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Titled
Improvement and protection of solar panels. Theoretical and experimental study

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Dedication

I dedicate this modest work to:

To my very dear parents who have always been there for me, who have given me a wonderful model of hard work and perseverance and who have sacrificed too much for me. I hope they find in this work all my gratitude and all my love.

To my husband 'Noureddine' and my daughter 'Amaris'

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To all who love Hana and those whom Hana loves.

We can meet next week to make a preparatory presentation with you

IMPROVEMENT AND PROTECTION OF SOLAR PANELS.
THEORETICAL AND EXPERMENTAL STUDY

ABSTRACT

In Algeria, solar panels are usually placed in desert and arid regions, where dust is deposited gradually on the surface of solar panels. Desert sand storms in southern Algeria can affect the performance of the solar panel. Sometimes they can also reduce the life of the solar panel, energy and solar cells, and periodic maintenance is often expensive. The purpose of this thesis is to study the effect of dust accumulation and the search for solutions to protect solar panels.

The first part of this thesis is devoted to the definition of solar panels, their different types and stages of manufacture. In the second part, we talk about the steps and tools needed to install and maintain a solar field. And then study the effects of climate factors on the performance of solar panels. In the final part: To study the impact of sand storm and dust on solar panels, we have innovated an artificial system to simulate the sand storms. So we can study the effect of this last on a solar panel with different intensity in the laboratory. The second step of our research is to protect the solar panels we offer a simple and inexpensive way of plastic cover. So this protective layer keeps the panel from getting scratches, we can also change this protective layer from time to time.

Key words: Solar panels, sand storms, dust accumulation, artificial system, protective layer.

RÉSUMÉ

En Algérie, les panneaux solaires sont généralement placés dans des régions désertiques et arides, les conditions climatiques de leur fonctionnement entrainent souvent le dépôt de la poussière à la surface de ces panneaux solaires. Les tempêtes de sable du désert sud Algérien peuvent affecter les performances du panneau solaire. Parfois, la durée de vie du panneau solaire et l'énergie peuvent être diminuée ainsi que la performance des cellules solaires, alors que leur maintenance et entretien périodique sont souvent coûteux. Le but de cette thèse est d'étudier l'effet de l'accumulation de la poussière et la recherche de solutions pour protéger les panneaux solaires.

La première partie de cette thèse est consacrée à la définition des panneaux solaires, leurs différents types et étapes de fabrication. Dans la deuxième partie, nous avons présenté les étapes et les outils nécessaires pour installer et entretenir un champ solaire. D'où l’étude des effets de plusieurs facteurs climatiques sur la performance des panneaux solaires qui vient compléter cette partie. Dans la dernière partie : Pour étudier l'impact des tempêtes de sable et de poussières sur les panneaux solaires, nous avons innové un système artificiel pour simuler les tempêtes de sable. On peut donc étudier l'influence de la tempête de sable pour différentes doses sur un panneau solaire en laboratoire. La deuxième étape de notre recherche est de protéger les panneaux solaires par la proposition d'une manière simple et peu onéreuse de couverture plastique. Donc, cette couche protectrice empêche le panneau de se rayer, on peut aussi changer cette couche de temps en temps. L'efficacité diminue d’une petite valeur (1%).

Mots clés : Panneaux solaires, tempêtes de sable, accumulation de poussière, système artificiel, couche protectrice.

ملخص

في الجزائر ، توضع الألواح الشمسية عادة في المناطق الصحراوية والقاحلة ، حيث يتم ترسب الغبار تدريجيًا على سطح الألواح الشمسية. يمكن أن تؤثر العواصف الرملية الصحراوية في جنوب الجزائر على أداء اللوحة الشمسية. في بعض الأحيان يمكنها أيضا تقليل عمر اللوحة الشمسية، الطاقة وكذا أداء الخلايا الشمسية، بالإضافة إلى أن الصيانة الدورية عادة ما تكون مكلفة. الغرض من هذه الرسالة هو دراسة تأثير تراكم الغبار والبحث عن حلول لحماية الألواح الشمسية.

الجزء الأول من هذه الأطروحة مخصص لتعريف بالألواح الشمسية، أنواعها المختلفة وكذا مراحل تصنيعها. في الجزء الثاني ، نتحدث عن الخطوات والأدوات اللازمة لتركيب و صيانة حقل شمسي. ومن ثم دراسة تأثيرات العوامل المناخية على أداء الألواح الشمسية. في الجزء الأخير: لدراسة تأثير العاصفة الرملية والغبار على الألواح الشمسية، ابتكرنا نظامًا اصطناعيًا لمحاكاة الزوابع الرملية. حتى نتمكن من دراسة تأثير هذه الاخيرة على لوحة شمسية بكثافة مختلفة في المختبر. الخطوة الثانية من بحثنا هي حماية الألواح الشمسية نقدم طريقة بسيطة وغير مكلفة من غطاء بلاستيكي(الطبقة الواقية).إذ تمنع هذه الطبقة الواقية من خدش اللوحة ، يمكننا أيضًا تغيير هذه الطبقة من وقت لآخر .

حيث وجدنا ان الكفاءة تنخفض بمقدار صغير(1 %).

الكلمات المفتاحية: الألواح الشمسية ، العواصف الرملية ، تراكم الغبار ، النظام الاصطناعي ، الطبقة الواقية.

Shapes Table

Tables table

Abreviations list

PV : photovoltaic

CPV : Concentrated Photovoltaics

ARL : Anti-reflection layer

SCZ : Space charge zone

MJ : Multi-junction

SJ : single-junction

I_{ph} ***: Photocurrent***

I_0***: Saturation current.***

Voc: Open circuit voltage

I_{SC} ***: Short circuit current***

FF : Fill Factor

QE: Quantum yield

EQE : External quantum efficiency

IQE : Internal Quantum Efficiency

Vm: Maximum Voltage

Im : Maximum current

Pm : Maximum Power

ITO : Indum Tin oxide

TCO : Transparent Conductive oxides

ZnO : Zinc Oxide

Abreviations list

TiO_2 ***: Titanium dioxide***

LSC : luminescent solar concentrator

PMMA : polymethyl methacrylate

DSSC : Dye Sensitized solar cells

CI (G) S : Copper-Indium-Gallium-Selenide

CIS : copper indium selenide ($CuInSe_2$***).***

CdTe : Cadmium Telluride

TFSC : Thin Film Solar Cell

PSC : Perovskite Solar Cells

MG-Si: Metallurgical silicon

SG-Si : Solar Grade Silicon

EVA: Ethylene Vinyl Acetate

FLA : Flooded Lead Acid Batteries

VRLA : Valve Regulated Lead Acid

NiCd : Nickel Cadmium

NiMH : Nickel metal Hydride

Li-ion : Lithium Ion

BoS : Balance of Systems

SOC : State of Charge

PET : Polyethylene terephthalate

PVC : Polyvinyl chloride

PS : polystyrene

Table of contents

Chapter I Bibliographic studies

Chapter II: Influence of the environment

Chapter III : Results and discussion

GENERAL INTRODUCTION

GENERAL INTRODUCTION

Due to the development of industry, transport and means of communication, a growth in global electricity consumption has been observed during the last decades [1].

The current global energy context is marked by a co-ordinated demand for energy needs in the context of the anticipation of a significant or even long-term decline in the equation of conventional fossil energy, especially oil. In the face of this difficult conjecture and the global problems of global warming, an energy transition through the use of renewable energies has become unavoidable. [2]. So Solar energy is one of the main promising clean energy sources in future of the world. The technology of Photovoltaic PV is always on continuous developing in many applications, so it is generate electricity without dangerous effect on environment [3].

Solar photovoltaic (PV) system uses solar cells to convert energy from sun radiation into electricity. The system is made up by one or more panels, a battery, a charge control and the load. Solar PV panels are normally mounted on roofs and wired into a building by an inverter, which converts the direct current energy received from solar panels into alternating current. There are many types of solar PV cells available [4]. Appropriate installation design (orientation, exposure, sun-tracers) to maximize solar radiation can potentially ensure sustained yield (electricity). However, these are vulnerable to, often overlooked, on-site omnipresent practicalities such as deposition of dust, bird droppings and water-stains (salts) can
significantly degrade the efficiency of solar thermal installations. For PV installations, module efficiency is further reduced by 10–25% due to losses in the inverter, wiring, and module soiling
(dust and debris) [5].

Algeria is the largest country in Africa, the Arab world, and the Mediterranean Basin. Its southern part includes a significant portion of desert environment (Sahara). The World Energy Council and the Algerian Ministry of Energy and Mining affirm that Algeria receives an

average insolation of 2000 hours per year [4, 6], moreover the high plateau and Sahara are receiving
3900 hours per year [5, 7]. The average solar energy received is 2400 kWh/m2/year, ranging from 1700 kWh/m2/year for the coastal region, 1900 kWh/m2/year for the high plateau, and 2650 kWh/m2/year for the south Algeria [8].This important solar energy in North Africa regions is negatively affected by the influence of sandstorms on the performances of the protective glass sheets of solar panels [9]. The sandstorm and dust in desert regions influence on the solar modules performance. In Sahara region, most dusts can be non-organic particles suspended in the dry wind (particles of dust and other impurities) that hang by electrostatic attraction on the glass surface of solar panels [10].

Possibilities to increase conversion efficiency and for long-term (life of solar panels) and reduce the cost of maintenance and protect solar panels against sandstorms. It is in this theme that comes this work of memory. This manuscript is presented as follows:

Chapter I, we present state of the art solar panels. Firstly: a definition of solar cells and their structure and the principle of operation of the latter, an overview of types of solar panels. Then in a second time we mention some uses of the solar panels. At the end of the chapter is a detailed explanation of the manufacturing steps of the solar panels.

Chapter II, second chapter is divided into two parts. The first part is devoted to the explanation of the different steps and tools for the installation of a solar field. After that, we present various methods of maintenance of solar panels. Part II We talk about the effect of climate on the performance and efficiency of solar panels.

Chapter III, in this chapter we will talk about the negative impact of dust accumulation on photovoltaic panels. The drop of efficiency of photovoltaic modules and the decrease coused by sandstorms. Firstly, we present our artificial system to study the effect of sandstorm on the performances of photovoltaic panels in the laboratory without displacement to desert regions (Sahara).Secondly we suggest a way to protect solar panels wichis very simple ‘plastis convering’ against the dust and the sandstorms.

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Chapter I :

Bibliographic studies

I-1- Introduction

Solar energy is becoming one of the main sources of energy in replacing fossil fuels because of its abundance. Solar cells convert this solar energy into electrical energy by absorbing photons by semiconductor materials. The semiconductors used in the manufacture of these solar cells are the subject of many researches, in order to improve the conversion efficiency of these devices which is the subject of our study. In this chapter we will describe in detail the structure and operating principle of solar cells, the different types of cells, and the manufacturing steps**.**

❖ Motivation

Renewable energy can be used when an energy resource regenerates naturally at a rate comparable to that of its use. The sun, the wind, the heat of the earth, waterfalls, tides or the growth of plants are thus renewable sources of energy. The oil and nuclear energies do not belong to this class since the world reserve of oil and uranium is limited. K.W. Ford reported that solar radiation energy at the earth's surface was 10^4 times greater than global energy demand [1]. The conversion of this energy into electricity can be done directly or indirectly. The use of photovoltaic cells to achieve this conversion is a promising way to exploit this sustainable energy source [2].

I-2- Solar Cell

I-2-1- Solar Cell Difinition

A photovoltaic cell is a device that transforms solar energy into electrical energy. This transformation is based on the following three mechanisms:

- Absorption of photons (whose energy is greater than the gap) by the material constituting the device.
- Conversion of the energy of the photon into electrical energy, which corresponds to the creating electron / holes pairs in the semiconductor material.
- Collection of particles generated in the device. [3,4]

I-2-2- Structure of a solar cell

The simplest structure of a solar cell, represented in Fig (I-1), comprises a junction between two differently doped zones (p-n) of the same material (homo-junction) or between two different materials (heterojunction).The least thick being subjected to the luminous flux. Each of the regions is connected to a metal electrode by means of an ohmic contact of low resistance [5].

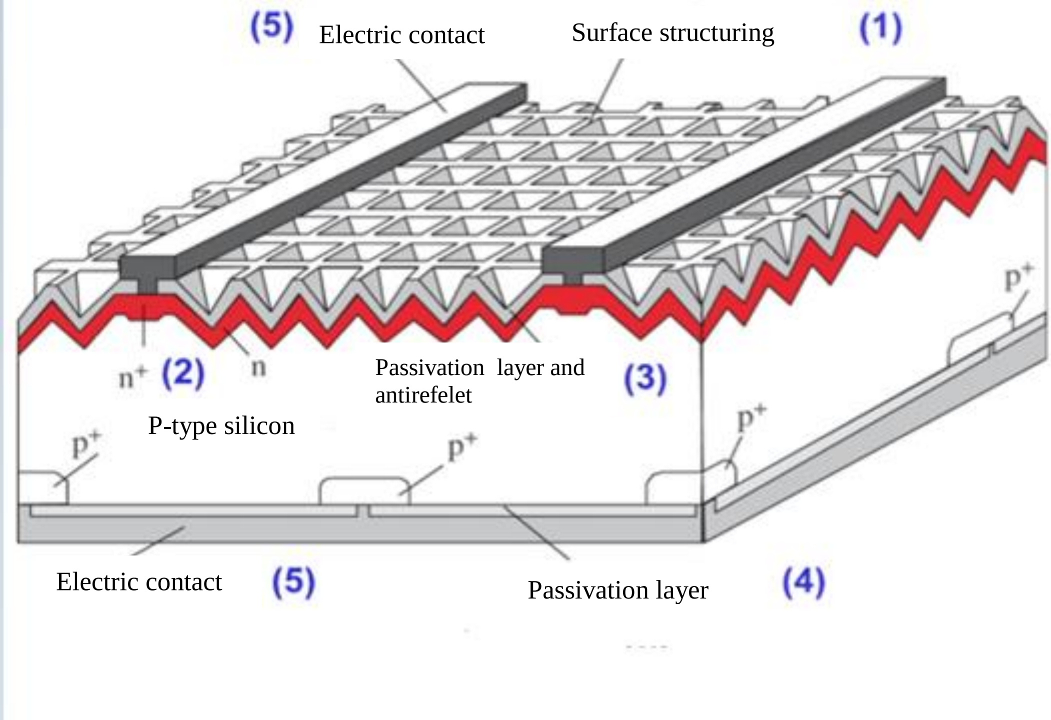


Fig.I.1. Structure of a solar cell [6]

A) P-type semiconductor layer (collector)

The semiconductor material contains external atoms that have a lower amount of free electrons. This results in a positive excess of charge carriers (electron holes) in the semiconductor material. These layers are called conductive semiconductor layers of the p-type (base), their role is to motivate the trapping of minority carriers.

B) N-type semiconductor layer (emitter)

The semiconductor material contains external atoms that have a greater amount of free electrons. This results in a negative excess of charge carriers (electrons) in the semiconductor material. These layers are called n-type conduction semiconductor layers (emitter) that are thinner than the base and highly doped.

C) Contact fingers and metal contact on the rear side

With the rear metal contact the contact fingers are the connections for connecting a consumer for example.

D) Anti-reflection layer

The purpose of the antireflection layer is to protect the PV cell and reduce reflection losses on the cell surface. Different ARLs are used in photovoltaics: TiO_2, SiO_2, ZnS, MgF_2, SiNx, etc. [7, 8].

I-2-3- Working Principle

The PV cell, also known as the solar cell, is the basic element of photovoltaic conversion. It is a semiconductor device that transforms into electric energy the light energy provided by an inexhaustible source of energy, the sun. It exploits the properties of semiconductor materials used in the electronics industry: diodes, transistors and integrated circuits [9].

In this section we briefly recall the principle of photovoltaic conversion without going into details, since the material part is not of capital importance in the context of this thesis.

The photovoltaic effect used in solar cells makes it possible to directly convert the light energy of the solar rays into electricity through the production and transport in a semiconductor material of positive and negative electrical charges under the effect of light [5]

The creation of electron-hole pairs is not enough because they can recombine naturally causing only thermal energy. The charges must be separated so that they can circulate without recombining.

There is one solution is to create an electric field in the material [10]. To create an electric current, it is necessary to dissociate the photogenerated electrons-hole peers and to collect them in an external electrical circuit before they recombine freely within the material. The electron-hole peel separation is in general realization in photovoltaic cells by creating a potential barrier in the semiconductor. The most common types of barriers are homojunction (junction p / n in the same semiconductor), heterojunction (junction p / n between two different materials) and Schottky barriers (metal / semiconductor). In the case of photovoltaic cells, the over-doping homojunction of silicon is the most used solution [11].

For this purpose, a portion of a semiconductor is doped into atoms having an additional valence electron with respect to the semiconductor atom. There will be, in this semiconductor part, an excess of negative charges. This part will therefore be an electron donor. It is said that it is n-type doped.

Another semiconductor portion will be doped into atoms having an electron valence of less than the atom of the semiconductor material. This time there will be an excess of positive charges. The material will then become an electron acceptor. It is said that it is p-type doped [10].

The basic component of a solar cell is the generally p-type absorber layer, where the conversion of photons, having an energy greater than the energy of the forbidden band (gap) of the semiconductor used, into electron-hole pairs occurs. This layer must be able to absorb a large part of the solar spectrum. To form a p-n diode, an n-type semiconductor layer is required to establish an electric field that repels electrons toward the n-zone and the holes toward the p-zone. This layer must be thin and strongly doped in order to obtain a sufficient electric field in the space charge zone (SCZ). When the absorption of photons takes place in the SCZ, the photo generated electron-hole pairs will be immediately dissociated by the electric field and they thus generate a generation photocurrent [12]. At the same time, the minority carriers, holes generated in the n region and electrons in the p region, create a concentration gradient and diffuse into the material. These carriers reach the SCZ, where the electric field makes them cross the zone of depletion, in order to reach the region where they become majority: it is the photocurrent of diffusion. These two contributions are added to create a resulting photocurrent I_{ph} [13]. Of course, some of the photo-excited electrons will be lost due to generation-recombination in the SCZ or in the quasi-neutral region, especially if the photo-excitation takes place far from the junction. Ideally, the n layer (buffer layer or emitter layer) has a much higher doping than the absorber (p-type), so that most of the space charge region extends into the absorber to have a high probability of collecting free carriers. In addition, the width of the forbidden band of the buffer layer must be wide, so that most of the incident radiation can be transmitted to the absorber. Due to the exponential decay of the light intensity caused by the absorption, the incident photons are then absorbed mainly in the front part of the absorber where most transporters are generated.

For the efficient transport of the photo-generated carriers, the front and rear ohmic contacts with high conductivities are necessary. The front contact (above the buffer layer, also called the "window" layer) must be transparent to the incident radiation as much as possible. The rear contact is usually made of an opaque metal film to ensure maximum reflection.

Specifying that the photocurrent is a current of minority carriers proportional to the luminous intensity. This current is opposed to the diode current, called I_{obs} dark current, which results from the polarization of the component [5]. The resulting current, I, is obtained by the following equation:

$$\boldsymbol{I = I_{ph} - I_{obs}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. \quad (\boldsymbol{I-1}) \qquad [14]$$

With

$$I_{obs} = I_0 \left(\exp\left(\frac{qV}{nKT}\right) - 1 \right) \dots\dots\dots\dots\dots\dots\dots\dots\dots. (I-2)$$ [14, 15, 16]

*q: charge of the electron (1.9 * 10^{-19} C).*

*k: the Boltzmann constant (k = 1.38 * 10^{-23} J.k^{-1})*

I_0: saturation current.

I_{ph}: Current Photo

V: voltage at the terminal of the diode.

T: absolute temperature (in kelvin).

n: the ideality factor of the diode, a function of the quality of the junction

(equal to 1 if the diode is ideal and equal to 2 if the diode is entirely governed by the generation / recombination)

The n-type region is now negatively charged while the p-type region is positively charged, this generates a photovoltaic voltage across the device, plus a photo-current resulting from the process already explained, so we have a photovoltaic power available for the consumer [13].

The following figure gives the schematic representation of a photovoltaic cell under illumination and the corresponding band diagram

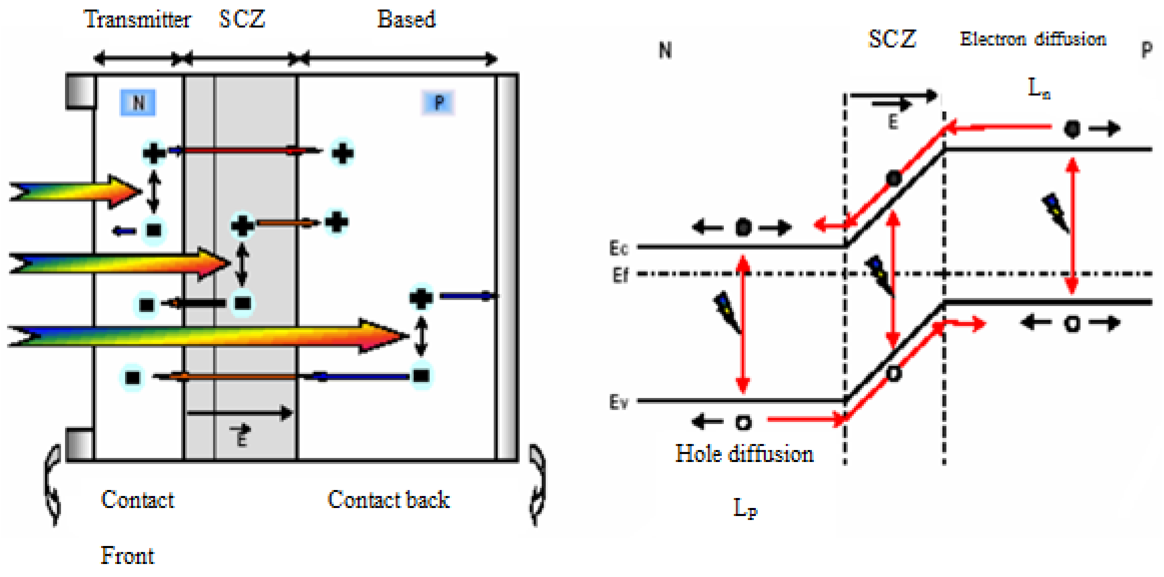


Fig.I.2. Structure and band diagram of a photovoltaic cell under illumination [17].

I-2-4- The electrical characteristics of a photovoltaic cell

After a reminder of the physics of the PV cell, this part deals with its main electrical characteristics.

The two main characteristics of a solar cell are:

I-2-4-1- Current-voltage curve

The plot of the I (V) characteristic of the solar cell is derived from equation (I.2) shown in Fig (I.3) which shows the variation of the current as a function of the voltage (I-V) for a typical solar cell. Under darkness, the characteristic curve is the same as that of a single diode, and under illumination, the curve is shifted down by a value equal to the photo-current *Iph*. The *Isc* and *Voc* are, respectively, the short circuit current and the open circuit voltage.

- *Short circuit current :*

  I_{SC} It is obtained by short-circuiting the terminals of the cell (V = 0). It corresponds to the photo-current *Iph* generated by the radiation. For a given spectral distribution, this photocurrent linearly increases with the illumination intensity of the cell, illuminated surface, radiation wavelength, carrier mobility and temperature [5].

- *Open circuit voltage* :

  If the cell is left in open circuit (zero current), the voltage measured across the electrodes is called open circuit voltage *Voc*. This is the voltage that should be applied to the diode in the forward direction to generate a current equal to the photocurrent [5]. It is given by the relation: [16]

$$V_{oc} = \left(\frac{kT}{q} \right) ln \left[\left(\frac{Isc}{I_0} \right) + 1 \right] \qquad \ldots\ldots \quad (I\text{-}3)$$

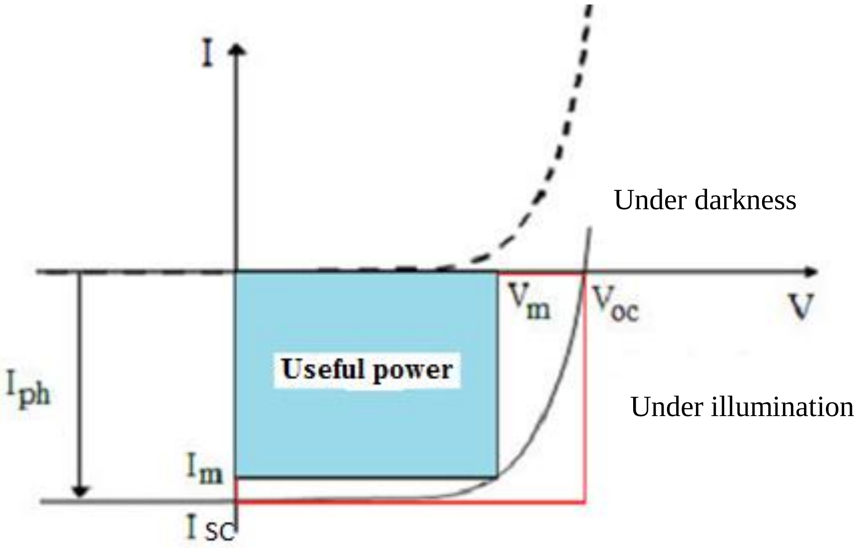


Fig.I.3. Characteristic of a photovoltaic cell

- *Form Factor*:

  The form factor or FF (Fill Factor) represents the efficiency of the solar cell. This is the ratio of the maximum power output *Vm. Im* (the surface of the smaller rectangle) and the ideal power *Voc. Isc* (the surface of the largest rectangle) [18]. Where *Vm* and *Im* are the voltage and current values corresponding to the operating point for which the power, which is equal to U.I, is maximum. The FF is given by the following relation: [11]

$$FF = \frac{Pmax}{Voc\ Isc} = \frac{Vm\ Im}{Voc\ Isc} \text{……………………… ……………}(I - 4)$$

- *Energy conversion efficiency*:

  The energy conversion efficiency is the ratio of the generated power and the power of the incident solar radiation P_0. The maximum yield is the ratio between the maximum power and the incident power P_0 [11, 19, 20, 21].

$$\eta_m = \frac{Vm\ Im}{P_0} = FF\frac{Voc\ Isc}{P_0} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots\dots\dots\dots.(I - 5)$$

I-2-4-2- Quantum yield

Quantum efficiency describes the probability, for an incident photon of a length given wave, to create an electron-hole pair actually collected by the cell. They'express according to the following equation: [5]

$$QE(\lambda) = \frac{Jph}{q\Phi_0(\lambda)} \text{………..…………………………… } (I – 6\ )$$

Where *Jph* (λ) is the photocurrent at the wavelength λ, q is the charge of an electron, Φ_0 (λ) is the flux of photons incident at the wavelength λ.

Two types of quantum efficiency are often considered in the case of solar cells:

- The external quantum efficiency (EQE), which takes into account the effects of optical losses, such as unabsorbed light or reflected light. It is the ratio of the number of carriers generated on the number of incident photons. For a given wavelength, the external quantum efficiency is equal to 1 if each photon generates an electron. If we consider the reflectivity of the surface of the photovoltaic cell, we determine its internal quantum efficiency IQE [22].
- The internal quantum efficiency or IQE (Internal Quantum Efficiency), it does not take into account the transmitted photons (incomplete absorption) and reflected.

The internal quantum efficiency and the external quantum efficiency are related by the following relation:

$$\boldsymbol{IQE}(\boldsymbol{\lambda}) = \frac{\boldsymbol{EQE}(\boldsymbol{\lambda})}{\mathbf{1}-\boldsymbol{R}(\boldsymbol{\lambda})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (I - 7)$$

R (λ): reflection coefficient

The quantum yield, obtained as a function of the wavelength of the photons (λ), corresponds to the number of electrons collected relative to the number of incident photons having a given wavelength. By summoning this curve with the illumination spectrum, the current generated in the cell can be determined. In addition, this curve is a good tool to try to identify the layers or interfaces of the solar cell that cause absorption losses. The quantum yield depends essentially on the absorption coefficient of the materials used, the ionization potential, and the efficiency of the collection [5].

I-2-5- Electrical modeling of a PV cell

The electrical modeling of a photovoltaic cell offers three important advantages: an ease of use thanks to the equivalent electric circuit, an extension of the properties of the system and thus the understanding of complex phenomena is facilitated.
In the case where the cell behaves as a power generator, there are several electrical models, also called equivalent circuits, to reproduce the behavior of the cell using electronic components [23]. The circuits used most frequently in the for modeling crystalline cells consisting of a p-n junction are the circuits with one and two diodes (Fig. I.4).

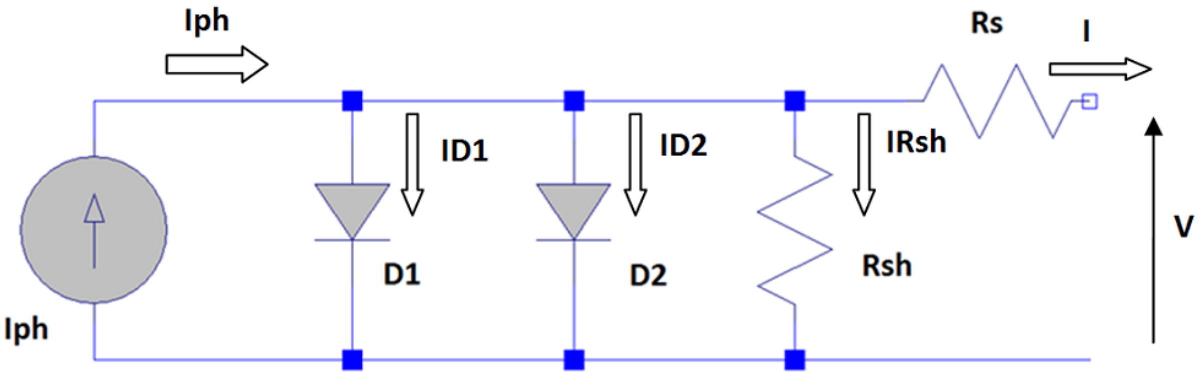


Fig .I.4. Equivalent diagram of a PV cell: two-diode model [23]

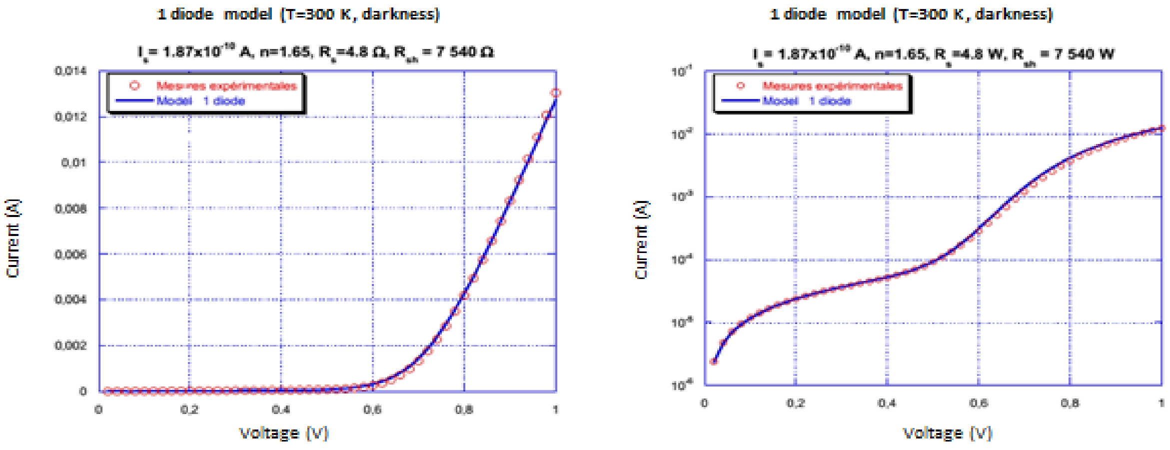
From the diagram of Fig.I.4, we deduce the equation characterizing the variation of the current as a function of the voltage using the laws of Kirchhoff: [23]

$$I = I_{ph} - I_{D1} - I_{D2} - I_{Rsh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (I - 8)$$

$$I = Iph - I01\left[exp\left(\frac{q(V+IRs)}{n_1\,kT}\right) - 1\right] - I0_2\ \left[exp\left(\frac{q(V+IRs)}{n_2\,kT}\right) - 1\right] - \frac{(V+IRs)}{Rsh} \ldots\ldots.(I-9)$$

I_{01} is the saturation current of the first diode due to scattering and I_{02} that of the second diode due to recombination, n_1 and n_2 are respectively the ideality factors of these two diodes. The ideality factor of the recombination diode varies greatly from one cell to another, which indicates a greater or lesser frequency of recombination depending on the material and its quality. The one-diode model does not distinguish between diffusion and recombination and includes both in the same diode. Resistances Rs and Rsh take into account dissipative phenomena at the cell level. Rs is due to the contribution of the base resistors, the front of the junction and the front and rear contacts. Rsh reports the leakage currents caused by metal impurities in the junction or imperfections of the crystal lattice. Knowledge of the values of these parasitic resistances is important in the study of the quality of the material and the search for the improvement of the efficiency of a cell. Indeed, the form factor is directly related to these two resistances. Whenever the Rsh is greater, the less leakage current and the better the form factor. Over Rs, the less there is of resistive losses at the interface between the metal and the semiconductor or on the surface of the semiconductor and the better form factor.

To calculate experimentally the parameters of these equivalent circuits we can use the current-voltage characteristic of the cell in the dark (see Fig-I-5). Since equation (I- 9) is non-linear, programs are used to adjust the parameters as much as possible so that the modeled curves correspond to the experimental values. Once we know these parameters, it is possible to reproduce, using the equivalent circuit, the behavior of a crystalline cell under any illumination. Then simply superimpose the light source (I_{ph} in the model) to the characteristics of diodes in the dark. In other words, we just vary I_{ph}. We will see a little further that this is not the case for amorphous silicon cells for which we must add a term if we wish to model their behavior correctly.



(a) (b)

Fig.I.5. I-V characteristics of an amorphous silicon cell and a 1-diode model implemented under Matlab darkness in linear scales *(a) and logarithmic (b). [24]*

Contrary to crystalline cells, it is not enough to vary the illumination through equation (I-1) to reproduce the behavior of an amorphous silicon cell. It is necessary for the latter to take into account the fact that the minority carriers do not diffuse linearly in the p-i-n junction. Amorphous silicon has pendant bonds that act as recombination centers. The recombination losses are proportional to the carrier concentration and therefore to the photocurrent [25]. It is therefore necessary to add to the "classical" model with 1 or 2 diodes, a term (I_{rec}) which takes into account these losses in the layer i, it is proportional to the luminous intensity [24].

I-3- Types of Solar Cells and Application

I-3-1- type of Solar Cells

Solar cells are usually named after the semiconducting material they are made of. These materials must have certain characteristics in order to absorb sunlight. Some cells are designed to handle sunlight that reaches the Earth's surface, while others are optimized for use in space. Solar cells can be made of only one single layer of light-absorbing material (single-junction) or use multiple physical configurations (multi-junctions) to take advantage of various absorption and charge separation mechanisms. Solar cells can be classified into first, second and third generation cells. The first generation cells—also called conventional, traditional [26], Generally 1 st generation's solar cells include a. Single Crystal Solar Cells b. Multi Crystal Solar Cells. This are the oldest and the mostly common used technology type due to high efficiencies. 1 st generation solar cells are produced on wafers [27]. Or wafer-based cells—are made of crystalline silicon, the commercially predominant PV technology, that includes materials such as polysilicon and monocrystalline silicon. Second generation cells are thin film solar cells, that include amorphous silicon, CdTe and CIGS cells and are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaics or in small standalone power system. The third generation of solar cells includes a number of thin-film technologies often described as emerging photovoltaics—most of them have not yet been commercially applied and are still in the research or development phase. Many use organic materials, often organometallic compounds as well as inorganic substances. Despite the fact that their efficiencies had been low and the stability of the absorber material was often too short for commercial applications, there is a lot of research invested into these technologies as they promise to achieve the goal of producing low-cost, high-efficient solar cells. “First generation” panels include silicon solar cells. They are made from a single silicon crystal (mono-crystalline), or cut from a block of silicon that is made up of many crystals (multi-crystalline - shown at right). “Second generation” thin-film solar cells are less expensive to produce than traditional silicon solar cells as they require a decreased amount of materials for construction. The thin-film PV cells are, just as the name implies, a physically thin technology that has been applied to photovoltaics. They are only slightly less efficient than other types but do require more surface area to generate the same amount of power [26,28]. Below we enumerate some of the different species of the most famous solar cells.

I-3-1-1- Solar cells of monocrystalline silicon

Silicon, which, next to oxygen, is the most represented element in the earth’s crust (27.6%) is used for the production of monocrystalline silicon solar cells. Silicon belongs to the group IV of the periodic system of elements, it is easily obtained and processed, it is not toxic and does not form compound that would be environmentally harmful. In contemporary electronic industry silicon is the main semiconducting element. Electronic components made of silicon are stabile at temperatures up to 200 ^{0}C.

Semiconducting silicon is polycristalline. For it to be converted into monocristalline it has to be melted at 1400^{0}C and by means of Czochralski process, or by method of float zone, converted into monocrystalline. Atoms of monocrystalline silicon are connected mutually by covalent bonds into surface centered crucible. Monocrystalline silicon is black, non-transparent, very shiny, hard and a weak conductor of electricity. With some additional substances monocrystalline silicon becomes a good conductor of electric current.

A solar cell composed of monocrystalline silicon has a front electrode, an antireflection layer, an n-layer, p-n bond, p-layer and back electrode (Fig.I.6). In order to obtain semiconductor of n-type, silicon is doped with phosphorous, and to obtain semiconductor of p-type, silicon is doped with boron. P-layer is 300 μm thick, while n-layer is 0,2 μm thick. For antireflection layer, materials with refraction index of 1,5-2 are used. These materials comprise SiO, SiO_2, TiO, TiO_2 Ta_2O_3, etc. Depending on the antireflection layer material, monocrystalline solar cells of different colours can be produced. Metal contacts are formed by vacuum vaporing of the corresponding materials on Splate. For this purpose, Ti/Pd/Ag coating is usually used.

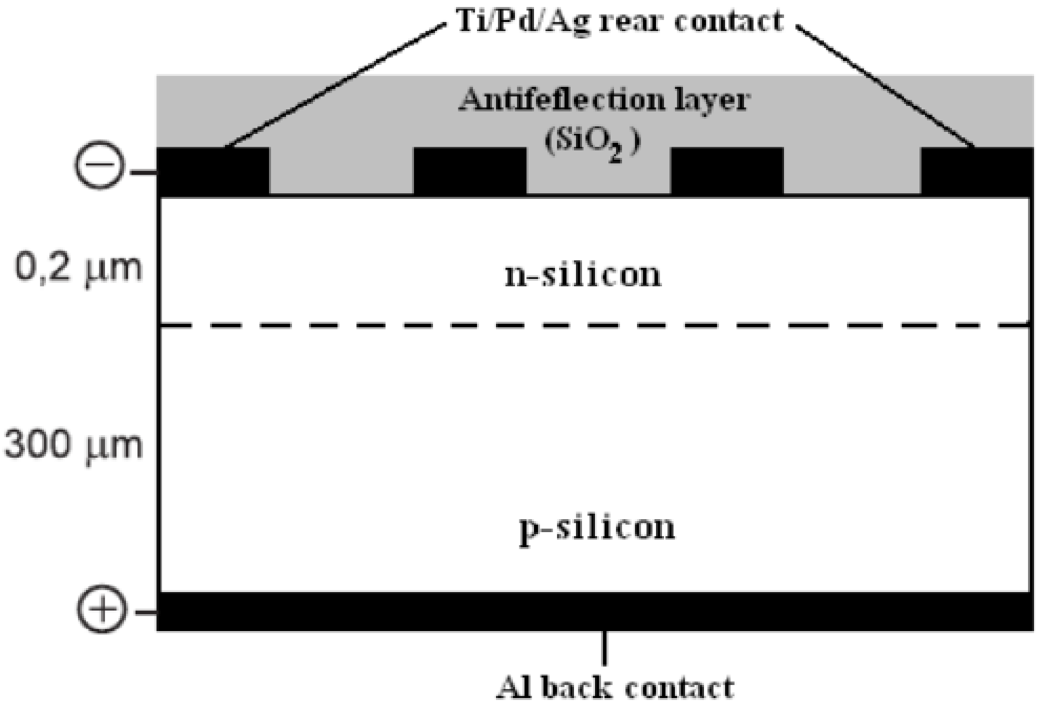


Fig. I.6. Schematic cross section of solar cell made of monocrystalline silicon

Monocrystalline silicon solar cell is sensitive to wavelengths of 0,4–1,1 μm, and its maximum sensitivity is within the range of 0,8–0,9 μm. Maximum of spectral sensitivity of the monocrystalline silicon solar cell does not coincide with the maximum of spectral distribution of sun irradiation [29, 30]. Monocrystalline solar cells show the hightest conversion efficiency of all silicon solar cells, but the production of monocrystalline silicon wafers requires the largest investment funds. In laboratory studies a single solar cell efficiency reaches the ordor of 24%. Solar cells produced on a mass scale have efficiency of around 17% [31].

I-3-1-2- Amorphous Silicon Solar Cell (A-Si)

Amorphous silicon (a-Si) is the non-crystalline form of silicon. It is the most well developed of the thin film technologies having been on the market for more than 15 years [26]. The perfectioning of the deposition techniques of amorphous silicon over large areas, in particular film homogeneity and the reproducibility of the electro-optical characteristics, has allowed a more accurate study of the most intriguing bane of this material: the degradation under sun-light illumination. Optical band-gap and film thickness engineering have enabled device efficiency to stabilize with only a 10–15% loss in the as-deposited device efficiency. [32]. It is widely used in pocket calculators, but it also powers some private homes, buildings, and remote facilities. United Solar Systems Corp. (UniSolar) pioneered amorphous-silicon solar cells and remains a major maker today, as does Sharp and Sanyo. Amorphous silicon panels are formed by vapor-depositing a thin layer of silicon material – about 1 micrometer thick – on a substrate material such as glass or metal. Amorphous silicon can also be deposited at very low temperatures, as low as 75 degrees Celsius, which allows for deposition on plastic as well.In its simplest form, the cell structure has a single sequence of p-in layers. However, single layer cells suffer from significant degradation in their power output (in the range 15-35%) when exposed to the sun. The mechanism of degradation is called the Staebler-Wronski Effect, after its discoverers. Better stability requires the use of a thinner layers in order to increase the electric field strength across the material. However, this reduces light absorption, hence cell efficiency.

This has led the industry to develop tandem and even triple layer devices that contain p-i-n cells stacked one on top of the other. One of the pioneers of developing solar cells using amorphous silicon is Uni-Solar. They use a triple layer system (see illustration below) that is optimized to capture light from the full solar spectrum)As you can see from the illustration, the thickness of the solar cell is just 1 micron, or about 1/300th the size of mono-crystalline silicon solar cell. While crystalline silicon achieves a yield of about 18 %, amorphous solar cells' yield remains at around 7 %. The low efficiency rate is partly due to the Staebler-Wronski effect, which manifests itself in the first hours when the panels are exposed to sunlight, and results in a decrease in the energy yield of an amorphous silicon panel from 10 percent to around 7 %. The principal advantage of amorphous silicon solar cells is their lower manufacturing costs, which makes these cells very cost competitive [26].

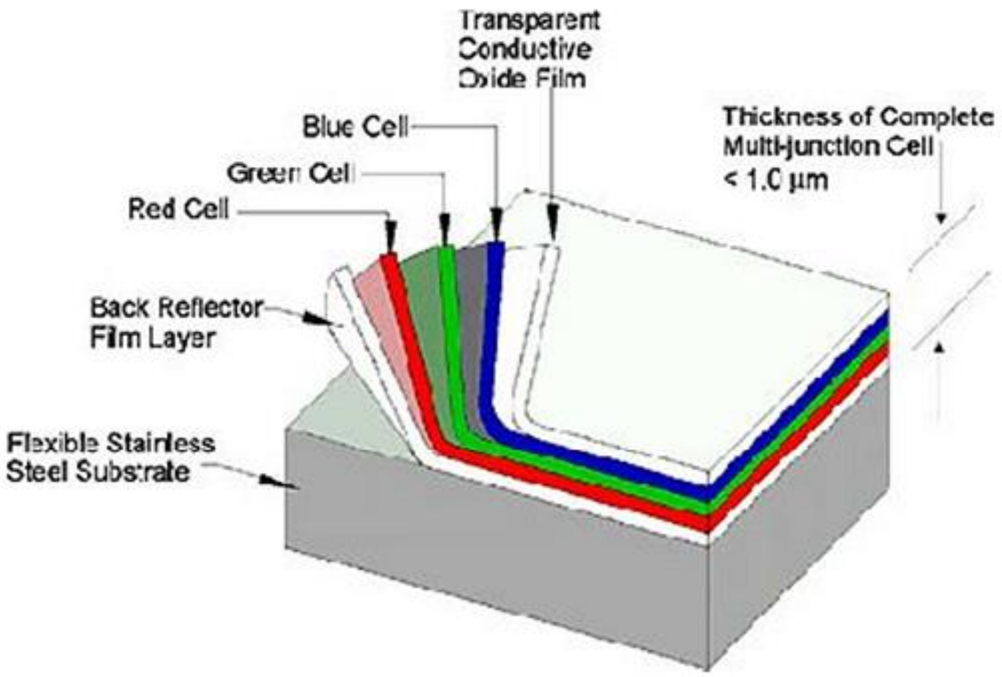


Fig.I.7. Amorphous silicon is Uni-Solar. They use a triple layer system.

I-3-1-3- CdTe solar cells

Cross section for a cadmium telluride solar cell is shown in Fig.I.8. A layer of cadmium sulphide is deposited from solution onto a glass sheet coated with a transparent conducting layer of thin oxide.

This is followed by the deposition of the main cadmium telluride cell by a variety of techniques including close-spaced sublimation, vapor transport, chemical spraying, or electroplating. CdTe solar cells have been used as low cost, high efficiency, thin-film photovoltaic applications since 1970. With the forbidden zone width of ~1,5 eV and the coefficient of absorption ~ 10^5 cm^{-1}, which means that a layer thickness of a few micrometers is sufficient to absorb ~ 90% of the incident photons, CdTe is almost an ideal material for manufacturing of solar cells. CdTe solar cells are sensitive in the wavelength of 0,3–0,95 µm with their maximum sensitivity within the wavelength range of 0,7–0,8 µm. Laboratory CdTe cells have the efficiency of 16%, and commercial ones around 8%. High toxicity of tellure (tellurium) and its limited natural reserves diminish the prospective development and application of these cells [33].

Accelerated long-term stability tests show that light soaking improves the efficiency of CdTe solar cells with ITO back contacts and performance does not degrade. Stability of CdTe solar cells has been measured after irradiation with high-energy protons and electrons of different fluences. These solar cells exhibit superior radiation tolerance compared to conventional Si and GaAs solar cells for space applications. Because of extreme stability, and high specific power (kW/kg) of flexible solar cells, CdTe has a promising potential for space applications [34].

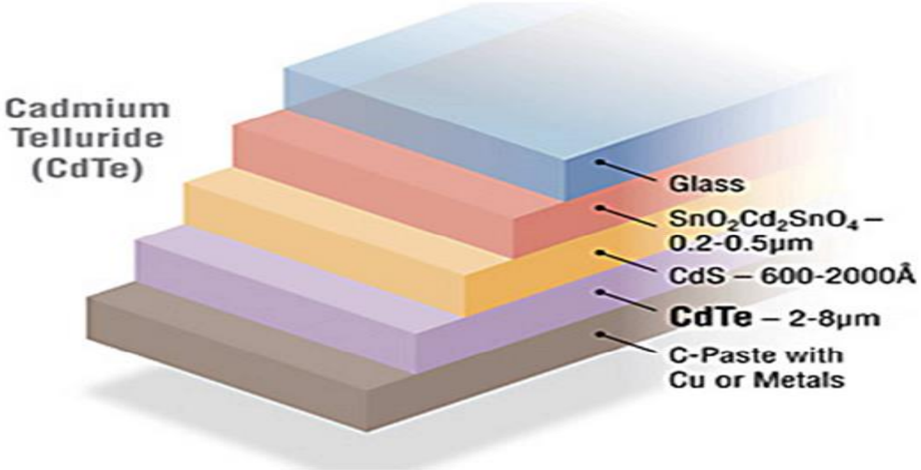


Fig.I.8. Graphic showing the five layers that comprise CdTe solar cells.

I-3-1-4- CIS solar cells

The materials based on $CuInSe_2$ that are of interest for photovoltaic applications include several elements from groups I, III and VI in the periodic table. CIS is an abbreviation for general chalcopyrite films of copper indium selenide ($CuInSe_2$).

CIS technology is a star performer in the laboratory with 19, 5% efficiency demonstrated for small cells, but has proved difficult to commercialize. Unlike the other thin-film technologies, which are deposited onto a glass substrate, CIS technology generally involves deposition onto a glass substrate as shown in Fig.I.9. An additional glass top-cover is then laminated to the cell/substrate combination. Present designs require a thin layer of CdS deposited from solution. Considerable effort is being directed to replacing this layer due to the issues associated with the use of cadmium [33].

The research progress of the copper-indium-selenium (CIS) base thin film solar cells is mainly introduced in the thin film cells. Since the key problems for restricting the solar cell development are the high manufacturing cost and low conversion efficiency, it is suggested to prepare the CIS-base thin film materials and their gradient band gap by chemical method. This method will open up the low cost novel way to prepare the CIS-base photoelectric thin film materials with high performance and their devices [35].

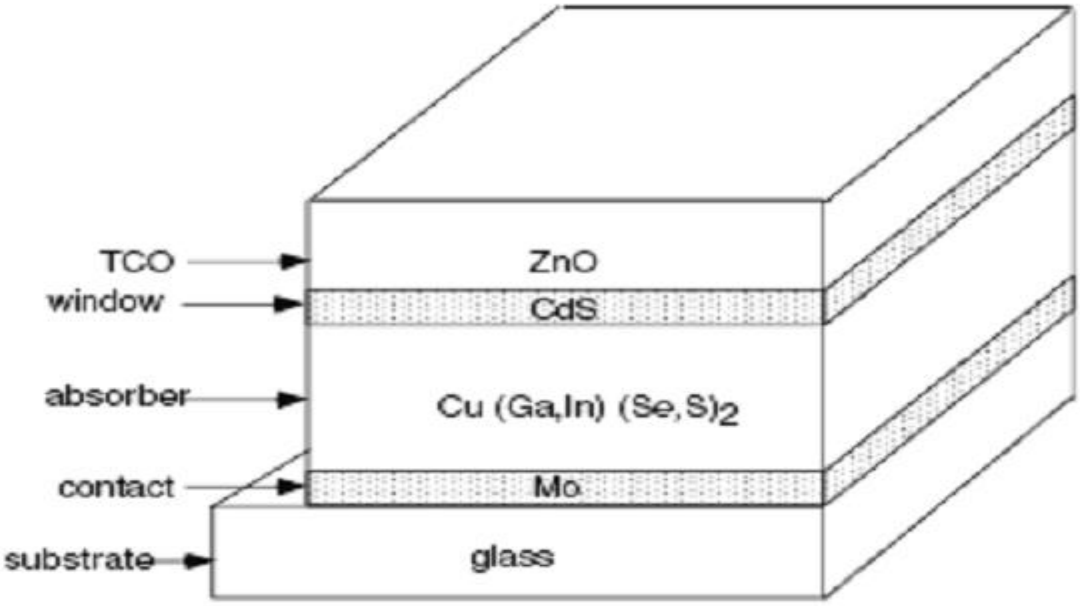


Fig I.9. Basic CIS (cupper indium diselenide) cell structure

CuInSe2 with its optical absorption coefficient exceeding $3 \cdot 10^4$ cm^{-1} at wavelengths below 1000 nm, and its direct band gap between 0,95 eV and 1,2 eV, is a good material for solar cells. A CIS solar cell is sensitive in the wavelength of 0,4–1,3 μm and maximum of its sensitivity is within the wavelength range of 0,7–0,8 μm [33]. Commercial CIS solar cells have the 8% efficiency. However, manufacturing costs of CIS solar cells at present are high when compared with silicon solar cells; however, continuing work is leading to more cost-effective production processes [30].

I-3-1-5- Copper Indium Gallium Selenide Solar Cells (CI (G) S)

One of the most interesting and controversial materials in solar is Copper-Indium-Gallium-Selenide, or CIGS for short. It was part of a solar thin-film-hype cycle where some CIGS companies such as Solyndra, NanoSolar and MiaSolé almost became household names. A copper indium gallium selenide solar cell (or CIGS cell, sometimes CI(G)S or CIS cell) is a thin film solar cell used to convert sunlight into electric power. They are manufactured by depositing a thin layer of copper, indium, gallium and selenide on glass or plastic backing, along with electrodes on the front and back to collect current. Because the material has a high absorption coefficient and strongly absorbs sunlight, a much thinner film is required than of other semiconductor materials.

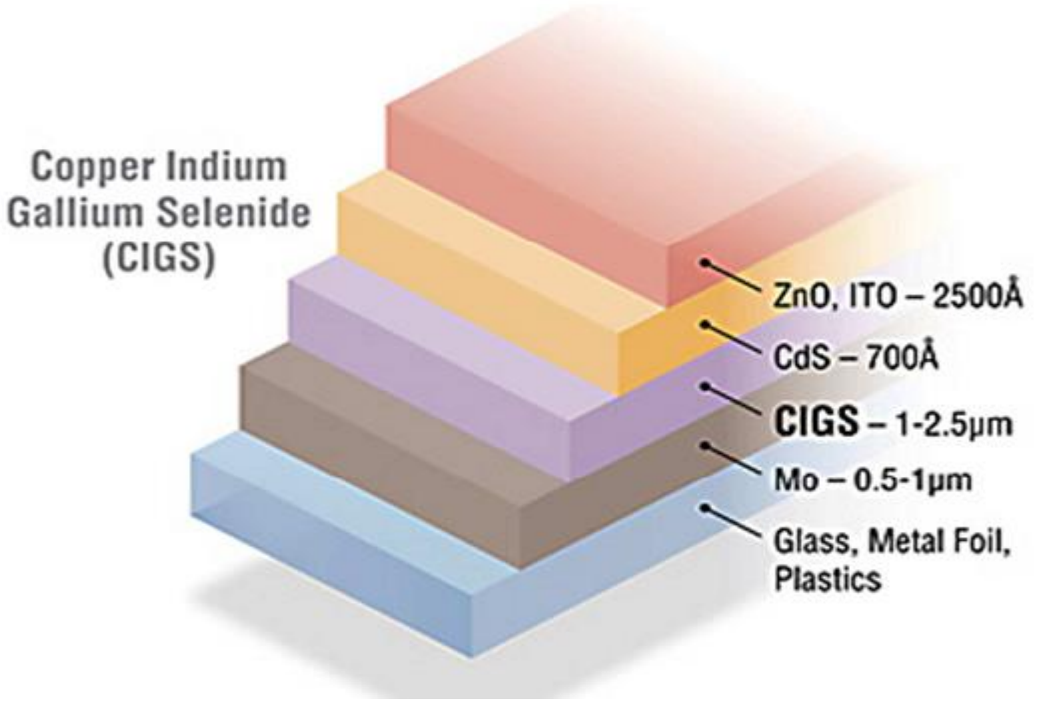


Fig.I.10. Graphic showing the five layers that comprise CIGS solar cells.

CIGS is one of three mainstream thin-film PV technologies, the other two being cadmium telluride and amorphous silicon. Like these materials, CIGS layers are thin enough to be flexible, allowing them to be deposited on flexible substrates. However, as all of these technologies normally use high-temperature deposition techniques, the best performance normally comes from cells deposited on glass. Even then the performance is marginal compared to modern polysilicon-based panels. Advances in low temperature deposition of CIGS cells have erased much of this performance difference. It is best known as the material for CIGS solar cells a thin-film technology used in the photovoltaic industry [36].

Solar cells based on chalcopyrite Cu (In, Ga)Se 2 (CIGS) absorber layers show the highest potential for low-cost solar electricity by yielding comparable efficiencies to polycrystalline Si wafer-based cells, while also offering inherent advantages of thin-film technology for cost reduction. Highest efficiency of 20.3% was recently achieved on rigid glass substrate [37].

I-3-1-6- Dye-Sensitized Solar Cell (DSSC)

Dye Sensitized solar cells (DSSC), also sometimes referred to as dye sensitised cells (DSC), are a third generation photovoltaic (solar) cell that converts any visible light into electrical energy.This new class of advanced solar cell can be likened to artificial photosynthesis due to the way in which it mimics nature's absorption of light energy. Dye Sensitized solar cells (DSSC) were invented in 1991 by Professor Michael Graetzel and Dr Brian O'Regan at École Polytechnique Fédérale de Lausanne (EPFL), Switzerland and is often referred to as the Gräetzel cell, we call it G Cell. DSSC is a disruptive technology that can be used to produce electricity in a wide range of light conditions, indoors and outdoors, enabling the user to convert both artificial and natural light into energy to power a broad range of electronic devices. A dye-sensitized solar cell (DSSC, DSC or DYSC) [38]. Is a low-cost solar cell belonging to the group of thin film solar cells [39]. We fabricate dye-sensitized solar cells (DSSC) using vertically oriented, high density, and crystalline array of ZnO nanowires, which can be a suitable alternative to titanium dioxide nanoparticle films [40]. The performance of the cell mainly depends on a dye used as photo-sensitizer. The absorption spectrum of the dye and the anchorage of the dye to the surface of TiO_2 are important parameters determining the efficiency of the cell [41]. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photo electrochemical system. The DSSC has a number of attractive features; it is simple to make using conventional roll-printing techniques, is semi-flexible and semitransparent which offers a variety of uses not applicable to glass-based systems, and most of the materials used are lowcost. In practice it has proven difficult to eliminate a number of expensive materials, notably platinum and ruthenium, and the liquid electrolyte presents a serious challenge to making a cell suitable for use in all weather. Although its conversion efficiency is less than the best thin-film cells, in theory its price/performance ratio should be good enough to allow them to compete with fossil fuel electrical generation by achieving grid parity. Commercial applications, which were held up due to chemical stability problems [42], are forecast in the European Union Photovoltaic Roadmap to significantly contribute to renewable electricity generation by 2020.

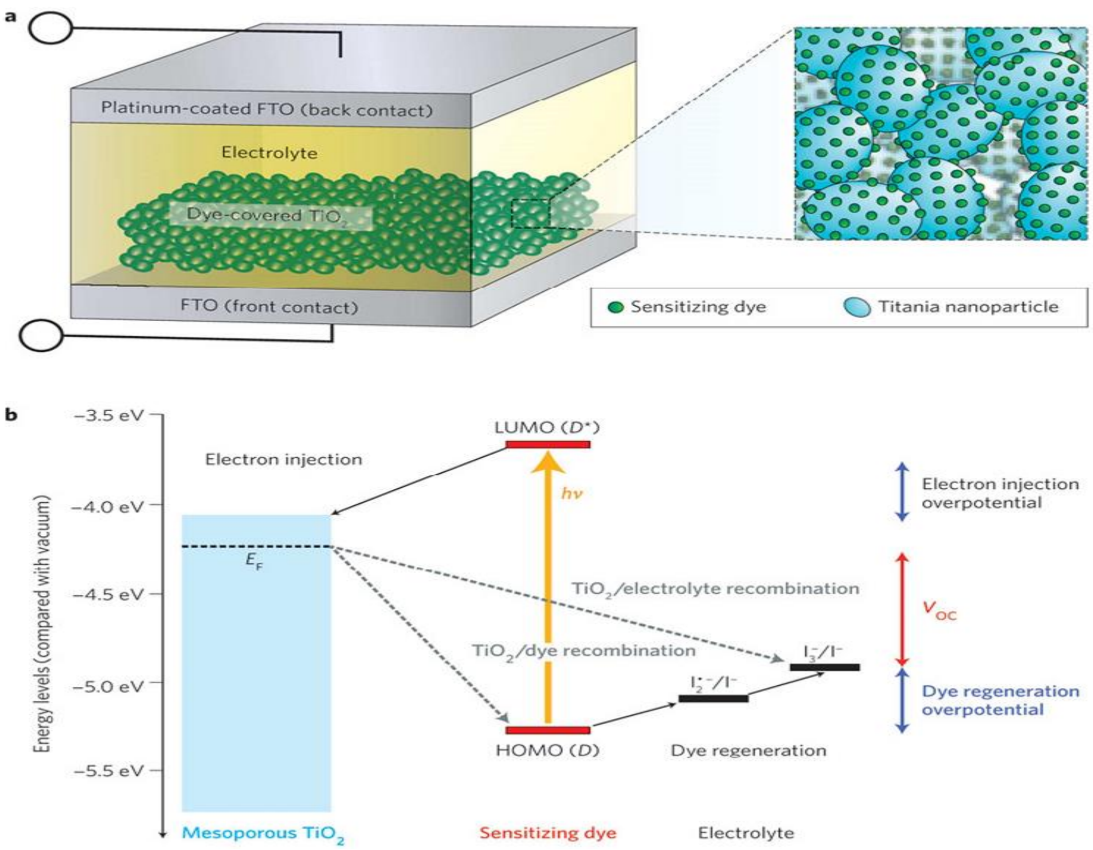


Fig.I.11. Dye-sensitized solar cell device schematic and operation [26]

I-3-1-7- Gallium Arsenide Germanium Solar Cell (GaAs/ Ge)

Gallium arsenide is composed of 2 base elements; gallium and arsenic. When these two individual elements bind together, they form the aforementioned compound, which displays many interesting characteristics. Gallium arsenide is a semiconductor with a greater saturated electron velocity and electron mobility than that of silicon . This makes it very useful in many applications. Another novel quality to gallium arsenide is that it has a direct band gap. This is a quality that denotes a compound that can emit light efficiently. Gallium arsenide (GaAs) is a compound of the elements gallium and arsenic. It is a III-V direct bandgap semiconductor with a zinc blende crystal structure. Gallium arsenide is used in the manufacture of devices such as solar cells and optical windows. For example due to the fact that it has a greater electron mobility than silicon it can be used in different ways that silicon cannot. TransistorsW made of this material can run at frequencies over 250 GHz. These transistors produce less noise when operating at the same high frequencies as their silicon counterparts. Gallium arsenide also has a higher breakdown voltage. Because of these factors, gallium arsenide has been a good candidate for many electrical applications ranging from the common to the extraordinary. Some of these include cellular telephones, satellites and satellite communication, micro and nano scale semiconductors, radar systems, and even nano based solar power. A solar cell is created to do one paramount task. That is the production of electricity through the absorption of photons. When light, in this case radiant energy from the sun, strikes the cell, a certain portion of it is absorbed within the semiconductor material, gallium arsenide, This means that the energy of the absorbed light is transferred to the semiconductor, in our case the gallium arsenide. The energy excites electrons, knocking them loose or otherwise removing them from their previous bound state. This allows them to flow freely. Solar and photo voltaic cells also have one or more electric fields that act as a mediator. This field forces electrons liberated by light absorption to flow in a certain direction. This flow of electrons, like many others, is a current. This current can be harnesssed by placing metal contacts on the top and bottom of the cell. With these newly placed contacts the current can be drawn off to power just about any external application. There are many ways to create a GaAs solar or photo voltaic cell. First the GaAs crystal must be created. Without this, the solar cell will not be able to function. Three effective means of growing crystals include: Molecular Beam Epitaxy, Metalorganic Vapour Phase Epitaxy, and Electrochemical Deposition (or Electroplating) [26].

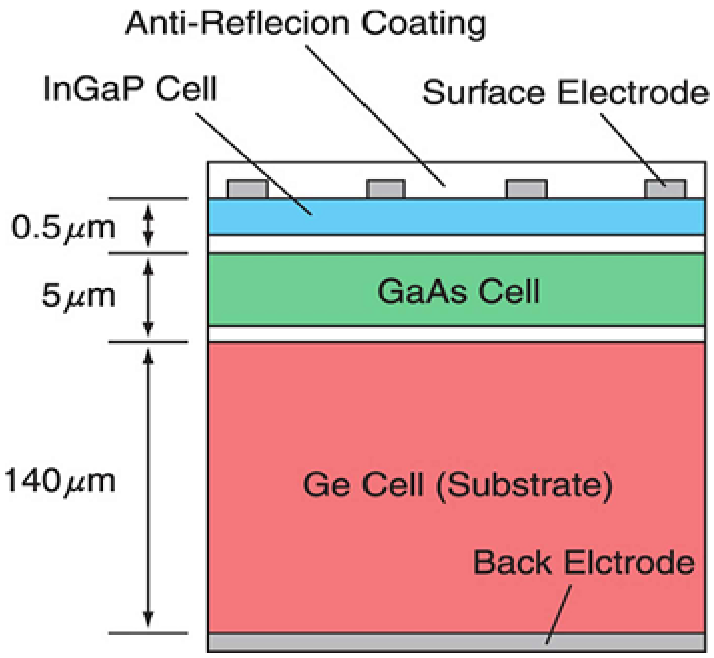


Fig.I.12. Cross-sectional diagram of InGaP/GaAs/Ge.

I-3-1-8- Hybrid Solar Cell

Hybrid and photoelectrochemical (dye sensitized) solar cells have been the cheap alternatives for conventional silicon solar cells.

Hybrid solar cells combine advantages of both organic and inorganic semiconductors. Hybrid photovoltaics have organic materials that consist of conjugated polymers that absorb light as the donor and transport holes [43]. Inorganic materials in hybrid cells are used as the acceptor and electron transporter in the structure. The hybrid photovoltaic devices have a potential for not only low-cost by roll-to-roll processing but also for scalable solar power conversion. In hybrid solar cells, an organic material is mixed with a high electron transport material to form the photoactive layer [44]. The two materials are assembled together in a heterojunction-type photoactive layer, which can have a greater power conversion efficiency than a single material. One of the materials acts as the photon absorber and exciton donor. The other material facilitates exciton dissociation at the junction. Charge is transferred and then separated after an exiton created in the donor is delocalized on a donor-acceptor complex. The energy required to separate the exciton is provided by the energy offset between the LUMOs or conduction bands of the donor and acceptor. After dissociation, the carriers are transported to the respective electrodes through a percolation network. The average distance an exciton can diffuse through a material before annihilation by recombination is the excitondiffusion length. This is short in polymers, on the order of 5– 10 nanometers. The time scale for radiative and nonradiative decay is from 1 picosecond to 1 nanosecond. Excitons generated within this length close to an acceptor would contribute to the photocurrent. To deal with the problem of the short exciton diffusion length, a bulk heterojunction structure is used rather than a phase-separated bilayer. Dispersing the particles throughout the polymer matrix creates a larger interfacial area for charge transfer to occur [26].

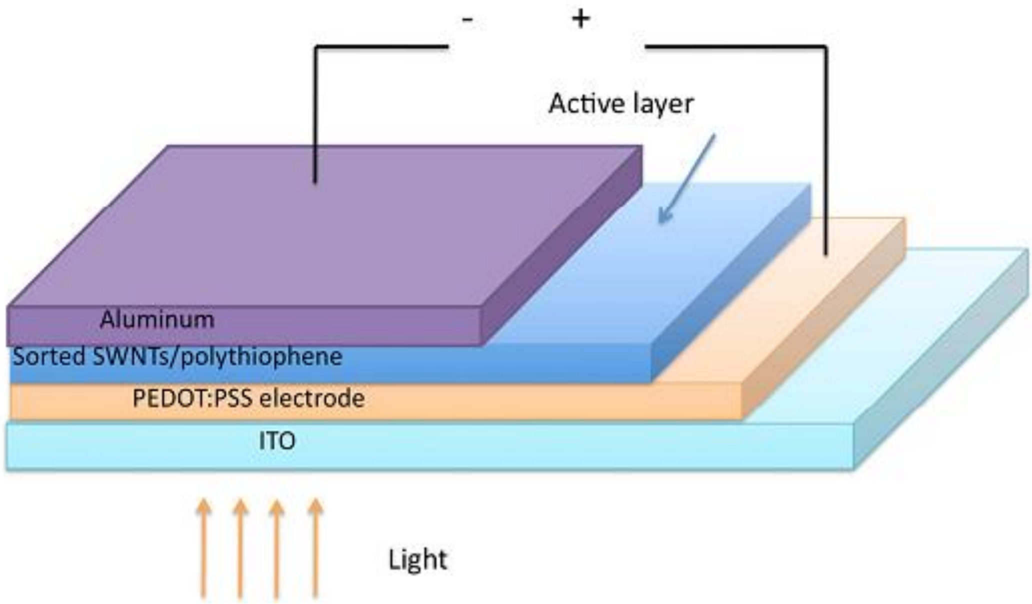


Fig. I.13. Structure of carbon nanotubes based solar cells.

I-3-1-9- Luminescent Solar Concentrator Cell (LSC)

A luminescent solar concentrator (LSC) is a device that uses a thin sheet of material to trap solar radiation over a large area, before directing the energy (through luminescent emission) to cells mounted on the thin edges of the material layer. The thin sheet of material typically consists of a polymer (such as polymethyl methacrylate (PMMA)), doped with luminescent species such as organic dyes, quantum dots or rare earth complexes [46]. The main motivation for implementing LSCs is to replace a large area of expensive solar cells in a standard flat-plate PV panel, with a cheaper alternative. Therefore there is both a reduction in both the cost of the module (£/W) and the solar power produced (£/kWh). A key advantage of over typical concentrating systems is that LSCs can collect both direct and diffuse solar radiation. Therefore tracking of the sun is not required [47].

The development of LSCs aims to create a working structure that performs close to the theoretical maximum efficiency. An ideal LSC would have the following properties: A broad absorption range to utalise the solar spectrum efficiently; 100% emission of light from the absorbing luminescent species; A large shift between the absorption and emission spectra to reduce absorption losses; and long term stability.

Initial designs typically comprised parallel thin, flat layers of alternating luminescent and transparent materials, placed to gather incoming radiation on their (broader) faces and emit concentrated radiation around their (narrower) edges. Commonly the device would direct the concentrated radiation onto solar cells to generate electric power.Other configurations (such as doped or coated optical fibers, or contoured stacks of alternating layers) may better fit particular applications.

The layers in the stack may be separate parallel plates or alternating strata in a solid structure. In principle, if the effective input area is sufficiently large relative to the effective output area, the output would be of correspondingly higher irradiance than the input, as measured in watts per square metre. The concentration factor is the ratio between output and input irradiance of the whole device. For example, imagine a square glass sheet (or stack) 200 mm on a side, 5 mm thick. Its input area (e.g. the surface of one single face of the sheet oriented toward the energy source) is 10 times greater than the output area (e.g. the surface of four open sides) - 40000 square mm (200x200) as compared to 4000 square mm (200x5x4). To a first approximation, the concentration factor of such an LSC is proportional to the area of the input surfaces divided by the area of the edges multiplied by the efficiency of diversion of incoming light towards the output area. Suppose that the glass sheet could divert incoming light from the face towards the edges with an efficiency of 50%. The hypothetical sheet of glass in our example would give an output irradiance of light 5 times greater than that of the incident light, producing a concentration factor of 5.Similarly, a graded refractive index optic fibre 1 square mm in cross section, and 1 metre long, with a luminescent coating might prove useful.[26]

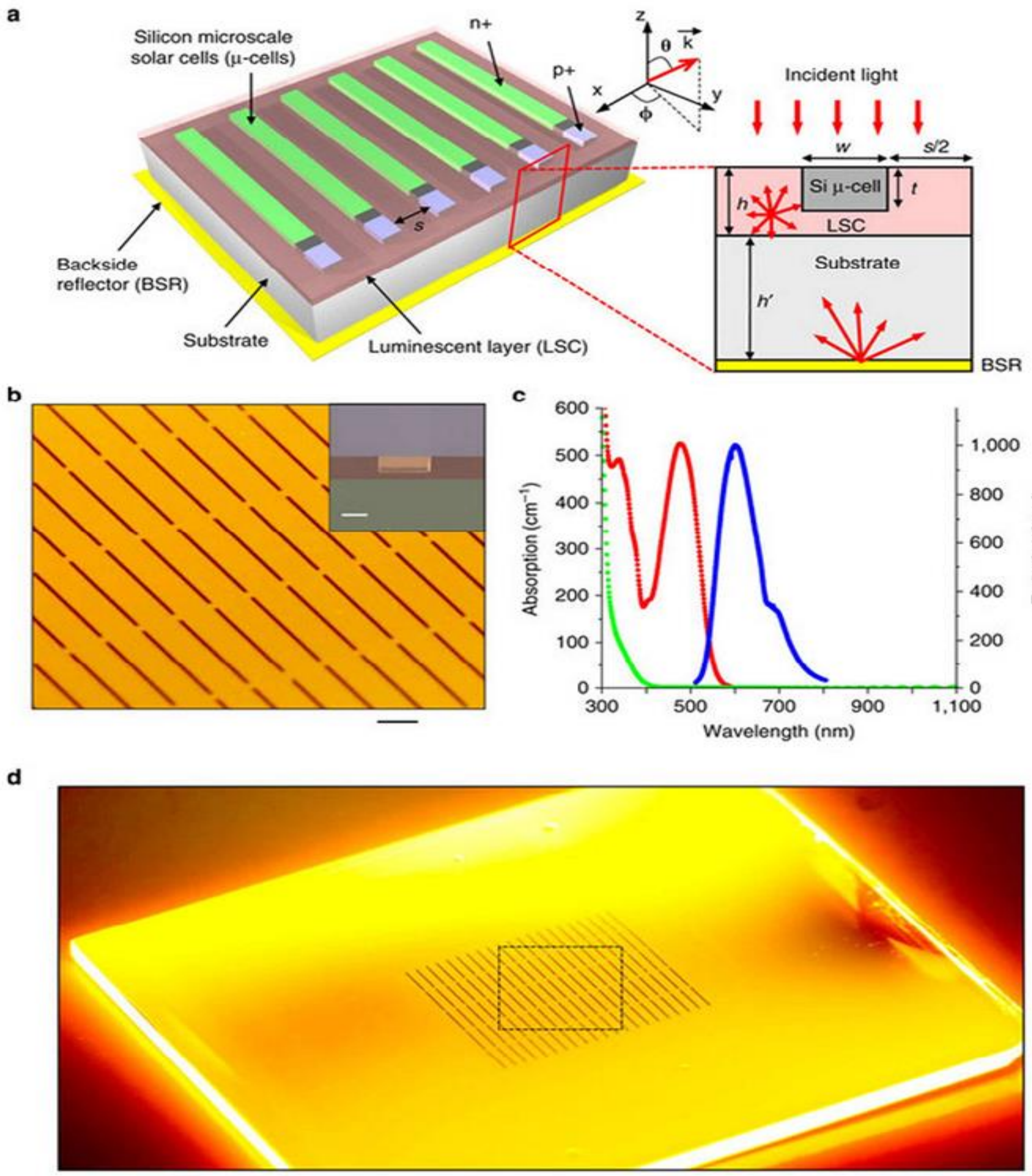


Fig.I. 14. A luminescent concentrator system with an array of surface-embedded monocrystalline silicon solar μ-cells (a) Schematic illustration of a device, consisting of an array of solar microcells (μ-cells), a luminescent layer (LSC layer), a supporting, transparent substrate and a BSR. The inset on the right shows a cross sectional view, with key.

I-3-1-10- Multijunction Solar Cell (MJ)

Future terrestrial concentrator cells will likely feature four or more junctions. The better division of the solar spectrum and the lower current densities in these new multijunction cells reduce the resistive power loss (I^2R) and provide a significant advantage in achieving higher efficiencies of 45–50% [48].

The multijunction cells are composed of different materials deposited in thin layers which allow an optimized use of the solar spectrum. Thus each junction works with its optimum efficiency absorbing the spectral range which is its own. In a single-junction cell, only photons whose energy is equal to or greater than the forbidden band of the material (denoted Eg in eV) are absorbed and able to create electron-hole pairs. Photons having a wavelength lower than that of the forbidden band are "lost". Thus, most photons pass through the material without creating electron pair holes. In addition, when the energy provided by a photon is greater than the forbidden band, the excess energy is dissipated in the form of heat by thermalization. One solution to limit losses consists in using multi-junction cells comprising several junctions made with materials having decreasing gaps. Thus it is possible to better exploit the solar spectrum with higher conversion yield [47].

Currently, the best lab examples of traditional crystalline silicon solar cells have efficiencies between 20% and 25%, while lab examples of multi-junction cells have demonstrated performance over 43%. Commercial examples of tandem, two layer, cells are widely available at 30% under one-sun illumination, and improve to around 40% under concentrated sunlight. However, this efficiency is gained at the cost of increased complexity and manufacturing price. To date, their higher price and higher price-toperformance ratio have limited their use to special roles, notably in aerospace where their high power-to-weight ratio is desirable. In terrestrial applications these solar cells have been suggested for use in concentrated photovoltaics (CPV), with numerous small test sites around the world. Tandem fabrication techniques have been used to improve the performance of existing designs. In particular, the technique can be applied to lower cost thin-film solar cells using amorphous silicon, as opposed to conventional crystalline silicon, to produce a cell with about 10% efficiency that is lightweight and flexible. This approach has been used by several commercial vendors, but these products are currently limited to certain niche roles, like roofing materials [49]. Multi-junction (MJ) solar cells use multiple semiconductor layers (subcells) to produce electricity at high operating efficiencies. Each layer has a unique band gap designed to efficiently absorb a specific segment of the solar spectrum. This has two important advantages over single-junction (SJ) devices: a wider range of absorption of incident photons W as well as a more effective energy extraction from these photons. The lowest band gap of a MJ cell will be lower than that of a typical SJ band gap. Therefore, the MJ cell can absorb extra photons that possess less energy than the SJ band gap but greater than its own lowest band gap. The MJ cell will absorb the same photons more efficiently since having band gaps closer to the photon energy will reduce thermalization losses.

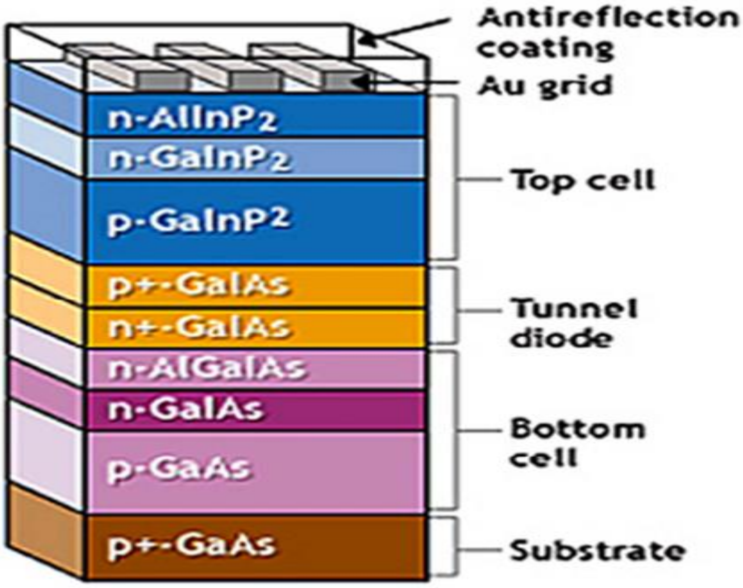


Fig.I. 15. Multi-junction Cell. [26]

I-3-1-11- Polymer Solar Cell

The material used to absorb the solar light in organic solar cells, is an organic material such as a conjugated polymer [26].

A polymer solar cell is defined by applying semiconducting conjugated polymers as active components in the photocurrent generation and power conversion process within thin film photovoltaic devices that convert solar light into electrical energy. In the year 2000, Heeger, MacDiarmid, and Shirakawa received the Nobel Prize for Chemistry for the “discovery and development of conducting polymers”, representing a new class of materials [50].

The basic principle behind both the polymer solar cell and other forms of solar cells, however, is the same, namely the transformation of the energy in the form of electromagnetic radiation (light) into electrical energy (a current and a voltage), i.e. a physical phenomenon called the photovoltaic effect. This energy conversion is possible with the use of semiconductors. The fact that polymers can behave as semiconductors. This discovery of conjugated polymers being able to transfer electrons upon doping with iodine made it possible to prepare solar cells from polymers and thereby a new research area was born.Polymer solar cells have for a long time lagged behind traditional solar cells on both performance and stability. However, they have always had a potential advantage; that is their ability to be produced from solution. This means that they can be printed or coated, instead of using expensive vacuum deposition as for the first generation silicon solar cells. Today, performances of 10% have been demonstrated for polymer solar cells.

The lifetime has also improved considerably and plastic solar cells with a shelf life of several years have been demonstrated. In addition, large scale production of polymer solar cells is today to some extent a reality.

A polymer solar cell is a type of flexible solar cell made with polymers, large molecules with repeating structural units, that produce electricity from sunlight by the photovoltaic effect. Polymer solar cells include organic solar cells (also called "plastic solar cells"). They are one type of thin film solar cell, others include the more stable amorphous silicon solar cell. Most commercial solar cells are made from a refined, highly purified silicon crystal, similar to the material used in the manufacture of integrated circuits and computer chips (wafer silicon). The high cost of these silicon solar cells and their complex production process generated interest in alternative technologies.Compared to silicon-based devices, polymer solar cells are lightweight (which is important for small autonomous sensors), potentially disposable and inexpensive to fabricate (sometimes using printed electronics), flexible, customizable on the molecular level and potentially have less adverse environmental impact. Polymer solar cells also have the potential to exhibit transparency, suggesting applications in windows, walls, flexible electronics, etc.

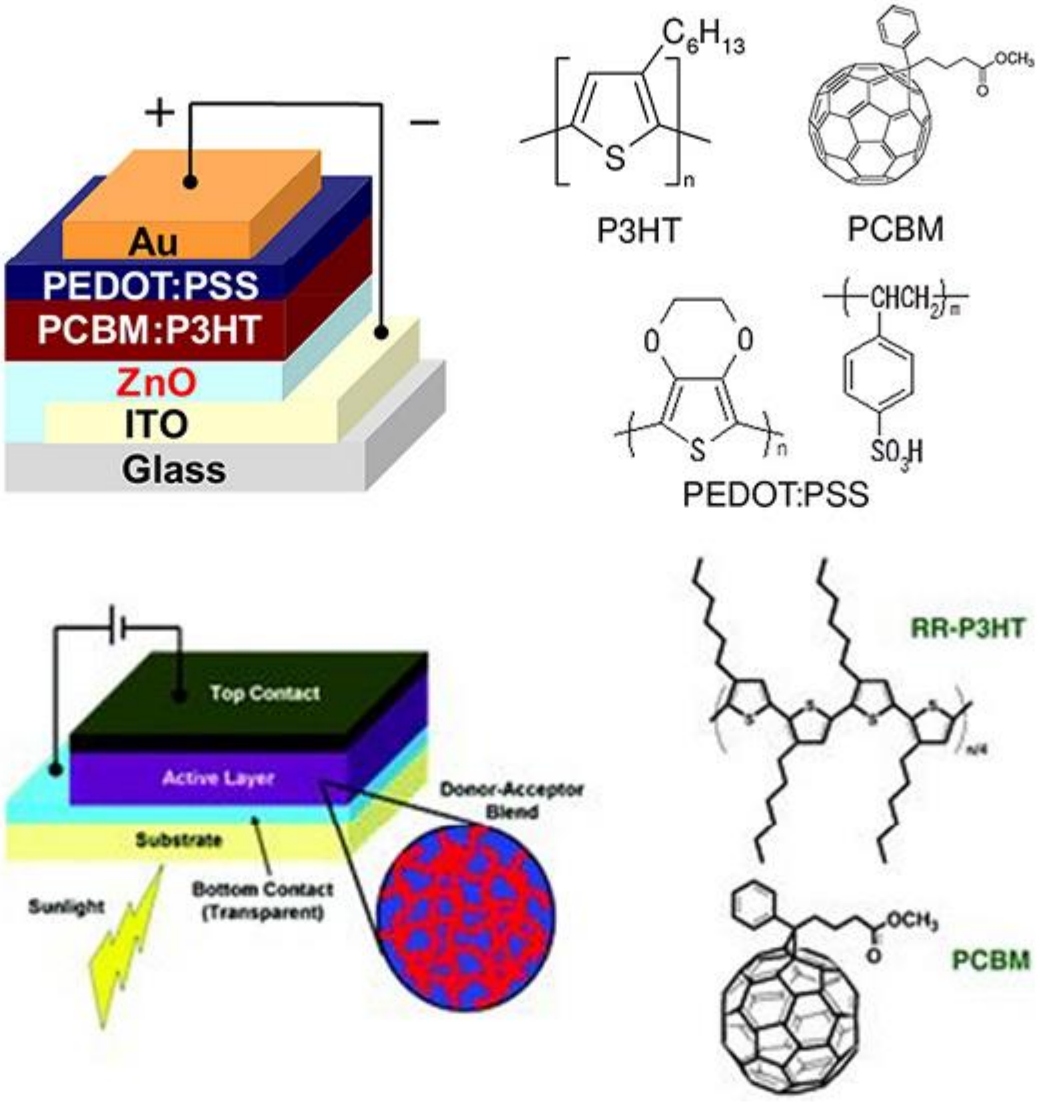


Fig .I .16. Currently, polymer solar cells

Listing the advantages of polymer solar cells reveals a very enticing selling point; however, polymer solar cells have a number of drawbacks. Firstly, while inorganic silicon-based solar cells may last on the order of 25 years; polymer based devices struggle to last a year. Efficiency has long remained the other major drawback of the technology. With polymer solar cell the efficiency is still behind more traditional technologies, but recent records exceeding 10% have been reported. For polymer solar cells to mature to the market, the strong points of the technology will have to match the weak points. However, it is still vital to optimize the weak points. Professor Fredrik C. Krebs have defined the unification challenge of polymer solar cells by stating that three issues share the same importance. These three issues were defined as; process, stability, and efficiency. The concept is very similar to the critical triangle for photovoltaics as presented by Professor Christoph J. Brabec, however substituting processability for cost. While no issue can be argued more important than another, the efficiency of solar cells have long been given special attention. As an area of focus, the power conversion efficiency is important in order to compete with the more mature silicon technology and to justify research in the field of polymer solar cells. As long as focus of research is not on all of the areas, progress towards application of the technology will remain slow. Within recent years the number of reports on both processability and stability has increased significantly. Roll-to-roll production is becoming an established technique for producing polymer solar cells. And more and more work has been published on the stability and degradation including guiding standards for testing OPV devices with respect to stability and operational lifetime [26].

I-3-1-12- Thin Film Solar Cell (TFSC)

A thin-film solar cell (TFSC), also called a thin-film photovoltaic cell (TFPV), is a second generation solar cell that is made by depositing one or more thin layers, or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal. Thin-film solar cells are commercially used in several technologies, including cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous and other thin-film silicon (a-Si, TF-Si). Film thickness varies from a few nanometers (nm) to tens of micrometers (µm), much thinner than thin-film's rival technology, the conventional, first-generation crystalline silicon solar cell (c-Si), that uses silicon wafers of up to 200 µm. This allows thin film cells to be flexible, lower in weight, and have less drag. It is used in building integrated photovoltaics and as semi-transparent, photovoltaic glazing material that can be laminated onto windows. Other commercial applications use rigid thin film solar panels (sandwiched between two panes of glass) in some of the world's largest photovoltaic power stations. Thin-film has always been cheaper but less efficient than conventional c-Si technology. However, they significantly improved over the years, and lab cell efficiency for CdTe and CIGS are now beyond 21 percent, outperforming multicrystalline silicon, the dominant material currently usedin most solar PV systems:23,24 Despite these enhancements, market-share of thin-film never reached more than 20 percent in the last two decades and has been declining in recent years to about 9 percent of worldwide photovoltaic production in 2013 [51]. Other thin-film technologies, that are still in an early stage of ongoing research or with limited commercial availability, are often classified as emerging or third generation photovoltaic cells and include, organic, dye-sensitized, and polymer solar cells, as well as quantum dot, copper zinc tin sulfide, nanocrystal, micromorph and perovskite solar cells.

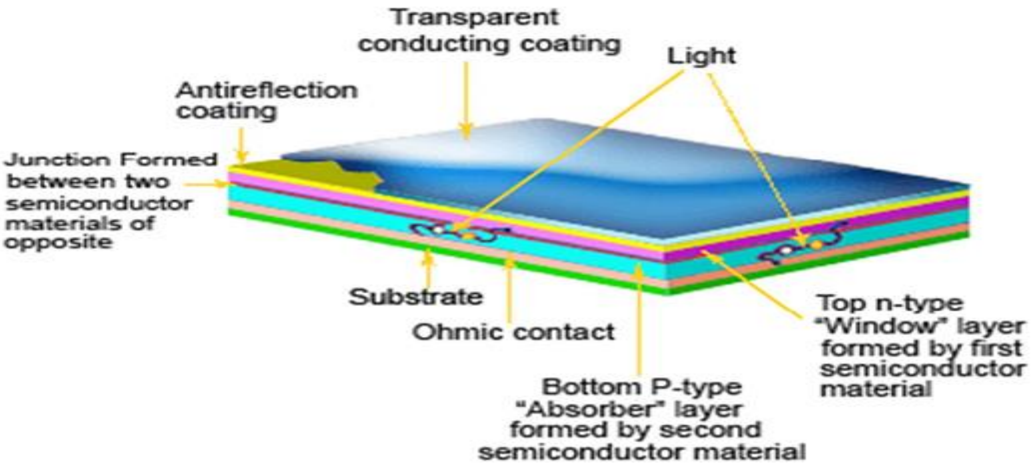


Fig.I. 17. Structure of thin film solar cells.

I-3-1-13- Perovskite Solar Cells

Perovskite Solar Cells (PSC) represent a new concept and design with respect to conventional third generation photovoltaics. These devices are a legacy of Dye Sensitized Solar Cells (DSSC) that were first demonstrated with high efficiency by Micheal Gratzel and Brian O'Regan [14]. DSSCs implement an organic semiconductor (a dye) by sensitizing a metal oxide anode that can be regenerated with an iodide electrolyte in liquid version, or a solid state hole extraction layer th at is typically a small organic molecule. Basically, these devices act as photoelectrochemical systems. In order to increase the interaction between the photo-anode and the dye these devices implemented mesostructured configuration of the photo-anode. The first prototype of PSC was realized with the structure of a liquid DSSCs in 2009 with the perovskite absorber replacing the conventional dye [17]. The name "perovskite" is given for the crystalline structure of the absorber material: ABX3. This material is conceptually an hybrid organo-lead halide compound obtained from a relative simple synthesis and deposited through conventional solution processed techniques [18]. In Fig I.17 is reported the structure of the perovskite with the relative XRD spectrum [52].

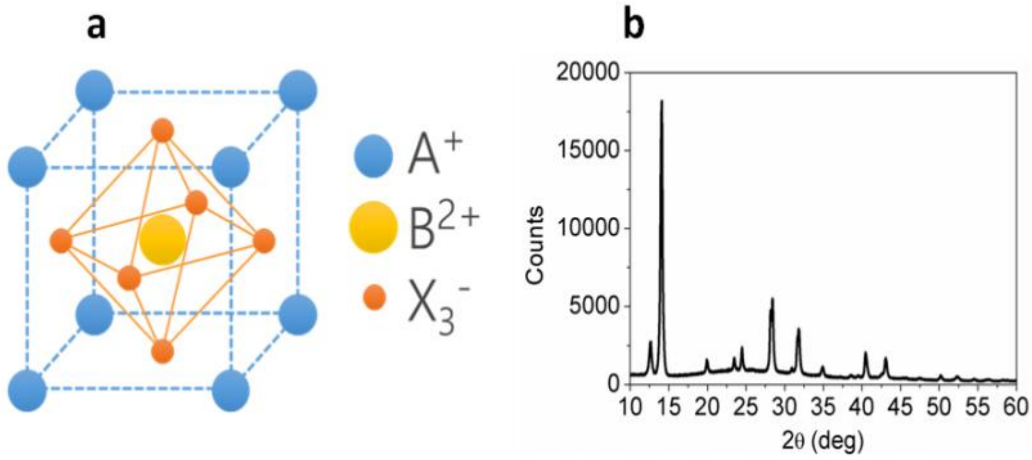


Fig I. 18. a) Structure of a perovskite ABX3. In photovoltaic applications A+ = CH 3NH 3+, B2+ = Pb2+, X^- = I^-. b) XRD spectrum of a perovskite thin film.

I-3-2- Applications of solar energy

Power plants: In conventional power plants non-renewable energy sources are used to boil water and form stream so that turbines can rotate and water to produce electricity. But with application of solar energy heat of sun can boil that water to create steam and rotate turbines. To convert sunlight into electricity solar panels, photoelectric technologies and thermoelectric technologies etc. are used.

1) Homes:

Use of solar energy is increasing in homes as well. Residential appliances can easily use electricity generated through solar power. Besides this solar energy is running solar heater to supply hot water in homes. Through photovoltaic cell installed on the roof of the house energy iscaptured and stored on batteries to use throughout the day at homes for different purposes. In this ways expenditure on energy is cutting down by home users.

2) Commercial Use:

On roofs of different buildings we can find glass PV modules or any other kind of solar panel. These panels are used there to supply electricity to different offices or other parts of building in a reliable manner. These panels collect solar energy from sun, convert it into electricity and allow offices to use their own electrical power for different purposes.

3) Ventilation System:

At many places solar energy is used for ventilation purposes. It helps in running bath fans, floor fans, and ceiling fans in buildings. Fans run almost every time in a building to control moisture, and smell and in homes to take heat out of the kitchen. It can add heavy amount on the utility bills, to cut down these bills solar energy is used for ventilation purposes.

4) Power Pump:

Solar power not just help in improving ventilation system at your homes but with that it can also help in circulating water in any building. You can connect power pump with solar power supply unit but you must run it on DC current so that water circulate throughout your home.

5) Swimming Pools:

Swimming pools are great joy for kids and adults in all seasons. But during winters it is tough to keep water hot in these pools with minimum power usage. Solar energy can help many in this matter as well. You can add a solar blanket in the pool that will keep the water hot with energy generated from sunlight. Besides this you can install a solar hot water heating system with solar hot water heating panels.

6) Solar Lighting:

These lights are also known as day lighting, and work with help of solar power. These lights store natural energy of sun in day time and then convert this energy into electricity to light up in night time. Use of this system is reducing load form local power plants.

7) Solar Cars:

It is an electrical vehicle which is recharged form solar energy or sunlight. Solar panels are used on this car that absorb light and then convert it into electrical energy. This electrical energy is stored in batteries used with the car, so that in night time as well we can drive these vehicles.

8) Remote Applications:

Remote buildings are taking benefit of solar energy at vast scale. Remote schools, community halls, and clinics can take solar panel and batteries with them anywhere to produce and use electric power. These are most common *applications of solar energy* that we get to see in our daily lives. As solar industry grows more diversified applications are expected to be seen in future [53].

I-4 - Fabrication of solar cells

Since the operation of a photovoltaic sensor does not generate particular nuisance, the environmental impacts are necessarily upstream of the chain, at the time of manufacture, and end of life during disassembly. It is therefore useful to know the manufacturing techniques in order to properly identify where do they come from and how are used the different flows of materials and energy involved. This part runs the manufacturing steps of a standard process, that is to say the most established, each manufacturer developing of course its own variants.

To make a photovoltaic system it is necessary to go through several steps are really necessary for the photovoltaic conversion starting with silicon and finally ends with the PV system. There are the following steps:

- ✓ **Step 1**: Elaboration of solar grade silicon from metallurgical silicon, itself obtained from quartz.
- ✓ **Step 2**: Crystallization of this solar silicon to form plates
- ✓ **Step 3**: Transformation of this crystallized silicon into active component to become a photovoltaic cell.
- ✓ **Step 4**: Assembly of photovoltaic cells in photovoltaic module.
- ✓ **Step 5**: Grouping of several modules to create a photovoltaic system built-in roof also including a load-bearing structure, components electronic and electrical.[4].

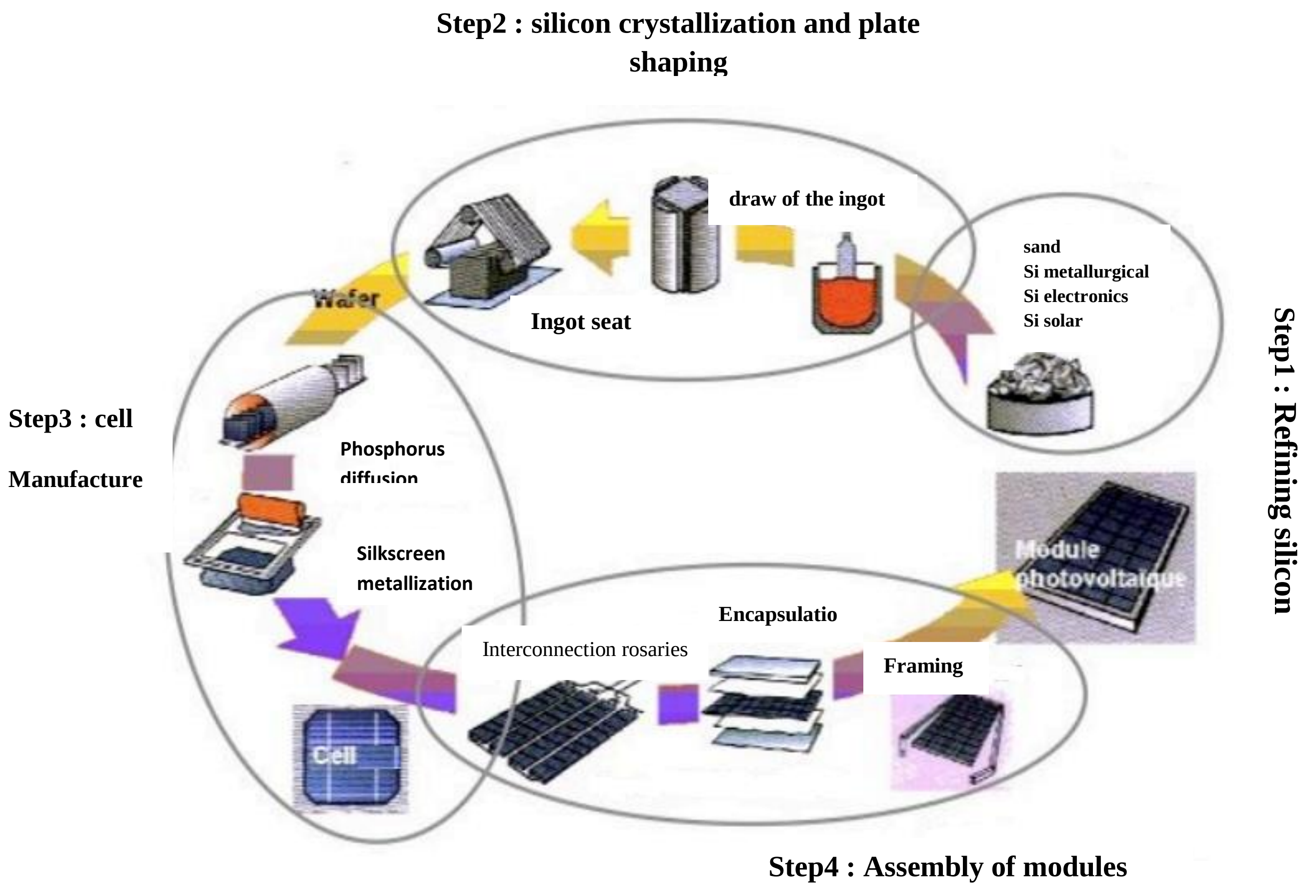


Fig.I .19. Sequence of the manufacturing steps of a crystalline silicon photovoltaic module

I-4-1 Step 1: Refining silicon

In 2006, 93% of the photovoltaic market was still based on silicon technologies (multicrystalline, monocrystalline and ribbon). On the basis of a need of 15t / MW, the photovoltaic industry would consume about 40000 tons of silicon each year to produce 5GW of photovoltaic panels, 90% of which are silicon-based. According to the US Geographical Survey, worldwide silicon production was around 5 million tonnes in 2007, the share of the photovoltaic industry thus represents a little less than 1% of world production..

Obtaining this material comes at the end of a refining process that can be separated into two main stages [54].

The transformation of quartz into metallurgical grade silicon

or MG-Si is carried out in an arc furnace, a typical tool in the metallurgical industry.
The purity of MG-Si is of the order of 98 to 99%. The second transformation is a purification of silicon metal silicon to solar grade or SoG-Si, with a purity of 99.9999%. The traditional road, inherited from electronics, uses chemical reactors to synthesize polycrystalline silicon or poly-Si. The entire photovoltaic module production chain is the most energy intensive stage. Because of the cost of this step and the fact that lesser purity can be tolerated,techniques for producing solar silicon from new chemical and metallurgical processes are explored.

I-4-1-1- Silica to metallurgical silicon

Silicon, the second element of the earth's crust, is obtained from silica or Silicon oxide SiO_2 contained in quartz or sand, whose planet reserves are abundant. Silicon metal, about 20% of global silicon production, is used mainly by the chemical industry and that of aluminum for silicones and metal alloys. For the solar industry, it will be used to manufacture solar grade silicon. The main manufacturers are Grupo Ferroatlantica SL, Glbe Specialty Metals Inc., Elkem AS, Dow Corning Corp. and AMG Advanced Metallurgical Group NV [55].

- **<u>Elaboration of metallurgical silicon</u>**

The metallurgical silicon (MG-Si) results from the transformation of the silica from which oxygen has been extracted. This reaction, called carbothermal reduction, consists of bringing to a very high temperature a mixture of quartz and carbon species (coke, coal and wood reducing agents), which will combine with the oxygen of the quartz to give monoxide then carbon dioxide. The wood also makes it possible to space the materials.
Reduction of silica by carbon at 1700 ° C

$$\mathbf{SiO_2 + 2\,C \rightarrow Si + 2CO}$$

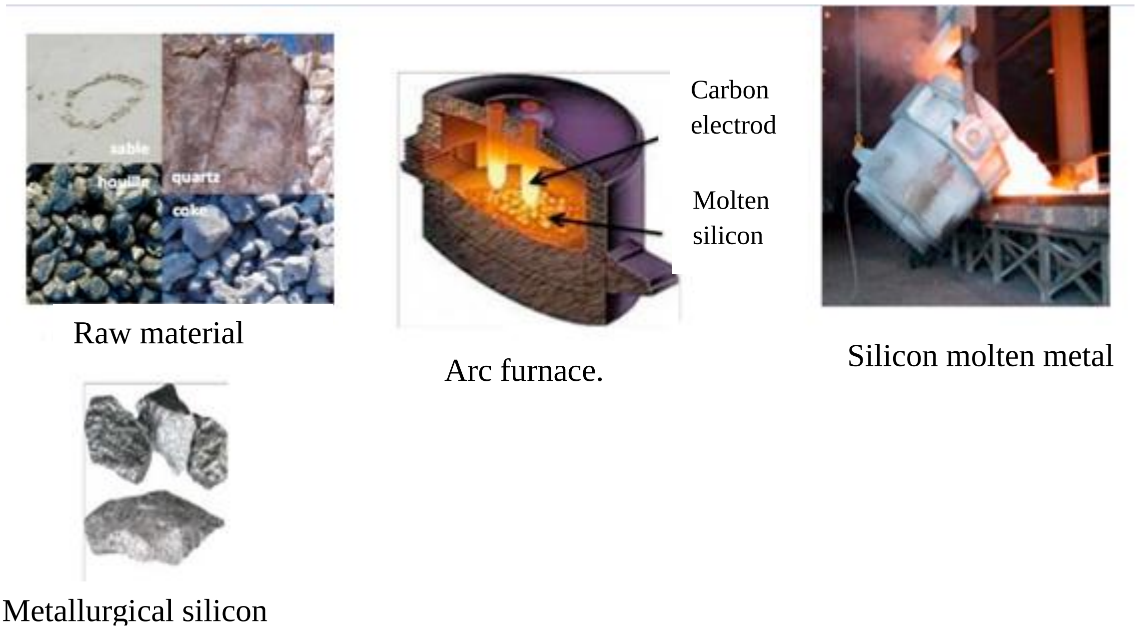
$$\mathbf{2CO + O_2 \rightarrow 2\,CO_2}$$

The energy required for the reaction is provided in the form of an electric arc by graphite electrodes, inside metallurgical furnaces known as arc furnaces.
The molten silicon thus obtained is recovered in "pockets", oxygenated by insufflation of air to form oxides of calcium and aluminum which will be extracted by separation of the slag (phase containing metal oxides, silicates, aluminates and lime, formed during the melting). The silicon is then shaped by cooling and molding in ingot molds. Several crushing and grinding steps then make it possible to obtain MG-Si beads of 2- 3 mm diameter. Another method is water granulation.

The final purity of the metallurgical grade silicon is 98 to 99%, ie an impurity level of approximately 15,000 ppm (Fe, Ca, Mg, Al, C, O, V, Cr, Mn, etc.), with the constraint boron and phosphorus contents of the order of 20 to 500 ppm.

This process is very energy intensive, since it takes about 14 kWh electric to produce 1 kg of MG-Si. CO_2 emissions are also very high: it is necessary to count a little more than 3.14 tonnes of CO_2 released for 1 tonne of MG-Si product, excluding CO_2 equivalent from the electricity consumption. The implementation of CO_2 emission quotas in the future may therefore be an important constraint for this process.

Other metallurgical silicon production processes have been developed. There is, in particular, the reduction in thermite, which consists of extracting oxygen from the silica with aluminum. It has the advantage of low energy consumption because it is highly exothermic [4].



Raw material

Arc furnace.

Silicon molten metal

Metallurgical silicon

Fig .I.20. Metallurgical silicon production processes [4]

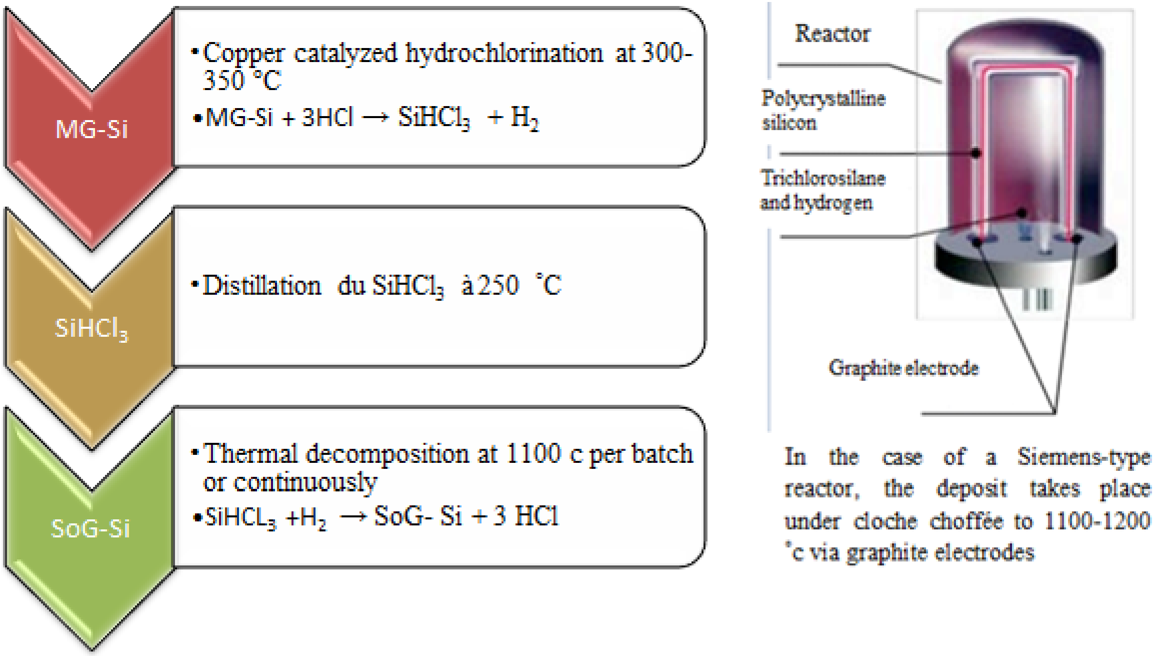
I-4-1-2- From metallurgical silicon to solar silicon

c), or polycrystalline silicon (poly-Si) better known in the electronics industry, is obtained by the purification of metallurgical silicon and will be used for making silicon ingots.

There are different processes for producing solar grade silicon that can be to classify in two great families: the chemical way and the metallurgical way. Currently, the chemical route occupies almost the entire market with two major processes starting from trichlorosilane (75%) and monosilane (25%). It requires greater energy consumption than the metallurgical route, and has the disadvantage of the dangerousness associated with the use of chlorinated products. It makes it possible to obtain a material of greater purity, one of the objectives of the electronic die for which it has historically been developed.

- **Chemical way: Siemens process**

This family of processes is based on the strong attraction of the silicon Si atom for Cl-chloride ions. They consist in synthesizing gaseous compounds containing silicon, generally chlorosilanes, to purify them by distillation and then to deposit the polycrystalline silicon by thermal decomposition. The main variants are the trichlorosilane, monosilane and tetrachlorosilane routes [56]. This route generates large volumes of chlorinated waste and requires operation on sites with high industrial capacity subject to stringent regulatory requirements (Seveso sites in the EU). Several types of recycling can be put in place; they concern chlorinated chemicals, hydrogen and heat. Detail of the Siemens process The Siemens process operates in three stages and generates a gaseous release of trichlorosilane $SiHCl_3$. Its yield is 25%, for an energy consumption of about 150 KWh EF / kg. This is the process historically used for the electronics industry.



In the case of a Siemens-type reactor, the deposit takes place under cloche choffée to 1100-1200 °c via graphite electrodes

Fig I.21. Siemens Process

In the modified Siemens process, the deposition is carried out continuously in a fluidized bed reactor. The silicon grains are formed on precursor silicon particles suspended in a silane / hydrogen gas mixture at 600-800 ° C., and are recovered by gravity at the bottom of the reactor. This latter option has the advantage of reduced energy consumption and deposition time. This technique, initially exclusive to monosilane, was applied to trichlorosilane-based silicon deposits.

❖ Metallurgical way: Elkem process

The challenge of the metallurgical process is to reduce production costs while guaranteeing sufficient quality for solar applications. Several industrialists and research centers are developing processes that make it possible to to avoid the passage of gaseous compounds, in order to achieve energy savings. Metallurgical processes traditionally consist of a series of successive melting and solidification to gradually eliminate impurities. Depending on the case, particular techniques can be used.

Among other examples, the European project SolSilc brought together research laboratories and industrialists from Sweden, Norway and the Netherlands to improve the process of carbothermic reduction from very clean materials (high purity quartz and carbon black): this time solar silicon is obtained directly from quartz.

The PhotoSil project, carried by the French company Apollon Solar, brings together the skills of CEA-Liten, CNRS and FerroPem. The method consists of realizing a first fusion-solidification making it possible to segregate metallic impurities much less soluble in the solid than in the liquid; the remaining impurities (in particular boron) are then extracted by treatment of the liquid with a reactive plasma leading to the formation of volatile compounds. The development was validated in early 2008 on batches of more than 50 kg, and cell yields were measured at 15% by the end of 2008.

Other companies are working on the metallurgical approach: Kawasaki Steel, Dow Corning ...

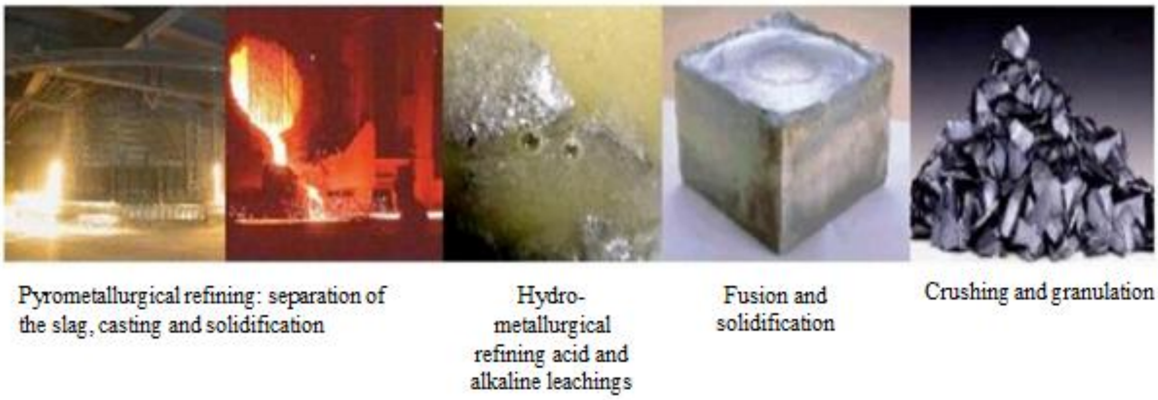
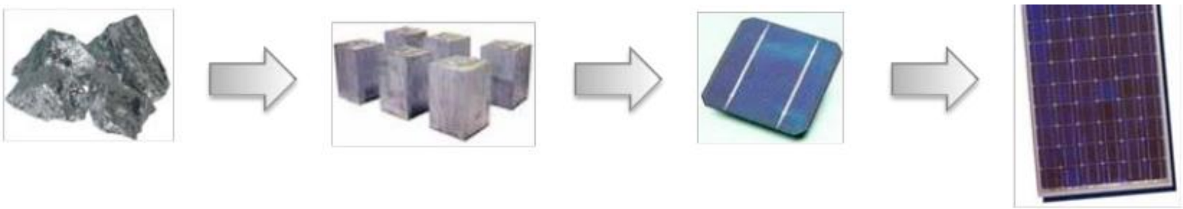


Fig.I.22. Elkem process

For large scale production, the energy consumption will be around 25-30 kWh / kg of initial material, 20% of the expenditure by the Siemens process.

I-4-2- Manufacture of solar panels, cells and modules

At this stage of the production are put into play the know-how specific to the photovoltaic industry [54].



The solar or polycrystalline silicon will be melted again and resolidified into ingots or ribbon in which the silicon wafers will be cut. These plates will undergo transformations that will allow them to convert light energy into electrical energy. Then they will be connected together and protected from bad weather in a photovoltaic module. The manufacture of the other components of a system, namely electrical equipment such as cables and inverters, will not be detailed.

I-4-2-1- Step 2: Crystallization of the silicon and shaping of the plates

These are the last stages of silicon processing before the manufacture of the photovoltaic cell itself. The silicon will be purified again, doped uniformly and cut into plates once cooled. The crystallization technique consists in gradually solidifying the molten polycrystalline silicon in a controlled manner. It is in the charge of molten silicon that will be added the doping element, usually boron which gives a p-type doping. The material ultimately has a crystal lattice, which is an ordered arrangement of silicon atoms.

Note: multicrystalline silicon, resulting from the controlled crystallization of silicon polycrystalline, is often called polycrystalline when it comes to modules. The removal of impurities is done by segregation. More soluble in the liquid phase than the solid, the impurities will migrate towards the areas that solidify last. In the case of a cooling not down, they will focus on the top of the ingot.

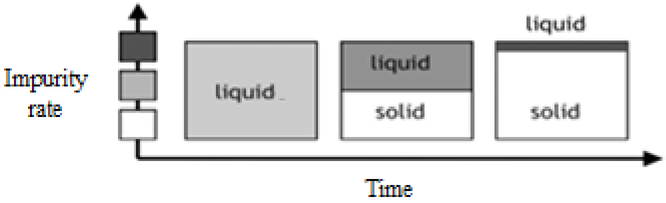


Fig. I.23.mechanism of segregation of impurities during crystallization

In terms of impurities, we can distinguish: The metals: Fe, Cr and Mn for the most troublesome. The dopants: B, Ga, Al, As and P oxygen O, carbon C and nitrogen N. They degrade in their own way the performance of the cell, usually by forming omplexes that reduce the conductivity of the material.

For crystallization, three major routes are possible according to the technological choice made by the manufacturer [57]. The Czochralski print gives cylindrical ingots of monocrystalline silicon or sc-Si, the directional solidification gives bricks of multicrystalline silicon or mc-Si and ribbon drawing techniques gives silicon multicrystalline ribbon.

- **Monocrystalline silicon sc-Si**

This material consists of a single crystal; its color is united, gray. It is obtained by growth or drawing of a cylindrical ingot from a "strain" single crystal according to the Czochralski or CZ process. The final cells have one of the best yields, around 15%, the counterpart is a greater energy expenditure for its shaping Monocrystalline silicon.

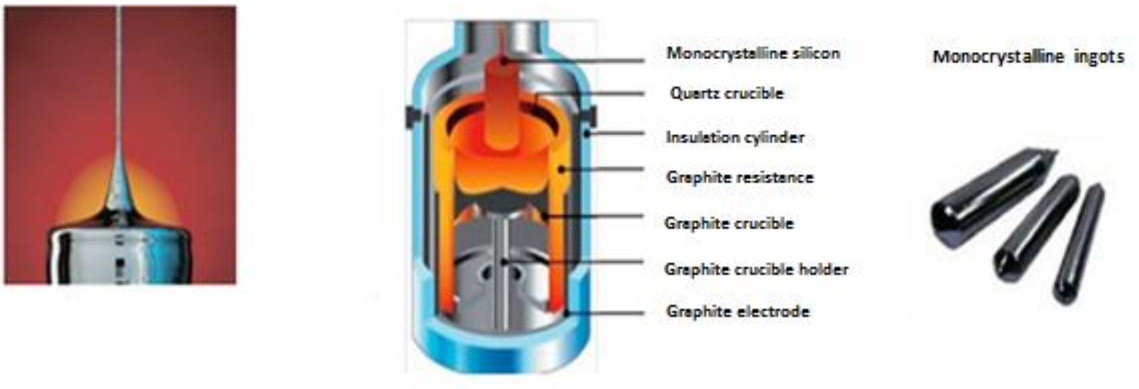


Fig.I.24. Draw ingots

Multicrystalline silicon (mc-Si)

This gray-colored material consists of a mosaic of silicon monocrystalline crystals of different orientation and size. It is obtained by casting in the mold in which a slow cooling takes place, of the order of a few tens of hours. Its development is less energy consuming, and the final cell yield is about 12%.

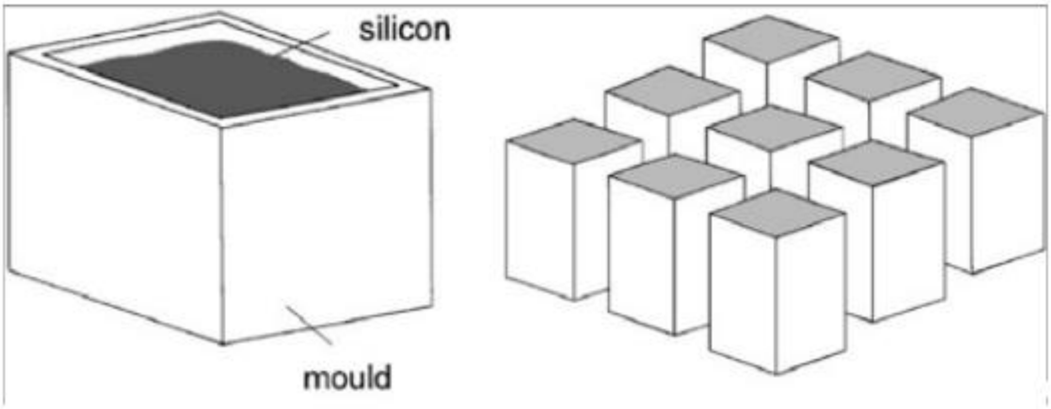
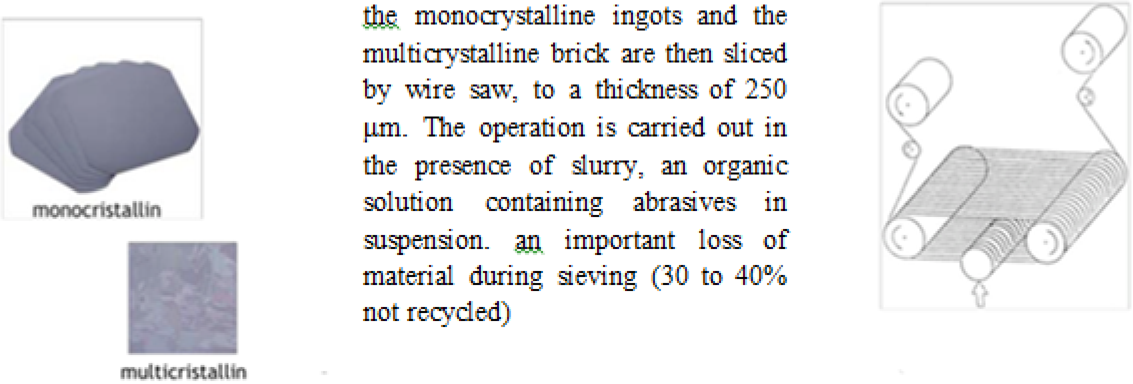


Fig. I.25. Implementation of multicrystalline silicon ingots



the monocrystalline ingots and the multicrystalline brick are then sliced by wire saw, to a thickness of 250 µm. The operation is carried out in the presence of slurry, an organic solution containing abrasives in suspension. an important loss of material during sieving (30 to 40% not recycled)

Fig.I.26. crystalline silicon plates and wire saw

Multicrystalline silicon ribbon

This last technological option combines the steps of crystallization and silicon processing, and has the advantage of minimizing material loss. It is obtained by driving a silicon ribbon on a plane support or tubular from a bath of molten silicon.

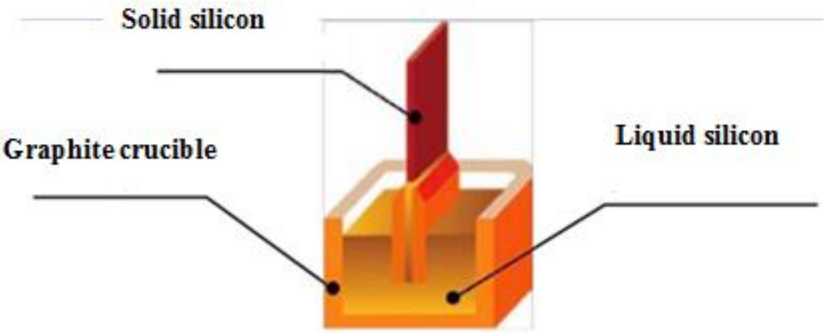


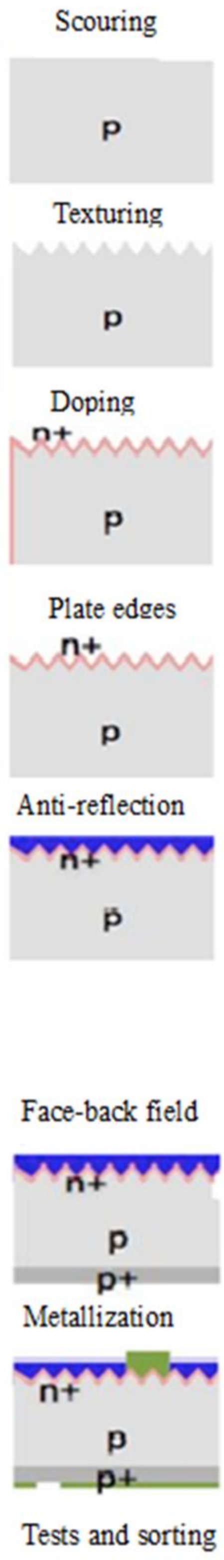
Fig .I.27. Stretching a silicon ribbon

I-4-2-2- Step 3: Making the cells

The particularity of silicon cells lies in fact that the substrate and the element are one and the same material, thanks to the reasonable cost of silicon compared to other semiconductor materials. Once the cut plates come the cell manufacturing, which will make it possible to exploit the semiconductor properties of the silicon and transform the captured light energy into electrical energy.

Sequence of manufacturing steps

Each manufacturer develops his own production line, which depends on his choices technological and economic. The sequence of steps below represents a standard industrial process which will have to be added the sub-stages of transport, cleaning and measuring. [58]



❖ The p-doped plates from boron during crystallization are pickled in a chemical bath to eliminate surface defect created by sawing.

* Acid bath based on hydrofluoric acid HF, acetic acid CH_3COOH and nitric acid HNO_3.

❖ The texturing of the surface in small pyramids or funnels makes it possibl improve the collection of photons in all directions by reducing the reflection. also speak of optical confinement.

* Selective etching with an alkaline bath of NaOH or potassium hydroxide KOH with organic additives of the IPA isopropyl alcohol type.

❖ The doped zone n is formed by phosphorus diffusion: n + layer on the surface and n at the junction.

*Thermal diffusion of phosphorus P from phosphoryl trichloride $POCl_3$ in a passing oven, 800 ° C <T <900 ° C, followed by annealing

* Removal of the residual layer of phosphorus silicate in a bath of hydrofluoric acid HF

❖ The n + layer is removed from the plate edges (on the wafer) to separat the transmitter from the back side.

* Plasma etching with a CF_4 tetrafluoromethane gas mixture and oxygen O_2 subjected to a radio frequency field.

❖ An anti-reflective layer based on oxides or silicon nitride or metal Oxides is deposited on the front face. It also serves to passivate the surface by limiting the recombinations between charges in order to maintain the conductivity of the material.

* Chemical deposit in the gas phase via plasma (PECVD) a layer of Si_3N_4 from SiH_4 silane and NH_3 ammonia

- The back side is p + doped by diffusion of aluminum. This layer also plays a role of ohmic conductor with the back electrode.

  * Heat diffusion of Al aluminum at 850 ° C from an aluminum paste deposite on the entire rear face
- The electrical contacts are metals deposited on the front face (electrode -) and on the back (electrode +)

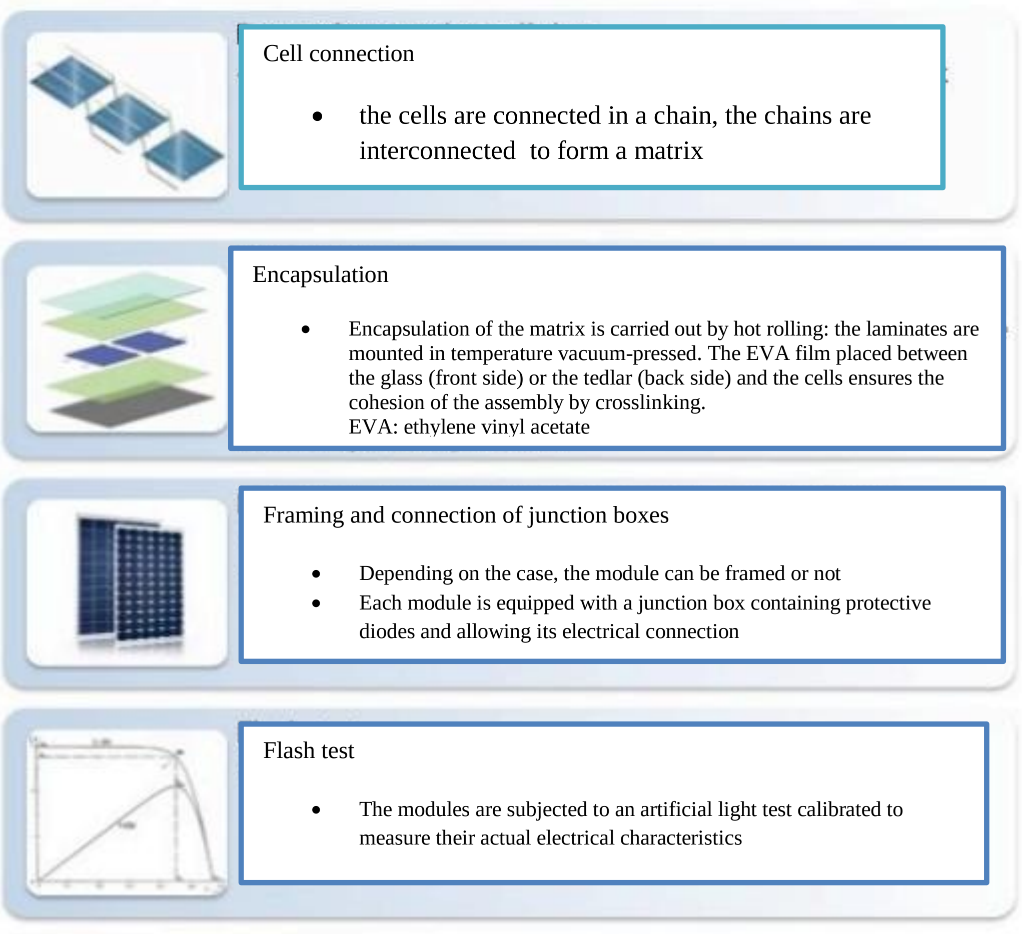
  * Silkscreen silver on the front and aluminum on the back by sintering metal pastes

The cells are measured electrically and sorted according to their characteristic to optimize their subsequent association.

There are of course many variants for each of these steps, which are highly dependent on the production equipment selected by the manufacturer. Some chemical baths can also be replaced by fluorinated gases when it comes to engraving the material (texturing, removing a layer, cleaning the walls of a reactor ...). There are also laser processes for insulating the edges of plates.

I-4-2-3- Step 4: Assembling the modules

The function of the modules is to protect the cells from the external environment and to facilitate their implementation, while limiting as much as possible the optical losses and the yield losses due to the heating of the cells in operation [4,59].



Cell connection

- the cells are connected in a chain, the chains are interconnected to form a matrix

Encapsulation

- Encapsulation of the matrix is carried out by hot rolling: the laminates are mounted in temperature vacuum-pressed. The EVA film placed between the glass (front side) or the tedlar (back side) and the cells ensures the cohesion of the assembly by crosslinking.
  EVA: ethylene vinyl acetate

Framing and connection of junction boxes

- Depending on the case, the module can be framed or not
- Each module is equipped with a junction box containing protective diodes and allowing its electrical connection

Flash test

- The modules are subjected to an artificial light test calibrated to measure their actual electrical characteristics

Fig. I.28. Assembly of photovoltaic modules

I-5- The PV Module

The PV module is thus composed of several cells associated in series and / or parallel, arranged in rows. This assembly of cells is done differently depending on the technologies and may cause additional losses to those already mentioned previously in the cell (optical and electrical losses). We will see in this part how the cells are assembled according to the technology used.

I-5-1- Encapsulation of PV cells

The association of PV cells is not done in the same way for a crystalline silicon module and for a thin film module.

I-5-1-1- The wiring of crystalline silicon modules

In order to connect the cells in series, the contact (-) on the front face of a cell at (+) of the rear face of the next cell is connected by means of a tin or silver-based contact. Once these connections are made, the cells are encapsulated in a resin, mostly EVA (ethylene-vinyl acetate), transparent and index close to that of glass. This coating is sandwiched between two supports: on the front face, high transmission tempered glass in the 350 to 1200 nm wavelength band (if an anti-reflection layer is added, this results in a transmission which can up to 96%), generally 3-4 mm thick, and on the back side, a plastic film, often a tedlar-aluminum-tedlar or dumylar sheet or also glass. The front must be able to withstand hail, UV and all weather, over time (25 years). It is also necessary to protect the back face, the exit of the connections as well as the edges of the panel against all the atmospheric aggression, the humidity, etc. Encapsulation also affects the performance of modules because of its optical properties that can sometimes degrade over time.

The assembly of the cells is a crucial step in terms of the life of the module because it is the main factor of degradation Error! Source of the return not found.

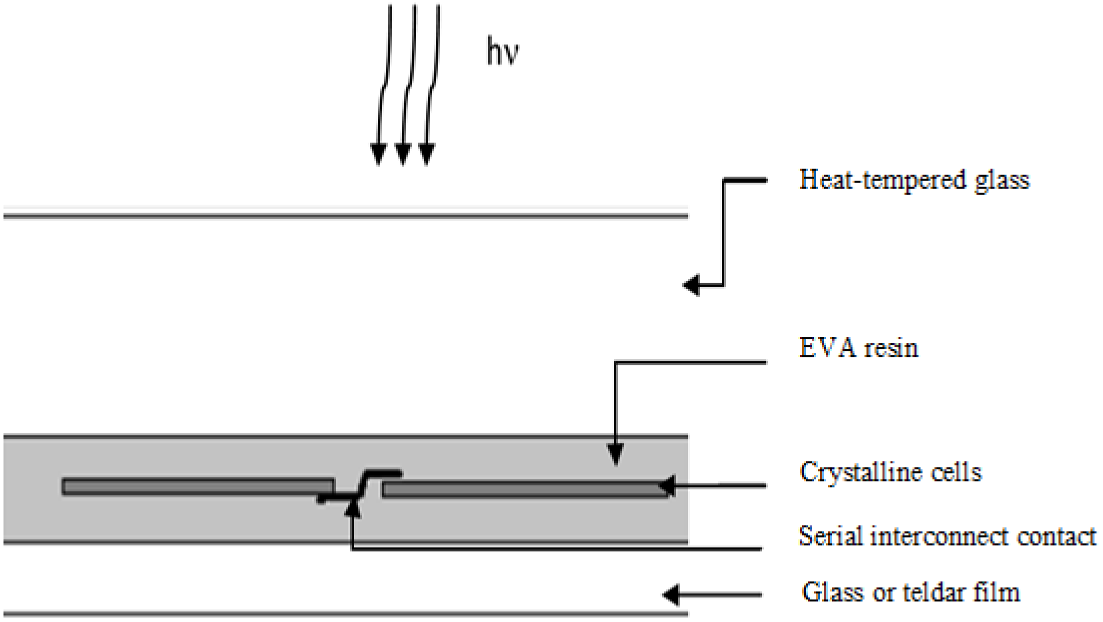


Fig. I. 29. Schematic representation of a sectional view of a crystalline silicon module

I-5-1-2- Thin film module wiring

The thin-film module manufacturing process differs from that of the crystalline silicon modules. Serialization of the cells is done by laser: very fine scratches are made on the thin layer deposited on the glass, composed of the transparent electrode, the pin junction and the rear metal electrode intercalated (Fig.I.30). Thanks to this process, the metal electrode of the

(-) layer is connected to the transparent electrode of the (+) layer of the next cell. The cells are thus put in series. These three laser stripes are so fine that to the naked eye it seems to us to see only one band (Fig.I.31. b). An advantage of this method is that it makes it possible to separate the cells as the user wishes and thus to adapt the module as needed. If you want a module with more voltage then just create more cells.

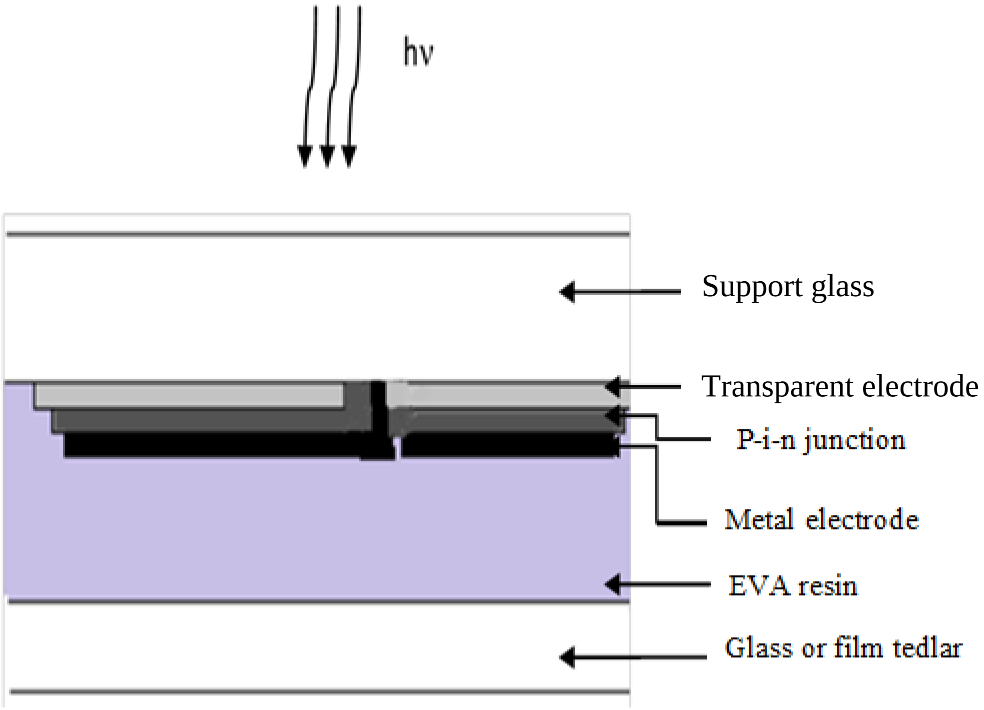


Fig.I.30. Schematic representation of a sectional view of a thin film module (amorphous silicon)

The glass on the front must be highly transparent, hail-resistant (thermally tempered), textured and rounded at the edges (frameless modules). This is a problem for amorphous silicon and CdTe technologies because the active materials are deposited on the glass receiving light with high temperature deposition processes, which soak the thermal tempering of the glass. It is therefore necessary that the rear face of the module is particularly solid so that the sandwich front / encapsulant / backside acts as a shock absorber. This problem does not arise for the CIS for which the active materials are deposited on the rear glass covered with molybdenum.

-a- -b-

Fig .I.31. Photographs of crystalline silicon (a) and thin film amorphous silicon modules (b)

I-5-1-3- The electrical connection box

Electrical connection boxes are generally fixed under the modules of any type, in the lower part. They are also a critical point because it is a favorable place for the accumulation of condensation water, dust and insects.

I-5-1-4- Electrical insulation

The encapsulant must be able to withstand a potential difference at least as great as that delivered by the panel. The metal frame must also be grounded for modules with a Voc greater than 50 V.

I-5-1-5- Mechanical protections

The modules must be both rigid, resistant and accept a certain degree of torsion during their assembly or during their operation on site (thermal expansion, wind, hail, etc.). The most sensitive points are the sides, the corners, the interconnections between cells and the support itself.

I-5-2 The association of photovoltaic cells

The I-V characteristic of any association of cells is homothetic to the classical I-V curve of a base cell. As a result, everything previously said about a cell is still valid for a group of PV cells.

To facilitate the understanding of electrical associations, the receiving convention will be used, contrary to what has been presented in. Fig.I.32, only the sign of the current of the characteristic I-V is reversed, which is only a matter of convention.

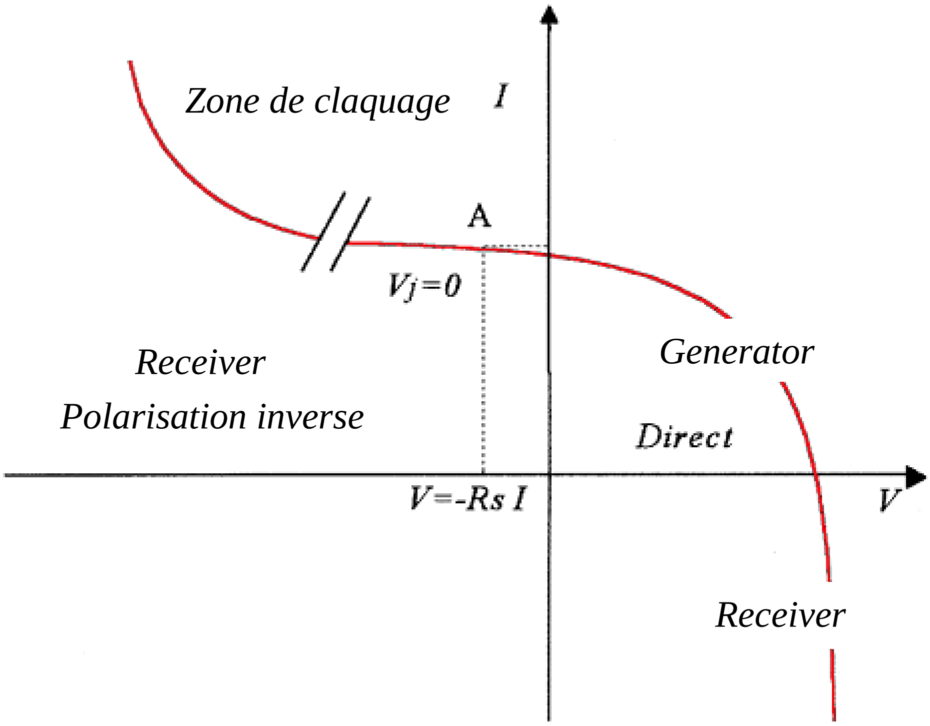


Fig. I.32. Characteristic I-V of a PV cell illuminated and polarized by an external source, with the convention used in the continuation of this chapter. [10]

I-5-2-1 Serial association

When we associate Ns PV cells in series, the voltages of these cells add up and the generated current is the same throughout the branch. The resulting I-V characteristic of the combination of Fig.I.33 is obtained by multiplying point by point and for the same current, the individual voltage Vi by Ns. We also note that the optimal impedance of the association will be Ns times greater than that of the base cell.

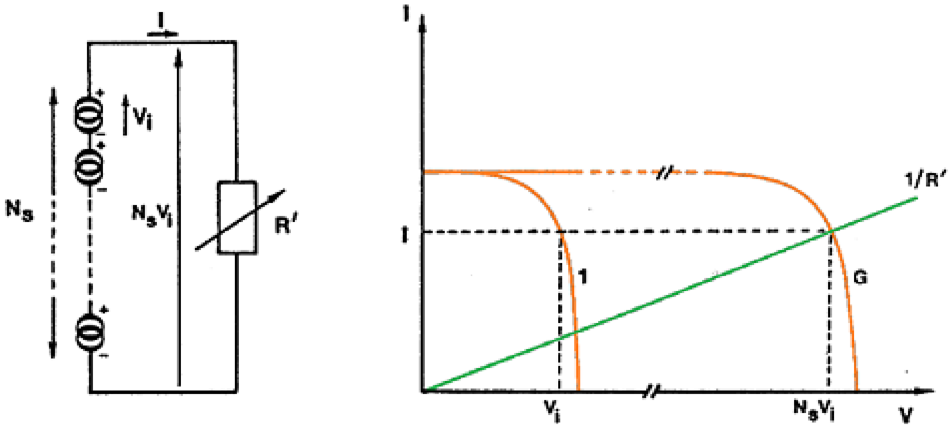


Fig.I.33. Association of Ns cells in series [10]

Since the current generated by Ns PV cells in series is the same throughout the branch and limited by the current of the weakest cell, care should be taken to connect only cells having the same current density in series. That's why in production, all the cells are tested and sorted according to their yield.

The series resistances are added. The increase of the series resistance induces a loss of power, it is thus necessary to pay attention to the resistance of interconnection of the cells, in an association in series. The form factor of a module can not generally be better than that of its constituent cells. As for the current, it is close to that of the worst cell. Parallel resistors are also added. [10]

I-5-2-2- Parallel association

This time, it is the voltage of each cell that must be identical, currents adding up. The new curve in Fig.I.34 is obtained by adding point by point and for each voltage value, the current of the base cell by Np. The optimal impedance of the association will be Np times smaller than that of an individual cell. [10]

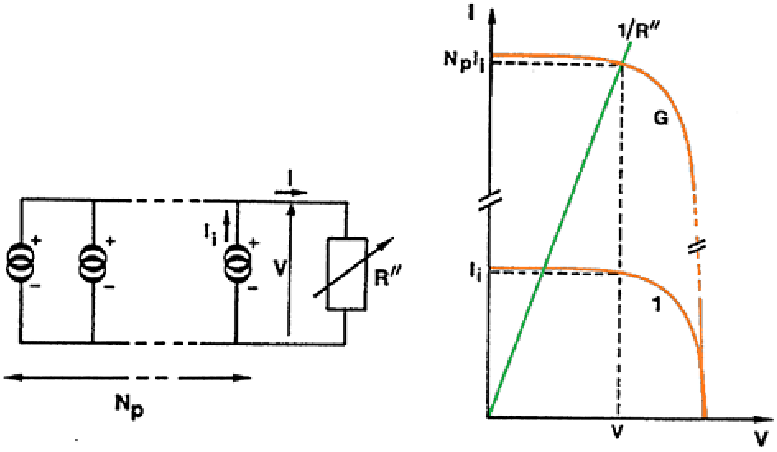


Fig.I.34. Association of Np cells in parallel [10]

It is the series and parallel conductances that are added. [60]

I-5-3- Imbalances in the association of PV cells

The problem of these assemblies is that the grouping is limited by the weakest cell: The weakest current, in the case of serialization, and lower voltage, in the case of paralleling. It is for this reason that it is important to select the most identical cells possible during the manufacture of a module. In manufacturing, this is called pairing. In reality, in spite of a careful sorting of the cells, it happens, on the one hand, that one finds some intrinsic disparities in their electrical characteristics, on the other hand, that the operating conditions induce these disparities.

I-5-3-1- The imbalance in a series association

Fig.I.35 gives the resultant characteristic of the point-by-point addition of two serially associated cells, one of which is less efficient than the other. For a load whose impedance corresponds to line L, cell 2 sees its voltage cancel itself (it does not function as a generator or a receiver). For a load with lower impedance, cell 2 becomes a reverse biased receiver. The cell 1 then supplies power to the cell 2. For a zero load (short circuit), the voltages at the terminals of the cells are identical but of opposite polarities.

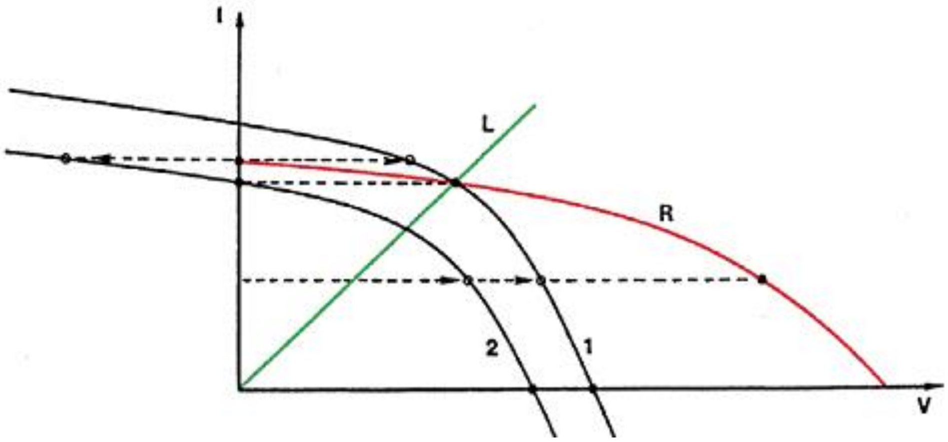


Fig I.35. Serial association of two non-identical PV cells

If we extrapolate the reasoning to a number Ns of cells in series (Fig.I.36), only one of which is very weak or partially obscured, for a zero load (short-circuit current), the latter will bear a voltage in inverse polarity equal to (Ns - 1). Vi where Vi is the direct polarization of the other cells.

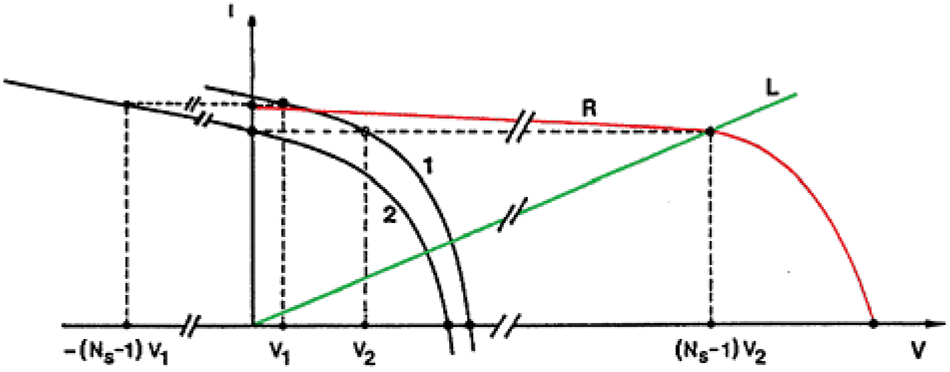


Fig. I.36. Serial association of (Ns - 1) identical PV cells and one weaker cell (2)

Under these conditions, it can be seen that the short-circuit current of the assembly is smaller than the short-circuit current of the (N s-1) cells.

More parallel resistance of cells is weak and lower will be the reverse bias voltage of the weakest cell. Conversely, ideal cells whose parallel resistance would be infinite, will be very sensitive to this problem of imbalance. Indeed, if the slope of the characteristic is very flat in this zone, it's enough that the forced current in the weakest cell slightly above its illumination current to send the operating point in areas of very strongly negative voltages. Typical breakdown voltage of a silicon PV cell crystalline lens being approximately 30 V, it is clear that this type of mismatch can quickly breakdown by breakdown the weakest cell, with a relatively low power.

I-5-3-2-The imbalance in an association in parallel

Fig.I.37 shows the resulting characteristic of the association of two PV cells in parallel. It is now the tension that is common, so it is the currents that must be added. For a load corresponding to the slope of the line L, the cell 2 produces no current. For a higher impedance load, the cell 2 goes into the first quadrant, operating as a receiver, in direct polarization.

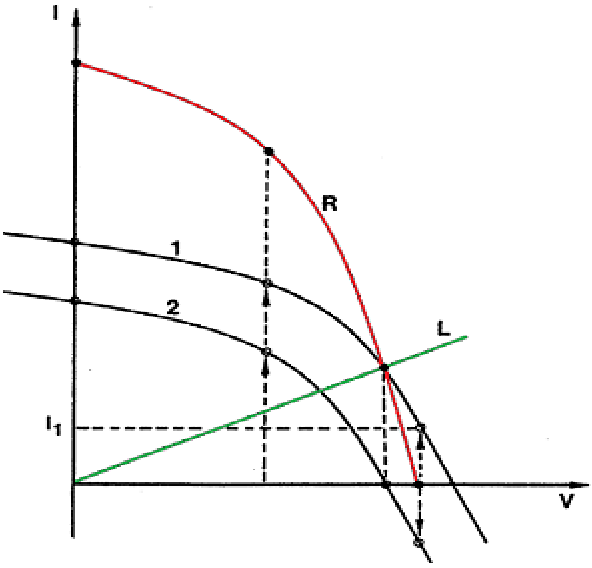


Fig.I.37. Parallel association of two non-identical PV cells

Like before, we can extrapolate to the case of N p cells in parallel (Fig.I.38). Beyond from a certain load impedance value, the weakest cell goes into the receiver. In open circuit, it must output a current (N p - 1) .I at Voc.

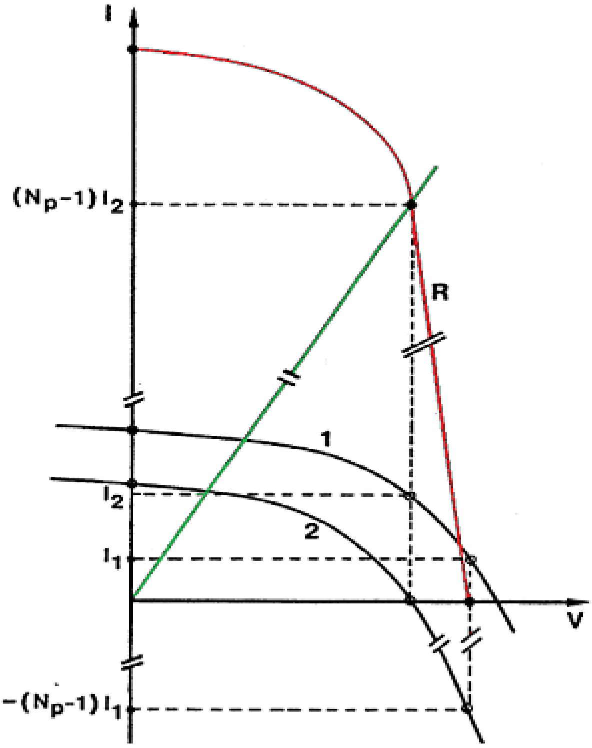


Fig.I.38.. Association in parallel of (Np - 1) identical PV cells and one weaker cell (2)

More series resistance of the cells is strong and lower will be the reverse current of the weakest cell.

Conversely, an ideal cell whose series resistance would be almost zero, will see his point of operation switch to high values negative current to maintain its voltage equal to that of others. The mismatch will be all the more critical that the load impedance is high. The again, a cell may have to dissipate an electric power such that the junction undergoes severe damage. [10]

I-6- Conclusion

It is recalled in this chapter the principle of photovoltaic conversion, the basic electrical characteristics of solar cells. Then we expose several electrical diagrams that allow modeling a PV cell that we compare to the I-V measurements. Next, we count the most important types of solar cells and their uses and so steps to make it. Finally, we have studied the design of a PV module which requires associating PV cells in series or parallel, which generates problems and losses related to the imbalance during the association of cells or partial shading.

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Chapter II :

Influence of the environment

II-1- Introduction

The world has known for more than a century an important economic development. Industrial development, the increase in the number of cars and the proliferation of domestic equipment have led to significant growth in energy demand. Unfortunately, this growth in demand has been largely covered by the import of fossil fuels, motivated by economic considerations. Other factors such as CO_2 emissions, the limited nature of our fossil reserves, and national energy independence have not been taken into account.

As an alternative to these concerns, the development and implementation of renewable energies is unavoidable. Unlimited and abundantly available energy resources exist and must be exploited. Some, such as wind or hydro, are already undergoing significant technical and commercial development and are economically competitive.

Others, such as solar and thermoelectric, are technically available, but their competitiveness requires greater confidence on the part of private companies and public institutions to promote the implementation of such systems and to promote a reduction of the costs through economies of scale [1].

In the context of electricity production, photovoltaic solar energy is the most advantageous solution mainly for isolated sites (Saharan regions, mountainous regions), where the connection to the public electricity grid is very expensive, and also because it is inexhaustible, clean and offers great security of use.

Photovoltaic systems do not require any external fuel input. In addition, the generator itself contains no moving parts and therefore requires virtually no maintenance. As a result, operation and maintenance costs are relatively low. For these reasons, this energy source is particularly suitable for use in rural areas. Where populations are spread in small communities and energy demand is relatively low [2].

In this chapter of the thesis we will discuss in detail the various steps and basic components in the installation of a solar field, then we move on to explain how to maintain the solar field and what the requirements for it, in the last we will talk about the effect of weather on the efficiency of solar panels.

II-2- Installation of solar panels

Although photovoltaic (PV) systems currently represent only a small percentage of total electricity generation, they are growing rapidly, both for commercial and decentralized electricity generation applications. Cost savings from technological advances, economies of scale in production, and innovations in financing have allowed solar energy to move closer to grid parity in a growing number of markets. Continued progress and further cost reductions will increase these opportunities, particularly in developing countries characterized by conditions conducive to the exploitation of solar energy. Renewable energy policy environments in the developing world are currently being informed by learning from the successes and failures of policies in the markets in which the first entrants were located. Currently, a number of regulatory models are successfully deployed in the developing world, resulting in increased investments and facilities. Solar energy is proving viable in more places and for more applications than many industry experts had predicted only a few years ago.

Many emerging economies have excellent solar resources and have adopted policies to encourage the development of the solar industry to achieve savings in their economies and energy security, as well as the local and global environment.

In addition, solar power plants can be built relatively quickly, often in six to 12 months, compared to projects development of hydropower and fuels fossils that require a construction period of four to five years. This is a major incentive in emerging markets that are growing rapidly, characterized by high unmet demand and an urgent need for electricity. Assuming that prices of PV technology will continue to fall relative to competing electricity sources, the market penetration rate of commercial solar power projects will likely continue to grow rapidly, including in emerging markets [3].

The purpose of this part of the chapter is to provide a better understanding of how to successfully develop, build and operate solar PV plants

II-2-1- Technology overview

Solar power plants are a relatively new technology with significant development potential. They offer an opportunity to sunny countries comparable to that of wind farms for coastal countries.

The most promising locations for the implementation of these technologies are those in the southwestern United States, South America, much of Africa, the Mediterranean and Middle East countries, the desert plains of India and Pakistan, China, Australia, etc.

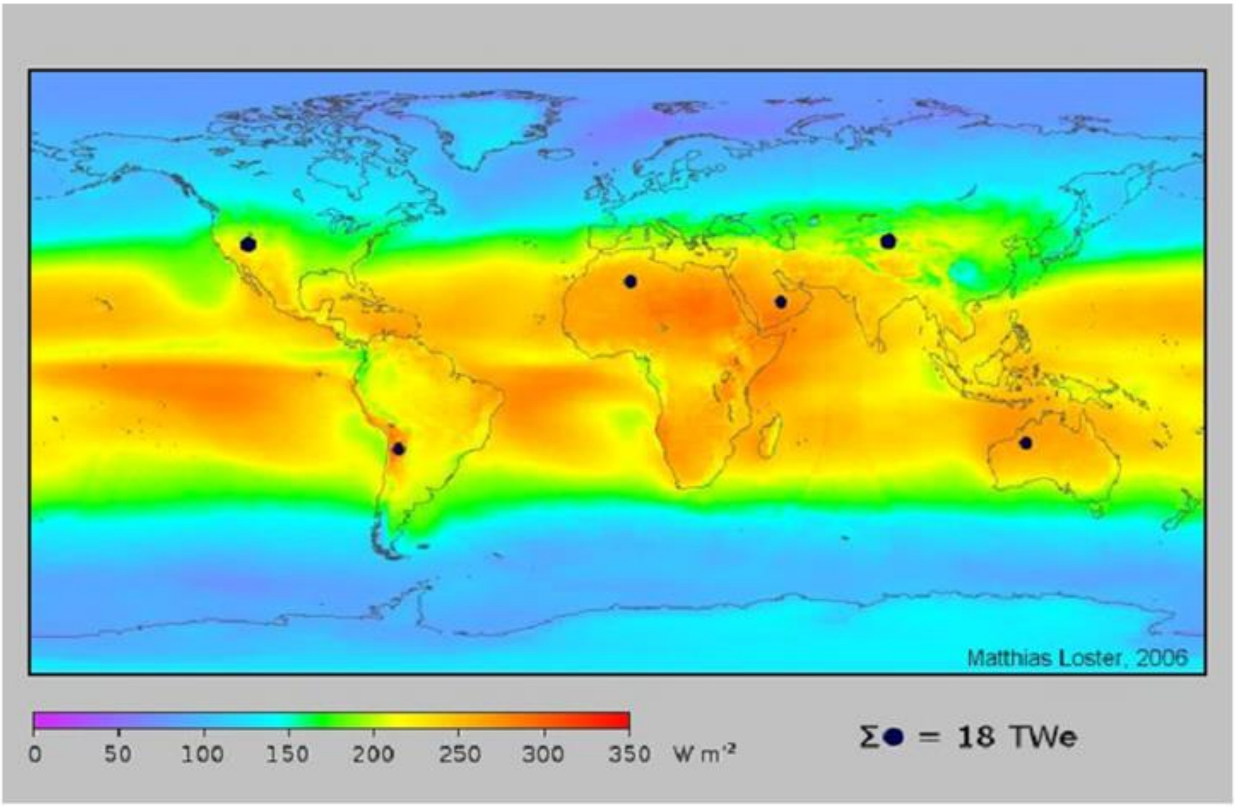


Fig.II.1. Irradiation solar moyenne

In many parts of the world, one square kilometer of land would be enough to generate up to 120 GWh of electricity a year, thanks to solar power plant technology. This energy is equivalent to the annual output of a conventional 50 MW plant [4].

II-2-2- Planning for photovoltaic system

Before designing a solar photovoltaic system several considerations are to be kept in mind such as

- The cost of the system should not be unusually high and at the same time the quality should also not suffer.
- Initial costs and lifetime costs shall also be taken into consideration.
- The system should be simple in design as far as possible with high reliability and efficiency.
- Whether central generation is beneficial or distributed is to be worked out.
- The system to be planned so as to cater for expected future growth.

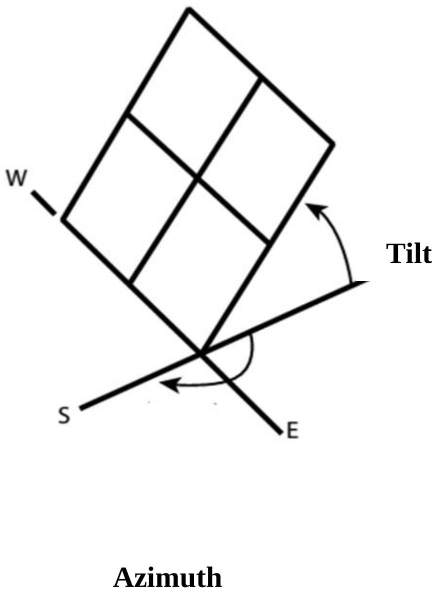
- Prevention of improper load to be ensured [5].

II-2-3- Installation of the solar field

II-2-3-1- Choice of location and inclination

The aim of the following part is to summarize the rules of the art concerning the installation of a photovoltaic field in an isolated site. The installation of a solar field opposite to a photovoltaic field connected network is done mainly on ground structures to benefit from the best inclination in the winter periods. This type of installation is also much easier compared to an integrated built-type installation [6].

Generally inclined relative to the horizontal plane so to maximize the annual sunshine they receive. The optimal angle of inclination depends on the latitude of the place where the site is located. The direction of the system is its orientation or azimuth, as shown in Figure 2. The ideal azimuth of a system in the northern hemisphere is geographic south, and geographic north in the southern hemisphere.



Tilting and azimuth of south oriented PV panel field

Figure.II. 2. Tilt and azimuth of PV array field [3]

Each site will have an optimal angle of inclination maximizing total annual irradiation (averaged over the year as a whole) in terms of the collector. For fixed-grid power plants connected to the network, the theoretical optimum inclination angle can be calculated from the latitude of the site. However, adjustments may be made to reflect the following:

- **Soiling:**

Higher angles of inclination are associated with losses due to less significant soiling. The natural flow of rainwater cleans the modules more efficiently and the snow slides more easily at higher angles of inclination.

- **Shading:**

More steeply sloped modules provide more shade on the modules behind them. Since shading affects energy efficiency much more than would be expected by simply calculating the proportion of the shaded module, a good option (other than by further spacing the rows of modules) is to reduce the energy yield. angle of inclination. It is generally preferable to use a lower angle of inclination to compensate for the loss of energy efficiency associated with the shade worn by the rows.

- **The distribution of seasonal sunshine:**

If a particular season dominates the annual distribution of the solar resource (monsoon rains, for example), it may be interesting to adjust the angle of inclination to compensate for the loss. A simulation software can evaluate the benefit provided by this option [3].

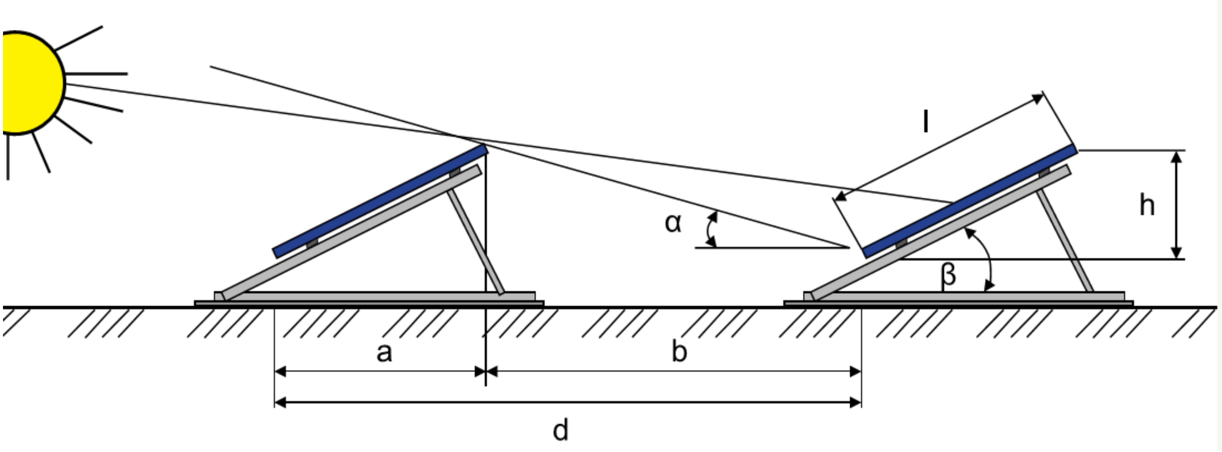


Fig. II.3. Diagram of the shading angle [3].

II-2-3-2- Components of a solar microgrid system

i. PV Module – variations on size/wattages

PV modules are the device that captures the Sun’s energy and converts it into electricity. There are a wide variety of modules available today which differ in the type of silicon used, the manufacturing process, and the product quality. The vast majorities of commercially available PV modules are made from silicon and differentiate into the three main varieties; mono-crystalline, polycrystalline and thin-film solar cells. The different types of PV module vary significantly by cost, efficiency and appearance. The choice is highly dependent on the application, however the most important thing is to ensure that they are compliant to the relevant codes and standards [7].

Fig.II. 4. The different components of the solar kit [7].

ii. Battery storage – type and classifications

In a standalone PV system, battery storage is required if electrical loads are required to operate at night time, or during extended periods of cloudy or overcast weather when the PV array by itself cannot supply enough power. The primary functions of a storage battery in a PV system are:

(i) Energy Storage Capacity and Autonomy
(ii) Voltage and Current Stabilization
(iii) Supply Surge Currents

In general, electrical storage batteries are broadly classified as Primary and Secondary Batteries. Primary batteries are not used in PV systems because they cannot be recharged. A secondary battery can store and deliver electrical energy, and can also be recharged by passing a current through it in an opposite direction to the discharge current.

Fig.II.5. Examples of PV battery types

The batteries that are commercially available and viable for use in photovoltaic system include:

- ✓ Flooded Lead Acid Batteries
- ✓ Valve Regulated Lead Acid (VRLA) Batteries
- ✓ Nickel Cadmium (NiCd)
- ✓ Nickel metal Hydride (NiMH)
- ✓ Lithium Ion (Li-ion)

iii. Inverters & other electronic equipment

The photovoltaic array and battery produce DC current and voltage. The purpose of an inverter is to convert the DC electricity into a form suitable for AC electrical appliances and/or exportable to the AC grid.

iv. Charge controller

Battery charge regulation and control of the energy produced by the PV array is a critical function in PV systems. The most important functions of battery charge regulators and system controls are listed below.

(i) Prevent Battery Overcharge
(ii) Prevent Battery Over discharge
(iii) Provide Load Control Functions
(iv) Provide Status Information to System Users/Operators
(v) Interface and Control Backup
(vi) Energy Sources
(vii) Divert PV Energy to an Auxiliary Load
(viii) Serve as a Wiring Centre

v. Balance of Systems Equipment

In addition to the PV modules, battery, inverter and charge controller there are other components required in a solar PV microgrid or grid system; these components are referred to as Balance of Systems (BoS) equipment.

BoS equipment includes:

- ✓ ***Solar Array Mounting System:*** The equipment used to safely secure the PV modules to the mounting surface or ground.
- ✓ ***Cabling***: Both DC and AC cabling is required to connect components.
- ✓ ***Array Junction Box:*** This may or may not be required depending on the PV array; it is used to combine the different array strings.
- ✓ ***Protection and Disconnect Switches:*** These components ensure the safety of the system.

- ✓ ***Lightning Protection:*** May or may not be required (depending on criteria) to protect the system from lighting strikes.
- ✓ ***Metering:*** Measures the quantity of electricity generated by solar or quantity of electricity consumed by a customer.
- ✓ ***System Monitoring:*** Shows the system owner exactly how much electricity their system is producing and can be helpful in detecting a problem within the system.
- ✓ ***Signage:*** PV systems installed requires various signs to ensure safety [7].

II-2-3-3- Setting up the field

Foundation for array mounting structure may be different for different sites, type and load bearing capacity of soil, wind velocity, waterlogging possibility and type of mounting structure. Conceptual drawing of foundation type generally used to hold PV array structure are presented below :

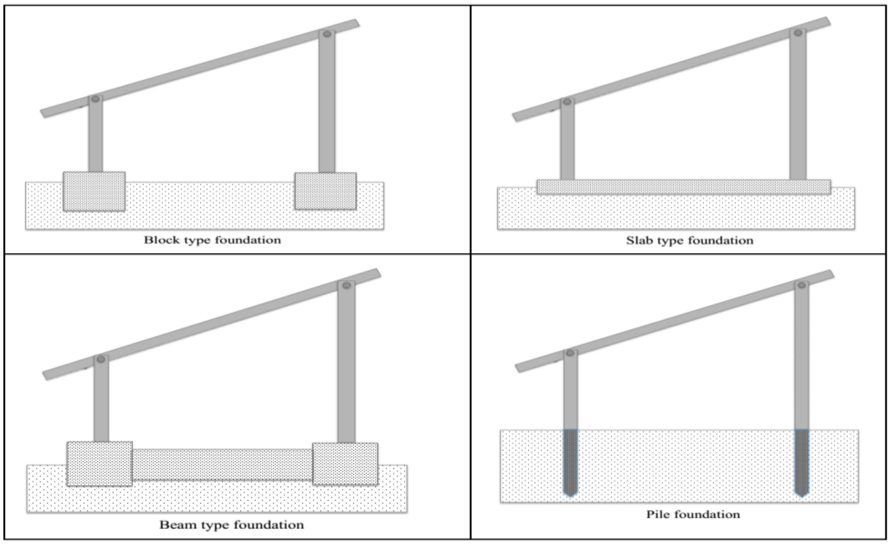


Fig.II. 6. Example of block type foundation

Fig.II. 7. Example of slab foundation

Installation procedure in the case of ground structure:

1 - Plant a first stake in the middle of your installation in the northern part

2 - Plant a second stake south of the first using a compass

3 - Stretch a string between the two stakes (this marking allows you to carry out the SOUTH mark).

4 - Plant two more stakes to draw the perpendicular (EAST / WEST).

5 - Realize the marking of concrete foundations

6 - Realize the foundations of type (plot) using an auger and a PVC tube to make the formwork

7 - Fixation of the structures can be carried out using a chemical seal (Figure 9: Fixing the structures by means of a chemical seal).

8 - In the case of solid concrete fastening the fastening can be carried out using an expansion anchor (Figure 10: Fastening the structures using an expansion anchor).[8]

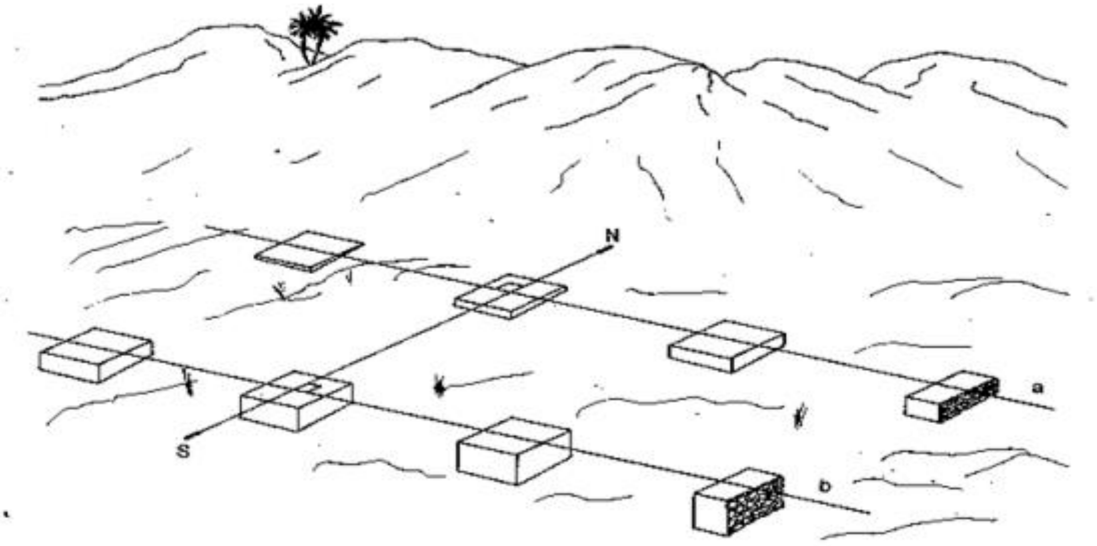


Fig.II. 8. Schematic diagram of realization of the foundations [8]

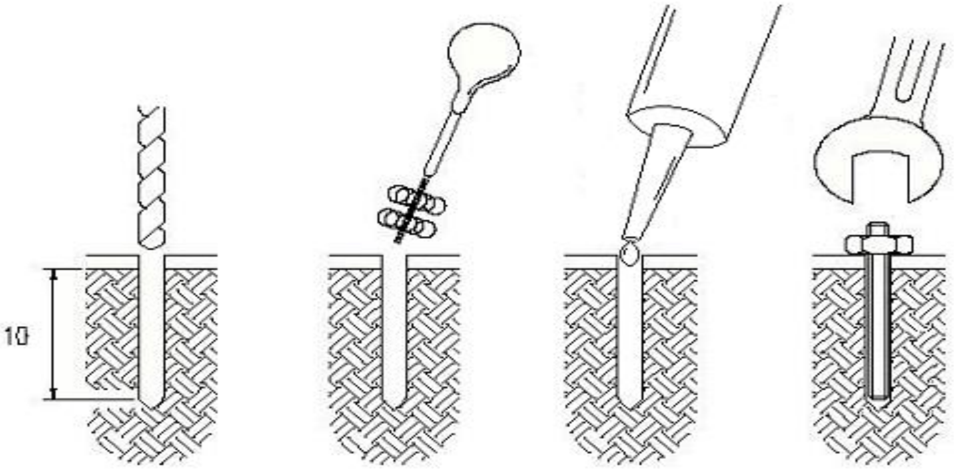


Fig. II.9. Fastening structures with a chemical seal [8]

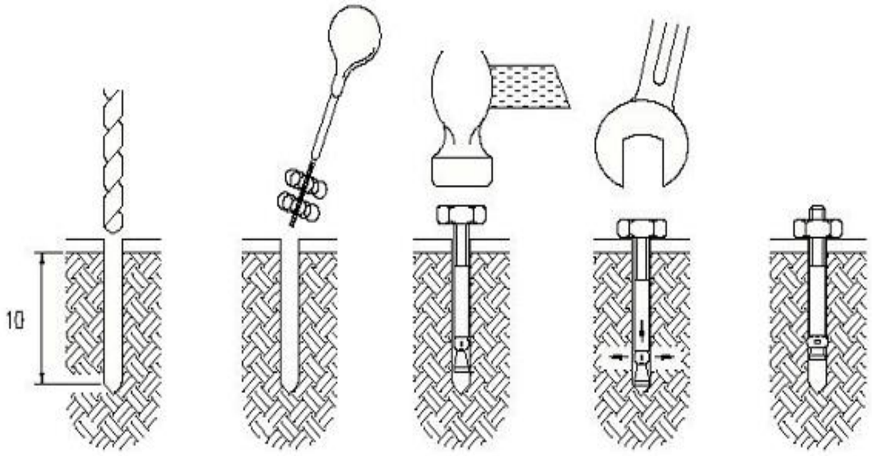


Fig.II. 10. Fastening structures with an expansion anchor [8]

II-2-3-4- Setting up modules

The solar panels are placed side by side, front face on the floor in order to mount them and assembled. Make sure that the boxes are all on the same side. For the installation of the structures, it is first necessary to mount the longitudinal members, that is to say the part of the structure on which the frame of the modules rests

The modules are fixed with stainless screws. To prevent theft, the use of anti-theft hardware is recommended. In this case it is necessary to glue the shattering nuts when tightening with the threadlocker.

Figure.II. 11 Self-locking antitheft nut, Panel mounting principle [8]

- After setting up the modules we move on to the next stage :

Step 1 - Fix the regulator

- The unit should be installed in a dry and well-ventilated place, as close to the batteries as possible, but not on top of it.
- Keep a free space of at least 10cm around the unit for cooling [9].

Step 2 - Connecting the batteries

1. Connect your batteries in series

- Tighten a cable between the positive (+) terminal and the negative (-) terminal of each of your aligned batteries (see below) :

2. Connect your charge controller to your battery bank:

a. Crimp the M8 lugs provided in the kit on one end of each (+) and (-) cable that will re-align the battery bank to the regulator.
b. Starting from your charge controller, connect the cable from the positive (+) battery slot to the positive (+) terminal of your battery bank.

c. Starting from your charge controller, connect the cable from the negative (-) battery slot to the negative (-) terminal of your battery bank.

Cables connecting the regulator and batteries must not be more than 2 m long. Otherwise, please use a larger cable section (6mm² up to 5m long) [9].

Step 4 - Connecting the solar panel

IMPORTANT: Always connect the batteries to the regulator BEFORE the solar panel (s).

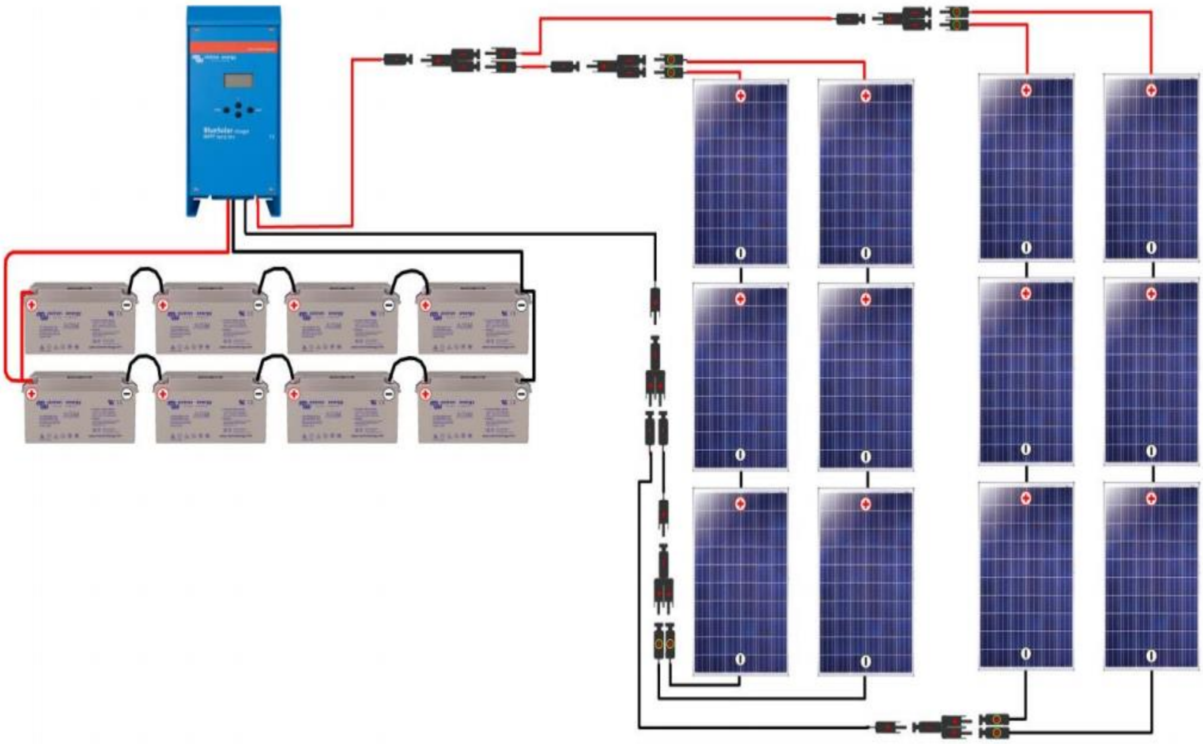
1. To connect the panel, make two extensions long enough to cover the length between the solar charge controller and your solar panels.

For each extension, it will be necessary:

- A first cable set with a male MC4 tip connected to the negative (-) terminal of the regulator.
- A second cable crimped with a female MC4 tip connected to the positive (+) terminal of the regulator.

2. Make four sets of three panels in parallel, as in the diagram below:

- Each group of 3 panels will have its positive (+) pole clipped on a MC4 Y connector.
- Each group of 3 panels will have its negative pole (-) clipped on a MC4 Y connector.
- Connect the MC4 Y on the respective extensions from the regulator performed previously [9].



Step 5 - Connecting devices

To use devices such as lighting or other, it will connect your equipment directly on the battery bank. Be careful not to discharge your batteries more than 50% at the risk of damaging them [9].

Step 6 - Connecting the voltage converter

To connect the voltage converter:

1. Crimp the M8 lugs (provided in the kit) on the ends of each (+) and (-) cable of the converter.
2. Connect the cable from the positive (+) terminal to the positive (+) terminal of the battery.

3. Connect the black cable from the negative (-) terminal to the negative (-) terminal of the battery [9].

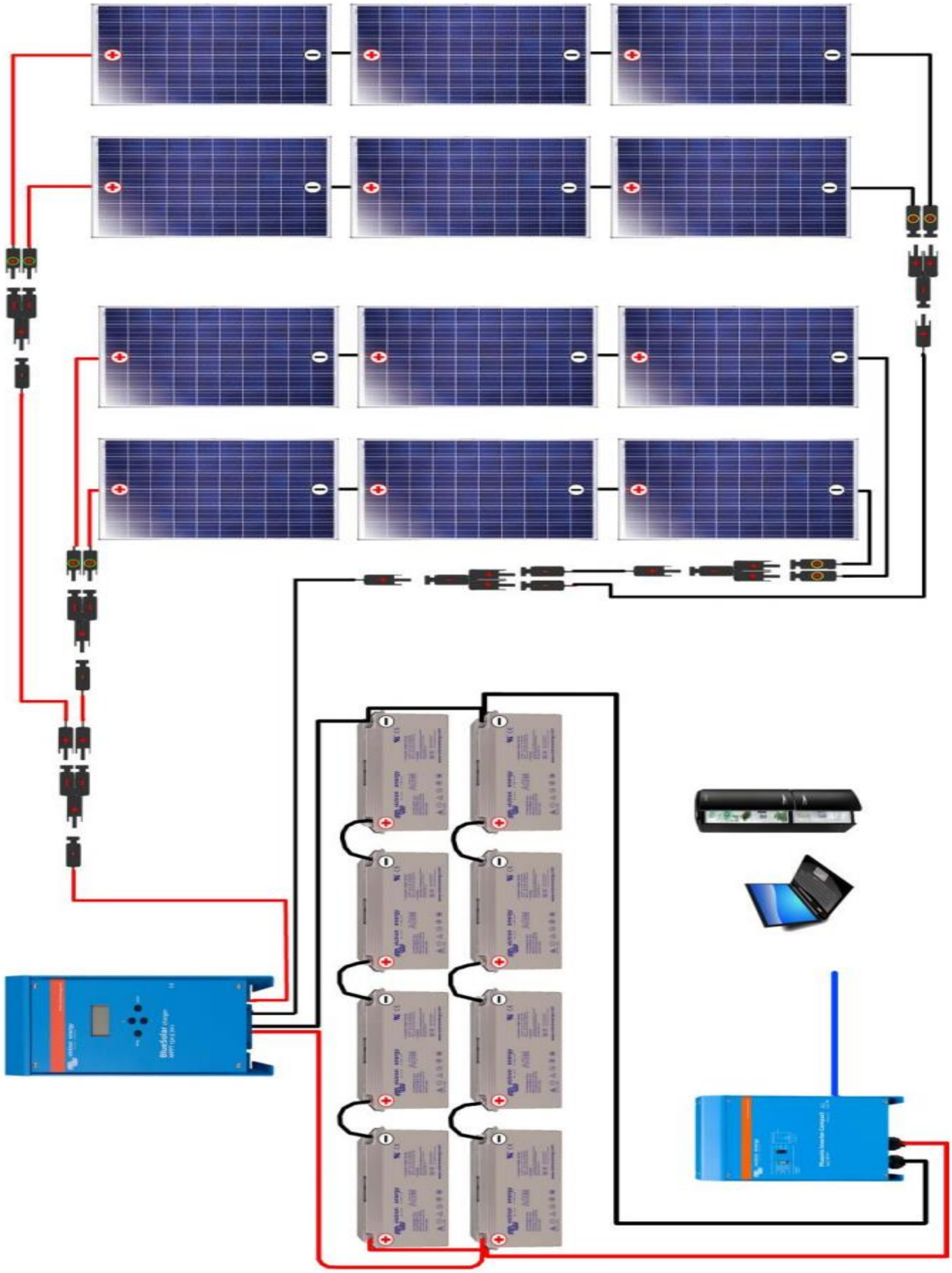


Fig.II .12. General scheme [9]

II-2-3-5- Other Equipment Location

One of the main steps of site survey is to determine the location of the control equipment, inverter, battery bank, earth pits and cable route.

- Controls and inverter should be placed in such a way that access is controlled.

- Switches are to be located in a place which is easily accessible.

Fig.II.13. Example of location for inverter, control and switching devices [7].

- ✓ Batteries should be installed in a separate room closed to the inverter /control room and access to the room should be controlled.
- ✓ Batteries to be located in cool and dry and well ventilated place.

Fig.II.14. Location of battery bank in a separate well ventilated room [7]

II-2-4-Power distribution system

Three basic configurations could be applied for distribution of power in solar microgrid systems. Applicability and techno-economic feasibility of these configurations depend on system capacity, configuration, equipment type and distribution of loads.

(i) DC distribution system;
(ii) AC single phase distribution system;
(iii) AC three phase distribution system.

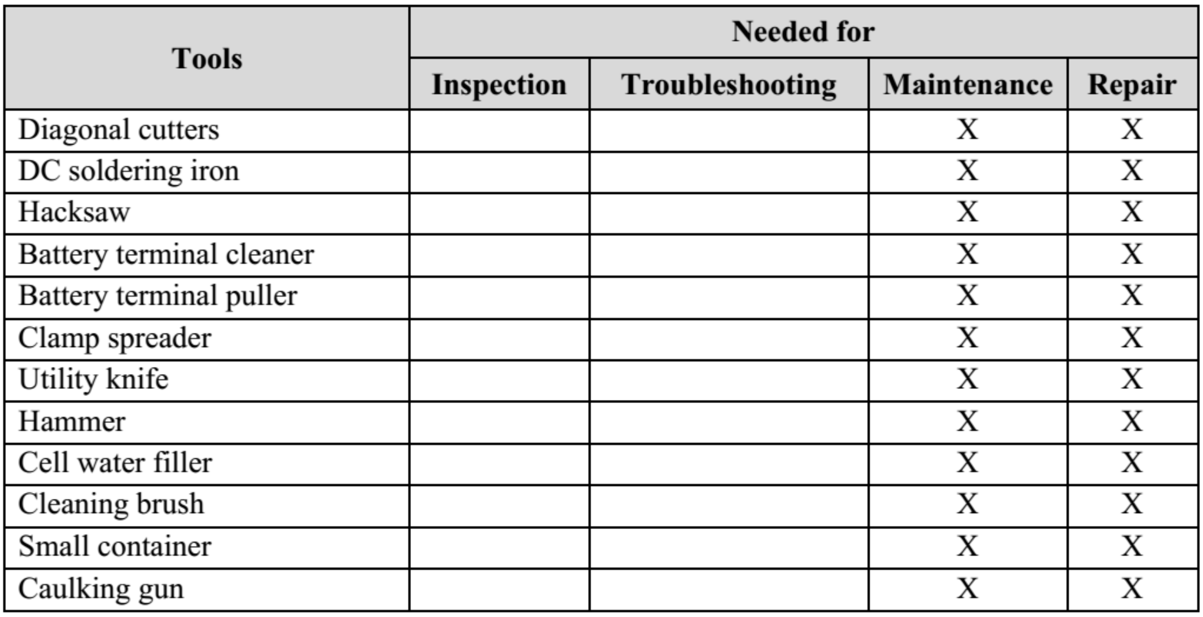
II-3- Solar system maintenance

II-3-1- Tools required for operation and maintenance

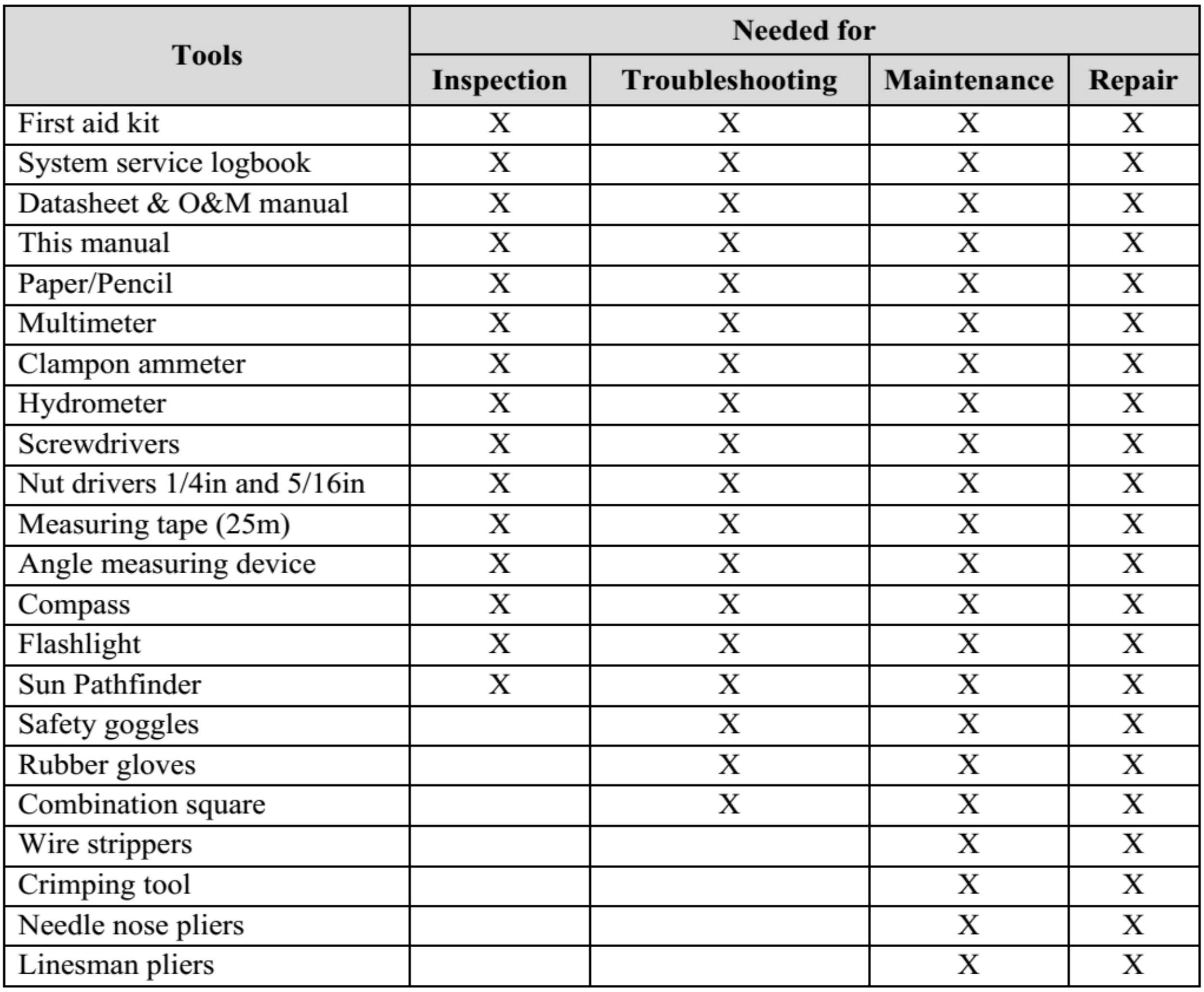
Solar systems are generally installed in remote locations. Therefore, it is important that all essential tools, spares and consumables are kept in the site ready for use. A list of such tools and materials are listed below. Some systems may require special tools not listed here. In such cases, tools required as per site condition or special tools recommended by the equipment manufacturer should be used.

Person responsible for O&M of solar microgrid systems must familiar and equipped with these tools & equipment. Also, they must be kept in a secured location and maintained properly. Measuring instrument must be checked regularly for its functionality and accuracy.

Table.II.1 : List of tools and materials required for O&M of solar microgrid systems.



Tools	Needed for			
	Inspection	Troubleshooting	Maintenance	Repair
Diagonal cutters			X	X
DC soldering iron			X	X
Hacksaw			X	X
Battery terminal cleaner			X	X
Battery terminal puller			X	X
Clamp spreader			X	X
Utility knife			X	X
Hammer			X	X
Cell water filler			X	X
Cleaning brush			X	X
Small container			X	X
Caulking gun			X	X



Tools	Needed for			
	Inspection	Troubleshooting	Maintenance	Repair
First aid kit	X	X	X	X
System service logbook	X	X	X	X
Datasheet & O&M manual	X	X	X	X
This manual	X	X	X	X
Paper/Pencil	X	X	X	X
Multimeter	X	X	X	X
Clampon ammeter	X	X	X	X
Hydrometer	X	X	X	X
Screwdrivers	X	X	X	X
Nut drivers 1/4in and 5/16in	X	X	X	X
Measuring tape (25m)	X	X	X	X
Angle measuring device	X	X	X	X
Compass	X	X	X	X
Flashlight	X	X	X	X
Sun Pathfinder	X	X	X	X
Safety goggles		X	X	X
Rubber gloves		X	X	X
Combination square		X	X	X
Wire strippers			X	X
Crimping tool			X	X
Needle nose pliers			X	X
Linesman pliers			X	X

Recommended materials and supplies list for repair or maintenance :

- ✓ Distilled water
- ✓ Baking soda
- ✓ Wire nuts
- ✓ Crimp connectors
- ✓ Ring, spade, and lug terminals
- ✓ Load, inverter, and charge controller fuses
- ✓ Rosin core electrical solder
- ✓ Conduit connectors
- ✓ Cable ties
- ✓ Rags or paper towels
- ✓ Dish soap or pulling grease
- ✓ Red and black electrical tape
- ✓ Assorted screws and nails
- ✓ Cable, wire and/or conduit, as needed
- ✓ Silicone sealant

II-3-2- Preventive Maintenance

A sample maintenance schedule is presented below to indicate typical frequencies of maintenance actions.

Weekly Maintenance:

- Clean PV array from dust, birds drop. Use clean water and avoid hard water.
- Observe battery state of charge (SOC) using hydrometer. In case of VRLA battery use voltmeter to measure voltage to check corresponding SOC [7].

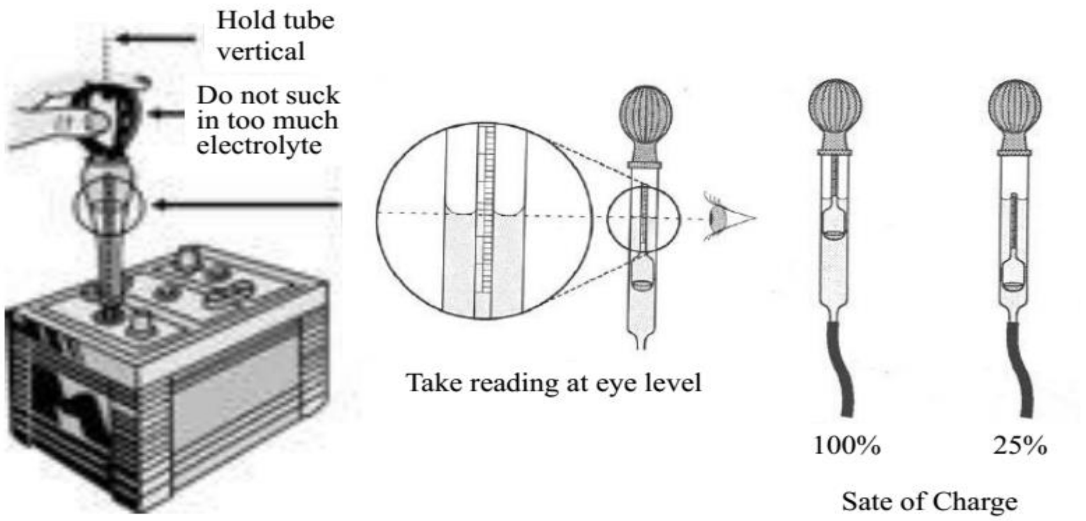


Fig.II.15. Observe battery state of charge (SOC)

Table.II. 2: Typical Battery Voltages as Function of State of Charge

SOC	Specific Gravity	Battery Voltage	
		12 volt	24 volt
100%	1.265	12.68	25.35
90%	1.250	12.60	25.20
80%	1.235	12.52	25.05
70%	1.225	12.44	24.88
60%	1.210	12.36	24.72
50%	1.190	12.28	24.56
40%	1.175	12.20	24.40
30%	1.160	12.10	24.20
20%	1.145	12.00	24.00
10%	1.130	11.85	23.70
0 %	1.120	11.70	23.40

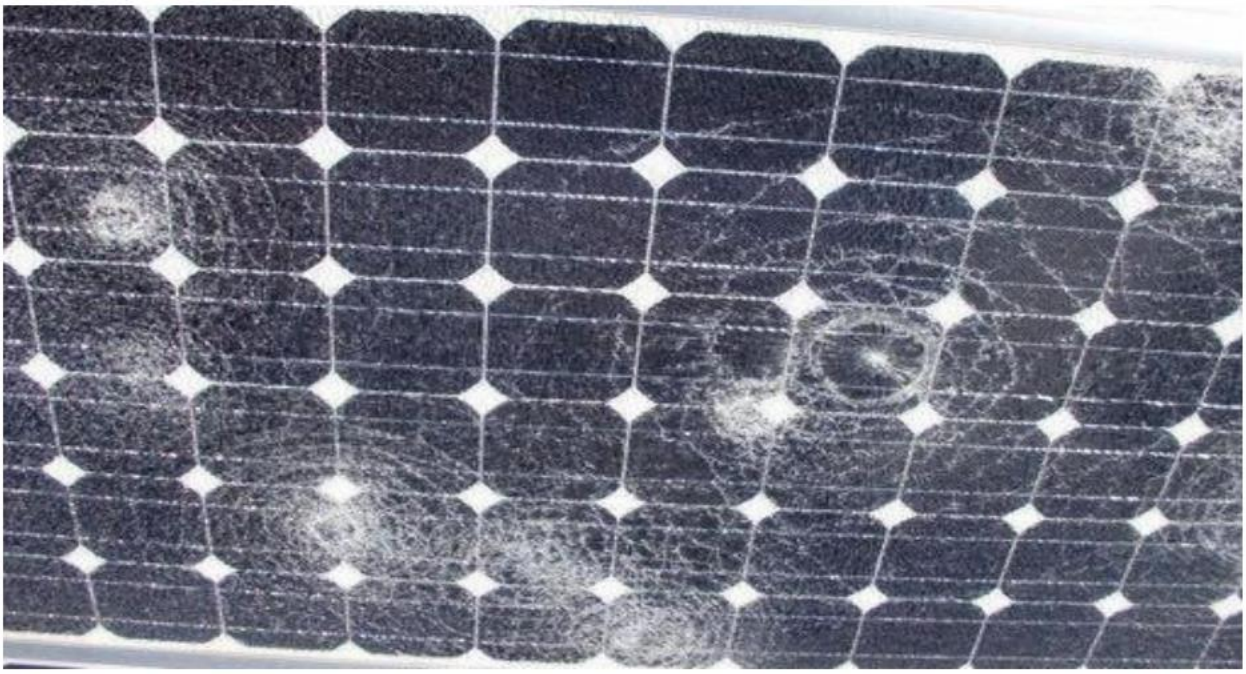
II-3-3- Monthly Maintenance:

- If flooded lead acid batteries are use check electrolyte level and top up if required. Wipe electrolyte residue from the top of the battery.

-Inspect all terminals for corrosion and loosened cable connections. Clean and tighten as necessary. After cleaning, add anti-oxidant to exposed wire and terminals.

-Check if new loads have been added and system is overloaded

-Inspect array for broken modules. If any, replace it with appropriate module



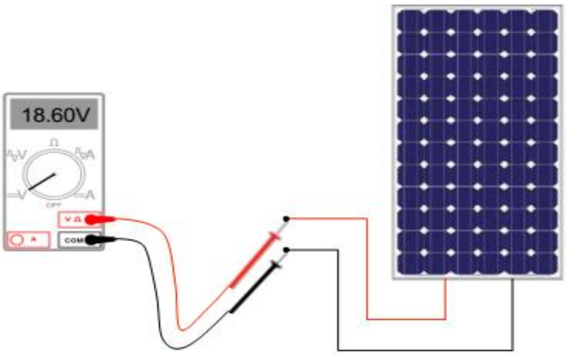
II-3-4- Annual Maintenance:

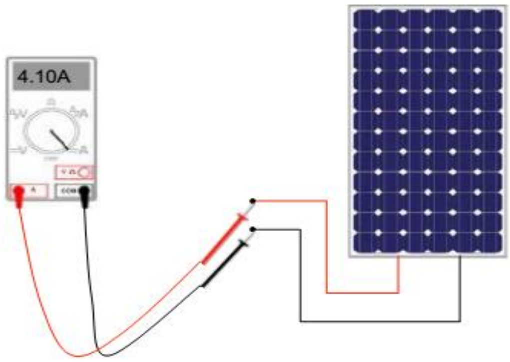
- Check array wiring for physical damage and wind chafing

- Check array mounting hardware for tightness

- Inspect inverter - remove dust or dirt, inspect system wiring for poor connections. Look for signs of excessive heating, inspect controller for proper operation

- Verify output from the array (Isc and Voc and if possible Imp and Vmp)





II-3-5- Inspection and maintenance of Earthing and Lightening Protection

- Use an ohmmeter to check the continuity of the entire grounding system.
- Make sure that all module frames, metal conduit and connectors, junction boxes, and electrical components chassis are earth grounded [7] .

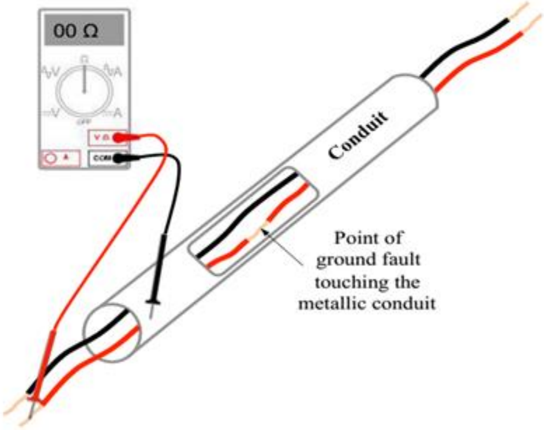


Fig.II. 16. Finding a ground fault

II-3-6- Inspection and maintenance of System Wiring

- Visually check all conduit and wire insulation for damage.
- Check for loose, broken, corroded, or burnt wiring connections.
- Check if all equipments are connected with proper wire and conduit
- Make sure all wiring is secured, by gently but firmly pulling on all connections.
- Check all terminals and wires for loose, broken, corroded, or burnt connections or components.

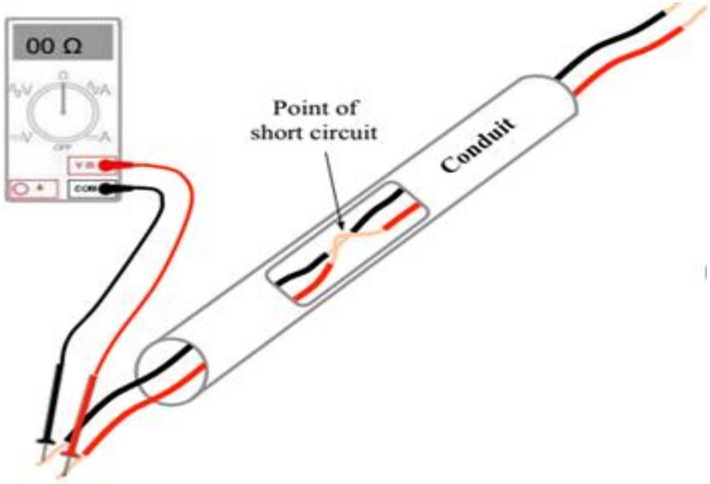


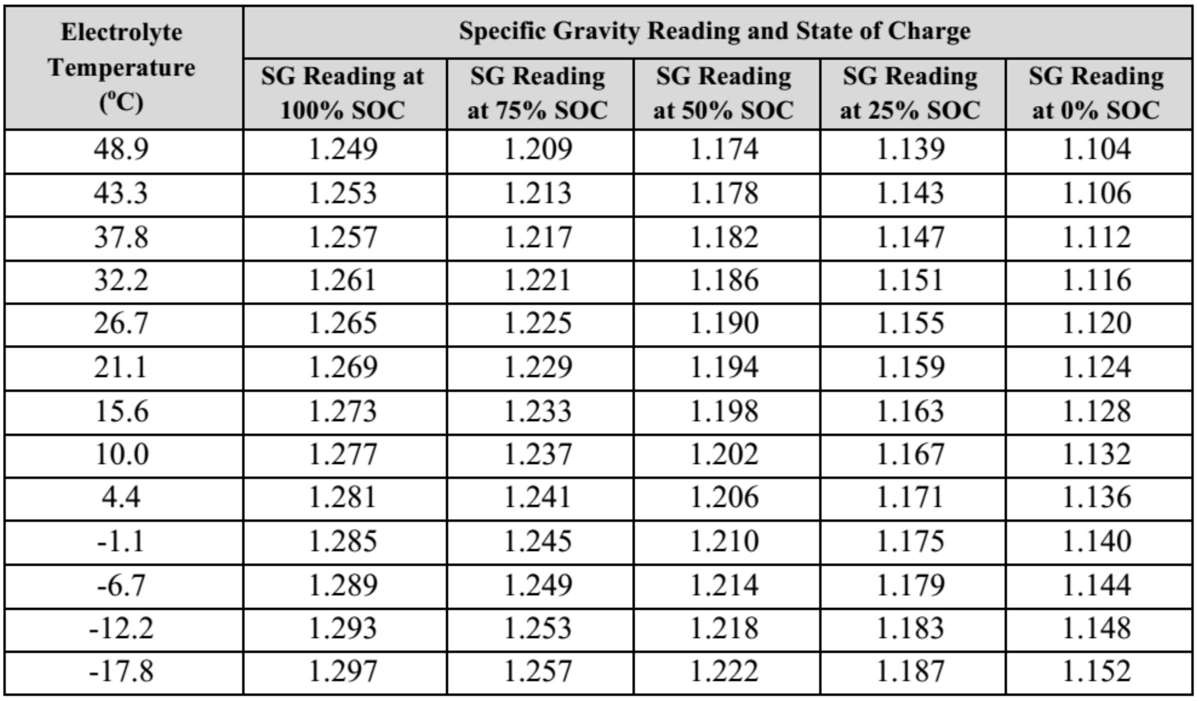
Fig.II .17. Finding a short circuit.

II-3-7- Inspection and maintenance of Batteries

Battery is very important component in the solar system; therefore proper care should be taken. For long life, battery should be cleaned monthly; the electrolyte level should be checked and kept in a high state of charge. When cleaning batteries, beware of the battery acid and do not short the terminals. Carry the battery outside when cleaning to avoid spilling acid, keep plenty of water nearby to rinse spills [10,11].

i. Checking state of charge

A hydrometer describes the state of charge by determining the specific gravity of the electrolyte. Usually, the specific gravity of electrolyte is between 1.120 and 1.265. At 1.120, the battery is fully discharged. At 1.265, it is fully charged.



Electrolyte Temperature (°C)	Specific Gravity Reading and State of Charge				
	SG Reading at 100% SOC	SG Reading at 75% SOC	SG Reading at 50% SOC	SG Reading at 25% SOC	SG Reading at 0% SOC
48.9	1.249	1.209	1.174	1.139	1.104
43.3	1.253	1.213	1.178	1.143	1.106
37.8	1.257	1.217	1.182	1.147	1.112
32.2	1.261	1.221	1.186	1.151	1.116
26.7	1.265	1.225	1.190	1.155	1.120
21.1	1.269	1.229	1.194	1.159	1.124
15.6	1.273	1.233	1.198	1.163	1.128
10.0	1.277	1.237	1.202	1.167	1.132
4.4	1.281	1.241	1.206	1.171	1.136
-1.1	1.285	1.245	1.210	1.175	1.140
-6.7	1.289	1.249	1.214	1.179	1.144
-12.2	1.293	1.253	1.218	1.183	1.148
-17.8	1.297	1.257	1.222	1.187	1.152

Table.II. 3: Battery specific gravity and corresponding state of charge [7]

ii. Battery load test:

For this test, an accurate DC voltmeter is required.
- Operate the system loads from the batteries for five minutes. This will remove any minor "surface charge" the battery plates may have. Turn off the loads and disconnect the batteries from the rest of the system.
- Measure the voltage across the terminals of every battery, as shown in Figure 18 below. If external cell connectors are used, measure the voltage across each cell, as shown in Figure 19 Do not attempt to measure individual cell voltages unless the connectors are external.

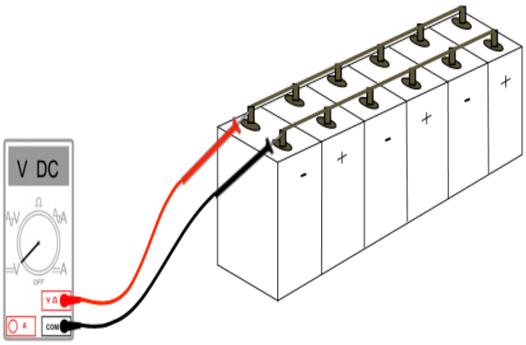


Fig .II.18.Measuring the Open Circuit Voltage of Cells with External Connections [7]

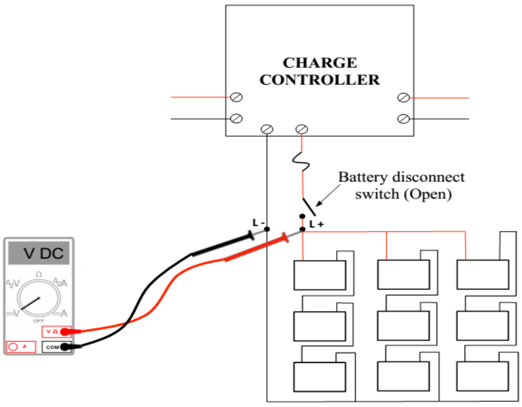
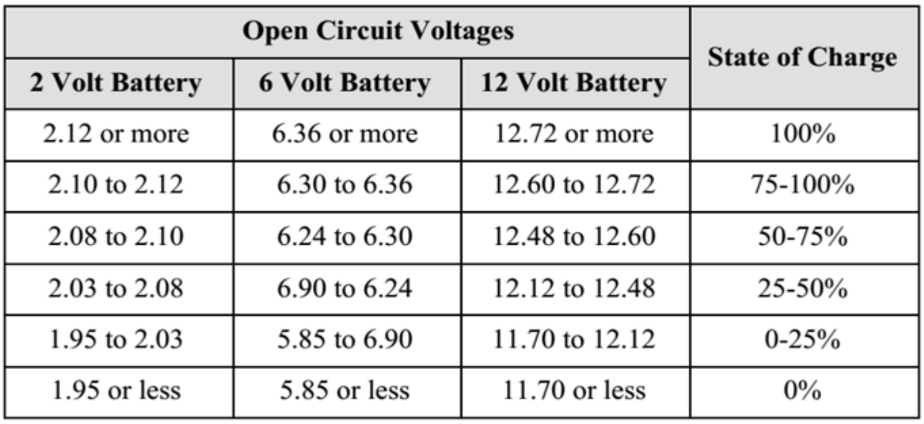


Fig .II.19.Measuring the Batteries' Open Circuit Voltage [7]



Open Circuit Voltages			State of Charge
2 Volt Battery	**6 Volt Battery**	**12 Volt Battery**	
2.12 or more	6.36 or more	12.72 or more	100%
2.10 to 2.12	6.30 to 6.36	12.60 to 12.72	75-100%
2.08 to 2.10	6.24 to 6.30	12.48 to 12.60	50-75%
2.03 to 2.08	6.90 to 6.24	12.12 to 12.48	25-50%
1.95 to 2.03	5.85 to 6.90	11.70 to 12.12	0-25%
1.95 or less	5.85 or less	11.70 or less	0%

Table.II. 4 : Battery open circuit voltage and corresponding states of charge [7]

II-3-8- Inspection and maintenance of Solar Arrays

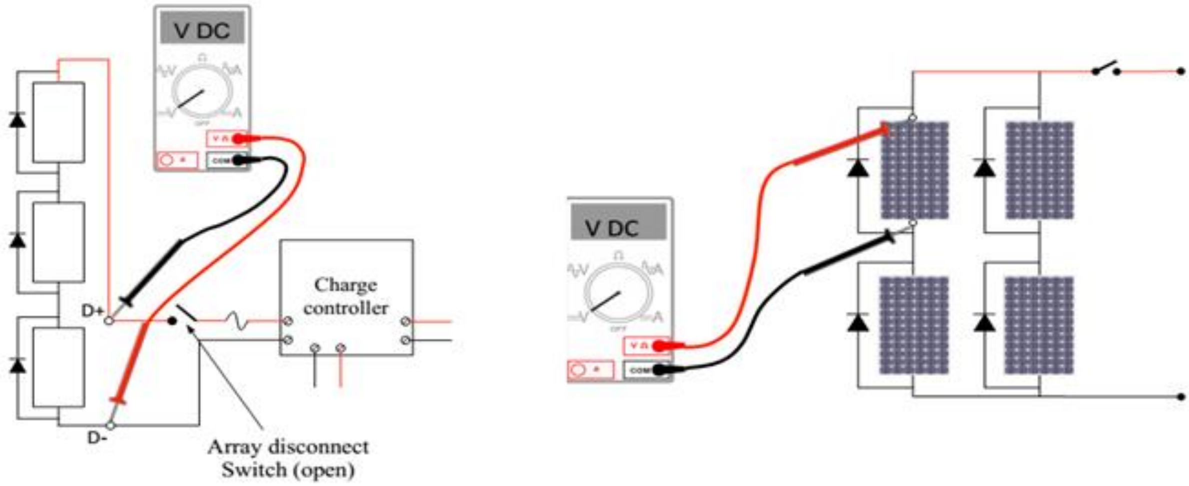
- Use a DC clamp-on ammeter to determine the array output current during a sunny weather.

- Conduit and connections must all be tight and undamaged. Look for loose, broken, corroded, vandalized, and otherwise damaged components. Check close to the ground for animal damage.

- You should wash the PV array, during the cool of the day, when there is a noticeable buildup of dust and dirt. Periodically inspect the system to make sure all wirings and supports are intact. Furthermore, check for tree growth that has shaded your modules and also check for birds' nests in your modules and junction boxes. Review the output of the system annually (assuming the array is clean) to see if the performance of the system is close to the previous year's reading. Do not scratch the glass casing of the module [11].

i. Measuring open circuit voltage

- Measure the open circuit voltage of the array as shown in the figure below. Compare the measured amount of open circuit voltage from the array against the manufacturer's specifications.



-a- -b-

Fig.II.20. a- Measuring the open circuit voltage of array b-Measuring the open cercuit voltage of module[7].

❖ Short circuit current:

- If your DC meter has leads, connect them to the positive and negative terminals of each module and set the meter to the 10A range.

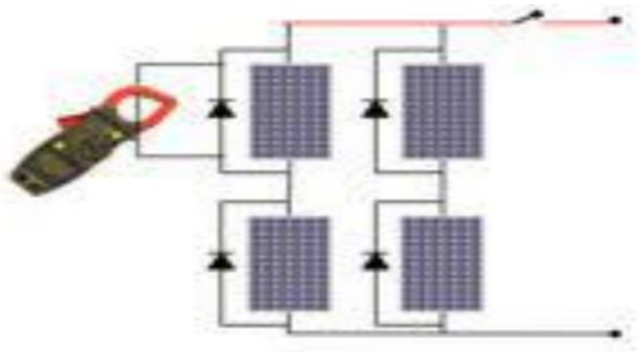


Fig .II.21. Measuring module short circuit current [7].

II-3-9- Inspection and maintenance of Inverters

- Check the operation of the inverter at the time of the inspection.
- Measure and record the current draw of the inverter in both idling and operating states.
- Check all inverter wiring for loose, broken, corroded, or burnt connections or wires.

Look for potential accidental short circuits or ground faults [7].

II-4- Influence of climate on solar panels

It is important to record the performance of PV modules under real climate condition since the outdoor PV electrical characteristic (voltage, current…) are different from those corresponding standard conditions (which are rarely occurs outdoor). The PV modules are rated at standard condition of 1000 W/m2 of irradiance, 25˚C of ambient temperature, air mass of 1.5, and 1 m/s wind speed different from outdoor environmental conditions [12]. Despite the fact that irradiation is the main indicator of PV potential, it is also necessary to consider secondary parameters such as PV technology, environmental parameters (wind, temperature, humidity) which allowed us to quantify with precision the amount of electricity produced by a PV system. Based on experimental investigation in Pakistan, it has been reported that monocrystalline silicon modules are more efficient than other modules, but have shown a higher decrease at higher module temperatures [13]. It has investigated that the impact of irradiance and temperature on PV system [14,15] . They have found that solar irradiance has the greatest impact on the power output of a PV system. Module temperature has significant influence on the behavior of a PV system, as it modifies system efficiency and output energy. Temperature affects how electricity flows through an electrical circuit by changing the speed at which the electrons travel. This is due to an increase in resistance of the circuit that results from an increase in temperature. Likewise, resistance is decreased with decreasing temperatures [16].

Because the current and voltage output of a PV panel is affected by changing weather conditions, it is important to characterize the response of the system to these changes so the equipment associated with the PV panel can be sized appropriately.

Solar panels work best in certain weather conditions, but since the weather is always changing and as engineers are installing solar panels all over the world in different climate regions, most panels do not operating under ideal conditions. That is why it is important for engineers to understand how panels react to different weather conditions. With this knowledge, they can design ways to improve the efficiency of solar panels that operate in non-optimal conditions.

II-4-1- Effect of temperature

Solar cells vary under temperature changes. The change in temperature will affect the power output from the cells. The voltage is highly dependent on the temperature and an increase in temperature will decrease the voltage [17].

The figure .II.22 below shows variation of efficiency with temperature at solar radiation of 1000W/m2. There is a linear relation between ambition temperature and module efficiency. Decreasing temperature results more efficiency. So for a desired efficiency of a photovoltaic module we can determine what temperature ambient of module is needed, so by changing temperature around PV module we can operate efficiency [17].

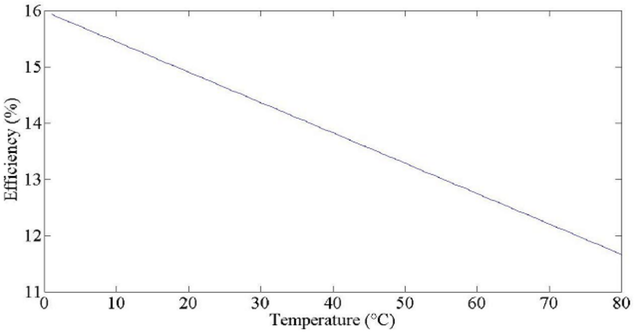


Fig.II.22. Photovoltaic cell efficiency versus temperature [17].

For each individual PV system, engineers must use specific equipment, such as inverters, to ensure that the system runs at maximum efficiency. Different inverters are rated for different maximum voltages and have higher efficiencies between different voltage ranges. Engineers must carefully size the PV system in different temperature environments to ensure that the output voltage is not too high, which could damage the equipment.

An active system might have fans to blow air over the panels, or pump water behind the panels to pull away heat. An active cooling system may be used in certain situations in which the added efficiency to the panels is greater than the energy needed to run the system, such as with a solar power plant in a desert. They also may be used in situations in which some additional purpose can be achieved, such as domestic water heating.

While it is important to know the temperature of a solar PV panel to predict its power output, it is also important to know the PV panel material because the efficiencies of different materials have varied levels of dependence on temperature. Therefore, a PV system must be engineered not only according to the maximum, minimum and average environmental temperatures at each location, but also with an understanding of the materials used in the PV panel. The temperature dependence of a material is described with a temperature coefficient. For polycrystalline PV panels, if the temperature decreases by one degree Celsius, the voltage increases by 0.12 V so the temperature coefficient is 0.12 V/C. The general equation for estimating the voltage of a given material at a given temperature is:

$$V_{OCambient} = \text{Temperature Coefficient} \times (T_{STC}\,[°C\,] - T_{ambient}\,[°C\,]) + V_{OC\ rated}\,[V] \quad \text{.....(II-1)}$$

Where :

Voc, mod = open circuit voltage at module temperature
TSTC [°C] = temperature at standard test conditions, 25 °C, 1000 W/m2 solar irradiance
Tambient [°C] = module temperature
Voc,rated = open circuit voltage at STC

As an example, for polycrystalline, the equation is:

$$V_{OCnew} = 0.12\,[V/C] \times (25\,[°C] - T_{ambient}\,[°C]) + V_{OC.rated}\,[V]\text{............(II-2)}$$

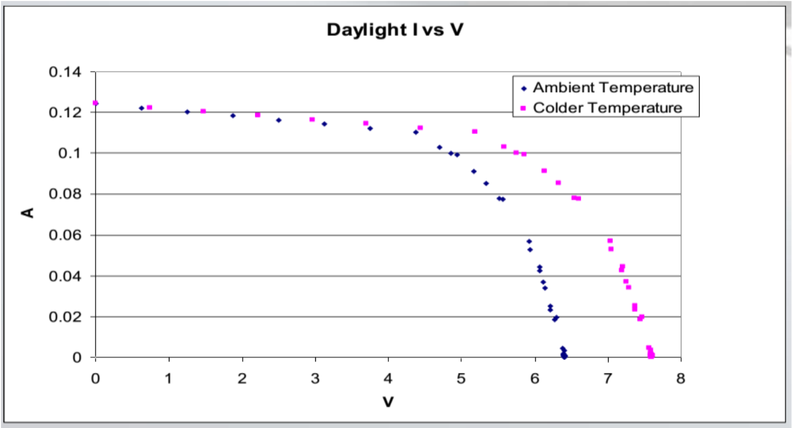


Fig.II.23. These two I-V curves show the temperature dependence of the voltage output for a PV panel. The voltage output is greater at the colder temperature. **.** *[18]*

The effect of temperature can be clearly displayed by a PV panel I-V (current vs. voltage) curve. I-V curves show the different combinations of voltage and current that can be produced by a given PV panel under the existing conditions. Two sample I-V curves at different temperatures for the educational modules are shown in Figure 23. To gather data for this graph, a PV panel was placed flat on the ground in Boulder, CO, at 40° latitude on December 11. The first measurements were taken in ambient temperature conditions, and then they were taken again after the panel was cooled in an ice bath for one minute. The resulting graph clearly shows that when the panel is at a colder temperature, a higher voltage, and thus a higher power output, is achieved [18].

II-4-2- Effect of Humidity on the Efficiency of Solar Cell (photovoltaic)

As per the fact that the earth's crust mainly consists of 70% of Water, the energy which strikes the earth is indirectly striking the water/oceans which helps in increasing of humidity level on the overall basis. The humidity doesn't only create hurdles for the energy actually received at the top of the atmosphere but also effects the device consumptions by many aspects [19].

The aspects what we covered is the effect of humidity on the Solar panels which create obstacles for drastic variation in the power generated, indirectly making the device work less efficient than it could have without it. The cities where in the humidity level is above the average range of 30 actually results in the minimal layer of water on the top of the Solar panel which results in decreasing of the efficiency [20].

As per the facts when the light consisting of energy/Photon strikes the water layer which in fact is denser, Refraction appears which results in decreasing of intensity of the light which in fact appears the root cause of decreasing of efficiency. Additional there appears minimum components of Reflection which also appears on the site and in that, there appears light striking is subjected to more losses [20].

The usage of the Solar Panel is readily effected by the effect of humidity and the values corresponds to change is the humidity is subjected to change

Various experiments were conducted and this one of them. The results showed the drastic change in the readings when the humidity was subject to gradually increase. Below is the chart in where the readings are noted :

Temerature (K)	Humidity (%)	Voltage(V) (DC)	Current (V) (DC)	Powers (Watts)
305	25	17.10	2.78	47.538
305	30	16.72	2.63	43.973
305	35	16.53	2.42	40.002
305	40	16.45	2.30	37.605
305	45	16.41	2.14	35.117
305	50	16.33	2.04	33.313
305	55	16.32	1.88	30.681

Table.II.5 : Humidity vs. Voltage.current and power readingstaken throuth the experimental set up as discussed [20].

Below are the graphs where in the relation between Humidity to voltage, current and power.

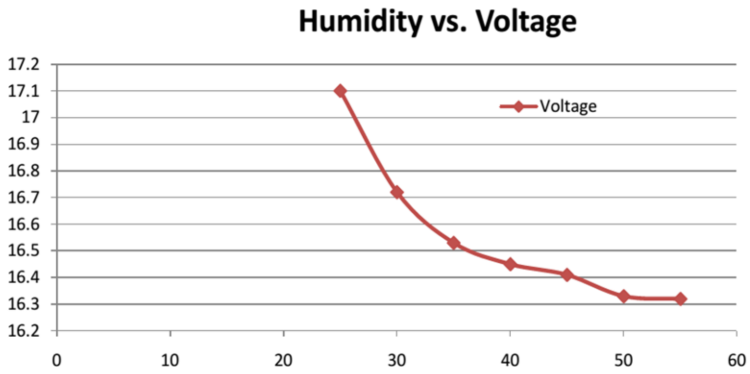


Fig.II.24. Graph between Humidity and Voltage. Humidity appears as X axis and Voltage appears at Y axis [18]

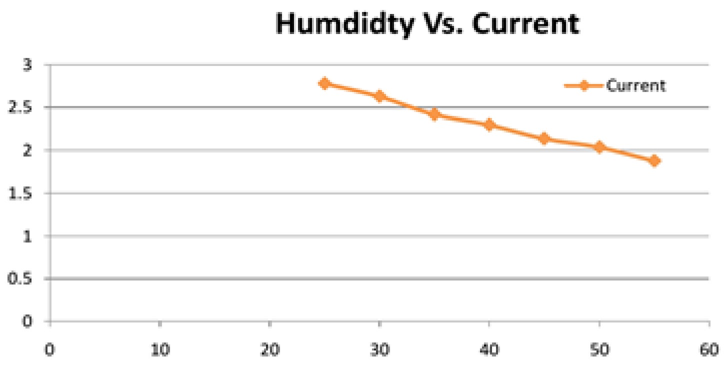


Fig.II.25. Graph between Humidity and Current. Humidity appears as X axis and Current appears at Y axis [20].

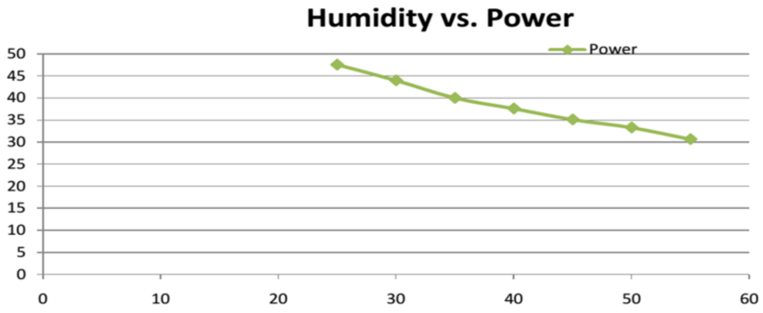


Fig.II.26. Graph between Humidity and Power. Humidity appears as X axis and Power appears at Y axis [20]

II-4-3- Effect of cloudiness on the production of electricity by photovoltaic panels

The ambient climate conditions in which the photovoltaic panels are located affects The production of electric energy. In this part, we will focus mainly on the impact of changing climatic conditions for the production of electricity. In particular, the incidence of various types of cloudiness which are formed during the day and at certain time intervals prevents impact of the direct solar radiation on the photovoltaic panels.

Basic international classification divides clouds into 10 cloud types. The following Figure 27 shows ten basic types of cloud [21].

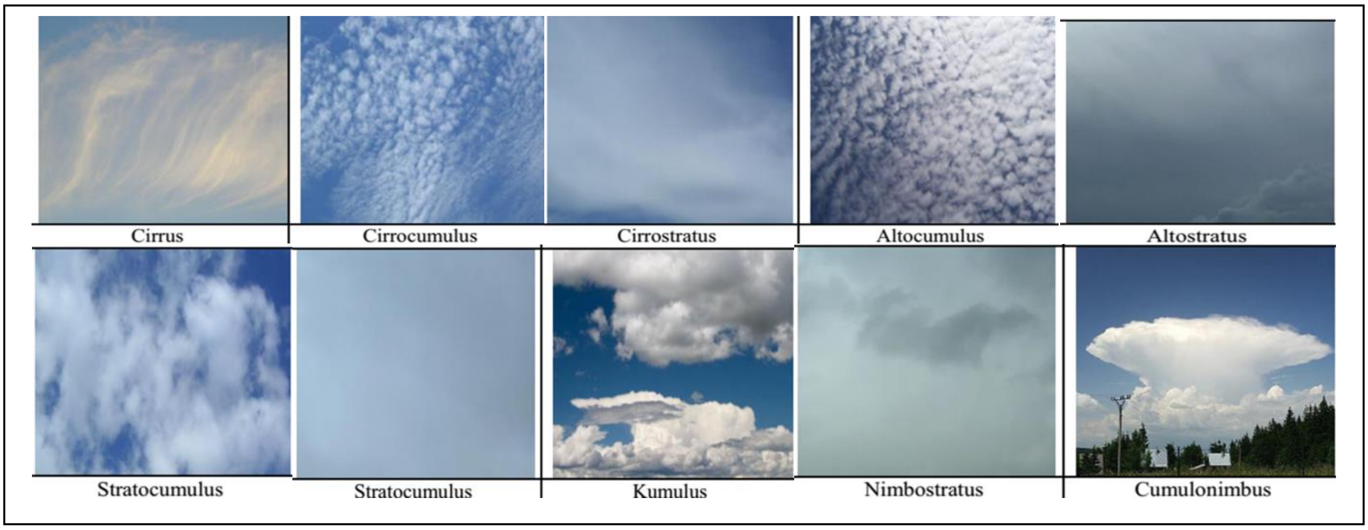
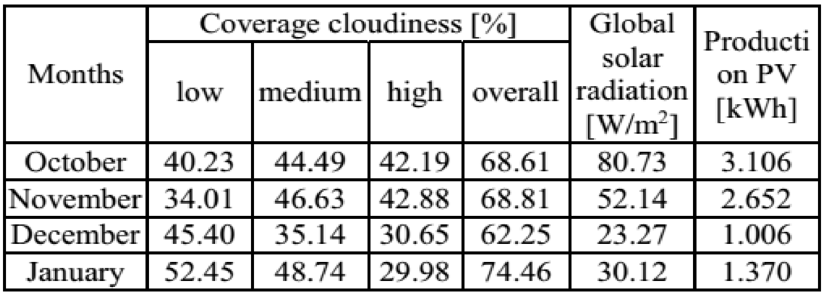


Fig.II.27. Basic types of cloud

On the roof of the building FAI TBU is a small photovoltaic plant. The system consists of 9 photovoltaic panels with a total area of 11.25 square meters. The panels used, are of the type of polycrystalline photovoltaic cells. The producer of these panels has declared an energy efficiency of 15 % (for angle of the panels surface inclined from the horizontal one of 45 ° with the southeast azimuth of the normal direction to the panel surface).

Collecting meteorological conditions occurred at the placement of photovoltaic panels in October, November, December, and January in year 2015 and 2016, respectively. For this purpose, the weather station on the building was used.

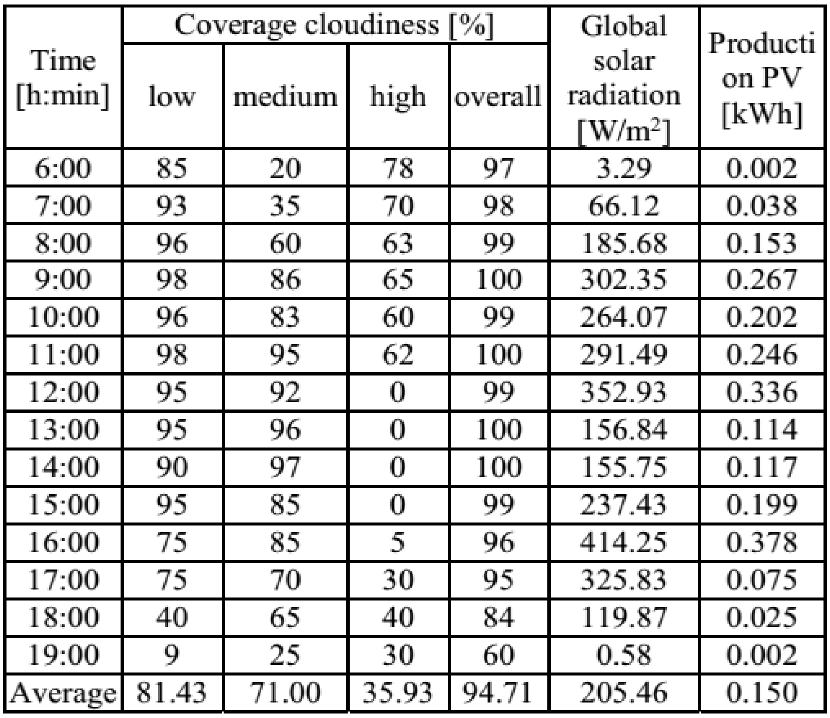
Tabale.II. 6. Coverage cloudiness in selected months.



Months	Coverage cloudiness [%]				Global solar radiation [W/m^2]	Production PV [kWh]
	low	medium	high	overall		
October	40.23	44.49	42.19	68.61	80.73	3.106
November	34.01	46.63	42.88	68.81	52.14	2.652
December	45.40	35.14	30.65	62.25	23.27	1.006
January	52.45	48.74	29.98	74.46	30.12	1.370

Table.II. 7 details the values of electrical energy production for selected day in the month of November.

Tabale.II. 7. Production of electricity in different parts of the day



Time [h:min]	Coverage cloudiness [%]				Global solar radiation [W/m^2]	Production PV [kWh]
	low	medium	high	overall		
6:00	85	20	78	97	3.29	0.002
7:00	93	35	70	98	66.12	0.038
8:00	96	60	63	99	185.68	0.153
9:00	98	86	65	100	302.35	0.267
10:00	96	83	60	99	264.07	0.202
11:00	98	95	62	100	291.49	0.246
12:00	95	92	0	99	352.93	0.336
13:00	95	96	0	100	156.84	0.114
14:00	90	97	0	100	155.75	0.117
15:00	95	85	0	99	237.43	0.199
16:00	75	85	5	96	414.25	0.378
17:00	75	70	30	95	325.83	0.075
18:00	40	65	40	84	119.87	0.025
19:00	9	25	30	60	0.58	0.002
Average	81.43	71.00	35.93	94.71	205.46	0.150

From the measured values, which are listed in table 7, the occurrence of cloudiness in the different parts of the year, showing that the overall power production in individual months affects irradiance photovoltaic modules. On the other hand, the individual cloudy days do not affect the overall production of electricity. Decisive in this case, that the average value of the solar radiation and the lighting time of photovoltaic panels which are different each part of the year. Table 7 lists grade cloud cover, solar radiation and the amount of electricity produced by photovoltaic panels for each hour. These values were measured for each day in months [22].

II-5- Conclusion

This part presents the techniques and steps of photovoltaic field installations, maintenance techniques. Finally, we discussed the effects of weather on the efficiency of solar panels.

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Chapter III :

Results and discussions

III-1- Introduction

One of the disadvantages of solar panels is their vulnerability to climate. And one of the most important climatic conditions affecting solar panels: sand storms

In this chapter we will discuss the effect of sandstorm and dust on solar panels.

The effect of the sandstorm and dust on solar panels has been studied, So we have innovated an artificial system shown in Figure III- 1. To study the influence of the sandstorm for different doses on a panel solar in the laboratory.

The results shows that with the increase in projected sand masses, roughness increases sharply, while optical transmission is steadily decreasing

And to protect solar panels and improve their yield for longer. In this work, we present a simple and cheap method to protect the solar panel. This method based on the covering the solar panel by a plastic sheet which can be changed from time to time.

III-2- Effect of dust on solar panels

Photovoltaic (PV) systems deployed in desert areas are exposed to wind-blown particles during most of their life [1].

So, the PV panels are operated in an open atmosphere, where it experiences a significant variation due to environmental parameters, such as wind speed, ambient temperature, solar radiation, humidity and dust pollutants [2]. These environmental parameters affect the performance of PV panel in an open atmosphere. Among these parameters dust plays a significant role in reducing the performance of PV panel. The deposition of dust on PV panel surface is the main cause for its performance degradation [3]. Dust creates a barrier between PV panel surface and sunlight falling on its surface, which attenuates the part of the incoming sunlight. The attenuation of sunlight depends on the size of dust, density of dust and type of dust. This attenuation of sunlight considerably reduces the performance of PV panel [4].

The research activity and development in PV field has usually been focused on solar radiation analysis, efficient operating strategies, design and sizing of these systems. Previous papers analyze the PV module in terms of panel modeling and I-V characteristic. However, in these works, critical aspects and external conditions that could involve the PV system are not taken into account. Solar cell efficiency is an important input parameter in PV-powered product design. Often, only limited space is available for the solar cells to be integrated. Cell efficiency can even become a criterion of principal system feasibility. As a basic parameter, cell efficiency serves as an input in calculating the optimal system configuration, eg, as a cost related trade-off between the storage unit and its lifetime, PV size and its efficiency, and finally the demand side (with correlated consumption profiles). Although these calculations are well known for autonomous PV systems, eg [5], device integrated PV systems, especially when used indoors, become more complex to model. Power measurements of PV modules in test laboratories and industry are usually performed with solar simulators. Dust is the lesser acknowledged factor that significantly influences the performance of the PV installations. Few studies analyzed this effect and the consequent efficiency degradation [6].

It appears that the sandblasting has a relatively weak effect on the solar cells' efficiency (Ef = 0.88). Besides, dust particles can lodge in the sites produced by sand grains. Also, the effects of dust on the performance of PV panels was studied [7]; dust has an effect on the performance of solar PV panel. The reduction in the peak power generated depends on size and density of dust particle [8, 9].

Previous studies [10, 11] showed that reduction could reach 15%.. It was also shown that under greater irradiation, the effect of dust became slightly reduced but not negligible. In this part of the thesis we assign it to explain the systeme we have innovated "artificial system" presented in Figure III-1. To study the influence of sandstorm for different doses on solar panel in laboratory.

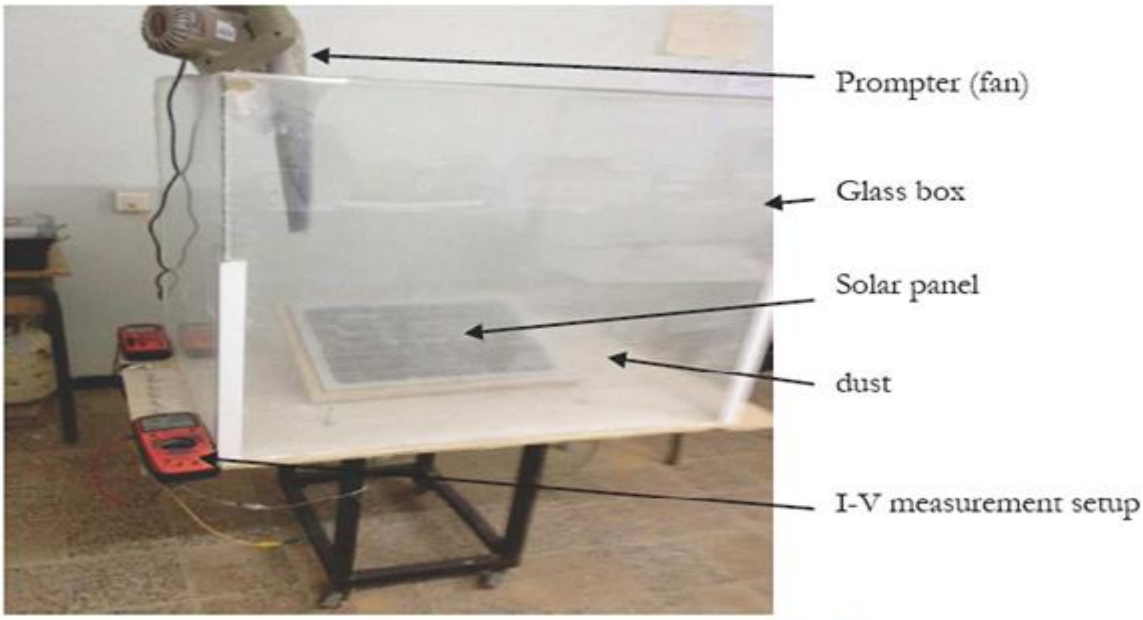

Fig.III.1 Our artificial system to study the influence of sandstorm on solar panel in laboratory

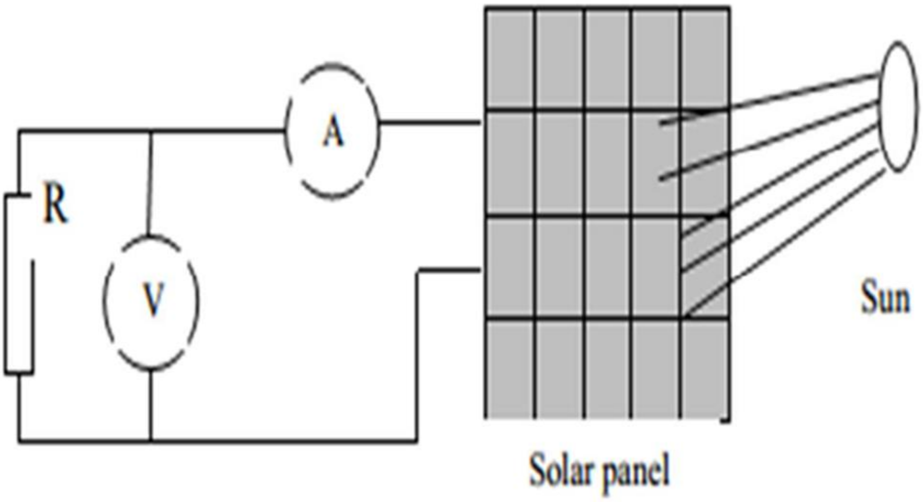

Fig.III.2 Shematic representation of I-V mesurements

III-2-1- Experiment apparatus and setup

We used our innovation which is a glass box with dimensions=78 cm x 78 cm x 78 cm, a solar photovoltaic panel which contain 72 cells (12 W as a power for each one) is placed inside the glass box, particles of dust (sand and gypsum) are produced by a prompter (in order to achieve the artificial sandstorm), I-V measurement setup (voltmeter and amper meter) are connected to solar panel in order to mesure the short circuit current (Isc) and open circuit voltage (Voc) and variable resistances are connected to circuit in order to mesure current-voltage characteristics. In order to compare the performance of the panels before and during the sandstorm, as well as how the performance changed when the density of the dust is increased. Figure III- 2 shows the schematic representation of experimental setup, Figure III-1 is a photo of our innovated system. The current voltage (I-V) characteristics were measured before, during the sandstorm using a volte meter and ampere meter. The Table 1 and Table 2 summarize the used doses (the volume of sand divided by the volume of the box).

Tabel III-1: *The different doses used for gypsum*

The material used	Gypsum	
Volume used (10^{-5} m^3)	46.15	92.32
Dose (%)	0.098	0.194

Tabel III-2: *The different doses used for Gypsum + Sand*

The material used	Gypsum + Sand	
Volume used (10^{-5} m^3)	92.32	138.5
Dose (%)	0.194	0.292

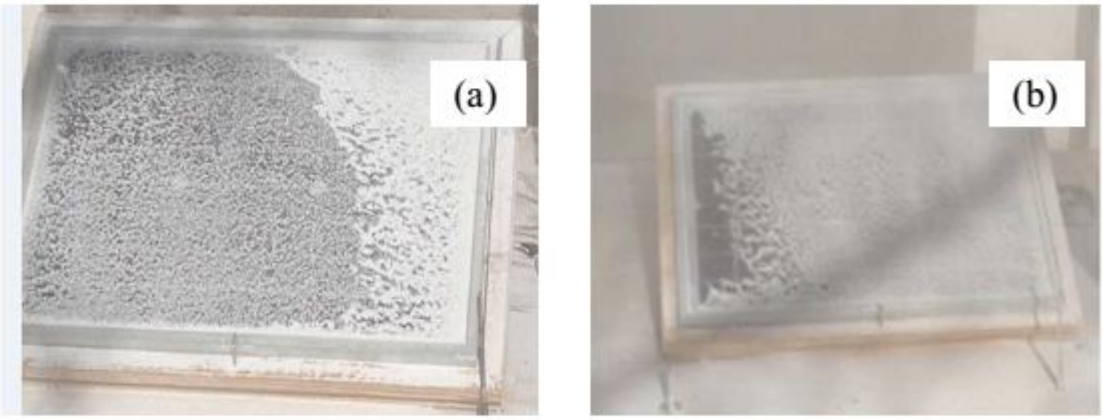

Fig. III.3. Experience with gypsum (a- first dose, b-second dose)

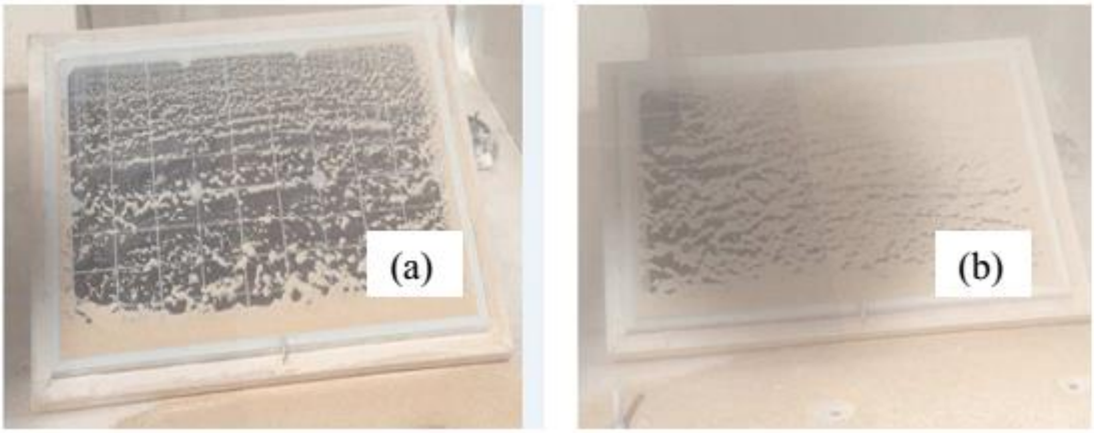

Fig.III.4.Experience with sand and gypsum (a- first dose, b- second dose)

III-2-3- Results and discussion

The qualitative results of artificial sandstorm are presented in Figure III- 3 and Figure III-4. The following photos are taken at different stages of the experiment with different doses. It is clear that the photovoltaic panel is influenced by sandstorm, this influence depends on the doses (the quantities of gypsum and sand). The same phenomena can be observed in desert regions with real sandstorm, so this is a real problem which demand scientific studies and solutions. Different published papers have studied the effect of dust on photovoltaic panels investigating two main parameters; short circuit current (Isc) and open circuit voltage (Voc) under environmental conditions such as; solar radiation, temperature and dust [12, 13]. Our I-V measurements are presented in Figure III- 5 and Figure III- 6. It is clear that the I-V measurements decrease with increasing the doses, which will influence on solar panel power.

Similar results was obtained in the middle East and Gulf regions [14]. In order to study the decreasing of the solar panel electrical power under the sandstorm, the short circuit current (I_{SC}) is measured for different doses (Table 3 and Table 4).

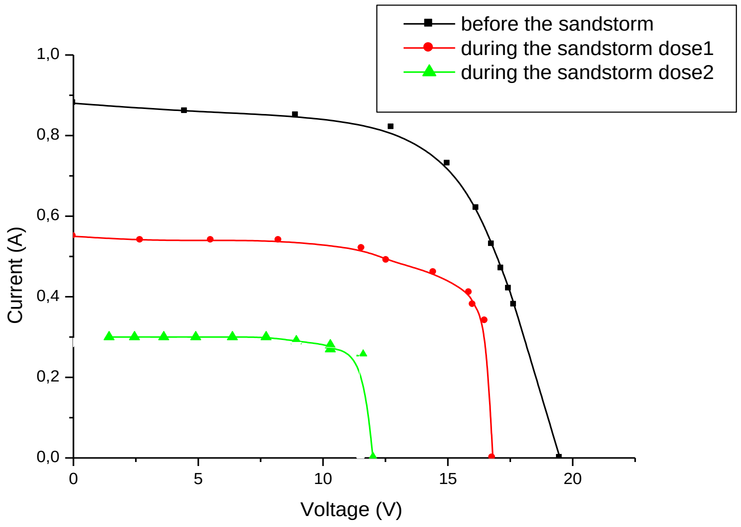

Fig.III.5. I-V curves of experience with gypsum using different doses presented in Table 1 (dose1=0.098% and dose 2=0.194%)

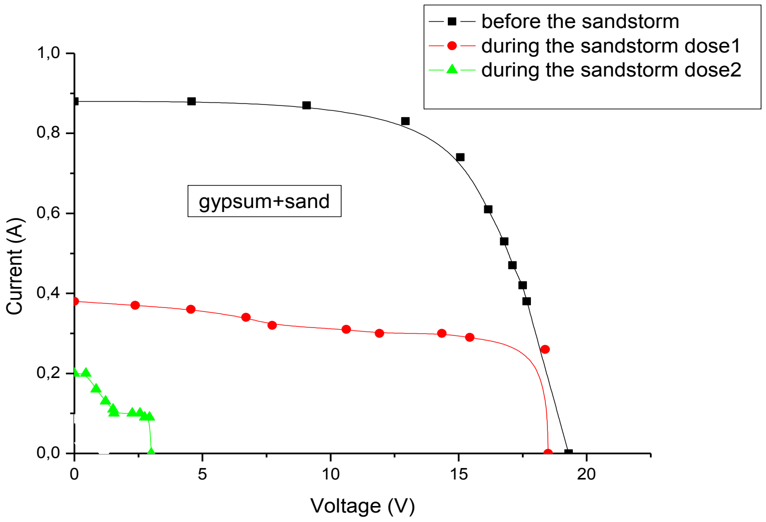

Fig.III.6. I-V curves of experience with gypsum and sand using different doses presented in Table 2 (dose 1= 0.194% and dose 2= 0.292%)

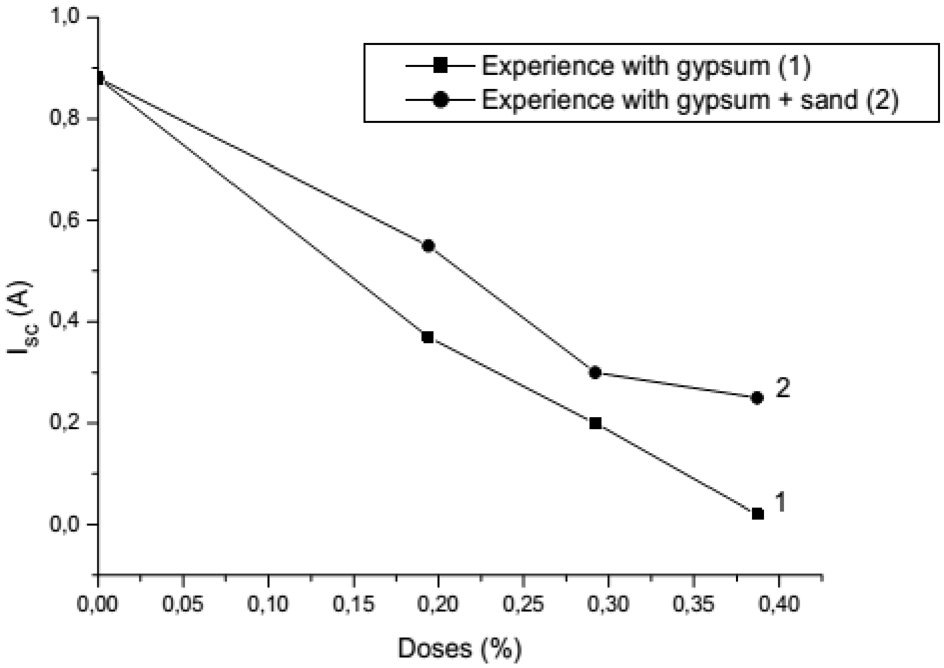

Fig.III.7. Variation of Isc as a function of doses of gypsum and (gypsum+sand)

The variation of the short circuit current under artificial sandstorm is presented in Figure III- 7. We can see in Fig III-7 that the optical transmission decreases regularly with increasing the quantities of dust (doses), also the nature and particle size of dust also influence on solar panel efficiency. The experience with gypsum influence greater than that of sand because the grain size of gypsum is less than that of sand, so the gypsum coating is very compact greater than of that of sand, consequently, the gypsum layer obscures the light more than that of sand.

Tabel III.3. Isc the variation as a function of doses used with gypsum

The used material :	Gypsum
Dose (%)	I_{sc} (A)
0.000	0.88
0.194	0.55
0.292	0.30
0.387	0.25

Table.III.4. Isc the variation as a function of doses used with gypsum and sand

The used material :	Gypsum + Sand
Dose (%)	I_{sc} (A)
0.000	0.88
0.194	0.37
0.292	0.20
0.387	0.02

From table 3, table 4 and fig III- 7 we can propose an empirical relation as:

$$I_{SC} = I_{SC0} - p.D \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(III-1)}$$

Where D is the dose of dust, p is a constant represent the slope of the curve in Figure III- 7 ,

Isc is short circuit current and Isc_0 is the short circuit current without dust .

D can be calculated as :

$$D = \frac{\text{Volume of dust}}{\text{Volume of box}} \;.\; 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(III-2)}$$

p is a constant depends on the type of dust (gypsum, sand, …..), it represents the slope of the curve. Using table 3, table 4 and equation (1), the Figure. III. 7 can be represented otherwise Figure.III.8

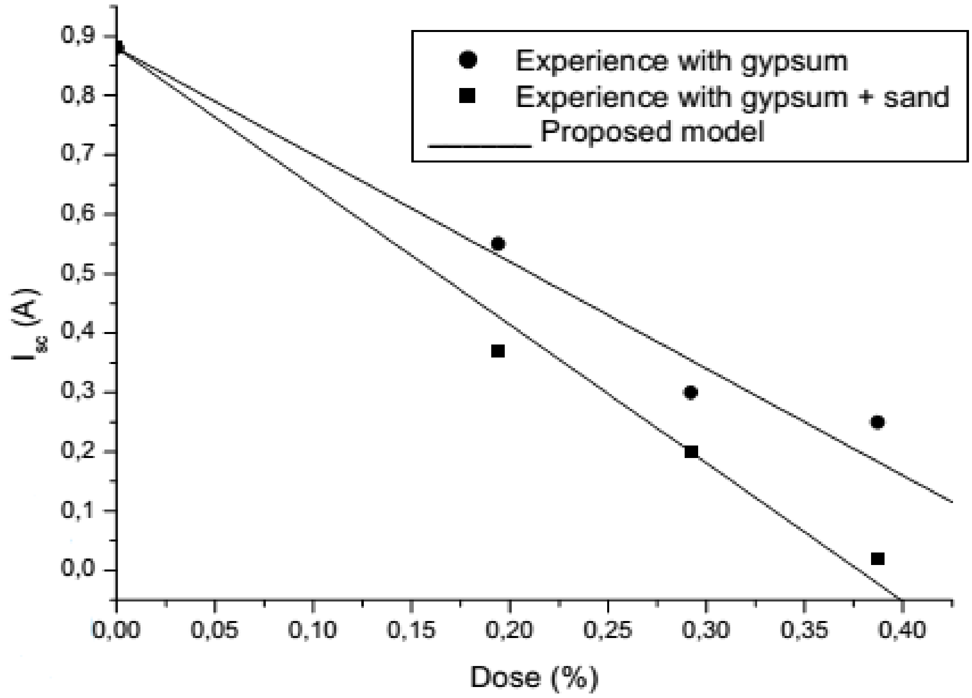

Fig.III.8. Variation of Isc as a function of doses of gypsum and (gypsum+sand) with fit of proposed model in equation (1)

The best fit of experimental data of table 3 and table 4 are presented in Figure III-8, the constant p for gypsum dust is 1.8 A and that of mixed (gypsum+sand) is 2.33 A. so this model can be used to simulate other types of dust.

The technical potentiel of solar energy in desert regions is enormous. However, sandstorms in these regions can seriously affect the surfaces of components of solar energy systems. The intraction beteween sand and wind has a sand blasting character and resultsing different, irreparable wear mechanisms. On dominant type of several general wear mechanisms is abrasion. In desert regions, abrasive damages of the solar glass surface and the accompanying decrease in the degree of transmittance can lead to high yield losses.

Therfore, testing the abrasion resistance of solar technical components under sandstorm conditions is of crucial impotrance and a major contribution to the use of solar energy systems in desert regions. An increasing number of requests from PV modules manufacturers for the resistance of thier modules against sand abrasion shows that this issue is taken seriously. [15]

III-3- Study of solar panel protection by plastique covers against sandstorm in desert regions

Sahara region, most dusts can be non-organic particles suspended in the dry wind (particles of dust and other impurities) that hang by electrostatic attraction on the glass surface of solar panels. In addition, the dust can be abrasive non-organic minerals (eg silica) that can damage and scratch the glass surface of the solar modules. In north of Algeria, most dusts will consist of deposits suspended in the wind dust, bird droppings and other animal droppings, urban pollution (particles of charcoal, soot burning fossil fuels) and organic material of plant leaves, pollen etc. It become wet dispersed on the surface of the solar panels. Also, the effects of dust on the performance of PV panels was studied [13]; dust has an effect on the performance of solar PV panel. The reduction in the peak power generated can be up to 18%. It was also shown that under greater irradiation, the effect of dust became slightly reduced but not negligible.

In addition to that the losses in transmittance and reflectance are coused by the increasing roughness of the tested material surfaces due to increasing the amount of trickling sand. The aluminum reflectors show an additional phenomenon on the surface. In addition to the increasing roughness, the surface becomes darker where the sand steam hits it.

Global technology focused on the direct and periodic cleaning of solar panels, but this method can damage the solar panel if the procedure used and the products are not respected. In addition, this method is expensive.

III-3-1- Suggested experience

All measurements were made at Oum El-Bouaghi. This region is situated in the high plateau.

The dimensions of the solar panel used in this study were 40 cm by 25 cm. Figure III-9 shows the solar panels covered by plastic coating. The I-V characteristics were measured before and after covering using a voltmeter and ampere meter. The power and efficiency were calculated using a appropriate formula.

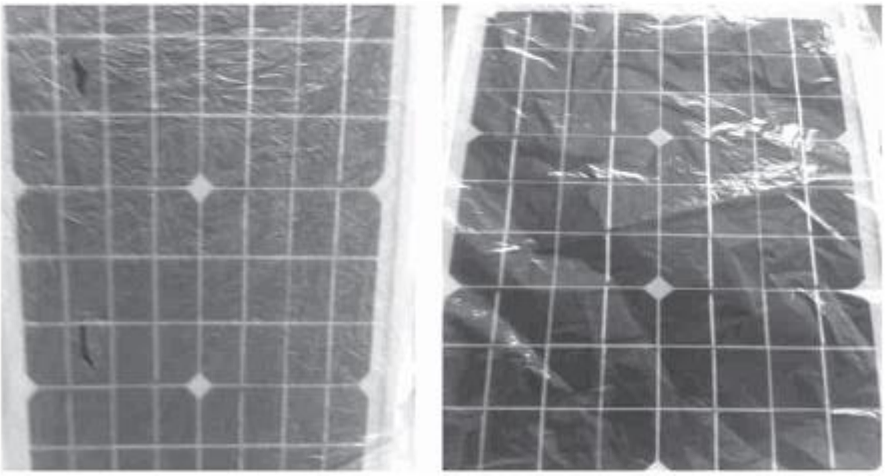

Fig III- 9 Solar panels covered by blue (left) and transparent (right) plastic [16]

III-3-2- Results

First, we have determined the best position of solar panel in Oum El-Bouaghi region. Figure III- 10 shows the variation of power as a function of orientation angle.

It is clear that the power is maximal for a range between 45° and 60°, this result is similar to other works realized by other searchers in different regions [17].

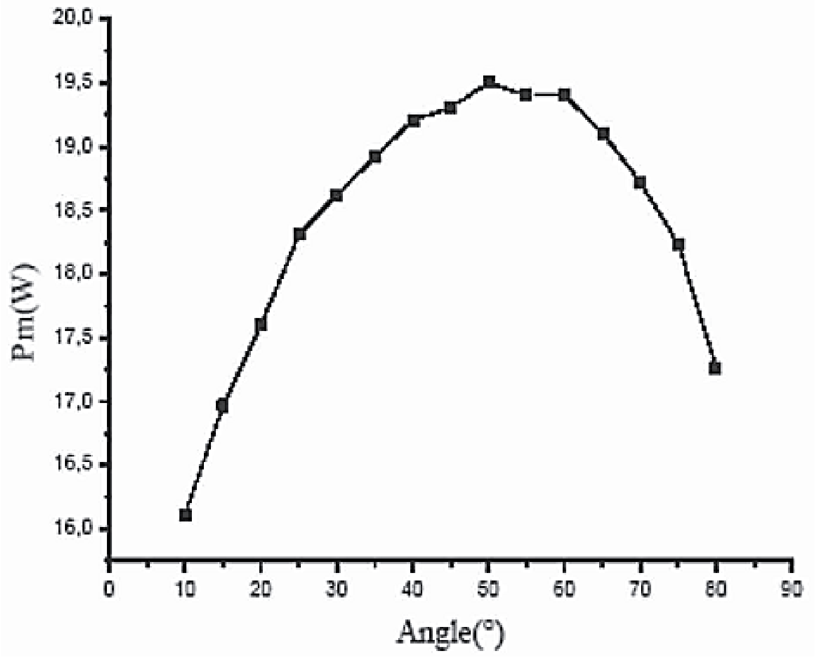

Fig. III.10. Power vs angle of solar panel without covering

Other measurements are made concerning the variation of power as a function of time during one day. The best time for a max of power is 12h around. This result confirms the Eqn (III-3) [18]:

$$E = E_m \sin\left\lfloor \frac{\pi(t-t_0\ )}{12} \right\rfloor \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(III-3)}$$

Where Em is the max power (W/m^2), t_0 is the morning start time (6h) and t is the time in hours. In addition, the results of Figure III.11 coincides with that measured and calculated by other researchers [19].

Hour	V_{OC} (V)	I_{SC} (A)	P (W)
10 :45	20.1	0.92	18.49
11 :00	19.8	0.94	18.61
11 :51	19.8	1.02	20.19
12 :00	19.5	1.02	19.89
12 :30	19.2	0.98	18.82
13 :00	19.2	0.98	18.82
13 :30	19.3	0.93	17.95
14 :00	19.3	0.89	17.18
14 :30	19.3	0.82	15.83
15 :00	19.6	0.72	14.11
15 :30	20.3	0.60	12.18
16 :00	20.3	0.55	11.16

Tabel III-5 : Evolution of I_{sc} and V_{oc} and Pm as a function of time [16].

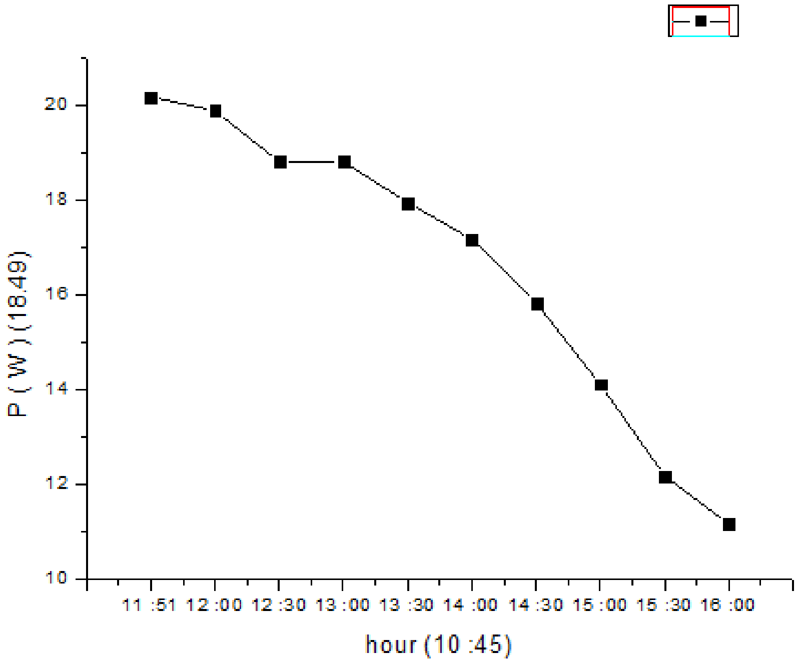

Fig . III. 11. Power vs time for solar panel without covering[16]

Figure III.12. shows I-V characteristics of the solar panel before and after plastic covering. The electrical power produced by the solar panel is calculated from the Eqn (III-4):

$$P_m\ (W) = V_m \,.\, I_m \quad . \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(III.4)}$$

Where Vm and Im are the voltage and current

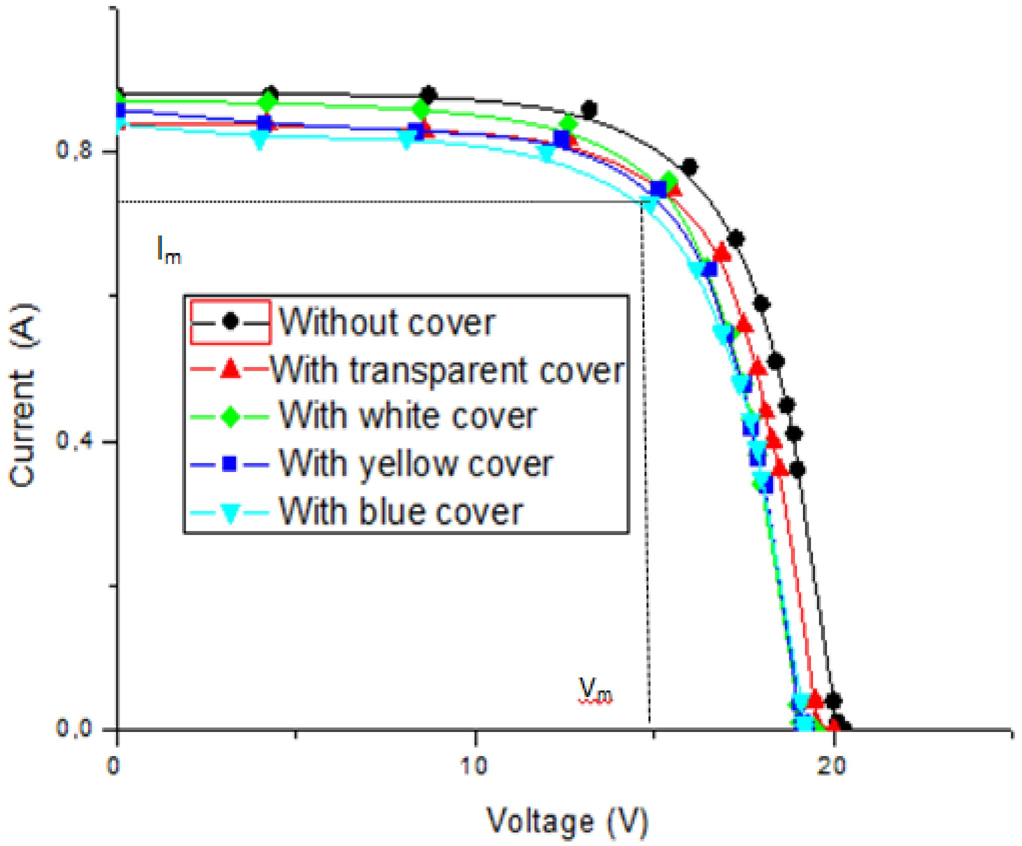

Fig .III. 12. Current vs Voltage for solar panel with and without covering [16]

Table III-6 : Electrical power, form factor and efficiency of solar panel before and after plastic covering.

Panel covering type	Power max P_m(W)	Form Factor (FF)	Efficiency ε *(%)*
Panel without covering	12.48	0.69	12.5
Covered with transparent palstic	11.65	0.69	11.6
Covered with white plastic	11.71	0.69	11.7
Covered with yellow plastic	11.33	0.68	11.33
Covered with blue plastic	10.88	0.67	10.9

Intensity correspond to the maximum power respectively (determined from Figure III -13). Figure III.13 shows power vs voltage of solar panel for different covering type.

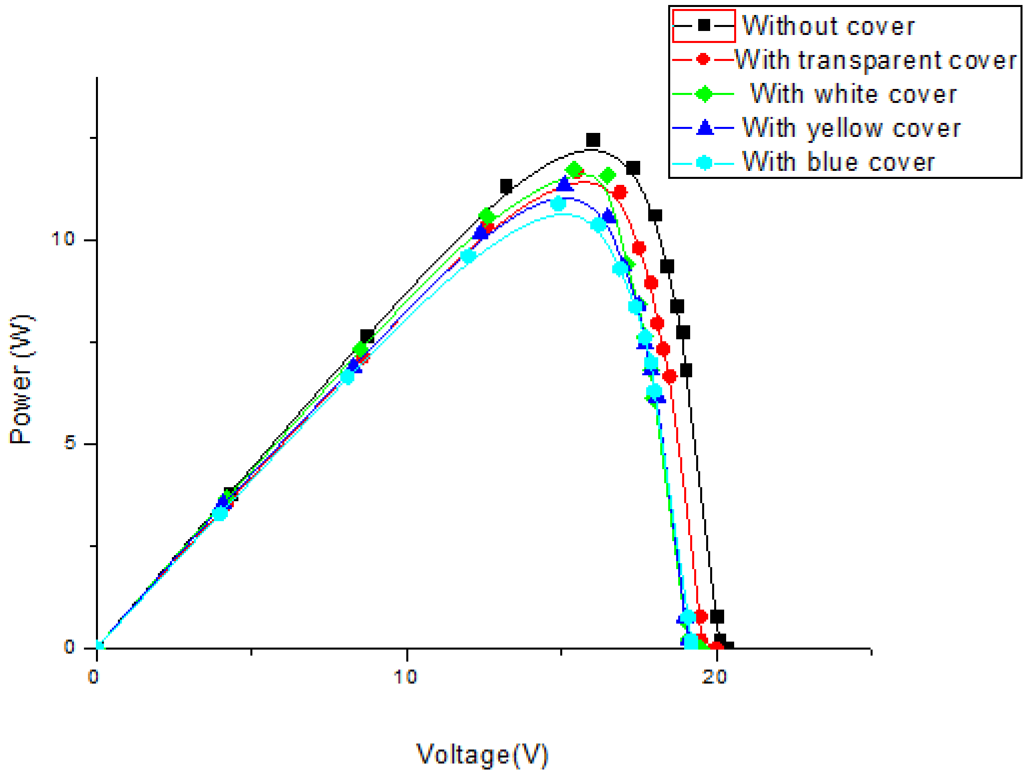

Fig.III.13. power vs voltage of solar panel with and without covering [16]

The efficiency of the solar panel is determined by the Eqn *III-5* Where *Ps* is the power of the incident solar radiation (W/m²), and *A* is the exposed area of the solar panel.

$$\eta = \frac{P_{max}}{P_{in}} = \frac{I_m V_m}{P_s A} \quad \text{……………………………………….} \quad (III\text{-}5)$$

The Eqn. *III-5* is intended for use under test condition; i.e. under a temperature of 9°C, angle 45°, humidity 35%, position 20° east and an irradiance of 1000 W/m² with an air mass 1.5 (AM1.5) spectrum. The results are collected in Table III-4.

According to Table III-6, the maximum power decreases by 10 % around (from 12.48 W to 11.65 W for transparent plastic for example). The form factor do not change because it depends on the fabrication parameters. Concerning the efficiency, the blue plastic covering decreases the solar panel efficiency more than the other colors, so the white and the transparent plastic are the best covering because the efficiency has not decreased significantly (1% around, from 12.5% to 11.6%).

Plastics prices in January 2018. The beginning of 2018 is a continuation of the year 2017 with little or no variation. Polystyrene (PS) remains at 1.76 euro per kilo just like polyvinyl chloride (PVC) at 1.07 and polyethylene [20]

The year 2019 begins in the continuity of the last months of 2018 with a wides pread ebb of plastics. Polyethylene terephthalate (PET) falls to 1.26 euro per kilo against 1.48 euro in November. All polyolefins are down by several cents. Crystal polystyrene (PS) stabilizes at 1.52 euro per kilo. Polyvinyl chloride (PVC) is approaching the bar of the euro per kilo.

The results obtained show that the decrease in yield is very low. Does not exceed 1% in the case of the use of transparent plastic, from there it can be said. This decrease is negligible compared to what we can draw from this protective layer:

- Protection of solar panels against sandstorms.

So if we can expect sandstorms, we cover the boards before the sandstorm goes off and dislodge them once they are finished.

So here we have kept the solar panels from getting scratches that can be caused by sandstorms which lose their effectiveness over time. This is due to the loss of solar radiation, ie scratches reduce the permeability of the radiation.

- By maintaining the surfaces of the solar panels.

We have improved the efficiency of the solar panels, so that the efficiency of the panels stays good longer and thus increases their lifetime while maintaining the same power generation capacity.Here we summarize the disadvantages of using water cleaning technology

- **Problems of cleaning modules**

Fouling photovoltaic modules is a real obstacle to maintaining production performance, it is instead a major player in the decline in their yields.
A common solution to this problem is a manual and periodic cleaning of the installations by application of water. This usual method is certainly effective, but several disadvantages can however emerge.

First :

A first problem concerns the "waste" of water. Indeed, very large photovoltaic plants (several hundreds of thousands of modules spread over a few hundred hectares) are regularly established in desert areas, thus promoting optimal sunshine. Unfortunately, such implantation zones have the disadvantage of accelerating the phenomena of fouling by sand and dust. The maintenance operations are therefore regular and require significant amounts of water for the cooling and the total cleaning of the plant ... quantities of water which prove to be in contradiction with the state of the resources in the dry or desert regions.

Secondly :

It has been found that the manual cleaning of panels (this mainly concerns small and medium sized photovoltaic installations) can also have a harmful effect. Micro-scratches appear over time on the surfaces following friction on grains of sand, for example. The consequences of these micro-scratches are radical since they change the optical properties of the material, by modifying the reflection and transmission properties, in particular.

Thirdly :

Regular cleaning operations required to maintain the performance of PV modules can be expensive. Indeed, it requires the intervention of a technical team to monitor the technical equipment for cleaning PV modules. This can have a significant impact on the economic depreciation period of photovoltaic generators. [21, 22, 23]

III-4- Conclusion

The negative impact of dust accumulation on photovoltaic panels implies a drop in energy efficiency of photovoltaic modules and thus a decrease of the corresponding energy yield [24].

In this direction, our objective was to find a way to study the effect of dust accumulation on the solar panels where we innovated an artificial system to study the effect of sandstorm on the performances of photovoltaic panels in the laboratory without displacement to desert regions (Sahara).The results obtained show that the PV panels efficiency decreases.

Second part of our project is to protect the solar panels so we studied a simple method ‘plastis convering’ against the dust and the sandstorms. The efficiency decreases by a small value (1% around) but the panel is protected. The plastic convering can be changed from time to time instead of the maintenance procedure which is expensive.

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GENERAL CONCLUSION

GENERAL CONCLUSION

Evolution and technological progress have a price: energy. The development of renewable energy is the most efficient response of the humankind to answer the demand for energy. Through this vision, the Sun represents an inexhaustible source of energy ready to be exploited in the near future. The solar cells are a suitable way to convert sunlight in energy and for this reason they experienced a constant development over time of the conversion efficiency.

However, we should Understand and solve the problems that degrade the solar cells efficiencies, lead to a real exploitation of the photovoltaic processes. The purpose of this thesis is to study the External factors affecting the performance of solar panels.

The first chapter introduces generalities concerning photovoltaic (history, principle of functioning, types of panels and manufacturing steps). The second describes in detail the installation steps of the solar panels Choices the best direction and best inclination for better performance and also the maintenance of this last. We also explained the impact of different climatic conditions on the performance of solar panels. In the third chapter, we present a new method for measuring the effect of sandstorms on I-V characteristics.

Where we made a glass box,we placed a solar panel with fan to simulate the sandstorm. This method allows us to control the size, dosage and material used: sand or gypsum ....ect. We can also use a mixture of these. After experiencing, we measure the I-V characteristicswe observe a decrease in the yield of solar panels by increasing the dose of sand. Through the results obtainedand we notice a greater reduction using gypsum because the size of the gypsum grains is smaller than that of the sand,

From the obtained results, we have proposed an empirical relation for the variation of short circuit current I_{sc} as a function of doses of gypsum and (gypsum+sand). This model can be used to simulate other types of dust

In the second part of the chapter, we suggest to protect the solar panels by using a thin layer of plastic of different colors.The results obtained show that the decrease in yield is very low.

Does not exceed 1% in the case of the use of transparent plastic, but in the other hand we protect the solar panels against sandstorms and the possibility of scratching over time, when this scratches reduce the permeability of the radiation.

In the same time, we have improved the efficiency of the solar panels, so that the efficiency of the panels stays good longer and thus increases their lifetime.