Republic Of Algeria Democratic And People's

Ministry of Higher Education And Scientific Reseach

KASDI Merbah – Ouargla University

Faculty of Mathematics and Material Science

Master's Thesis

Sector: Physics

Field: Energy Physics and Renewable Energies

Presented by:

SANDJEL Asma

Theme

EXPERIMENTAL STUDY OF DUST ON PHOTOVOLTAIC SYSTEM EFFICIENCY

14/06/2022

In front of the jury members

GAMA Amor	Pr	URAER	Supervised
BACHKI Djamel	Pr	University Kasdi Merbah Ouargla	Co-supervised
BOUANANE Rabeh	MAA	University Kasdi Merbah Ouargla	President
TEKHA Mohamed	MAA	University Kasdi Merbah Ouargla	jury

Academic year : 2021/2022

THANKING

First of all, we thank God for the blessed and kind above all, we thank him for the great success.

Thanks to The University of Qasdi Marbah- Wargla - Faculty of Material Sciences, The Center for The Development of Renewable Energies and the Applied Research Unit in Renewable Energies in Ghardaia who gave me the opportunity to join them.

I give great thanks and appreciation to the Professor GAMA Omar and Dr. Dean of the College Mr. BECHKI DJemal for their cooperation. He gave me the information, guidance, inquiries and thanks to all those who helped me.

I also want to thank the members of the jury, Mr. BOUANAN Rabah and Mr.TEKHA Mohamed it was an honor for me to accept and judge my work.

without forgetting to thank faculty members specializing in energy physics: Mr. TEKHA, Mr. MOHSSIN, Mr. SATOU, Mr. SOUDANI, Mr. ZAIN, Mr. BOUGHALI.... and all my teachers from Masters 1 to Masters 2.

To my teachers at the school

Primary to universit

DEDICATION

I dedicate this study project to:

to the one who taught me will and steadfastness...to the one who taught me patience to fight for knowledge and supported me and encouraged me to get to where I am ...To my bond and refuge in life to my precious father.

To the one who raised me and taught me morals, my hero, my soul mate and my first teacher... she has always dreamed to seeing my success in my studies... To the symbol of love and the source of kindness and tenderness... To my beloved mother.

To those who have always been by my side to those who supported me in life, my strength my brothers :Sid Ahmed and Mohammad Ayman.

To all my family and relatives.

To the most beautiful coincidences of life" Fatima and Maria".

To all the dear friends "Noussiba, Zahra, Afraa, Abdellah, Abdelazziz, Abd elbassat".

To my soul mates and my life-supporter, my sisters, who were not born by my mother "Sabrina and Chamia".

Finally, I dedicate my success to the youngest ,cutes baby in my family "Hachim and Ahmed".

To all those who are dear to us.

Thank you all.

Abstract:

Electricity is produced around the world mainly using non-renewable energy sources, especially fossil fuels. But these resources can be exhausted at some point in the not-too-distant future. Accordingly, electricity production will be used from various renewable energy sources. Among these sources, solar energy has shown great success for many reasons. For example a permanent source, it is the oldest and most thoroughly researched, and has been tested and implemented for a long time around the world. PV applications have shown that their reliability and efficiency depend on many factors, the most important of which are geography (longitude, latitude and solar density), the environment(temperature, wind, humidity, pollution, dust, rain, etc.) and the type of PV used. One of the most important factors to study Before the construction of any photovoltaic plant is dust , which has a significant impact on the performance of units. Recently ,PV technology has been widely transferred to desert areas as hot spots and has been successful for the system. Besides, these areas are most often dust-prone and dust is the main barrier to PV use. This POSTER reviews research into the impact of dust on the performance of the photovoltaic system as climatic conditions vary.

Dust deposition studies have shown that PV units lose 22% to 100% of their efficiency due to the accumulation of dust on their capture surface as well as rain and wind have a significant impact on the performance of the pv unit.

Keywords: Desert environment, dust, weather conditions, PV panels, rain, wind (wind speed) ,efficiency, spectrum, Effect of dust deposition, air pollution, temperature, humidity and sandstorms.

Résumé:

L'électricité est produite partout dans le monde principalement à partir des sources non renouvelables en particulier les combustibles fossiles cependant ces ressources disparaitront avec le temps .en conséquence, nous avons recours à la production d'énergie à partir de différents sources qui sont différentes parmi ces sources, l'énergie solaire qui a connu un grand succès pour plusieurs raisons ;source permanent . c'est la plus ancienne et la plus étude ,testée et mise en œuvre depuis longtemps .les applications photovoltaïques montré que sa fiabilité et son efficacité dépendent de nombreux facteurs dont les plus importants sont la géographie (longitude, l'altitude et densité solaire) ,l'environnement (température , vent, humidité, pollution, poussière, pluie...etc) et le type de PV utilisé.

Mots-clés : environnement désertique, poussière, conditions météorologiques, panneaux photovoltaïques, pluie, vent (vitesse du vent), efficacité, spectre, effet du dépôt de poussière, pollution de l'air, température, humidité et tempêtes de sable

الملخص:

يتم إنتاج الكهرباء في جميع أنحاء العالم بشكل أساسي باستخدام مصادر الطاقة غير المتجددة ، وخاصة الوقود الأحفوري. ومع ذلك ,فان هذه الموارد ستختفي مع مرور الزمن وفي المستقبل الغير بعيد.وفقًا لذلك ، نلجأ إلى إنتاج الطاقة من مصادر مختلفة والتي تتمثل في مصادر الطاقة المتجددة المختلفة. من بين هذه المصادر ، أظهرت الطاقة الشمسية نجاحًا كبيرًا لأسباب عديدة. على سبيل المثال مصدر دائم ، فهو الأقدم والأكثر بحثًا بدقة ، وقد تم اختباره وتنفيذه لفترة طويلة حول العالم. أظهرت التطبيقات الكهروضوئية أن موثوقيتها وكفاءتها تعتمد على العديد من العوامل ، من أهمها الجغرافيا (خطوط الطول وخط العرض والكثافة الشمسية) ، والبيئة (درجة الحرارة ، والرياح ، والرطوبة ، والتلوث ، والغبار ، والمطر ، وما إلى ذلك) و نوع PV المستخدم. يعتبر الغبار من أهم العوامل التي يجب دراستها قبل إنشاء أي مصنع للطاقة الكهروضوئية ، والذي له تأثير كبير على أداء الوحدات. حديثاً، تم نقل التكنولوجيا الكهروضوئية على نطاق واسع إلى المناطق الصحراوية كنقاط ساخنة وقد نجح النظام. إلى جانب ذلك ، غالبًا ما تكون هذه المناطق معرضة للغبار والغبار هو العائق الرئيسي لاستخدام الكهروضوئية. يستعرض هذا المنشور البحث في تأثير الغبار على أداء النظام الكهروضوئي حيث تختلف الظروف المناخية.

أظهرت دراسات ترسب الغبار أن الوحدات الكهروضوئية تفقد 22٪ إلى 100٪ من كفاءتها بسبب تراكم الغبار على سطح التقاطها وكذلك المطر والرياح لها تأثير كبير على أداء وحدة الكهروضوئية.

الكلمات المفتاحية : البيئة الصحراوية,الغبار,الظروف الجوية,الألواح الكهروضوئية ,المطر ,الرياح (سرعة الرياح) ,الكفاءة ,الطيف ,تأثير ترسب الغبار ,تلوث الهواء ,درجة الحرارة ,الرطوبة والعواصف الرملية.

Index

List of symbols

PV:Photovoltaic.

I:Current [A].

V:Voltage [V].

$\mathbf{I_{ph}}$: Current delivered by the PV cell[A].

V_{OC}: Open circuit voltage[V].

I_{SC}: Short circuit current[A].

FF: Form factor.

P_{Max}: Maximum power[W].

η: Performance[%].

P : Power[W].

K: Boltzmann constant (1.38.10-23 J / K).

T :Effective cell temperature [K].

$\mathbf{E_{p\square}}$: The energy of a photon [J].

$\mathbf{I_d}$:The junction current [A].

$\mathbf{R_s}$:Resistance series [Ω].

a-Si: Amorphes Silicon.

Cd-Te : Cadmium Telluride.

CIGS: Copper Indium Gallium Selenite.

RCS :Robotic cleaning system.

ECS :Electrostatic cleaning system .

CCS :Coating cleaning system .

LIST OF FIGURES

List of tables

General Introduction

General Introduction

The world at present depends entirely on the energy electric. This energy is one of the facilitators of life and this is due to its reliance in all sectors: industrial, transport, entertainment, health, home, production, communications and others. Human, also needs energy to live and develop this knowledge, and energy consumption increases with agricultural, industrial development and population.

Currently, all over the world, including Algeria, is totally dependent on fossil sources (coal, oil, natural gas) and nuclear in electricity production. However, it has not been taken into account that these sources are not renewable in nature and are accessible and disappearing on the one said, but on the other said this energy is produced by the combustion of coal, oil and natural gas, which causes the emission of harmful greenhouse gases, especially carbon dioxide, which is harmful to the environment.

Given all the obstacles that result from fossil sources. Researchers and scientists are looking for solutions where they are other sources that do not pollute the environment and are also reliable and cost-effective techniques. These sources include (hydraulic energy, wind energy, solar energy as well as biomasses energy).

Algeria is starting a green energy dynamic by launching an ambitious project for the development of renewable energies and energy efficiency. This vision of the Algerian government is based on a strategy focused on the development of endless resources such as solar, wind energy and their use to diversify energy sources and prepare the Algeria of tomorrow. Thanks to the combination of initiative and intelligence, Algeria is embarking on a new sustainable energy era. The updated renewable energy programmers consist of installing renewable power of around 22,000 MW by 2030 for the national market, with the export option maintaining as a strategic objective, market conditions permitting.[1]

Algeria currently ranks 10th in the world in terms of space and fifth in solar energy use. With 86% of its area including the desert region, this area is characterized by massive solar energy, sandstorms and dust in the air. The development of solar PV faces a number of difficulties, including the high cost of kilowatt-hour produced and the long return on the investment period. In addition, certain aspects of the installation and operation of PV units are added. Most PV sensors have been observed to suffer from dust deposited on the surfaces of units. As part of this work, we are trying to assess the effects of dust and sediment on the effectiveness of solar systems and to clarify the role of climatic factors on this.

The impact of dust on the performance of the photovoltaic system is one of the most important factors to be studied before constructing any photovoltaic station. In previous studies, Monto and Rohit reviewed the impact of dust on PV performance based on two time periods: from 1940 to 1990 and from 1990 to 2010, Mishra and Tarisan in 2015.Hottel and Woertz were also among the pioneers who studied the impact of dust on solar systems. They recorded the maximum degradation in the complex's performance by 4.7%, with a loss rate of less than 1%. In a study by Salem et al. The accumulation of dust on the village's solar PV system near Riyadh indicated a 32% decrease in performance after eight months.Wakim noted a 17% reduction in PV due to sand accumulation on panels in Kuwait City six days later.[2]

Our work is entitled "Experimental study of dust effect on photovoltaic system efficiency". The work presented in this thesis focused on the impact of dust and climatic factors on the characteristics of the electrical performance of PV units; summarize it in the following steps:

In the first chapter, the principle of operation of the PV cell, Different types of solar cells also have the effect of radiation, temperature, shadow and cell properties on the I-V and P-V curve.

In the second chapter, we introduced the polluters of PV units, the most important of which is dust, and also touched on the factors controlling the accumulation of dust on the surfaces of the units where we find: Environmental factors, Location installation factors and Dust type. Also, we touched in this work to for the different cleaning systems of solar panels.

In the third chapter we introduced the experimental procedure and various measuring devices used to study the effect of dust on the electrical properties of PV units. Two new and clean single-crystalline units were selected for comparison, an electric card (Arduino based) and a LabVIEW program to display measured results. accordingly, we provided dust effect results on the short circuit stream, open circuit effort, power points: maximum (P_{Max} , I_{Max} and V_{Max}), shape factor (FF) and efficiency(η) analysis of this result. Besides, we provided an infrared image of the two units to see the effect of dust on raising cell temperature .

Finally, we will conclude this brief with a general conclusion that summarizes our study.

Chapter I: Generality on Photovoltaic Systems.

I-1: Introduction:

Solar photovoltaic is an elegant technology which produces electricity from sunlight without moving parts using a technology based on the photoelectric effect. This process uses a semiconductor device called a photocell ;the interconnection of several cells forms a photovoltaic solar panel (or module) and assembled in a photovoltaic solar plant is called a photoelectric field.

In this chapter we begin by briefly recalling the principle of the conversion of solar energy into electrical energy based on the photoelectric effect of semiconductors, thus the characteristics of a photovoltaic generator.

I-2: Solar radiation received on the ground:

Solar energy is the most abundant renewable resource. It is a source of emissions for electromagnetic waves. The amount of sunlight received by the surface of the earth depends on several factors including; Geographical location, time of day, season, local landscape and local weather. However, the role of the atmosphere in modifying the spectral composition of extraterrestrial solar radiation cannot be neglected through reflection, absorption, refraction and dispersion phenomena, because of cloud cover and the scattering of sunlight.[3]

The radiation received by a surface will be have two components one which is direct and will depend on the distance the rays travel (air mass). The other component is called diffuse radiation. See **Figure**(**I-1):**

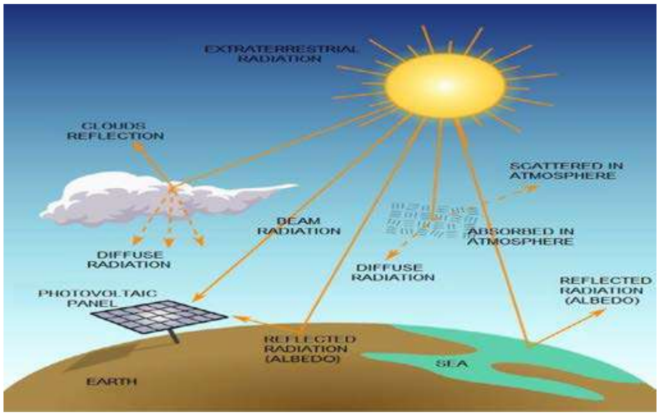


Figure (I-1): Direct and diffuse sunlight**.**

- **Direct radiation:** Arrives from the Sun in a straight line and is at no time broadcast.
- **Diffuse radiation:** Corresponds to the light that has been scattered either by the atmosphere, or by the clouds. On overcast or very clear days, it is considered isotropic.
- **Albedo**: The albedo is a part of radiation reflected from the ground and reflects very little light, and is often overlooked in studies.
- **Global radiation**: Present the sum of the three components listed above. It's the latter which is systematically measured by weather stations.

A closer look at the **Figure (I-2)** shows the importance of ozone. The flow of solar energy travels in the form of waves whose wavelengths differ completely from the black body in space, but more soon the sea (Earth).

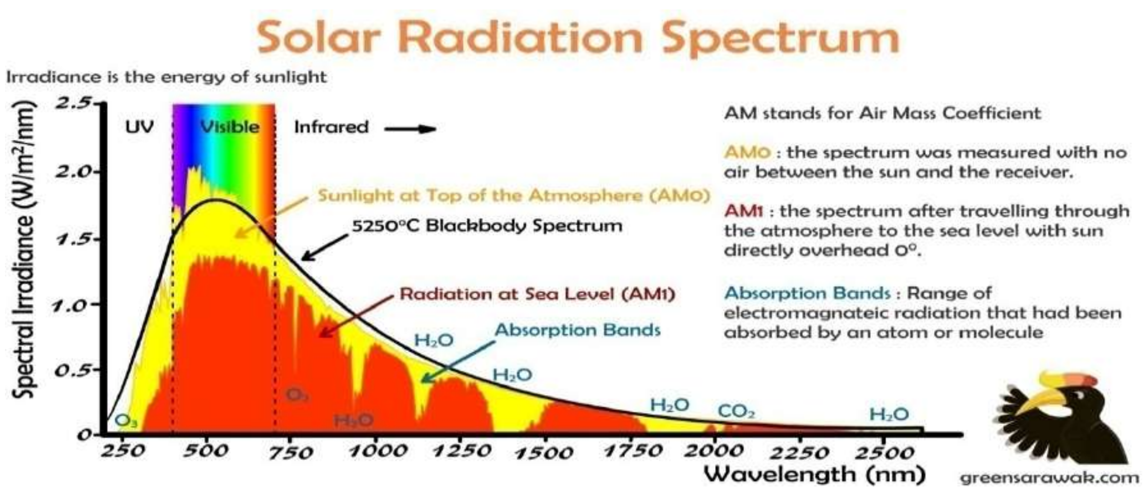


Figure (I-2): Spectral distribution of solar wavelength (nm).

The average annual solar radiation reaching the top of the Earth's atmosphere is about 1,361 watts/m^2. Radiation is distributed within the wavelength range of ultraviolet radiation (**λ**= 385-495 nm), visible (**λ**= 495-695nm)to infrared light(**λ**= 695-2800nm) are absorbed by carbon dioxide;50%of this energy lies between 400 and 700 nm. The global radiation spectroscopy

Distribution is expected to be almost insensitive as it is adjusted by a few tenths of a per cent with the largest change in the UV spectral range.

I-3: The photovoltaic effect:

The principle of producing electricity from solar radiation is called the Photovoltaic effect, it was observed for the first time in 1839 by a French scientist Alexander Edmond Becquerel. In experiments involving wet cells, he noted that the cell's voltage increased when its silver plates were exposed to sunlight. [4]

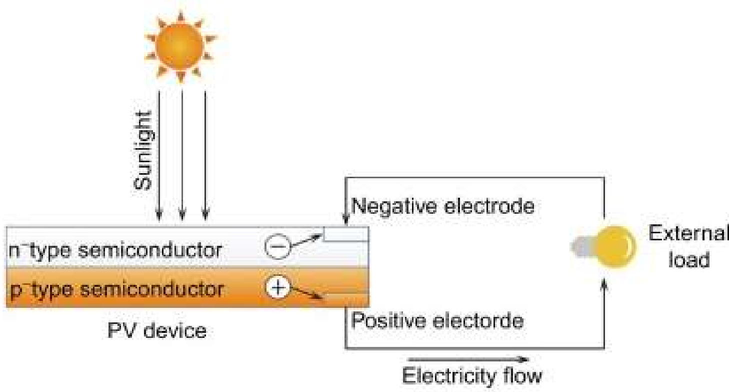


Figure (I-3): Photovoltaic cell.

The beam of sun-Light consists of photons, which are tiny bundles of electromagnetic radiation. These photons bear an energy E_{ph} that is subject to the following relationship:

$$E_{ph} = h * \frac{c}{\lambda} = h * f \qquad (I-1)$$

E **:** The energy of a photon J.

h : The Planck constant equal to$6.626 * 10^{-34} J.s$.

C : The speed of light $m/_s$.

f: The frequency of a photon.

λ: The wavelength of a photon [**nm**].

II-4: The PV effect principle:

Photovoltaic effect is known as a physical process in which the PV cell converts sunlight into electricity. Photons can be absorbed by photovoltaic cells composed of two different regions of semiconductors-region and an-region usually based of silicon (Si).[3]

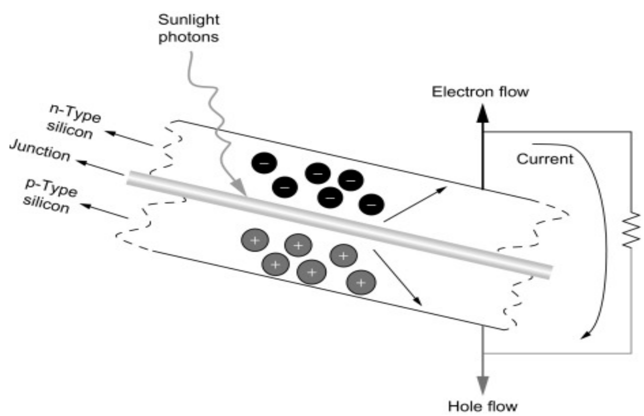


Figure (I-4): Principle of a PV cell.

When PV cells are exposed to sunlight, they absorb energy that activates electrons in the atom (E_p). With this energy, these electrons move from natural position in the semiconductor PV materials. Two layers of different semiconductor materials are placed in contact to create a P-N injunction. As a result, induction an electrical field. The plate region- N there are excess of electrons with a negative charge. The other plate region-p is charged positive and abundance of holes. This difference in charges and other requires attraction; the flow of excess electrons topositive-side and holes in the opposite side. Thus, create a positive charge in n-side of the interface negative charge along the p-region side and close the current path.as a result, an electrical field is crated in the P-N junction(at the surface where the layers meet).

II-5: Characteristic of the photovoltaic cell:

The cell module or PV is usually represented by a single exponential model or a double exponential model. The single exponential model (**FigureI-5**) as an electric current generator equivalent to its current ideal source representing the photoelectric current (I_{ph}), associated witha parallel binary valve shaped by the P-N junction that determines the voltage as shown in the equation(I-2).[4]Although this is the most commonly used model in a test testing of Photovoltaic modules the double exponential model(Figure **I-6**) is more accurate take(account of temperature and irradiance).[5]

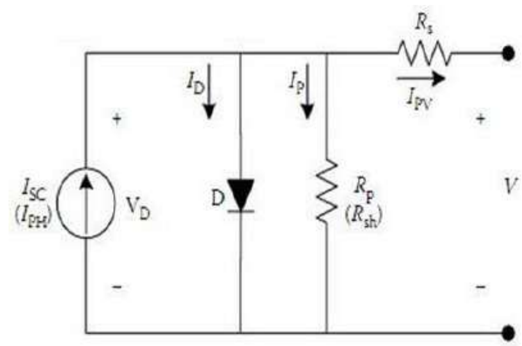


Figure (I-5): The single exponential model of photovoltaic cell.

$$\mathbf{I = I_{ph} - I_d - I_p} \qquad \mathbf{(I-2)}$$

The junction current (I_d) is given by:

$$\boldsymbol{I_d = I_s\left[\exp\left(\frac{V+I*R_s}{V_t}\right)-1\right] = I_s\left[\exp\left(q*\frac{(V+I*R_s)}{A*k*T}\right)-1\right]} \qquad \boldsymbol{(I-3)}$$

The current flowing through the parallel resistor (I_p) is given by:

$$\boldsymbol{I_p = \frac{V+I*R_S}{R_p}} \qquad \boldsymbol{(I-4)}$$

Replacing the expressions of I_d and I_p in equation **(I-2)**, we obtain:

$$\boldsymbol{I = I_{ph} - I_s\left[\exp\left(q*\frac{(V+I*R_s)}{A*K*T}\right)-1\right] - \frac{V+I*R_S}{R_p}} \qquad \boldsymbol{(I-5)}$$

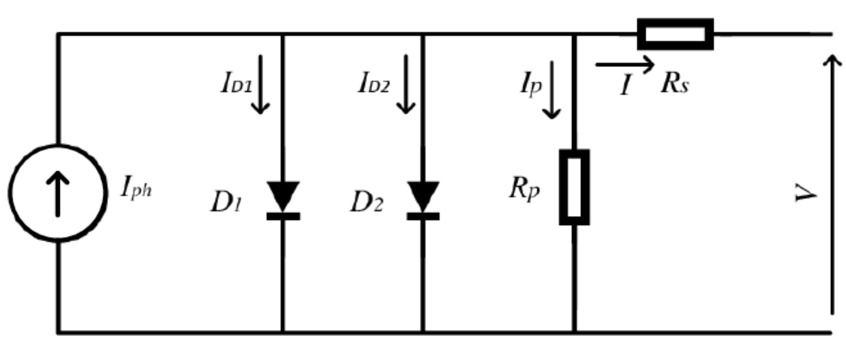


Figure (I-6): The double exponential model of photovoltaic cell.

$$\mathbf{I = I_{ph} - I_{d1} - I_{d2} - I_p} \qquad (I-6)$$

So, the equation becomes:

$$I = I_{ph} - I_{s1} * \left[\exp\left(q\frac{(V+I*R_s)}{k*T}\right) - 1\right] - I_{s2} * \left[\exp\left(q * \frac{(V+I*R_s)}{A*k*T}\right) - 1\right] - \frac{V + I * R_S}{R_p} \qquad (I-7)$$

Where:

$\mathbf{I_{ph}}$: The photo-generated current.

I_s : The dark saturation current.

I_{s1} **: S**aturation current due to diffusion.

I_{s2} : The saturation current due to recombination in the space charge layer.

R_S: Cell series resistance.

R_p: The cell (shunt) resistance.

A: The diode quality factor.

q: The electronic charge ,$\mathbf{1.6 * 10^{-19} C}$.

k: The Boltzmann's constant, $\mathbf{1.38 * 10^{-23} J/K}$.

T: The ambient temperature, in **Kelvin**.

A photovoltaic cell is characterized by two performance descriptors is its current-voltage curve (I-V) and power-voltage (P-V).It can be distinguish that are three electrical coefficients for a photovoltaic cell:[6]

The vacuum voltage (V_{oc}): Corresponds to the maximum voltage of the cell without load (I = 0):

$$V_{oc} = \left(\frac{k * T}{q}\right) * \ln\left(\frac{I_{ph}}{I_s + 1}\right) \qquad (I-8)$$

The short circuit current (I_{sc}): this value would represent the maximum current that can provide the cell connected to itself (v = 0):

$$I_{sc} = I_{ph}$$

The maximum power point MPP: Corresponds to the maximum power that can be delivered by the cell, it is obtained for a voltage and optimal current:V_{MPP},I_{MPP}: [4]

$$P_M = V_{MPP} * I_{MPP} \qquad (I-9)$$

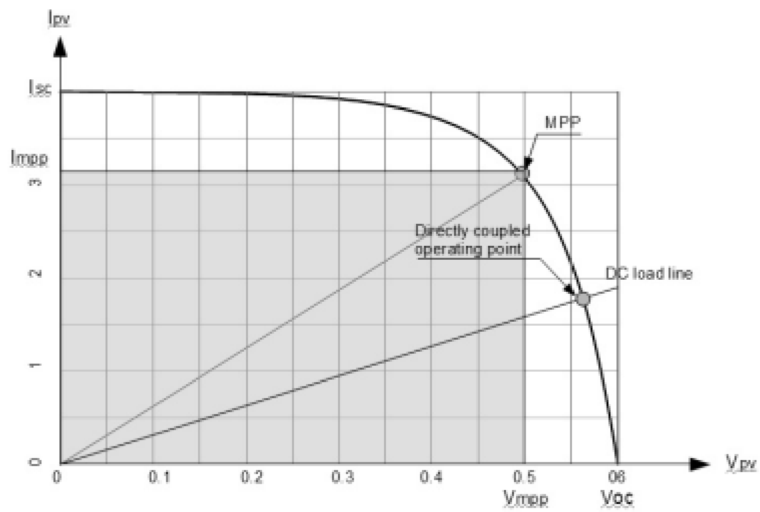


Figure (I-7): I-V and P-V characteristics of PV Generator.

APV module is usually rated in the condition (STC) :

Irradiance=1000W/m^2.

Air mass=1,5.

Cell temperature=25°C.

The fill factor represents the relation on to the product ($V_{MPP} * I_{MPP}$) by the product generated ($V_{oc} * I_{sc}$). which is defined as:

$$FF = \frac{V_{MPP} * I_{MPP}}{V_{oc} * I_{sc}} \qquad (I-10)$$

Finally, the important factor in the system PV is the efficiency (**η**) of the solar cell, and it is given by:

$$\eta = \frac{FF * V_{oc} * L_{oc}}{P_{in}} \qquad (I-11)$$

I-6: Types of PV technology:

There are different technologies constituting photovoltaic cells illustrated in the following **Figure (I-8):**

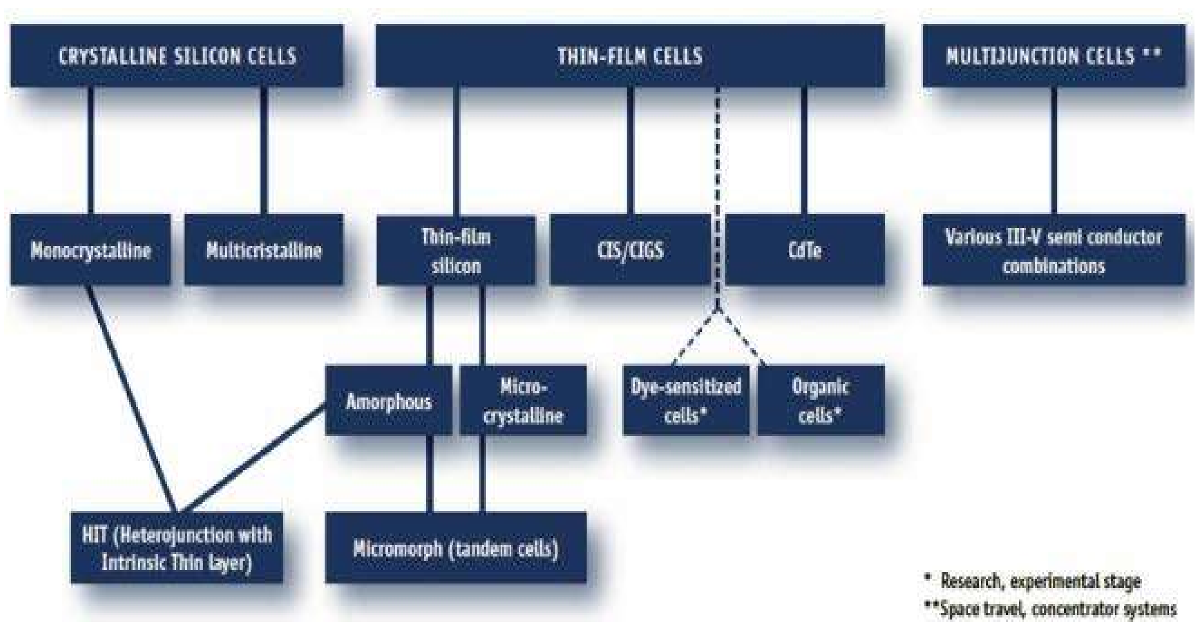
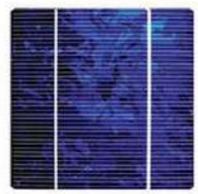
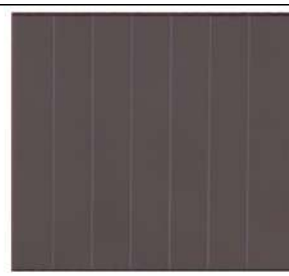


Figure (I-8): Different photovoltaic cell technologies**.**

There is a difference between these thin films in terms of material fabrication and efficiency. However, we found silicon cells to be the most common in the industry for the production of PV panels; the following table shows some types of panels that show their efficiency: [4]

Table (I-1): Different types of cells and their performance.

Type of cells	cell shape	The performance
<u>Mon crystalline silicon</u>: It is more expensive compared to other types because it is made of pure silicone.		Has high efficiency:14% - 20%
<u>Multi crystalline silicon</u>: Considered a little cheaper than mono as it's made from numerous grains of mono crystalline.		Slightly less efficient:13%-17%
<u>Amorphous Silicon (a-Si):</u> Amorphous cells represent a thin flexible layer deposited on glass, is absorbs more effectively than crystalline silicon.		6%-7%

There are other types like Cadmium Telluride (**Cd-Te**) and Copper Indium Gallium Selenite (**CIGS**); among the thin films listed under modern technology and the best-selling in terms of low price as they have an estimated performance of 10-11% and 10-13% respectively, it’s also toxic.

Typically, the maximum power delivered by a photovoltaic cell under standard sunshine conditions (1000 W/m², 25C°) is about 2 to 3 watts peak under approximately a voltage of 0.5V, so the power delivered by a photovoltaic cell remains insufficient vis-à-vis the needs of most industrial or domestic applications.In order to obtain an energy level compatible with power consumption, it is necessary to combine a large number of these cells on the sequence to increase voltage and / or form photovoltaic units in parallel in order to obtain a greater electric current.

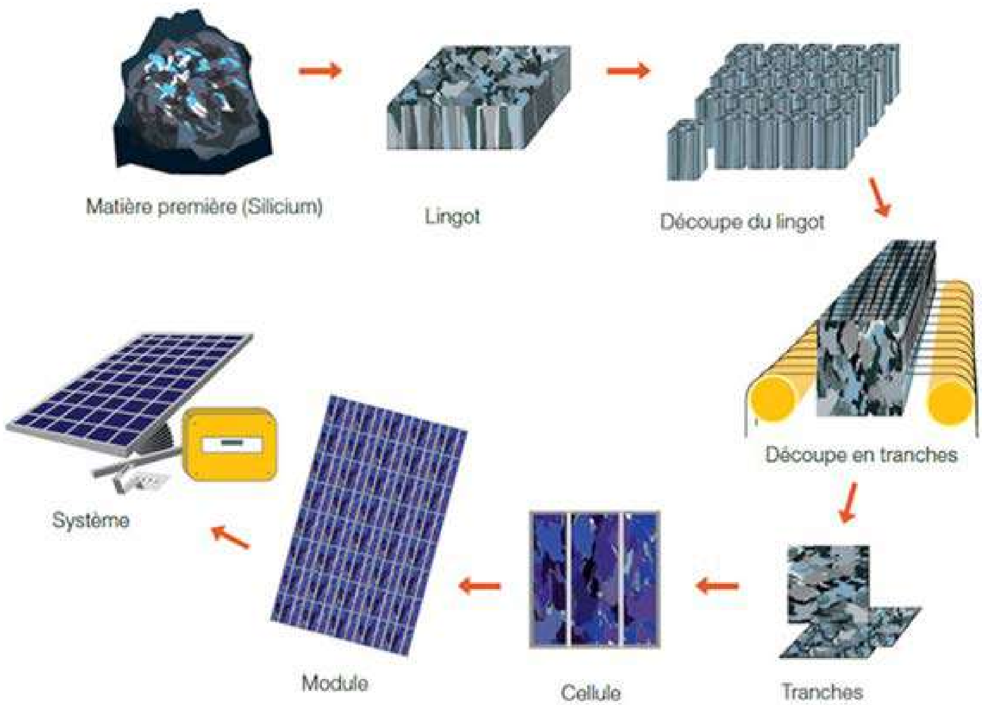


Figure (I-9): Production line of a photovoltaic module.

I-7: The effect of sunlight and temperature on solar panels:[3][4]

- **The effect of sunlight:**

The current produced by a solar cell I_{Ph} is linearly proportional to solar lighting; on the other hand, the voltage at intersection stations varies slightly because it is a function of the potential difference at the N-P junction of the same material. This means that the voltage increases logarithmically by increasing solar radiation:

- Optimum cell power (P_m) is practically proportional to lighting.
- Maximum power points at about the same voltage (see **Figure (I-10)**).

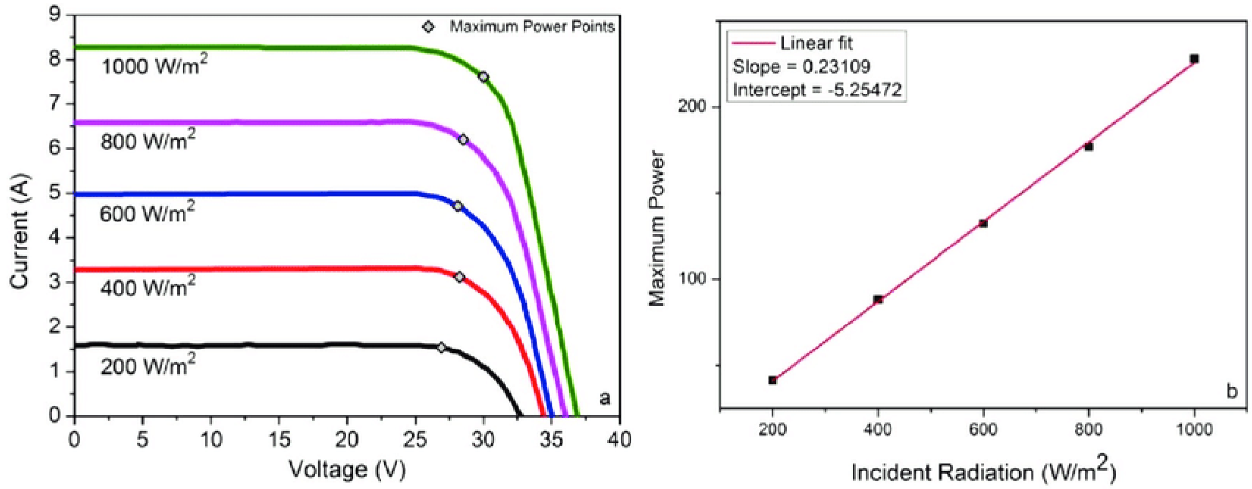


Figure (I-10): Influence of sunlight on I-V curves**.**

- **Temperature effect:**

The effect of temperature on the current properties/voltage of the cell cannot be neglected (see **Figure (I-11).** As for temperature change, we can see that the difference in current is not very important, as it increases slightly with the increase in cell temperature. As for voltage, it reduces linearly with an increase in cell temperature, thus cell efficiency drops.

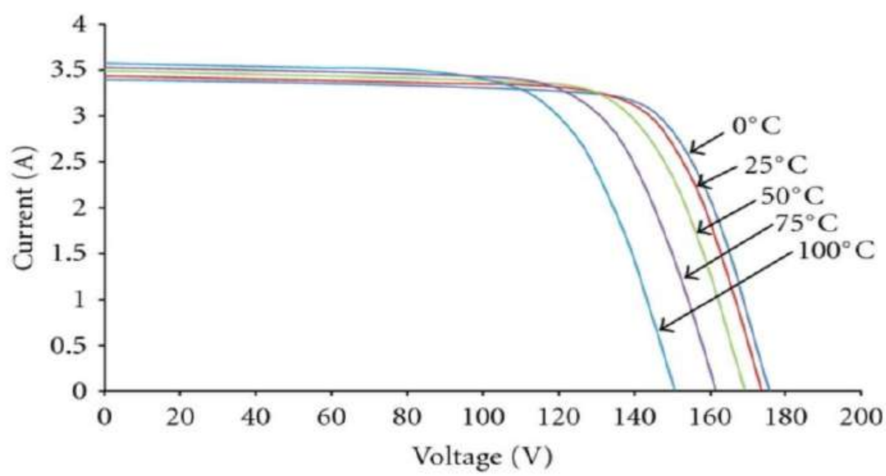


Figure (I-11): Influence of temperature on the I-V curves.

- **Shadow effect:**[4]

It is a barrier or obstacle that prevents the direct or diffuse sunlight from the photovoltaic sensors and is represented by houses, trees or clouds; Two types of partial and total shading (by elements which fall on the PV system surface such as leaves) can be distinguished.

In a photovoltaic panel, the cells are connected in series. The presence of a shaded cell in the model affects the performance of other cells and thus decreases the level of energy production in the system and therefore the larger the size of shading, more the system has lost its effectiveness in energy production.

As a solution to ensure the continuity of output and avoid unexpected shadow problems, PV systems (or panels) are provided for bypass diodes.

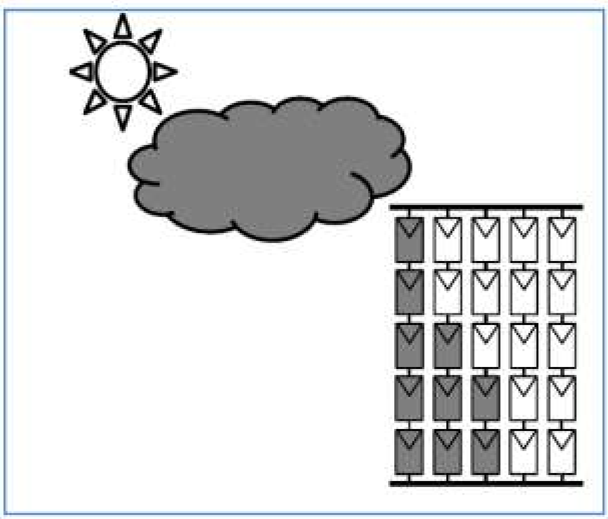


Figure (I-12): PV in conditions partially shaded by passing clouds.

Ideally, we consider that identical photovoltaic cells are subjected to the same sunlight and temperature; it becomes easy to add voltages in the case of the assembly of a series of photovoltaic cells. But in fact, there is a difference between PV cells in addition to the fact that the latter is prone to several factors and obstacles as mentioned earlier, so it becomes difficult to predict electrical behavior in this case depends on the characteristics and conditions of each cell.

Figure (I-13) shows atypical current - voltage (I−V) curve of a photovoltaic cell. It can be observed that if the current flowing through the cell for solar lighting and an ambient temperature is greater than the short circuit current, the cell will work in reverse with a negative voltage (negative voltage experience) and here the cell becomes energy-consuming rather than produced. In this case, excess energy such as heat in the shaded cell that causes the effects of aging on the cell will be dissipated and the cell or cell packaging may be irreparably damaged. This effect is called a “hot spot”.

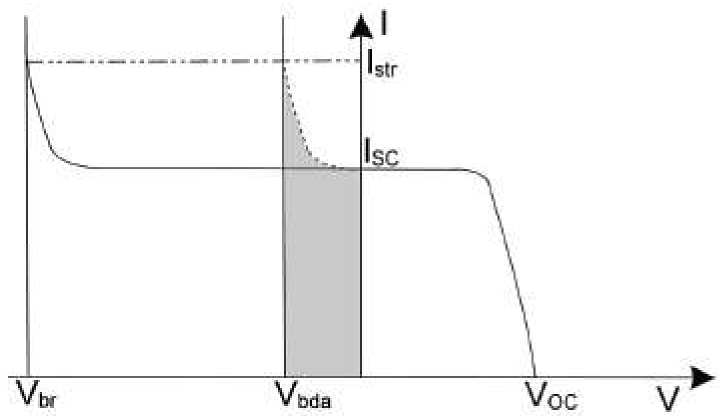


Figure (I-13): Characteristic I −V of a PV cell.

In the positive field (normal mode of operation), the open circuit voltage of the cell is of the order of 0.6 V for crystalline cells while in the negative direction (reverse polarization), the voltages can reach more than 20 V for the case of silicon.

I-8: Conclusion:

In this chapter we have presented the principle of photovoltaic conversion as well as the different characteristics and parameters of influence on the photovoltaic cell.

But photovoltaic energy has a number of advantages and disadvantages among them we quote:

Advantages:

- This source is free, sun is the only resource a solar panel needs and the sun will shine until the end times. In addition, most photovoltaic cells are made from silicon, an abundant and non-toxic material (second most abundant material on Earth)
- Photovoltaic solar energy generates no noise, no harmful emissions or polluting gases solar electricity uses only the sun's energy as a source. It does not create any harmful co-product and actively contributes to reducing global warming.
- Photovoltaic solar energy requires little maintenance solar modules require virtually no maintenance and are easy to install.
- Solar PV provides electricity to the most remote rural areas

Disadvantages:

- Photovoltaic modules do not work when solar energy is not available.
- The manufacture of the photovoltaic module is high-tech and requires high-cost investments.
- The actual conversion efficiency of a module is low (the theoretical limit for a cell to crystalline silicon is 28%).
- Photovoltaic generators are not competitive with diesel generators for low energy demands in remote areas.

Chapter II:

Comprehension of soiling and dust parameters and cleaning systems

II-1: Introduction:

Solar Photovoltaic (PV) technology has been widely applied in recent years due to its sustainability and cleanliness. However, it is clear that they are exposed to a range of pollutants, including the deposition of airborne dust particles on solar photovoltaic panels, which in turn reduces the spectral permeability of covered glass and thus significantly reduces the efficiency of photovoltaic output. The traditional water cleaning method is still the main way to reduce dust deposition on solar photovoltaic panels. However, the cost of cleaning water is always high and lacks water in dry areas. In this chapter we will address a set of different mechanisms.

II-2: Soiling losses: [7]

We say about a system that is in soiling in the sense that there is a barrier on the surface of cells that basically prevents solar radiation from reaching the cell. This is an obstacle either snow, bird droppings, dust, or other particles covering the surface of PV units; the accumulation of dust is one of the biggest factors to be taken into account before starting to create any photovoltaic station and it is one of the most important areas that researchers focus on in the present time.

The accumulation of dust over time aggravates the soiling effect on the system and is represented in:

- Significantly reduces the energy generated as dust acts as a shading element for the unit.
- Irregular solar irradiation (reduces the amount of radiation received by the cell).

There are also other undesirable effects, such as the appearance of hot spots due to the shading effect of the dust on some parts of the module, the deterioration of units if they are left for long periods without scheduled maintenance and cleaning (resulting in permanent cleaning and therefore excessive arrays) leading to loss of efficiency cells.

The amount of dust accumulated generally affects the total energy that must be provided by PV units on a daily, monthly or even seasonal basis. Previous studies have determined that the rate of losses can be from 1% per day up to (40-60%) in dry seasons. These changes are due to climate factors (wind) as well as the location and environment surrounding the station, both vehicle traffic factories and others.

II-3: Dust intensity around world:

Solar radiation and cell temperature are among the most important factors affecting the performance of PV units. In addition to these factors, the environmental conditions of the medium should be studied. As we mentioned in the past wind, sandstorms and dust ... Etc. accumulated on the surfaces of the units, it in turn affects the amount of energy provided by the latter.

Dust particles are the dominant components of aerosols in many regions of the world and are one of the most important obstacles that contribute to a significant fluctuation in the productivity of the unit. In 2014, scientist SANAZ Ghazi conducted a study that indicated that the northern regions of Africa and China rank first and second in the world in terms of dust emissions respectively, followed by the Middle East as arid and sandy regions [7]. This is what we find in the II-1 form document, which represents dust-dense areas around the world in different proportions. Dust loaded with storms can travel thousands of kilometers (Across continents and oceans). winds scatter dust from the desert - the planet's main source - towards the Americas to the west, Europe from the north and China from the east to Central Asia and other region [8]Shown in the **Figure(II-1)**.

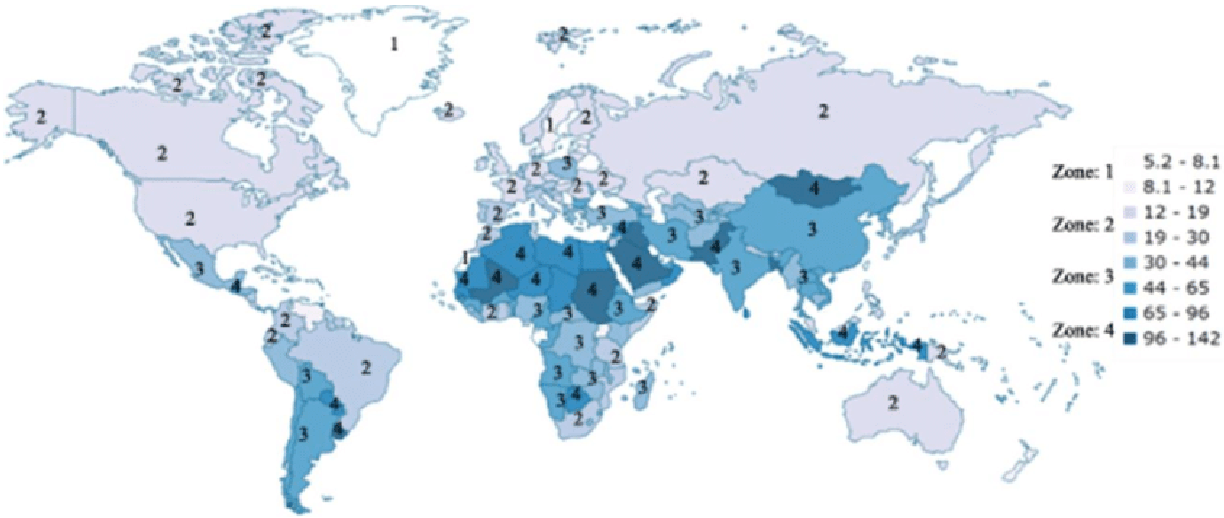


Figure (II-1): Dust intensity around world.

Through the map we can distinguish between four areas depending on the degree of color, the darker the color indicates the higher the density of the dust. This last one is distributed around the world with values of $[\,5.2 - 8.1\mu g/m^3\,]$to$[96 - 142\ \mu g/m^3]$. Dust emissions from Great Sahara Desert and northern China are estimated at $30 - 44\mu g/m^3$ and $96 - 142\mu g/m^3$accounting for above 20% and 50% of global dust emission, respectively. In third and fourth place are the Arabian Peninsula and Australia, the arid regions of the Americas and South Africa rank fifth with nearly 5% of global dust emissions.

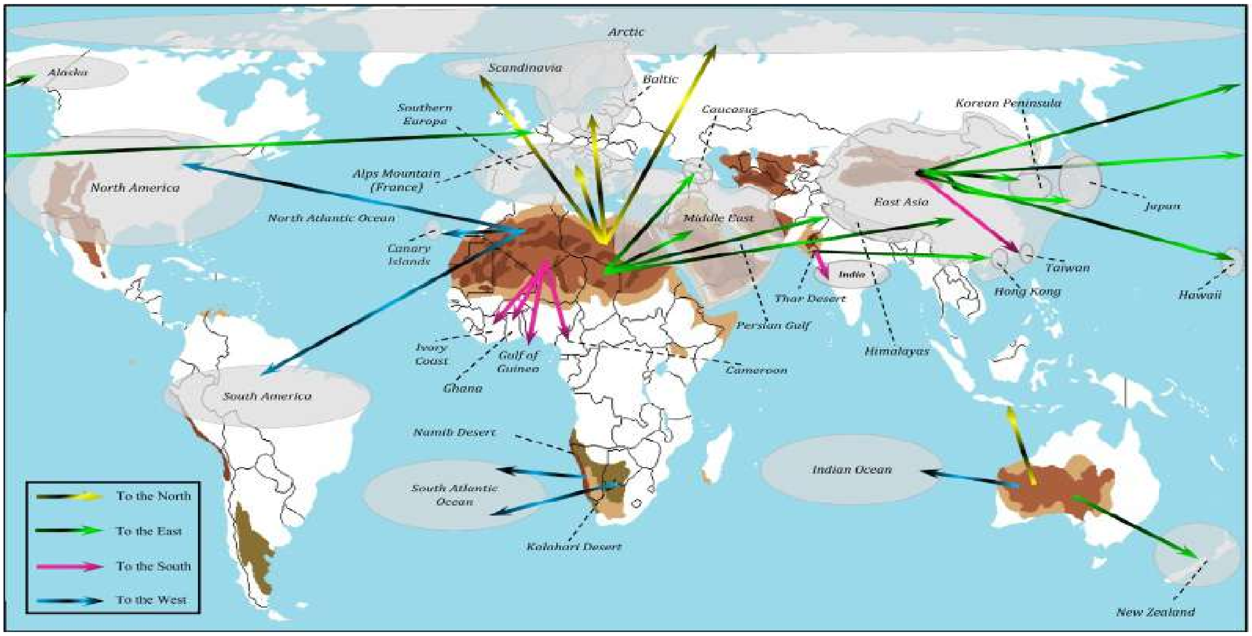


Figure (II-2): Dust sources and destinations of dust emission around the world.

II-4: Cause of dust accumulating on the surface of solar array:

Before starting the construction of any PV plant, most of the factors and environmental conditions surrounding them must be addressed, resulting in the displacement of several types of soil (dust). That's what we're going to address in the following paragraphs:

II-4-1: Environmental factors: [9]

- **Wind speed :**

Wind movement indirectly affects the performance of the solar cell, affecting the temperature of the surface of the solar cell and thus affecting its internal temperature. Since wind movement affects thermal load currents and thus raises the load heat transmission factor, which in turn helps to transfer heat from the cell surface to the outer ocean, this leads to a decrease in the internal temperature of the cell and thus improves its efficiency. On the speed side, it affects the accumulation of dust, where an air breeze can increase the accumulation of dust, unlike if the wind is strong, it has the ability to scatter and remove dust on the surface. The flow of air due to the wind is able to dissipate or accumulate dust on solar panels.

Air speed and pressure are factors that are not fixed on the surface of PV units. Accordingly, in the presence of wind, the air speed is higher and the pressure is lower, resulting in the lowest possible accumulation of soil and vice versa.

- **TEMPERATURE:**

Among the various factors that have an impact on the efficiency of the photovoltaic system we find the temperature of the medium. In other words, the electrical energy produced from the cell decreases as the temperature rises, resulting in a decrease in cell efficiency. Thus, we have an inverse relationship between temperature and voltage produced where the latter decreases by $2.3\ mV$ per °C per cell.In addition, the amount of dust or dust accumulated on the surface of the units generally contributes to the increase in the temperature of the cell itself. This accumulation results in hot spots that in turn destroy the unit. The cleaner and cooler the unit surfaces (solar panels are recommended to be equipped with cooling systems, especially areas with high temperatures), the greater the energy and thus the high efficiency of the system.

- **HUMIDITY:**

As we mentioned previously, temperature has a role in reducing the efficiency of PV cells on the one hand, on the other hand, humidity also has the same role. The effect of humidity appears in two cases, the first case is the entry of moisture into the solar cell container, while the second is the accumulation of water vapor particles at the surface level, affecting it by 3 phenomena may be refracted, reflected or diffracted the amount of solar radiation received by the panel and thus the deterioration of the level of reception of the board, which is what we find in **Figure (II-3)** , which indicates a significant deterioration of direct solar radiation with high humidity. The presence of water droplets inside the cell slowly reduces performance until the unit is damaged due to the corrosive caused by the latter. In addition, the effect of dust increases in wet weather as a concrete layer is formed that makes the cleaning process difficult and necessary.

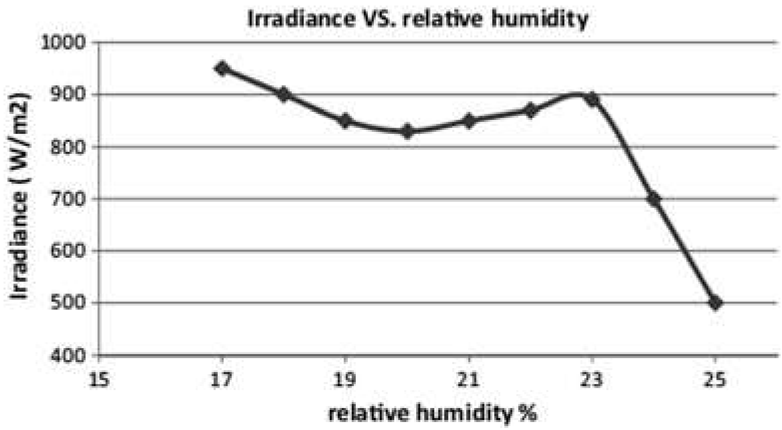


Figure (II-3): Variation of irradiance level with relative humidity.

This effect leads to a little variation in V_{oc} and vast discrepancy in I_{sc} with radiation, which is what we find in **Figure (II-4)**, from which we can calculate the efficiency of the conversion in the following relationship.

$$\eta = \frac{I_{sc\_max} * V_{oc\_max}}{A_C(\text{ irradinace level})} \qquad (II-1)$$

With:

η: The effective area of the module.

The snow, volcano, sandstorms are all environmental factors that affect the efficiency of solar arrays and play a role in the accumulation of dust on their surface.

II-4-2: Location and installation factors:

In general, the position of PV panels depends on the direction of sunlight and wind for high performance efficiency. According to this, we determine the angle, height and area…etc. To avoid the total problems to which the units are exposed. Besides, these factors intervene and are considered one of the causes of dust accumulation on the surfaces, which is what we find shown below:

- **Area:**

One of the most important studies before the establishment of any solar plant is to study the location and environment of the region. Dust is generated from several sources such as wind pollution in sandy areas, residues of dust and waste in industrial and other areas. Over time, the accumulated dust constitutes surface pollution and a barrier to the passage of sufficient direct radiation.

- **Flat surface:**

The nature of the surface is an important factor that plays a major role in the process of dirt. It allows more soil to accumulate if it is sticky or rough rather than smooth. In addition, the wider the surface area, the more dust it allows to accumulate.

- **Tilt angle and direction:**[10]

Tilt angle and direction are one of the important factors determining the performance of photovoltaic panels. In previous studies it has been shown that by placing a fixed mile angle with different directions, the dust accumulated on the samples is approximately equal. According to the set of external experiments conducted in different regions of the world in order to know how the slope angle in dust accumulation affects the performance of solar systems. The results of the work done by Saying et al. to deposit dust on a slanted glass panel located in Kuwait City. showed that it reduces the permeability of the board from 64% to 17% for tilt angles ranging from 0˚ to 60˚ respectively after 38 days of exposure to the environment. Also, Hijazi studied the deposition of dust on glass panels at different tilt angles, and how it affects the permeability of the plate under different weather conditions, and has concluded that the deterioration in solar permeability depends on the angle of inclination. Kano and others focused on the relationship between the angle of inclination and the loss of pollution after a three-month experiment showing that horizontal PV units have dirt loss of about 2.02%, while units with 23˚and 33˚ degrees lost nearly 50 % of the loss of pollution. Abedin and others were interested in affecting the accumulation of dust on the energy generated by PV units at different angles. According to their experiments 10 months later, they found that units with angles of 15˚and 45˚ experienced a decrease in the energy produced, estimated at 43% and 25.5%.

For that in practical applications, it is not recommended to arrange the oblique angle at an angle of 0 degrees due to the accumulation of dust and water during the rain, preferably allowing the small angle of inclination to allow dust and water to fall using the angle of gravity which will increase the efficiency of the overall system.

- **<u>Height:</u>**

The rise has to do with atmospheric pressure where Atmospheric pressure decreases as it rises above sea level. Therefore, as we have mentioned in environmental factors, low pressure has a lower dust accumulation rate.

II-4-3: Dust type: [11]

This part processes some types of dust that can be deposited on the surfaces of photovoltaic units. From previously conducted trades, spectral transition results and SEM and PV performance were displayed when “acrylic plastic and glass “vouchers were deposited with one of the dust varieties (charts and images shown below).

- **<u>Clay:</u>**

Clay is composed of tiny particles with high cohesion, expansion and plasticity and low permeability. When the particles are dry, they become solid, but when wet, they become sticky due to their high-water retention. Tiny silicates are the main minerals found in clay soils. They are lightweight and can be carried by wind from the atmosphere to photovoltaic surfaces, which can cause a decrease in light transmission to photovoltaic cells.

A decrease in light permeability was recorded when dry clay was deposited in coupons of approximately 43% on acrylic plastic and 8% on low-iron glass. On the other hand, a significant decrease was documented when wet clay was deposited on coupons with a record of about 100% acrylic plastic and 77% low-iron glass. In addition, clays are composed of fine metals with low plasticity and permeability, and appear to be partially transparent and opaque with a low-light effect. The density of the mineral appears to be high, which can result in a lower flow density.

The particles contain a soft, precise surface that improves dispersion, and the shape appears to be the structure of a round shell, causing light to reflect or dilute. These particles are very small and heavy, but can be blown by wind or gravitational effects, causing them to roll, slide and rise in the air.

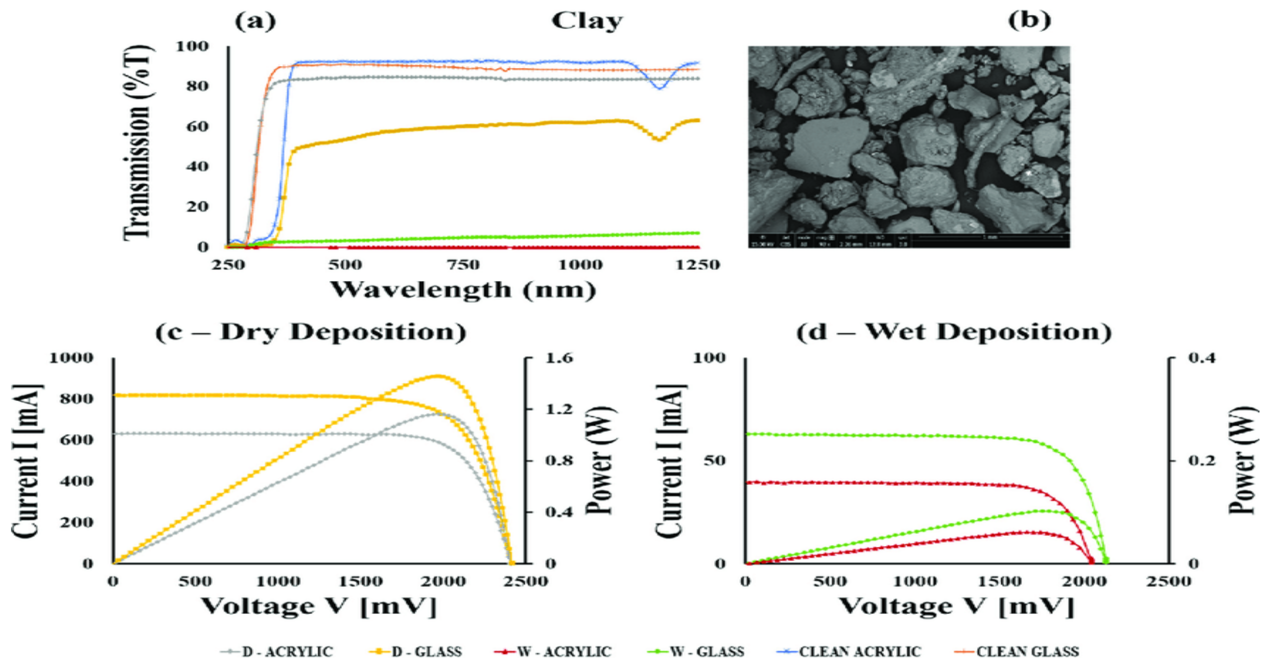


Figure (II-4): Clay - (a) Spectral transmittance (b) SEM imaging (c and d) PV performance.

The **Figure (II-4)** shows the results of photoelectric performance whereby the short-circuit current deteriorates by about 33% when clay samples deposited on acrylic plastic and clay samples on 14% low iron glass are dried. A significant increase in degradation was observed when wet clay samples were deposited on various specimens, with approximately 96% recorded on acrylic plastic and 93% recorded on low iron glass.

- **Sandy soil:**

Sand particles are an abundant element in nature, easy to deal with as they are deposited in water and easy to compress and lift when fully dry. This type of soil is affected by wind erosion and can be lifted to the surface of the PV unit, becoming a barrier that prevents light from reaching PV cells.

Light permeability decreases when dry sand on vouchers is deposited by 51% on acrylic plastic and 11% on low-iron glass. On the other hand, a significant decrease was recorded when the damp sand was deposited on the vouchers with both registrations down about 99%.The sand structure looks opaque and partially semi-transparent. Particle sizes range from small to medium, which can cause light to be weakened. The particle structure appears to be complex and mono herald. It is also heavy, which means it will easily settle down and accumulate on the platform.

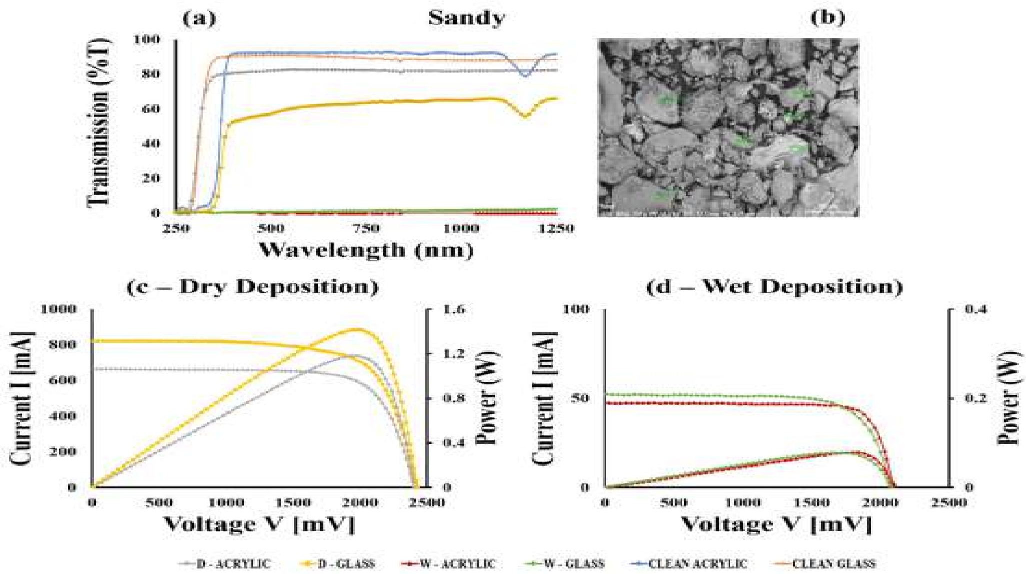


Figure (II-5): Sandy - (a) Spectral transmittance (b) SEM imaging (c and d) PV performance.

From the curve above we note that the degradation of the short circuit current of the PV cell is about 30% if it is the dry sandy soil that is deposited on acrylic plastic and about 13% on low-iron glass. The rate of deterioration is higher when vouchers are deposited in moist soil where about 95% of degradation is recorded on acrylic, and about 94% on low-iron glass.

- **Stone dust:**

As we mentioned earlier, among the sources of dust we find factories and quarries ... etc. Strong winds or sandstorms lift this dust and move to deposit it on the surface of PV units and reduce the permeability of light. Light depletion decreases when sedimentary stone dust dries up by 16% on acrylic plastic and 5% on low-iron glass. In the case of wet dust, the rate of decline is estimated at 87% for acrylic plastic and 100% low iron glass. The particle surfaces look rough and heavy, forming an easy-to-install compact layer and placing them on the surface of the units.

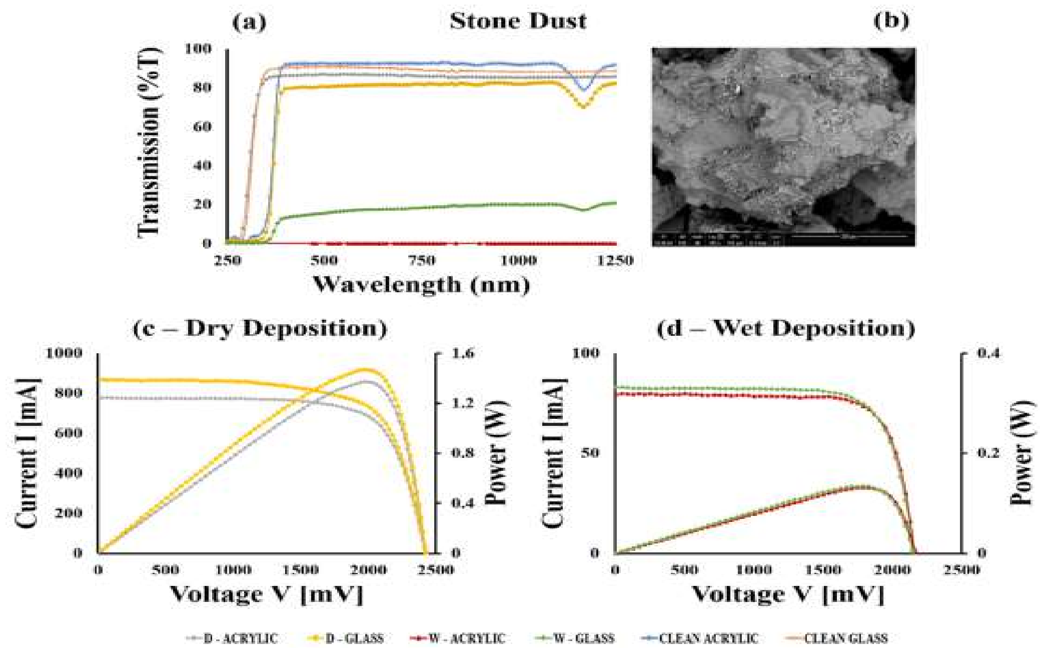


Figure (II-6): Stone dust - (a) Spectral transmittance (b) SEM imaging (c and d) PV performance.

From the curve above we note that the short circuit current decreased by about 18% when the stone dust was deposited on acrylic plastic and by 9% on the surface of low-iron glass plastic. A worrying increase in degradation was observed when stone dust deposited on different coupons by about 92%Record degradation on acrylic plastic and about 91% on low iron glass.

➢ **<u>Coarse sand:</u>**

It is a soil mixed with large pieces of heavy gravel, so it's hard to move by wind unless it's strong. The latter is deposited on surfaces and reflects or scatters direct solar radiation. Rough sand is dry, light run-out decreases by about 33% on acrylic plastic and 4% on low-iron glass. In the case of wet rough sand deposition, the reduction is about 74% on acrylic plastic and 63% on low-iron glass.

The image below describes the structure and components of coarse sand where the particles look heavy, and appear to have a spherical and/or quad-angle structure with a partial rough surface, providing favorable visual properties. It also contains broken rock particles with semi-transparent metals, allowing a certain percentage of light to pass. According to this type of dust, light can pass through the voids and large dust particles can also be affected by gravitational forces and light winds and scatter from the surface.

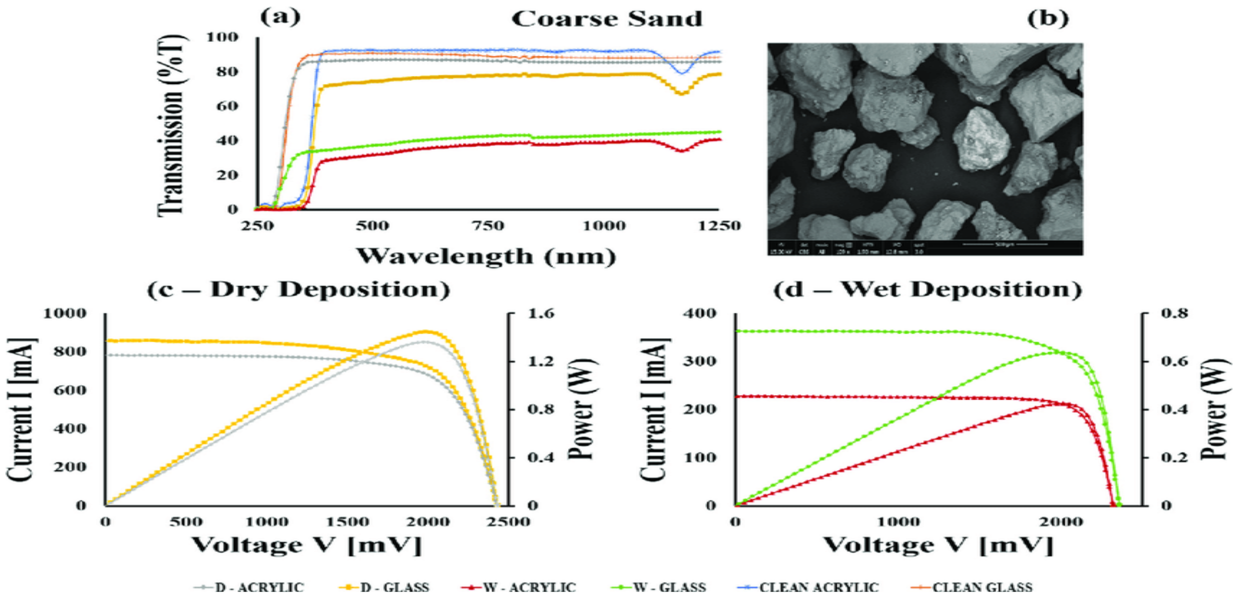


Figure (II-7): Coarse sand - (a) Spectral transmittance (b) SEM imaging (c and d) PV performance.

The PV performance chart shows that the short circuit current deteriorates by about 17% when the raw sand sample was dry deposited on acrylic plastic and about 10% on a low-iron glass coupon. We note an increase in degradation when a wet raw sand sample is deposited on different vouchers where about 76% of degradation was recorded on acrylic plastic and 62% on low iron glass.

II-5: Cleaning systems of solar panels: [12]

Cleaning with a chiffon:

The most common way. Depend on the manual labor to clean solar panels and this using water and cloth. Gently wash the surface of the panel to remove dust and debris and then use a rubber mop to remove excess water. This method is simple and less expensive. On the other hand, the disadvantage is that it is tiring for large areas, water consumption in large quantities and the most important indirect degradation of the surface of units.

Brush cleaning system (BCS):

The Brush Cleaning System (BCS) is a waterless cleaning device consisting of several electromechanical components operated by an electronic controller to remove dust from solar panels. It works automatically by detecting its current status and predefined program. The cleaning system consists of cleaning and drives units, usually working with brushes in the x and y directions. The unit of the automation system is Clean in the transverse direction with a brush that sweeps quickly in the longitudinal direction. The unit detects its state and manages the cleanliness of the panel according to a program predefined by the user. This technology provides a sustainable cleaning system with minimal complexity in construction and maintenance costs.

This mechanism is self-contained and BCS can be easily programmed and operated based on requirements. The human factor intervenes in a small part such as removing consistent dust taking into account the surface (avoiding scratches on the surface due to brush friction) and using external energy sources.

Figure (II-8): Brush cleaning system.

Electrostatic cleaning system (ECS):

Among the alternative cleaning systems, electrostatic waves are used to clean up dust accumulated on the roofs of photovoltaic units. Among the pioneers of the use of electrostatic force are Masuda and others. These pioneers considered the system to be highly efficient, automatic, does not consume any external and economical materials in the consumption of external energy (it has very low energy consumption).

In this technique, a high voltage is applied to a transparent panel consisting of parallel electrodes printed on a glass substrate to generate an electrostatic wave on the solar panel. This resulting force pushes small dust particles on the board in one direction. This technique can separate and remove more than 90% of the molecules in addition to not damaging the surface of the units.

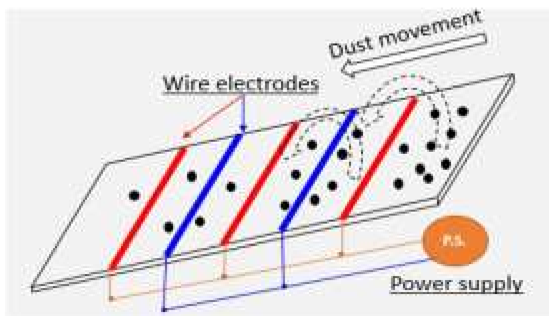


Figure (II-9): Electrostatic cleaning system (ECS).

<u>Robotic cleaning system (RCS):</u>

RCS is one of the latest PV cleaning joiners because it is up to date with high-efficiency, lightweight and programmable technology that is easy to control. This system can be relied upon in remote and dry areas as it works in two ways either in the absence of water (use of nylon or silicon brushes) or using very small amounts (wet cleaning; use of mops).

Most robots are built using the Arduino console to enable the robot to work automatically without connecting to an external computer. This system consists of two command units operating in two directions at a time. It is also safe on the surfaces as it is transmitted by soft plastic wheels that do not cause any scratches or eat to the surface. This robot can be integrated with sensors whether for dust, sun and even infrared to provide up to 32% improvement in efficiency of total board production from loss.

Figure (II-10): Robotic cleaning system (RCS).

Coating cleaning system (CCS):

Paint cleaning systems (CCS) apply to substrates using gases, solids or liquids. This technique is considered a self-ejection technique that prevents the accumulation of dust particles. CCS reduces water consumption; however, dust clusters on the surface of the panel may result during cleaning.

Recently, self-cleaning coatings such as super-waterproof or water-loving materials have been adopted to reduce dust deposition on solar PV panels. As highly resistant materials that use surfaces and low-energy surface materials such as gonorrhea, silicon, nanoparticles and polymers. As for the hyper water-loving film, it spreads water on TiO_2, then rinses the dust; Water droplets that reach the surface roll quickly and pull dust particles and other particles. This technique can achieve a recovery rate of up to 93%.

Figure (II-11): Coating cleaning system (CCS).

In addition to these mechanisms there are several other ways such as cleaning techniques for drone retrofitting, Heliotex cleaning system (HCS)and the cleaning of panels using compressed airflow.

II-6:Conclusion:

Many factors determine the ideal output or optimum yield in aphotovoltaic module. The environment is one of the contributing factors which directly affect photovoltaic performance. Dust property is among the factors influencing dust formation on PV, causing degradation of its performance. This chapter presented a detailed indoor experimental study of the effect of dust samples on PV performance, considering two different PV surfaces and using two deposition conditions (effect of dust properties, effect of PV system parameters and effects of environment parameters).

Many methods of cleaning solar panels have been addressed by some researchers and studies and positively affect solar panel applications. We can classify this automatic self-cleaning where the methods are divided into two main categories, which are known as active and passive methods. Active methods are those that require energy for self-cleaning methods such as electrostatic and mechanical methods. By contrast, negative methods, which do not require any use of energy for self-cleaning such as the paint method.

Chapter III:

Experimental study of dust effect on PV modules

III-1: Introduction:

The effect of dust on the energy behavior of PV system is very important. This chapter is devoted to studying the impact of dust on the electrical performance properties of PV generator and determining the approximate duration of the cleaning process. Two new and clean single PV modules are selected for comparison. Experimental tests are conducted at the Renewable Energy Research Unit in Ghardaïa.

III-2: The purpose of the experiment:

The main purpose of the experiment is to understand the extent to which weather conditions, particularly dust, effect the productivity of PV generator. Through this study, approximate periods of time can be set to enforce maintenance and cleaning of PV panels in order to maximize power generation.

III-3: The measurement site:

The studied photovoltaic system has been installed at the Applied Research Unit in Renewable Energies in Ghardaïa, 600 km south of Algeria.

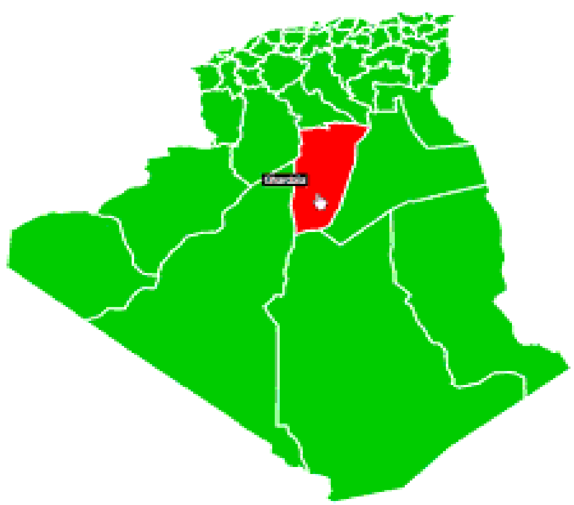


Figure (III-1): Geographical situation of the measurement site**.**

Site information:

• Latitude: 32° North.

• Longitude: 3° East.

• Site altitude: 489m.

• Site climate: dry and hot desert climate.

The area has a dry desert climate. The region is hit by sand-laden southwest winds in spring and summer, with very large solar potential and can be exploited practically throughout the year with an average annual solar radiation of 6.82kWh/m².

III-4: Solar potential of the site:

Solar irradiation is given for the chosen study site (per day). The solar data were obtained from the OUED-NACHOU photovoltaic power plant (GHARDAIA) through a sensors system that measures the daily values of global radiation received on an inclined plane (32°), for each month in (kWh/m²).

Table III-01: Monthly average daily solar irradiation of the GHARDAIA region.

	Jan	Feb	Mar	April	May	June	July	Augu	Sep	Oct	Nouv	Dec
Hm (kWh /m²)	190.58	178.26	230.26	229.92	236.64	221.28	233.41	208.31	198.31	199.66	187.01	186.62
Hd (kWh /m²)	6.15	6.14	7.43	7.66	7.63	7.38	7.53	6.72	6.61	6.44	6.23	6.02

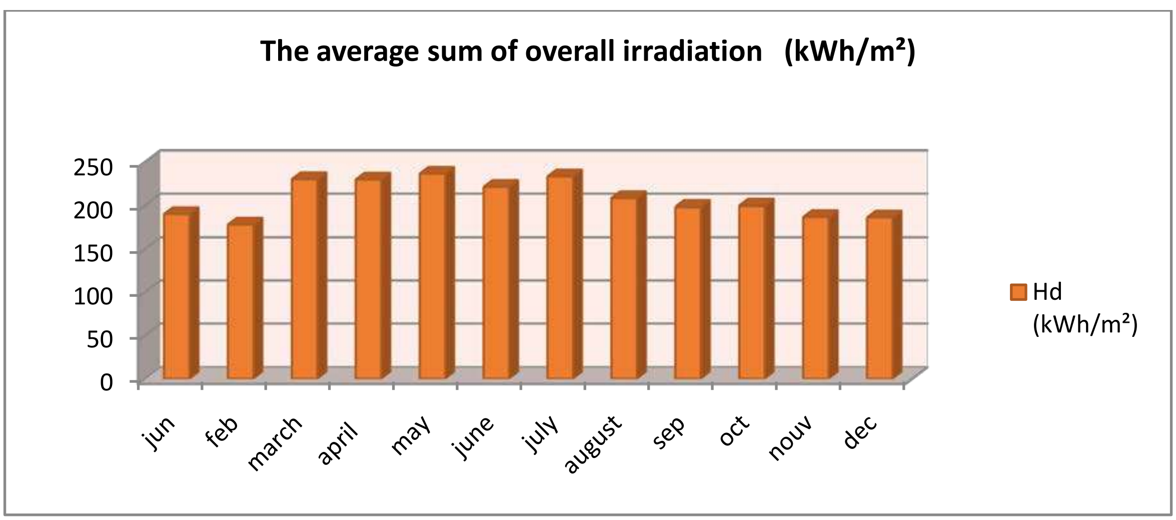


Figure (III-2): The change in annual overall irradiation.

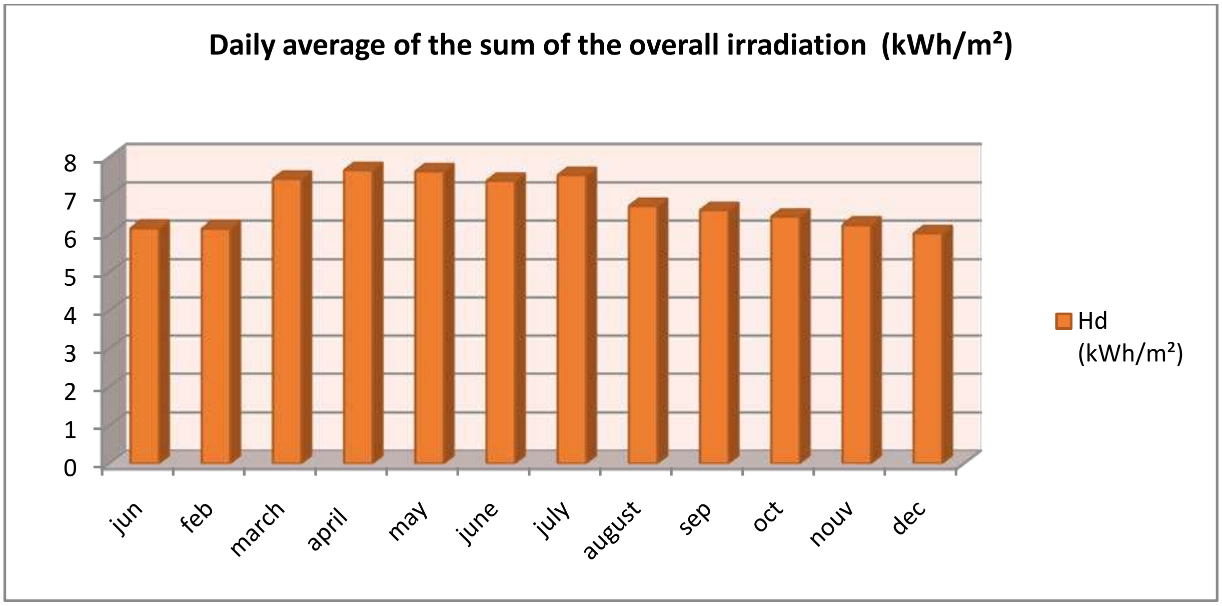


Figure (III-3): The daily average irradiation variation at GHARDAIA.

As shown in the graph above **Figure (III-1)**; the average solar irradiation values vary between 6.02 kWh/m² in December and 7.66 kWh/m² in April with an average annual radiation of 6.82 kWh/m². This potential is quite significant and practically exploitable all year round.

III-5: Methods and Materials:

In this study, we tested two external photovoltaic modules that were exposed to different climatic factors, using LabVIEW we measure PV characteristics (I.V) by electronic card as shown in the figure (III-4) this experiment was conducted for a period of time from 28/03/2022 to 11/05/2022.

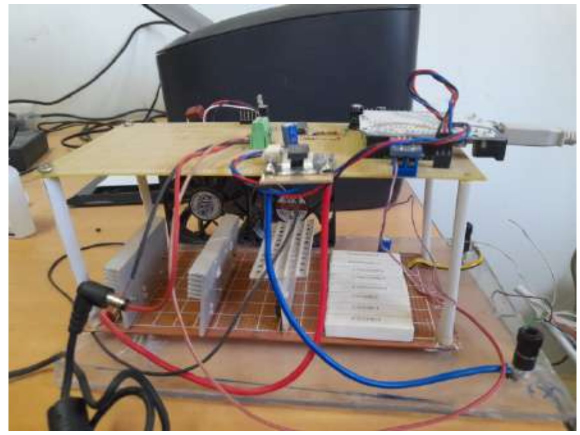


Figure (III-4): Arduino-based electronic board.

During the experimental tests of the two PV modules, we relied on unit-A status as a witness that was cleaned before each measurement, while Unit B remained under the influence of climatic factors (focusing on dust) that would not be cleaned for the duration of the experiment .The measurement process is programmed (every two days) to determine how long the solar panels on which the dust builds up can function.

The effect of dust on PV modules is displayed through the I-V curve, open circuit voltage (V_{co}), short circuit current (I_{cs}), and maximum power (P_{Max}).

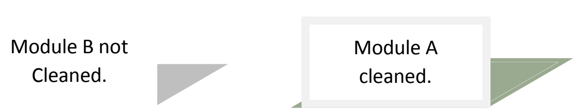


Figure (III-5): Dust deposition experiment facility.

III-5-1: Photovoltaic modules:

The experimental facility consists of two identical Photovoltaic modules (even manufacturer, same technology and identical technical characteristics). The modules are in mono crystalline silicon of the glass/cell/polymer type and with a peak power of 30 Watt. The dimensions of the panel were 430 mm by 545 mm by 25 mm. They are installed in free field (not integrated into the frame) with an angle of inclination of 32 ° with respect to the horizontal and orientation towards the south. Technical specifications modules given by the manufacturer are recorded in **Table III-02.** These modules have never been exposed to solar radiation before they were installed in the measurement facility.

Table III-02: Technical specification of photovoltaic modules.

Parameters	**Unit**	**Values**
Rated power (Wp)	30	watts
Short circuit current (I_{sc})	1.801	Amps
Open circuit voltage (V_{sc})	22.2	Volts
Cell surface(S)	0.23435	m2
Weight	2.5	kg

Figure (III-6): Photovoltaic module SPM30-12/3a mono.

III-5-2: The Arduino UNO board:

III-5-2-1: Description of the ARDUINO UNO board:

UNO is probably the most famous Arduino plate in the market and industry. It has all the features of a classic microcontroller as well as easy to use. Powered by an Atmega328 processor that operates at 16MHz. Arduino Uno is widely used, with a large storage space of 32 kb dedicated to receiving the program, 1 kb of EEPROM (reading only data memory) and 2 kbps of RAM. In addition, this electronic unit features only 14 digital inputs/outputs, 6 analog inputs that can generate PWM (pulse display adjustment), and 5-volt and 3.3-volt power bars.

Each Arduino Ono card comes with a power socket. The power socket is important because it allows Arduino Uno to be operated by an external wall wart. There is also an alternative way to connect to a power source known as VIN. The VIN option is available to connect UNO to batteries. Uno's physical dimensions (69mm length and width 54mm) make it a small development panel that can easily fit into many projects.

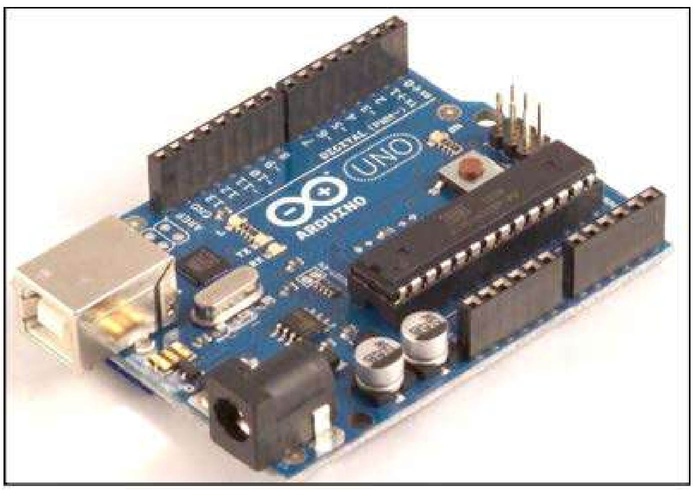


Figure (III-7): The Arduino UNO board.

III-5-2-2: Characteristics of the Arduino UNO boar:

Micro controller	ATmega328
Internal supply voltage	5V
Supply voltage (recommended)	7 to 12V, limits = 6 to 20 V
Digital inputs/outputs	14 including 6 PWM outputs
Analog inputs	6
Max current per I/O pins	40 MA
Max current on output	3.3V 50MA
SRAM Memory	2 KB
EEPROM Memory	1 KB
Clock frequency	16 MHz
Flash Memory	32 KB of which 0.5 KB used by the boot loader

III-5-2-3: The different components of the Arduino UNO board:

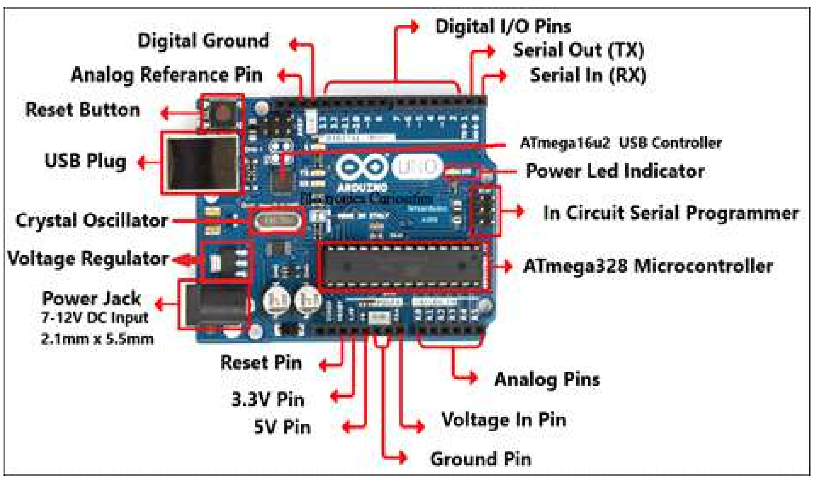


Figure (III-8): Description of an **Arduino Uno** board.

III-5-3: Voltage sensor:

This module works on the principle of the voltage divider. It divides by 5 the input current on the terminals. The input voltage must therefore not be higher than 25V (if connected in 5V) or 16.5V (if connected in 3.3V). The accuracy is 0.00489V in 5 volts, and the minimum detection threshold is 0.02445V in 5 volts.

- 100% compatible with Arduino.
- Operating output voltage: 3.3 V-5 V MAX.
- Input voltage range : 0.0245 V~25 V MAX.
- Analog input.
- The Voltage Sensor Module allows to detect the supply voltage from 0.0245 V to 25 V.

Figure (III-9): Voltage sensor module.

III-5-4: Current sensor:

The ACS758 device provides a cost-effective and accurate means of detecting AC and DC currents. This ACS758 current sensor is based on the principle of the Hall effect, which was discovered by Dr. Edwin Hall in 1879 according to this principle; The thickness of the copper conductor allows the device to survive under high overcurrent conditions. The ACS758 emits an analog voltage output signal that varies linearly with the detected current. This current sensor allows you to monitor the currents in your project every second for energy saving or circuit protection purposes.

The output of the device has a positive slope when an increasing current flow through the copper conduction path. The ACS758 can measure current up to ± 50 A and provides the output sensitivity of 40 mV/A, which means that for every 1A increase in current through the terminals of conduction in the positive direction,

Figure (III-10): Current sensor module.

- Compatible with Arduino interface.
- Typical bandwidth of 120 kHz.
- Output voltage proportional to AC or DC currents.
- Factory cut for more precision.
- Extremely stable output offset voltage.
- Magnetic hysteresis almost zero.
- Total improvement of the output error thanks to the gain and adjustment of the offset on the temperature.
- Monolithic IC Hall for high reliability.
- Ultra-low power loss: internal conductor resistance of 100μΩ.

III-5-5: Transistor MOSFET:

The term "MOSFET" is actually a meaning abbreviation (transistor effect of the semiconductor field for metal oxide - which translates into the structure of metal oxide field effect transistor and semiconductors). Simply put, MOSFETS are one of two large families of transistors that we find today (the other big family is bipolar transistors).

These transistors have a field effect. They also very similar to bipolar transistors in:

- Polarity: Each has a potential polarity.
- Both contain 3 pins.
- Each of them has a crucial input amount and the same output size.

Figure (III-11): Transistor MOSFET.

Benefits:

- Ideal in power electronics for fast switching and linear operation.
- Requires little energy to control it (almost controlled in voltage).
- Single channel, works either on channel “N” or on channel “P”.
- The current passing through the steering pin (Grid) is zero.

Disadvantage:

- residual resistance to the passing state (not 0 Ohm like a real wire)
- losses during these switches. The faster the switching, the smaller the loss.
- It is essential to correctly size the MOSFET transistor and optimize the control of its gate to minimize these losses.

III-6: LabVIEW program:

III-6-1: Generality about LabVIEW:

LabVIEW is a system design platform and development software with a graphical language called “G”. Developed by the American company National Instrument in 1986 exclusively for the Apple Macintosh, but now is available for the most of all operating systems like: Microsoft Windows, MacOS, Linux... This software can be used in a large number of domains, which is more particularly intended for data acquisition and signal processing. The most beautiful feature in LabView is offering wide possibilities of communication between the computer and the physical world (by analog or digital acquisition cards, GPIB cards, network, serial and parallel links, USB etc.) as well as important mathematical libraries allowing perform multiple processing on the measured signals.

The object of **LabVIEW** is to replace laboratory measurement and analysis instruments with a computer equipped with specific cards and appropriate software. As part of the measurement, the cards convert electrical signals from sensors into digital data. Thus, a single computer equipped with an analog acquisition card and **LabVIEW** is capable of replacing a voltmeter, a frequency meter or an oscilloscope. In addition, the measurements taken can be automatically processed, analyzed and archived on disk.

LabVIEW is available in three editions (LabView Base, Test Workflow Standard, Test Workflow Pro) and is a part of the Test Workflow bundle, which scale in features and capabilities to meet your application requirements.

III-6-2: G programming language:

The G language is based on the principle of data flow, to which programming structures have been added in order to obtain a complete programming language.

A data flow diagram is used to express a function graphically. Such a diagram is composed of:

- Terminals: these are the inputs (bold rectangle) and the outputs (thin rectangle) of the function.
-

- Nodes: they define the operations to be performed. We will see later that these operations can be functions already developed. These nodes are represented by a square containing an image which serves to illustrate their functionality.
- Directed arcs: they are used to connect the nodes and the terminals between them to indicate the path of the data. By convention, these arcs are oriented from left to right,
- Tokens: they represent the data transiting on the arcs. They are represented by dots.

Evolution rules allow this diagram to evolve:

- On initialization, the input terminals each produce a token,When a node has a token on each of these incoming arcs, and only in this case, the node can be executed: each input token is consumed and the node produces a token on each of its outgoing arcs.

A data flow diagram can be encapsulated in order to be reused, as a node (function), by other data flow diagrams. The terminals of the diagram then become the inputs/outputs of the node.

The G language implements the notion of data encapsulation which consists in representing a set of operations by a node, therefore defining functions and sub-functions. For the previous diagram, the encapsulation node will have 3 inputs a, b and c and two outputs d and e.

III-6-3: Principle of operation:

Figure (III-12): LabVIEW software interface.

We saw earlier that the programming language that LabVIEW uses is a language represented in the form of a graph. LabVIEW allows you to perform IV (for Virtual Instrument), to develop the graph of a function (set of operations) and define the relationships between the terminals and the input/output points of the graph. A VI that can appeal to another VI during its execution (as Arduino, …etc.), any application made with LabVIEW will be called VI. The latter is distinguished by three parts linked to each other:

- ✓ **<u>A Front-Panel</u>:** This is the user interface of the function. This front-end, customizable at leisure, is composed of graphic objects such as switches, potentiometers, graphics areas, etc. It is like a screen where we can read the results of the experiment through which it appears in a form previously defined by the user (curve, counter, cutter... etc.).

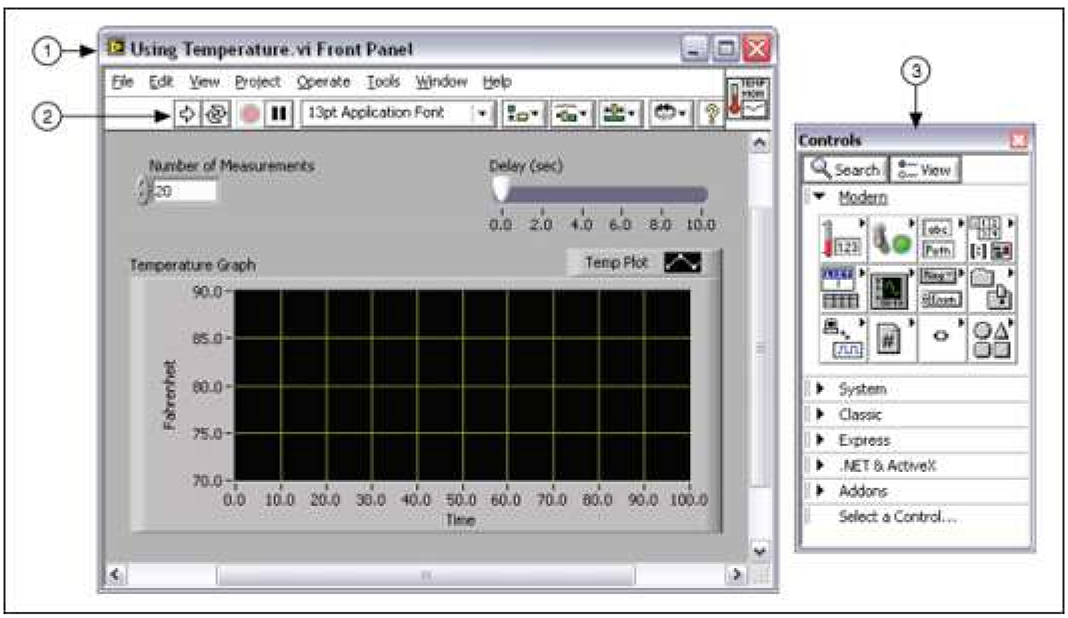


Figure (III-13): The Front-Panel of the program.

- ✓ **<u>A diagram (Block-Diagram):</u>** this part describes the internal functioning of the VI. The G language is therefore used to describe how this functioning occurs. Intended for use by engineers and scientists, who are not computer scientists by training, LabVIEW uses a graphical programming language G (for Graph) to describe programs that dictate application behavior. Thus, the user is freed from the heavy syntax of textual programming languages such as C, Basic, etc.

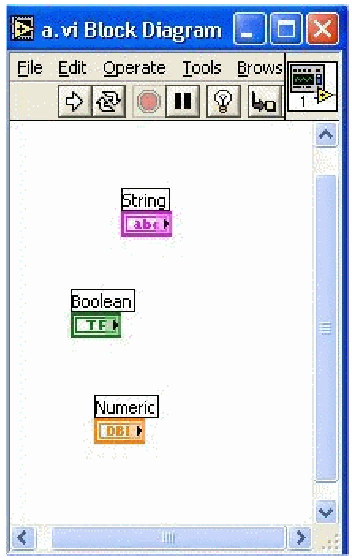


Figure (III-14): Graphic interface**.**

- ✓ **<u>An icon (Icon):</u>** it is the symbolization of the virtual instrument that will make it possible to use a virtual instrument already created inside another virtual instrument, it is a principle of hierarchical structure and modularity. It is through this that we will define the global entry and exit points of our function.

A VI (set of a front end and a flow diagram) is represented by its icon. Indeed, we have seen the notion of encapsulation that exists in the G language, which makes it possible to define IVs of functions that can be used by other IVs. It is therefore interesting to be able to distinguish and identify them easily.

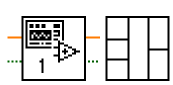


Figure (III-15): Sample of Icons in LabVIEW**.**

III-7:LinkingLabVIEW and Arduino:

It is known that the language of Arduino is different from the language of The LabVIEW. on the other side, we find that they both do not understand each other's language. So the solution is to download a library in the program LabVIEW carrying a special program (depending on the factor to be measured) this library works as an interpreter for the language of Arduino in the program then the code within the latter is sent to the Arduino device to read the information and turn it into display in the interface of the LabVIEW.

Figure (III-16): Linking LabVIEW and Arduino.

III-8: Experimental study of dust deposits on pv modules:

III-8-1: The experimental measurement facility:

Figure (III-17) displays the experimental measurement facility. The system consists of two identical mono crystal PV modules (the same manufacturer, the same technology and identical technical characteristics), a desktop computer and an electric card.

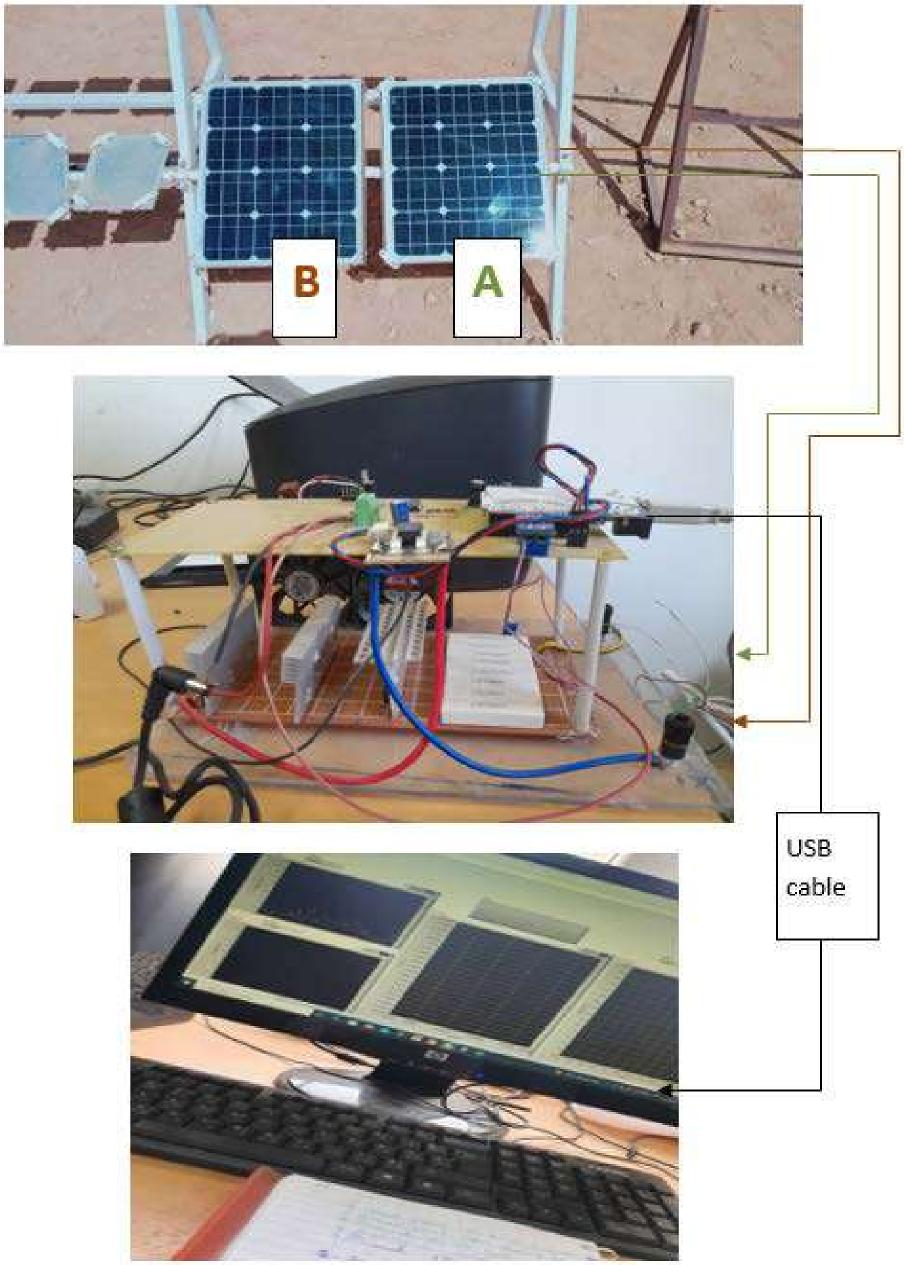


Figure (III-17): Experimental facility.

LABVIEW 2019 can provide data measured in excel® file form and can also display I-V and P-V curves and actual parameters, as shown in figure (III-18).Besides, this program is able to control and adjust the preview through the floor described in the following form .See**Figure (III-19).**

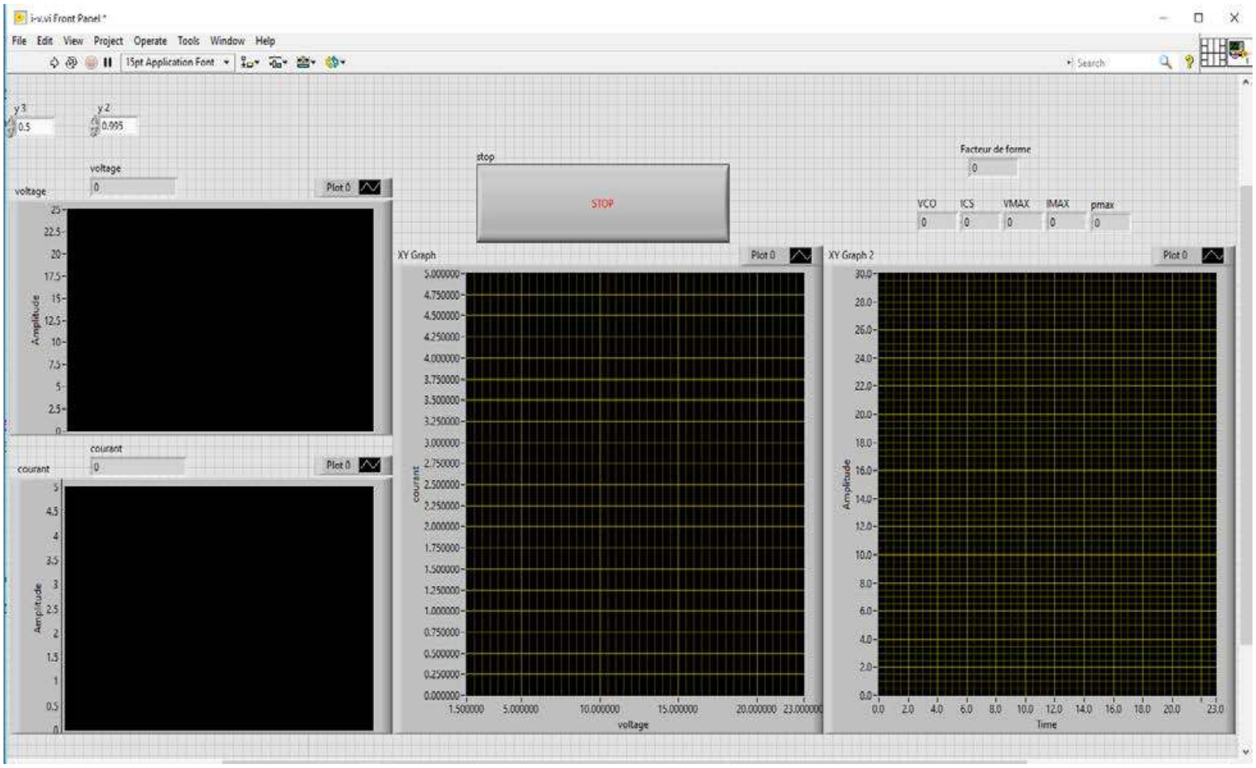


Figure (III-18): Trial results view interface**.**

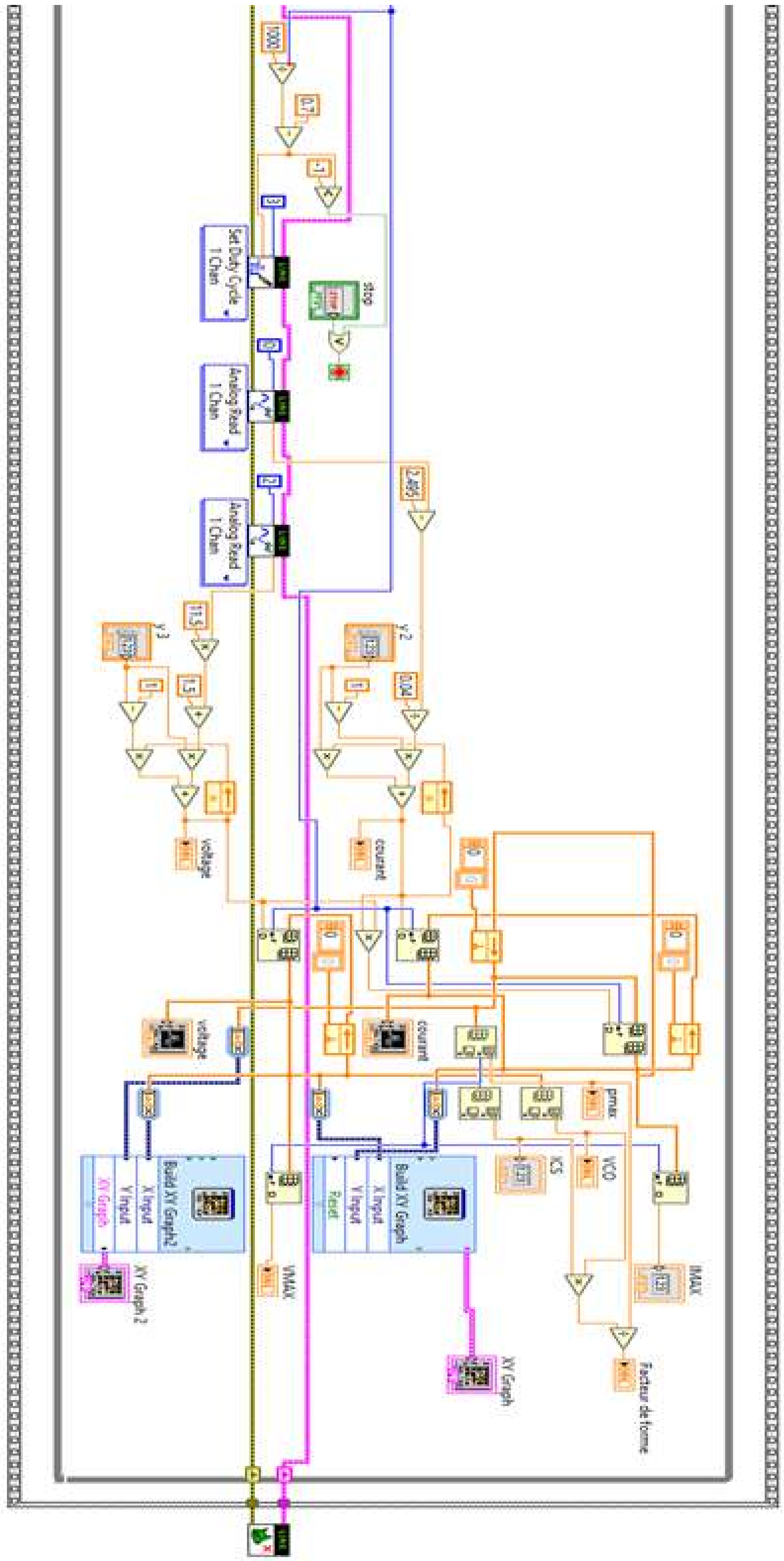


Figure (III-19): The experience diagram.

III-8--2:Result and interpretation of the study of dust deposits about PV modules:

<u>First experiment: Check the match rate of the two PV modules.</u>

Before starting our study, it is necessary to check whether the exact two PV modules are identical. In order to indicate the difference.

That's why units A and B have already been cleaned well. By taking Unit A as a reference, we measured the short circle current and the power in the same amount of sunlight. The following table shows the results and the calculated error.

$$\Delta\% = \frac{X_A - X_B}{X_A}$$

- ✓ **<u>Measuring information:</u>**

Table III-3:Information for measuring the first experiment

Date	Monday 28 march2022
Hour	11:50
weather condition	Sunnier and clear skies
Temperature (°C)	18.4
Wind speed (m/s)	1.763
Humidity(%)	29.5
Radiation(W/m²)	767,7153

Figure (III-20): Experimental facility (beginning of measurements).

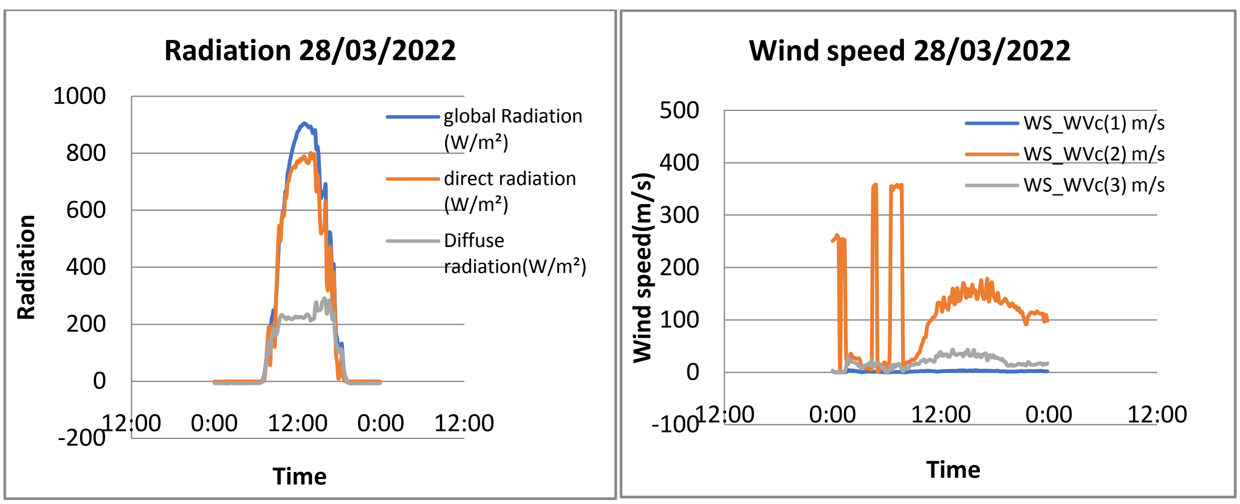


Figure (III-21): Radiation and wind speed on 28/03/2022.

Table III-4: Comparison of the 2 cleanly cleaned modules.

	A	B	$X_A - X_B$	%
Vco	20.4165	20.3111	0.1054	0%
Ics	1.04292	1.03517	0.00775	0%
Vmax	17.8768	18.3115	0.02	0%
Iman	0.818908	0.792739	0.026	0%
Pmax	14.6395	14.5162	0.1233	0%
FF	0.687	0.96	-0.273	0%
η%	8.136%	8.068%	0.068	0%

Since the difference was 0%, we verified that the two panels were identical as also shown in the curve below.

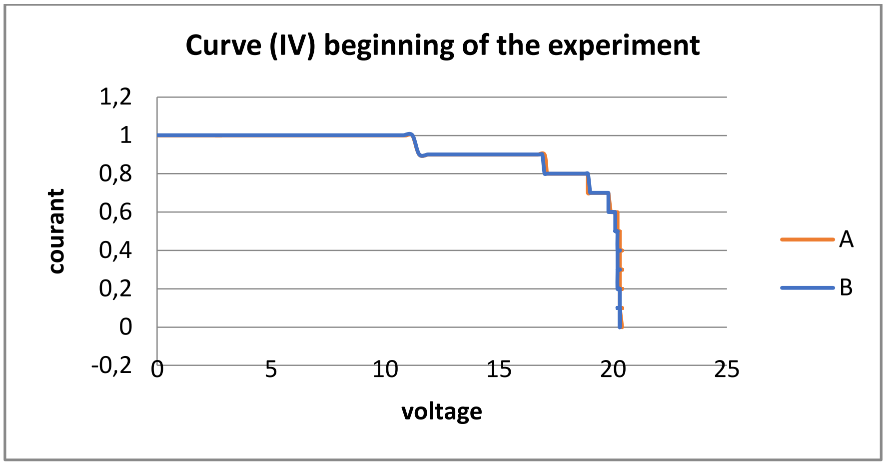


Figure (III-22): Curve (IV) PV modules (A and B are clean).

<u>Second experiment: measurements with the presence of rain and dust:</u>

- ✓ **<u>Measuring information:</u>**

Table III-5: Information for measuring the Secondexperiment.

Date	Wednesday March 30, 2022
Hour	10:50
weather condition	Rainy and cloudy
Temperature (°C)	14
Wind speed (m/s)	3.67
Humidity (%)	56.47
Radiation(W/m²)	3.11951

Figure (III-23): Experimentation facility (30/03/2022)**.**

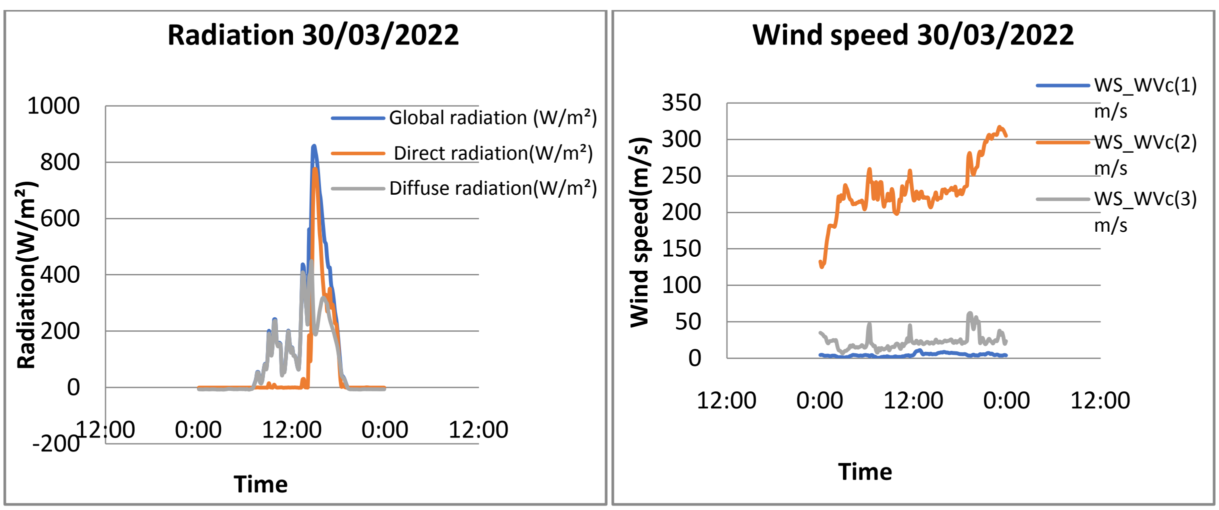


Figure (III-24): Radiation and wind speed on 30/03/2022.

Table III-6: Measurementvalues (30/03/2022).

	V	**B**	$X_A - X_B$	**%**
Vco	**17.6578**	**18.4161**	***-0.7583***	**0%**
Ics	**0.101472**	**0.08365**	***0.0178***	**0%**
Vmax	**15.9296**	**15.7316**	***0.1953***	**0%**
Iman	**0.07874**	**0.06027**	***0.01847***	**0%**
Pmax	**1.25433**	**0.948194**	***0.306***	**0%**
FF	**0.7**	**0.615**	***0.085***	**0%**
η%	**2%**	**1%**	***1***	**0.5%**

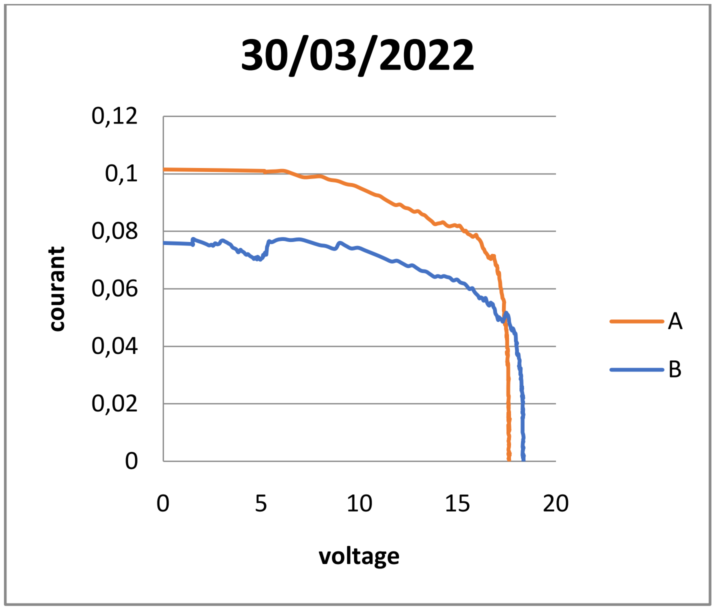


Figure (III-25): Curve I-V of the PV modules (30/03/2022).

<u>The third experiment: measurements in the presence of only dust:</u>

- ✓ **<u>Measuring information:</u>**

Table III-7: Information for measuring the third experiment.

Date	Sunday April10, 2022
Hour	11:00
weather condition	Clear
Temperature (°C)	18.6
Wind speed (m/s)	2.746
Humidity(%)	34
Radiation(W/m²)	973.6436

Figure (III-26): Experimentation facility (10/04/2022).

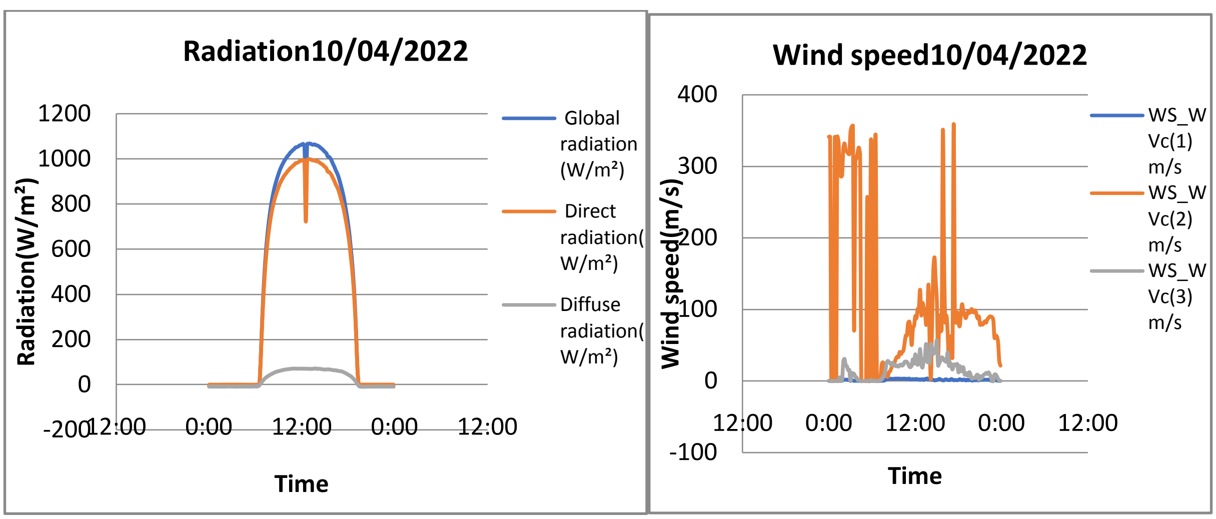


Figure (III-27): Radiation and wind speed on 10/04/2022.

Table III-8: Measurement values(10/04/2022).

	V	B	$X_A - X_B$	%
Vco	**20.0935**	**20.1782**	***-0.0847***	**0%**
Ics	**0.945568**	**0.919728**	***0.2584***	**0%**
Vmax	**18.2347**	**17.5771**	***0.6576***	**0%**
Iman	**0.732898**	**0.712093**	***0.0208***	**0%**
Pmax	**13.3642**	**12.5165**	***0.8477***	**0%**
FF	**0.703**	**0.6744**	***0.0286***	**0%**
η	**6%**	**5%**	***1***	**0%**

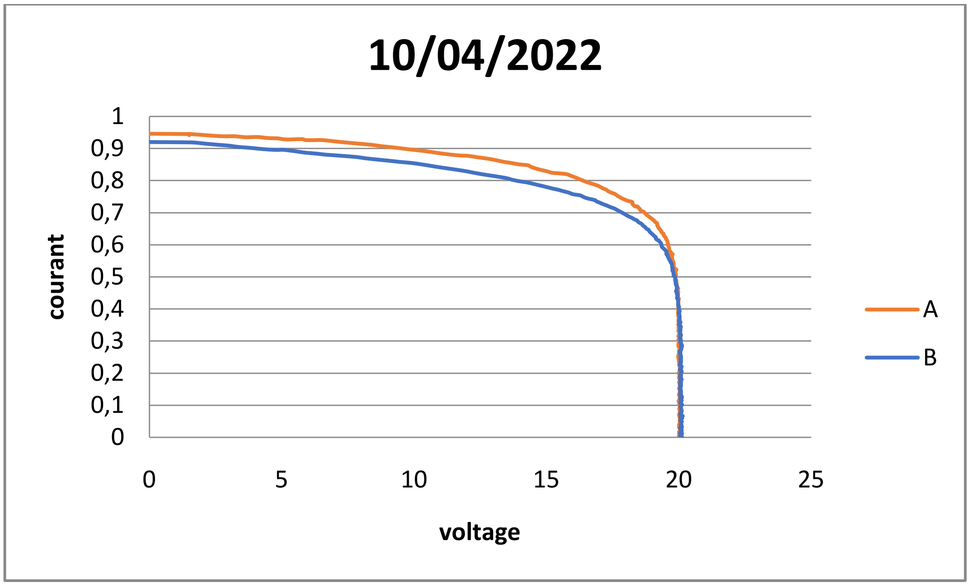


Figure (III-28): Curve I-V of the PV modules (10/04/2022).

Fourth experiment: measurements in the presence of clouds and dust:

- ✓ **Measuring information:**

Table III-9: Information for measuring the fourth experiment.

Date	Tuesday April 12, 2022
Hour	11:20
weather condition	clouds and it's hot.
Temperature (°C)	20.3
Wind speed (m/s)	4.483
Humidity(%)	42
Radiation(W/m²)	634.6594

Figure (III-29): Experimentation Scheme (12/04/2022).

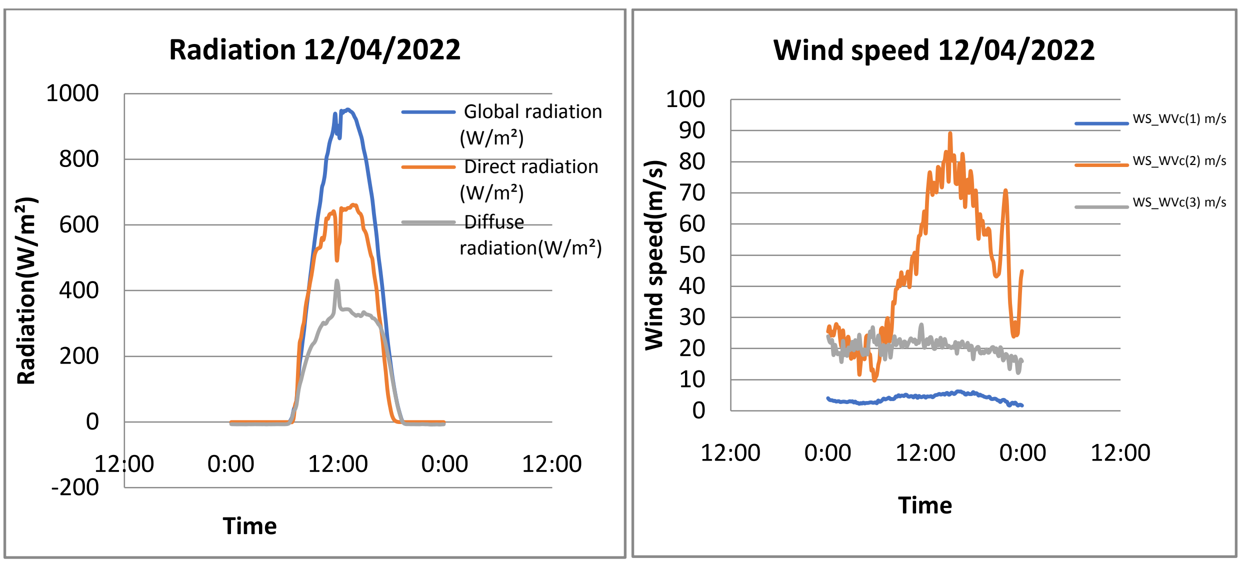


Figure (III-30): Radiation and wind speed on 12/04/2022.

Table III-10: Measurement values (12/04/2022).

	V	B	$X_A - X_B$	%
Vco	**20.7945**	**20.7851**	***0.0094***	**0%**
Ics	***0.98018***	**0.96113**	***0.01888***	**0%**
Vmax	***18.4043***	**18.2607**	***0.1436***	**0%**
Iman	***0.750433***	**0.738036**	***0.012397***	**0%**
Pmax	***13.8112***	**13.477**	***0.3342***	**0%**
FF	***0.6776***	**0.6746**	***0.003***	**0%**
η	***9%***	**9%**	***0***	**0%**

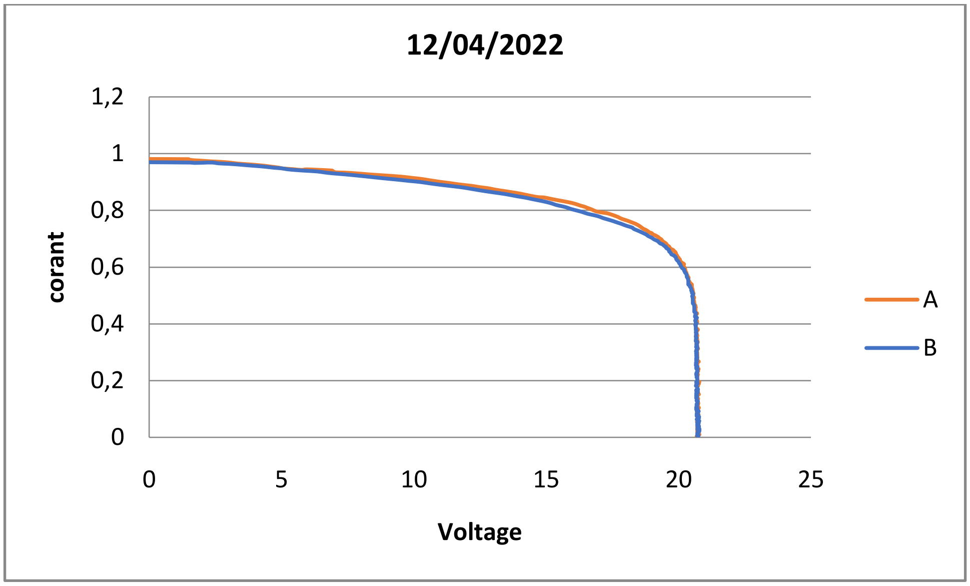


Figure (III-31): Curve I-V of the PV modules (12/04/2022).

<u>The fifth experiment: measurements in the presence of clouds:</u>

- ✓ **<u>Measuring information:</u>**

Table III-11: Information for measuring the fifth experiment.

Date	Sunday April 17, 2022
Hour	11:00
weather condition	clouds
Temperature (°C)	19.4
Wind speed (m/s)	4.103
Humidity(%)	45
Radiation(W/m²)	881.0549

Figure (III-32): Experimentation facility (17/04/2022)**.**

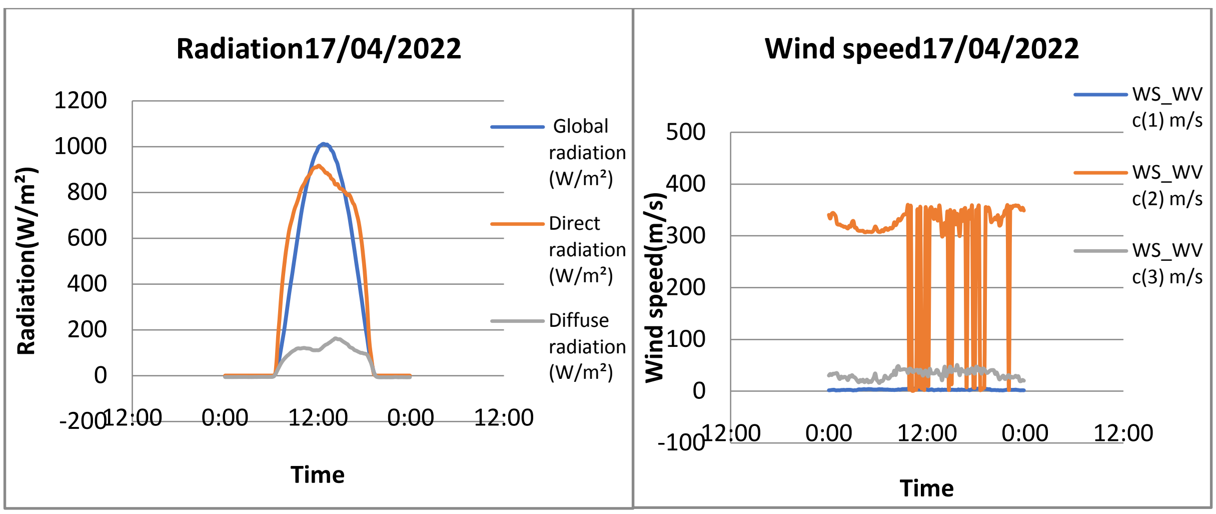


Figure (III-33): Radiation and wind speed on 17/04/2022.

Table III-12: Measurement values (17/04/2022).

	V	B	$X_A - X_B$	%
Vco	**21.3954**	**21.2594**	**0.136**	**0%**
Ics	**0.993359**	**1.01016**	**-0.016**	**0%**
Vmax	**19.0147**	**18.6244**	**0.3903**	**0%**
Iman	**0.760015**	**0.768762**	**-0.00874**	**0%**
Pmax	**14.4515**	**14.3181**	**0.1334**	**0%**
FF	**0.6799**	**0.666**	**0.0139**	**0%**
η	**7%**	**7%**	**0**	**0%**

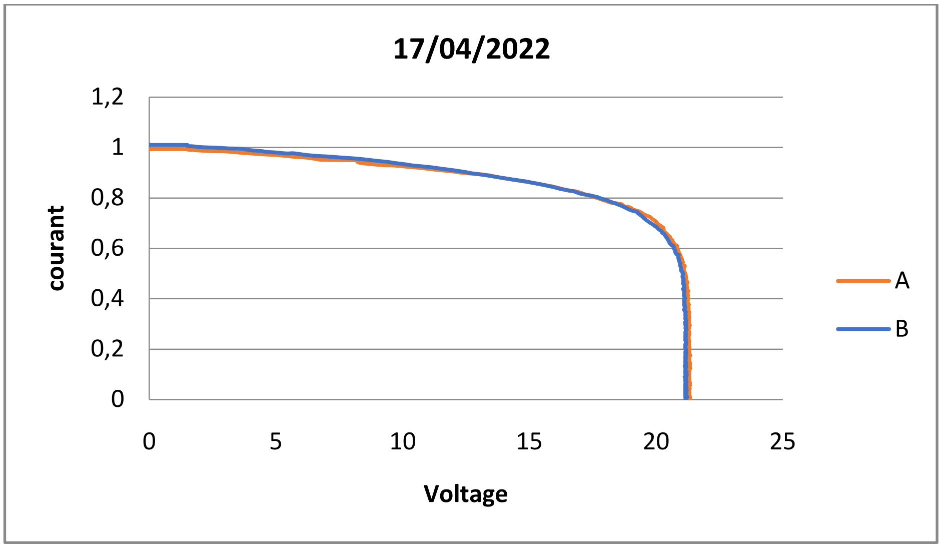


Figure (III-34): Curve I-V of the PV module (17/04/2022).

<u>Sixth experience: Measurements in the presence of wind:</u>

- ✓ **<u>Measuring information:</u>**

Table III-13: Information for measuring the sixth experiment.

Date	Tuesday April 19, 2022
Hour	12:10
weather condition	wind
Temperature (°C)	26.6
Wind speed (m/s)	5.344
Humidity(%)	21.5
Radiation(W/m²)	721.326

Figure (III-35): Experimentation facility (1**9**/04/2022)**.**

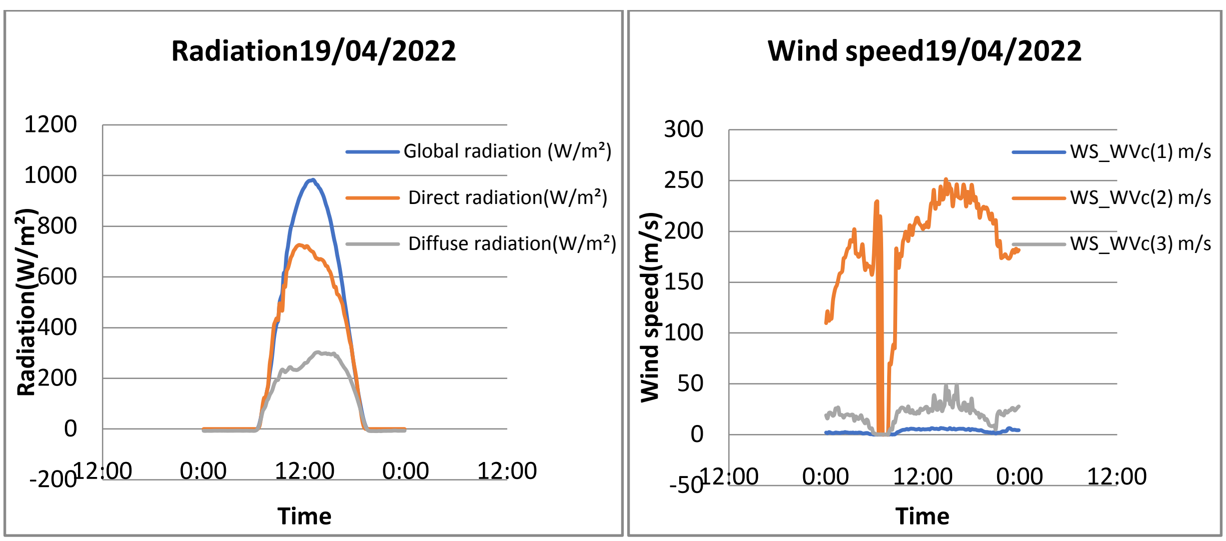


Figure (III-36): Radiation and wind speed on 19/04/2022.

Table III-14: Measurement values (19/04/2022).

	V	B	$X_A - X_B$	%
Vco	**20.7839**	**20.7299**	**0.054**	**0%**
Ics	**1.05237**	**0.81878**	**0.23359**	**0%**
Vmax	**18.6898**	**17.0754**	**1.6144**	**0%**
Iman	**0.802979**	**0.07848**	**0.724499**	**1%**
Pmax	**15.0075**	**1.34024**	**13.66726**	**1%**
FF	**0.686**	**0.0789**	**0.6071**	**1%**
η	**9%**	**1%**	**8%**	**9%**

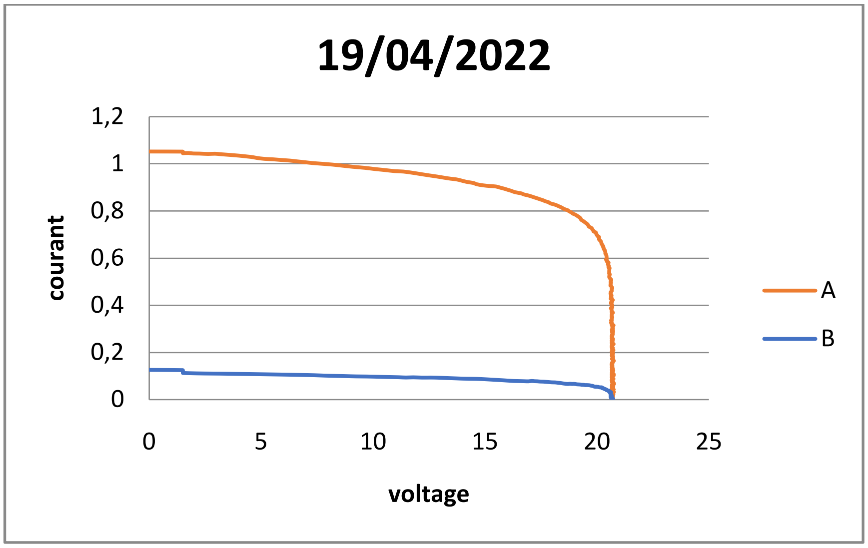


Figure (III-37): Curve I-V of the PV module (19/04/2022).

The Seventh experiment: measurements in the presence of Winds and clouds:

- ✓ **Measuring information:**

Table III-15: Information for measuring the sixth experiment.

Date	Thursday April 21, 2022
Hour	10:00
weather condition	Wind with clouds
Temperature (°C)	16.4
Wind speed (m/s)	6.877
Humidity(%)	39
Radiation(W/m²)	494.8275

Figure (III-38): Experimentation facility (**21**/04/2022)**.**

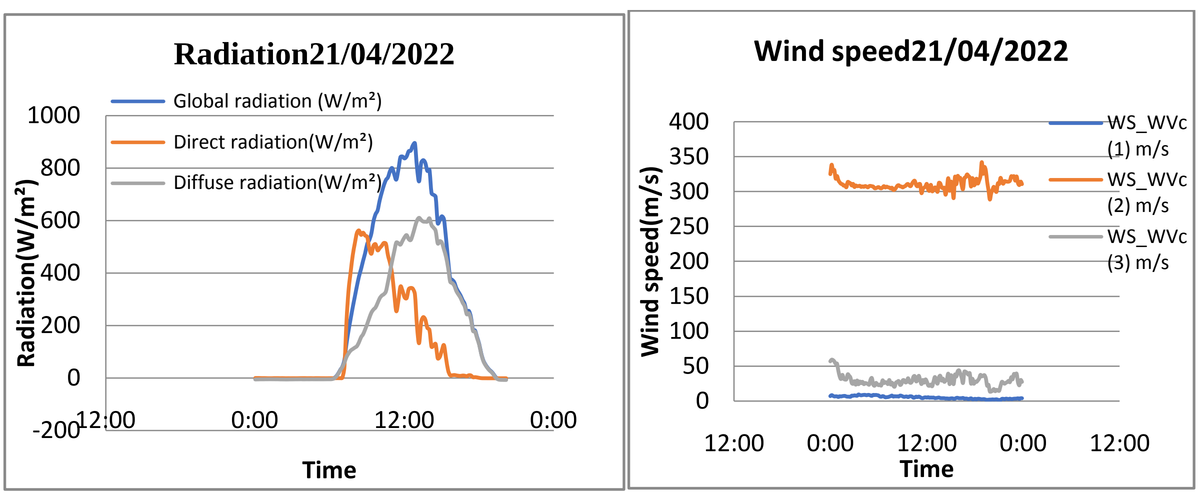


Figure (III-39): Radiation and wind speed on **21**/04/2022.

Table III-16: Measurement values (21/04/2022).

	V	B	$X_A - X_B$	%
Vco	**21.8527**	**21.8432**	**0.0095**	**0%**
Ics	**0.02899**	**0.00848**	**0.02051**	**1%**
Vmax	**21.6768**	**21.6678**	**0.009**	**0%**
Iman	**0.02899**	**0.00848**	**0.02051**	**1%**
Pmax	**0.628508**	**0.18377**	**0.444738**	**1%**
η	**0.5%**	**0%**	**0.5**	**1%**

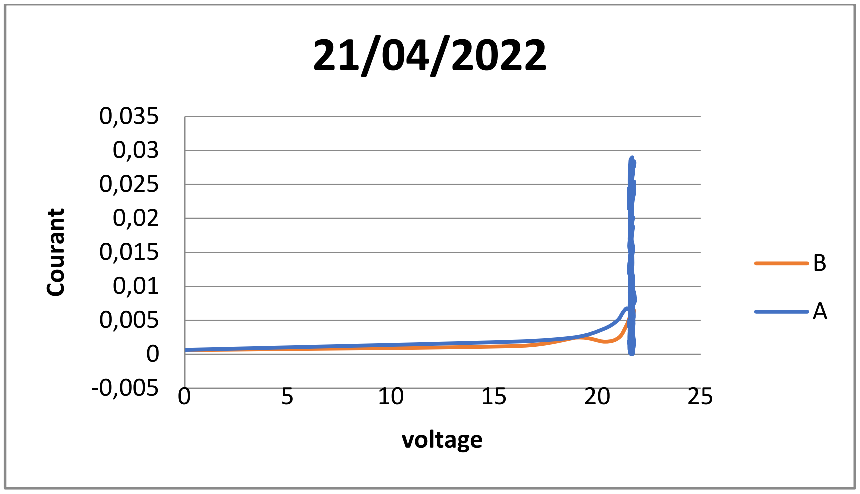


Figure (III-40): Curve I-V of the PV module (21/04/2022).

Latest experiment: Measurements in the presence of dust on the unit:

- ✓ **Measuring information:**

Table III-17: Information for measuring theLatest experiment.

Date	Wednesday May 11, 2022
Hour	10:30
weather condition	Clear and dust on the unit
Temperature (°C)	35.64
Wind speed (m/s)	3.975
Humidity(%)	18.48
Radiation(W/m²)	775.0204

Figure (III-41): Experimentation facility (11/05/2022).

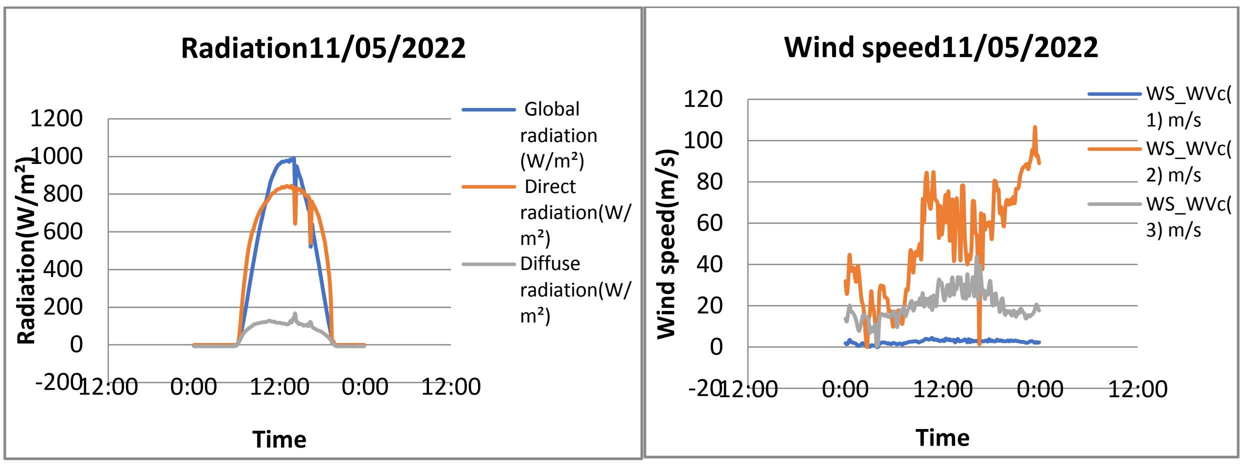


Figure (III-42): Radiation and wind speed on 11/04/2022.

Table III-18: Measurement values (11/04/2022).

	V	B	$X_A - X_B$	%
Vco	**20.6802**	**20.8518**	**-0.1716**	**0%**
Ics	**0.961285**	**-0.0201**	**0.981385**	**100%**
Vmax	**17.7622**	**20.6573**	**-2.8951**	**0%**
Iman	**0.749223**	**-0.0201**	**0.769323**	**1%**
Pmax	**13.3079**	**-0.4164**	**13.7243**	**1%**
FF	**0.6694**	**0.9935**	**-0.3241**	**0%**
η	**7%**	**0%**	**7**	**100%**

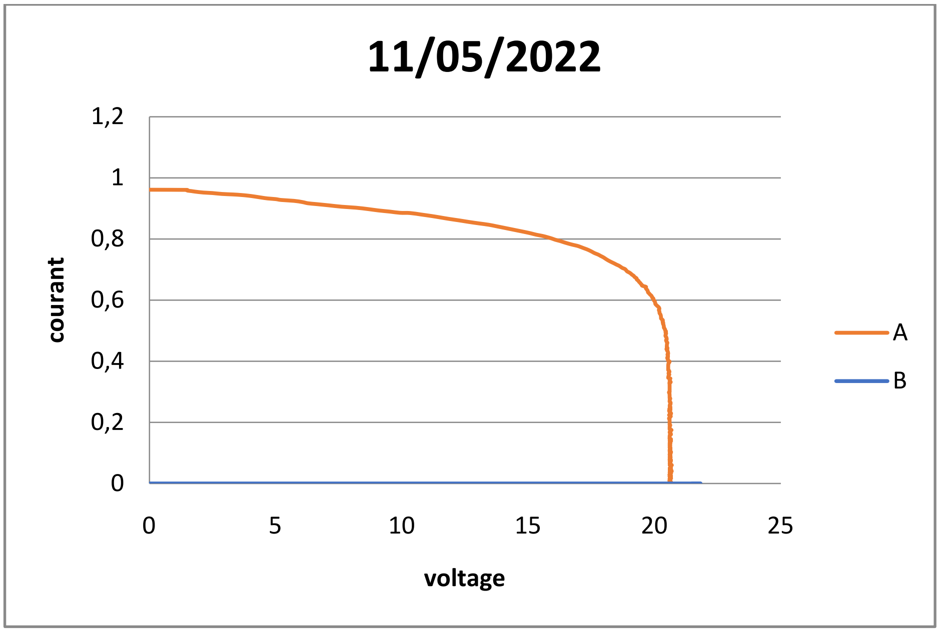


Figure (III-43): Curve I-V of the PV module (11/05/2022).

III-8-3: Discussion of results:

The above shapes show 7 to 9 solar radiation curves, wind speed and current voltage (I-V) of solar PV modules in all conditions: wind, rain, clouds, dust, hot and cold weather... etc. Photovoltaic solar panels produced a maximum of power 15.0075 w and Maximum voltage measured was 21.6768 volts.

The first experiment of the two photovoltaic modules is in a clean state (0 mg/m² of dust). For 767,7153 (W/m²) and the favorable climatic conditions described in **Table III-3**(no factor that hinders solar radiation from reaching the surface of the two PV modules) the efficiency of the two modules was 8%. With a $I_{sc} = 1.04292A$ and $V_{oc} = 20.4165V$.

after Two days, the efficiency rate decreased significantly compared to the first day due to the presence of rain and clouds thus increased humidity and solar radiation decreased as shown in **Table III-5**. The electrical properties ofV_{OC}, I_{SC} and cell efficiency **η** showed a decrease of 13.5%, 90% and 75% respectively for the clean unit A. unit B decreased by 9.32%, 92% and 87.5% with some dust particles as shown in **figure (III-23).**

After 13 days of exposure 12/04/2022. We find that the efficiency of the two PV modules is constantly increasing during this period, reaching 9% as the maximum value during our trial phase. It was also noted that the difference between PV modules A and B is 0%. The I_{SC} and V_{OC} show a significant increase of 89% and 15%, respectively.

In the fifth experiment, measurements were taken in the presence of clouds. We also find that the difference in efficiency between the two PV modules is 0% while 22.22% compared to the last day where the temperature and wind speed were almost equal (see **Table III-9** and **Table III-10**).

On 19/04/2022, the efficiency of the soiled unit was reduced to 1%, while the clean unit remained 9%. The results showed a slight decrease in the short circuit current I_{sc} and V_{oc} by 0.3% and 22.19%, respectively.

In the seventh experiment; The results showed that the efficiency of the two photovoltaic units is 0% approximately. The efficiency rate in the clean unit was 0.5% due to an obstacle preventing solar radiation from reaching the surface of the cells.

On the last day it was sunny (all climatic conditions appear in the tables and curve 11/05). The results showed that unit B was not efficient (0%) due to the amount of dust accumulated on the surface. On the other hand, we find the clean unit working with a 7%. In addition, we note a significant variation in the current of the short circuit estimated at 100%.

From these results we can conclude that changing climatic conditions and the presence of dust on the surface of PV units have a significant impact on cell efficiency.

This leads us to take into account the conditions and clean the cells periodically, especially in areas where sandstorms are repeated, such as Ghardaïa in particular and the states of southern Algeria in general.

II-9:Average power (V_{OC} x I_{SC}) evolved throughout the trial period:

Table III-19: Average power Dayle.

	Average Power of the Cleaned Module (W)	Average Power of the Uncleaned module (W)
28/03/2022	21.29277	21.02544
30/3/2022	1.791825	1.540506
10/4/2022	18.99977	18.55846
12/4/2022	20.38235	19.9771
17/04/2022	21.25331	21.47539
19/02/2022	21.87235	16.97323
21/04/2022	0.6335	0.1852
11/5/2022	19.87951	-0.41912

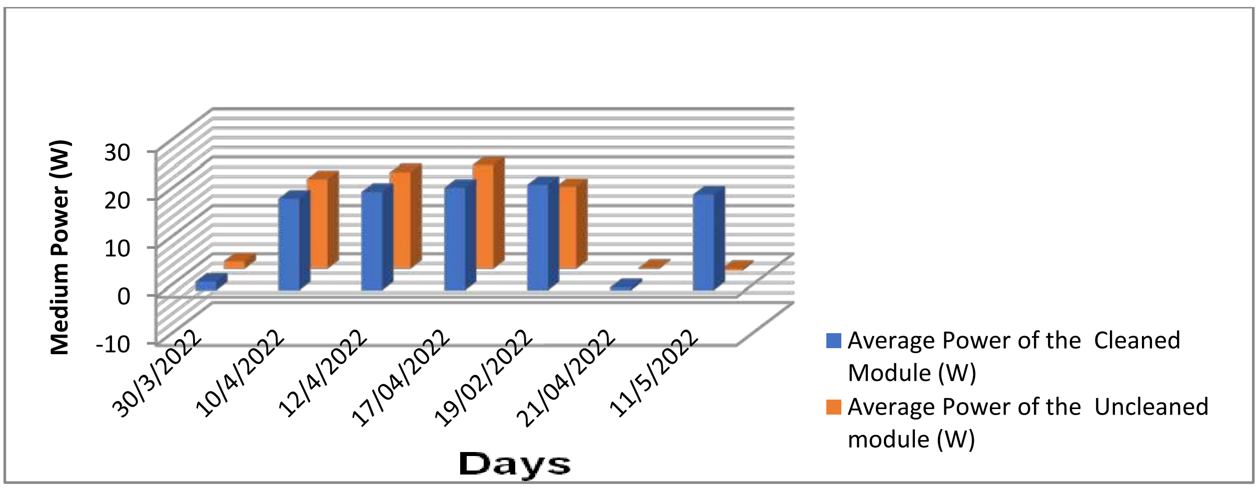


Figure (III-44): Evolution of the Average Power (V_{oc} x I_{SC}).

In general, it is found that the average power of the cleaned module is higher than that of the uncleaned module. This is explained by the fact that the cleaned module receives the entire the sunshine on its surface and that the uncleaned module loses part of it. Also, we notice that the average powers of the two modules are not regular, they are variable because the sunshine is not continuous and varies according to the month and the hours of the day.

Our experiments were conducted from the end of March to May marked by the passage of various climatic factors (thermal disturbances, precipitation, clouds, sandstorms... etc.) which sometimes weakens the irradiation of the accident.

Regardless of the time of the experiment and the conditions (clear or cloudy sky), the effect of dust deposits on photovoltaic units is evident through the graphs. This leads us to examine the values of the power gains generated by the cleaned module compared to the uncleaned module.

III-10:Power gains ($V_{oc} * I_{sc}$) average if cleaned our photovoltaic modules every day:

The following table summarizes the power gains obtained with our measurements Experimental.

Table III-20: Average power gain.

	Daily Average Power Gains
28/03/2022	1%
30/03/2022	14%
10/04/2022	2%
12/04/2022	2%
17/04/2022	1%
19/02/2022	22%
21/04/2022	70%
11/5/2022	98%

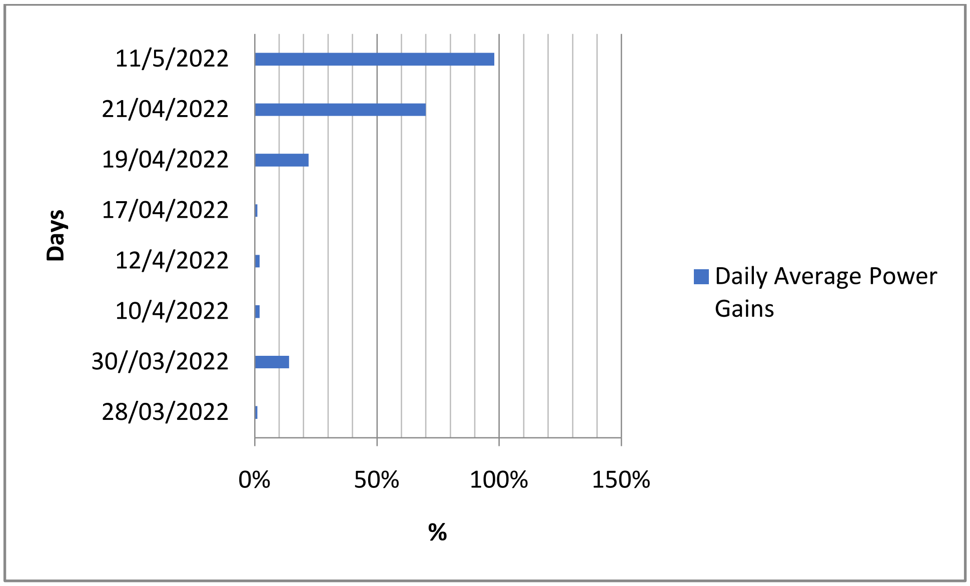


Figure (III-45): Summary of Average Power Gains (V_{oc} xU_{sc}) Daily.

From 28/03/2022 to 12/04/2022, we consider that energy gains are stable by approximately 2% excluding 30/03/2022 profits were high due to the fact that the atmosphere was rainy with winds. Decreases from 12 to 17 April 2022. This decline in profits is due to lower lighting Cloudy skies are affected on the roofs of photovoltaic units. From 17/04/2022 it grew again by more than 50% during the last 19 days of the experiment.

Over the course of the test, if we clean the modules, we will have an average daily increase in power of more than 20%.

III-11:Cleaning process and determining the duration of cleaning:

To measure the amount of dust deposited on the device, we use a high-resolution scale. After the total deterioration of the PV function, we cleaned it in the traditional way; cleaned with a piece of cloth. As shown in the **figure (III-46**), we measured the piece of cloth before the experiment weighing about 0.7526 grams, after which the cleaning was carried out and weight measurement were performed again.

Figure (III-46): Measuring the amount of dust**.**

After 43 days. We can see that it is 0.3462 grams making a significant difference in the efficiency of PV units, where efficiency has deteriorated by about 100%. So, we can clean-up the PV modules every 15 to 21 days depending on the climatic conditions.

III-12: Conclusions:

The low electrical efficiency of the PV module during years of operation is a real problem and the presence of a barrier on the surface of the PV modules is one of these problems.

In this chapter we present the results of the study Experimental implementation to highlight the effect of dust on the electrical performance properties of PV generator. These results show that photovoltaic modules containing dust deposits on the front surface can experience significant variation in the short circuit current (Isc), open circuit voltage (Voc) and efficiency (P) up to 0.3%, 22.22% and .88.88%, respectively. All electrical properties of PV modules are also affected by dust deposits. The results also show that PV modules in the event of

Climate disturbance can experience significant variation in the short circuit current (Isc), open circuit effort (Voc) and efficiency (P) up to 9.32%, 29% and .87.5%, respectively.

To overcome the problem of unit degradation, cleaning operations are performed. In this study by simple cleaning with a cloth piece, we get an average daily energy profit of 26.25%.

The study conducted this chapter also allowed us to identify the cleaning patrol of photovoltaic units except for the days of sandstorms.

GENERAL CONCLUSION

General conclusion:

Major constraints related to the operating conditions of PV systems in the desert environment, as well as high temperatures, sandstorms and the presence of dust deposits on the surface of modules. In fact, the desert grid is characterized by frequent and permanent bouts of sandstorms. However, opinions remain divided on the significant impact on the production of photovoltaic modules.

The purpose of this work is to study the effect of dust on the electrical performance properties of PV modules. So, we set up a small experimental facility consisting of two PV Panels, electronic card and a computer. We also used the LabVIEW software to display measured results during the experiment.

From the results of this study we can be said:

- The amount of dust accumulated on the PV surface of the module affects the total energy provided by the PV modules on a daily, monthly, seasonal and annual basis.
- Dust has an effect on the performance of solar PV panel. The reduction in the peak power generated can be up to (22-70%). It was also shown that under greater irradiation, the effect of dust became slightly reduced but not negligible.
- If we don't clean our panels, we lose up to 88% of their performance, and this loss leads to a decrease in energy production indicated by manufacturers.
- For a calm climate free of bad weather and clear skies, mono crystal PV panels provide 9% efficiency, which is good.
- Soft shading takes place when some materials such as smog are in the air and hard shading occurs when a solid such as accumulated dust blocks the sunlight. The result shows that soft shading affects the current of the PV module, but the voltage remains the same.
- Lighting, temperature, wind and sand (dust) have an impact on the production of electric power. It is related to the productivity of the PV cell and therefore the production of the PV module, if we change one of the meteorological parameters, there is also a change in

the energy produced, we can get a good result using a high return or we can get a decrease in performance.

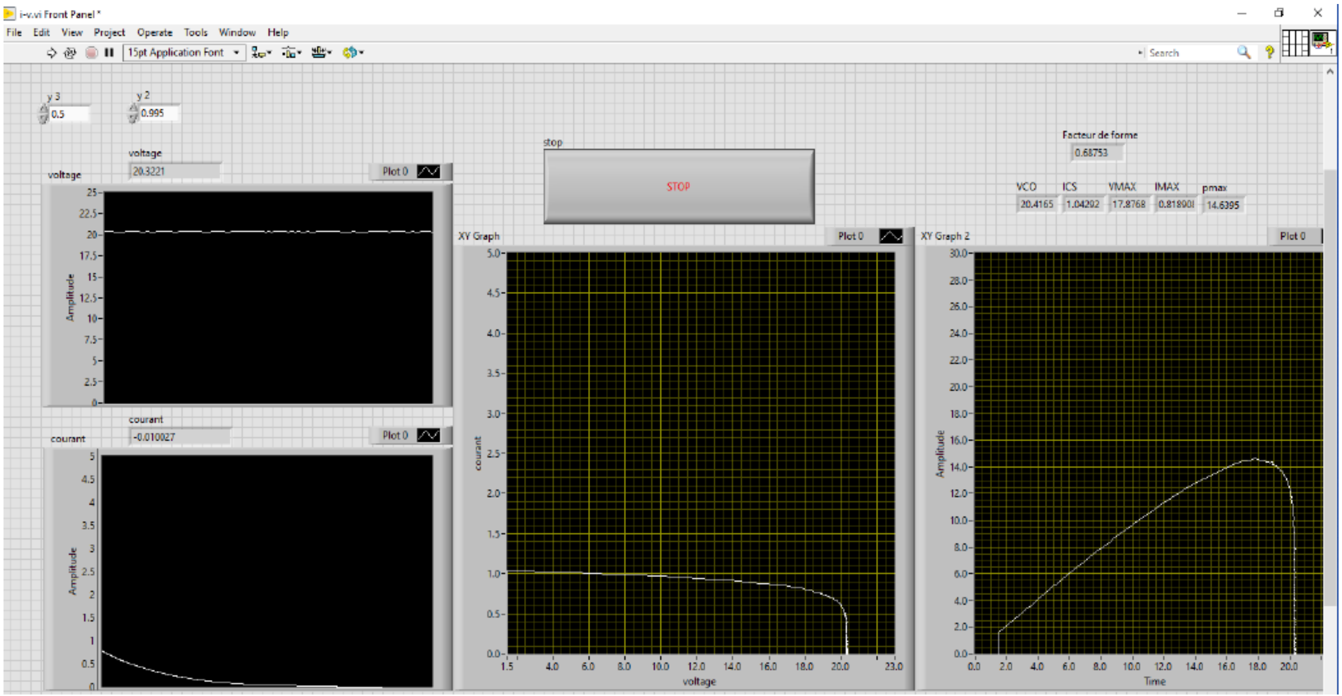
- The electricity generated by the cell decreases as the temperature increases. So, we can say the resulting PV is affected by the ambient temperature the cleaner and cooler the PV, the more energy generated and more efficient.
- Humidity is affected on two sides; Either on the surface of the module it reflects or distorts the path of radiation and thus leads to a deterioration of the cell's level of reception of direct solar radiation or the entry of moisture into the cell cavity and thus damage and erosion of the cell.
- Winds. On the one hand, it affects the behavior of solar radiation, but on the other hand, it negatively and positively affects the efficiency of PV modules. Since wind movement affects thermal load and thus affects cell temperature, it decreases, improving efficiency as well as wind speed strength that cleans cell surfaces from accumulated dust. If wind speed is low, this greatly helps to accumulate dust on the surface and thus reduce the PV efficiency of the cell.
- Cleaning PV modules every 21 days is subject to change as dust increases or decreases in the atmosphere.

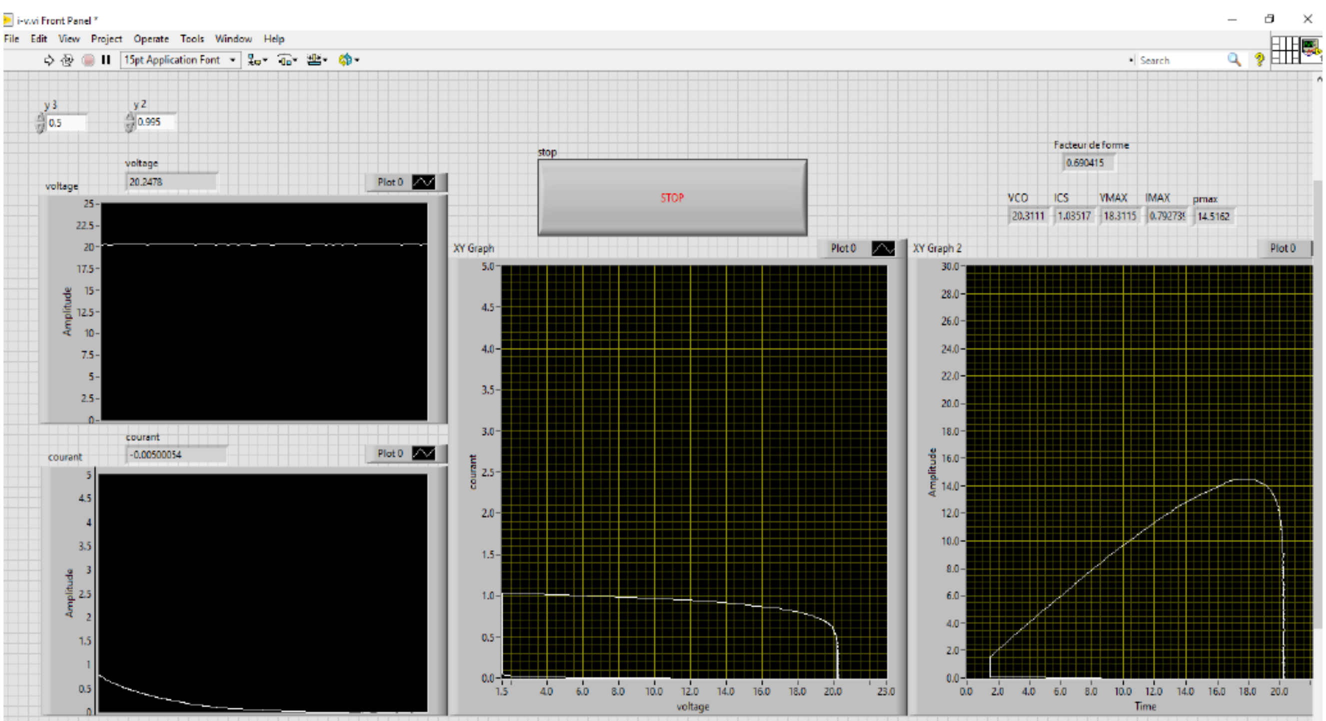
As a perspective, this area must always remain open and under consideration. On the one hand, the development of unit cleaning can be done by a drone (By processing images) that determines which modules to clean in order to optimize the water an energy used for cleaning. Also, Calculating the rate of deterioration of cell life due to the temperature caused by dust accumulation is very important to estimate the efficiency of this system under desert climate.

ANNEX III

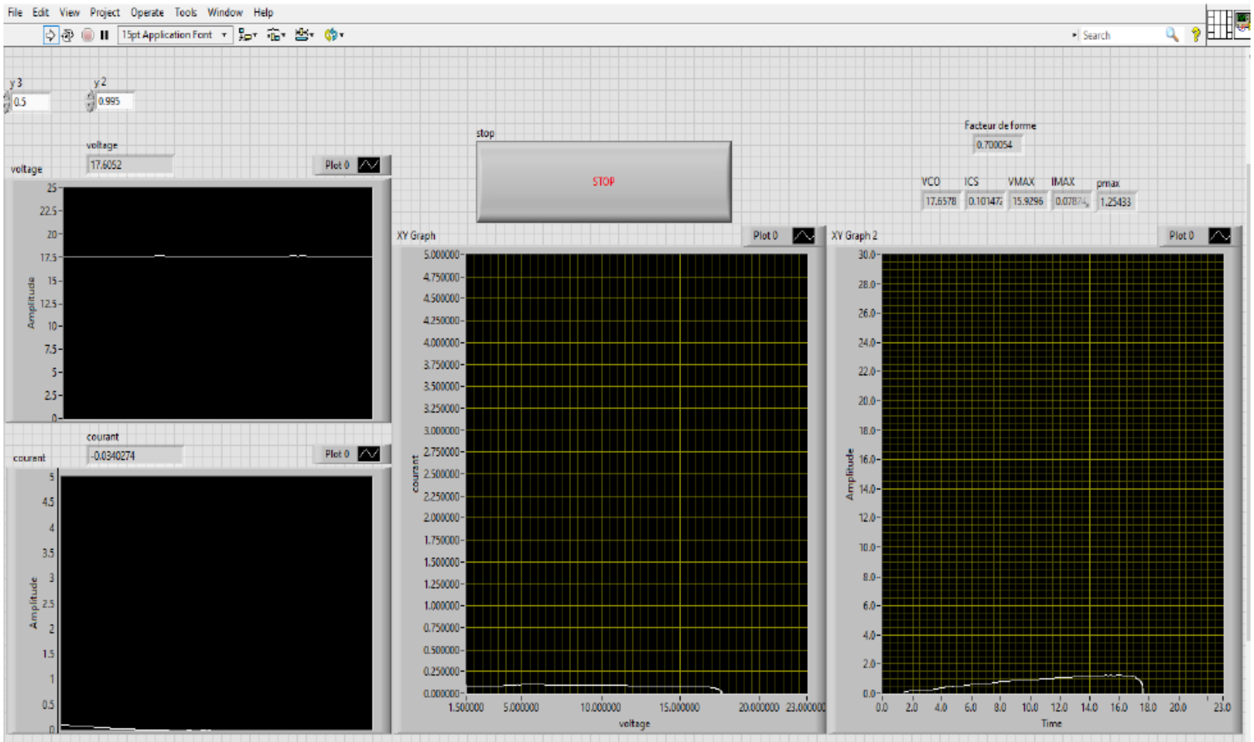
ANNEX III- 1: Measurments on the deposition of dust on the surface of PV modules.

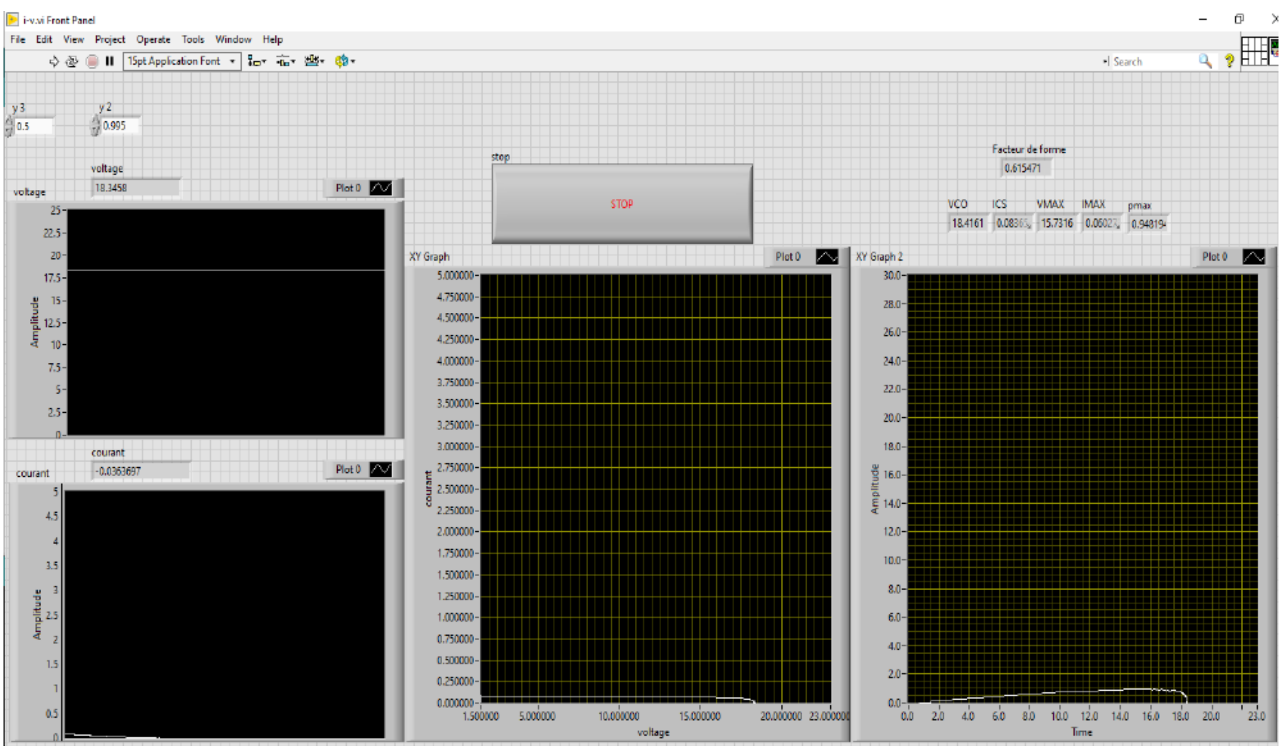
28/03/2022



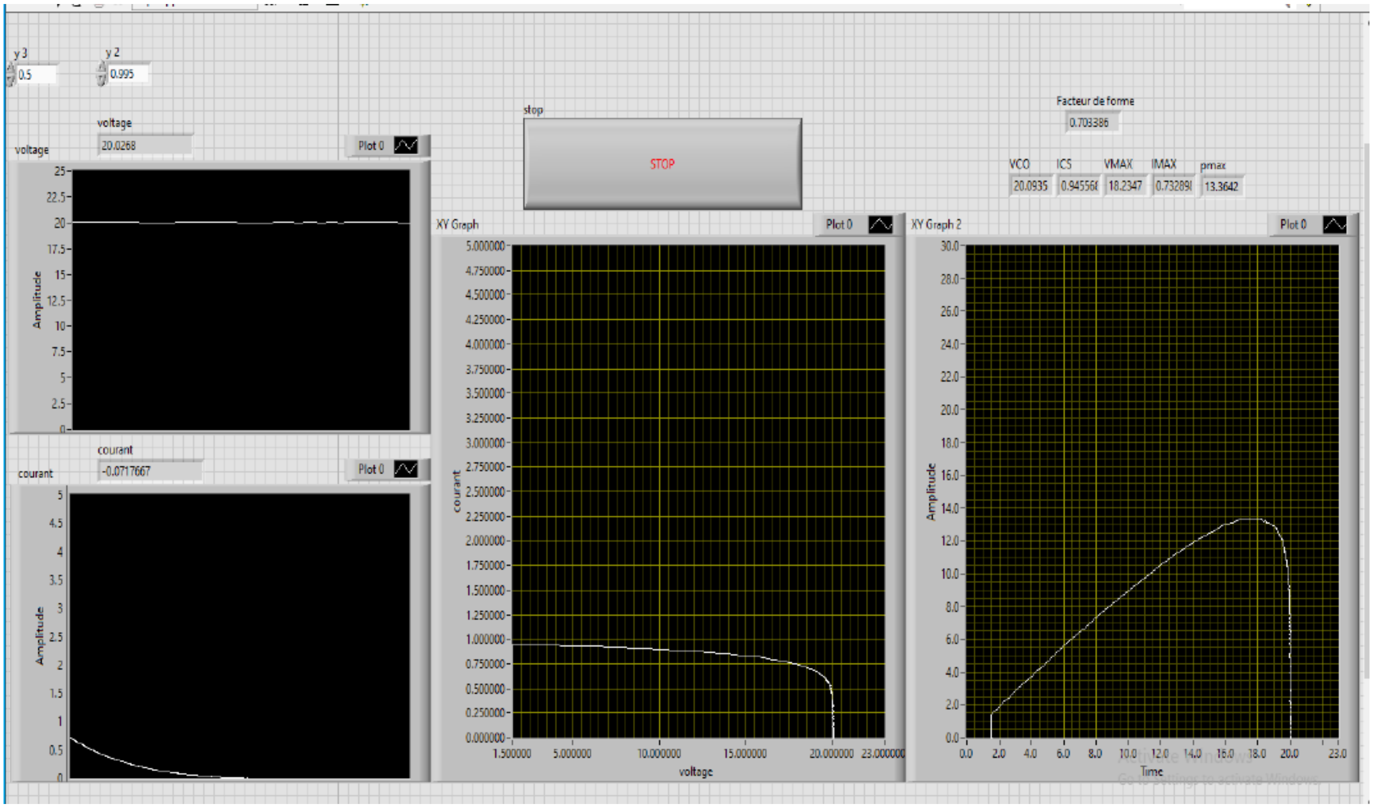


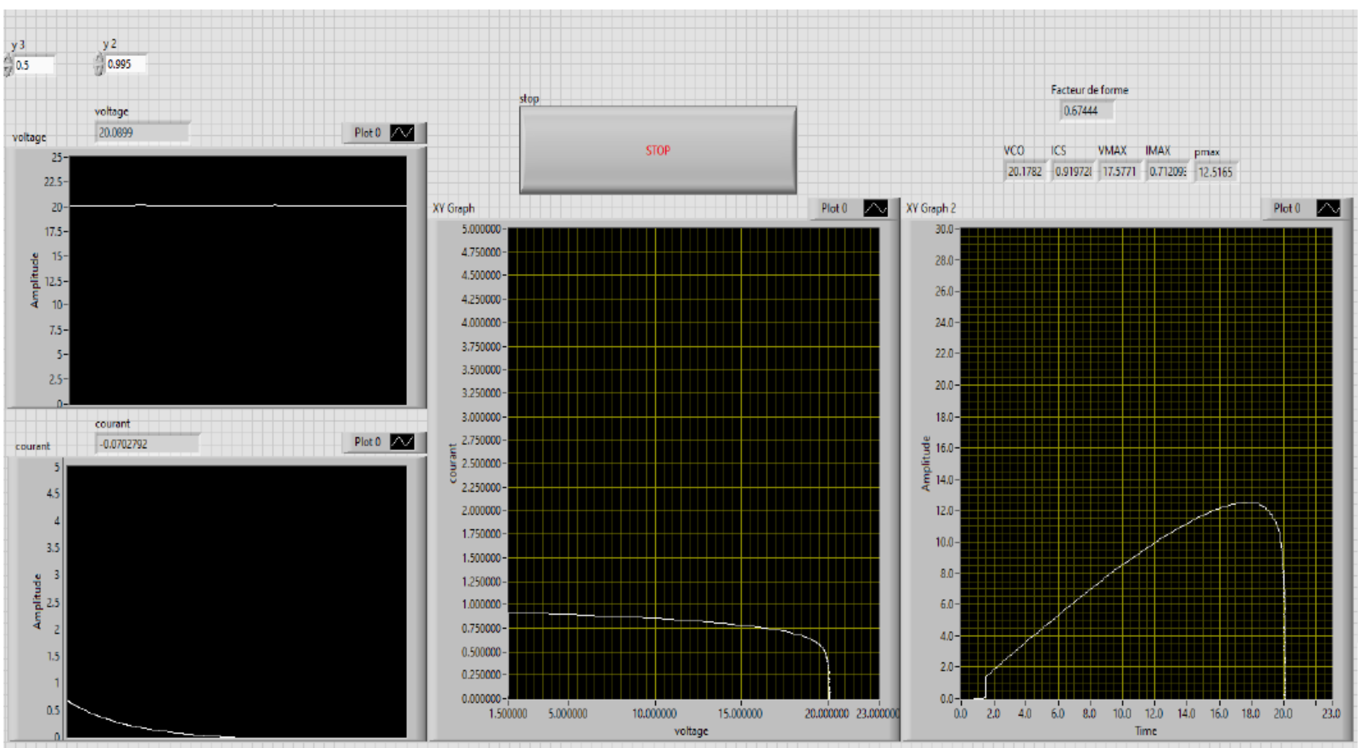
30/03/2022


File Edit View Project Operate Tools Window Help
y 3
0.5
y 2
0.995
stop
STOP
Facteur de forme
0.700054
voltage
17.6052
VCO
17.6578
VMAX
15.9296
pmax
1.25433
courant
-0.0340274
XY Graph
XY Graph 2
Plot 0
Amplitude
courant
voltage
Time

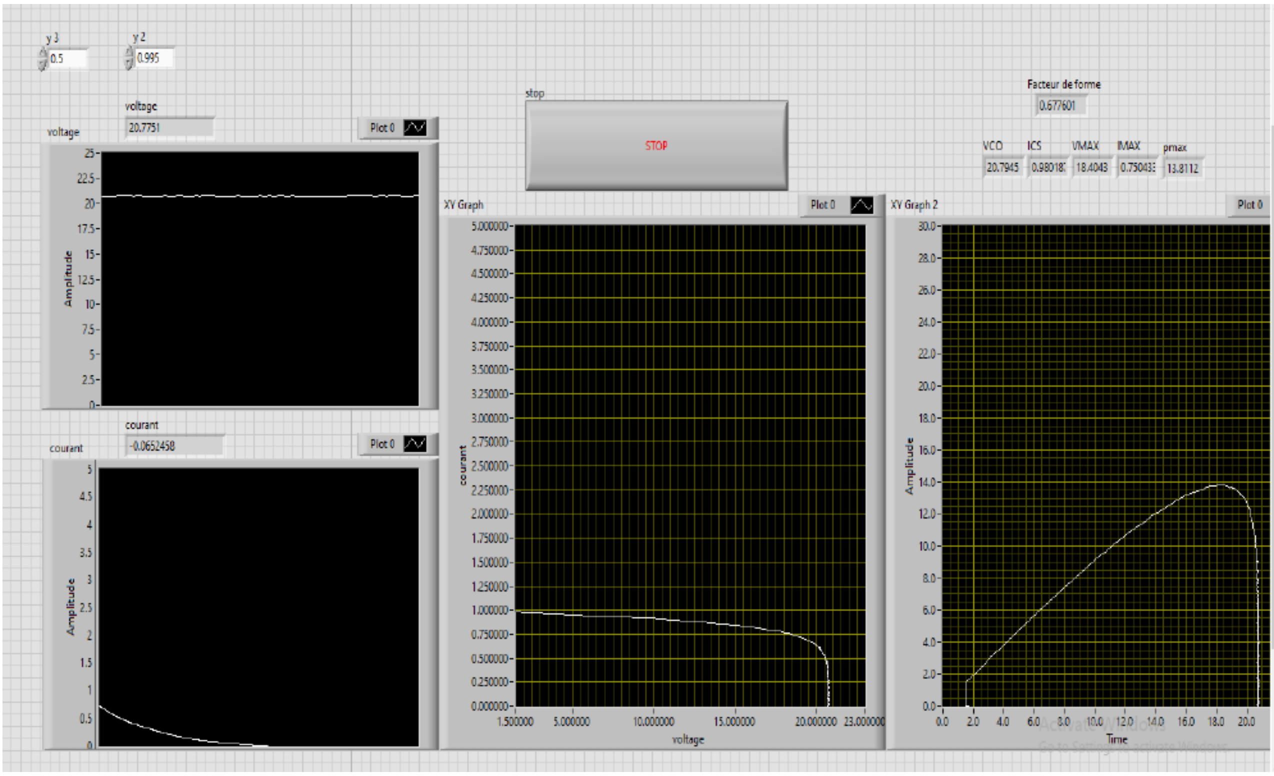

i-v.vi Front Panel
File Edit View Project Operate Tools Window Help
y 3
0.5
y 2
0.995
stop
STOP
Facteur de forme
0.615471
voltage
18.3458
VCO
18.4161
VMAX
15.7316
courant
-0.0363697
XY Graph
XY Graph 2
Plot 0
Amplitude
courant
voltage
Time

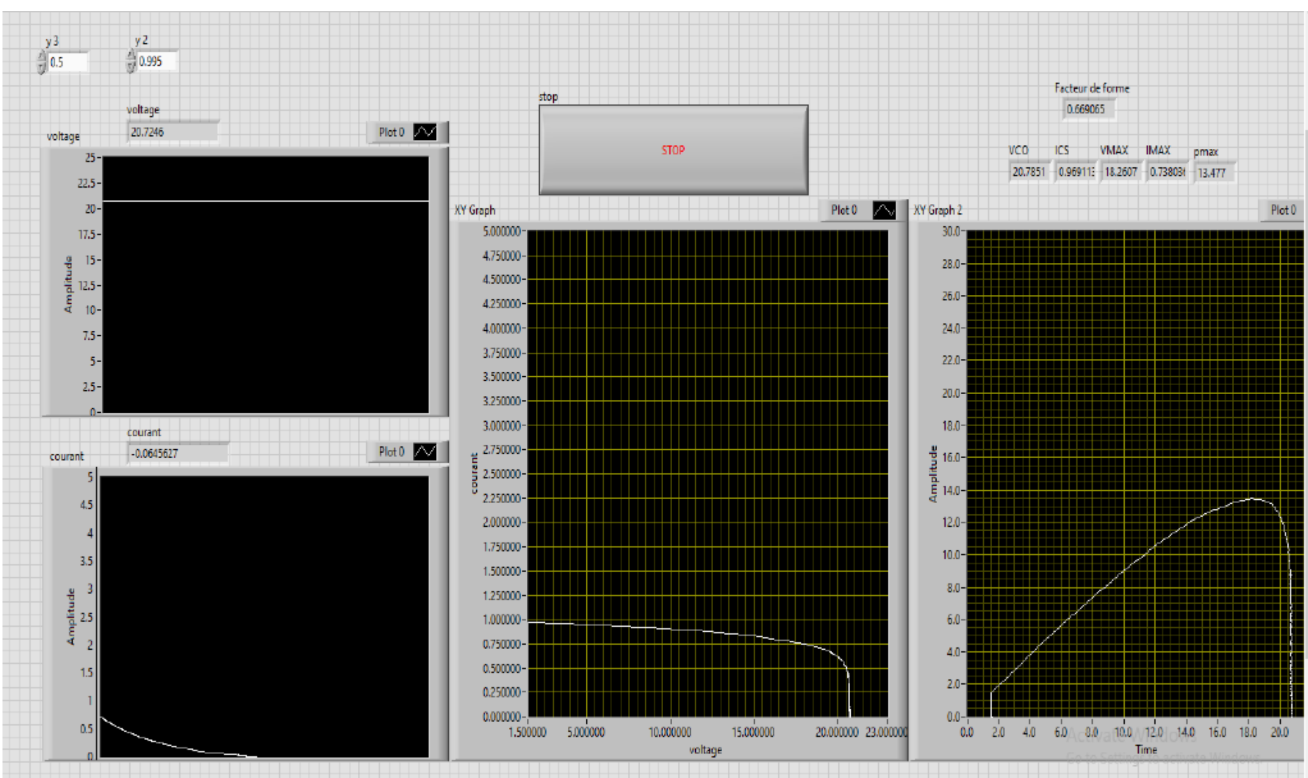
10/04/2022


y 3
0.5
y 2
0.995
voltage
20.0268
Plot 0
stop
STOP
Facteur de forme
0.703386
VCO
ICS
VMAX
IMAX
pmax
20.0935
18.2347
13.3642
courant
-0.0717667
XY Graph
XY Graph 2
Amplitude
courant
voltage
Time

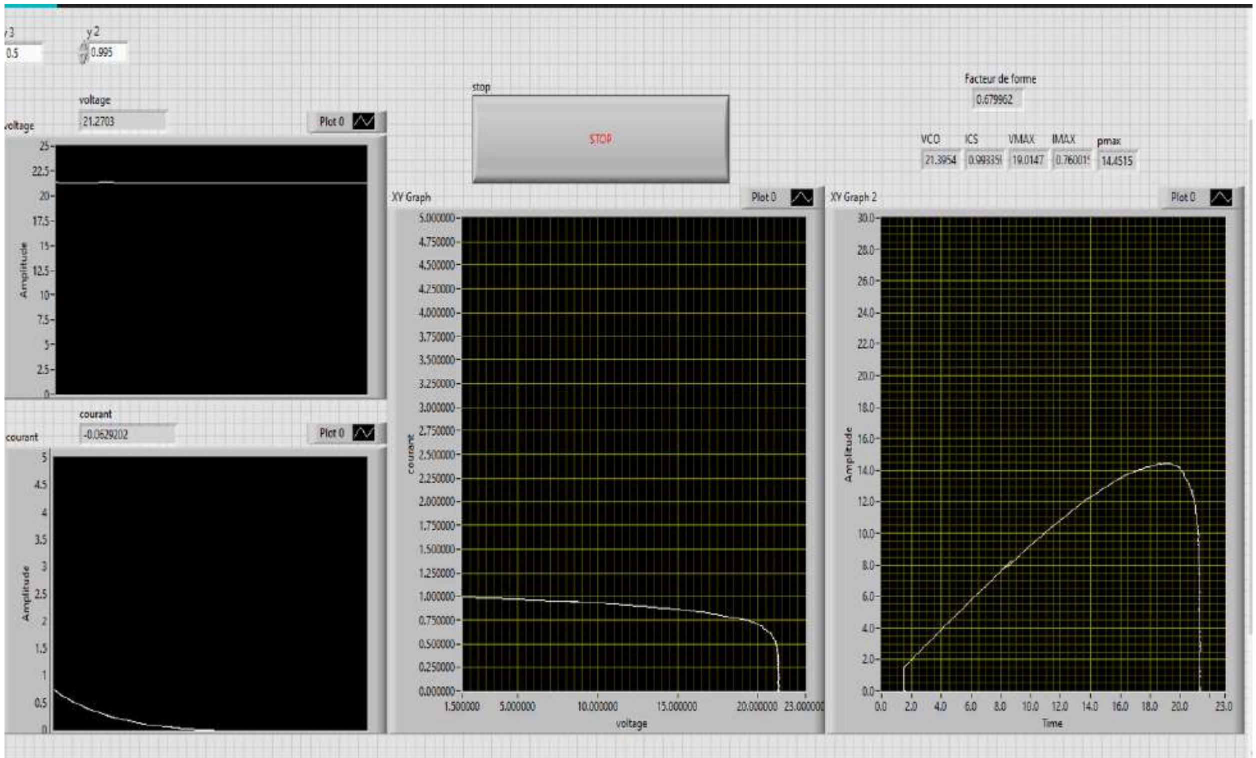

y 3
0.5
y 2
0.995
voltage
20.0899
Plot 0
stop
STOP
Facteur de forme
0.67444
VCO
ICS
VMAX
IMAX
pmax
20.1782
17.5771
12.5165
courant
-0.0702792
XY Graph
XY Graph 2
Amplitude
courant
voltage
Time

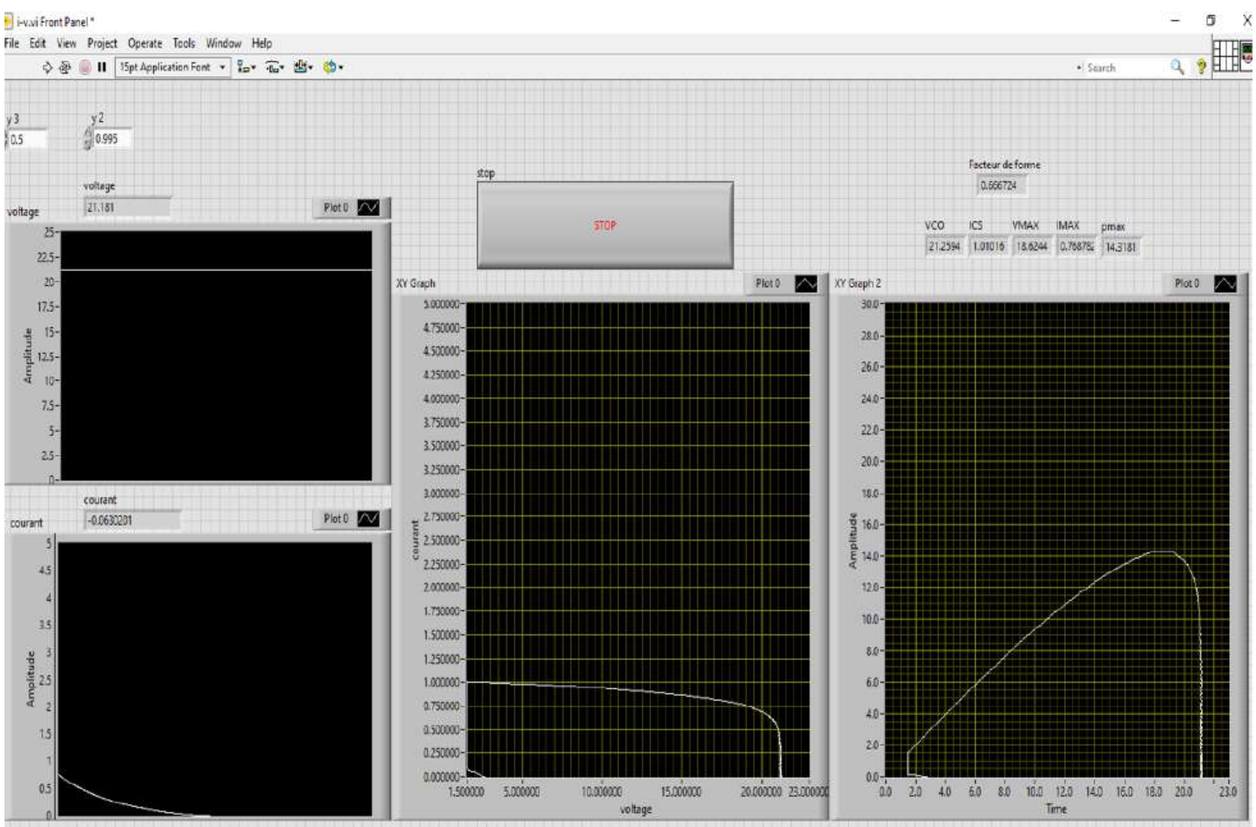
12/04/2022


y 3
0.5
y 2
0.995
voltage
20.7751
Plot 0
stop
STOP
Facteur de forme
0.677601
VCO
ICS
VMAX
IMAX
pmax
20.7945
18.4043
13.8112
XY Graph
XY Graph 2
Amplitude
courant
-0.0652458
voltage
Time

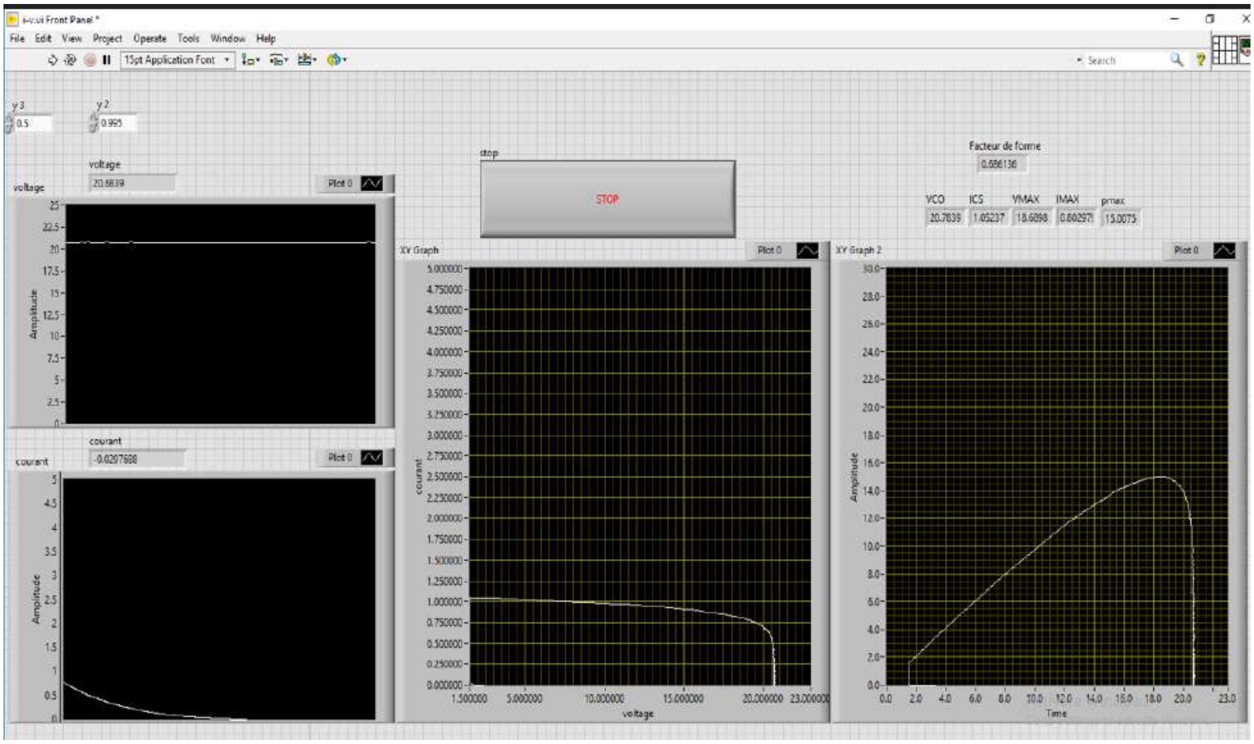

y 3
0.5
y 2
0.995
voltage
20.7246
Plot 0
stop
STOP
Facteur de forme
0.669065
VCO
ICS
VMAX
IMAX
pmax
20.7851
18.2607
13.477
XY Graph
XY Graph 2
Amplitude
courant
-0.0645627
voltage
Time

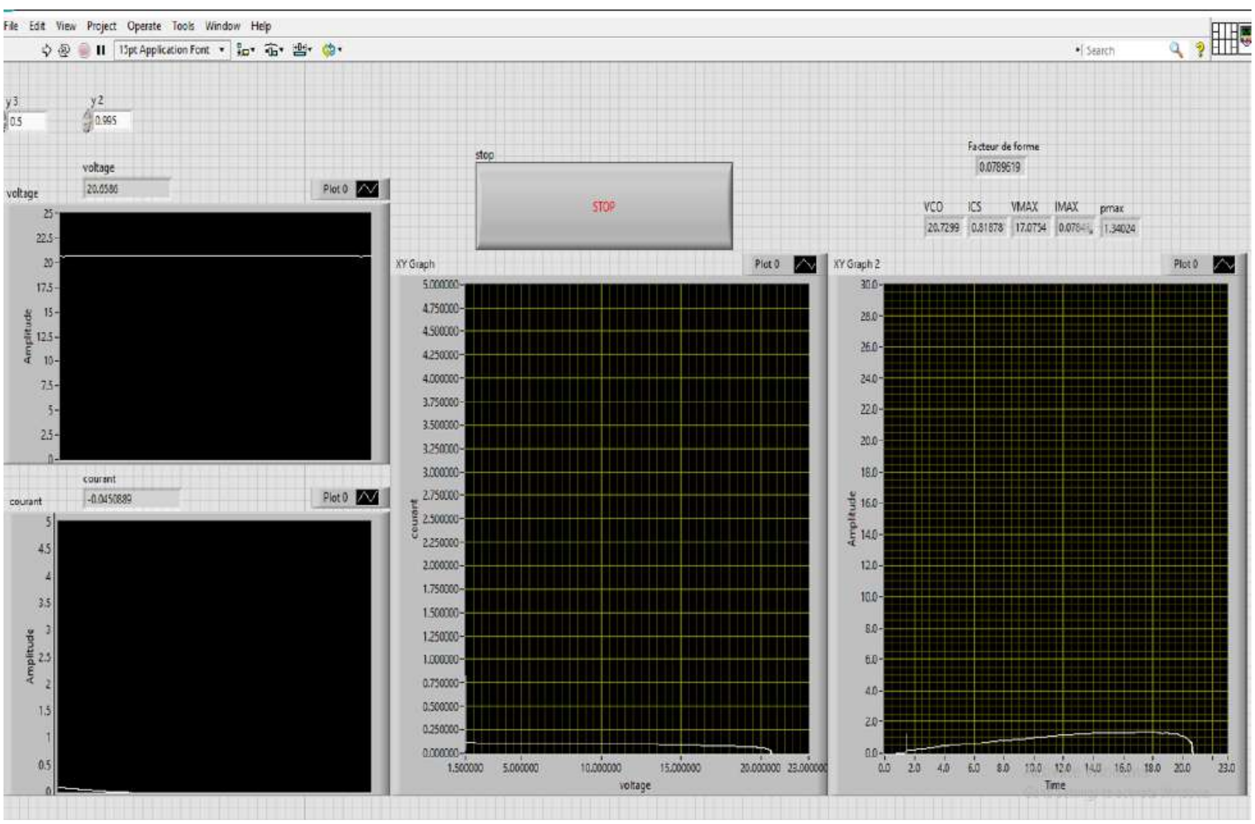
17/04/2022


y3
0.5
y2
0.995
Facteur de forme
0.679962
stop
STOP
voltage
21.2703
VCO ICS VMAX IMAX pmax
21.3954 0.99335 19.0147 0.76001 14.4515
courant
-0.0629202
XY Graph
XY Graph 2
voltage
Time
Amplitude

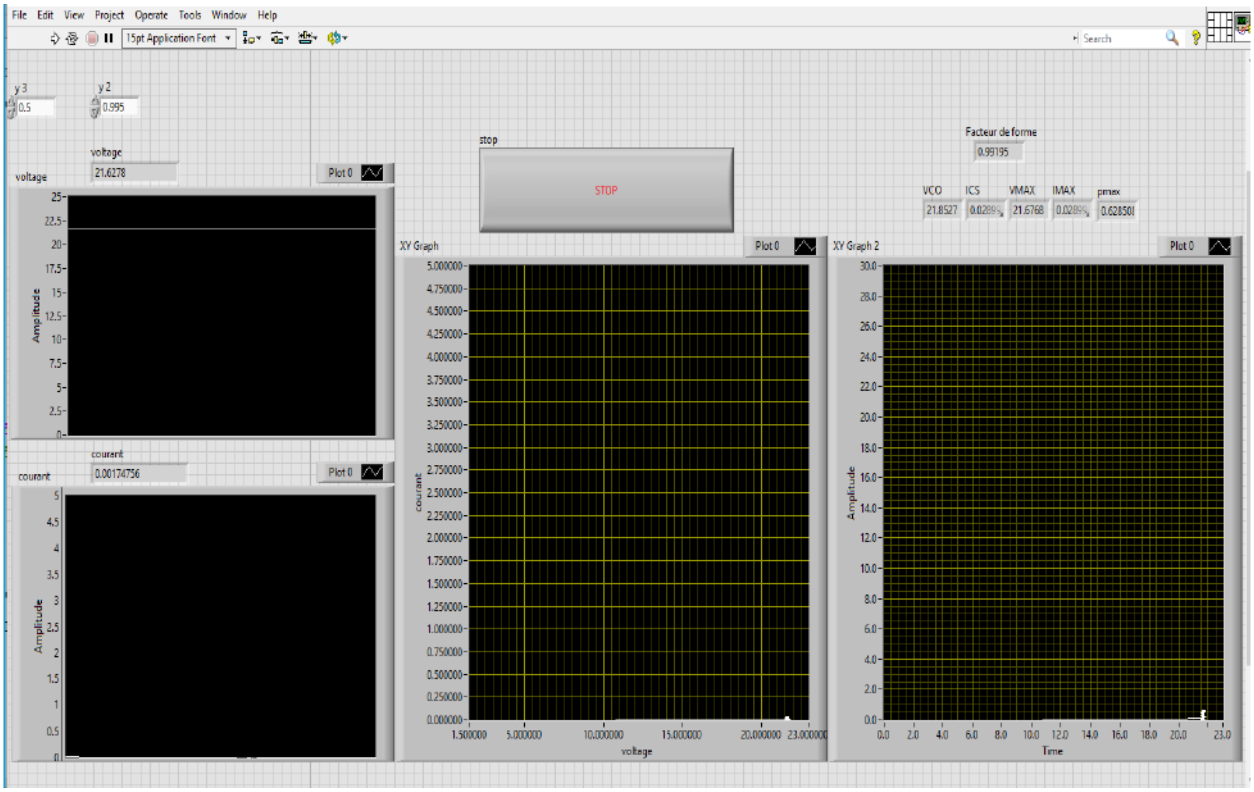

i-v.vi Front Panel *
File Edit View Project Operate Tools Window Help
15pt Application Font
y3
0.5
y2
0.995
Facteur de forme
0.666724
stop
STOP
voltage
21.181
VCO ICS VMAX IMAX pmax
21.2594 1.01016 18.6244 0.76878 14.3181
courant
-0.0630201
XY Graph
XY Graph 2
voltage
Time
Amplitude

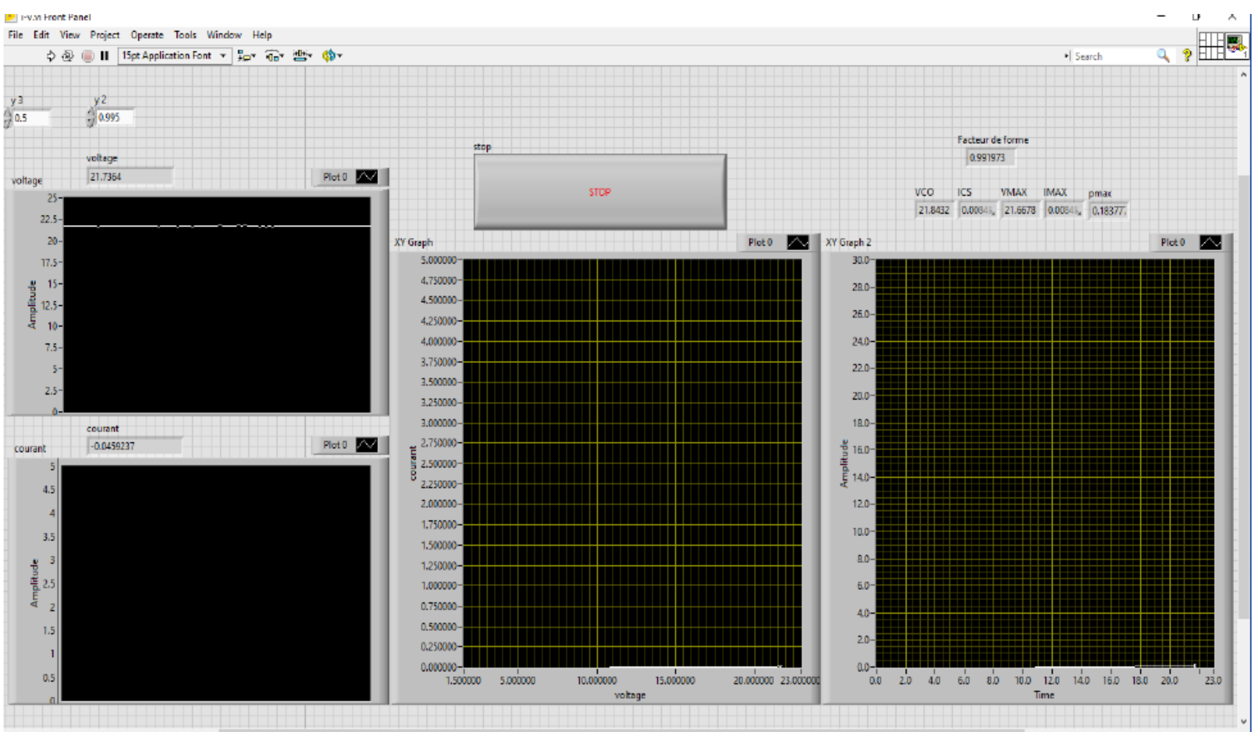
19/03/2022


File Edit View Project Operate Tools Window Help
15pt Application Font
Search
y 3
0.5
y 2
0.995
voltage
20.6839
Plot 0
stop
STOP
Facteur de forme
0.686136
VCO
20.7839
ICS
1.05237
VMAX
18.6898
IMAX
pmax
15.0075
Amplitude
courant
-0.0297688
XY Graph
XY Graph 2
voltage
Time

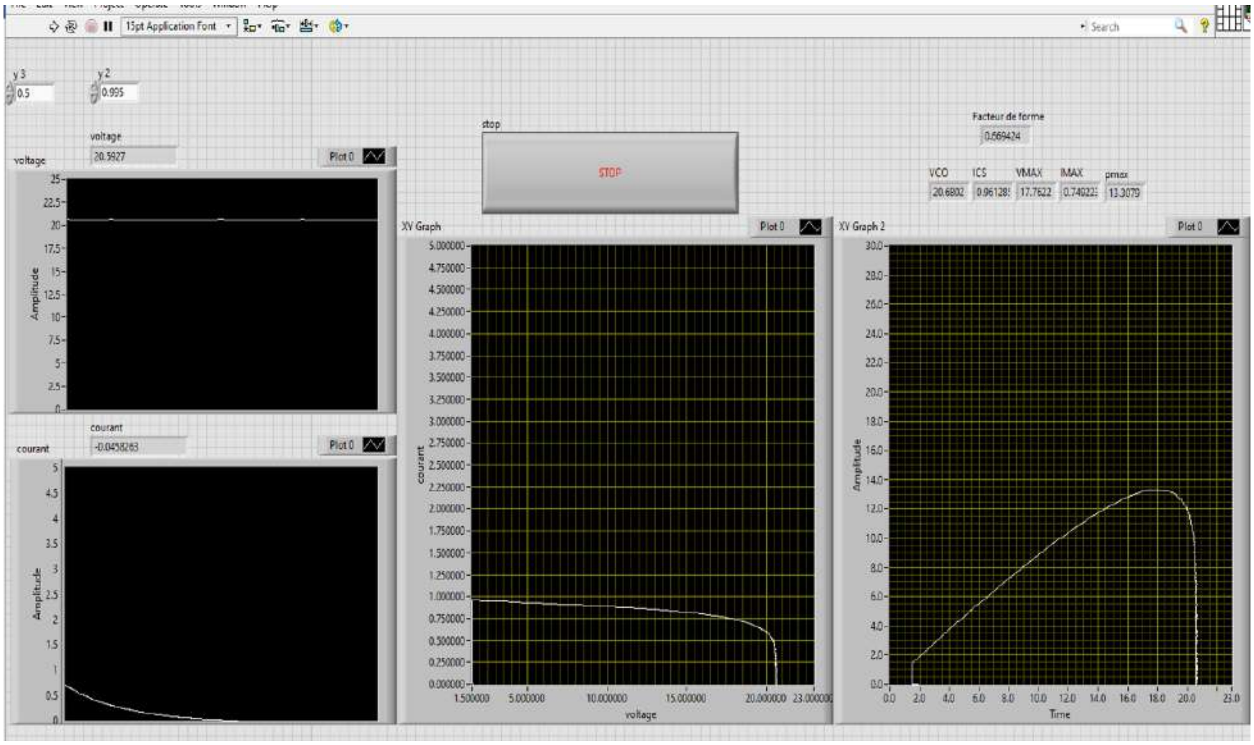

File Edit View Project Operate Tools Window Help
15pt Application Font
Search
y 3
0.5
y 2
0.995
voltage
20.6586
Plot 0
stop
STOP
Facteur de forme
0.0789619
VCO
20.7299
ICS
0.81878
VMAX
17.0754
IMAX
pmax
1.34024
Amplitude
courant
-0.0450889
XY Graph
XY Graph 2
voltage
Time

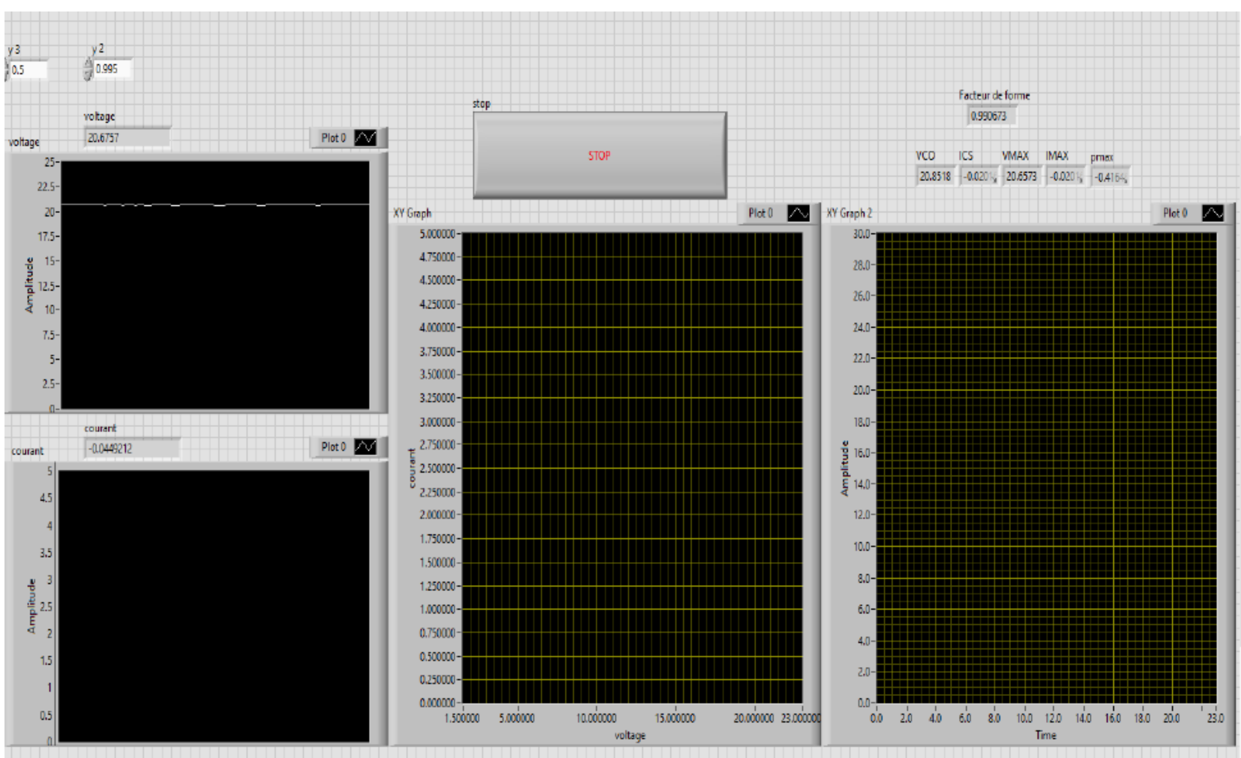
21/04/2022


File Edit View Project Operate Tools Window Help
15pt Application Font
y 3
0.5
y 2
0.995
voltage
21.6278
stop
STOP
Facteur de forme
0.99195
VCO
ICS
VMAX
IMAX
pmax
21.8527
21.6768
XY Graph
XY Graph 2
Plot 0
Amplitude
courant
0.00174756
voltage
Time


File Edit View Project Operate Tools Window Help
15pt Application Font
y 3
0.5
y 2
0.995
voltage
21.7364
stop
STOP
Facteur de forme
0.991973
VCO
ICS
VMAX
IMAX
pmax
21.8432
21.6678
XY Graph
XY Graph 2
Plot 0
Amplitude
courant
-0.0459237
voltage
Time

11/05/2022


y3
0.5
y2
0.995
voltage
20.5927
Plot 0
stop
STOP
Facteur de forme
0.669424
VCO
ICS
VMAX
IMAX
pmax
20.6802
17.7622
13.3079
XY Graph
XY Graph 2
courant
-0.0458263
Amplitude
Time


y3
0.5
y2
0.995
voltage
20.6757
Plot 0
stop
STOP
Facteur de forme
0.990673
VCO
ICS
VMAX
IMAX
pmax
20.8518
20.6573
XY Graph
XY Graph 2
courant
-0.0449212
Amplitude
Time

References

References

[1] https://www.energy.gov.dz/?rubrique=a-propos-du-ministere-de-l-energie.

[2] AHMED, Zeki, KAZEM, Hussein A., et SOPIAN, K. Effect of dust on photovoltaic performance: Review and research status. *Latest trends in renewable energy and environmental informatics*, 2013, vol. 34, no 6, p. 193-199.

[3]SALAMEH, Ziyad. *Renewable energy system design*. Academic press, 2014.

[4] KALOGIROU, Soteris A. *Solar energy engineering: processes and systems*. Academic press, 2013.

[5] D. Sera, R. Teodorescu, and P. Rodriguez, "Pv panel model based on datasheet values," Industrial Electronics, 2007. ISIE 2007. IEEE International Symposium on, pp. 2392–2396, June 2007.

[6]

[7] MAGHAMI, Mohammad Reza, HIZAM, Hashim, GOMES, Chandima, *et al.* Power loss due to soiling on solar panel: A review. *Renewable and Sustainable Energy Reviews*, 2016, vol. 59, p. 1307-1316.

[8] Tozer, P. and Leys, J. (2013). Dust storms – what do they really cost? The Rangeland Journal, 35, 131-
142. http://www.publish.csiro.au/rj/pdf/ RJ12085

[9]AHMED, Zeki, KAZEM, Hussein A., et SOPIAN, K. Effect of dust on photovoltaic performance: Review and research status. *Latest trends in renewable energy and environmental informatics*, 2013, vol. 34, no 6, p. 193-199.

[10] KHODAKARAM-TAFTI, Amin et YAGHOUBI, Mahmood. Experimental study on the effect of dust deposition on photovoltaic performance at various tilts in semi-arid environment. *Sustainable Energy Technologies and Assessments*, 2020, vol. 42, p. 100822.

[11] CHANCHANGI, Yusuf N., GHOSH, Aritra, SUNDARAM, Senthilarasu, *et al.* An analytical indoor experimental study on the effect of soiling on PV, focusing on dust properties and PV surface material. *Solar Energy*, 2020, vol. 203, p. 46-68.

[12] DERAKHSHANDEH, Javad Farrokhi, ALLUQMAN, Rand, MOHAMMAD, Shahad, *et al.* A comprehensive review of automatic cleaning systems of solar panels. *Sustainable Energy Technologies and Assessments*, 2021, vol. 47, p. 101518.