

Original Research Article

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

ABSTRACT

The goal of this paper is to give a general review about photovoltaics with necessary information to satisfy the knowledge. Different electronic models of photovoltaic cells are given. This paper presents also the functioning of the photovoltaics, the model Using MATLAB/Simulink, the algorithm used to extract the maximum power from a PV panel. Simulated results, advantages and disadvantages are discussed. Economic study to build a 100 MW photovoltaic farm in Lebanon with a comparative table between its tariff and existing tariffs such as from Power Authority, Private Generators, and Regional Distributors. Some other integration are also proposed.

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 Algorithm, Advantages and disadvantages, and the most important thing is to compare its economic study in 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 according to other studies in the world but this time is 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 the difference between different tariffs 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 integration is also proposed for example between the PV Farm and a lake in Lebanon which it is possible in order to gain surfaces on the lake and reduce surfaces on the earth.

Results: The main interesting results in this paper is 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 source 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 an 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, hybridization between PV system and hydroelectric power station is proposed, and it is clear that this hybridization is powerful because it is able to produce between 25.6% and 53% of the total installed power in Lebanon which will resolve big problems.

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 general 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, the Maximum Power Point Algorithm is presented, it serves to extract the maximum power from a PV panels. In the fifth Section, a MATLAB model of photovoltaic panel is presented. The section 6 treats and discusses the results obtain from section 3. The Section 7 studies the economic study to build a 100MW photovoltaic farm in Lebanon. The Section 8 presents some advantages and disadvantages of photovoltaic panels. Hybridization and integration of photovoltaic panels are sown in section 9, some of them are proposed. And finally, a conclusion is presented in Section 10.

2. DESCRIPTION AND FORM OF PHOTOVOLTAIC CELLS

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

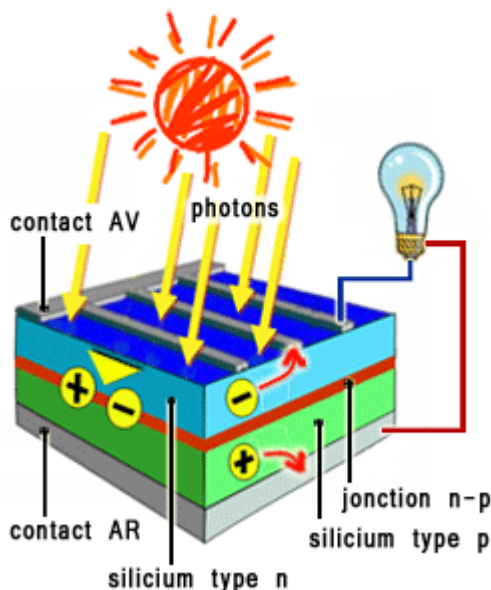


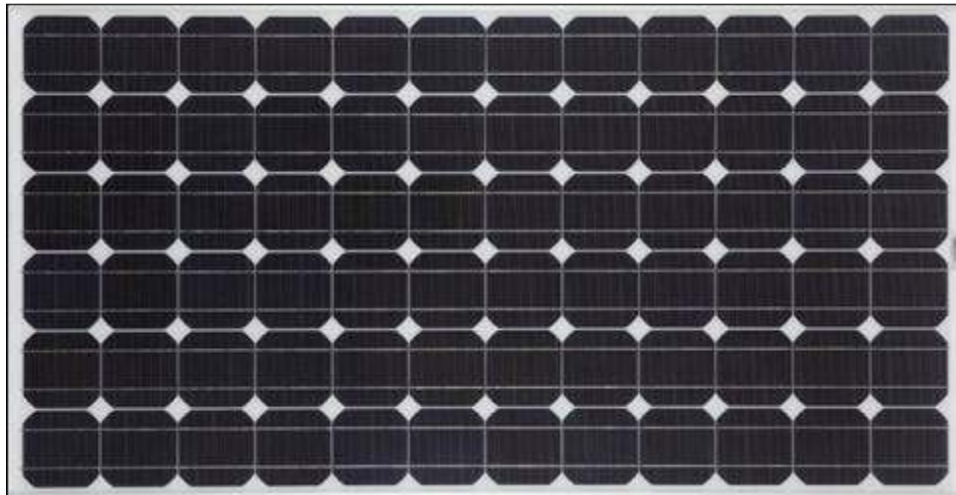
Fig. 1: Conversion of the solar energy into kinetic energy of the electrons [20].

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



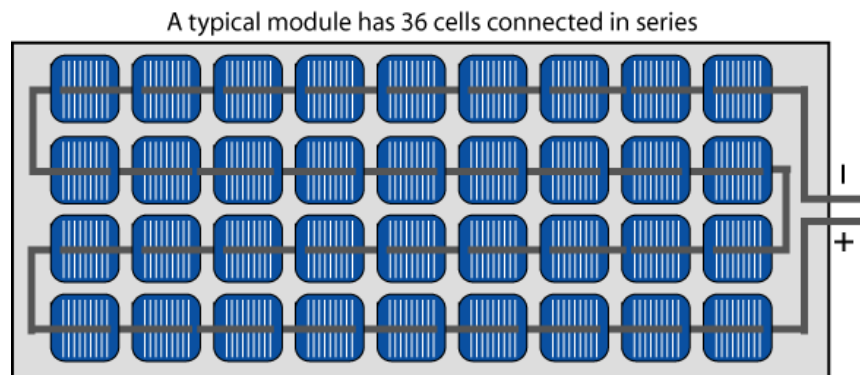
Fig. 2: represents a single photovoltaic cell [1].

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



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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 ($25^{\circ}C$, and $AM=1.5$ (Air Mass)).

In figure 4, a Photovoltaic Farm is composed of many parallel and series module arranged in a way to give high voltage and current according to the need.



Fig. 4: Photovoltaic Farm [28].

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.

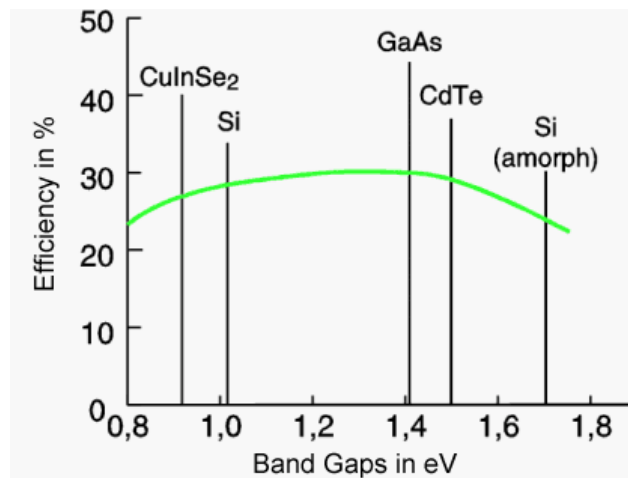


Fig. 5: common known materials for solar cells [23].

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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2.2 Fabrication of PV cells

The process of the fabrication of PV cells is not simple, it passes within different processes and it demands a high technology manufacturer. The process begins by separating the Silicon from the sand, and by making large ingot, then cutting the ingot into wafers, then diffusing phosphorus and so on... as depicted in the figures 6 and 7.

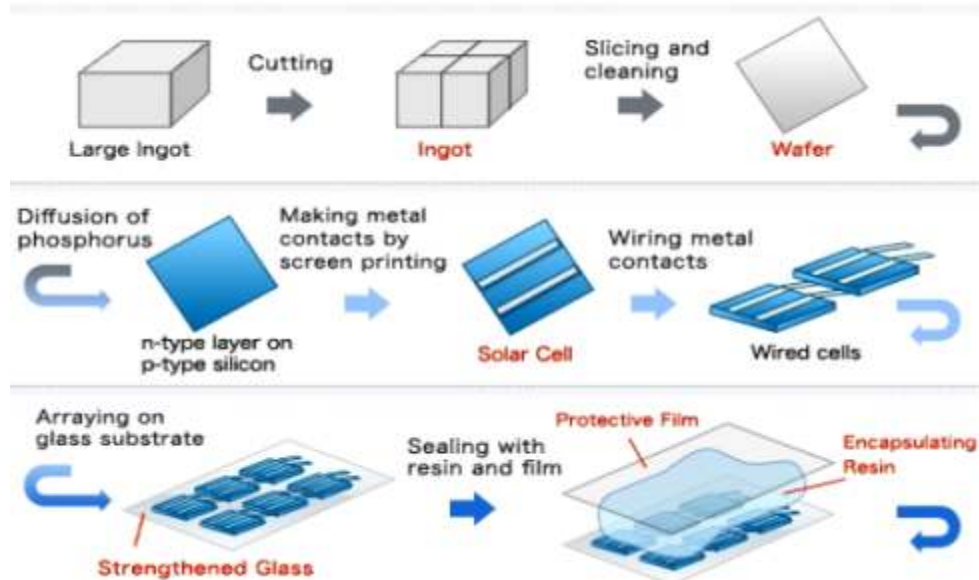


Fig. 6: Process to fabricate PV cells [23].

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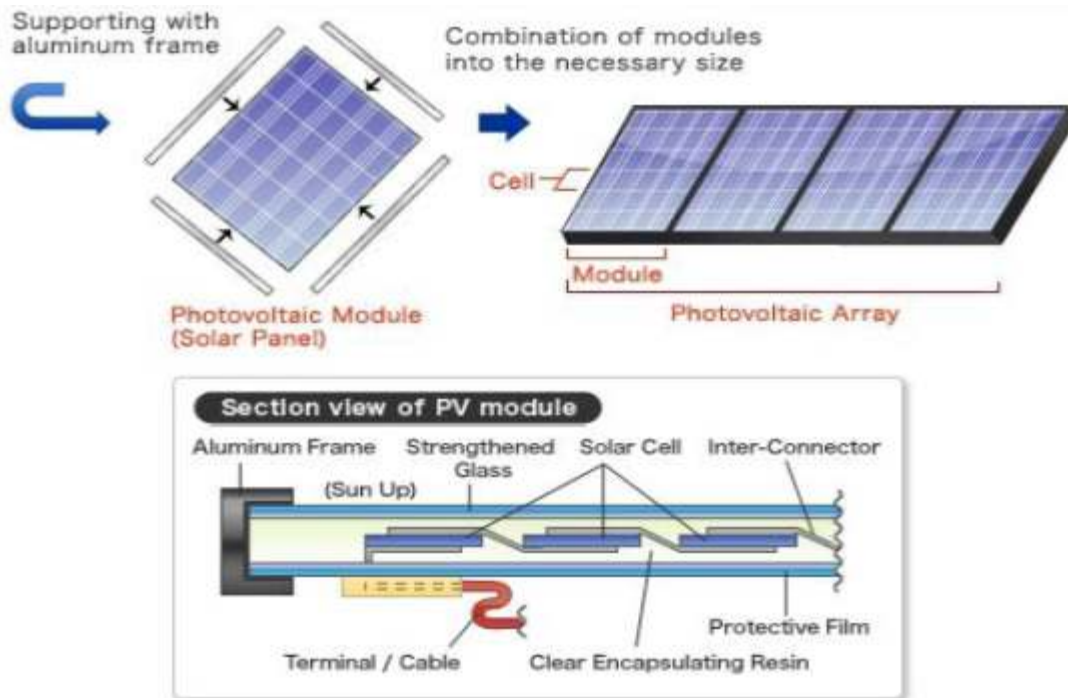


Fig. 7: Process to fabricate PV panel [23].

2.3 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:

2.3.1 Ideal Model

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

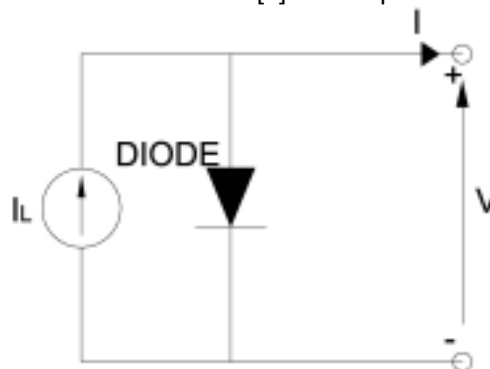


Fig. 8: Ideal model of the Photovoltaic cell.

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]:

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

Where,
 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.
 V_{cell} is the terminal voltage of the PV cell.
 $V_T = \frac{kT}{q}$ presents the thermal voltage, its value is in Volt.

2.3.2 Simple model

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

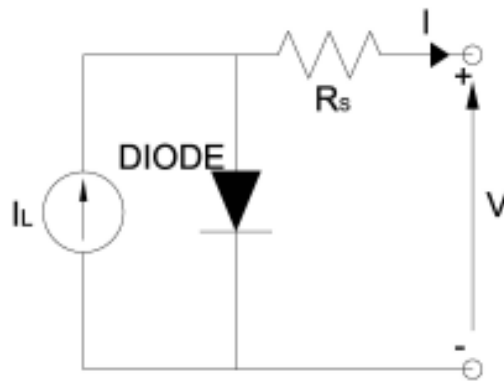


Fig. 9: Simple model of the Photovoltaic cell.

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]:

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

2.3.3 Standard model

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

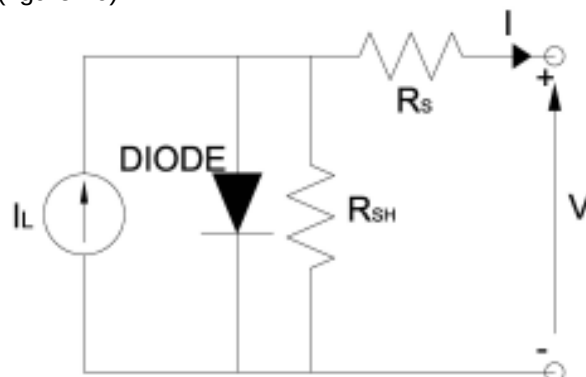


Fig. 10: Standard model of the Photovoltaic cell.

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

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

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

2.3.4 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].

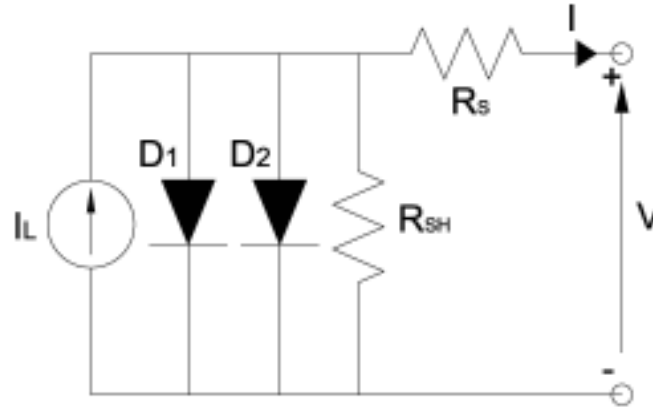


Fig. 11: Standard model with two diodes of Photovoltaic cell.

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

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

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:

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

Where,

$V_T = \frac{kT}{q}$ is the thermal voltage, its value is in Volt.

k is the Boltzmann's constant, it is equal to $1.3806488 \cdot 10^{-23} \text{ Joule/Kelvin}$.

T presents the temperature in Kelvin, $(273.15 + T^{\circ}C)$, standard temperature is $25^{\circ}C$.

q designs the elementary charge, it is equal to $1.60217 \cdot 10^{-19} \text{ Coulomb}$.

n_{cell} is the correction coefficient, its value is between 1 and 2, in this paper we take it equal to 1.6.

I_{cell} presents the output current of the PV cell.

V_{cell} designs the terminal voltage of the PV cell.

$I_{L,cell}$ is the light generated current produced by the incident light on the Photovoltaic cell.

193 $I_{O,cell}$ presents the internal p-n junction saturation current, its value is between 10^{-4} and
 194 10^{-15} Ampere. It varies with the variation of the temperature.
 195 $R_{S,cell}$ designs the series resistance of the photovoltaic cell. It includes all factors of
 196 resistance and the carriers' movement, its value is less than 1Ω .
 197 $R_{SH,cell}$ is the shunt resistance of the photovoltaic cell. It represents the leakage of carriers
 198 due to recombination in different part of the cell, its value is greater than 1000Ω .
 199

200 Consider a PV module with N_p parallel strings (columns) and N_s PV cells per string, then the
 201 equation of the PV module will be as following [7-8], [12]:
 202

$$203 \quad I_{module} = N_p I_{cell} =$$

$$204 \quad N_p I_{L,cell} - N_p I_{O,cell} \left(e^{\left(\frac{N_s V_{cell} + N_p I_{cell} \left(\frac{N_s}{N_p} \right) R_{S,cell}}{N_s n_{cell} k T} \right)} - 1 \right) - \frac{N_s V_{cell} + N_p I_{cell} \left(\frac{N_s}{N_p} \right) R_{S,cell}}{\left(\frac{N_s}{N_p} \right) R_{SH,cell}}$$

(6)

205 Where,
 206 N_p is the number of parallel strings.
 207 N_s is the number of cells per string.
 208

209 And
 210

$$211 \quad I_{module} = I_L - I_O \left(e^{\left(\frac{V + I_{module} R_S}{n V_T} \right)} - 1 \right) - \frac{V + I_{module} R_S}{R_{SH}}$$

(7)

212 Where
 213 $I_{module} = N_p I_{cell}$ is the module current.
 214 $I_L = N_p I_{L,cell}$ presents the module current.
 215 $I_O = N_p I_{O,cell}$ designs the total equivalent saturation current of the diode.
 216 $V = N_s V_{cell}$ is the module voltage.
 217 $n = N_s n_{cell}$ presents the correction coefficient of the module.
 218 $V_T = \frac{kT}{q}$ designs the thermal voltage, its value is in Volt.
 219 $R_S = \left(\frac{N_s}{N_p} \right) R_{S,cell}$ is the equivalent series resistance.
 220 $R_{SH} = \left(\frac{N_s}{N_p} \right) R_{SH,cell}$ presents the equivalent shunt resistance.
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 223 The equivalent circuit of the PV module is depicted in figure 12.
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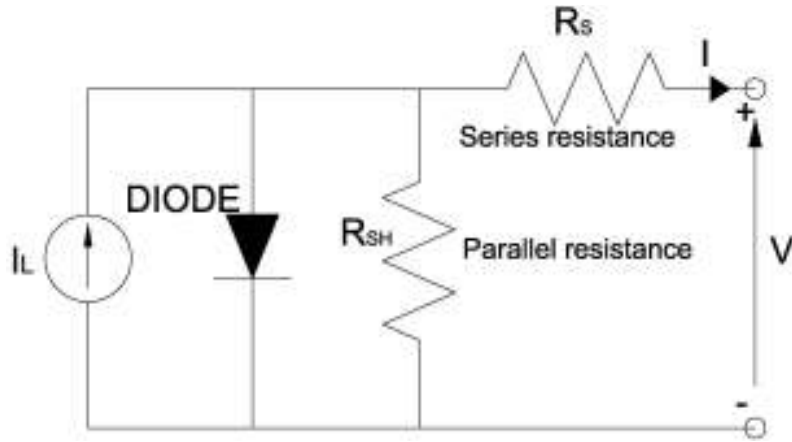


Fig. 12: Equivalent circuit of the PV Module.

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

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

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

$$V \approx -IR_S + nV_T \ln \left(\left(\frac{I_L - I_{module}}{I_o} \right) + 1 \right) \quad (9)$$

$$I_{SC} \approx I_L - I_o \left(e^{\frac{IR_S}{nV_T}} - 1 \right) \quad (10)$$

$$V_{OC} \approx nV_T \ln \left(\frac{I_L}{I_o} + 1 \right) \quad (11)$$

• 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]:

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

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

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

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

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

Where,

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

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.

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

256

257 Where

$$258 \quad E_g(T) = N_s E_g(0) - \frac{N_s C_{EG1} T^2}{C_{EG2} + T} \quad (18)$$

259 where

260 XTI is the temperature coefficient for the I_0 for the panel.

261 $E_g(0)$ presents the energy gap for the temperature $T = 0^0 K$ ($\approx 1.17 eV$ for Silicon).

262 C_{EG1} designs the temperature coefficient ($\approx 4.73 \cdot 10^{-4} eV/^0 K$).

263 C_{EG2} is the temperature coefficient ($\approx 636^0 K$).

264

265 To determine the value of parameters such as R_{SH} , n , R_{SO} , I_0 , R_S , and I_L , one has to
266 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,
267 11].

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269 By finding the value of these parameters one can find the values of the following parameters
270 [7]:

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$$272 \quad R_{SH} \approx R_{SHO} = \frac{V_{min}}{I_{SC} - I_{max}} \quad (19)$$

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$$274 \quad R_{SO} = \frac{V_{OC} - V_{max}}{I_{min}} \quad (20)$$

$$275 \quad n \approx \frac{1}{V_T} \frac{(V_{mp} + I_{mp} R_{SO} - V_{OC})}{\left(\ln \left(\frac{(I_{SC} - I_{mp}) R_{SH} - V_{mp}}{I_{SC} R_{SH} - V_{OC}} \right) + \frac{I_{mp}}{(I_{SC} - R_{SH})} \right)} \quad (21)$$

$$276 \quad I_0 \approx \frac{I_{SC} - \frac{V_{OC}}{R_{SH}}}{e^{\frac{nV_T}{V_{OC}}}} \quad (22)$$

$$277 \quad R_S \approx R_{SO} - \frac{nV_T}{I_0 e^{\frac{nV_T}{V_{OC}}}} \quad (23)$$

$$278 \quad I_L = I_{SC} \left(1 + \frac{R_S}{R_{SH}} \right) + I_0 \left(e^{\frac{I_{SC} R_S}{nV_T}} - 1 \right) \quad (24)$$

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280 4. MAXIMUM POWER POINT TRACHKING (MPPT)

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282 4.1 The Perturb and Observe Algorithm

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

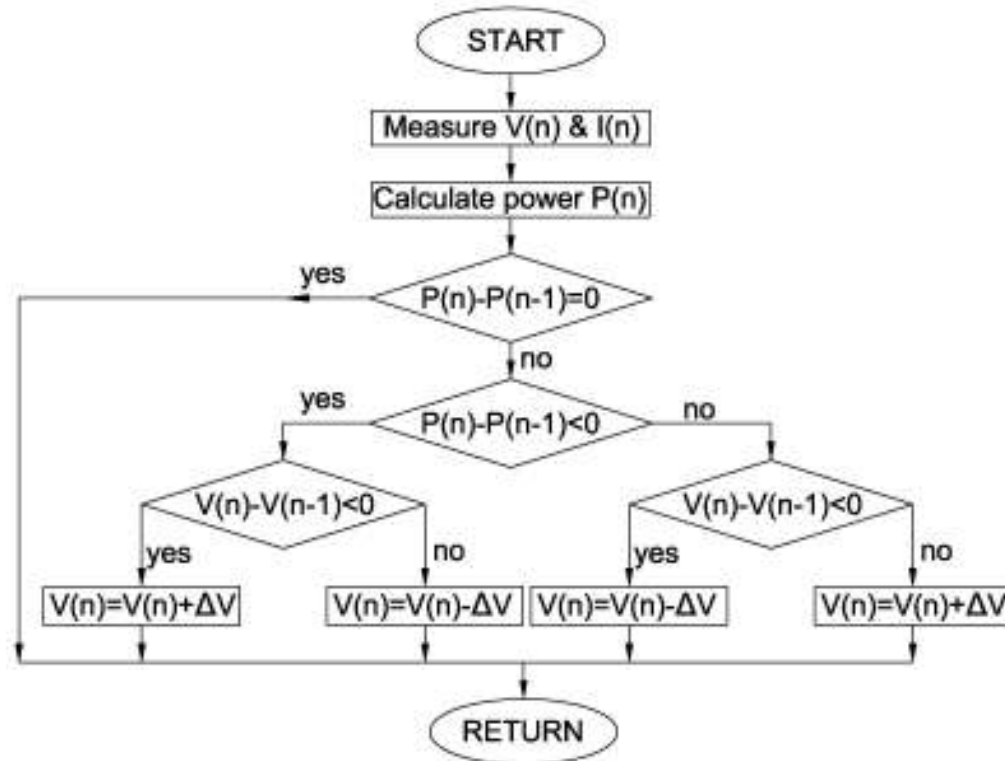


Fig. 13: Perturb and Observe Algorithm.

4.2 The Perturb and Observe Algorithm and P-V curve

The P&O algorithm is used to extract the maximum power from a photovoltaic panel or module; it compares the power and voltage of the last two values and varies the voltage in a way to obtain the highest output power. The following picture shows how the Perturb and Observe 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 14).

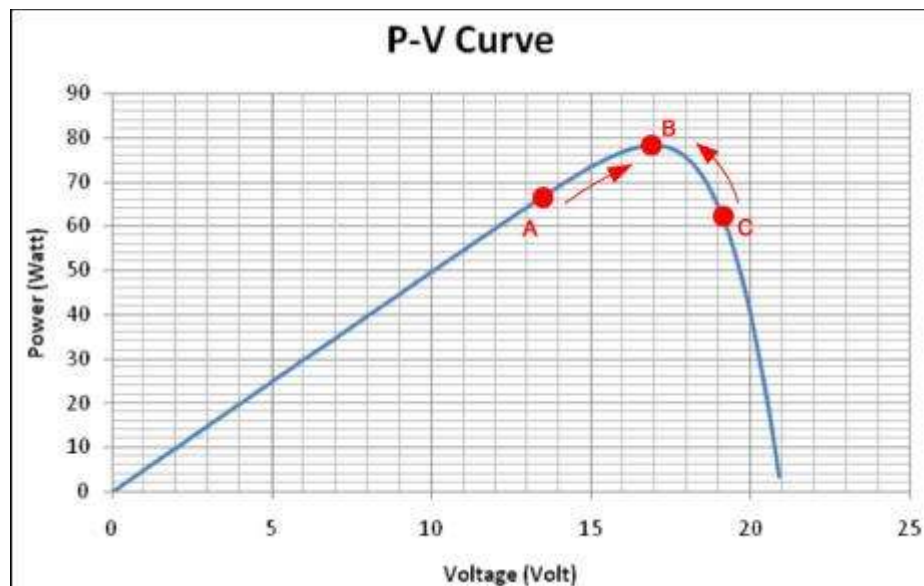


Fig. 14: Perturb and Observe algorithm and its oscillation around the maximum power point.

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

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

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

$V_{OC} = 21V$

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

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

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

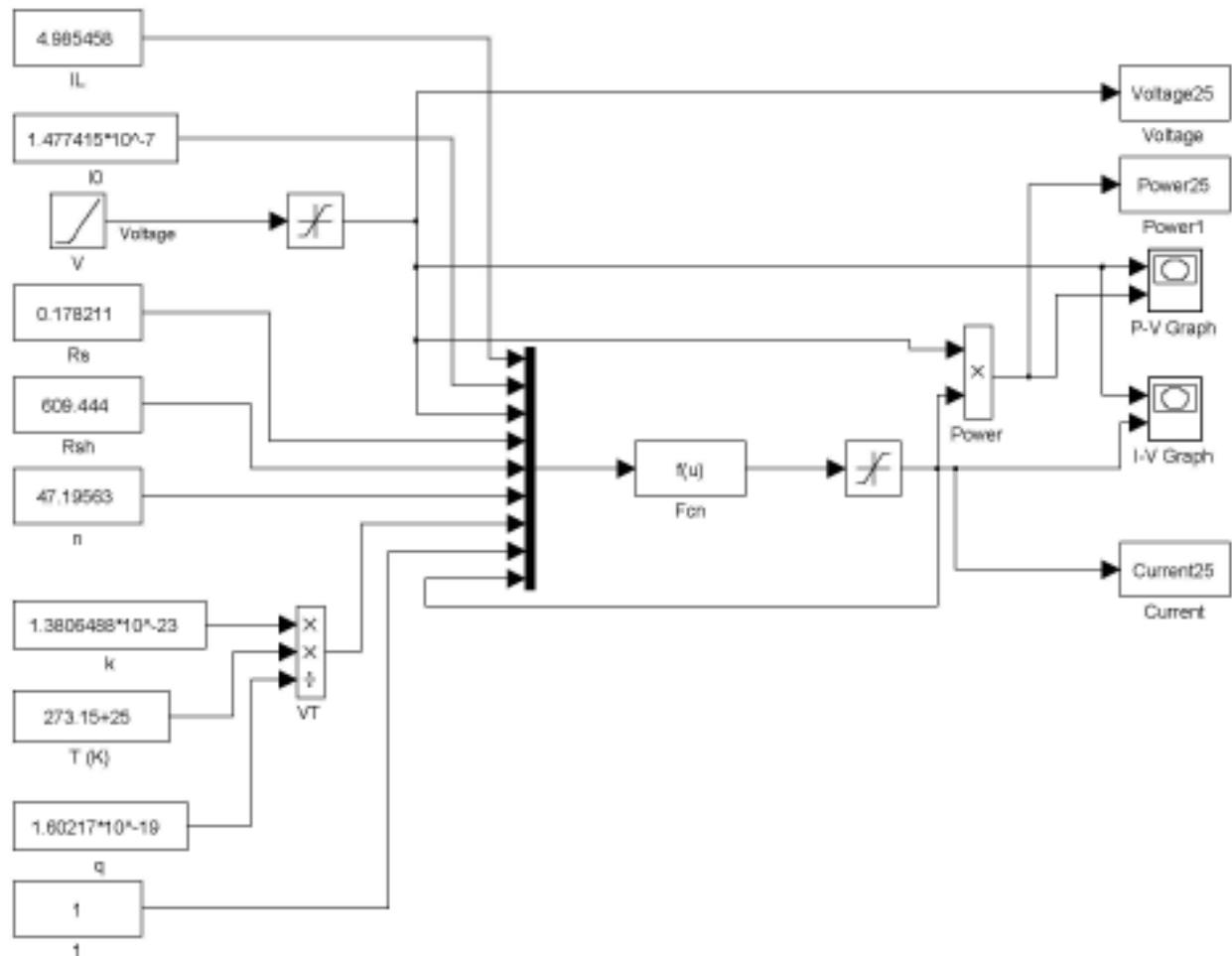


Fig. 15: Modeling of the Photovoltaic panel using Matlab/Simulink, presenting I-V and P-V characteristics.

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 characteristics 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}).

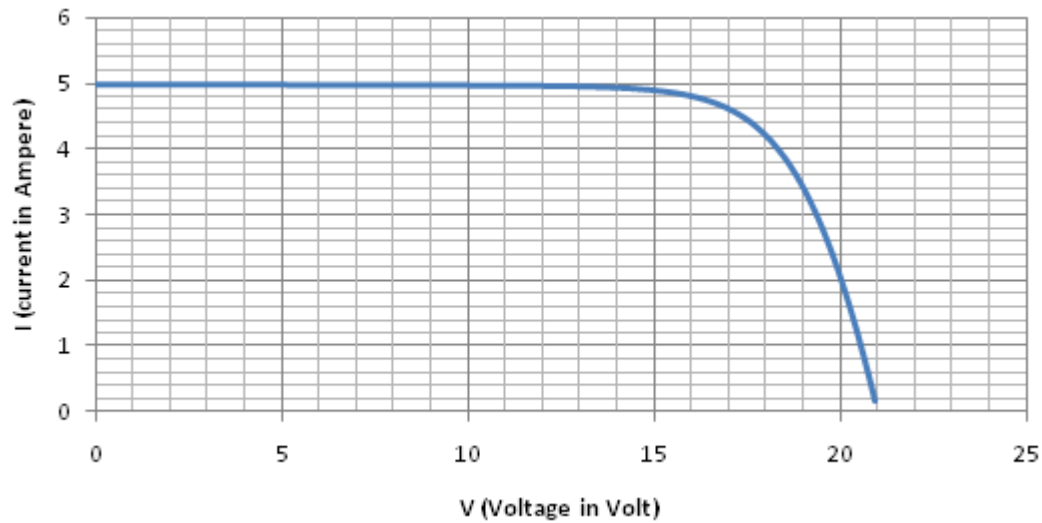


Fig. 16: I-V characteristic of the PV module, for $I_{SC} = 5A$ and $V_{OC} = 21V$.

6.2 The characteristic of the P-V curve

From the 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}).

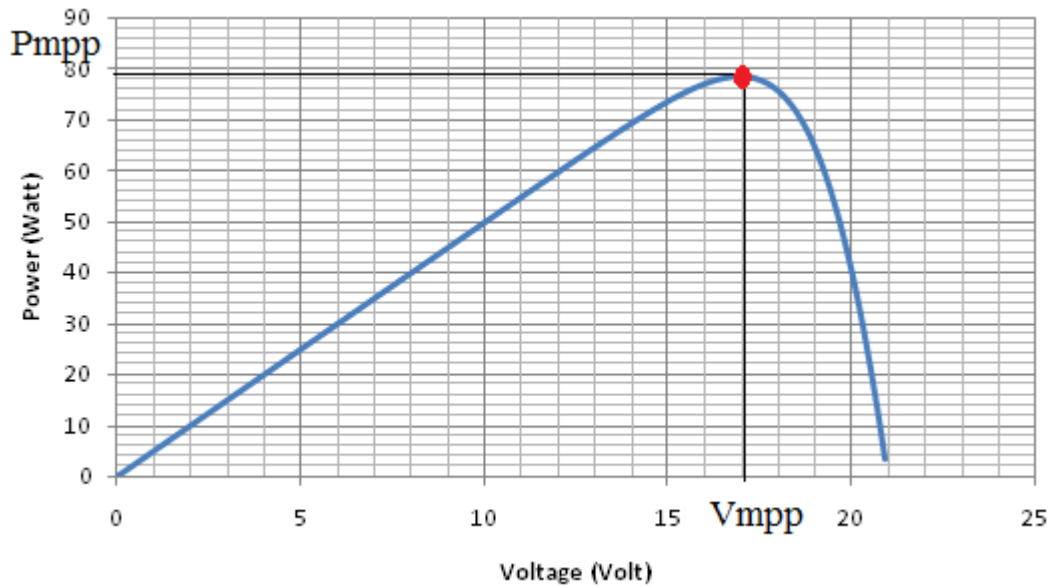


Fig. 17: P-V characteristic of the PV module.

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 .

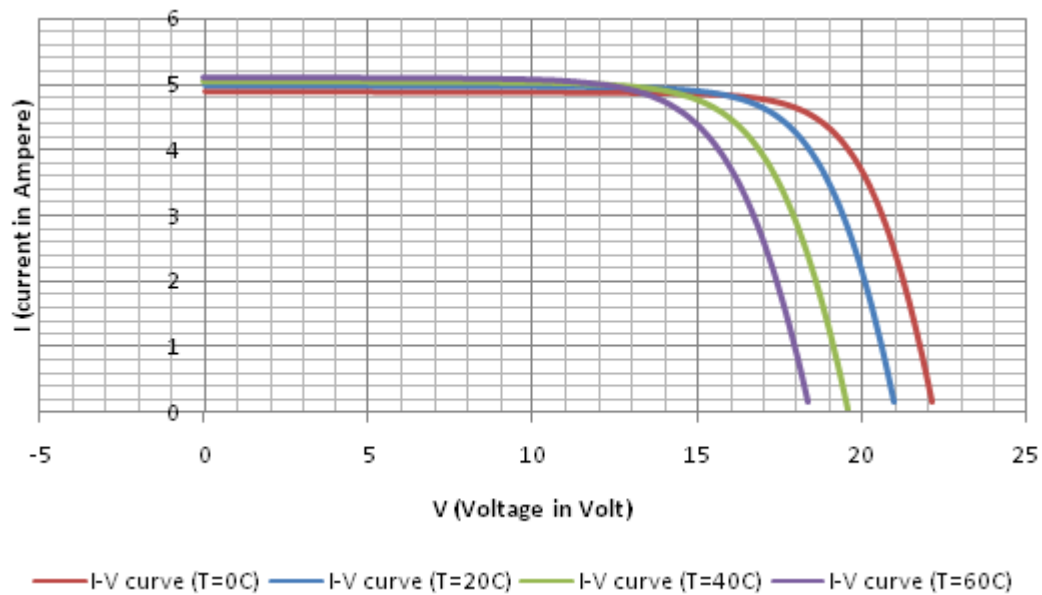


Fig. 18: I-V curves for different temperatures.

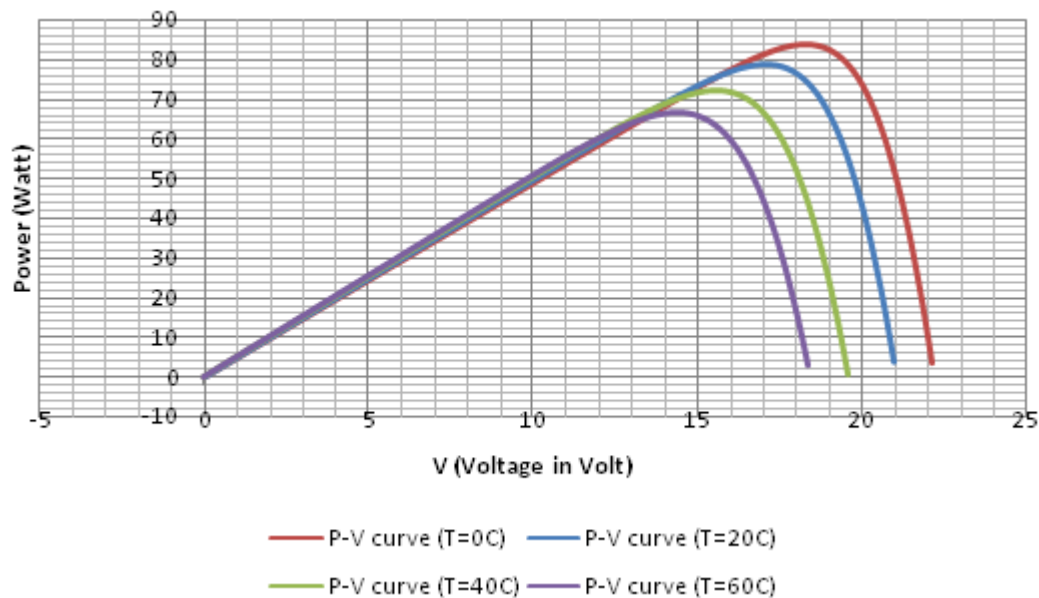


Fig. 19: P-V curves for different temperatures.

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 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.

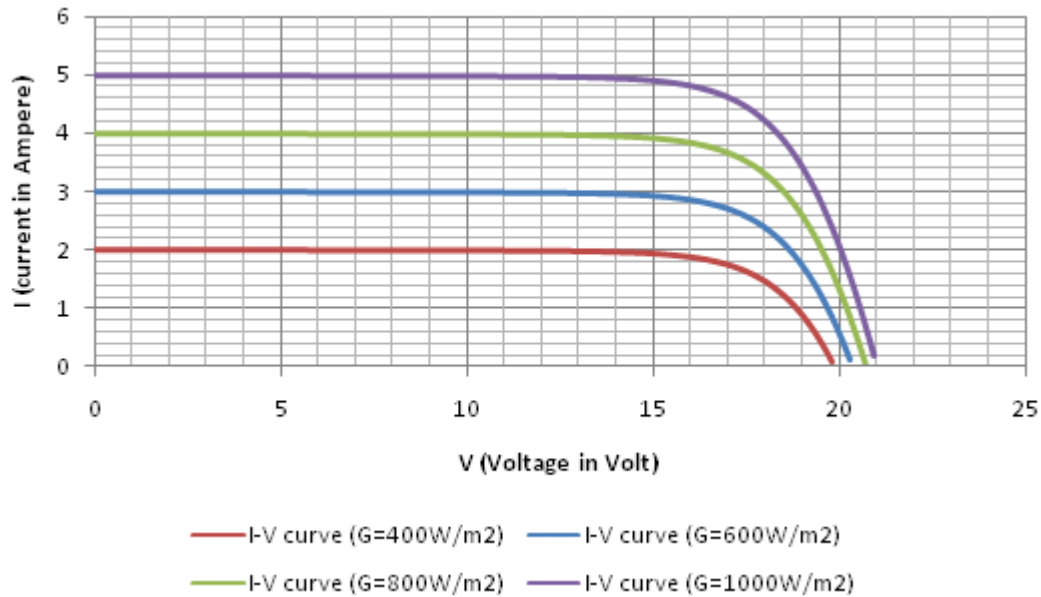


Fig. 20: I-V curves for different solar irradiance form 400 W/m^2 to 1000 W/m^2 .

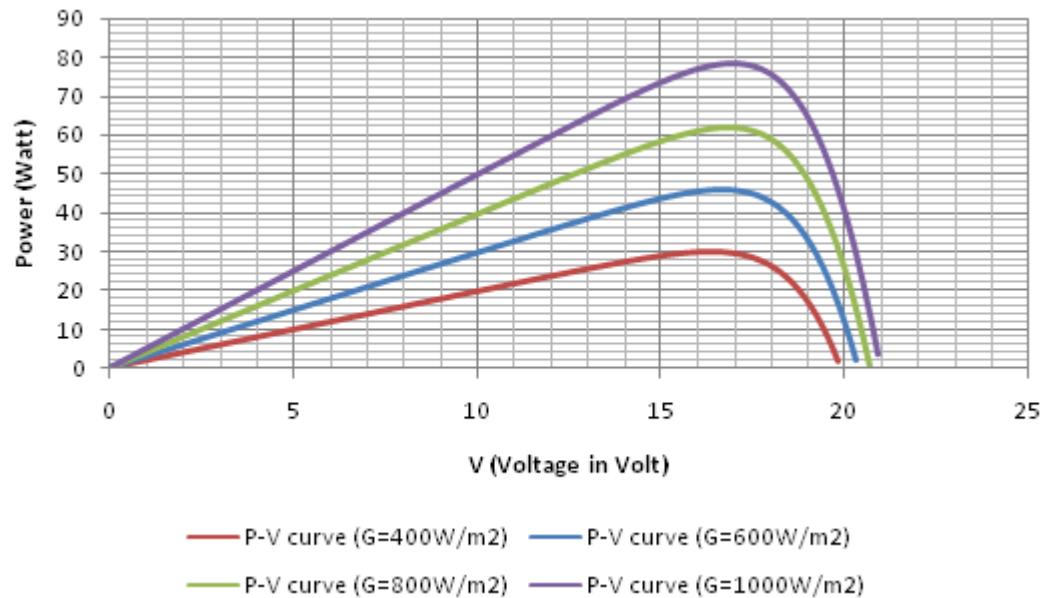


Fig. 21: P-V curves for different solar irradiance form 400 W/m^2 to 1000 W/m^2 .

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

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

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

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

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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.

395
396 Example of calculation:
397 The cost of 1W of Photovoltaic Farm is approximately \$2.5, for the mono-crystalline (refer to
398 table 1), thus, the total cost of the PV Farm is $100,000,000(W) \times 2.5(\$)$ = \$250 Million,
399 The Engineering, testing, and indirect cost is approximately equal to 17% of the total
400 installation, thus, its value is equal to \$ 42.5Million.
401 The Annual Operation and Maintenance is equal approximately 7% of the Total cost, thus,
402 its value is equal to \$20.475 Million. In the same way one can calculate other values.

403
404 **Comparison between the Electricity from Photovoltaic farm, Power authority and**
405 **private generators**

406 In this subsection, a comparative study between the Electricity form Photovoltaic farm,
407 Power authority, private generators and regional distributors is proposed (Table 3).
408

409 **Table 3: Comparison between the electricity cost of Photovoltaic farm, Power**
410 **Authority, Private Generator and Regional distributor.**
411

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

412
413 In the Table 3, the tariff of the Photovoltaic Farm can't be competitive with the Power
414 Authority from EDL, because the tariff from EDL is not updated and it is based on a very
415 ancient tariff when the price of one barrel was about \$20, and it is very important that the
416 EDL is losing every year about one billion dollars because its tariff is not updated, thus the
417 tariff must be updated in order to impose the real price. But the tariff from PV Farm is very
418 competitive with other sources of energy such as from Private Generator and Regional
419 Distributor because its tariff is less than them, moreover the price of PV is decreasing every
420 year and its efficiency is improving every year, thus it is very clear that the best solution in
421 Lebanon is to install Photovoltaic Farm on the Lebanese scale and to install private PV
422 panels on roofs of buildings which will deliver free energy from the sun without using
423 traditional generators.
424

425 **8 ADVANTAGES AND DISADVANTAGES**

426
427 This Section presents the advantages and disadvantages of the photovoltaics.
428

429 **8.1 Advantages**

- 430 1. Solar radiation is the source of Energy.
431 2. Available free energy during the day.
432 3. Create jobs in the renewable energy domain (over 300 jobs).
433 4. Increase energy independence for a country that doesn't have fuel.
434 5. It doesn't emit toxic and harmful gases such as CO₂, SO_x, NO_x etc..., produced by
435 the natural gas, fossil fuel, coal etc...
436 6. No water is required compared to other power plants.
437 7. PV panels can be recycled.
438 8. PV panels can be Integrated into building, windows, or any electrical and electronic
439 application.
440 9. It can be used from very small applications such as "Solar powered toothbrushes" to
441 very huge plants with several hundreds of Mega Watts.

10. Promising technology.
11. The cost of fabrication decrease each year.
12. The efficiency of PV cells increase each year.
13. The needed surface of installation decrease with the improvement of the technology.
14. Reduce the effect of climate changes and global warming.
15. Categorized as Renewable Energy.
16. Construction cost is low compared to other systems.

8.2 Disadvantages

1. PV panels can have one axis of tracking system.
2. The output power depends mainly on the efficiency of the solar irradiance, if the solar irradiance is high, then the output power is high and vice versa.
3. The general efficiency of converting the solar energy to electricity is low, less than 14%.
4. The output energy depends mainly on the direct light.
5. Shading and blocking effects are presented and they affect the efficiency of the output power.
6. Complicated technology.
7. Maintenance frequency and cost are very high.

9 HYBRIDIZATION AND INTEGRATION OF PHOTOVOLTAIC PANELS

In this Section, the hybridization of the photovoltaic panels with other systems is discussed. The first subsection proposes hybridization between photovoltaic and hydroelectric power station. The second section proposes a vertical Photovoltaic plant in countries when a flat surface is not available. Finally photovoltaics can be integrated in buildings in an aesthetic way.

9.1 Hybridization with hydropower station

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

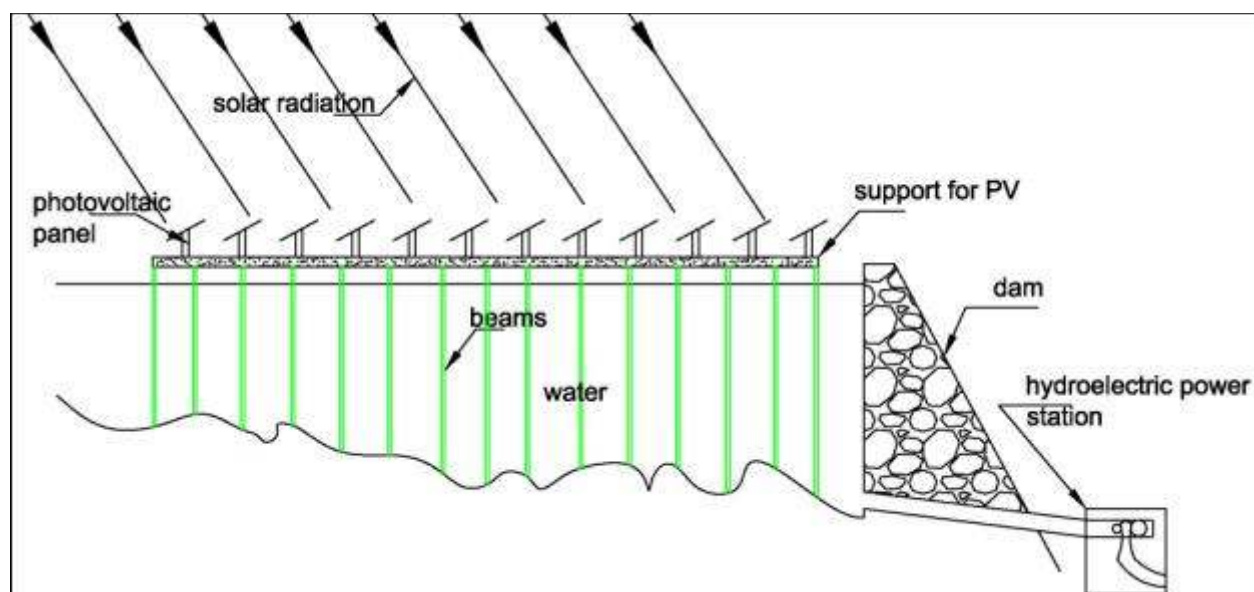


Fig. 22: Hybridization between photovoltaics and hydroelectric power station.

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 lake Qaraoun, it produces 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.

9.2 Vertical PV plant

In a region or country when a large flat surface is not available to install photovoltaic farm, it is proposed to create a vertical surface in order to install photovoltaics. This vertical surface will resolve the problem but the cost of installation will be much more important, the same for the supports of the photovoltaic panels (figure 23). In other hand, the cost of the land is reduced.

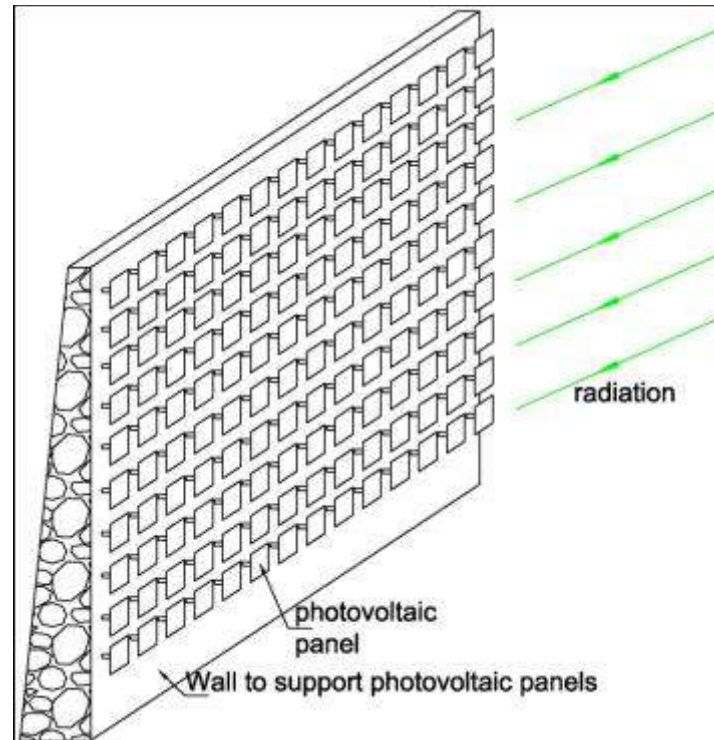


Fig. 23: vertical photovoltaic farm.

9.3 Is the hybridization between PV plant, Solar Chimney, CSP Tower possible?

The hybridization in this term is to use the same surface of land to generate two different energies from two different plants. In this case the hybridization is not possible for many reasons as following:

9.3.1 Hybridization between PV plant and Solar Chimney

PV panels placed under the collector of the solar chimney imply a loss in the heating of a great surface of the soil under the collector, therefore, the output power and efficiency of the solar chimney are reduced, and the efficiency and output power of the PV panels are also reduced due to the elevation of the temperature and due to the reflection of the collector of the solar chimney. So it is not possible to install photovoltaics under the collector of the solar chimney.

9.3.2 Hybridization between PV plant and CSP Tower

Some people may ask if it is possible to install photovoltaic panels instead of the heliostats, because a part of the solar energy will be absorbed by the photovoltaic panel and other part is reflected to the receiver of the CSP Tower. In fact, this proposition works only for PV panels and doesn't work for the CSP tower because the photovoltaic panels will absorb a part of the solar energy and generate electricity but the other part is diffused. So it has no sense to put a CSP tower to generate electricity from diffused radiations, such project will never return the invested money.

9.3.3 Hybridization between Solar Chimney and CSP Tower

The hybridization between CSP tower and Solar Chimney by installing heliostat inside the collector of the solar chimney and by installing the receiver on the tower will not work for both plants for many reasons as following:

- The Solar Chimney needs solar energy to heat the soil which increases the temperature inside the collector and creates a wind with high speed, and if heliostats are placed in the collector, the absorbed energy inside the collector will be reduced because the energy will be reflected by the heliostats and diffused by the collector, so both plants will not work correctly.
- The heliostats are very high compared to the collector, thus it is not possible to install a heliostat inside the collector.
- If the receiver of the CSP tower is installed on the solar chimney, then a large part of the heated air will not pass through the chimney which will reduce the extracted energy from the collector etc.

10 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 over pass 50% in the next decades, the price of photovoltaic system is decreasing which will give it an 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, hybridization between PV system and hydroelectric power station is proposed, and it is clear that this hybridization is powerful because it is able to produce between 25.6% and 53% of the total installed power in Lebanon which will resolve big problems.

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