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Theme

Influence of meteorological parameters on PV panel efficiency

12/06/2022

In front of the jury members

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Our most sincere and warmest thanks

Address our promoter

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Dedication

I have the honor to dedicate this modest work carried out thanks to the help of Almighty God

To my parents who have always been by my side to support me and give me the courage to continue my studies.

Thank you ***Mom "Leila"*** *and* ***Dad "Abdelhafid"*** *I love you very much.*

To my dear brothers ***YAZID, MOHAMED AMINE*** *and* ***OMAR***, *with* ***BAHA***

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To all my paternal and maternal cousins and these children

To all the ***BEN AROUS*** *and* ***KEDDAM*** *family*

To all the people of my promotion teachers and students

FATMA

Dedication

I have the honor to dedicate this modest work carried out thanks to the help of Almighty God

To my parents who have always been by my side to support me and give me the courage to continue my studies.

*Thank you **Mom** and **Dad** I love you very much.*

To my dear brothers

To my dear sisters

*To my buddy **FATMA***

*To my dear friend **ASMA***

*And without forgetting the little **KAMAL DIN** and **RAHEF***

To all my paternal and maternal cousins and these children

To all the people of my promotion teachers and students

MARIA

Summary

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PV	Photovoltaic
DLR	Deutsches Zentrum für Luft- und Raumfahrt (The German Center for Aeronautics and Astronautics)
SKTM	Shariket Kahraba wa Taket Moutadjadida
AVR	Automatic Voltage Regulator
IDE	Integrated Development Environment
MQTT	Message Queuing Telemetry Transport
URAER	Applied Research Unit in Renewable Energies
CSV	comma-separated values

General

Introduction

General Introduction

A majority of the communities around the world rely heavily on oil, natural gas and coal for their energy needs. These fuels draw on lots of resources that will eventually diminish, which in turn makes them too expensive or too environmentally damaging to recover. This thesis discusses the advantages and disadvantages of renewable energies; therefore based on the benefits of these energy resources, the use of renewable energies, instead of, fossil fuels will be a good solution for the control of the environmental, social and economical problems of our communities.

The interest for the development of renewable energies was perceived very early in Algeria with the creation of the solar energy institute in 1962. Algeria plays a very important role in world energy markets, both as a significant hydrocarbons producer and exporter, as well as a key participant in the renewable energy market. Due to its geographical location, Algeria holds one of the highest solar reservoirs in the world. The use of renewable energies, especially solar energy, light energy and other clean energies in Algeria, has proved to be a result of huge revenues for the public treasury without harming the sustainable environment. In early 2011, Algeria adopted a new strategy that extends to 2030-2040 in which it refuses to increase its use further to close to 12,000MW in 2030.

In general renewable energies are not adaptable to every single community because of two main factors, the distribution of the natural resources that has dependency on the geographical locations and energy-use with its dependency on the culture of individual community. The other limitations are growth rate and infrastructure. The problems of renewable energies in Algeria (study site "Ghardaia") are: strong wind (dust), high temperature and weather fluctuations, especially in March and April.

Our end-of-study project proposes the realization of a mini automatic weather station working with WiFi to study the efficiency of photovoltaic panels, it measures temperature, humidity, radiation and wind speed. This work revolves around three chapters describing the steps we followed to implement an electronic matrix that can be used pedagogically in the practical work of shaping electronics for embedded systems. Thus, the content of these sections is:

Chapter 1 is devoted to the solar field ;

Chapter 2 illustrates the photovoltaic energy ;

Chapter 3 realization of our project.

Finally, we close this work with a conclusion and possible perspective.

Chapter 01:

The solar field

I.1. Introduction

As clean source of energy, the solar energy considered one of the most common and important renewable energy in term of global installed capacity specially in rural areas , it defined as the energy produced by the sun's radiation.

This chapter provides a brief overview of both of the radiation solar generally and the potential solar in Algeria specially and the Measuring Instruments used.

I.2. Solar radiation

The solar radiation is a radiant energy emitted by the sun as result of its nuclear fusion reaction. Over 99% of the energy flux from the sun is in the spectral region of 0.15-4µm, with approximately 50%in the visible light region of 0.4-0.7µm. The solar radiation received by the Earth's atmosphere at normal incidence is constant and close to 1370 W / m². the radius solar arrives on the ground with several components: a direct component, a diffuse component and a reflected component (the albedo of the ground) and the global radiation [1].

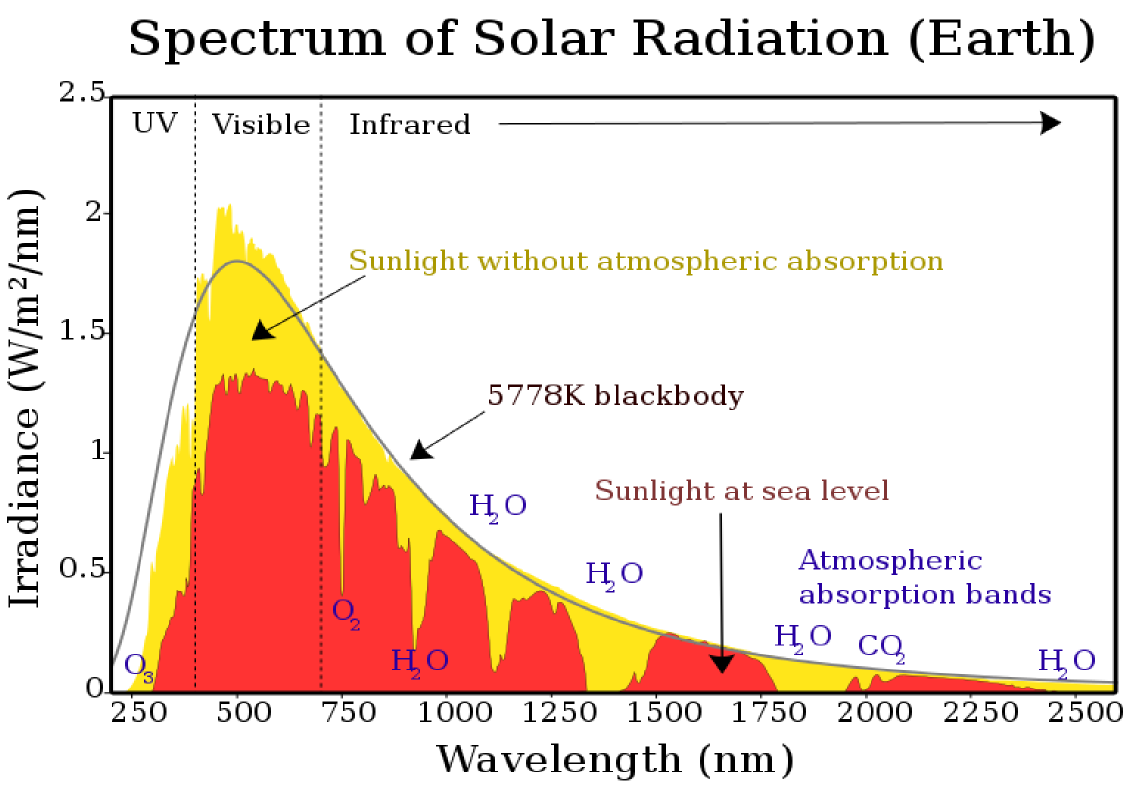


Figure I.1. The spectral of solar radiation.

I.2.1. The sun

The sun is the star at the centre of the solar system, it's a nearly perfect ball of hot plasma. It devise its thermal energy from a group of nuclear reactions in its core. Chemically the sun consists of about 73% hydrogen and around 25% helium plus carbon, neon, and iron with quite small quantities.

The sun's core fuses around 600 million tons of hydrogen into helium every second, converting 4 million tons of matter into energy every second which is the source of sun's light and heat [2].

Identity Card of the Sun:

Mass: 1,989 x 10^{30} kg.

Diameter: 1 391 000 km.

Radius: 695,500km .

Surface: 6 087 799 000 000 km^2

Volume of the Sun: 1.412 x $10^{18} km^3$.

Density of the Sun: 1,409 g/cm^3.

I. 2.2. The atmosphere layers

The atmosphere is actually a gaseous area envelope the planet earth, it divides into several concentric layers, this division resulting primarily from the variation in temperature that characterize each layer which is mainly due to direct solar radiation. About 99% of total atmospheric mass is concentrated in first 20 miles about 32 Km above earth's surface. It contains five major and several secondary layers from lowest to highest: the troposphere, the stratosphere, mesosphere and thermosphere. Further region beginning about 500 km above the earth's surface is called the exosphere [2].

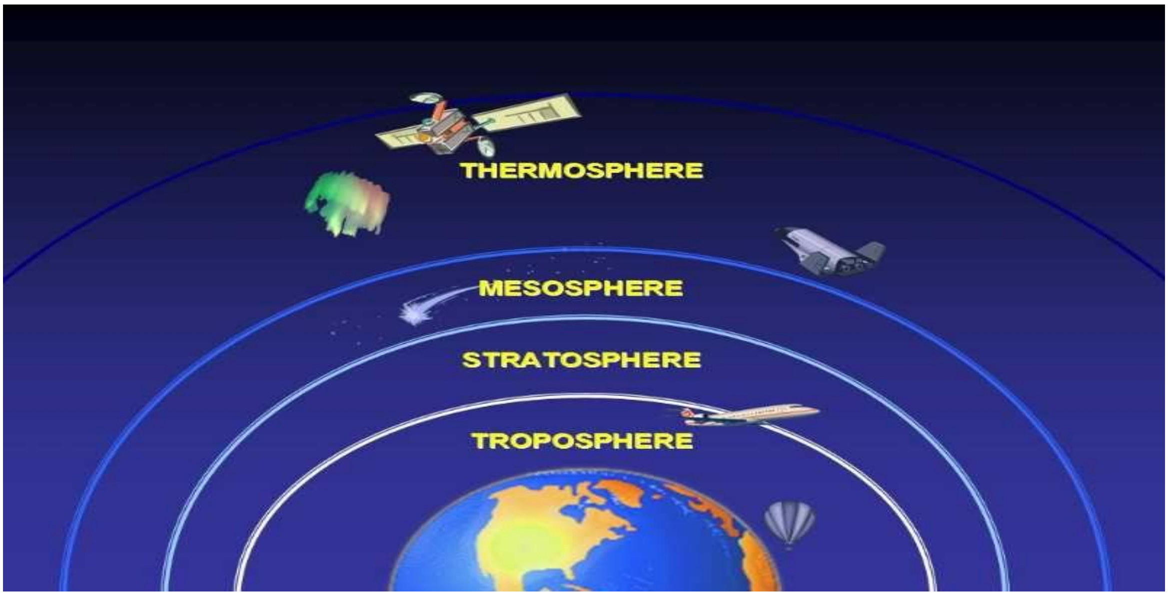


Figure I.2. The atmospheric layers.

1. Troposphere

Is the lowest layer of earth's atmosphere. It extends from earth's surface to about 12 Km in height vary in terms of some factors, including: The location geographic : on average 9 km at the geographic poles ,about 17 km at the equate. The seasons: the height of the troposphere increases in summer while it gets lower in winter. This very shallow layer contains all the air that creatures and human needs to breath, it contains about 99 % of all water vapor and aerosols. In other wise, the temperature and water vapor content in this layer decrease rapidly with altitude.

2. Stratosphere

It represents the second major layer approximately 12 and 50 km above earth's surface. Actually, this strata contains much of the ozone in the atmosphere which make this zone protect us from the sun's harmful ultraviolet radiation.

3. Mesosphere

Located between 50 and 85 km above earth's surface. It characterize by a noticeable decrease in temperature with average temperature around minus 85. In fact, the coldest temperature in earth's atmosphere occur at the top of mesosphere. A very small percentage of water vapor at the top of this layer forms a noctilucent clouds, these are the highest clouds in the atmosphere.

4. Thermosphere

Is located between 80 and 700km above earth's surface. The lowest part of this layer contains the ionosphere. It is cloudless and free of water vapor. The temperature in thermosphere increases with altitude due to the low density of the molecules.

5. Exosphere

It extends from earth's surface of about 700 km, to about 10,000 km. Exosphere merges with the solar winds in its top. In this layer there's no weather, where all particles escape into space. The molecules in this part of atmosphere have extremely low density which make this layer doesn't behave like a gaz.

I.2.3. Types of solar radiation

1. Direct radiation

It is the fraction of solar radiation that arrive earth's surface directly. Its trajectory is linear with a few unique slight deviations which occur on the same time.

2. Diffuse radiation [3]

This radiation occur when the absorption and scattering part of the solar radiation by the atmosphere (air, cloudiness and aerosols) and reflection by the clouds. In clear sky, it constitutes 20% of global energy. In overcast sky, the spectral composition of diffuse radiation is close to that of direct solar radiation.

3. Reflected radiation[4]

Is the radiation that is reflected from the ground or from objects lying on its surface. This radiation depends on the albedo of the soil and it can be important when the ground is particularly reflective (water, snow).

$$Albedo = \frac{reflected\ energy}{recieved\ energy} \qquad \textbf{(I.01)}$$

4. The global radiation

A horizontal surface : It represents all the radiation arrived from the sun that reaches a horizontal surface on the terrestrial globe and equals the sum of direct solar radiation (Direct Normal Irradiance (DNI)) and Diffuse Horizontal Irradiance (DHI). GHI can be expressed as:

$$GHI = DNI + DHI \times cos(z) \qquad \textbf{(I.02)}$$

With z is the solar zenith angle [5].

A inclined surface: the Global radiation on an inclined surface is the sum of the radiations: Direct, Diffuse and Reflected [5].

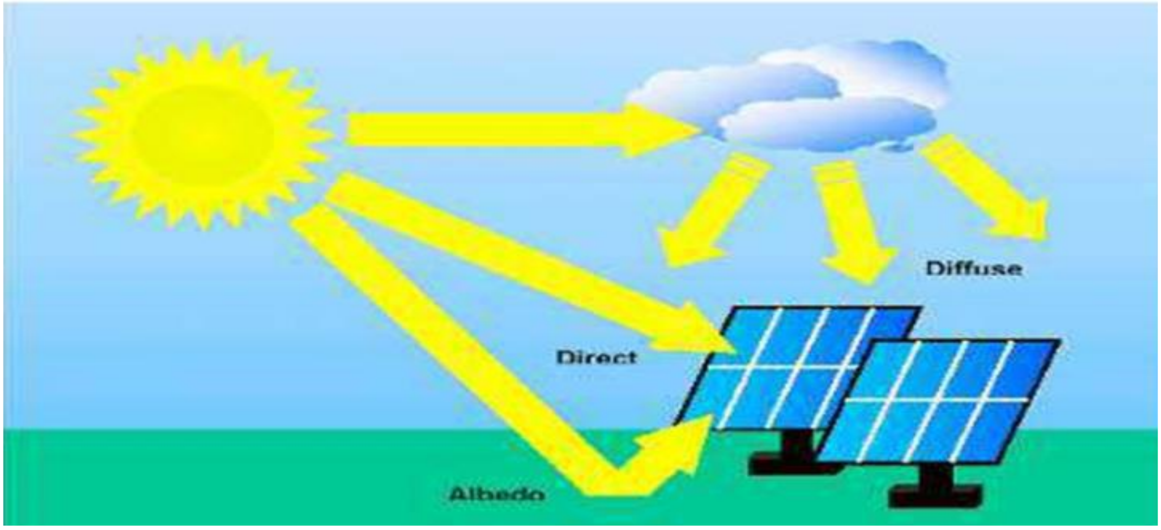


Figure I.3. The components of global radiation.

Air mass : In solar energy, air mass actually refers to relative Air mass that is measured relative to the path length at the zenith. For an ideal homogeneous atmosphere, simple geometrical considerations the air mass can be expressed as following: [6]

$$AM = \frac{1}{\cos z} \qquad \textbf{(I.03)}$$

I.3. Measuring Instruments

The classic principle of illuminance measurements is the thermoelectric effect: a black body receives solar radiation, the increase in its temperature is measured by a series of thermoelectric couples; an electromotive force is therefore recorded. Accurate measurement is always tricky, especially since the device is located outside [7].

I.3.1. Heliograph

The heliograph measures the periods of the day during which the intensity of the direct radiation has exceeded a certain threshold. As long as shadows can be observed on the ground $\left(E > \frac{120W}{m^2}\right)$, meteorologists speak of direct radiation to which is sensitive the heliograph. The sum of these periods represents the daily sunshine duration to define the insolation fraction. In the Campbell-Stokes heliograph, a glass sphere concentrates the direct radiation in a point which burns a special paper. In moving, the burnt point describes the apparent movement of the sun by tracing a curve whose length is proportional to the duration of insolation. Jordan's heliograph uses photographic paper. We now use automatic heliograph consisting of photovoltaic cells arranged on a cylindrical strip whose axis is perpendicular to the plane of the apparent path of the sun. An electronic device totals the sunshine time intervals; care must be taken that each heliograph has the same threshold, that is to say the minimum recorded direct illuminance [7].

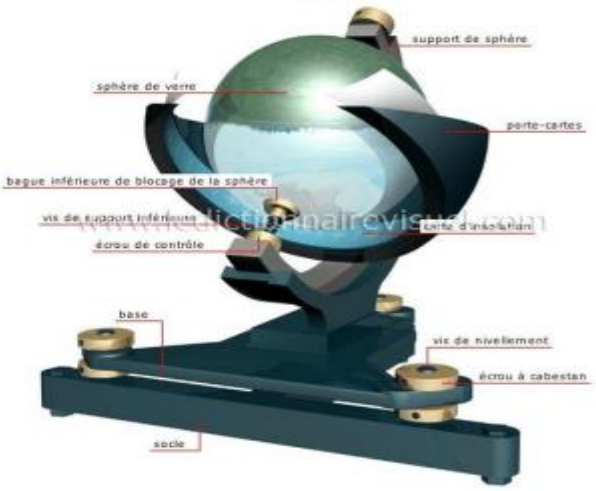


Figure I.4. Campbelle Heliograph [7].

I.3.2. Pyranometer

Pyranometers measure the global radiation (direct + diffuse) of any the celestial hemisphere in the 0.3 to 3 µm wavelength band. The pyranometer from Eppley is a suitable thermopile for this purpose. The receiving surface has two silver concentric rings; the outer ring covered in white. The difference of temperature measured between the two rings by thermocouples in thermal contact with the inner surfaces of the rings but electrically isolated, can be recorded at reason of one reading per hour in the form of an output voltage of the order of mV (in fact 10µV/W/m^2) [7].

Figure I.5. Eppley’s Pyranometer [8].

To eliminate direct radiation, some pyranometers are fitted with a cover to orient according to the season to follow the declination [7].

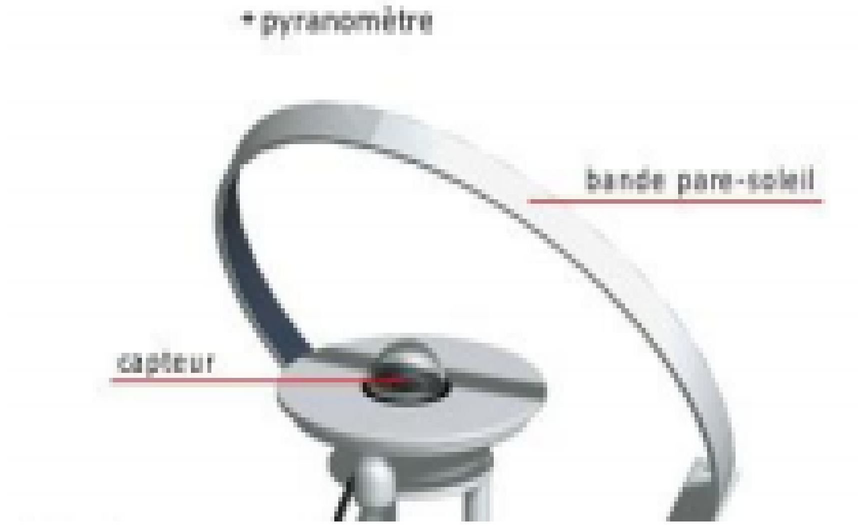


Figure I.6. Pyranometer with cover [8].

I.3.3. Pyrheliometer

Pyheliometers measure direct radiation. They have an opening reduced and a receiving surface which must be maintained normal to the radiation not a automatic tracking system. The sensitive surface is a blackened silver disk placed at the base of a tube fitted with a shutter and a diaphragm limiting the opening angle to 5.7°. The tube is fixed on a mount equatorial. The temperature of the silver disc is measured at regular intervals by opening and alternately blocking the entrance to the device [7].

Figure I.7. Pyheliometer [8].

I.4. Solar Energy Potential in Algeria

According to its geographical location, Algeria holds one of the highest solar potential. Indeed, following an assessment by the satellites, the German Aerospace Center (DLR) concluded that Algeria has the largest solar potential in the Mediterranean basin: 169,440 TWh / year. Sunshine duration on almost all the country over 2000 hours per year and can reach 3900 hours in the Highlands and the Sahara. The daily energy obtained on a horizontal surface is about 5 kWh on most of the national territory, about 1700 kWh / m² / year for the North and 2263 KWh / m² / year for the South [9]. The distribution of solar potential by climatic region at the territorial level Algerian is represented in the following table:

Table I.1. Solar Energy Potential in Algeria [9].

Region	Coastal region	Highlands	Sahara
Area	**4%**	**10%**	**86%**
Average duration of sunshine (Hour/year)	**2650**	**3000**	**3500**
Average energy received (KWh/m²/year)	**1700**	**1900**	**2650**

I.5. PV Power Plants in Algeria

As part of the management of environmental issues and the promotion of sustainable development, Algeria is committed to the development of renewable energy.

SKTM is the only renewable energy company in Algeria that invests in this field with a 343 MWp project embodied by the construction of 22 power plants, 258 MW/Day was founded by Chinese operators in the highlands to the east (Batna, Souk Ahras, Setif, BourdjBouararidj and Mila), center (M'sila, Djalfa, Laghouat, and Ouargla), the Ain Salah-Adrar-Timimoun pole (Adrar, Kabertene, Aoulef, Reggane, ZaouyetKounta, Ain Salah and Timimoun).

Tableau I.2. SKTM Power plants [10]

The plants installed	Power installed (MWc)
Kabertene wind turbine	10.2
Adrar	20
Kabertene	03
In Salah	05
Timimoune	09
Regguen	05
ZaouiatKounta	06
Aoulef	05
Tamanrasset	13
Djanet	03
Tindouf	09
Oued Nechou PV (Ghardaia)	1.1
SedretLeghzel (Naama)	20
Oued El kebrit (Souk Ahras)	15
Ain Skhouna (Saida)	30
Ain El Bel (Djelfa) 1 and 2	53
Lekhneg (Laghouat) 1 and 2	60
Tlagh (Sidi-Bel-Abbes)	12
Labiodh Sidi Chikh (El-Bayadh)	23
El Hdjira (Ouargla)	30
Ain-El-Mel (M'Sila)	20
Oued El Ma (Batna)	02

As well as the three (03) RIS (Isolated Networks of the South) power stations located in Tindouf, Djanet and Tamanrasset, while the western highlands lot (Sidi Belaabes, Saida, Naama, and El Bayath) with 85 MW made by the Germans[10].

Chapter 02:

The photovoltaic energy

II.1. Introduction

Since it advent, the electricity has become a critically important element of human life. Since it forming the basis for the lifestyle of modern era, must develop new technologies for meet the world's global needs. Nowadays the photovoltaic technology has dramatically increased. Scientists are trying to improve the efficiency of converting this energy into electricity with develops more technique for make the PV cell more productive such as: Concentrated PV cell…

This chapter of our research mainly focuses on the photovoltaic energy which based on the phenomena of the PV effect, the main types of solar cells and its electric characterizes.

II.2. Photovoltaic cell

Semiconductors solar cells are fundamentally quite simple devices. They are capable to product electrical energy from solar radiation due to phenomena called the photovoltaic effect. Thus the solar cells are designed to absorb perfectly sun's light.

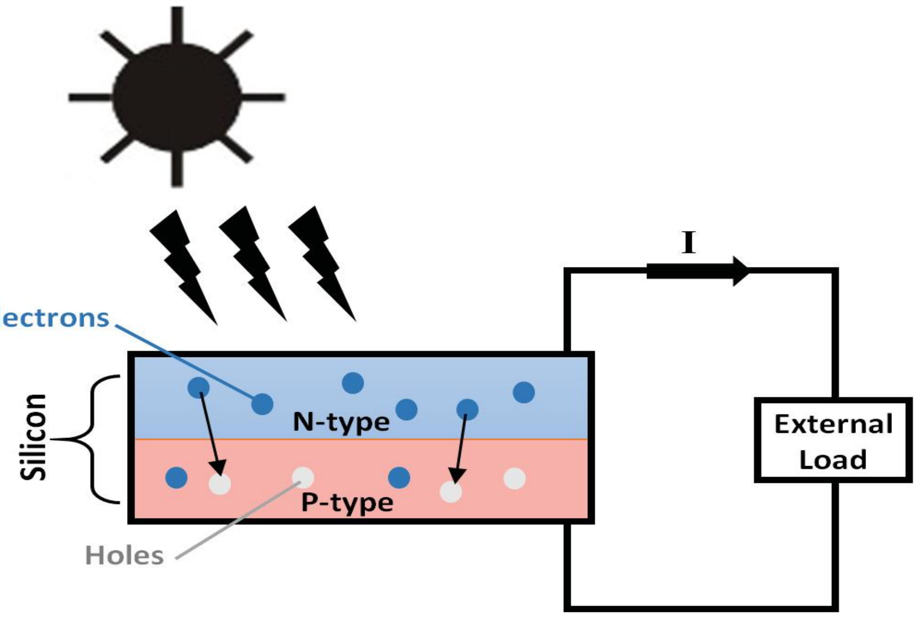


Figure II.1. Photovoltaic cell operation.

The semiconductor diode is based typically to a PN-junction (figure II.1) thus its fashioned when an N-type semiconductor and P-type conductor are brought together to form a metallurgical junction .This is typically occurred through diffusion or implantation of specific impunities or via a deposition process. Usually the dopants used are boron atom (P-type) and phosphorus atom(N-type) [11].

The sun's light is defined as electromagnetic radiation which is consist a particles called photons carry amount of energy determined by the fallowing relation:

$$E_{\gamma} = \frac{hc}{\gamma} \qquad \textbf{(II.01)}$$

Where his Plank's constant and c is the speed of light.

The amount of energy characterize every photon is depend the spectral properties of their source. When light shines on the solar cell surface the photons energy produce the electron-holes pairs by the interaction with atom of the cell. The electric field creates by the cell junction causes the photon generated electron hole pairs to separate with the electrons drifting into the N-region and the holes drifting into the P-region [12].

Since the photons are absorbed by the absorbing material which occurs in the superficial layer (N-region), the energy of the photons incident will then transfer to the electrons, thus liberate them so they are capable of moving through the crystal. Hence that moving creates a DC current at output of the cell. Noteworthy that the energy transmits is governed by the rules of conservation of momentum and conversation of energy [12].

II.3. Types of solar cells

Solar cells can fabricated from a number of semiconductor materials most commonly silicon (Si) , crystalline , polycrystalline, amorphous and cdTe.

II.3.1. Mono-Crystalline silicon

The most common type of PV cells and one of the most expensive because of its requirement of high purity and the energy consumption. The cut crystal is made of thin slices making it or almost square, operated in direct sunlight (from 1000W / m2) with efficiency (14 to 20%) and a lifespan maximum 25 years.

II.3.2. Multi-crystalline cell

This kind is less expensive has a yield slightly lower than mono, its efficiency varies between 10 and 15%. The pole with a mosaic aspect comes back to several crystals which compensate for it. It is considered to be one of the most widely used technologies on the world market, since it is a good compromise between price and performance used at moderate illuminances (from 200W/m²).

II.3.3. Thin film solar cell

This technology of solar cells is a second generation of solar cell. It made by depositing one or many thin layers of photovoltaic materials (figure II.2) on substrate of glass or plastic, Film thickness varies from a few nanometers (nm) to tens of micrometers (µm). The most common thin film materials used nowadays are including: cadmium telluride (CdTe), copper indium gallium dieseline (CIGS), and amorphous and other thin-film silicon (a-Si, TF-Si). The efficiency of thin film PV cells is depends of the semiconductors chosen and growth technology [13].

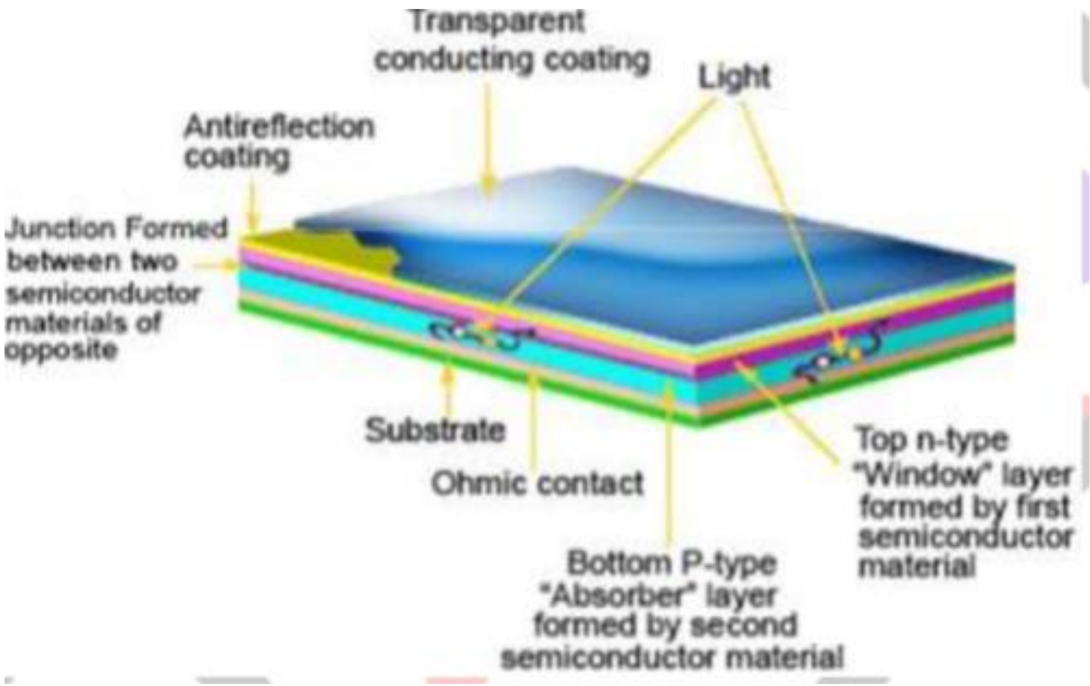


Figure II.2. Structure of thin film solar cell.

II.3.4. Black silicon solar cell

In fact this type of PV cells are just so similar to silicon crystalline the difference is that black silicon cells are treated to appear black on the surface. They manufactured by added a dense network of nanoscale needle on top of standard piece of silicon. Since the black surfaces tend to absorb more sunlight with less reflective the black silicon solar cells could increase the yield of solar cell further more they could also be cheaper with no antireflection coatings used [13].

II.3.5. Cadmium telluride

Cadmium telluride photovoltaic solar cell is technology used a thin semiconductor layer designed to absorb and convert sun light into electricity. The cadmium telluride is less cost than other PV cells technologies. Noteworthy that this material is toxic which is an environmental concern. The efficiency of this PV cells may vary between about 9% to 11.1% [13].

II.3.6. Concentrated PV cell

It converts sunlight into electricity in the same way that traditional photovoltaic technologies do. But what's my take on this new technology is that an advanced optical system is used to focus a large area of sunlight into each cell for maximum efficiency. There are several designs they can be distinguished by the concentration factor such as Low concentration (LCPV) and High Concentration (HCPV). Currently, this type of photovoltaic cell possesses the highest efficiency of all existing photovoltaic technologies (about 40% for production module), and thus has the ability to compete in the near future [13].

Figure II.3. The concentration PV cells [13].

II.4. PV electrical characteristics

The number of cells in a module depends on the application for which it is intended. Terrestrial solar modules were originally designed for charging 12 V lead-acid batteries;

thus, many modules are nominally rated at 12 V. These PV modules typically have 36 series-connected cells, but there are also self-regulating modules with fewer cells. These modules produce a voltage output that is sufficient to charge 12 V batteries plus compensate for voltage drops in the electrical circuits and in the energy control and management systems. With the increased growth of grid-tied PV in recent years, there is a growing assortment of larger modules (e.g., 300 Wp) for these applications with more cells and higher voltages [14].

All PV modules produce direct current (DC) power. For AC applications, it is important to match the array voltage to that of the inverter under real-world operating conditions rather than standard test conditions (STCs). There are also some "AC modules" on the market, but in reality the inverter is built into the back of the module junction box; the PV cells themselves always produce DC power .

The most common solar cells are basically large p–n (thought of as positive–negative) junction diodes that use light energy (photons) to produce DC electricity. No voltage is applied across the junction; rather, a current is produced in the connected load when the cells are illuminated. The electrical behavior of PV modules is normally represented by a current versus voltage curve (I-V curve). Current–voltage relationships are used to measure the electrical characteristics of PV devices and are depicted by curves. The current–voltage, or I-V, curve plots current versus voltage from short circuit current I_{sc} through loading to open circuit voltage V_{oc} [14].

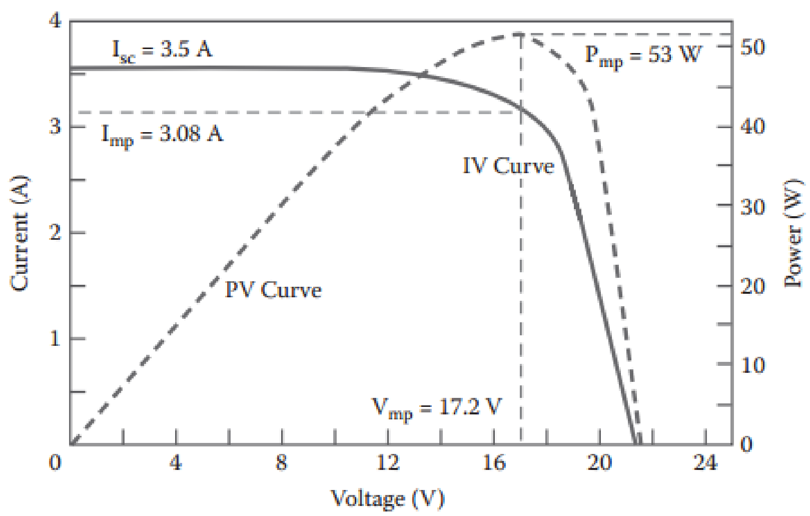


Figure II.4. Typical I-V and power curves for a crystalline PV module operating at 1,000W/m² (STC) [14].

II.4.1. Short-circuit current I_{sc}

This is the current obtained by short-circuiting the terminals of the cell (V=0). This current increases linearly with the intensity of illumination of the cell, it depends on the illuminated surface, radiation wavelength, carrier mobility and temperature.

We can write:

$$I_{sc}\ (V = 0) = I_{ph} \qquad \textbf{(II.02)}$$

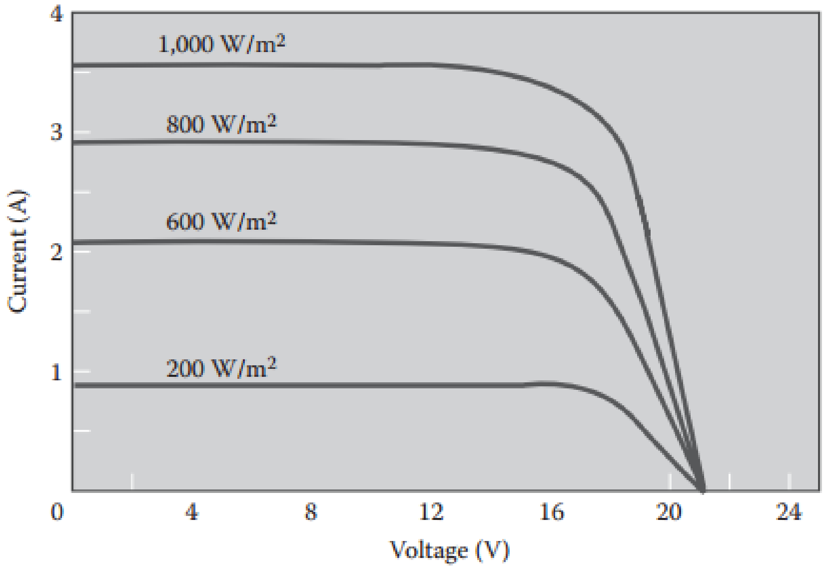


Figure II.5. PV module current diminishes with decreasing solar irradiance [14].

II.4.2. Open circuit voltage V_{oc}

As the name suggests, it is the voltage across the cell when not connected to a load or when connected to an infinite resistance load. It essentially depends on the type of solar cell, materials of the active layer and the nature of the contacts of the active layer-electrode. She depends more on the illumination of the cell.

$$\mathbf{V_{oc} = \ln \frac{nkT}{q}} \qquad \textbf{(II.03)}$$

n : ideality factor of the diode.

k : Boltzmann constant ($1{,}381.10^{-23}$ Joule/Kelvin).

T : temperature of the p-n junction of the cells.

q : electron charge ($1{,}602.10^{-19}$ C).

It can also be calculated by:

$$V_{oc} = \frac{nkT}{q} \ln\left(\frac{I_{DC}}{I_S} + 1\right) \qquad \textbf{(II.04)}$$

I_{DC} : DC cell current.

I_S : diode saturation current.

II.4.3. Maximum power

Under fixed ambient operating conditions (temperature, illuminance, …), the electric power (P) available at the terminals of a PV cell is equal to the product of the direct current supplied (I) by a given direct voltage (V):

$$P = I \times V \qquad \textbf{(II.05)}$$

P : power measured at the terminals of the PV cell (Watt).

I : intensity measured at the terminals of the PV cell (Ampere)

V : voltage measured at the terminals of the PV cell (Volt).

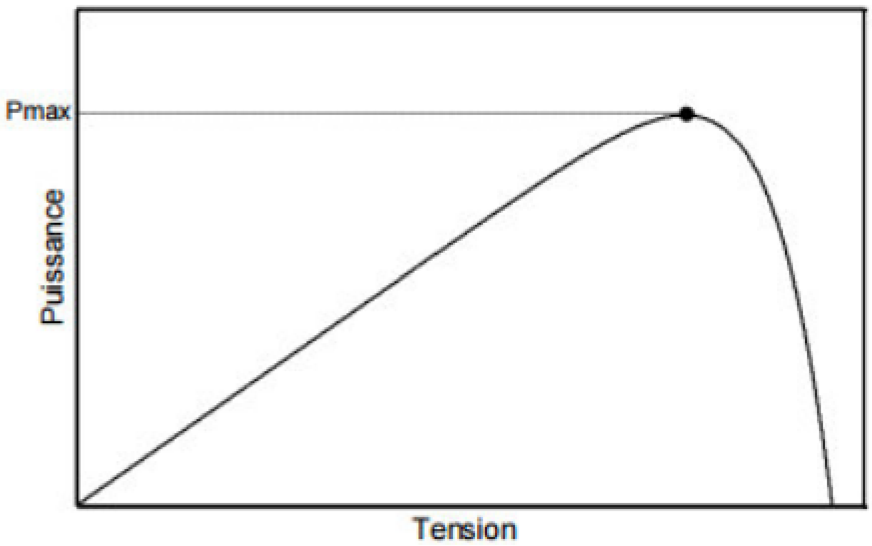


Figure II.6. P-V characteristic curve.

For an ideal solar cell, the maximum power $P_{max\text{-}ideal}$ would therefore correspond to the open circuit voltage V_{oc} multiplied by the short circuit current I_{sc} :

$$P_{max-ideal} = V_{oc} \times I_{sc} \qquad \textbf{(II.06)}$$

$P_{max\text{-}ideal}$: power measured at the terminals of the ideal PV cell (Watt)

V_{oc} : open circuit voltage measured at the terminals of the PV cell (Volt).

I_{sc} : short-circuit intensity measured at the terminals of the PV cell (Ampere).

II.4.4. The fill factor FF

We call fill factor FF the ratio between the maximum power supplied by the cell P_{max}, and the product of the short-circuit current (I_{sc}) and the open-circuit voltage (V_{oc}) :

$$FF = \frac{P_{max}}{(I_{sc}V_{oc})} \qquad \textbf{(II.07)}$$

FF : the fill factor

II.4.5. Conversion efficiency

The efficiency of PV cells refers to the power conversion efficiency. It is defined as being the ratio between the maximum power delivered by the cell and the incident light power P_{in}:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{FF \times V_{oc} \times I_{sc}}{P_{in}} \qquad \textbf{(II.08)}$$

P_{in} : incident power.

This efficiency can be improved by increasing the form factor, the short-circuit current and the open-circuit voltage.

II.5. Photovoltaic Solar Panel

II.5.1. History

The term '"photovoltaic" comes from the word "photo" and the word "volt" (surname of the physicist Alessandro Volta) [15], also called photovoltaic module or PV it allows the direct transformation of sunlight into electricity by a process called "the photovoltaic effect" using cells generally based on silicon.

The development of photovoltaic cells began in 1893 when Henri Becqueral observed the electrical behavior of electrodes immersed in a liquid conductor exposed to light [16].

In 1883, Charles Fritts developed the first functional cell. It is based on selenium and gold, it has a yield of about 1% [17].

In 1905, Albert Einstein explained the photoelectric effect. The direct application of this major discovery in physics did not take place until the middle of the 20th century with the development of the first solar cell based on crystalline silicon with an energy efficiency of 6% at the Bel laboratory (USA) in 1954 [18]. However, the marketing panel photovoltaic cells have failed due to their prohibitive costs.

A few years later, the conquest of space began, which allowed cells based on semiconductors such an silicon to emerge as applications commercial. In 1958 a cell with a conversion efficiency of 9% was developed and the first satellites powered by solar cells are sent into space.

However, until the mid-1970s, solar cells were really too expensive to be economically used on earth, which has delayed this new source of energy from impose outside the spatial domain.

II.5.2. Technology

It was not until the early 1980s that photovoltaic technology experienced a period in full swing all over the world, many possibilities of exploitation are then studied despite the difficulties, the manufacturing methods were then improved, reducing production costs and thus allowing an increase in production volumes.

Today, silicon technology dominates the photovoltaic conversion market with around 90% of the production of solar panels [19]. Most modules currently have a peak efficiency of between 13 and 16%, while record efficiency in laboratories are between 20 and 25% for the different types of crystalline materials [20]. However, the purification of silicon and the use of products highly toxic are today a major obstacle to the development of energy Photovoltaic [21]. In this context, promising new sectors under development have emerged such as concentrated photovoltaic's, perovskites but have not yet proven themselves in the industrial field [22].

A wide variety of photovoltaic cells exists and can be divided into three large families according to the technologies used.

1. **First-generation technologies based on crystalline silicon**

Considered the most efficient and dominant photovoltaic technology, the first generation includes monocrystalline and polycrystalline. Monocrystalline silicon remains even more expensive than polycrystalline silicon but allows to obtain a higher efficiency, with nearly 19.8% against 24.7% efficiency in the laboratory [23] [24].

2. Second-generation thin-film technology

Thin-film solar cells are promising candidates for future photovoltaic generations because they offer several advantages :first, the material often used for semiconductor direct band gap, including their absorption coefficient is very high [25][26][27]. Second, a thin absorbent layer (several micrometers) is sufficient to absorb the entire incident light, which reduces the cost of materials. Third, due to the small size of the active material of the solar cell, rare and expensive materials can be used. Fourth, although the conversion efficiency of thin film solar cells is lower than the crystalline silicon cells, but their manufacture is less costly because of the various vacuum deposition techniques used, which further reduces costs treatment [28][29]. Finally, the deposition of thin films on a variety of substrates (flexible substrates, light substrates such as polymeric sheets, etc.), expands the range of applications of these solar cells [30][31].

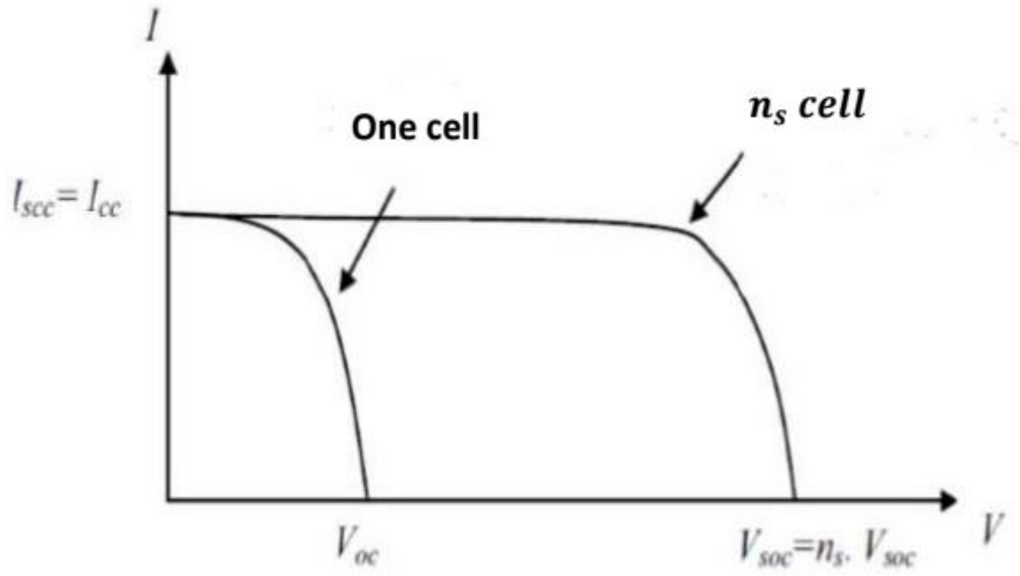
3. Third generation technology “Organic Cells”

The most general strategy today in organic cells, is the heterojunction cell, in which electron donors (P3HT) and electron acceptors (Graphene) have mixed to form a blend layer. In organic materials, the process of photo generation of charge carriers is generally, attributed to the dissociation of molecules in the excited state in the presence of an internal electric field generated by an interface, an impurity or defects [32]. The Light absorption leads to the creation of electron-hole pairs strongly bound by electrostatic attraction [33].

II.5.3. Serial and parallel connection of PV cells

1. PV cells in series:

When a number PV cells connected in series, the voltage of the module will equal the sum of voltage of each cell. The current passing through the PV panel is equal (As shown in the figure below ...).



FigureII.7. Characteristics of series PV cells.

2. PV cells in parallel

In parallel connected cells the current of the panel will equal the sum of each cell's current. The total voltage of PV panel is The single PV cell voltage. (As shown in the figure below ...)

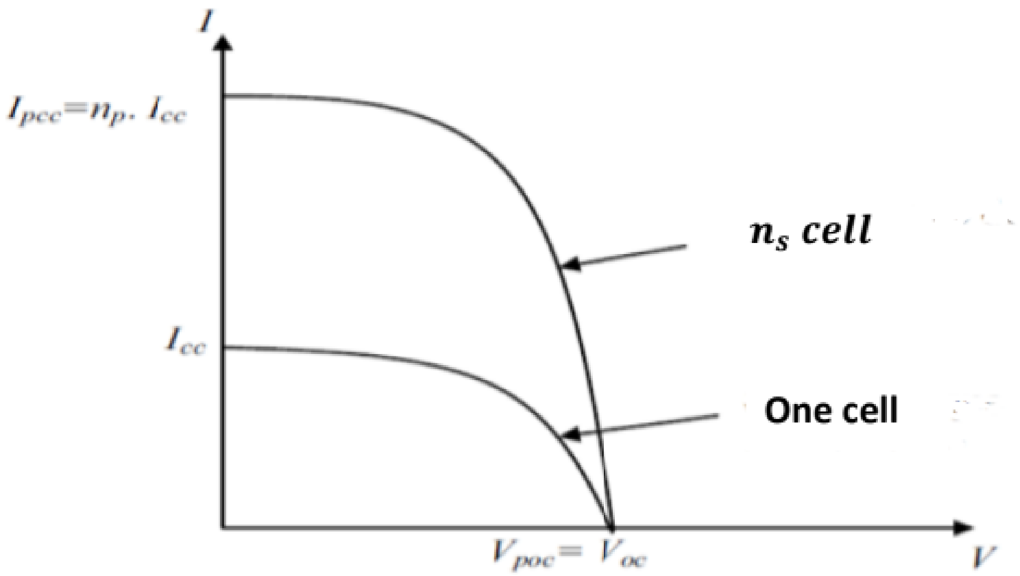


Figure II.8. Characteristics of parallel PV cells.

Chapter 03: Project realization

III.1. Introduction

The following chapter presents the experimental work of this research, where we will explain all steps of realization of this project from the materials used to the programming part .On the other hand, this part will contain the results achieved through the period of study.

We focused on some climatic factors that depend on some reasons related basically to the geographic location.

III.2. The physical quantities measured:

1. **Temperature:** like all other semiconductor devices, solar cells are sensitive to temperature. Its increase caused reduction of the open circuit voltage V_{oc}. Thus, it is necessary to keep the panel temperature at low values especially in hot areas in order to exploit this energy that the area blessed with by using moderna cooling mechanisms [34]. Therefore we should measure both the ambient temperature and PV temperature using sensors placed in the location.
2. **Humidity:** we can consider that the value of the relative humidity doesn't affect much in saharien locations which is our case , but it is necessary to Take it into consideration to guarantee accuracy of our study.
3. **The voltage and current:** as we mentioned previously, the PV panel is technically a DC generator, its production depends on several factors the most important are the surrounding environmental conditions such as temperature, humidity. Therefore, we will make sure to monitor the output voltage and current of the PV panel, that will give us an idea on its performance throughout our study.
4. **Luminosity:** the human found a way to exploit sunlight and convert this energy into a current through a phenomena of photovoltaic effect.th PV cell is a device Relies on the photons of the light . The experimental results show that the open circuit voltage, short-circuits current, and maximum output power of solar cells increase with the increase of light intensity. Therefore, it can be known that the greater the light intensity, the better the power generation performance of the solar cell and this is what we will prove more during our study.
5. **Dust:** Several studies have been conducted to observe and analyze the dust deposition effects. Most if not all agree on the fact that dust reduces the efficiency of a PV panel [35]. The desert is more likely to have sandstorms specially in spring

Which made us choose this season to do our study. We will rely only on visual observation to conduct our experiment on the effect of dust on cell production .

6. **Wind:** the impact of wind on PV performance is described by factors such as module temperature, surface structure and dust deposition. In positive way , the wind blows away dust particles from the PV module surface and reduces dust deposition. In the other side, it negatively impacts the desert area, where wind itself carries a significant amount of dust and sand particles.

III.3. Material

III.3.1. Introduction to Arduino

Arduino boards are designed to build rapid prototypes and models of electronic boards for embedded systems, these boards allow simple and inexpensive access to embedded systems. In addition, they are completely free of rights, both in terms of the source code (Open Source) and the material aspect (Open Hardware). Thus, it is possible to rebuild your own Arduino board in order to improve it or remove unnecessary features from the project. The Arduino language differs from the languages used in the embedded systems industry by its simplicity. Indeed, many libraries and basic functionalities hide certain aspects of embedded software programming in order to gain simplicity. The possibilities of Arduino boards are enormous, a large number of applications have already been made and tested by many Internet users.

➢ Area of use and these applications

The Arduino system allows us to do a large number of things, which have application in all fields, the scope of use of the Arduino is gigantic. To give you some examples:

- Industrial and embedded electronics.
- Control home appliances.
- Make your own robot.
- Make a light show.
- Communicate with the computer.
- Remote control a mobile device (model making).
- Physical computing: In a broad sense, building interactive physical systems that use software and hardware that can interface with sensors and actuators.
- Art/Entertainment.

- Hacking, Prototyping and Education [36].

III.3.2. Arduino uno board

The UNO model from ARDUINO is an electronic card whose heart is an ATMEL microcontroller reference ATMega328. The ATMega328 is an 8-bit microcontroller from the AVR family whose programming can be done in C/C++ language. It can be used to develop interactive objects, equipped with switches or sensors, and can control a wide variety of lights, motors or any other hardware outputs.

Arduino UNO is a very valuable addition in electronics that consists of a USB interface, 14 digital I/O pins(of which 6 Pins are used for PWM), 6 analog pins and an Atmega328 microcontroller. It also supports 3 communication protocols named Serial, I2C and SPI protocol.

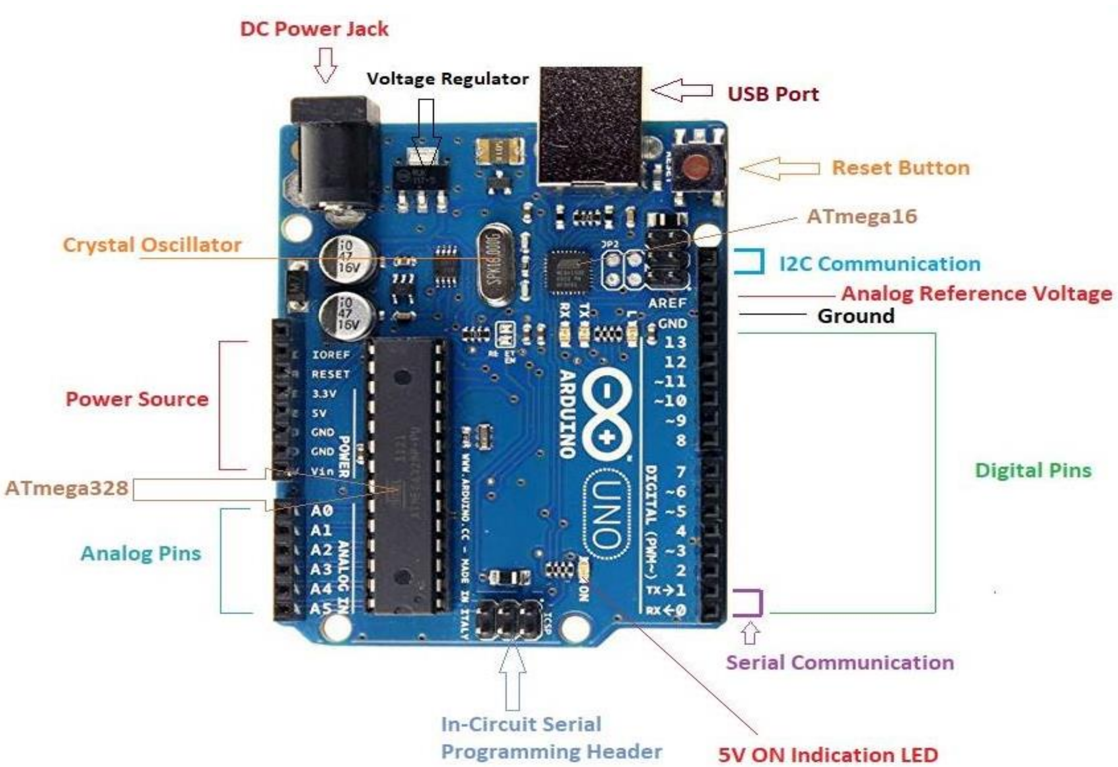


Figure III.1. Description of the Arduino Uno board [36].

III.3.3. ESP32 board (NodeMCU)

ESP32 is designed for mobile, wearable electronics, and Internet-of-Things (IoT) applications. It features all the state-of-the-art characteristics of low-power chips, including fine-grained clock gating, multiple power modes, and dynamic power scaling. For instance, in a low-power IoT sensor hub application scenario, ESP32 is woken up periodically only when a specified condition is detected. Low-duty cycle is used to minimize the amount of energy that the chip expends. The output of the power amplifier is also adjustable, thus contributing to an optimal trade-off between communication range, data rate and power consumption. It is a single 2.4 GHz Wi-Fi-and-Bluetooth combo chip designed with the TSMC ultra-low-power 40 nm technology. It is designed to achieve the best power and RF performance, showing robustness, versatility and reliability in a wide variety of applications and power scenarios.

NodeMCU is very popular and used as an essential component in various applications, for example household appliances, wireless control, sensor networks and security identification tags.

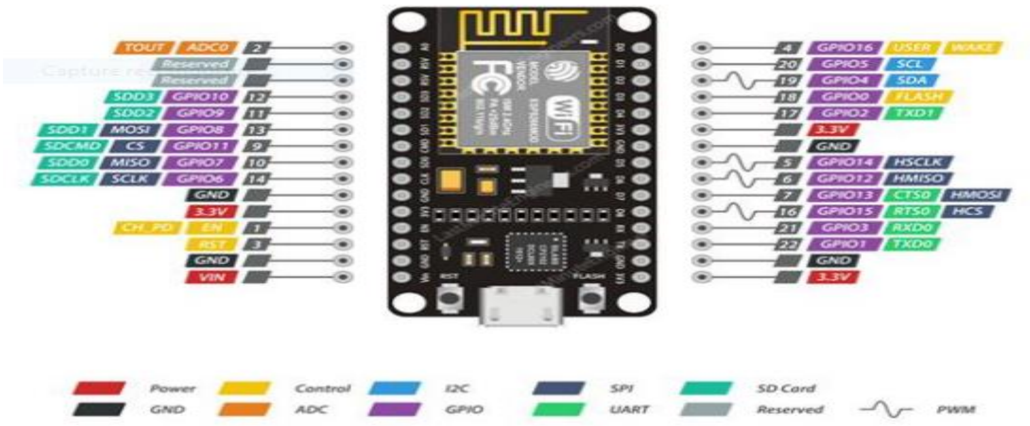


Figure III.2. The different pins of the card.

III.3.4. DTH11

In our project, we chose DHT11 sensor for a measure of temperature and air humidity which is features a temperature and humidity sensor complex with a calibrated digital signal output.

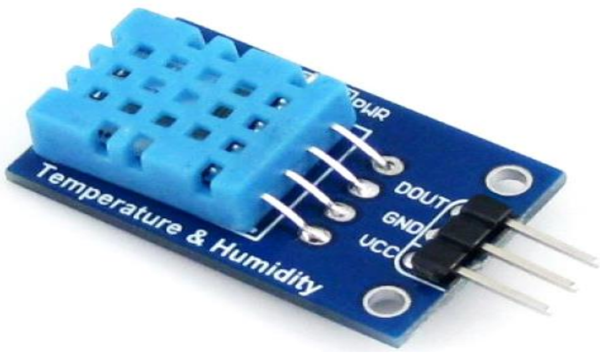


Figure III.3. DHT11 sensor.

The main characterizes of DHT11:

- low price.
- power supply from 3 to5.5V DC.
- current supply from 0.5mA to2.5Ma..
- a range measurement between 20 to 90% humidity readings with 5% accuracy.
- a range measurement between 0 to50 C temperature readings with 2˚C accuracy.

Wiring DHT11 sensor with Arduino:

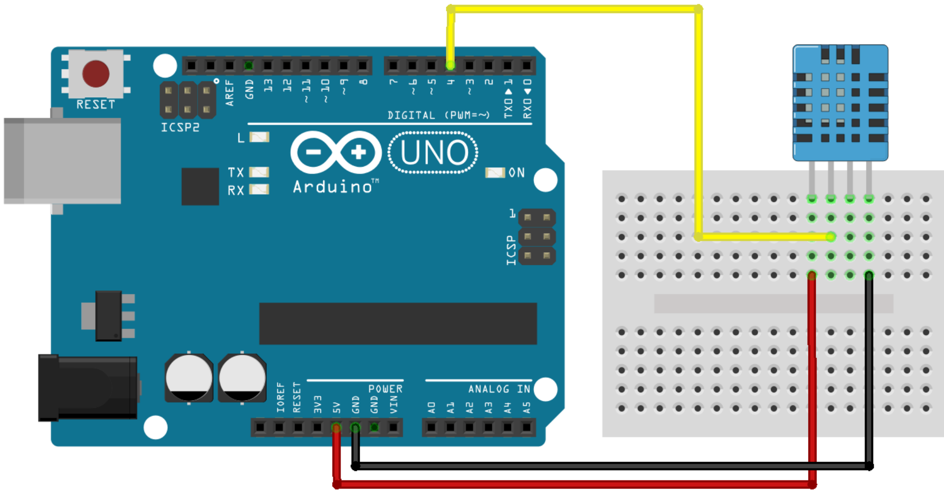


Figure III.4. The wiring of the DHT11 sensor.

III.3.5. MAX6675 K-TYPE Thermocouple

A thermocouple MAX6675 the type K will be useful to give us an idea of our PV surface temperature and its variations. (Figure III.5) Presents a real image of this sensor:

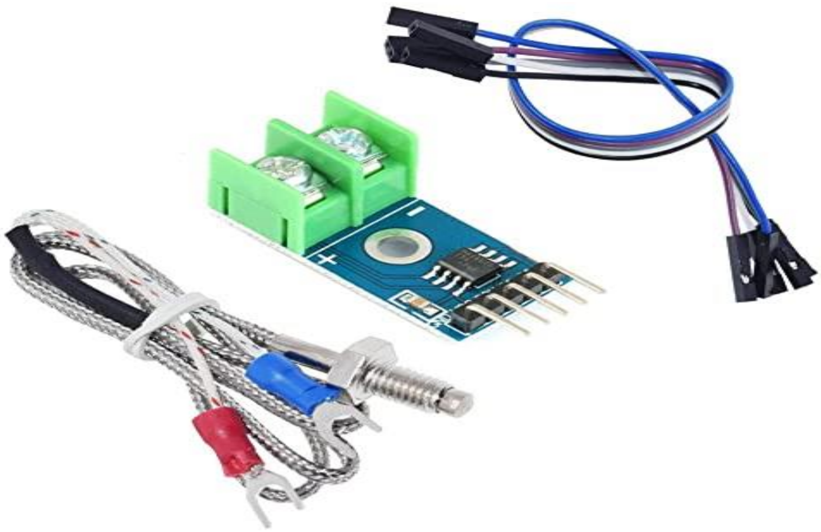


Figure III.5. MAX6675K-TYPE Thermocouple.

The sensor provide a high accuracy readings .It resolves temperatures to 0.25°C, allows readings as high as +1024°C.

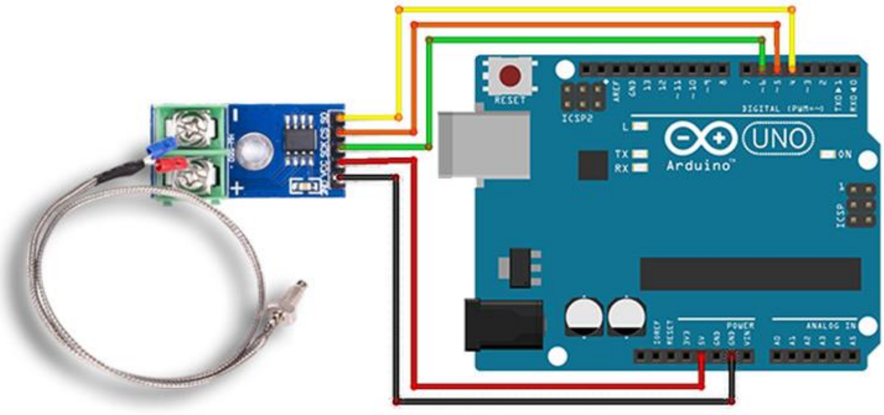


Figure III.6. The connection of the sensor with Arduino board.

III.3.6. The voltage

The voltage measurement is made by a voltage divider to have a voltage between 0 and 5V. The output voltage of the divider is given by the following formula:

$$V_{out} = \frac{R1}{R1+R2} * V_{in} \qquad \textbf{(III.01)}$$

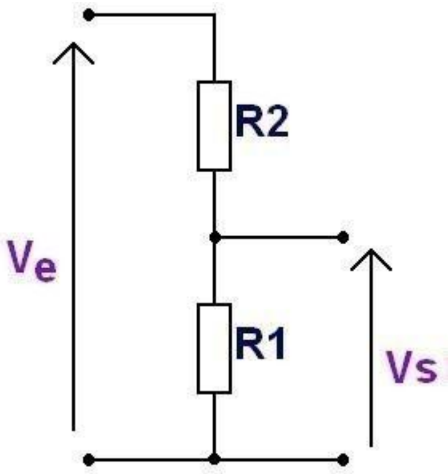


Figure III.7. A simple voltage divider.

As we know that our Arduino board has an analog input voltage equal to 5V and if we assume that the maximum voltage delivered by the PV generator is 48V then the ratio between the two voltage is 0.1. So in this work, we adopt R1=1200 Ω, R2=10000Ω.

III.3.7. ACS712 current sensor

The current represents one of the main factors in our study, As we know, the intensity of the panel's output is mainly related to solar radiation. so we chose for the measurement the sensor Allegro ACS712 .

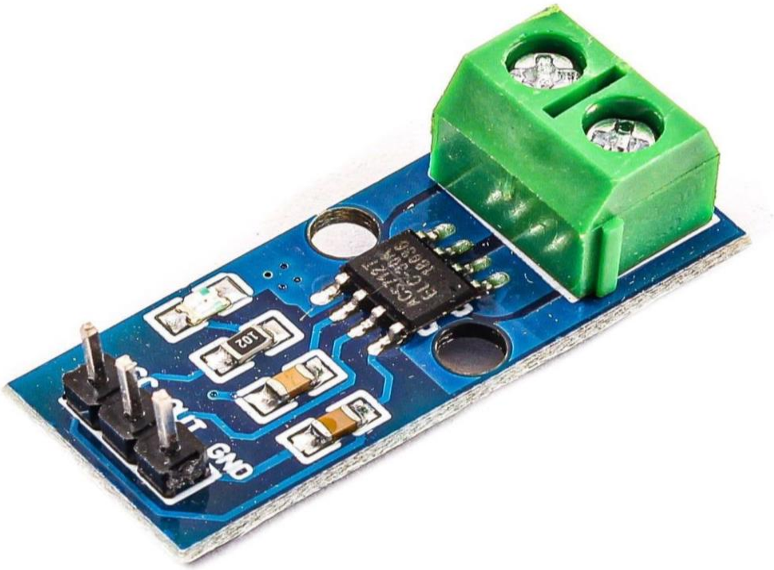


Figure III.8. Current sensor ACS712.

The ACS712 provides economical and precise solutions for AC or DC current sensing in industrial and communications systems.

The main characterizes of ACS712:

- Measure current up to 20A.
- Output sensitivity of 100mV/A which means that for every 1A increase in current through the conduction terminals in the direction positive, the output voltage also increases by 100 mV.
- It has 4 pins.

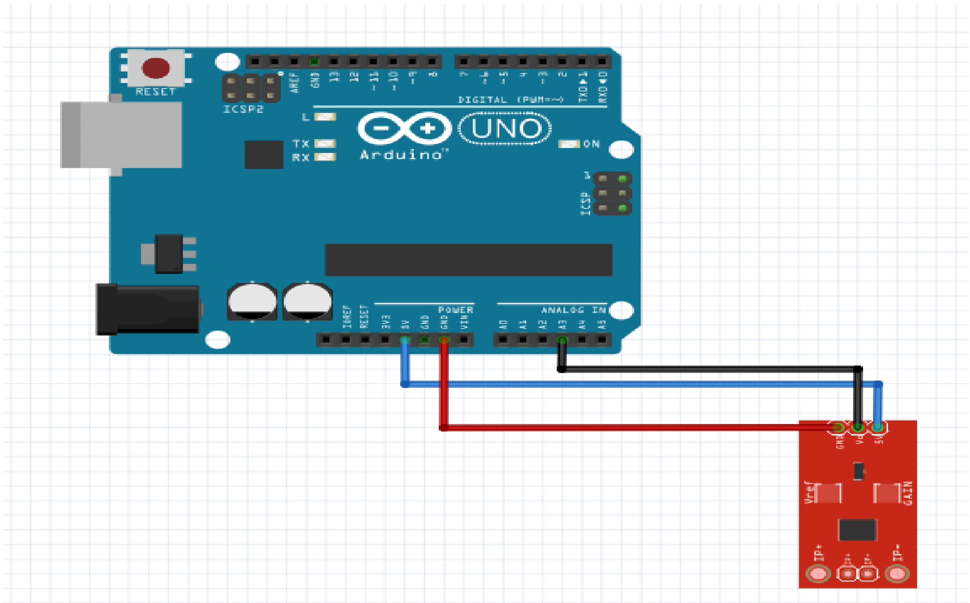


Figure III.9. The connection of ACS712 with Arduino.

III.3.8. The irradiance

For the measurement of solar irradiation , we used a solar cell installed in side to the panel. The arduino analog pin reads the voltage delivered by the PV cell which converts to a current by the following relation :

$$I_{cell} = \frac{V_{cell}}{R} \qquad \text{(III.02)}$$

Note that the value of the résistance has been calculated R=45Ω .

The irradiation is obtained by using the correspondence equation. The correspondence curve is a mathematique equation that describes the relation between the solar irradiation and the measured current of the used PV cell , its equation is like following:

$$f(I) = 12323(I) + 9.9897 \qquad \text{(III.03)}$$

III.3.10. Wind speed

The wind speed is measured surrounding and nearly to our panel. The measurement is made using Testo model 440 anemometers which permitted manual testing done every (15 min).

Figure III.10. Anemometer Testo 440.

III.4. Software overview

III.4.1. Arduino IDE

The open-source Arduino Software (IDE) makes it easy write code and upload it to board. This software can be used with any Arduino board ,while it can be used in programming some other boards such as ESP32.A free and open IDE (Integrated Development Environment) is distributed on the Arduino site (compatible with Windows, Linux and Mac) at the address https://www.arduino.cc/en/software .

The interface of the Arduino IDE is rather simple (Figure III.13), it offers a minimal and uncluttered interface to develop a program on Arduino boards. It has a code editor with syntax highlighting (1) and a quick toolbar (2). These are the two most important elements of the interface, they are the ones we use most often. There is also a more classic menu bar (3) which is used to access the advanced functions of the IDE. Finally, a console (4) displaying the results of the compilation of the source code, operations on the card.

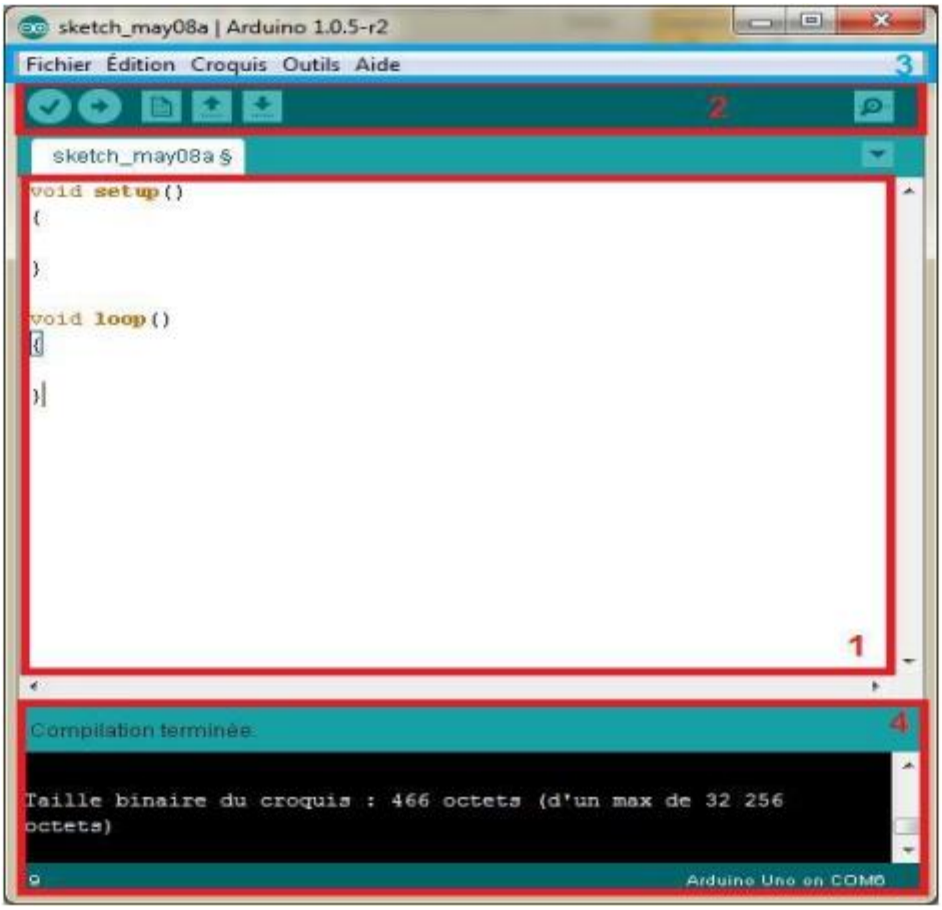


Figure III.11. Arduino IDE.

Buttons

We will present the buttons numbered in red

Figure III.12. Presentation of buttons.

- Button 1 (verify): This button allows you to verify the program, it activates a module that looks for errors in your program.
- Button 2 (upload): Compile and upload the program to the board.
- Button 3 (new): Create a new file.
- Button 4 (open): Load an existing program.
- Button 5 (save): Save the current program.
- Button 6 (serial monitor): Allows access to the serial port (in RX/TX) , its provides visualize and monitors data (figure III.15).

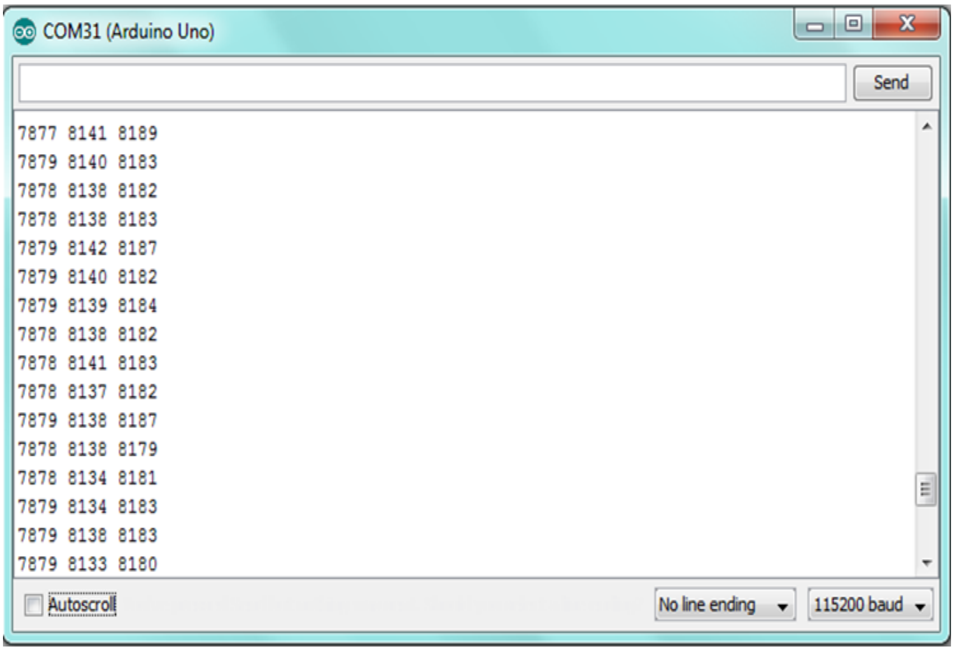


Figure III.13. Serial monitor window.

III.4.2. The flowchart of the code

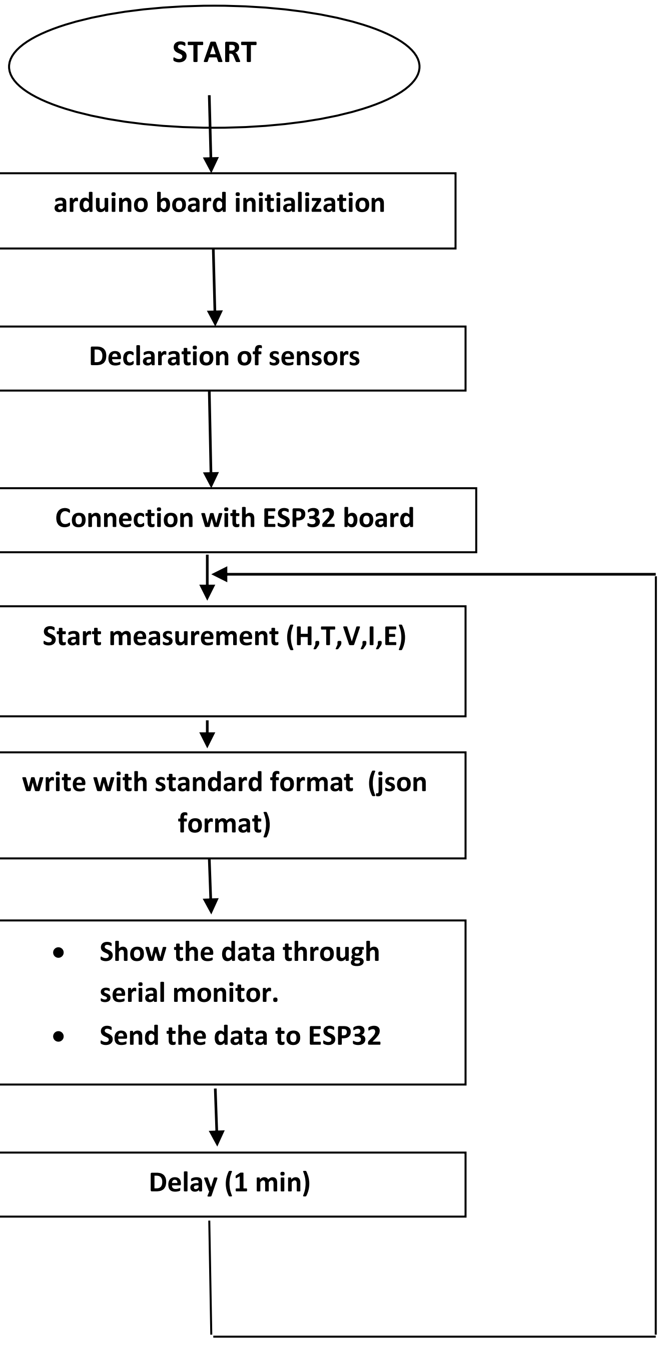


Figure III.14. The flowchart of Aduino.

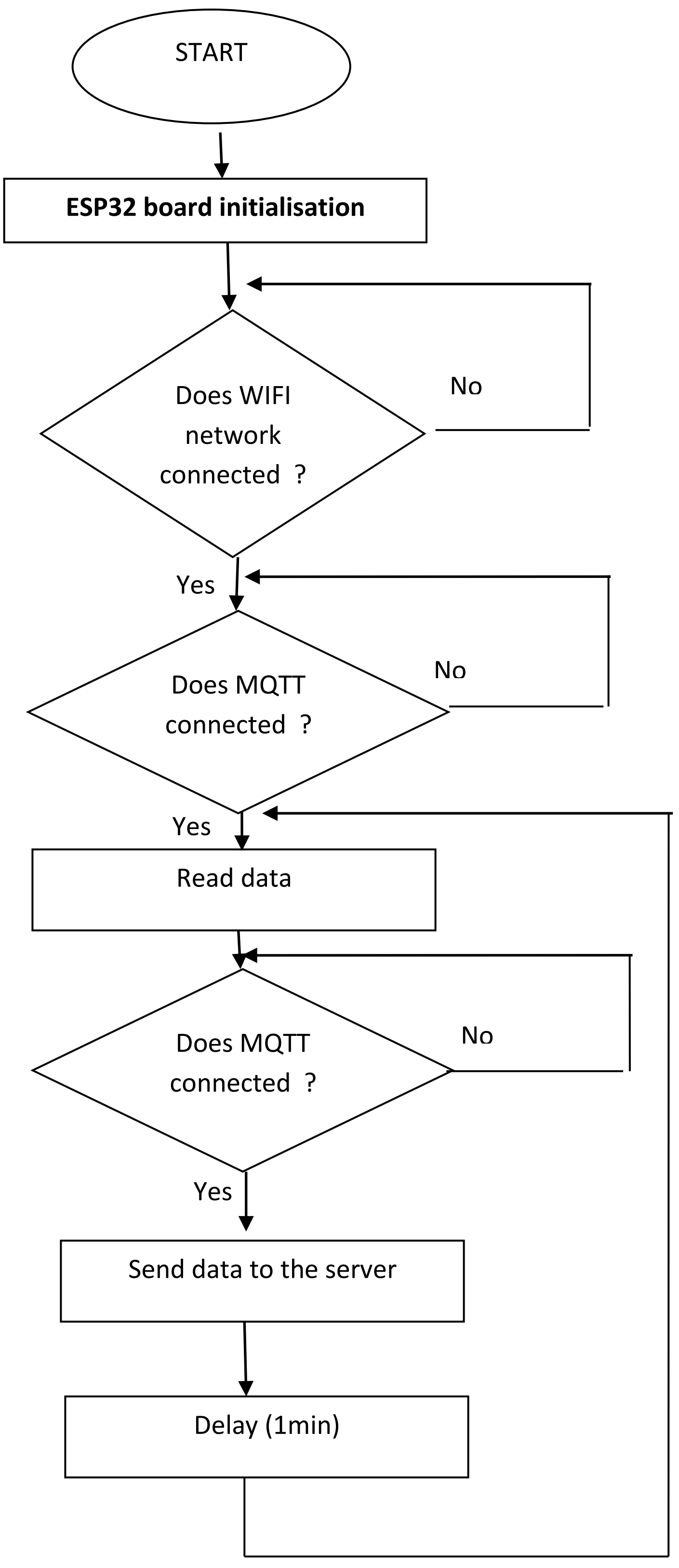


Figure III.15. The flowchart of ESP32 (WiFi card).

III.4.3. Display and save (storing) data

After execute the program it's necessary to find a way to visual our data and save them so we can analyze it later , the fallowing illustration (Figure.III.18) explain the path of the data from sensors to our server , as we mentioned previously the board ESP32 is programmed to connect to the network used then send the information to the MQTT broker .

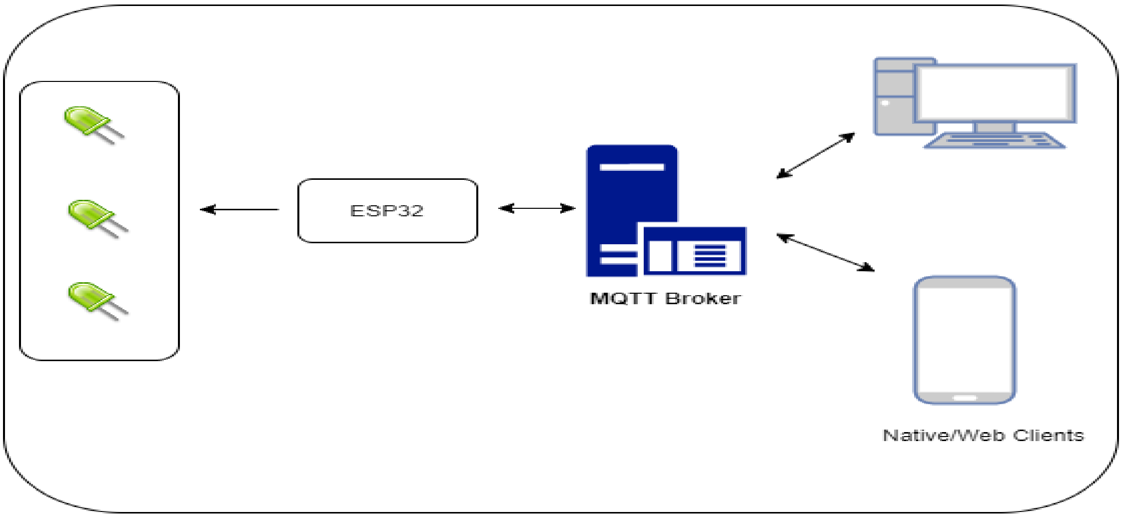


Figure III.16. Illustration present the system.

The MQTT protocol (Message Queuing Telemetry Transport) is designed to transport the messages between devices , whilst the MQTT broker is a piece of software running on a computer receives the MQTT messages and distribute them to the subscribed clients . in this project we used program called "mosquitto'' as a MQTT broker .

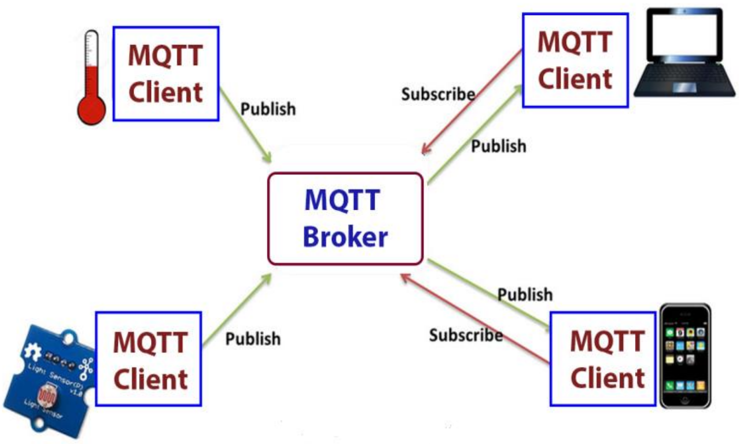


Figure III.17. MQTT publish and subscribe architecture.

To receive our data we can't just subscribe with the broker but we must create a subject line called ‘’ topic’’ ,hence Anyone who subscribes receives a copy of all messages for that topic. For displaying results we used ‘’Node red’’ which allow us to access and read the results easily , it also can save data as a ‘json’ into csv file.

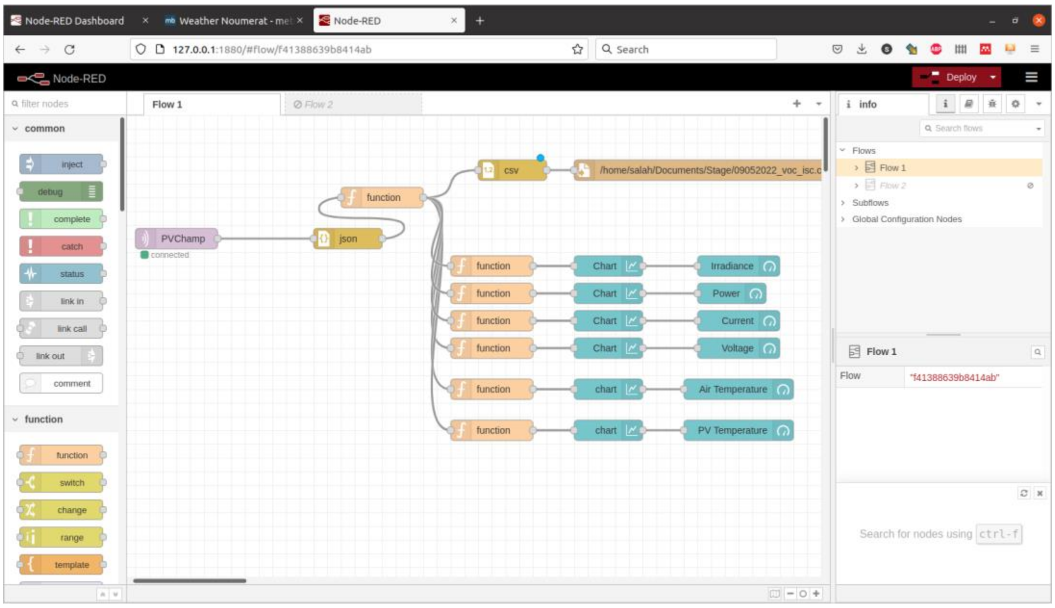


Figure III.18. Photo node red platform.

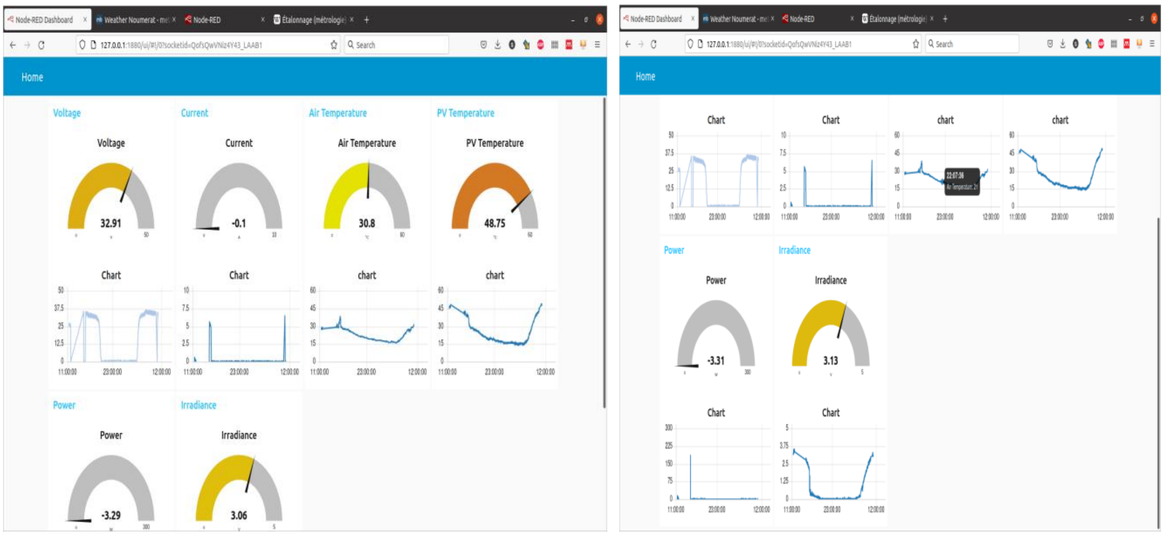


Figure III.19. Dashboard.

III.4. Project description

In this project, we created a Weather Station using a variety of sensors based on Arduino Uno board, as mentioned before. In this process, we create the software sketch that will run the weather station using the Arduino IDE (Integrated Development Environment).

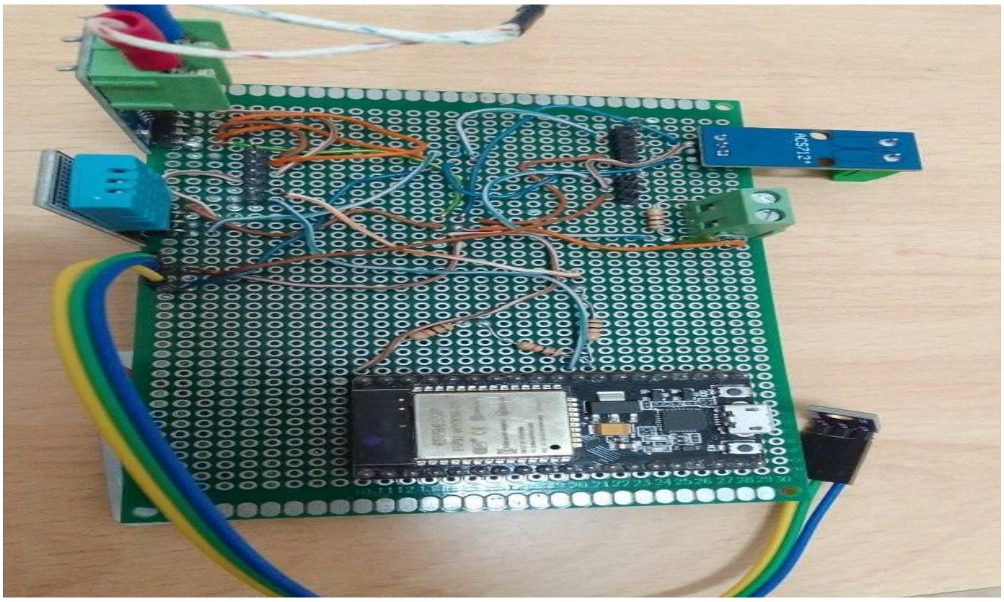


Figure III.20. Mini weather station.

The Arduino IDE includes libraries for each sensor with examples. The code is broken up into many parts to organize the process. To simplify collecting data, we connected our station with a wifi network using ESP32 board. The data are sent directly to the computer every minute. The use of WiFi network allows us to connect with distant weather station without using wires. In addition, it provides continuous monitoring of the station round the clock.


```
#include <SoftwareSerial.h>
SoftwareSerial sw(2, 3);

#include <DHT.h>
#include <DHT_U.h>
#include <max6675.h>
#include"max6675.h"
#include "DHT.h"
#define VOLTAGE_PIN A0
#define CURRENT_PIN A1
//#define temt6000_Pin A2 // à eviter les pin 0 et 1, ce sont utilisé pour Serial
#define solarCell_pin A2
#define sw_pin 8
int thermoSO =5;
int thermoCS =6;
int thermoSCK =7;
int capteur = 4;
float vout = 0.0;
float vin = 0.0;
//float R1 = 1200.0;
//float R2 = 10000;
float volt_coef = 10;
/*float current_lx = 0;
float lx = 0;
float valeur_lx = 0;
float tension_lx = 0;*/
float courant_v = 0;
double AcsOffset = 2.49;
double Sensibl = 0.1;
```

Figure III.21. Arduino IDE interface (project code).

The PV panel used in the test is a Mono-crystalline panel which characteristics is described in table (III.1). We preferred to take our measurements respectively in a short-circuit and the open-circuit in order to clarity the measurements due to the absence of a load in the solar system. moreover, The mini-project is placed in the structure of the solar panel as shown in the picture(figure III.21) and supplied with 220 V.

Figure III.22. Clean panel.

Figure III.23. Unclean panel.

Tableau III.1. The mono-crystalline panel's characteristics, Rating at 1000W/m² irradiance, temperature 25 C°

V_{MPP}	30.6 V
I_{MPP}	6.87A
V_{oc}	37.4V
I_{sc}	7.5A
P_{MPP}	240Wp

III.5. Results

Experiments were done in the Applied Research Unit in Renewable Energies - GHARDAIA in south Algeria , from 09/05/2022 to 15/05/2022. Weather station recorded weather parameters like outdoor Temperature, humidity, wind speed and solar radiation. With 1 minute intervals and these measurements were recorded during the day. The test is token in a dusty panel then in a clean one. The results are shown below:

III.5.1. Clean panel

III.5.1.1. The effect of the temperature of the panel

Figure III.24. Curve fitting graphic of the effect of the T(C°) on the Voc.

Note 01: the curve shown that there is a negative relationship between the temperature of the PV panel and the open-circuit.

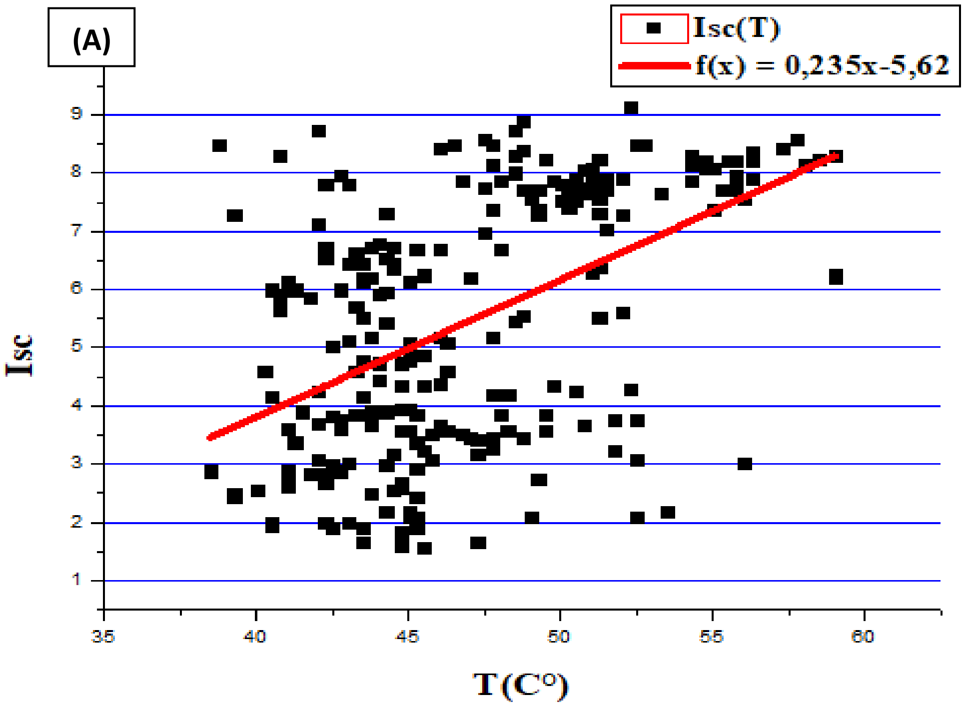


Figure III.24. Curve fitting graphic of the effect of the T(C°) on the Isc.

Note 02: we observe that the Isc significantly increased right with the increasing of the temperature , so we can say that there is a proportionality between Isc and PV temperature .

III.5.1.2. The effect of the solar irradiance

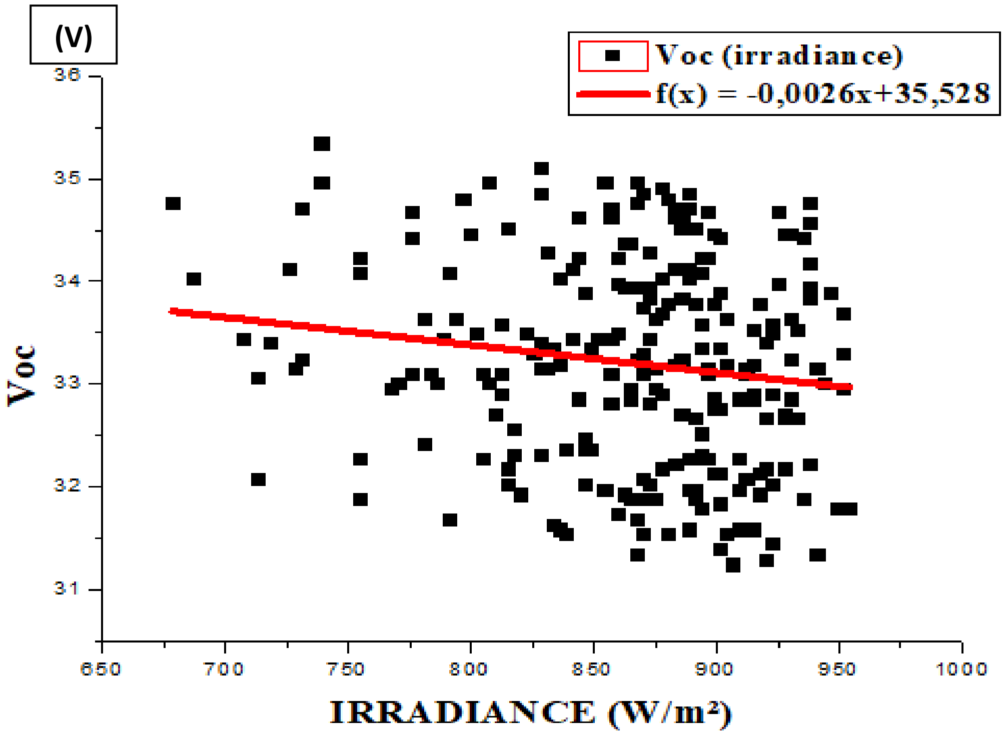


Figure III.25. Curve fitting graphic of the effect of the irradiance on the Voc.

Note 03: no doubt that the irradiance has an effect on the Voc, like the figure shows the Voc is slightly desencresed as the irradiance increased.

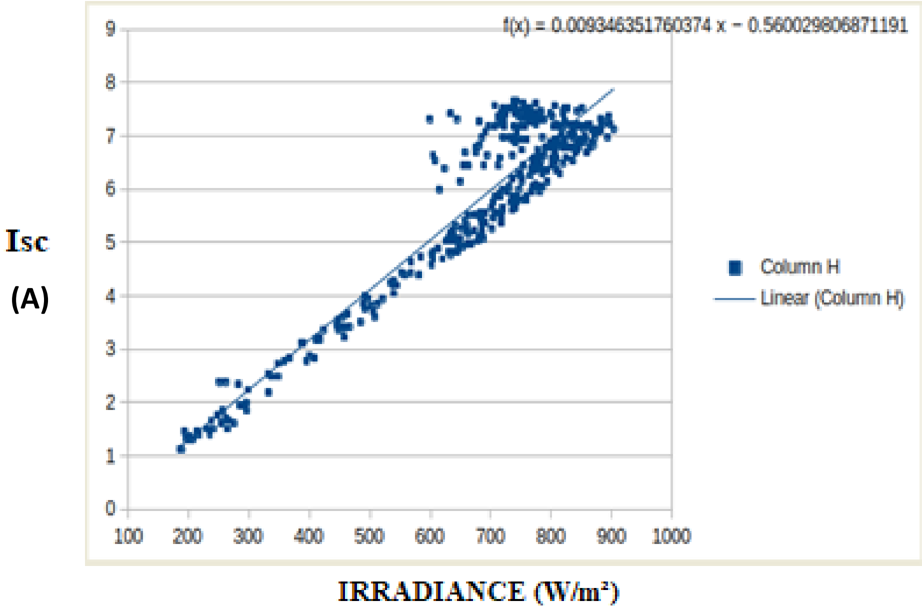


Figure III.26. Curve fitting graphic of the effect of the irradiance on the Isc.

Note 04: the curve is clearly increasing .It reaches its maximum value (about 7.5 A) in high radiation ,when its attains a very small value (about 0.5 A) in low irradiation .

III.5.1.3. The effect of the wind speed

The experiments were conducted in order to investigate the effect the wind speed spatially on the open-circuit like shown in the curve below:

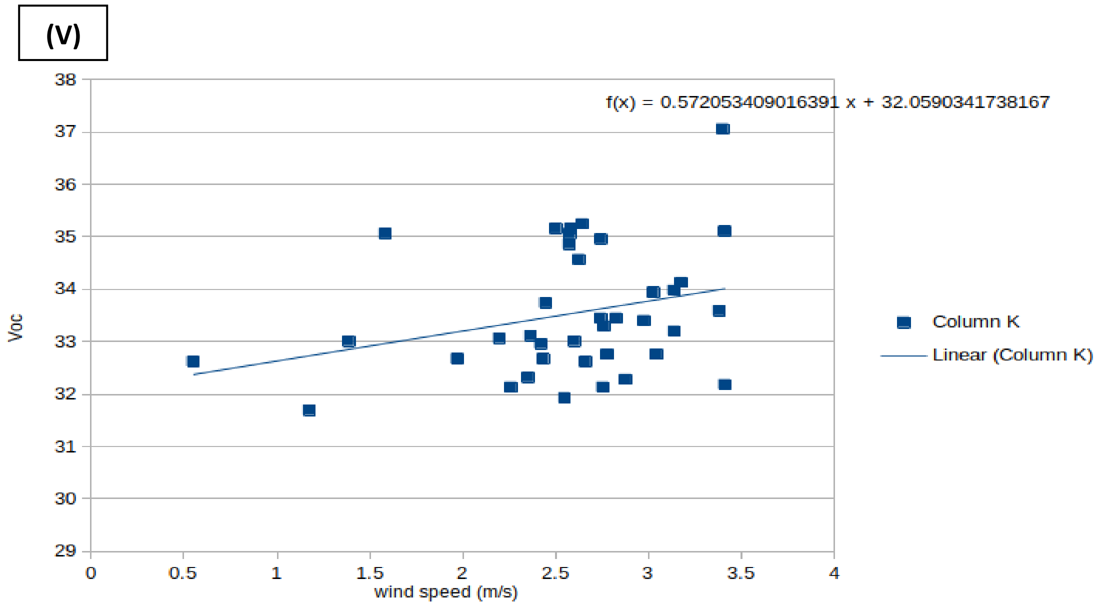


Figure III.27. The effect of the wind speed on the Voc.

Note 05: from the figure we can observe that the Voc has proportional relationship with the wind speed , we can say that the effect of the wind speed on the Voc is slight.

III.5.2. Unclean panel

III.5.2.1. The effect of the temperature of the panel

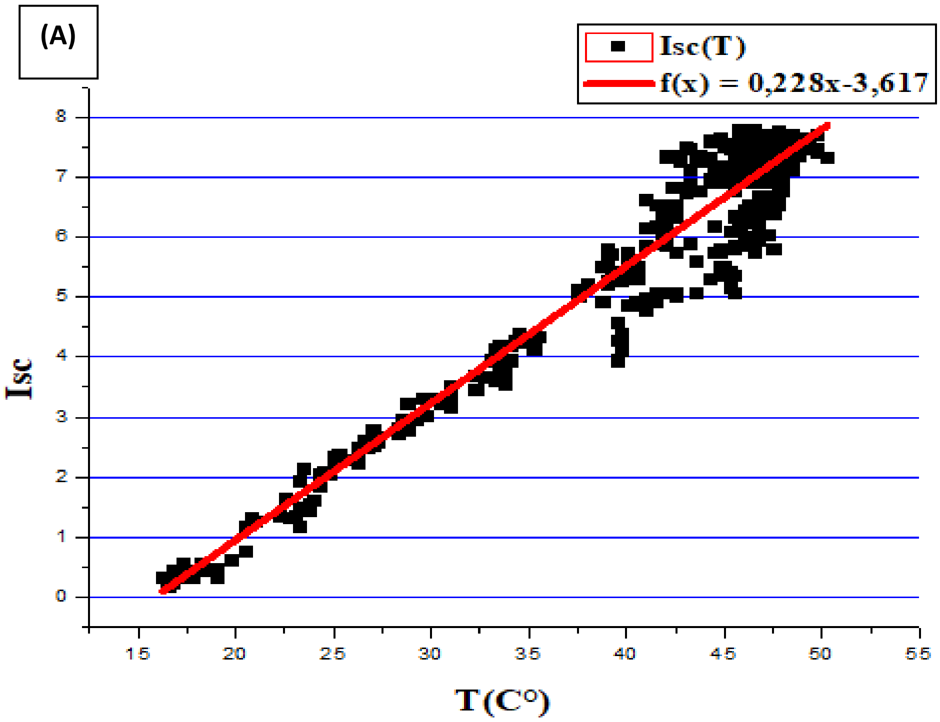


Figure III.28. Curve fitting graphic of the effect of the T(C°) on the Isc.

Note 06: we note from curve above that the Isc is clearly increase with the increasing of the temperature of the panel , when the Temperature reaches its maximum value about 47 C°, the short-circuit current also attains its maximum value as shown in its characterizes table (table III.1).

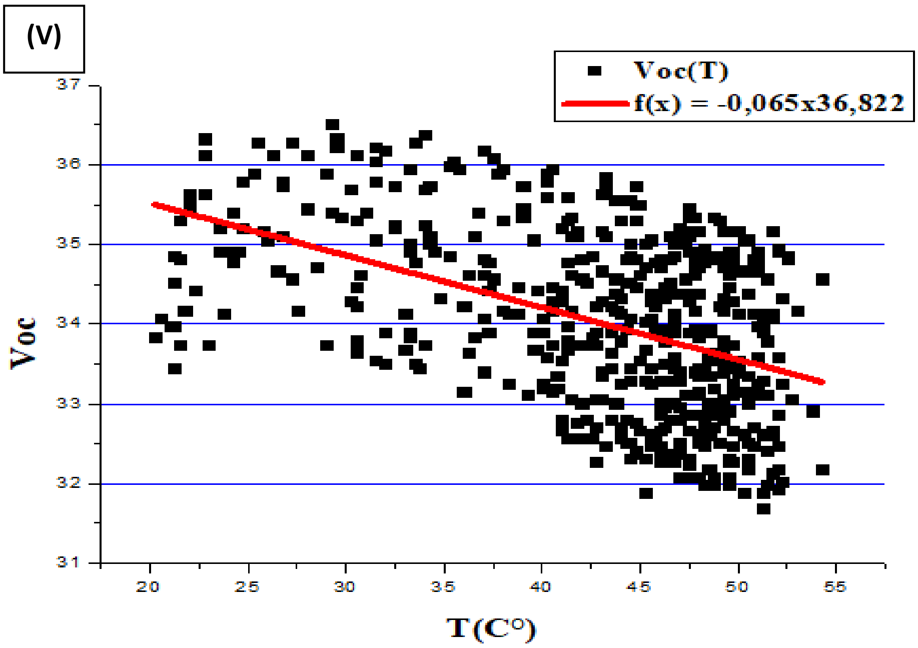


Figure III.29. Curve fitting graphic of the effect of the T(C°) on the Voc.

Note 07: in case of dusty panel ,we can observe that the relationship still the same with some variation in the values.

III.5.2.2. The effect of the solar irradiance

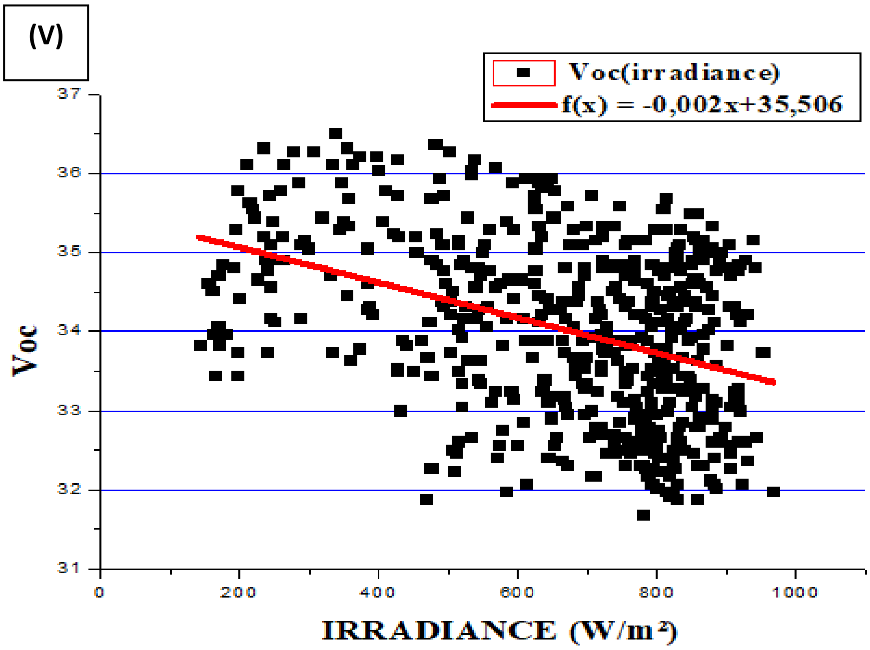


Figure III.30. Curve fitting graphic of the effect of the irradiance on the Isc.

Note 08: we can note that the measurements conducted in a case of unclean panel show almost a same results in comparison to a clean one. Thus, the dust in the panel doesn't affect much on Voc.

In this point, we meet tow situation concerning the irradiance solar that must take into consideration :

- **A sunny and stable day**

(A)

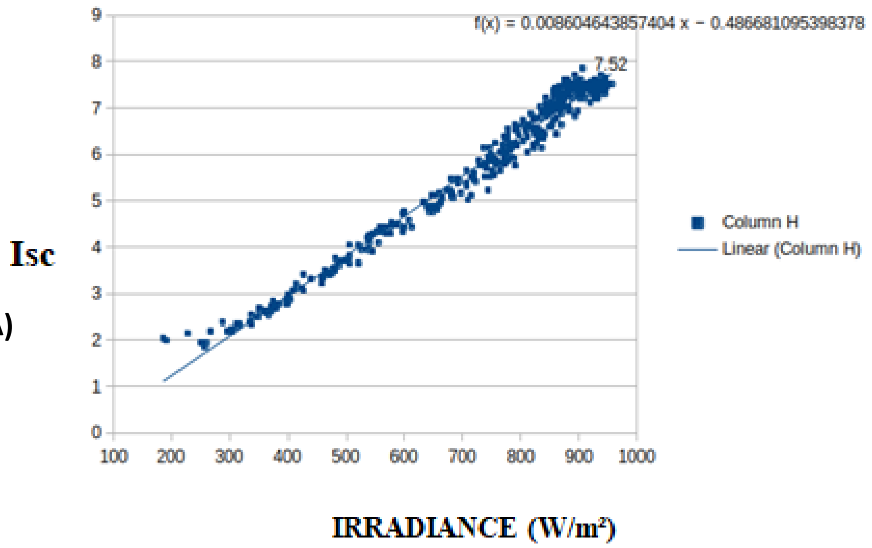


Figure III.31. Curve fitting graphic of the effect of the effect of the irradiance on the Isc.

Note 09: we observe that the irradiance has a direct effect to the Isc.

- **A cloudy day :**

(A)

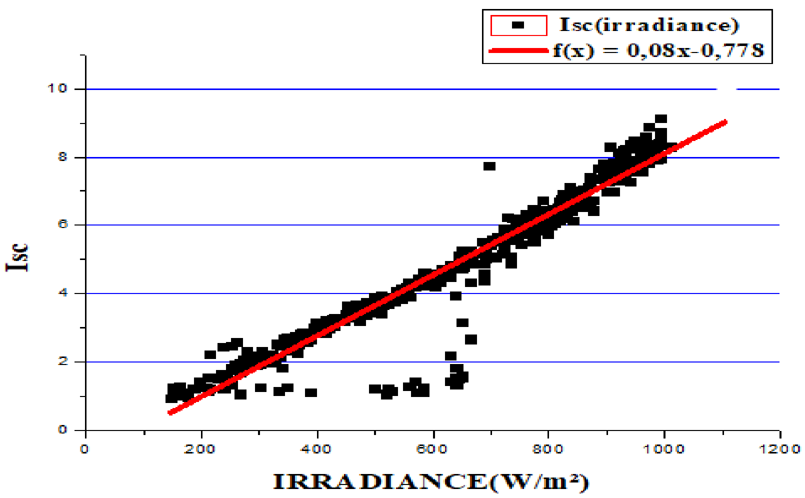


Figure III.32. Curve fitting graphic of the effect of the irradiance on the Isc.

Note 10: the figure shows a slight disturbance caused by the variation of the solar irradiance during the test (turbulent weather). The Isc reaches about 10 A as maximum value.

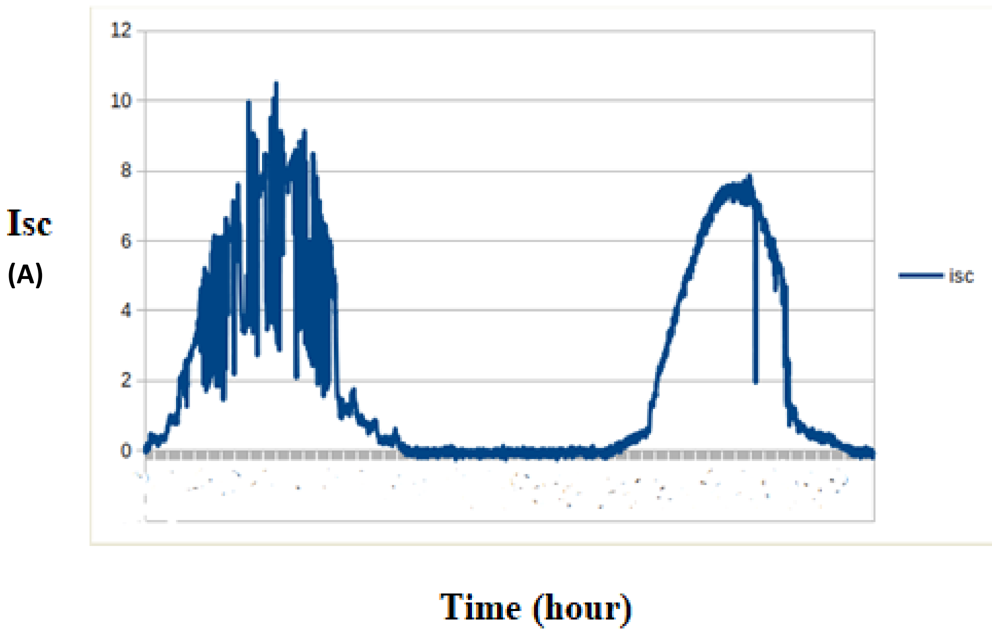


Figure III.33. The figure shows the performance of the Isc in two different days.

III.5.2.3. The effect of the wind speed

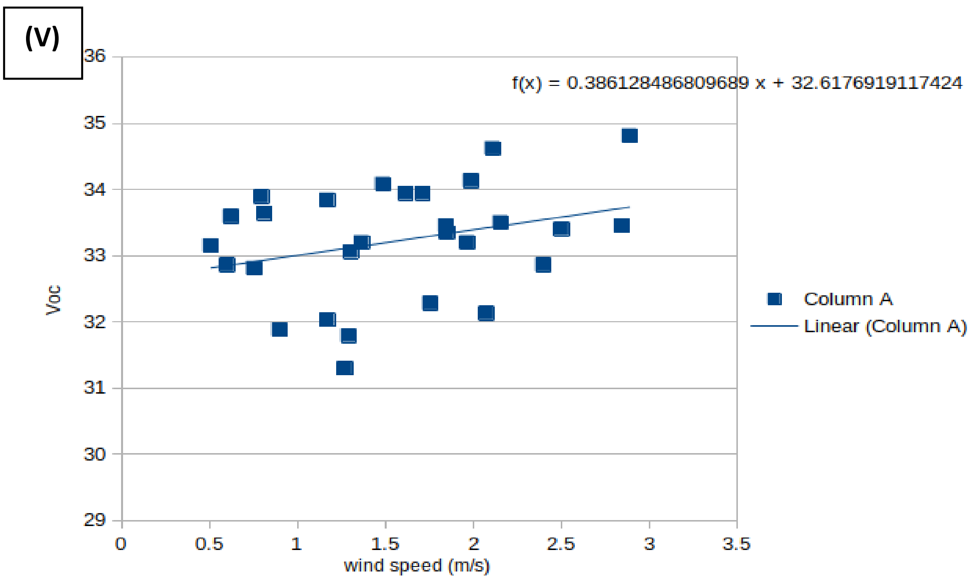


Figure III.35. The effect of the wind speed on the Voc.

Note 11: the increasing of the wind speed causing an augmentation in Voc value. Moreover, we observed that the affection of the wind speed is little less in a dusty panel.

II.5.3. The efficiency

The efficiency of the panel is calculated with the following equation :

$$\eta = \frac{P_{max}}{P_{in}} = \frac{FF \times V_{oc} \times I_{sc}}{P_{in}}$$

When

$$FF = \frac{P_{max}}{(I_{sc}V_{oc})} = \frac{210}{7.5 \times 37.4} = 0.74$$

The results are shown below:

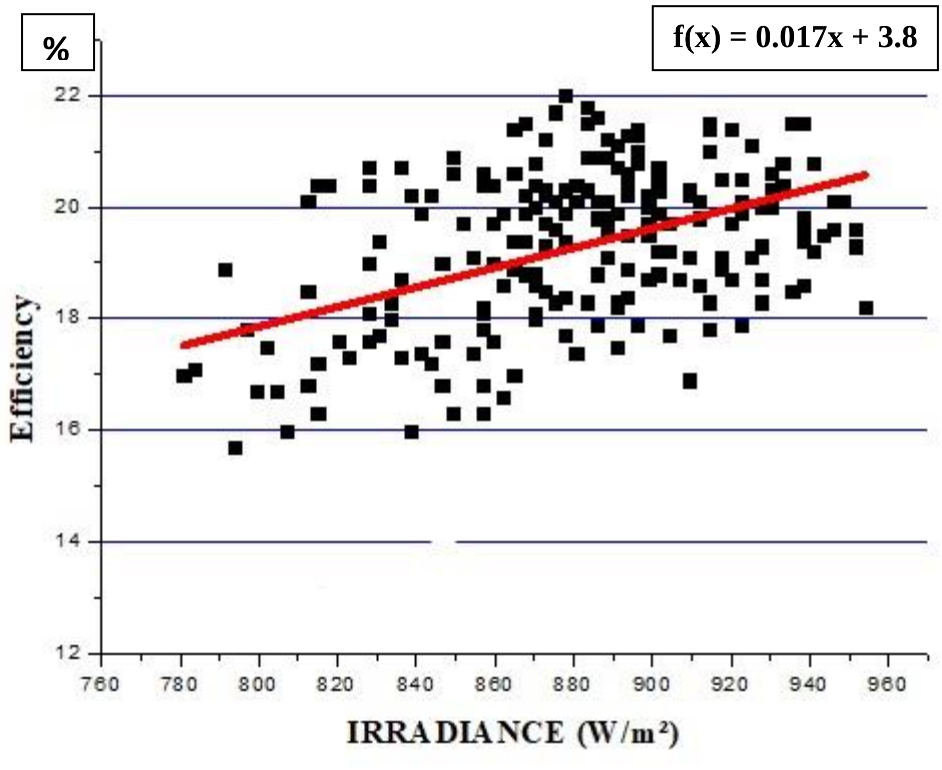


Figure .III.36. The curve of the variation of the efficiency with the irradiance.

Note 11: we observe that the value of the efficiency increases significantly.

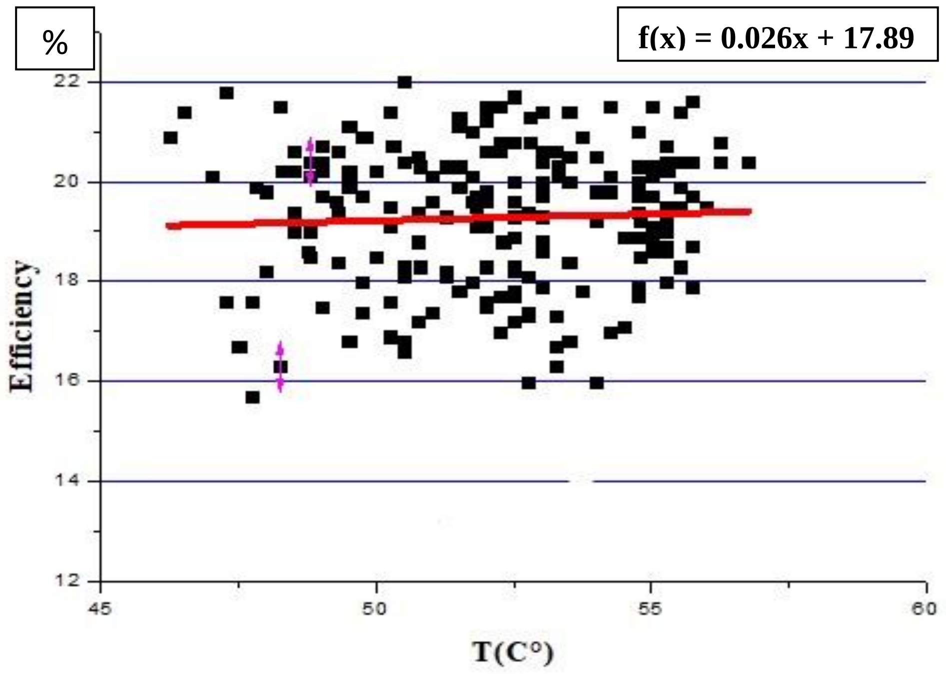


Figure.III.37. The curve of the variation of the efficiency with the temperature.

Note 12: we observe that the value of the efficiency increases slightly.

General

Conclusion

General Conclusion

The work developed in this thesis concerns the study of the effect of the weather parameters on the performance of photovoltaic modules based on mono-crystalline silicon, for this purpose we created a mini-weather station based on Arduino board . Based on the data measurements recorded by this mini weather station ,We were able to observe the electrical behavior of this mono-silicon module according to the weather changes during the days along the period of study.

Experiment results have recorded during the period of the study which covers the different cases of weather. According to experiment results, we concluded the following:

- The augmentation of the irradiance caused a significant increase in the Isc beside a decrease in Voc. Solar energy has an indirect effect on the open-circuit voltage, where the concentration of sunlight causes an increase in the temperature of the solar panel, and thus a decrease in the voltage value. This result agree with the equation of the open-cuircuit voltage (II.04).
- The temperature, particularly the PV temperature has an important effect on the performance of the panel.
- Despite of the high amount of the irradiance arrives at GHARDAIA site, The negative effect of the temperature can cause an important reducing in the production of the solar system. Thus, the solar system needs a cooling mechanism specially in hot areas in order to exploit this energy that the area blessed with.
- In the case of fluctuating solar radiation, the value of the short-circuit current reaches its highest value, which exceeds the experimental value mentioned in its data sheet Due to sudden solar peaks, which must take into consideration while sizing of the solar system .
- In fact , we observed that while the augmentation of the wind speed, the open-circuit voltage was slightly increased and therefore, the performance of the PV module improved..
- The wind can play a role in solar panel booster by reducing module temperature instead of the artificial cooling mechanism that will reduce the cost and provide a good performance of the module.

- The dust did not have a significant effect on the open circuit voltage. However, the short-circuit was slightly decreased with the of the dust. The dust disposition at the surface of the panel could cover the sun’s rays which caused a reducing of the amount of the solar radiation absorbed by the panel thus reducing the Isc of the module.
- Voc was found to decrease with increasing module surface temperature while Isc increased slightly with the rising temperature. on average, the efficiency increased with increase in irradiance. Consequently, the temperature has a slight effection on the efficiency of PV panel, while the augmentation of the solar irradiance caused an important increasing in the efficiency.
- In this research, we highlighted the importance of the weather and the region on the performance of the solar system. The Saharian regions is blessed with an abundance of solar energy and has the opportunity to utilize this abundance of natural energy effectively. In order to exploit this energy we have to find effective methods to reduce the temperature of the system, this generated thermal energy can be utilized for other purposes .

We keep this research open for future developments, we encountered some limitations during this research in the equipment and the short period of study. Therefore, we recommend increasing the duration of the experiment to investigate the effect of climate fluctuations on the performance of the solar system throughout the year.

Bibliography

[1] Z.Beddiaf, «solar pannels and photovoltaic materiel» , published by lentechopen, page 01, London 2018 .

[2] https://climate.nasa.gov, 25/02/2022.

[3] M.Missoum, magestre«contribution de l'énergie photovoltaïque dans la performance énergétique de l'habitat à haute qualité» , university of Hassiba Ben Bouali, 30-32, 2011.

https://www.sciencedirect.com/topics/earth-and-planetary-sciences/diffuse-radiation

[4] www.sciencedirect.com, 12/01/2022.

[5] B.M.Alluhaidah, mastre «most influential variables for solar radiation forecasting using artificial neural networks »,university of Dalhousie , page 14, Halifax Nova Scotia 2014.

[6] J.R.Matthew W.Clifford , S.Joshua , «Global Horizontal Irradiance Clear Sky

Models: Implementation and Analysis»,Sandia National Laboratoires, page 21, new mexico 2012.

[7] M. Ghassemi, Solar Ressource from « Solar Energy: Renewable Energy and the Environment », 40-41, 2009.

[8] F.Merad, magistre « conception d'un programme de calcul du rayonnement solaire , cas particulier de la région de Mostaganem»,university of Abdel Hamid Ibn Badis, 40-42 , Mostaganem 2013.

[9] A. Mefti, M. Y Bouroubi, H. Mimouni, «Evaluation du potentiel énergétique solaire, Bulletin des Energies Renouvelables», N°2, page 12, décembre 2002.

[10] www.sktm.dz, 03/02/2022.

[11] A.Luque, S.Hegedus, «Photovoltaic Science and Engineering», published by Wiley, page 31, 2003.

[12] R.Messenger, J.Ventre, «photovoltaic systems engineering»,publidhed by CRC press, 2^{sd}edition , page 335, 2004.

[13] M.Arum, «types of solar cells and its applications », International Journal of Scientific Development and Research, vol 4, 2019.

[14] M. Ghassemi, Solar Ressource from « Solar Energy: Renewable Energy and the Environment », page 137, 2009.

[15] S. Poignan, «L'ENERGIE PHOTOVOLTAIQUE», Rapport D'information, Assemblée Nationale Constitution du 4 Octobre 1958 Treizième Législature, 2009.

[16] A. Labouret, M. Viloz, « Energie solaire photovoltaïque ». Edition le Moniteur, Dunod, 2éme Edition, 2005.

[17] Fritts, «On a new form of selenium photocell. American Journal of Science», page 97, 1883.

[18] G. Gomard, «Cristaux photoniques pour le contrôle de l'absorption dans les cellules solaires photovoltaïques silicium ultramince», Thèse de Doctorat, Université de Lyon, 2011.

[19] M. Urien, «Cellules photovoltaïques organiques à base copolymères à blocs de type rigide-flexible», Thèse de Doctorat. Université de Bordeaux, page 71, 2008.

[20] M.A. Green, K. Emery, D.L. King, S. Igariand W. Warta, «Progress in Photovoltaics», page 49, 2005.

[21] P. Destruel, I. Seguy, Techniques de l'Ingénieur, 2004.

[22] https://lejournal.cnrs.fr/articles/quel-futur-pour-lenergie-solaire

[23] J. Zhao, A. Wang, P. Altermatt, S.R. Wenham, M.A. Green, «Photovoltaic Energy Conversion», Elsevier, 1477 – 1480, 1994.

[24] J. Zhao, A. Wang, P. Campbell, M.A. Green, "A 19.8% efficient honeycomb multicrystalline silicon solar cell with improved light trapping". Electron Devices, IEEE Transactions, Volume 46, 1978–1983, 1999.

[25] F. Abdo, Croissance de Couches Minces de Silicium par Epitaxie en Phase Liquide à basse Température pour Applications Photovoltaïques, page 128, 2007.

[26] J. Rao, S. Varlamov, Light trapping in thinfilm polycrystalline silicon solar cell using diffractive gratings, Energy Procedia33, 129–136, 2013.

[27] M. Zeman, O. Isabella, K. Jäger, R. Santbergen, S. Solntsev, M. Topic, J. Krc, Advanced light management approaches for thin-film silicon solar cells, in International Conference on Materials for Advanced Technologies 2011 Symposium , Energy Procedia15, 189–199, 2012.

[28] F. Oehler, Croissance et Caractérisation de Nanofils de Silicium. Ph.D. thesis, Claude Bernad Lyon 1 University, 12-13,2007.

[29] K.v. Maydell, K. Grunewald, M. Kellermann, O. Sergeev, P. Klement, N. Reininghaus, T. Kilper, Microcrystalline SiGe absorber layers in thin-film silicon

solar cells, E-MRS Spring Meeting Advanced Inorganic Materials and Structures for Photovoltaics, Strasbourg, France, 27–31, 2013.

[30] L.W. Veldhuizen, C.H.M. van derWerf, Y. Kuang, N.J. Bakker, S.J. Yun, R.E.I. Schropp, Optimization of hydrogenated amorphous silicon germanium thinfilms and solar cells deposited by hot wire chemical vapor deposition, Thin Solid Films595, 226–230, 2015.

[31] M. Oukachmih, Les cellules photovoltaïques à base de matériaux organiques Discotiques (Thèse de Doctorat à l'Université Paul Sabatier, Toulouse), 5-7, 2003.

[32] S. A. Beldjilali, Springer Proceedings in Energy, page 368, 2019.

[33] Sid Ahmed Beldjilali, Springer Proceedings in Energy, page 368, 2019.

[34] M. Dida, S. Boughali, D. Bechki, H. Bouguettaia, Experimental investigation of a passive cooling system for photovoltaic modules efficiency improvement in hot and arid regions, Energy Conversion and Management 243 (2021) 114328.

[35] M. Dida, S. Boughali, D. Bechki, H. Bouguettaia, Output power loss of crystalline silicon photovoltaic modules due to dust accumulation in Saharan environment. Renewable and Sustainable Energy Reviews 124 (2020) 109787.

[36] Astalaseven, Eskimon, Olyte, Arduino pour bien commencer en électronique et en programmation, Licence Créative Commons BY-NC-SA 2.0, page 09, 2012.

Annex

Program (01) with USB cable

```
#include <SoftwareSerial.h>

SoftwareSerial sw(2, 3);

#include <DHT.h>

#include <DHT_U.h>

#include <max6675.h>

#include"max6675.h"

#include "DHT.h"

#define VOLTAGE_PIN A0

#define CURRENT_PIN A1

//#define temt6000_Pin A2 // à eviter les pin 0 et 1, ce sont utilisé pour Serial

#define solarCell_pin A2

#define sw_pin 8

int thermoSO =5;

int thermoCS =6;

int thermoSCK =7;

int capteur = 4;

float vout = 0.0;

float vin = 0.0;

//float R1 = 1200.0;

//float R2 = 10000;

float volt_coef = 10;
```

```
/*float current_lx = 0;
float lx = 0;
float valeur_lx = 0;
float tension_lx = 0;*/
float courant_v = 0;
double AcsOffset = 2.49;
double Sensibl = 0.1;
double courant = 0;
double tension = 0;
DHT dht(4, DHT11);
MAX6675 thermocouple(thermoSCK, thermoCS, thermoSO);
void setup() {
  pinMode(sw_pin,OUTPUT);
  digitalWrite(sw_pin, HIGH);
  Serial.begin(115200);
  //Serial.println(("Humidity,Temperature ambiante, Temp PV, V, I, E")); // pas besoin
  dht.begin();
  Serial.println("Interfacting arduino with nodemcu");
  sw.begin(115200);
  delay(500);
}
void loop() {
  float humidity = dht.readHumidity();
```

```
float temperatureamb = dht.readTemperature();
float temperaturePV = thermocouple.readCelsius();
int valeur = 0;
float solarCell_value, solarCell_voltage; //Irradiance;
// Lecture Tension Circuit Ouvert
digitalWrite(sw_pin, HIGH);
delay(2000);
valeur = analogRead(VOLTAGE_PIN);
// Lecture Courant Court Circuit
digitalWrite(sw_pin, LOW);
delay(2000);
double ValeurLue = analogRead(CURRENT_PIN);
digitalWrite(sw_pin, HIGH);
//valeur_lx = analogRead (temt6000_Pin);
vout = (valeur*5)/1024.0;
vin = vout*volt_coef;
courant_v = (ValeurLue*5.0/1024);
courant = (courant_v-AcsOffset)/Sensibl;
/*tension_lx = (valeur_lx*5)/1024;
current_lx = tension_lx/10;  // courant en mA
lx = current_lx*2000;*/
solarCell_value = analogRead(solarCell_pin);
solarCell_voltage = solarCell_value * 5.0/1024;
```

```
Serial.println("Sending data to nodemcu"); // pas ici
Serial.print("{\"humidityValue\":");
Serial.print(humidity);//offset
Serial.print(",");
Serial.print("\"temperatureamValue\":");
Serial.print(temperatureamb);
Serial.print(",");
Serial.print("\"temperaturePVValue\":");
Serial.print(temperaturePV);
Serial.print(",");
Serial.print("\"tensionValue\":"); //Voc
Serial.print(vin);
Serial.print(",");
Serial.print("\"courantValue\":");  //Isc
Serial.print(courant);
 Serial.print(",");
Serial.print("\"Irradiance\":");
Serial.print(solarCell_voltage);
Serial.print("}");
Serial.println();
sw.print("{\"humidityValue\":");
sw.print(humidity);//offset
sw.print(",");
```

```
  sw.print("\"temperatureambValue\":");

  sw.print(temperatureamb);

  sw.print(",");

  sw.print("\"temperaturePVValue\":");

  sw.print(temperaturePV);

  sw.print(",");

  sw.print("\"tensionValue\":");

  sw.print(vin);

  sw.print(",");

  sw.print("\"courantValue\":");

  sw.print(courant);

  sw.print(",");

  sw.print("\"Irradiance\":");

  sw.print(solarCell_voltage);

  sw.print("}");

  sw.println();

delay(56000);

}
```

Program (02) without USB cable (by WiFi)

```
#include <WiFi.h>

#include <PubSubClient.h>

// Update these with values suitable for your network.

const char* ssid = "Bloc E";

const char* password = "";

const char* mqtt_server = "10.200.3.247";

#define mqtt_port 1883

#define MQTT_USER "uraer"

#define MQTT_PASSWORD "URAERGhardaia"

#define MQTT_SERIAL_PUBLISH_CH "PVChamp"

WiFiClient wifiClient;

PubSubClient client(wifiClient);

void setup_wifi() {

  delay(10);

  // We start by connecting to a WiFi network

  Serial.println();

  Serial.print("Connecting to ");

  Serial.println(ssid);

  WiFi.begin(ssid, password);

  while (WiFi.status() != WL_CONNECTED) {

    delay(500);

    Serial.print(".");
```

```
    }
    randomSeed(micros());
    Serial.println("");
    Serial.println("WiFi connected");
    Serial.println("IP address: ");
    Serial.println(WiFi.localIP());
}
void reconnect() {
  // Loop until we're reconnected
  while (!client.connected()) {
    Serial.print("Attempting MQTT connection...");
    client.publish("outTopic", "hello world");
    // Create a random client ID
    String clientId = "ESP32Client-";
    clientId += String(random(0xffff), HEX);
    // Attempt to connect
    if (client.connect(clientId.c_str(),MQTT_USER,MQTT_PASSWORD)) {
      Serial.println("connected");
      //Once connected, publish an announcement...
      client.publish(MQTT_SERIAL_PUBLISH_CH, "hello world");
    } else {
      Serial.print("failed, rc=");
      Serial.print(client.state());
```

```
      Serial.println(" try again in 5 seconds");
      // Wait 5 seconds before retrying
      delay(5000);
    }
  }
}
void setup() {
  Serial.begin(115200);
  Serial.setTimeout(500);// Set time out for
  Serial2.begin(115200);
  Serial2.setTimeout(500);// Set time out for
  setup_wifi();
  client.setServer(mqtt_server, mqtt_port);
  reconnect();
}
void publishSerialData(char *serialData){
  if (!client.connected()) {
    reconnect();
  }
  client.publish(MQTT_SERIAL_PUBLISH_CH, serialData);
}
void loop() {
   client.loop();
```

```
  if (Serial2.available() > 0) {
    char bfr[501];
    memset(bfr,0, 501);
    Serial2.readBytesUntil( '\n',bfr,500);
    Serial.println(bfr);
    publishSerialData(bfr);
  }
}
```

Abstract

This research focuses on studying influence of meteorological parameters on PV panel efficiency, as work has been done to establish a project for a mini-meteorological station. This kind of application is a hot topic, recent and open. These points have encouraged us to invest in this field, to improve and deepen our scientific knowledge by the realization of a prototype of meteorological station to study the influence of meteological parameters on the performance of photovoltaics panels based on Arduino card and NodeMCU Esp32 card.

Les mots clés: photovoltaic panel, arduino, météorological station, meteorological parameters.

Résumé

Cette recherche se concentre sur l'étude de l'influence des paramètres météorologiques sur l'efficacité des panneaux PV, car le travail a été réalisés pour établir un projet de mini-station météorologique. Ce genre d'application est un sujet d'actualité, récente et ouvert. Ces points nous ont encouragé de s'investir dans ce domaine, d'améliorer et approfondir nos connaissances scientifiques par la réalisation d'un prototype de station météorologique pour étude l'infuluence de paramètres météologiques sur le rendement de panneaux photovoltaiques à base d'une carte Arduino et NodeMCU Esp32.

Les mots clés: panneau photovoltaique, arduino, station météologique, paramétres météologiques.

ملخص

يركز هذا البحث على دراسة تأثير العوامل المناخية على كفاءة الألـــــواح الكهروضوئية ، حيث تم الـــــعمل على إنشاء مشروع لمحطة أرصاد جوية مصغرة. هذا النوع من التطبيقات موضوع رائج ، حديث ومفتوح. لقد شجــــــعتنا هذه النقاط على الاستثمار في هذا المجال ، لتحسين معرفتنا العلمية وتعميقها من خلال تحقيق نموذج أولي لمحطة الأرصــــــــاد الجوية لدراسة تأثيرالعوامل المناخية على أداء الالواح الكهروضوئية بناءً على بطاقة ARDUINO و بطــــاقة 32ESP NodeeMCU.

الكلمات المفتاحية : اللوح الشمسي , اردوينو , محطة ارصاد جوية , العوامل المناخية.