37 presents Nomenclature.

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40 2. DESCRIPTION AND FORM OF PHOTOVOLTAIC CELLS

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42 The photovoltaic cell is formed by a thin layer of p-n junction of semiconductor. The solar
43 radiation with a frequency greater than the threshold frequency able to pull out the peripheral
44 electrons will hit the peripheral electrons in the p-n junction and the electrons will go from the
45 p-doped silicon to the n-doped silicon then go through a negative electrode to the load and
46 return back to the p-n junction through the positive electrode and so on [1-6] (figure 1). The
47 characteristics of the PV cell and module are not linear; they depend on many factors such
48 as the temperature of the cells and the irradiance intensity.



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Fig. 1: Conversion of the solar energy into kinetic energy of the electrons [20].

52 Photovoltaic cell is the smallest element that composes a photovoltaic panel (figure 2), a PV
53 module is formed by many PV cells arranged in series and parallel in order to give a certain
54 voltage and a certain current at its output (figures 3.1 and 3.2), and a PV panel is formed by
55 many PV modules.



Fig. 2: represents a single photovoltaic cell [1].

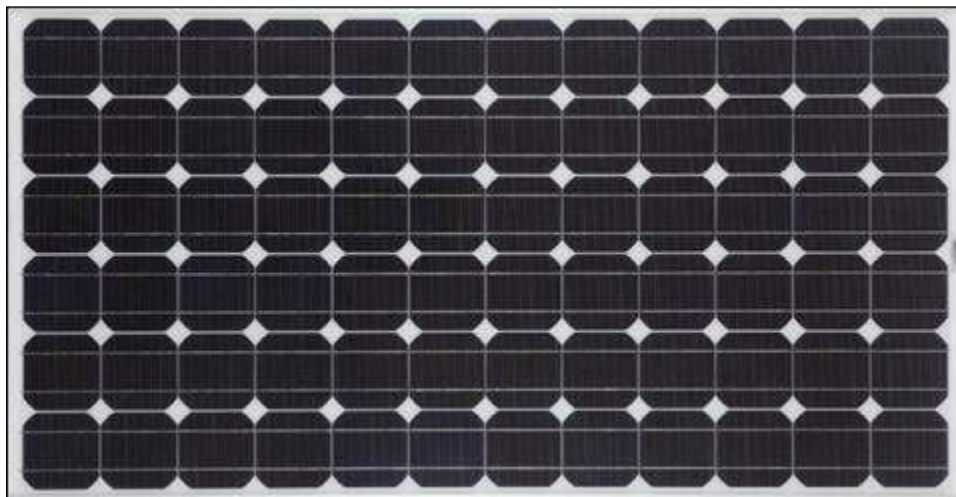


Fig. 3.1: PV module composed of many PV cells in series and in parallel [21].

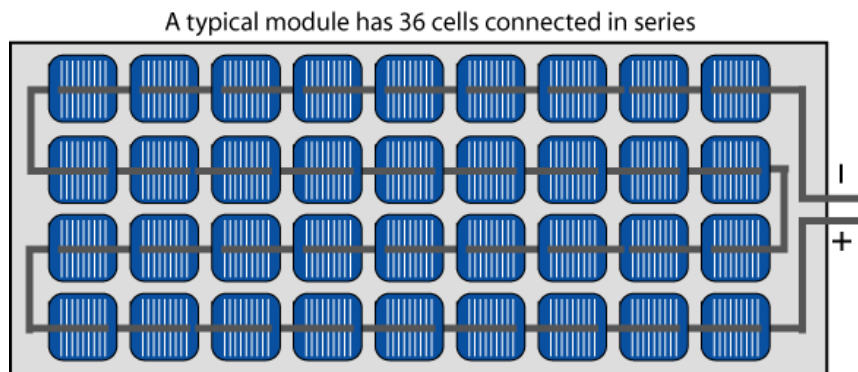


Fig. 3.2: PV module composed of many PV cells in series [22].

In figure 3.2, a module with 36 PV cells connected in series in order to give an output voltage equal to 21.6V at standard conditions (25°C, and AM=1.5 (Air Mass)).

68 In figure 4, a Photovoltaic Farm is composed of many parallel and series module arranged in
69 a way to give high voltage and current according to the need.
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Fig. 4: Photovoltaic Farm [28].

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2.1 Different type of photovoltaic cells

The photovoltaic cell can be made using different materials and elements such as Copper Indium Selenium (CuInSe_2), Cadmium Telluride (CdTe), Silicon (Si), Gallium Arsenic (GaAs) and others. The efficiency and band gap of each material is presented in figure 5.

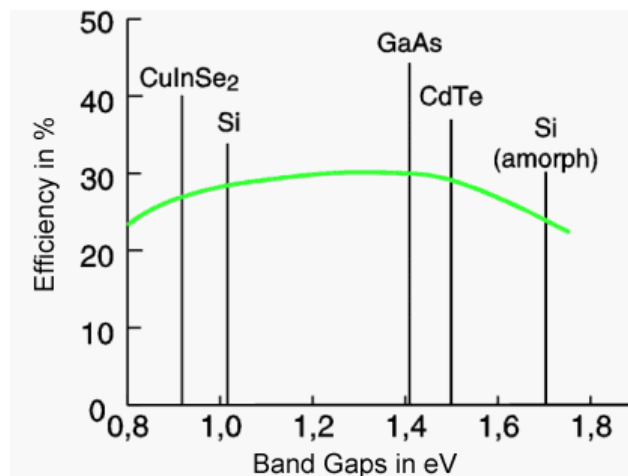


Fig. 5: common known materials for solar cells [23].

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The energy payback time of the [23]:

- Monocrystalline (Si) cell: ~ 4 years.
- Polycrystalline (Si) cell: 1.6 to 2.7 years.
- Amorphous (Si) cell: 0.9 to 1.6 years.

In table 1, a comparison between commercial photovoltaic cells is presented.

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Table 1: Comparison between commercial photovoltaic cells [23].

	Crystalline Silicon	Amorphous Silicon	CIGS	CdTe	Organic
Conversion Efficiency	13-18%	5-10%	10-12%	10.5%	5%
Current cost per Watt*	\$2.5-3.5	\$2-2.5	\$0.6 (predict)	\$1.3 <\$1 (predict)	
Material Shortage	No	Silane	Indium	Te(?)	No
Toxic Substance	NA	NA	Cadmium Selenium	Cadmium Tellurium	NA
Reliability	Excellent	Fair	Good	Good	Poor
Company in the field	Suntech, SunPower	AMAT, Dupont	Nanosolar, Solyndra	First Solar	Konarka

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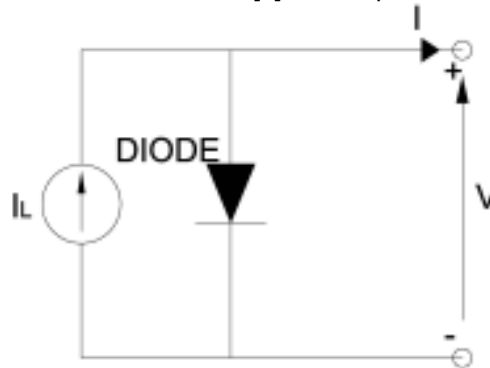
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2.2 Equivalent electronic circuit of Photovoltaic cell

The photovoltaic module and cell have been modeled with different electronic circuits, the main electronic circuit models are presented as following:

2.2.1 Ideal Model

A single diode is parallel to the source current [9]. It is depicted as in the figure 8.



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Fig. 8: Ideal model of the Photovoltaic cell.

The accuracy of this model is low, but it is simple and fast to use. In presence of developed software such as MATLAB and LABVIEW this model is not used.

The equation of the current functions of the voltage is [9]:

$$I_{cell} = I_{L,cell} - I_{O,cell} \left(e^{\left(\frac{V_{cell}}{V_T} \right)} - 1 \right) \quad (1)$$

For nomenclatures refer to section 10.

2.2.2 Simple model

The simple model uses a parallel diode and a series resistance [8]. It is presented in figure 9.

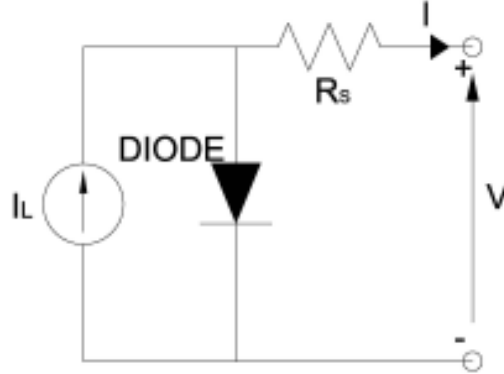


Fig. 9: Simple model of the Photovoltaic cell.

The accuracy of this model is good; this model can be used to present the form of a PV cell. But to obtain a better accuracy, one has to choose more advanced models.

The equation of the current functions of the voltage is [8]:

$$I_{cell} = I_{L,cell} - I_{O,cell} \left(e^{\left(\frac{V_{cell} + I_{cell} R_{S,cell}}{V_T} \right)} - 1 \right) \quad (2)$$

For nomenclatures refer to section 10.

2.2.3 Standard model

In this model, the electronic circuit uses one parallel diode, one parallel resistance and one series resistance [8] (figure 10).

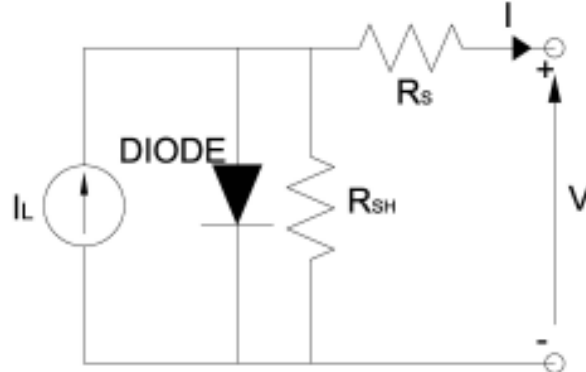


Fig. 10: Standard model of the Photovoltaic cell.

This model is the most used model to describe the function of a photovoltaic cell and module [7-8], this model is used in this paper. The accuracy of this model is good.

The equation of the current functions of the voltage is [8]:

$$I_{cell} = I_{L,cell} - I_{O,cell} \left(e^{\left(\frac{V_{cell} + I_{cell} R_{S,cell}}{V_T} \right)} - 1 \right) - \frac{V_{cell} + I_{cell} R_{S,cell}}{R_{SH,cell}} \quad (3)$$

For nomenclatures refer to section 10.

2.2.4 Standard model with two diodes

The standard model with two diodes has a very good accuracy (figure 11), but it is somewhat complicated [12], it can be used with powerful software such as MATLAB and LABVIEW [12].

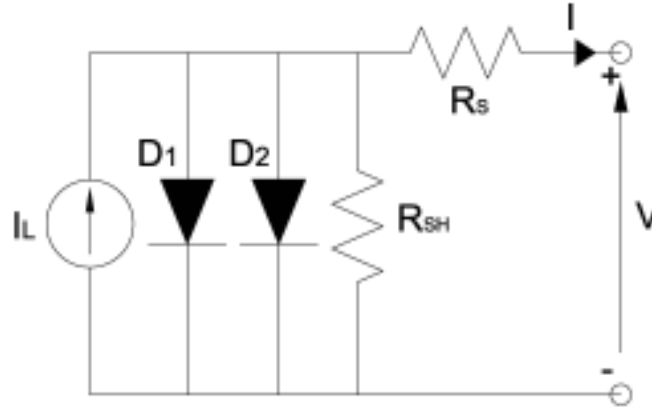


Fig. 11: Standard model with two diodes of Photovoltaic cell.

The equation of the current functions of the voltage is [12]:

$$I_{cell} = I_{L,cell} - I_{O1,cell} \left(e^{\left(\frac{V_{cell} + I_{cell} R_{S,cell}}{V_{T1}} \right)} - 1 \right) - I_{O2,cell} \left(e^{\left(\frac{V_{cell} + I_{cell} R_{S,cell}}{V_{T2}} \right)} - 1 \right) - \frac{V_{cell} + I_{cell} R_{S,cell}}{R_{SH,cell}} \quad (4)$$

For nomenclatures refer to section 10.

2.2.5 Generalized Photovoltaic Model

Paper [40] presents a generalized form of Photovoltaic Model using software such as MATLAB/Simulink, this model is suitable for any PV cell, module or array, which is used to analyze and design the MPPT.

3 MATHEMATICAL MODELING OF PHOTOVOLTAIC PANEL

In this section, the mathematical model of photovoltaic cell and module is presented, the modelling of the PV cell and PV module used the standard form (1 parallel diode, 1 parallel resistance and 1 series resistance).

Mathematical model of a PV cell [7-8] is:

$$I_{cell} = I_{L,cell} - I_{O,cell} \left(e^{\left(q \frac{V_{cell} + I_{cell} R_{S,cell}}{n_{cell} k T} \right)} - 1 \right) - \frac{V_{cell} + I_{cell} R_{S,cell}}{R_{SH,cell}} \quad (5)$$

For nomenclatures refer to section 10.

Consider a PV module with N_p parallel strings (columns) and N_s PV cells per string, then the equation of the PV module will be as following [7-8], [12]:

$$I_{module} = N_P I_{cell} = N_P I_{L,cell} - N_P I_{O,cell} \left(e^{\left(\frac{N_S V_{cell} + N_P I_{cell} \left(\frac{N_S}{N_P} \right) R_{S,cell}}{N_S n_{cell} k T} \right)} - 1 \right) - \frac{N_S V_{cell} + N_P I_{cell} \left(\frac{N_S}{N_P} \right) R_{S,cell}}{\left(\frac{N_S}{N_P} \right) R_{SH,cell}} \quad (6)$$

For nomenclatures refer to section 10.

And

$$I_{module} = I_L - I_O \left(e^{\left(\frac{V + I_{module} R_S}{n V_T} \right)} - 1 \right) - \frac{V + I_{module} R_S}{R_{SH}} \quad (7)$$

For nomenclatures refer to section 10.

The equivalent circuit of the PV module is depicted in figure 12.

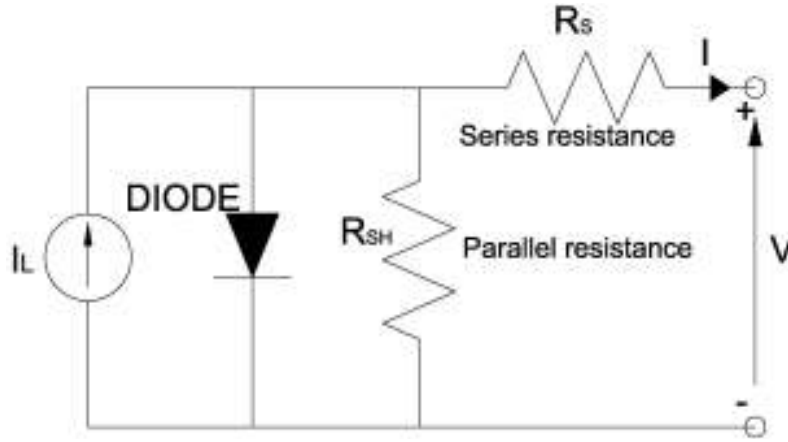


Fig. 12: Equivalent circuit of the PV Module.

When $R_{S,cell} \ll R_{SH,cell}$, therefore the equation (7) can be written as following [7, 8, 10, 11]:

$$I_{module} \approx I_L - I_O \left(e^{\left(\frac{V + I_{module} R_S}{n V_T} \right)} - 1 \right) \quad (8)$$

• The output voltage can be determined from the equation (7), the short circuit current and the open circuit voltage are [7, 8, 10, 11]:

$$V \approx -I R_S + n V_T \ln \left(\left(\frac{I_L - I_{module}}{I_O} \right) + 1 \right) \quad (9)$$

$$I_{SC} \approx I_L - I_O \left(e^{\frac{I R_S}{n V_T}} - 1 \right) \quad (10)$$

$$V_{OC} \approx n V_T \ln \left(\frac{I_L}{I_O} + 1 \right) \quad (11)$$

• Dependence of parametric model on irradiance [7, 8, 10, 11]:

The variation of the irradiance will affect mainly three parameters I_L , V_{OC} , and I_{SC} .

$$I_L^{GkW/m^2} = \frac{G}{1000} I_L^{1kW/m^2} \quad (12)$$

• Dependence of parametric model on temperature [7, 8, 10, 11]:

208 The variation of the temperature affects the voltage and the current at the output, V_{OC} and
 209 I_{SC} .

$$210 \quad I_{SC}^{(25+dT)^{\circ C}} = I_{SC}^{25^{\circ C}} \left(1 + \frac{C_{TI}}{100} dT \right) \quad (13)$$

$$211 \quad I_L^{(25+dT)^{\circ C}} \approx I_L^{25^{\circ C}} \left(1 + \frac{C_{TL}}{100} dT \right) \quad (14)$$

$$212 \quad V_{OC}^{(25+dT)^{\circ C}} \approx V_{OC}^{25^{\circ C}} - \frac{C_{TV}}{1000} dT \quad (15)$$

$$213 \quad V_T^{(25+dT)^{\circ C}} = \frac{k(273.15+(25+dT))}{q} \quad (16)$$

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215 For nomenclatures refer to section 10.

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$$217 \quad I_0(T) = I_0(T_r) \left(\frac{T}{T_r} \right)^{\frac{XTI}{n_{cell}}} e^{\left(-\frac{1}{n_{cell}k} \left(\frac{E_g(T)}{T} - \frac{E_g(T_r)}{T_r} \right) \right)} \quad (17)$$

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219 Where

$$220 \quad E_g(T) = N_S E_g(0) - \frac{N_S C_{EG1} T^2}{C_{EG2} + T} \quad (18)$$

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222 For nomenclatures refer to section 10.

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224 To determine the value of parameters such as R_{SH} , n , R_{SO} , I_0 , R_S , and I_L , one has to
 225 measure some other parameters which are V_{OC} , I_{SC} , V_{mp} , I_{mp} , V_{min} , V_{max} , I_{min} , I_{max} [7, 8, 10,
 226 11].

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228 By finding the value of these parameters one can find the values of the following parameters
 229 [7]:

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$$231 \quad R_{SH} \approx R_{SHO} = \frac{V_{min}}{I_{SC} - I_{max}} \quad (19)$$

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$$233 \quad R_{SO} = \frac{V_{OC} - V_{max}}{I_{min}} \quad (20)$$

$$234 \quad n \approx \frac{1}{V_T} \frac{(V_{mp} + I_{mp} R_{SO} - V_{OC})}{\left(\ln \left(\frac{(I_{SC} - I_{mp}) R_{SH} - V_{mp}}{I_{SC} R_{SH} - V_{OC}} \right) + \frac{I_{mp}}{(I_{SC} - R_{SH})} \right)} \quad (21)$$

$$235 \quad I_0 \approx \frac{I_{SC} - \frac{V_{OC}}{R_{SH}}}{\frac{V_{OC}}{e n V_T}} \quad (22)$$

$$236 \quad R_S \approx R_{SO} - \frac{\frac{n V_T}{I_0 e} \frac{V_{OC}}{n V_T}}{\frac{V_{OC}}{I_0 e n V_T}} \quad (23)$$

$$237 \quad I_L = I_{SC} \left(1 + \frac{R_S}{R_{SH}} \right) + I_0 \left(e^{\frac{I_{SC} R_S}{n V_T}} - 1 \right) \quad (24)$$

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240 4. MAXIMUM POWER POINT TRACKING (MPPT)

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242 Maximum Power Point Trackers are used in Photovoltaic systems in order to maximize their
 243 output power for different ambient conditions, and they maintain the operation of PVs at their
 244 maximum power point [34]

245 There are many algorithms which are developed to improve the performance of the
 246 Photovoltaic output power and to extract the maximum power, such as:

247 1- Incremental Conductance Method (ICM) [32], [39],

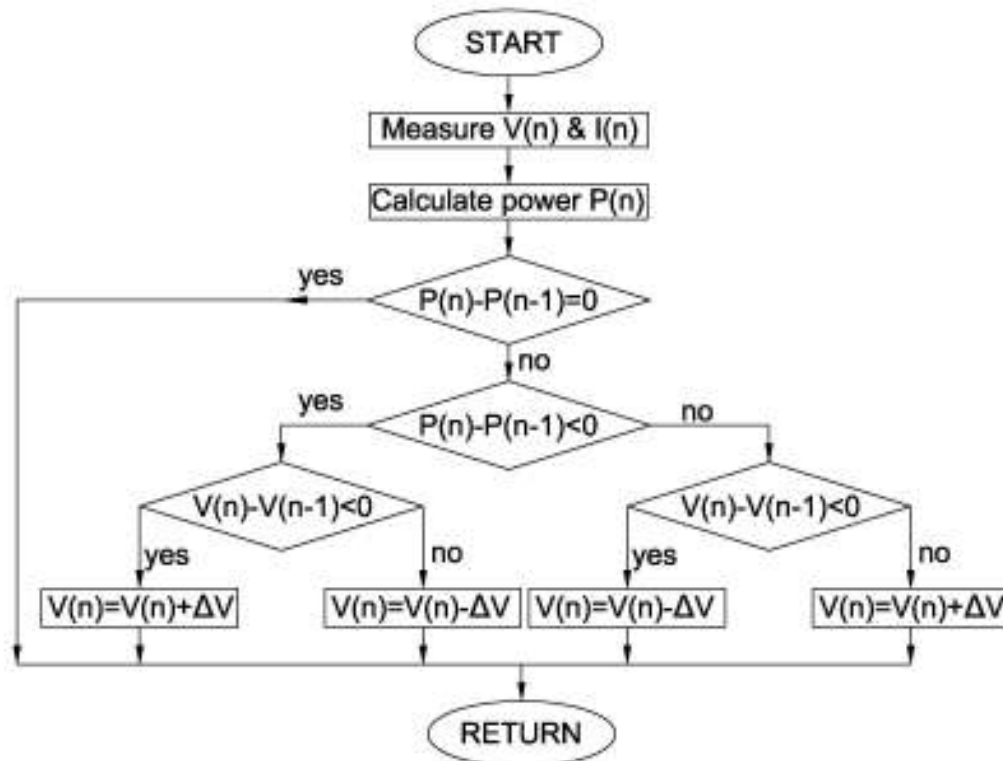
248 2- Parasitic Capacitance [37],

- 249 3- Perturb and Observe (P&O) [7], [24],
- 250 4- Hill Climbing algorithm [33],
- 251 5- Estimate-Perturb-Perturb (EPP) Method [31],
- 252 6- Voltage control maximum point tracker [38],
- 253 7- Current control maximum power point tracker [38],
- 254 8- MP&O method [31],
- 255 9- Etc.

257 This paper gives a brief description of only two methods, because it is impossible to explain
 258 all algorithms within few lines, and because it is not the objective of this paper. Only Two
 259 methods are presented and discussed, their advantages and disadvantages are also
 260 presented in the following subsections.

262 4.1 The Perturb and Observe Algorithm (P&O)

264 There are many different algorithms used to detect the maximum power point of PV panels
 265 or modules, one of the most used methods is the Perturb and Observe (P&O) also called Hill
 266 climbing method [7], [24]. This algorithm is described in figure 13.



267
 268 Fig. 13: Flowchart of the Perturb and Observe Algorithm.

270 4.1.1 The Perturb and Observe Algorithm and P-V curve

272 The P&O algorithm is used to extract the maximum power from a photovoltaic panel or
 273 module; it compares the power and voltage of the last two values and varies the voltage in a
 274 way to obtain the highest output power. Figure 14 shows how the Perturb and Observe
 275 Algorithm works, if the current power is A, then the algorithm tries to move the point to the
 276 right side to attain the maximum power at B, if the current power is C, then the algorithm
 277 tries to move the point to the left to attain the maximum power at B and so on (figure 14).

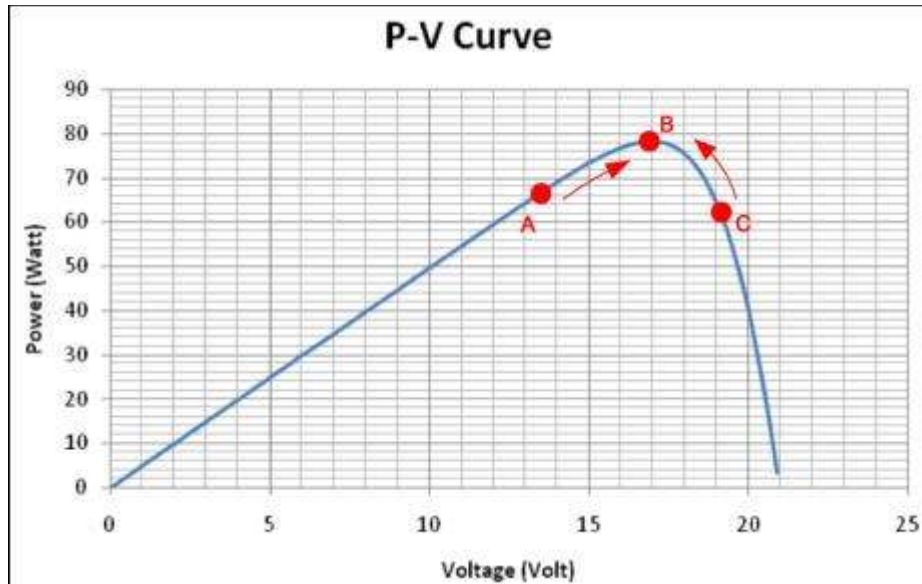


Fig. 14: Perturb and Observe algorithm and its oscillation around the maximum power point.

4.1.2 Advantages and disadvantages of the P&O Algorithm

The P&O Algorithm has many advantages and disadvantages, some of them are stated as following:

4.1.2.1 Advantages:

- It is a simple algorithm.
- It is the most used algorithm for commercial PV panels [30].

4.1.2.2 Disadvantages:

- Oscillation around the point of functioning.
- It finds only the local maximum point and not the global maximum point.
- If ΔV is very small, the algorithm will take a longer time to find the maximum point.
- If ΔV is very large, the algorithm will never find the maximum point.
- Time response is higher than the "ICM" Algorithm, in [30] it shows that the time response for the P&O algorithm is $1.8\mu s$, while it is $0.5\mu s$ for the "ICM" Algorithm.
- Average output Power is less than the "ICM" Algorithm, [30] shows a good comparison.
- Ripples take high values.

4.2 MPPT Algorithm using Incremental Conductance Method

The Incremental Conductance Method is another way used to extract the maximum power from a photovoltaic panel or module [32]; it compares the variations of the voltage and the current of the last two values (Figure 15), and varies the voltage in a way to obtain the highest output power. Figure 16 shows how the Incremental Conductance Method Algorithm works, if the current power is A, then the algorithm tries to move the point to the right side to attain the maximum power at B, if the current power is C, then the algorithm tries to move the point to the left to attain the maximum power at B and so on (Figure 16). This method can be calculated using the following equations:

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = \frac{d(V)}{dV} I + \frac{d(I)}{dV} V = I + \frac{d(I)}{dV} V \quad (25)$$

Where,
 P is the Power extracted from the PV Panel (Watt),
 dP presents the variation of the Power on the terminal of the PV Panel calculated by the Algorithm,
 V designs the voltage on the terminal of the PV Panel (Volt),
 dV is the variation of the Voltage on the terminal of the PV Panel calculated by the Algorithm,
 I presents the current circulating on the terminal of the PV Panel (Ampere),
 dI designs the variation of the current on the terminal of the PV Panel calculated by the Algorithm,

• To obtain the Maximum Power Point, $\frac{dP}{dV}$ should be equal to zero, thus,

$$\frac{dP}{dV} = I + \frac{d(I)}{dV} V = 0 \quad (26)$$

$$\Rightarrow \frac{d(I)}{dV} = -\frac{I}{V} \quad (27)$$

• If $\frac{dP}{dV} > 0$, it means that the Power and the Voltage are increasing together, and they are running from the left side to the right side (Figure 15), thus, the point A will approach to the point B, and

$$\frac{d(I)}{dV} > -\frac{I}{V} \quad (28)$$

• If $\frac{dP}{dV} < 0$, it means that the Power is decreasing while the Voltage is increasing, and vice versa. To obtain the Maximum Power Point, the Voltage must run from the right side to the left side (Figure 15), thus, the point C will approach to the point B, and

$$\frac{d(I)}{dV} < -\frac{I}{V} \quad (29)$$

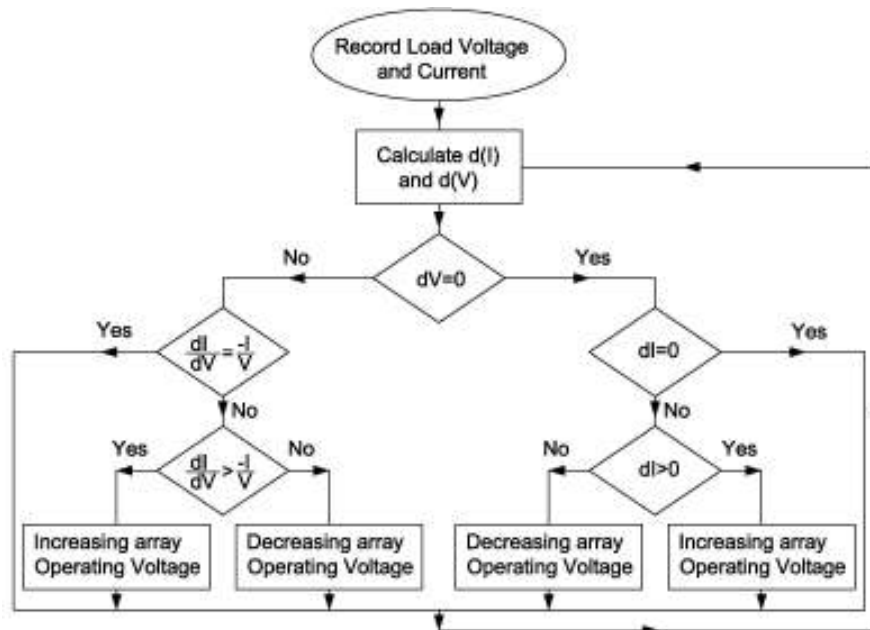


Fig. 15: Flowchart of the Incremental Conductance Method

4.2.1 Incremental Conductance Method Algorithm and P-V curve

Figure 16 presents an explained P-V curve which indicates how the Incremental conductance Method works.

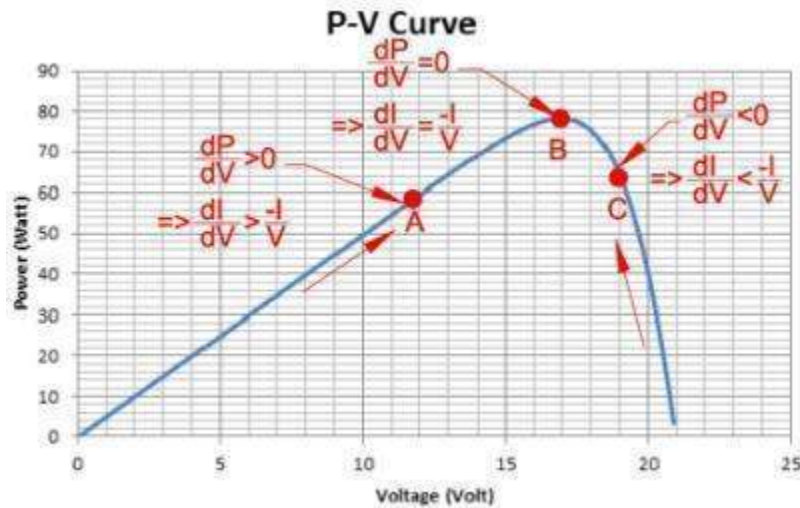


Fig. 16: Incremental Conductance Method is used to obtain the Maximum Power Point.

4.2.2 Advantages and disadvantages of the Incremental Conductance Method Algorithm

The Incremental Conductance Method Algorithm has many advantages and disadvantages, some of them are stated as following:

4.2.2.1 Advantages:

- Its time response is relatively low compared to the P&O Algorithm.
- Its Average Output Power is better than the P&O Algorithm, reference [30] shows a good comparison.
- Ripples are lower than the P&O Algorithm.
- It is able to determine if the Maximum Power Point is reached or not.
- It is more stable than the P&O Algorithm.
- It doesn't oscillate around the Maximum Power Point as P&O does.
- It is an accurate algorithm.
- It rapidly controls the variations of the external phenomena as radiation and temperature changes.
- It tracks rapidly the variation of solar irradiance with higher accuracy compared to the P&O Algorithm [35-36].

4.2.2.2 Disadvantages:

- It is a complex algorithm [35-36].
- Its realization is also complex.
- Its cost of realization is high.
- It finds only the local maximum point and not the global maximum point.

5 MATLAB MODEL OF THE PHOTOVOLTAIC PANEL

The model of a photovoltaic panel and module can be simulated using Matlab/Simulink. In figure 15, a PV module is simulated according to the equations (6) and (7). In figure 16 and 17, the I-V (Current-Voltage), and P-V (Power-Voltage) characteristics are presented, the power is obtained by multiplying the output current I_{module} by the voltage V .

In this paper, the PV module has the following information [7]:

Model: MSX77

Manufacturer: Solarex

$P_{Max} = 77W$; $V_{MP} = 16.9V$

$I_{MP} = 4.56A$; $I_{SC} = 5A$

$V_{OC} = 21V$

$CTI = 0.065 \pm 0.015 \text{ } \%/^{\circ}\text{C}$

$CTV = -(0.5 \pm 0.05)mV/^{\circ}\text{C}$

Standard Test Conditions: $G=1kW/m^2$, $AM=1.5$, $T^0 = 25^{\circ}\text{C}$.

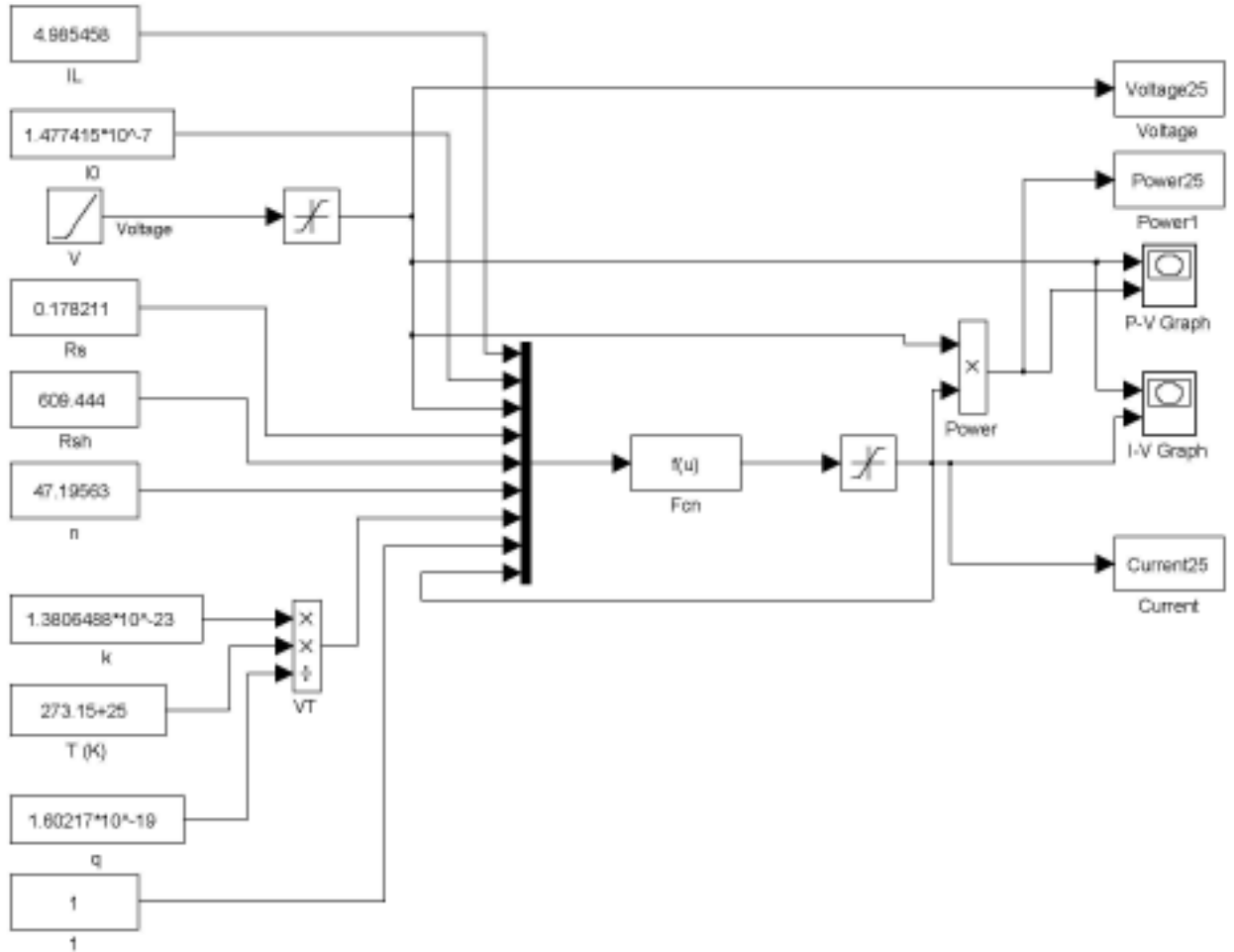


Fig. 15: Modeling of the Photovoltaic panel using Matlab/Simulink, presenting I-V and P-V characteristics.

The values presented for this model can be obtained using the equations presented in the previous Section [7-9], [12-17].

6 RESULTS AND DISCUSSIONS

Using the MATLAB/Simulink model in the previous section, the obtained characteristics of the PV module are illustrated in figures 16 and 17.

6.1 The characteristic of the I-V curve

From the equations (6) and (7), the characteristic of the I-V curve of the photovoltaic module can be drawn taking into consideration the variation of the voltage from 0 up to 21 Volt (figure 16), therefore, the curve of the current functions of the voltage goes from 5 Amperes (current of the short circuit I_{SC}) to zero Ampere (current for Open circuit V_{OC}).

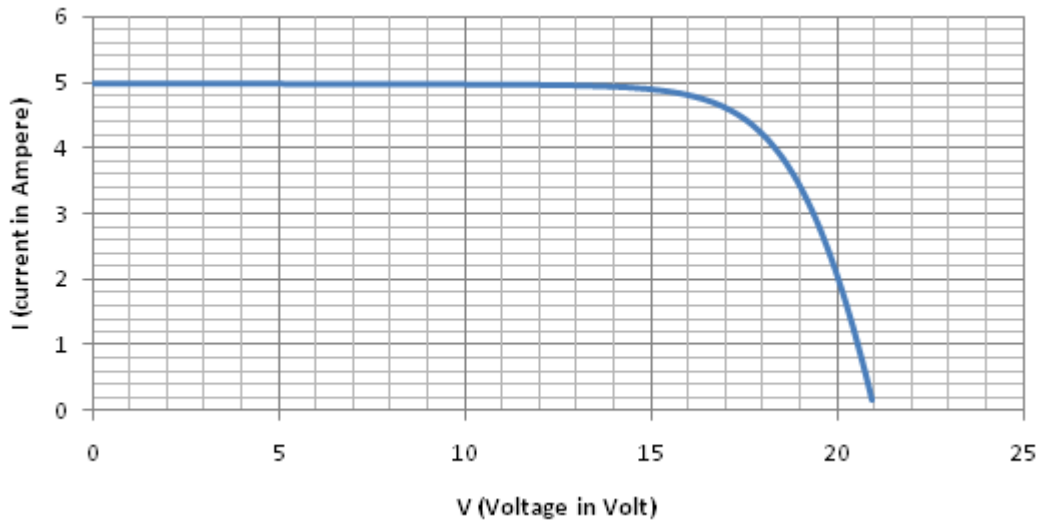


Fig. 16: I-V characteristic of the PV module, for $I_{SC} = 5A$ and $V_{OC} = 21V$.

6.2 The characteristic of the P-V curve

From equations (6) and (7), the characteristic of the P-V curve can be drawn (figure 17) by finding the power functions of the voltage taking into consideration the variation of the voltage from 0 up to 21 Volts, therefore the curve of the power functions of the voltage goes from 0 Watts (power of the short circuit I_{SC}) to the maximum power $P_{MPP} = V_{MPP}I_{MPP}$, and finally return to zero Watt (power for Open circuit V_{OC}).

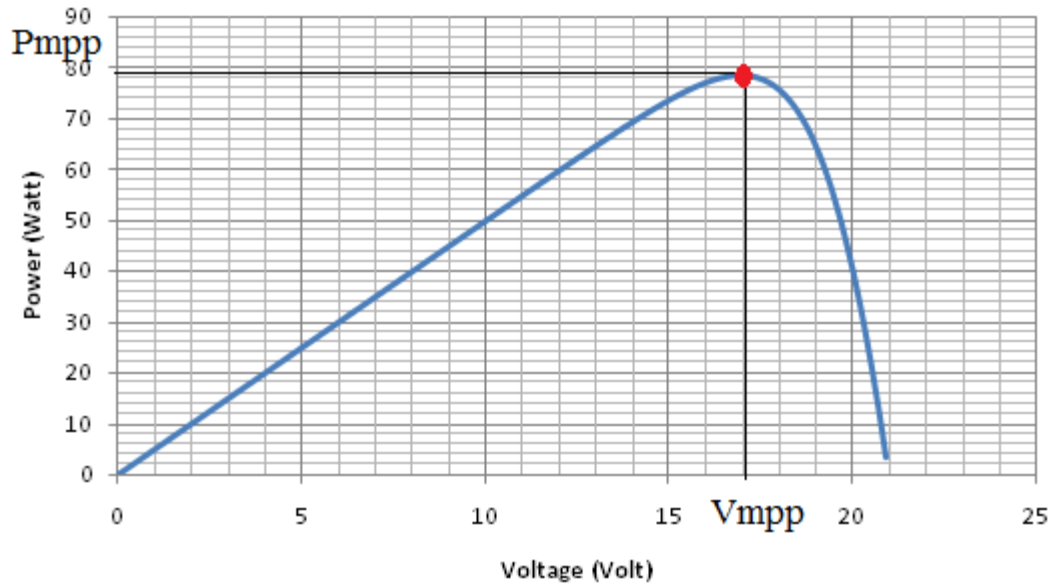


Fig. 17: P-V characteristic of the PV module.

6.3 Characteristics of the I-V and P-V curves by varying the ambient temperature

From the equations (6) to (18), the characteristics of the I-V and P-V curves of the photovoltaic module are drawn in figure 18 and 19 by varying the ambient temperature between 0°C and 60°C.

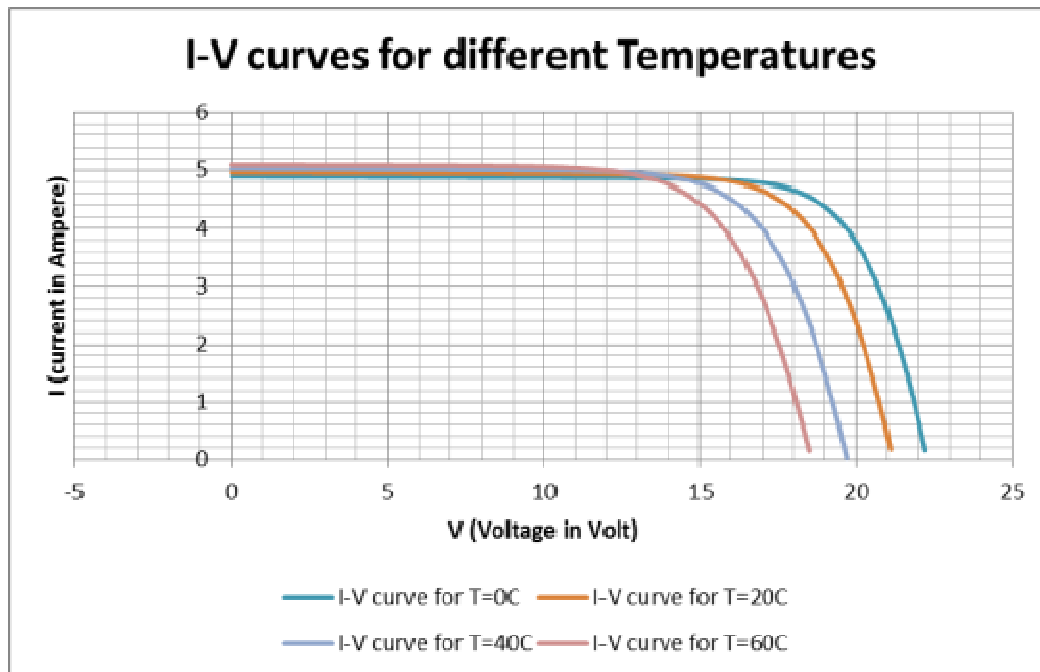


Fig. 18: I-V curves for different temperatures.

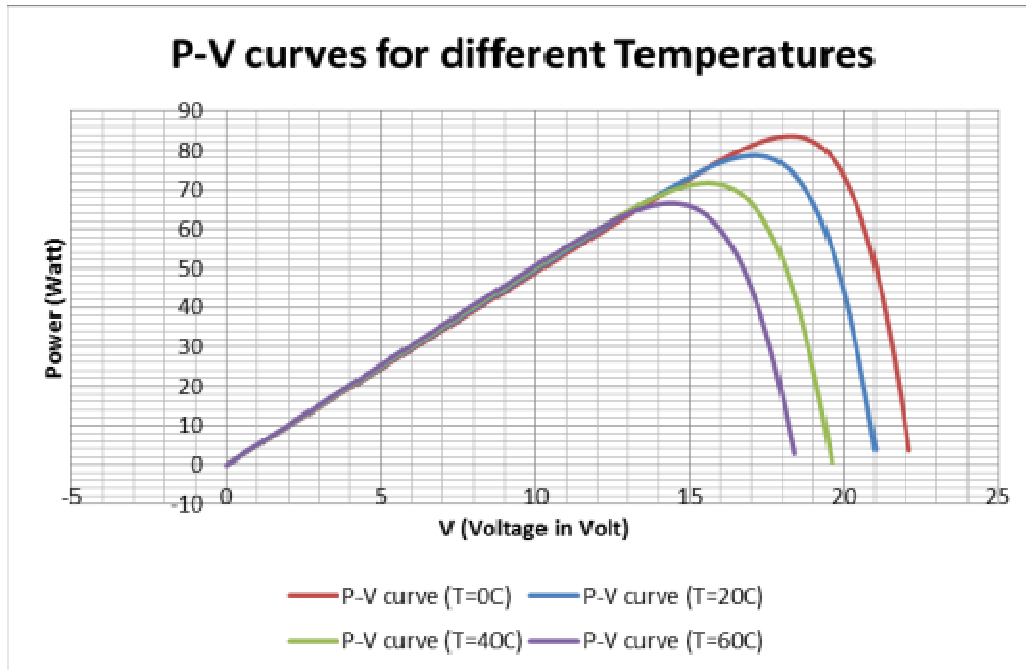


Fig. 19: P-V curves for different temperatures.

6.4 Characteristics of the I-V and P-V curves by varying the solar irradiance

The variation of the solar irradiance has a great effect on the output power and on the I-V and P-V curves. By varying the solar irradiance between 400 W/m^2 and 1000 W/m^2 , and from the equations (6), (7), and (12) the characteristics of the I-V and P-V curves of the photovoltaic module are given in figure 20 and 21.

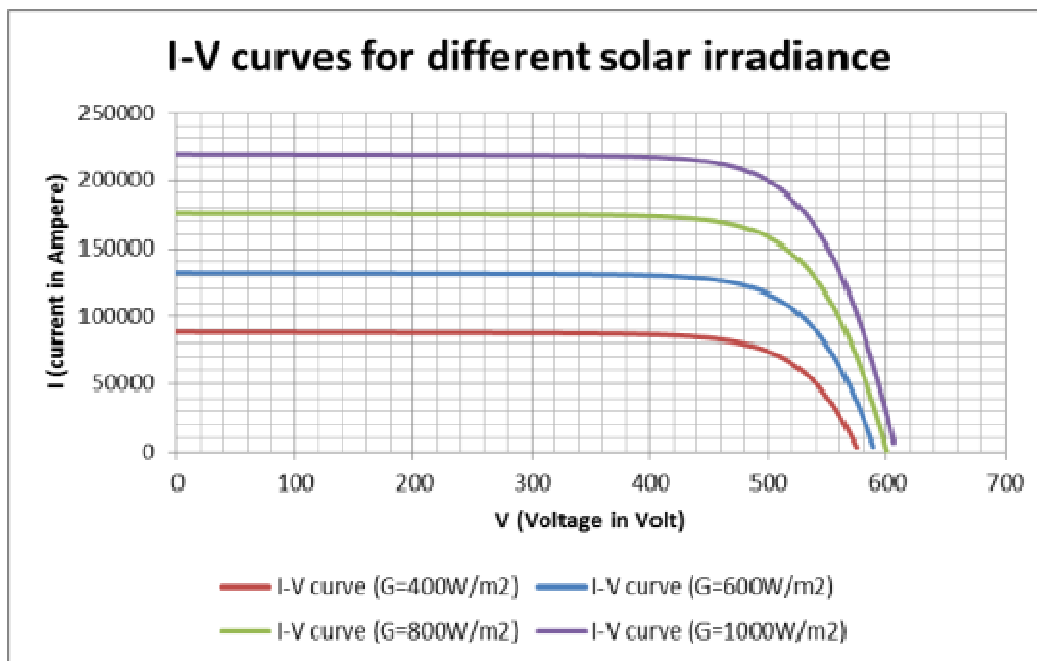


Fig. 20: I-V curves for different solar irradiance form 400 W/m^2 to 1000 W/m^2 .

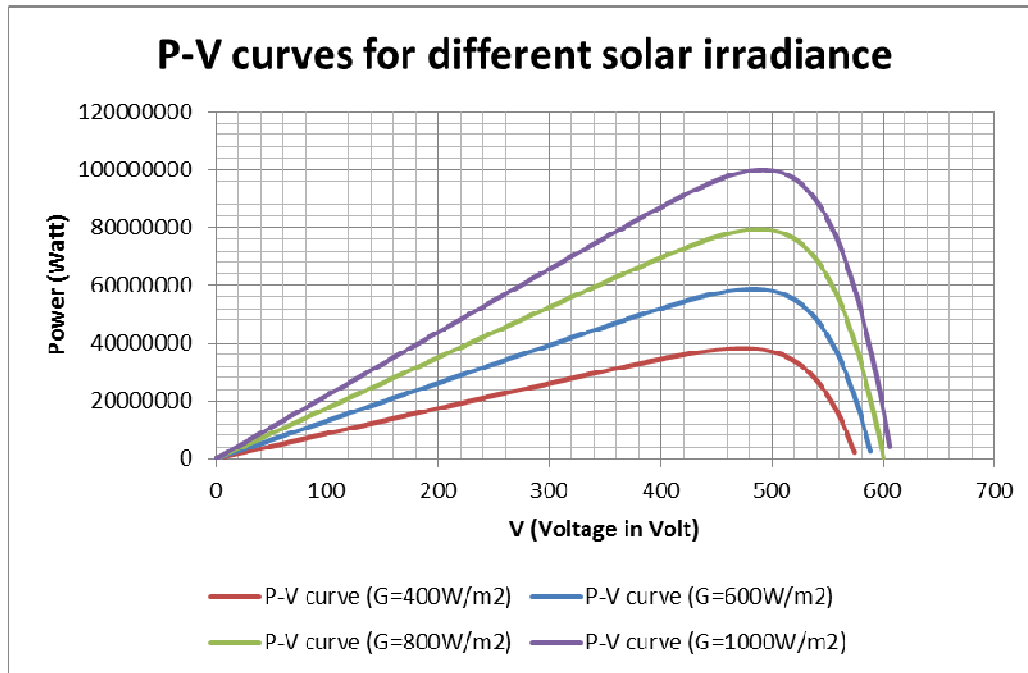


Fig. 21: P-V curves for different solar irradiance form 400 W/m^2 to 1000 W/m^2 .

It should be noted that when the solar irradiance increase, the current, voltage and power increase for the same point on the x axis (Voltage axis).

7 ECONOMIC STUDY TO BUILD 100MW PHOTOVOLTAIC FARM IN LEBANON

As discussed in other countries [25-27], in this Section, an economic study of building photovoltaic farm of 100 MW in Lebanon is treated. Table 2 presents the necessary information to calculate the cost of the project.

Table 2: Economic study to build a photovoltaic farm of 100 MW in Lebanon.

Description	Values
•Cost to construct a Photovoltaic farm of 100MW	\$ 250Million
•Engineering, test, miscellaneous and indirect cost (17% of the cost to construct a Photovoltaic farm)	\$ 42.5Million
•Total Cost, excluding the cost of the land (sum of the first two costs)	\$292.5 Million
•Annual Operation and Maintenance cost including the replacement of old parts and other costs (between 47 and 60\$/kW)	\$6.2 Million
•Total lifetime cost (Total cost of installation+(other costs per year *lifetime))	\$447.5 Million (lifetime 25 years)
•Annual Production of energy (100MW * 365 days * 8h * 70% efficiency of PV panels)	204.4GWh [44]
•Electricity cost [Total lifetime cost/Produced energy during lifetime] (= \$447.5 Million/204.4GWh)	0.08757\$/kWh
•Cost of sold Electricity per year (=Electricity cost * Annual Production of energy)	\$17,900,000

•Price of 1kWh to be sold (for a payback period of 10 years)	0.26\$/kWh
•Price of 1kWh to be sold (for a payback period of 20 years)	0.19\$/kWh
•Payback period [Investment/(Annual Gain-Annual cost)]	10 years
•Needed surface for the whole PV plant (for Monocrystalline Silicon cell technology)	1-2 km ²
•Net Present Value $NPV = G \left(\frac{1 - \frac{1}{(1+i)^n}}{i} \right) - INV$,	
with i=6%, n=25 years ^{*1}	\$160,669,975
with i=4%, n=25 years ^{*2}	\$261,302,734
(For a payback period of 10years)	
•Net Present Value $NPV = G \left(\frac{1 - \frac{1}{(1+i)^n}}{i} \right) - INV$,	
with i=6%, n=25 years ^{*1}	\$-26,286,608.00
with i=4%, n=25 years ^{*2}	\$32,829,814.83
(For a payback period of 20years)	
•Cost per square meter , excluding the cost of the land [total cost/needed surface]	146.25 \$/m ²
•Cost per 1kW [total cost/nominal power] excluding the cost of the land	2925\$/kW
•CO2 emission during lifetime (from construction to dismantling) per kWh	40-50g CO2/kWh [6]
•Lifetime of the Photovoltaic Panel	25 years

Note: the presented values in Table 2 may vary from one manufacturer to another, from one chosen material to another, from one contractor to another, and from one region to another, but in general, the indicated values give an idea about how approximately such project costs in Lebanon.

Example of calculation:

The cost of 1W of Photovoltaic Farm is approximately \$2.5, for the mono-crystalline (refer to table 1), thus, the total cost of the PV Farm is 100,000,000(W)*2.5(\$)= \$250 Million, The Engineering, testing, and indirect cost is approximately equal to 17% of the total installation, thus, its value is equal to \$ 42.5Million.
The Annual Operation and Maintenance is equal approximately 7% of the Total cost, thus, its value is equal to \$20.475 Million. In the same way one can calculate other values.

Comparison between the Electricity from Photovoltaic farm, Power authority and private generators

In this subsection, a comparative study between the Electricity form Photovoltaic farm, Power authority, private generators and regional distributors is proposed (Table 3).

Table 3: Comparison between the electricity cost of Photovoltaic farm, Power Authority, Private Generator and Regional distributor.

•Source of Energy	Value of sold 1kWh
•Power Authority (EDL)	0.09333\$/kWh
•Photovoltaic Farm	0.26\$/kWh (ROI 10 years)
	0.19\$/kWh (ROI 20 years)
•Private Generator	0.3\$/kWh
•Regional distributor	0.32\$/kWh

489 In Table 3, the tariff of the Photovoltaic Farm can't be competitive with the Power Authority
490 from EDL, because the tariff from EDL is not updated and it is based on a very ancient tariff
491 when the price of one barrel was about \$20, and it is very important that the EDL is losing
492 every year about one billion dollars because its tariff is not updated, thus the tariff must be
493 updated in order to impose the real price. But the tariff from PV Farm is very competitive with
494 other sources of energy such as from Private Generator and Regional Distributor because its
495 tariff is less than them, moreover the price of PV is decreasing every year and its efficiency
496 is improving every year, thus it is very clear that the best solution in Lebanon is to install
497 Photovoltaic Farm on the Lebanese scale and to install private PV panels on top roofs of
498 buildings which will deliver free energy from the sun without using traditional generators.
499

500

501 **8 POSSIBLE IMPLEMENTATION OF PHOTOVOLTAIC IN SMALL COUNTRIES** 502 **LIKE LEBANON**

503

504 In small countries like Lebanon with a total area of 10,452 km², it is challenging to find a land
505 to install a large plant such as the calculated one in this paper with a surface between 1 and
506 2 km², for a small amount of energy production such as 100MW. Therefore, it is important to
507 find other solutions, and try to benefit from other surfaces such as lakes, rivers, top roofs of
508 buildings, photovoltaics can be integrated in buildings in an aesthetic way, etc. in this section
509 some solutions are proposed to resolve this problem.

510

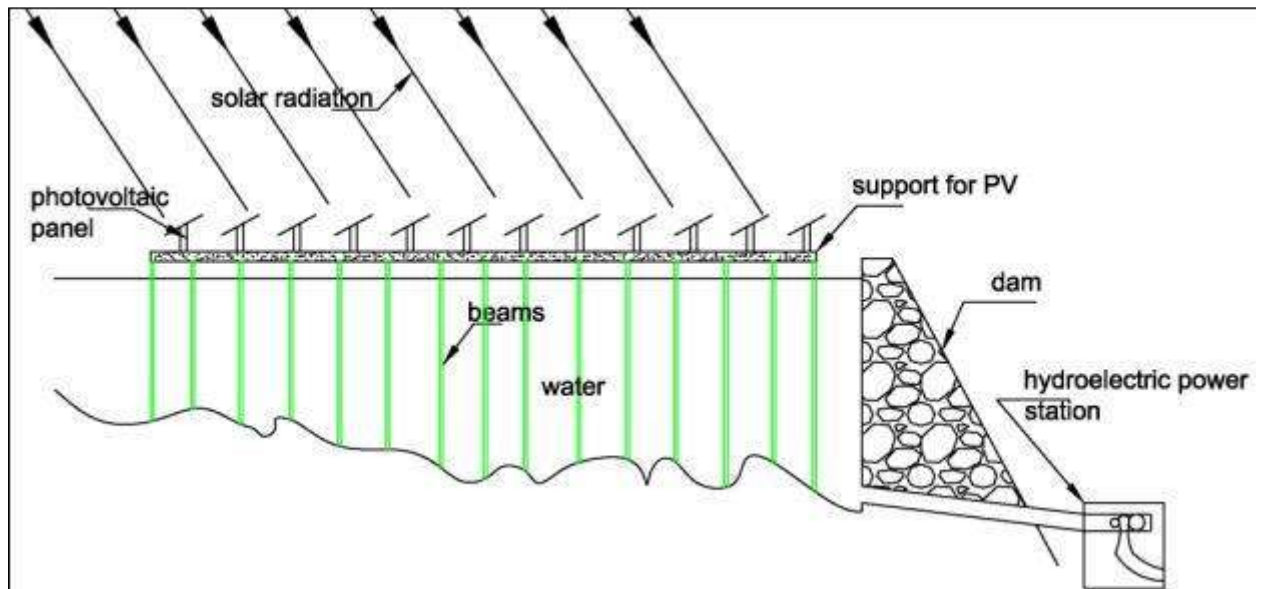
511

512 **8.1 Installation of Photovoltaic plant on lakes and rivers in Lebanon**

513

514 In countries when rivers and lakes exist, one can install photovoltaic panels above the
515 surface of the water as it is indicated in figure 22. This will lead to gain flat surfaces on the
516 earth and use it for other things. The same design can be applied in hydroelectric power
517 station where PV panels can be placed above the surface of the lake, in this way, one can
518 produce electricity from two different sources, the first one is from the hydroelectric power
519 station and the second one is from photovoltaics.
520

521



522

523

Fig. 22: Hybridization between photovoltaics and hydroelectric power station.

For the Lebanese case, due to lack of surfaces in Lebanon, it is possible to build PV Farm above rivers and lakes. For instance the surface of the lake Qaraoun is approximately 12km^2 , which means it is possible to build PV Farm with a capacity of production between 600MW and 1200MW which is a large power for the Lebanese scale. For example, the Thermal Power production in Lebanon is 2.038GW [29], and from Hydraulic power plants is 220.6MW [29], which means if the PV Farm is installed only above the Qaraoun lake, it will produce about 26.5% to 53% of the total power installed in Lebanon. This is very important, because it will resolve the problem of electricity in Lebanon. The same concept can be applied on the surface of rivers in Lebanon, in fact many rivers are not used for any purpose, therefore, the utilization of these rivers may produce electricity which is necessary for the energy sector in Lebanon. For instance, Lebanon has 16 main rivers, with an estimated total length of 940km, and if we consider the average diameter of a river is 3 meters, we obtain a total surface of 2.8 km^2 , which is a surface that we can build photovoltaic panels and produce power between 140MW and 280MW, which is approximately between 6.2% and 12.4% of the total consumed power in Lebanon. In conclusion, if the government benefits from the surface of rivers and lakes in Lebanon, it will produce approximately between 740MW and 1480MW which is an important source of free energy.

8.2 Vertical PV plant

Other solution is to install vertically Photovoltaic panels on buildings or create vertical walls where photovoltaics can be installed (figure 23), in this way a small surface produces a large amount of energy and the ratio Energy/Surface is very high. The cost of installation and reparation will be high, but this is the best solution to produce energy where large surface of lands are not available in a certain country or region.

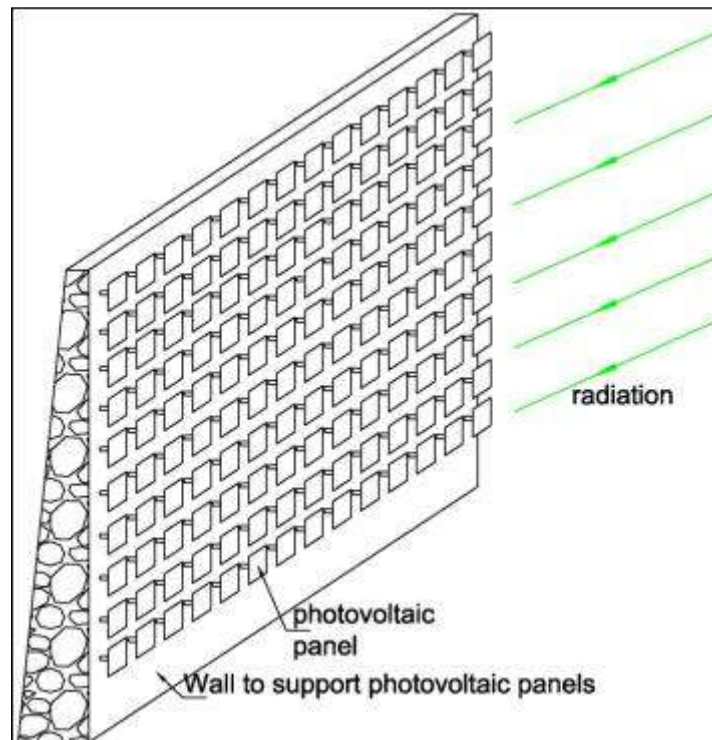


Fig. 23: vertical photovoltaic farm.

8.3 PV panels on the top roof of buildings

If the first two solutions are difficult to be implemented, therefore, the government should use the rooftop of buildings in order to install PV panels and generate electricity from the sun radiations; this is the best solution for such situation. For instance, there is not any official document for the total number of buildings in Lebanon for this year; in 1996 it was 518,858 buildings according to [41], where the population was about 3.5 million, in another meaning 6.7 persons in one building. In 2015, the population is about 4.5 million according to [42], and number of foreigners in Lebanon is about 1.7 million (there is no an official and accurate data about this number, but it is estimated due to problems in Lebanon, Syria and the region). Table 4 presents a summary about the estimated power that can be produced using only rooftops of residential buildings.

Table 4: Estimated Power that can be produced in Lebanon using only rooftops of residential buildings.

Description	Values
•Lebanese Population (2015)	4.5 million [42]
•Foreigners in Lebanon (2015)	1.7 million
•Total Population (2015)	6.2 million
•Estimated number of buildings (2015)	925,373
•Average surface of top roof per building	200m ²
•Total available surface of top roofs	185km ²
•Estimated installed power from PV on the top roofs	9.25-18.5 GW

In conclusion, the energy sector in Lebanon consumes about 2.3GW, and if the government benefits from only 12.5% of the total rooftop surfaces of the residential buildings, it will be able to supply electricity to the whole country even without using any power plant. This is the big advantage of the PV system over any other power production systems. And this is the future of power production in small countries such as Lebanon.

9 CONCLUSION

The photovoltaic system is preferred with respect to other source of energy. The future of photovoltaics is promising, the efficiency increase each year and it is expected to overpass 50% in the next decades, the price of photovoltaic system is decreasing which will give it advantages with respect to other renewable energy systems.

In conclusion, this paper presents a general review on photovoltaic system. The models and mathematical expressions of photovoltaic cells are presented. The MATLAB model of the standard expression of photovoltaic module is designed. The results are discussed, many characteristics such as I-V curves and P-V curves are simulated using different parameters. An economic study of building 100MW photovoltaic farm is presented and discussed. Finally, some propositions of the installation of PV panels above lakes and rivers in Lebanon can produce power about the half consumed power in the country, which is a very efficient way to produce energy using non utilized surfaces. This will resolve the problem of electricity in Lebanon.

10 NOMENCLATURES

C_{EG1} designs the temperature coefficient ($\approx 4.73 \cdot 10^{-4} eV / K$).

C_{EG2} is the temperature coefficient ($\approx 636 K$).

C_{TI} is the coefficient representing the change of I_{SC} for each degree, it is expressed in %/°C.

C_{TV} presents the coefficient representing the change of V_{oc} for each degree, it is expressed in $V/^{\circ}C$.
 dT designs the difference in temperature.
 $E_g(0)$ presents the energy gap for the temperature $T = 0\text{ K}$ ($\approx 1.17\text{eV}$ for Silicon).
 I_{cell} is the output current of the PV cell.
 $I_{L,cell}$ presents the light generated current produced by the incident light on the Photovoltaic cell.
 $I_{O,cell}$ designs the internal p-n junction saturation current, its value is between 10^{-4} and 10^{-15} Ampere. It varies with the variation of the temperature.
 $I_{module} = N_P I_{cell}$ is the module current.
 $I_L = N_P I_{L,cell}$ presents the module current.
 $I_O = N_P I_{O,cell}$ designs the total equivalent saturation current of the diode.
 k is the Boltzmann's constant, it is equal to $1.3806488 \cdot 10^{-23}\text{Joule/Kelvin}$.
 n_{cell} is the correction coefficient, its value is between 1 and 2, in this paper we take it equal to 1.6.
 N_P is the number of parallel strings.
 N_S is the number of cells per string.
 $n = N_S n_{cell}$ presents the correction coefficient of the module.
 q designs the elementary charge, it is equal to $1.60217 \cdot 10^{-19}\text{Coulomb}$.
 $R_{S,cell}$ designs the series resistance of the photovoltaic cell. It includes all factors of resistance and the carriers' movement, its value is less than 1Ω .
 $R_{SH,cell}$ is the shunt resistance of the photovoltaic cell. It represents the leakage of carriers due to recombination in different part of the cell, its value is greater than 1000Ω .
 $R_S = \left(\frac{N_S}{N_P}\right) R_{S,cell}$ is the equivalent series resistance.
 $R_{SH} = \left(\frac{N_S}{N_P}\right) R_{SH,cell}$ presents the equivalent shunt resistance.
 T presents the temperature in Kelvin, $(273.15 + T^{\circ}C)$, standard temperature is $25^{\circ}C$.
 V_{cell} is the terminal voltage of the PV cell.
 $V_T = \frac{kT}{q}$ presents the thermal voltage, its value is in Volt.
 $V = N_S V_{cell}$ is the module voltage.
 XTI is the temperature coefficient for the I_0 for the panel.

REFERENCES

- [1] Luque A, Hegedus S. Handbook of Photovoltaic Science and Engineering. John Wiley & Sons Ltd; 2003.
- [2] Hersch P. Basic photovoltaic principles and methods; February 1982.
- [3] Trykozko R. principles of photovoltaic conversion of solar energy. Opto-electric revision, COSiW SEP, Warsaw, 1997; 5(4).
- [4] Green MA. Photovoltaic principles. Physica E 14; 2002: 11–17.
- [5] Markvart T. Photovoltaic solar energy conversion. European Summer University: Energy for Europe, Strasbourg; 7-14 July 2002.
- [6] Markvart T, Castañer L. Practical Handbook of Photovoltaics, fundamentals and applications. Elsevier Ltd; 2003.
- [7] Rikos E. Modeling of Photovoltaic Cells and Modules. Centre for Renewable Energy Sources Dept. of Photovoltaics and DER Systems. Power point presentation.
- [8] Abdulkadir M, Samosir AS, Yatim AHM. Modeling and simulation based approach of photovoltaic system in Simulink model. ARPN Journal of Engineering and Applied Sciences. May 2012; 7(5).

- 646 [9] Da Silva RM, Fernandes JLM. Hybrid photovoltaic/thermal (PV/T) solar systems
647 simulation with Simulink/Matlab. *Solar Energy*. 84. 2010: 1985-1996.
- 648 [10] Nishioka K, Sakitani N, Uraoka Y, Fuyuki F. Analysis of multicrystalline silicon solar cells
649 by modified 3-diode equivalent circuit model taking leakage current through periphery
650 into consideration. *Solar Energy Materials and Solar Cells*. 2007; 91(13): 1222-1227.
- 651 [11] Villalva MG, Gazoli JR, Filho ER. Comprehensive Approach to Modeling and Simulation
652 of Photovoltaic Arrays. *IEEE Transactions on power electronics*. 2009; 24 (5).
- 653 [12] Bonkougou D, Koalaga Z, Njomo D. Modelling and Simulation of photovoltaic module
654 considering single-diode equivalent circuit model in MATLAB. *International Journal of
655 Emerging Technology and Advanced Engineering*. March 2013; 3(3): 493-502.
- 656 [13] Jena C, Das A, Panigrahi CK, Basu M. Modelling and Simulation of Photovoltaic Module
657 with Buck-Boost Converter. *International Journal of Advanced Engineering and Nano
658 Technology*. February 2014; 1(3): 18-21.
- 659 [14] Belhaouas N, Ait Cheikh MS, Malek A, Larbes C. Matlab-Simulink of photovoltaic
660 system based on a two-diode model simulator with shaded solar cells. *Revue des
661 Energies Renouvelables*. 2013; 16(1): 65 – 73.
- 662 [15] Jiang Y, Qahouq JA, Orabi M. Matlab/Pspice Hybrid Simulation Modeling of Solar PV
663 Cell/Module. *Applied Power Electronics Conference and Exposition (APEC), 2011
664 Twenty-Sixth Annual IEEE*. 2011: 1244– 1250.
- 665 [16] Salmi T, Bouzguenda M, Gastli A, Masmoudi A. MATLAB/Simulink Based Modelling of
666 Solar Photovoltaic Cell. *International Journal of Renewable Energy Research*. 2012;
667 2(2): 213-218.
- 668 [17] Kachhiya K, Lokhande M, Patel M. MATLAB/Simulink Model of Solar PV Module and
669 MPPT Algorithm. *Proceedings of the National Conference on Recent Trends in
670 Engineering and Technology*. 2011.
- 671 [18] Chouder A, Silvestre S, Taghezouit B, Karatepe E. Monitoring, modelling and simulation
672 of PV systems using LabVIEW. *Solar Energy*. May 2013; 91: 337-349.
- 673 [19] Abdulkadir M, Samosir AS, Yatim AHM. Modeling and Simulation of a Solar Photovoltaic
674 System, Its Dynamics and Transient Characteristics in LABVIEW. *International Journal
675 of Power Electronics and Drive System*. June 2013; 3(2): 185-192.
- 676 [20] Anonymous. Principe de fonctionnement de la cellule photovoltaïque. Accessed 09 May
677 2014. Available: [http://tpeenergiephotovoltaique.e-monsite.com/pages/la-cellule-
678 photovoltaique/principe-de-fonctionnement-de-la-cellule-photovoltaique.html](http://tpeenergiephotovoltaique.e-monsite.com/pages/la-cellule-photovoltaique/principe-de-fonctionnement-de-la-cellule-photovoltaique.html).
- 679 [21] Anonymous. ReneSola achieves record third quarter results. plans 2011 capacity
680 expansion. Accessed 10 May 2014. Available: [http://www.pv-
681 magazine.com/news/details/beitrag/renesola-achieves-record-third-quarter-results-
682 plans-2011-capacity-expansion_100001519/#axzz2yZ5lQBx6](http://www.pv-magazine.com/news/details/beitrag/renesola-achieves-record-third-quarter-results-plans-2011-capacity-expansion_100001519/#axzz2yZ5lQBx6), 2010.
- 683 [22] Anonymous: Module Circuit Design. Accessed 10 May 2014. Available:
684 <http://pveducation.org/pvcdrom/modules/module-circuit-design>, 2014.
- 685 [23] Cheung N. Solar Cells Fabrication Technologies. Lecture 26, U.C. Berkeley, Available:
686 http://www-inst.eecs.berkeley.edu/~ee143/fa10/lectures/Lec_26.pdf.
- 687 [24] Sahu TP, Dixit TV, Kumar R. Simulation and Analysis of Perturb and Observe MPPT
688 Algorithm for PV Array Using ĆUK Converter. *Advance in Electronic and Electric
689 Engineering*. 2014; 4(2): 213-224.
- 690 [25] Anonymous. Swaziland to construct 100 MW solar farm. Accessed 10 May 2014.
691 Available: [http://www.pv-magazine.com/news/details/beitrag/swaziland-to-construct-
692 100-mw-solar-farm_100013261/#axzz2z98oXnPK](http://www.pv-magazine.com/news/details/beitrag/swaziland-to-construct-100-mw-solar-farm_100013261/#axzz2z98oXnPK). 2013.
- 693 [26] Anonymous. Scotland tops 100 MW solar milestone. Accessed 10 May 2014. available
694 at: [http://www.pv-magazine.com/news/details/beitrag/scotland-tops-100-mw-solar-
695 milestone_100013799/#axzz2z98oXnPK](http://www.pv-magazine.com/news/details/beitrag/scotland-tops-100-mw-solar-milestone_100013799/#axzz2z98oXnPK). 2013.
- 696 [27] Anonymous. 100 MW Solar Farm For New South Wales. Accessed 10 May 2014.
697 available:

- 698 http://www.energymatters.com.au/index.php?main_page=news_article&article_id=1272
699 . 2011.
- 700 [28] Anonymous. Grid-connected Photovoltaic System (GCPV), Solar Farm. Accessed 10
701 May 2014. Available: [http://www.solarissolar.com.my/Grid-](http://www.solarissolar.com.my/Grid-connected+Photovoltaic+System+%28GCPV%29_6_1.htm)
702 [connected+Photovoltaic+System+%28GCPV%29_6_1.htm](http://www.solarissolar.com.my/Grid-connected+Photovoltaic+System+%28GCPV%29_6_1.htm).
- 703 [29] Anonymous. Electricite du Liban official website. Thermal power plants, Accessed 10
704 May 2014. Available: <http://www.edl.gov.lb/ABOUTEDL.htm>
- 705 [30] Moubayed N, El-Ali A, Outbib R. A comparison of two MPPT techniques for PV system.
706 WSEAS Transactions on Environment and Development. December 2009; 5(12): 770-
707 779.
- 708 [31] Liu C, Wu B, Cheung R. Advanced Algorithm for MPPT Control of Photovoltaic
709 Systems. Canadian Solar Buildings Conference, Montreal. August 20-24, 2004: 1-7.
- 710 [32] Ankaiah B, Nageswararao J. MPPT Algorithm for Solar Photovoltaic Cell by Incremental
711 Conductance Method. International Journal of Innovations in Engineering and
712 Technology. February 2013; 2(1): 17-23.
- 713 [33] Xiao W, Dunford WG. A modified adaptive hill climbing MPPT method for photovoltaic
714 power systems. in Conf. Rec. 2004 IEEE Annu. Power Electronics Specialists Conf.
715 (PESC'04). June 2004; 3: 1957-1963.
- 716 [34] Hohm DP, Ropp ME. Comparative Study of Maximum Power Point Tracking Algorithms.
717 Progress in Photovoltaics: Research and Applications. 2003; Vol. 11: 47-62.
- 718 [35] Chaudhari VA. Automatic Peak Power Tracker for Solar PV Modules Using dSpacer
719 Software. in Maulana Azad National Institute Of Technology. vol. Degree of Master of
720 Technology In Energy. Bhopal: Deemed University. 2005: 98.
- 721 [36] Zainudin HN, Mekhilef S. Comparison Study of Maximum Power Point Tracker
722 Techniques for PV Systems. Proceedings of the 14th International Middle East Power
723 Systems Conference (MEPCON'10). Cairo University, Egypt, December 2010: 19-21.
- 724 [37] Hohm DP, Ropp ME. Comparative Study of Maximum Power Point Tracking Algorithms
725 Using an Experimental, Programmable, Maximum Power Point Tracking Test Bed.
726 Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth
727 IEEE. 2000:1699-1702.
- 728 [38] Masoum MAS, Dehbonei H, Fuchs EF. Theoretical and Experimental Analyses of
729 Photovoltaic Systems With Voltage- and Current-Based Maximum Power-Point
730 Tracking. IEEE Transactions on Energy Conversion. December 2002; 17(
731 4).
- 732 [39] Lokanadham M, Bhaskar KV. Incremental Conductance Based Maximum Power Point
733 Tracking (MPPT) for Photovoltaic System. International Journal of Engineering
734 Research and Applications. Mar-Apr 2012; 2(2): 1420-1424.
- 735 [40] Tsai HL, Tu CS, Su YJ. Development of Generalized Photovoltaic Model Using
736 MATLAB/SIMULINK. Proceedings of the World Congress on Engineering and Computer
737 Science 2008 WCECS 2008. San Francisco, USA. October 22 - 24, 2008.
- 738 [41] Anonymous. Lebanon State of the Environment Report, Section 4. Ministry of
739 Environment/LEDO. Available:
740 [http://www.unep.org/dewa/westasia/Assessments/national_SOEs/west%20asia/Lebano](http://www.unep.org/dewa/westasia/Assessments/national_SOEs/west%20asia/Lebanon/Chap4Construction.pdf)
741 [n/Chap4Construction.pdf](http://www.unep.org/dewa/westasia/Assessments/national_SOEs/west%20asia/Lebanon/Chap4Construction.pdf).
- 742 [42] Lebanon Population. Countrymeters. Accessed 04 June 2015. Available at:
743 <http://countrymeters.info/en/Lebanon>.