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## Université Amar Thelidji- Laghouat

**FACULTE : Science et Technologie**

**DEPARTEMENT : Electronique**

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**FILIERE : Energies renouvelables / Micro-electroniques**

**OPTION : Energies renouvelables en électrotechnique.**

## *Thème*

# Forecast of photovoltaic production using NN for the realization of an autonomous PV system within a tertiary building: Application to the electronics department

**Jury de soutenance :**

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# *Thanking*

*We are grateful to ALLAH for all the blessings he has given us. We thank Mme MESRI MERAD Mokhtaria, Miss VILBOIS Leila as well for their guidance and feedback that made this work as impeccable as possible, their confidence testified, without forgetting their human qualities and patience*

*Our thanks also go to those who have honored us and accepted to judge the work, the President of jury and the examiner. We thank all the teachers of the electrical engineering department for their contributions to our training.*

*Furthermore, we would like to express our thanks to all those who participated directly or indirectly in carrying out this work.*

# *Dedication*

*This dissertation is dedicated to Our Parents, who instilled in us the virtues of preserving and commitment and relentlessly encouraged us to strive for excellence.*

*Our Brothers and Sisters.*

*Our relatives*

*All our friends.*

# Summary

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# Abbreviations

**AC**: Alternative Current.

**AC-AC**: Inverter alternative /alternative.

**AC-DC**: Inverter alternative /direct.

**CV**: Constant Voltage.

**CS**: Static Converter.

**DC**: Direct Current.

**DC-AC**: Direct/ Alternatif converter.

**DC-DC**: Inverter direct/direct.

**DP**: Depth of discharge

**GPV**: Photovoltaic generator

**PMW**: Pulse-width modulation

**MPPT**: Maximum Power Point Tracking

**NN**: Neural Network

**SNG**: Sonalgaz.

**PV**: Photovoltaic

**PPM**: The maximum power point.

# List of Symbols

**A**: The cross-sectional area of the diode

**Aut**: Number of days of battery autonomy

**AM**: Air mass

**BC**: Band of conduction.

**Bj**: Daily consumption.

**BV**: The band of valence.

**C**: The capacity.

**D**: The diode.

**G**: Irradiation.

ω: Hour angle

**Hz**: Hertz.

$I0$: Saturation current.

**Iph**: Photo-current.

**Is**:  Output current.

**Iopt**: Optimal current.

**Icc**: Short circuit current.

**NA**: The acceptor concentration in the p-region

**ND**: The donor concentration in the n-region

**Nm**: Number of modules.

**Nms**: Number of series modules.

**Nmp**: Number of parallel modules.

**ni**: Intrinsic carrier concentration

**kB**: Boltzmann's constant (kB)

**ŋb**: Battery efficiency.

**Pm**: Maximum power.

**Pm**: Power in one module.

**Pout**: Output power

**Pin**: Input power

**Pc**: Peak power.

**PLoss**: Loss power.

**q**: The magnitude of the electronic charge

**Vs**: Output voltage.

**Rs**: Series resistance.

**Rsh**: Shunt resistance.

**Ropt**: Optimal resistance.

**Vco**: Emptiness tension

**Vopt**: Optimal voltage.

**V:** The Volt.

**Vch**: Nominal voltage of charge.

**Vm**: Nominal voltage of one module.

**WC:** Watt-peak.

**Wh/J:** The watt hour per day.

α: Altitude Angle

**λ**: Coefficient of temperature

δ: Declination

ϕ: Latitude

**θZ**:Zenith angle

**γS:**Solar azimuth angle

γ: Surface azimuth angle

## Abstract

The installation of a solar system meets a specific need on a given site. It should only be considered after a study of photovoltaic (PV) system production in order to have a fairly precise idea of the return on investment of the installation.

This study aimed to forecast PV Production using Neural network (NN) for the realization of a stand-alone PV installation within a tertiary building, Department of electronics at Amar Telidji, Laghouat .

We set out to forecast PV production in the short and long terms using 10 months (hourly steps) weather data. MATLAB programs were needed to treat the data for training. The first step was the calculation of the energy needs of the location. Then we did the sizing with two methods: by calculation and with the PVsys (a software that offers a detailed sizing reports and simulation) using PVgis ( offers sunshine maps irradiation in kWh / m² ).Next , We enriched our work with an economical features. Finally, We used NN to forecast PV production.

The results obtained show that NN are a very effective means for PV forecasting, in the short and even in the long term with a fairly low error rate.

**Key words:** Forecasting, Neural Network, Stand-alone PV system, PVsys, PVgis., Photovoltaic production.

## Résumé

L'installation d'un système solaire répondant à un besoin précis sur un site donné. Elle ne doit être envisagée qu'après une étude de la production PV afin d'avoir une idée assez précise du retour sur investissement de l'installation.

Cette étude visait à prévoir la production photovoltaïque à l'aide du réseau neuronal (RN) pour la réalisation d'une installation photovoltaïque autonome dans un bâtiment tertiaire, Département d'électronique à Amar Telidji, Laghouat.

Nous avons décidé de prévoir la production photovoltaïque à court et à long terme en utilisant des données météorologiques de 10 mois (pas horaires), des programmes MATLAB étaient nécessaires pour préparer les données pour la formation. La première étape a été le calcul des besoins énergétiques du site. Ensuite, nous avons fait le dimensionnement avec deux méthodes : par calcul et avec le PVsys (c'est un logiciel qui propose un rapport de dimensionnement détaillé et une simulation) en utilisant PVgis (il propose l'irradiation des cartes d'ensoleillement en kWh / m²). Ensuite, nous avons enrichi notre travail avec une caractéristiques économiques. Enfin, nous avons utilisé NN pour prévoir la production photovoltaïque.

Les résultats obtenus montrent que les réseaux neurones sont un moyen très efficace pour la prévision PV, à court et même à long terme avec un taux d'erreur assez faible.

**Mots clés :** Réseau neurone, Production photovoltaïque, PVsys, PVgis, Prévision, Système PV autonome

**ملخص**

يلبي تركيب النظام الشمسي حاجة معينة في موقع معين. يجب أن يؤخذ في الاعتبار فقط بعد دراسة إنتاج النظام الكهروضوئي (PV) من أجل الحصول على فكرة دقيقة إلى حد ما عن عائد استثمار التثبيت.

هدفت هذه الدراسة إلى التنبؤ بالإنتاج الكهروضوئي باستخدام الشبكة العصبية (NN) لتحقيق التركيب الكهروضوئي المستقل داخل مبنى جامعي ، قسم الإلكترونيات في عمار تليجي، الأغواط.

انطلقنا للتنبؤ بالإنتاج الكهروضوئي على المدى القصير والطويل باستخدام بيانات الطقس لمدة 10 أشهر (خطوات كل ساعة)، كانت هناك حاجة إلى برامج MATLAB لإعداد البيانات للتدريب. كانت الخطوة الأولى هي حساب احتياجات الطاقة من الموقع. ثم قمنا بإجراء التحجيم بطريقتين: عن طريق الحساب ومع PVsys (وهو برنامج يقدم تقارير تحجيم تفصيلية ومحاكاة) بالاستعانة ب PVgis (يوفر إشعاع خرائط أشعة الشمس بـ (kWh / m²). بعد ذلك ، قمنا بإثراء عملنا مع ميزات اقتصادية. أخيرًا ، استخدمنا NN للتنبؤ بالإنتاج الكهروضوئي.

تظهر النتائج التي تم الحصول عليها أن الشبكات العصبية هي وسيلة فعالة جدًا للتنبؤ الكهروضوئي ، على المدى القصير وحتى على المدى الطويل مع معدل خطأ منخفض إلى حد ما.

**الكلمات المفتاحية:** الإنتاج الكهروضوئي،التنبؤ ، الشبكة العصبية ، النظام الكهروضوئي المستقل ، PVsys ، PVgis.

# General Introduction

# General Introduction

Solar energy supports continuity of energy supply, which is a key strategic issue for many countries to guarantee their industry growth.

They contribute to the use of inexhaustible energy sources, to the preservation of power generation and, to a more environment friendly production of energy.

However, the need for precise predictions of how much power will be fed into the grid at any given moment is becoming increasingly important and, due to the intermittent nature of solar energy, optimizing solar systems is based on criteria of sizing and power maximization generated to have a good yield and the dependency of photovoltaic (PV) energy on the climatic conditions, forecasting and scheduling are essential for stable and efficient grid.

Many forecasting methods have been proposed for the energy prediction where Artificial Neural Networks (ANN) are one of them.

Neural network (NN) have been widely touted as solving many forecasting and decision modeling problems.

In this dissertation, we present methods to do the estimation and forecast of the solar power using ANN. Our application is divided between the sizing of PV system and the PV production forecast. It is applied on the department of electronic, University of Laghouat, Algeria.

By going through different steps from collecting the data of this region, the electricity needs of our department, the surface of our department and the economically optimized and available materials of the PV system as well as the right algorithm for NN method.

The methodology carried out in this modest dissertation is structured around four main chapters:

The first chapter is devoted to general information about the solar resources. Like the sun and its components, we detailed the sun-earth angles and the electromagnetic radiation received on earth.

The second chapter illustrates the photovoltaic cells and its characteristics, Definition of conversion system besides to PV system utility and safety and energy storage.

In the third chapter, we are interested in sizing and economics of the PV installation using first calculation and then using PVsyst 7.0 ( A software package for the study, sizing and data analysis of complete PV systems)with the help of PVgis (offers sunshine maps and precise high definition temperature maps for most countries in the world) we ended the chapter by the cost estimation for the PV system.

In the last chapter we represent the results of forecasting using neural network for long and short terms. After treating the weather data with some MATLAB programs for training.  Also, we cited the effects of each weather data on PV production.

Finally, we end our work with a general conclusion of the outlook.

# CHAPTER I

## SOLAR RESOURCES

## I.1 Introduction

Solar electricity generation represents a clean alternative to electricity from fossil fuels, with no pollution, no risks of electricity price spikes, and no threats to our public health. Solar energy will play a prominent role in the generation of electrical energy. The sun's energy contains about 1,300 watts, just 18 days of sunshine on Earth contains the same amount of energy as is stored in all of the planet's reserves of coal, oil, and natural gas. All measures described in this chapter mainly aim to shed light to the solar resources, including energy irradiated from the Sun, the geometrical relationship between the Sun and the Earth, and orientation of energy receivers, as well as the importance of acquiring reliable solar information for engineering design, operation, and management of solar technologies.

## I.2 Solar radiation

The solar radiation that reaches the surface of the earth without being diffused is called direct solar radiation. It is measured by instrument named as pyrheliometer.

As sun light passes through the atmosphere, some part of it is absorbed, scattered and reflected by air molecule, water vapors, clouds, dust and pollutants. This is called diffuse solar radiation. The diffuse solar radiation does not have unique path.

The sum of the direct and diffuse solar radiations is called total radiation or global solar radiation. Pyranometer is used for measuring the total radiation.[1]

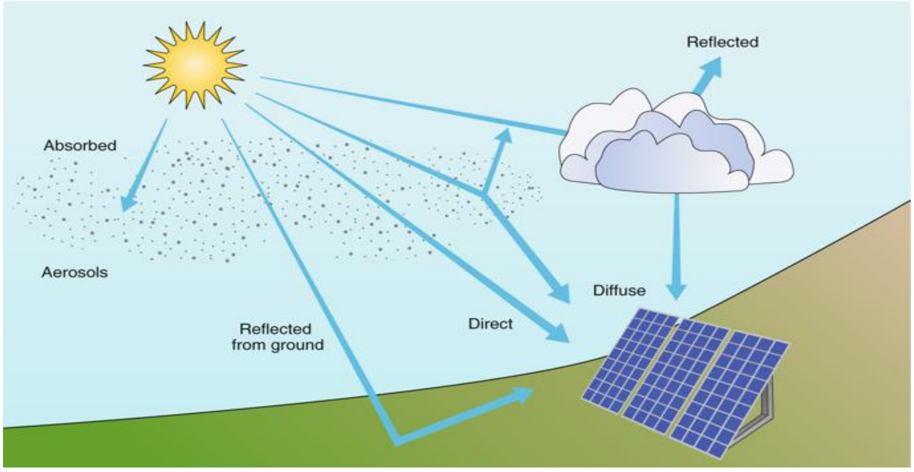



**Figure I. 1:**Solar radiation

## I.3 Sun – Earth angles

### I.3.1 Latitude(ϕ)

The latitude of a location is the angle made by the radial line joining the location to the centre of the earth with the projection of the line on the equatorial plane [1]:

$-90° \leq \phi \leq +90°$

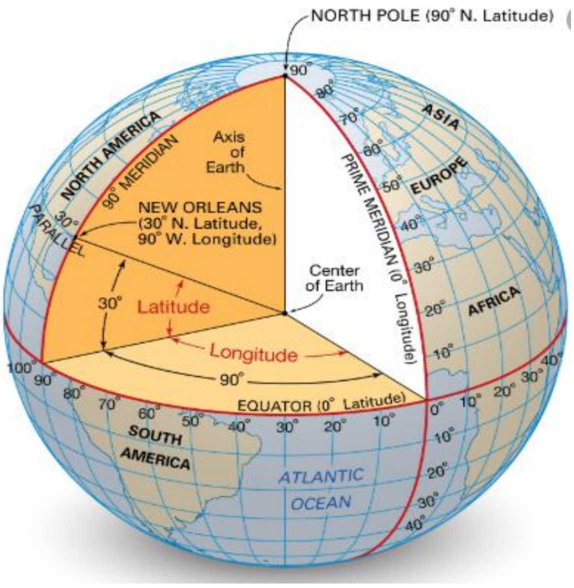



**Figure I. 2 :**The latitude of a location

### I.3 .2 Declination (δ)

The declination angle is the angle made by the line joining the centre of the sun and the earth with its projection on equatorial plane.

The declination angle varies from a maximum value of +23.45° on June 21 to a minimum value of -23.45 on December 21.

$$\delta = 23.45 \ \sin(\frac{360}{365}(nj + 284)) \quad (I.1)$$

(Where, n- number of days)δ< 0 – for winters in northern hemisphere δ> 0 – tor summer in northern hemisphere

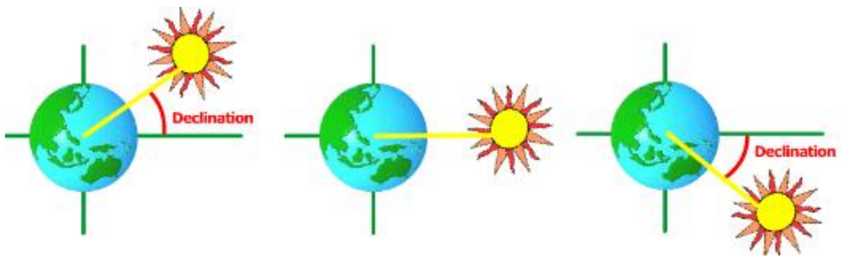



**Figure I.3 :**The declination angle

## I.3 .3 Hour angle($\omega$)

It is the angle through which the earth must be rotated to bring the meridian of the plane directly under the sun. Because it is 24 hours for 360° of rotation, so each one hour correspond to[1] :

$$15° \quad \omega = 15\,(ST - 12) \qquad (I.2)$$

Where, **ST**=solar time

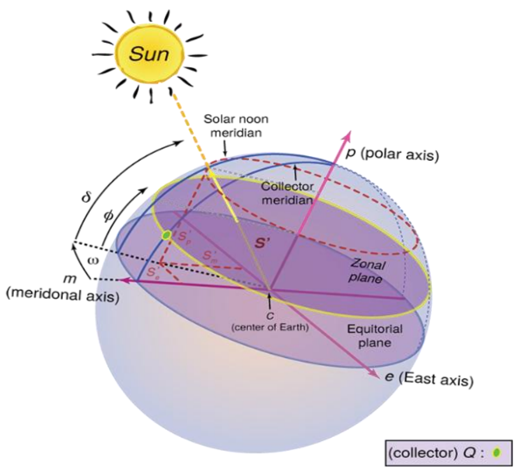



**Figure I.4 :** Hour angle

## I.3 .4 Altitude Angle ($\alpha$) and Zenith angle($\theta_Z$)

Altitude angle is the angle between the incident sun ray and the projection of sun's rays on the horizontal plane.

Zenith angle is the complementary angle of sun's altitude angle$\theta_Z = 90° - \alpha$ , zenith angle is the angle between the incident sun ray and the perpendicular line to the horizontal plane[2].

$$\cos \theta_Z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega \quad (I.3)$$

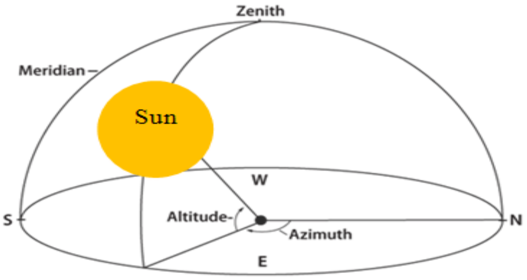



**Figure I.5 :**Altitude and zenith angles

## I.3 .5 Surface azimuth angle ($\gamma$) and solar azimuth angle($\gamma_S$)

Consider a surface with slope “β”. Draw a outer normal to this surface and take a projection of normal on horizontal plane.

Surface azimuth angle is the angle between line due south and the projection of normal to the surface on horizontal plane.

Solar azimuth angle is the angle between line due south and the projection of sun rays on horizontal plane[2].

$$\cos \gamma_S = \cos\theta z . \sin \phi - \sin \delta \sin \theta z . \cos \phi \quad (I.4)$$

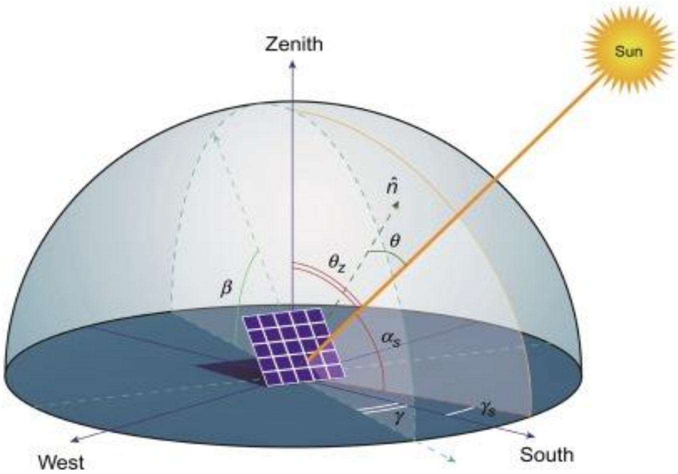



**Figure I.6:** surface and solar azimuth angles

## I.4 Position of the Sun with Respect to a Horizontal Surface

The angle that sunlight strikes a surface affects how much solar energy is transferred to that surface. The solar radiation striking a horizontal surface is affected by the angle of the sun (the solar angle) which is in turn influenced by latitude, season and time of day. When the sun is lower in the sky, its rays strike a horizontal surface with less concentration, lowering the portion of the insolation in the air that will be transferred to a horizontal surface. If the sun is directly overhead, the solar elevation angle of the sun, SEA above the horizon is 90° and the sunlight hits the surface directly. This is the best possible energy-transferring case. At any lesser angle, the sun hits the surface less directly and less solar energy is transferred to the surface.

## I.5 Position of the Sun with Respect to a Tilted Surface

The tilt angle has a major impact on the solar radiation incident on a surface. For a fixed tilt angle, the maximum power over the course of a year is obtained when the tilt angle is equal to the latitude of the location. However, steeper tilt angles are optimized for large winter loads, while lower title angles use a greater fraction of light in the summer.

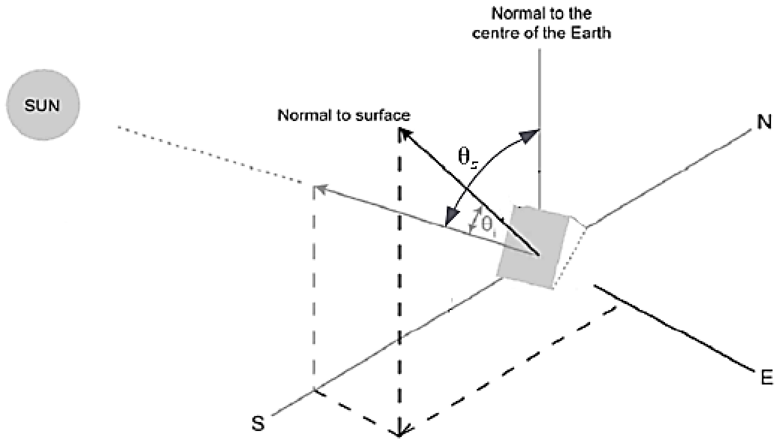



**Figure I.7:** Sun ray angle with a tilted surface

## I.7 Electromagnetic Radiation

The solar radiation from the sun's surface is relatively constant throughout the year, often indicated as the solar constant (1367 W/m2). But as it reaches the earth's surface, it has been affected by the earth's atmosphere due to absorption and scattering. On clear, cloud-freedays, the maximum radiation reaching the earth's surface occurs as the sun is directly overhead, because of shorter path length through the atmosphere. The figure illustrates the spectrum of solar radiation, where the black line represents the idealized radiation from the sun which can be seen as a blackbody with temperature at approximately 5778 K, the yellow area represents the radiation outside the atmosphere and the red area represents the radiation at sea level[3].

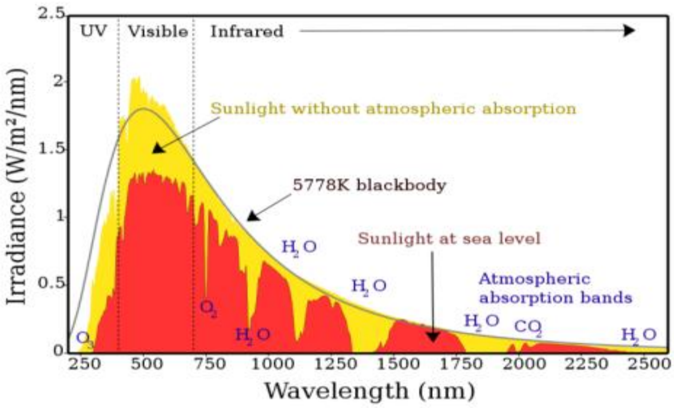



**Figure I. 8:** Extraterrestrial Solar Radiation

The red curve is varying due to absorption bands occurring in the atmosphere from various gases. Due to scattering of radiation in the atmosphere, the solar radiation reaching the earth's surface is not constant. This scattering is occurring due to molecules, aerosols and dust particles and scattered light is known as diffuse radiation. The path length the sunlight travels through the atmosphere to reach the earth's surface is referred to as the air mass. It varies throughout the day, depending on the location of the sun relative to the earth. Equation (I.4) can be used to calculate the air mass based on the assumption of a homogenous, non-refractive atmosphere.

$$AM = \frac{1}{\cos(\theta z)} \quad (I.4)$$

## I.8 Extraterrestrial Solar Radiation:

Some variations in the extraterrestrial radiation above the atmosphere are not due to solar changes but rather to the Earth–Sun distance throughout the year as stated in

$$I_0 = I_{SC}\left(1 + 0.033cos\frac{360n}{365}\right) \quad (I.5)$$

Where $I_o$ is the extraterrestrial radiation, $I_{SC}$ is the solar constant, and $n$ is the day of the year. The units are Joules per second per square meter (J/s-m2).Also, of interest is the amount of beam energy received by a horizontal surface outside the atmosphere at any time. This value corresponds to the maximum possible if there were no atmosphere:

$$H_0 = I_{SC}\left(1 + 0.033cos\frac{360n}{365}\right)sin\alpha_S \quad (I.6)$$

## I.9 Terrestrial Solar Radiation

In space, solar radiation is practically constant; on Earth, it varies with the day of the year, time of the day, the latitude, and the state of the atmosphere. In solar engineering, the surfaces that capturer redirect solar radiation are known as solar collectors. The amount of solar radiation striking solar collectors depends also on the position of the surface and on the local landscape. Solar radiation can be converted into useful forms of energy such as heat and electricity using a variety of thermal and photovoltaic (PV) technologies, respectively. The thermal systems are used to generate heat for hot water, cooking, heating, drying, melting, and steam engines, among Photovoltaic are used to generate electricity for grid-tied or stand-alone off-grid systems. The total solar radiation incident on either a horizontal ($H$) or tilted plane ($I$) consists of three components: beam, diffuse, and reflected radiation. As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by air molecules, water vapor, clouds, dust [3].

## I.10 Measurement of Terrestrial Solar Radiation

Solar radiation data are required for resource assessment, model development, system design, and collector testing among other activities in solar engineering and research. The basic solar radiation measurements are the beam, diffuse, and global radiation components. The expense of radiometric stations and high maintenance make impossible the spatially continuous mapping of solar radiation. Due to the scarcity of real data, the use of representative sites where irradiance data are measured or modeled has been a common practice for engineering calculations.

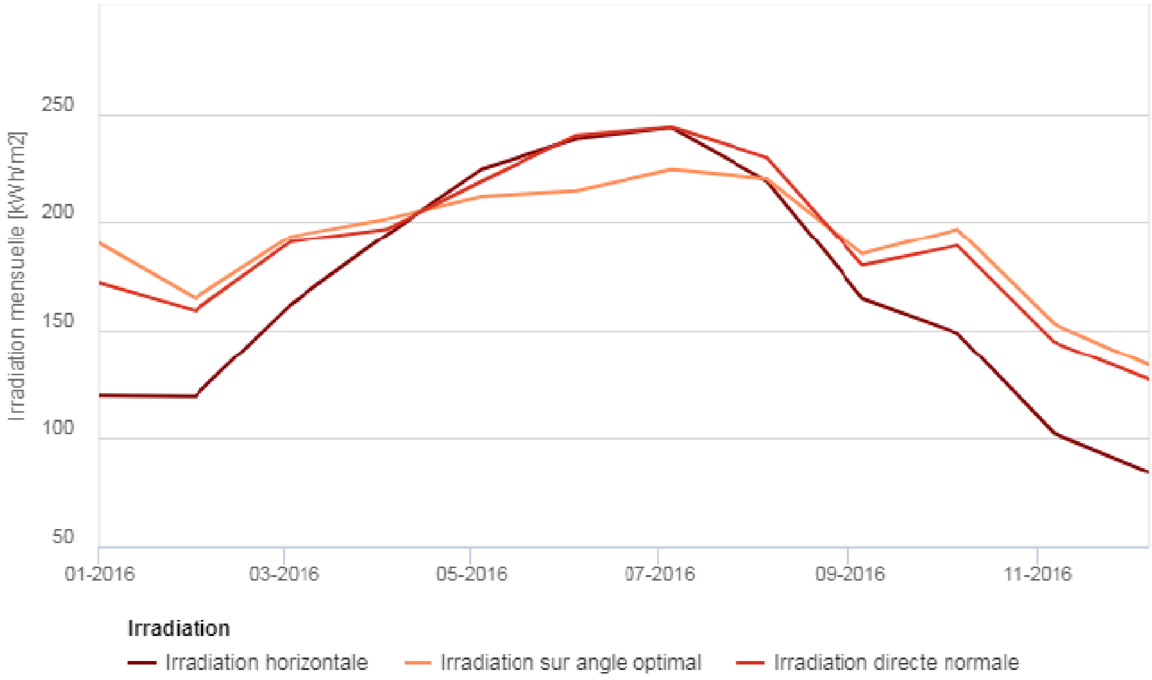



**Figure** I.**8:** Monthly irradiation of laghouat for 2016 from PVGIS [4]

Thermopile pyranometer is a sensor based on thermopiles designed to measure the broad band of the solar radiation flux density from a 180° field of view angle. It usually measures 300 to 2800 nm with a largely flat spectral sensitivity.

**Figure I.9:** Thermopile pyranometer

## I.12 Conclusion

In this chapter we presented important notions on the solar deposit, like the astronomical and meteorological factors and their definitions, which are taken into account before any expose's exploitation of solar energy. Then, we presented the different types of radiation (direct, diffuse, and global), Also the mathematical expressions and calculation methods of each radiation according to the variation of inclination and orientation. In the next chapter we will present the physics of a pv cell and its relation with the meteorological factors besides the PV conversion system

# CHAPTER II

## THE PHOTOVOLTAIC SYSTEM

## II.1 Introduction

Electricity can be produced from sunlight through a process called the PV effect, where “photo «refers to light and “voltaic” to voltage. The term describes a process that produces direct electrical current from the radiant energy of the Sun. The PV effect can take place in solid, liquid, or gaseous material; however, it is in solids, especially semiconductor materials, in this chapter we abstract what a PV cell made of and all its characteristic and how can we turn light into power using the PV conversion system.

## II.2 Crystal Structure

Silicon and many semiconductor materials on a microscopic scale are crystalline structures arranged in an orderly fashion from the atoms from which they are composed. The smallest subsection of this orderly arrangement, whereby the entire structure may be reproduced without voids or overlaps, is called the primitive cell. Often the primitive cells have awkward shapes, so we use a simpler unit cell, typically defined by three orthogonal axes such as x, y, and z, with unit vectors located along each axis. The length of the edge of the unit cell is called the lattice constant. The orientation of planes within the crystal can be expressed by using Miller indices, as shown in Figure above [5]:

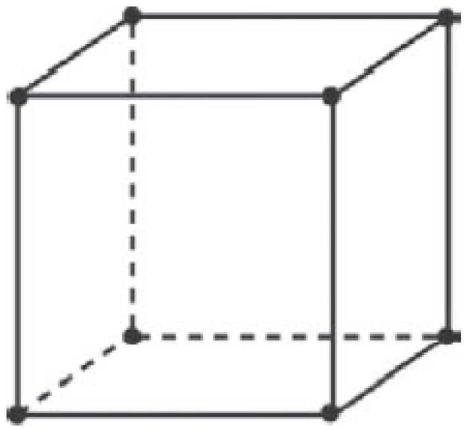


**Figure 1:** Simple cube crystallattice

## II.3 PN junction

A PN junction is the metallurgical boundary between an n-type region and a p-type region in a semiconductor. The space charge region is formed around the metallurgical junction while the remaining parts of the diode remain neutral under no bias. This layer is formed because of immigration of holes from the p-side to the n-side and the electrons from the n-side to the p-side around the metallurgical junction. They leave behind them un-neutralized acceptor and donor ions. The electric field associated with the charges establishes opposing forces for further migration of holes and electrons, leading to equilibrium such that no net current of either type exists. The width of this field region under no bias is of the order of few tenths of a micrometer depending on the doping concentrations $N_A$ and $N_{D.}$

## II.4 Solar Cell Equations

In order to derive the ideal current-voltage characteristics of a p–n junction diode when illuminated by light, mathematical results from the ideal diode equation are combined with the illuminated characteristics of the solar cell. The ideal diode law is expressed as the following equation [5]:

$$I = I_0(\exp\left(\frac{qV}{K_B T}\right) - 1) \qquad \text{(II.1)}$$

Where *Io,* the saturation current density, is given by:

$$\boldsymbol{I_0} = \boldsymbol{A}\left(\frac{qD_e n_i^2}{L_e N_A} + \frac{qD_h n_i^2}{L_h N_D}\right) \qquad \text{(II.2)}$$

where

*NA* = the acceptor concentration in the p-region

*ND* = the donor concentration in the n-region

*ni* = intrinsic carrier concentration

*Dh* = diffusion coefficient of the holes

*De* = diffusion coefficient of the electrons

*Le* = diffusion length (how far into the material before electrons diffuse) of the electrons

*Lh* = diffusion length of the holes

*A* = the cross-sectional area of the diode

q = the magnitude of the electronic charge (same as in Equation 5.2)

kB = Boltzmann's constant (kB) (can also simply use "k")

The assumption is made for solar cells that the generation rate of electron–hole pairs by the light (*gop*) is constant throughout the device. The typical diode equations for determining the excess minority carrier concentrations include an additional term relating *gop*as follows:

$$\frac{d^2(\Delta p)}{dX^2} = \frac{\Delta p}{L_h^2} = \frac{g_{op}}{D_h} \quad \text{(II.3)}$$

## II.5 Characterization

Typically, three parameters are used to characterize solar cell output: short circuit current (*Isc*), open circuit voltage (*Voc*), and fill factor (*FF*). In order to find open circuit voltage, *I* in previous Equation is set to 0 (meaning short circuit current) to give the ideal value as follows:

$$Voc = \frac{\text{Kb T}}{\text{q}} \ln(\frac{\text{IL}}{\text{I0}} + 1) \quad \text{(II.4)}$$

This equation illustrates the interdependence of *Isc* and *Voc.* The fill factor uses *Isc* and *Voc* as well as maximum power points of both current and voltage (*Imp* and *Vmp*) in the following expression:

$$FF = \frac{\text{Vmp Imp}}{\text{Voc Isc}} \quad \text{(II.5)}$$

Where υ*oc*is a normalized voltage defined as:

$$Voc = \frac{\text{Voc}}{(\text{KbT/q})} \quad \text{(II.6)}$$

The energy conversion efficiency for solar cells is calculated using the following equation

$$\eta = \frac{\text{Vmp Imp FF}}{\text{Pm}} \quad \text{(II.7)}$$

Where *Pin* is the total power in the light incident on the cell. This equation demonstrates the dependency of efficiency calculations on the fill factor. Fill factor is defined by dividing the square area on the graph in the following Figure by a larger outer square area formed by the intersection of *Isc* and *Voc*. Note from the figure that results from illumination are in a region in the fourth quadrant, indicating where electrical power can be extracted from the device. when no light is incident on the cell, a solar cell is equivalent to a diode or semiconductor current rectifier [7].

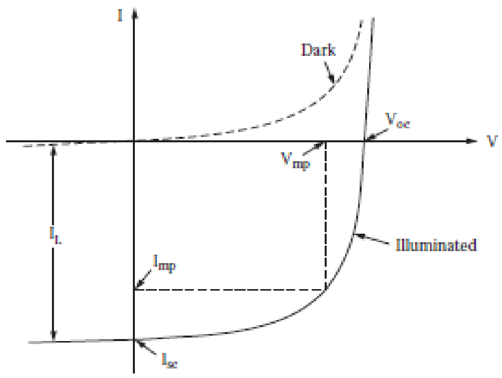



**Figure 2:** Curve of a solar cells.

The graphical representation of the relation between the current and voltage produced by a solar cell is the standard form of representing the output of the pv cell. It represents the snap-shot of all the potential combinations of current and voltage possible from a cell underspecified environmental conditions like irradiance, air mass and surrounding temperature.

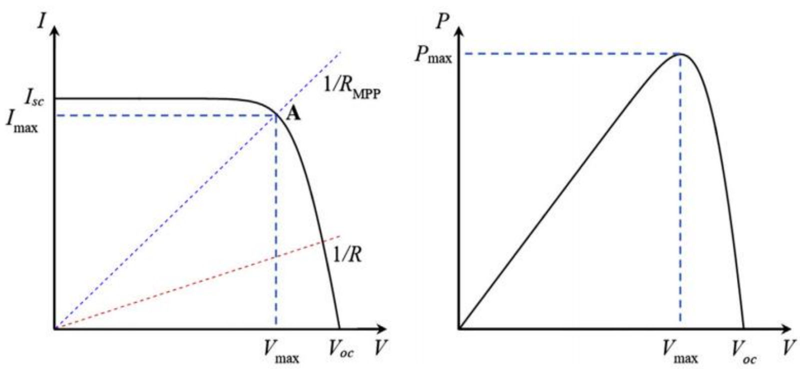



**Figure 3 :** I-V and P-V characteristics

## II.6 Efficiency

Values that affect the efficiency of solar cells are the band gap of the semiconductor, operating temperature, incident light, type and purity of the material, and parasitic resistances.

for some recent efficiency claims. Construction of the current-voltage (I-V) curve is crucial to estimating efficiencies in the solar cell. As shown in the previous equations, *Io* needs to be as small as possible for maximum *Voc.* The generally accepted estimate of the minimum value of the saturation current density is [7]:

$$Io = 1.5 \times 10^5(-\frac{Eg}{KbT}) \quad \text{(II.8)}$$

### II.6.1 Temperature

Studies have yielded empirical results that prove there is an approximately linear decrease in *Voc* with increasing temperature (≈2.3 mV/°C; Talbot 2007). The ideal fill factor depends on the value of Voc normalized to $K_B T/q$, *so* that the fill factor will also decrease with an increase in temperature.

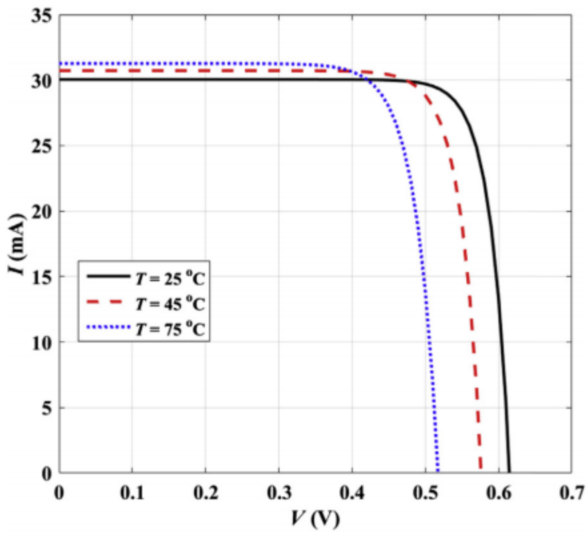



**Figure 4:** The effects of the temperature of a solar cell.

### II.6.2 Light

Light affects primarily the short circuit current. Effects to consider in order to increase efficiency are antireflective coatings (bare silicon is very reflective), minimization of the surface grid (shadowing will reduce $Io$), light trapping, and the thickness of the semiconductor.

### II.6.3 Type and Purity of Material

Solar cells for terrestrial applications are typically made from silicon as single-crystal, polycrystalline, or amorphous solids. Single-crystal silicon is the most efficient because the crystal is free of grain boundaries, which are defects in the crystal structure caused by variations in the lattice that tend to decrease the electrical and thermal conductivity of the material. They can be thought of as barriers to electron flow. Polycrystalline silicon has obvious grain boundaries; the portions of single crystals are visible to the naked eye.

#### a. Monocrystalline solar cell

These types of solar cells belong from first-generation solar cell technologies. The width of the wafer used in these types of solar cells is up to $200\mu m$. The cell slice is cut from a pure silicon bar and the silicon used is single-crystal silicon. The complete celli aligned in the same direction, so when the light falls on the cells at the accurate direction, they are very efficient. Cost of the production of these types of solar cells is more than in the comparison of a polycrystalline cell.

#### b. Polycrystalline solar cell

These types of solar cells also belong from first-generation solar cell technologies. These cells are made up of several silicon cells joined together instead of using a single crystal of silicon. In general, the cost of production of a polycrystalline solar cell is not much higher than monocrystalline. Therefore, they are also more affordable. In comparison with a monocrystalline solar cell, the power conversion efficiency of polycrystalline solar cell is less.

c. Amorphous solar cell

Amorphous silicon ($a - Si$) solar cells belong from a thin-film solar cell. In these types of solar cells, one or more layers of photovoltaic materials are deposit on a substrate. In comparison with other technologies, they have low manufacturing cost. They are produced by placing one or more thin layers of photovoltaic composite on a substrate. [7].

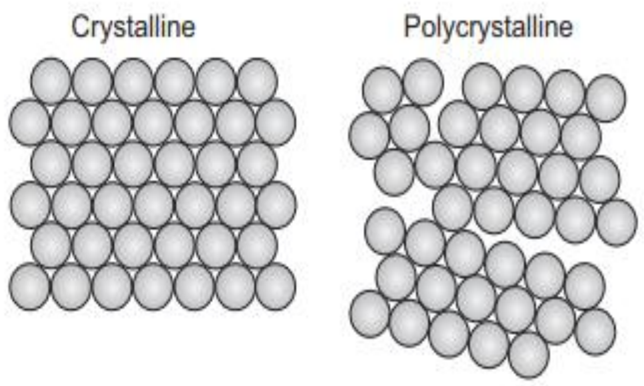



**Figure II. 5:** Monocrystalline, polycrystalline, and amorphous solids.

**II.6.4 Parasitic Resistances**

The solar cell can be schematically depicted, As shown in the following figure, the model shows the parasitic series and shunt resistance, depicted as Rs and Rsh, respectively.

Major components of series resistance are the bulk resistance of the semiconductor material, bulk resistance of the metallic contacts and interconnections, and the contact resistance between the metallic contacts and the semiconductor. Shunt resistance is caused by leakage across the p–n junction caused by crystal defects and foreign impurities in the junction region.

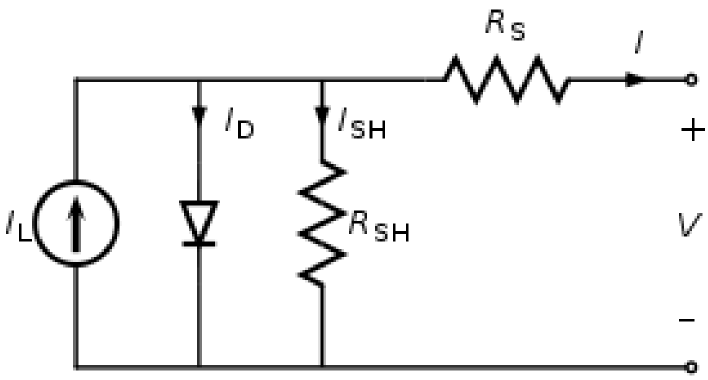



**Figure II.6:** Equivalent circuit of a solar cell.

The serial resistance Rs due to the contribution of the base and front resistances of the junction and the front and rear face contacts.

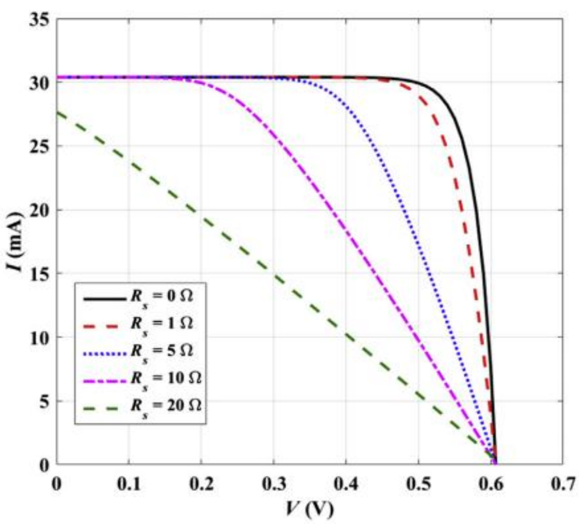



**Figure 5 :**Effect of Rs on solar cell characteristics

The parallel resistance Repulsed for the effects, such as the leakage current through the edges of the cell, it is reduced due to the penetration of metal purities in the junction.

## II.7 PV Arrays

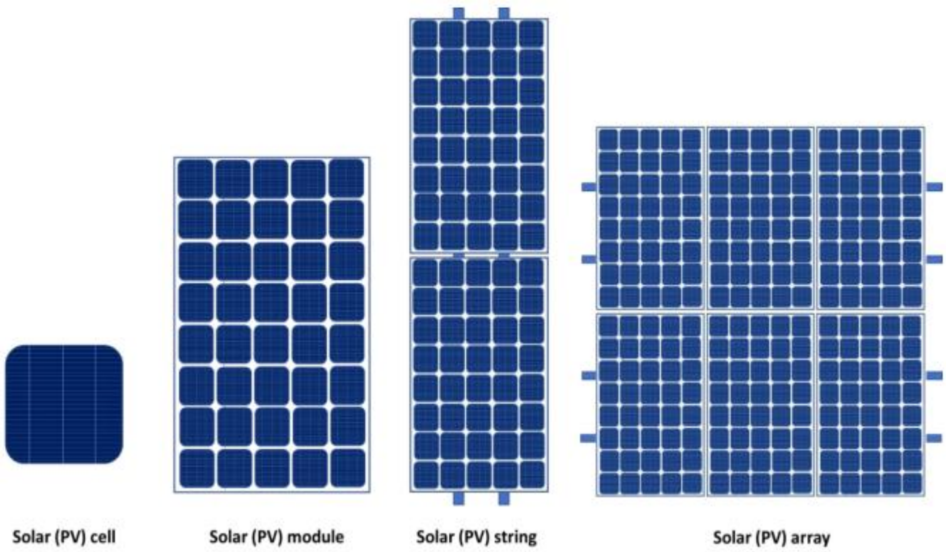
Individual solar cells electrically connected together are called a PV array, and are done so to increase their power output. The cells are packed so that they are protected from the environment and to protect the user from electric shock. The effects that are considered the most important in PV modules are:

• Losses due to mismatched solar cells interconnections

• Module temperature

• PV modules failure modes

A representation of how the different terms from PV cells to arrays can be seen in following figure.




**FigureII.8:** From solar cell to solar array

## II.8 PV Array Tilt

Maximum energy is obtained when the Sun's rays strike the receiving surface perpendicularly. In the case of PV arrays, perpendicularity between the Sun's rays and the modules can be achieved only if the module's mounting structure can follow the movements of the Sun (i.e., track the Sun). Mounting structures that automatically adjust for azimuth and elevation do exist. These types of structures are called trackers.

For the case in which a tracker is not used, the array is mounted on a fixed structure. This structure has the advantage of simplicity. Because the angle of elevation of the Sun changes during the year, the fixed-tilt angle of the array should be chosen so that maximum energy production is guaranteed.

## II.9 PV Balance of Systems

Several PV cells make up a PV module, several modules connected in series is referred to as a PV string and several PV modules (strings) make up a PV array. By having several PV arrays connected together make up a PV system. This latter is broadly classified into three part, Standalone (off-grid) PV system. Grid connected (on-grid) PV system and Network connected solar power plants. The balance of system (BOS) encompasses all components of a photovoltaic system other than the photovoltaic panels [8].

### II.9.1 Energy storage

Energy storage for PV systems commonly consists of batteries to store and discharge electrical energy as needed. Batteries vary by type, depth of discharge, rate of charge, and lifetime (in PV applications). The most common types of batteries used with PV systems are lead-acid, but other more exotic and expensive batteries are sometimes used, such as nickel metal hydride.

The technology lead-acid battery capable of long cycle and most efficiently recycled commodity metal. The selection of lead-acid battery depends on its sustainability of chemistry, completely recycled energy storage system and partially recycled metal parts. In addition, that electrochemical models have been computationally complex in terms of parameter identification and constant phase element dynamics. The selection of battery depends on various factors such as fast charge, heavy duty, deep cycle, high capacity and long life[8].

### II.9.2 Charge controllers

Charge controllers manage the flow of electricity among the array, battery, and loads. The appropriate charge control algorithms and charging currents should be matched for the batteries used in the system; no one size controller fits all batteries. Better quality charge controllers allow for adjustable regulation voltages, multiple stage charge control, temperature compensation, and equalization charges at specified intervals for flooded batteries. The main purpose of a charge controller is to protect batteries from damage from excessive overcharging or discharging.

### II.9.3 Inverters and Converters

#### a.Inverters

An inverter is a device that converts direct current into alternating current. The solar inverter is directly connected to the solar PV panel.

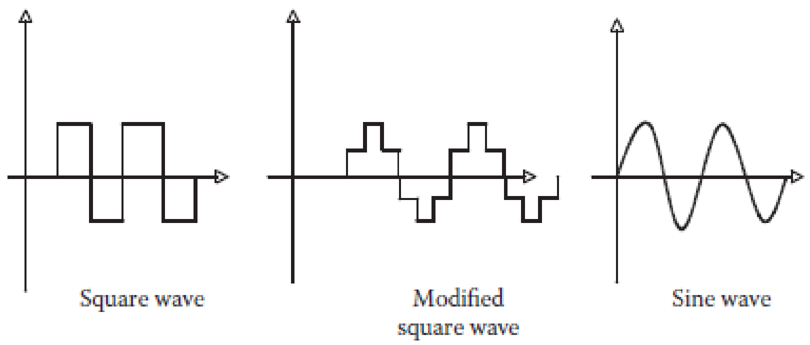



**Figure II.9:** Inverter wave outputs.

- The centralized inverter, the PV modules are connected in series and form the strings and are all connected in parallel to a central inverter.
- String Inverters are reduced form of central inverters. In the circuit topology with string inverters, diodes between strings are eliminated which reduce the power loss. Also, string inverters let each string operates at its own.
- The multi-string inverter, has a DC/DC converter for each string that allows the integration of heterogeneous PV strings. The DC/DC converters increase the number of control freedoms in the system, the MPPT, system protection, and ancillary services can be realized with more flexibility. stages are involved.

**b.Converters**

- Step-down converter, which is the basic converter is known as buck converter. As it is understood from its name the main function of this converter is to convert the input DC voltage level to another and lower voltage level.
- Step-up converter, is called boost converter which consists of inductor L, capacitor C, controllable semiconductor S, diode D and load resistance R.
- Buck-boost converter,Non-isolated buck-boost converter which consists of input voltage Vs, inductor L, capacitor C, load R and controllable switch S .

Usually in PV systems more than one conversion stage is used, for example DC-DC plus DC-AC. These configurations must be adapted to the topology of the PV system by taking account the efficiency of the total system, the size (fixed or embedded system) and also, to a certain extent, the price.

## II.10 PV System Safety

A safe PV system is installed according to applicable building codes and standards, even PV installers safety includes considerations for a safe work area, safe use of tools and equipment, safe practices for personal protection, and awareness of safety hazards and how to avoid them. It addresses many safety categories as:

Hazard Assessment and Training

- Use a hazard assessment checklist to document and describe the hazards and sources: Electrical, falls and falling objects, impacts, penetrations, heat, chemical, etc.
- Select the appropriate personal protective equipment (PPE) when all engineering controls and work practices cannot eliminate the hazards (Protection for the head, eyes, face, hands, feet and other parts of the body)

**Figure II.10:** Impact splash-resistant goggles

**Figure II.11:** Cut-Resistant Leather Glove

- Record and report work-related fatalities, injuries and illnesses.

<u>Electrical Hazards</u>

Electrical accidents are caused by a combination of three factors:

- Unsafe equipment and/or installation.
- Work places made unsafe by the environment
- Unsafe work practices

How to prevent

- Wear electrical hazard (EH) rated foot protection
- Use properly grounded or double-insulted power tools.
- Work on electrical equipment and circuits in a de-energized state using lockout and tag out procedures.
- Beware of overhead power lines and buried electrical conductors

Power Tools

- Disconnect tools when not in use, before servicing and cleaning, and when changing accessories.
- Secure work with clamps or vise, freeing both hands to operate the tool.
- Keep tools sharp and clean.
- Do not wear loose clothing and jewelry that can get caught in moving parts.
- Do not use electric cords to carry; hoist or lower tools.
- Remove damaged electric tools and tag them by “Do Not Use” [9].

## II.11 Conclusion

In this chapter we presented the physics, characterization and applications of a solar cell. Also, we have seen the effects of the temperature, purity of material and light on it. Also, we discussed the PV conversion system which is the most important part of a PV installation.

In the next chapter we will illustrate a PV system sizing, designing application and the economics study.

# CHAPTER III

## PHOTOVOLTAIC SYSTEM SIZING APPLICATION

## II.1 Introduction

When considering planning stand-alone PV system, the most important factor should be energy balance of the system which means balancing the energy consumption with the supply. In this section it is desired to show the stand-alone PV system on the electronic department of Laghouat University.

## III.2 Location

The department is situated in Laghouat, Algeria, Northern Africa, it has sufficient solar radiation to support the construction of photovoltaic power plants. Data sourced from Photovoltaic Geographical Information System (PVgis) website using geographical coordinates; longitude 33.7744 and latitude 2.8264.

**Figure III.1:** Place Location Using Google earth.

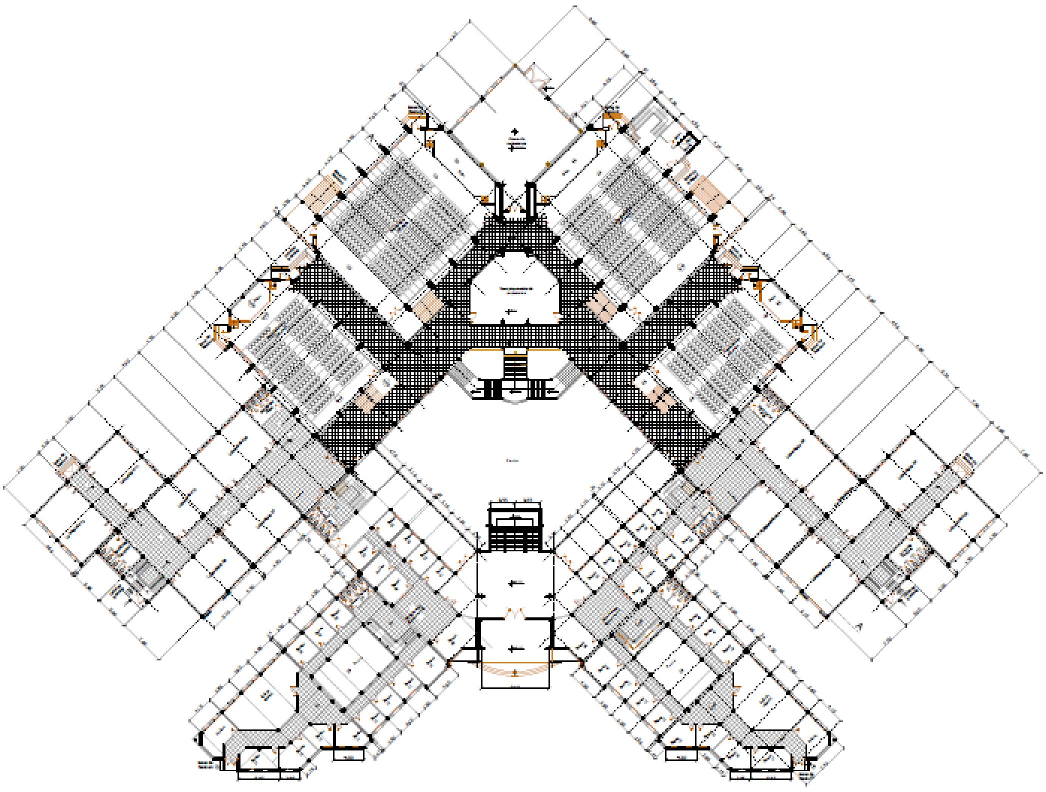


**Figure III.2:** Department plan by ORCAD.

## III.3 Electrical needs of the faculty

First, we need to know the daily consummation of power in our department and calculate the global power consumed by each electrical machine or light, and it is presented in the above (refer to appendix A):

**Table III.1:** Daily measured consumption of the studied place.

| UNIT | KW | KWh/jr | KWh/mois |
|---|---|---|---|
| **Power consumed** | 245.371 | 2208.339 | 66250.17 |

**Table III.2:** Yearly consumption of energy in the faculty

| Bill number | Date of bill | Energy bill (Kwh/mois) |
|---|---|---|
| **831908000889** | 01/09/2019 | 59808 |
| **831909000886** | 01/10/2019 | 56449 |
| **831910000887** | 03/11/2019 | 61994 |
| **831911000889** | 01/12/2019 | 72217 |

## III.4 Sizing the studied photovoltaic field

### III.4.1 Using calculations

#### III.4.1.1. Peak power calculation

$$Pc = \frac{Bj}{Ej \times ŋb \times ŋi} \qquad (III.1)$$

**Bj**: Average Daily Consumption (kWh/j)

**Ej** : Average yearly insolation in Laghouat city 5.51 kWh/m²/jour

ŋ**i**: Installation efficiency 90%

ŋ**b** : battery charge and discharge performance 80%

$$Pc = \frac{2208.339}{5.51 \times 0.9 \times 0.8} = 556.649kWc$$

#### III.4.1.2 Assembly of modules

We have chosen IF-P320-72 of IFRISOL panels. (refer to appendix c)

The total number of modules:

$$Nm = \frac{\mathrm{Pc}}{\mathrm{Pm}} = \frac{556649.27}{320} \approx 1740\mathrm{pannels} \qquad \text{(III.2)}$$

**Nm**: modules number

**Pc**: consumed power

**Pm**: power for one pv module

### III.4.1.3 Inverter sizing

We will divide the photovoltaic field on sub-fields with a 50kw inverter for each one

For this purpose, we need 5 inverters with integrated controller from a proposed brand SMA connected in string structure.

-Total power of all components = 245,371

-Inverter nominal power = 250,000

$\frac{250,000}{5}$ = 50000W

Each field will be assembled as follows:

**a- Series mounting:**

To find the suitable voltage for supplying a given load by placing several PV modules in series, the number of these modules is calculated by the following expression:

$$Nms = \frac{\mathrm{Vch}}{\mathrm{Vm}} = \frac{1000}{37.56} = 27 \qquad \text{(III.3)}$$

**VM**: the nominal voltage of the module.

**VCh**: the nominal voltage of the load.

**b- parallel mounting:**

The paralleling of the module gives the intensity necessary for the load. The number of branches is calculated by the following equation:

$$Nmp = \frac{\text{Nm}}{\text{Nms}} \quad \text{(III.4)}$$

$$Nmp = \frac{1740}{27} \approx 65$$

### III.4.1.4 Sizing of a solar electric cable

- We want to determine the section of cables to minimize losses during the transport of electricity. To do this sizing, we need to know the intensity of the current flowing in these cables.

- There will therefore be 15 meters of cable between the module and the batteries.

- The aim is to reduce losses to less than 3% of the energy produced.

Cable's section

$$R = \frac{\boldsymbol{\rho} \times \boldsymbol{L}}{\text{S}} \quad \text{(III.5)}$$

$$0.045 = 17 \times 10^{-9} \times 15/s$$

$$S = 5.7 \times 10^{-6} m^2 = 5.7 mm^2$$

### III.4.1.5 Regulator sizing

The regulator chosen must be able to withstand at least the following intensities:

The voltage of the controller must be the same with the generator (48v)
The current of the PV module must be exceeded by the current of the controller
(Isc × $modules\ in\ parallel$) = 9.03 × 65 = 586.95A
In our system, the best command to apply is the MPPT.

### III.4.1.6 Size the battery bank (U and Ah)

In stand-alone PV systems the battery plays an important role in matching the load requirement for the system. In the locations where there is a big fluctuation in irradiation, we will need at least 2-3 days reserve for the winter months. The battery capacity depends on certain parameters such as the desired storage autonomy in days, the battery voltage, the maximum authorized degree of discharge and the efficiency [10].

The nominal capacity of the batteries results in the following law:

$$c = \frac{\mathrm{Bj} \times \mathrm{Aut}}{\eta\mathrm{b} \times \mathrm{Dp} \times \mathrm{v}} \quad \text{(III.6)}$$

C : battery capacity required (Ah)

Aut : days number of battery life (J)

**Bj**: Result of the balance of electrical consumption (Wh / d)

**Dp**: Coefficient of deep discharge at the end of autonomy (0.7).

V: Nominal voltage of the photovoltaic generator (V)

ŋb: 85% battery efficiency

$$c = \frac{2208339 \times 1}{0.85 \times 0.7 \times 48} = 77322.8 \text{ ah}$$

Number of accumulators in series

$$\mathrm{Ns} = \frac{48}{12} = 4$$

Number of accumulators in parallel when using batteries of 400ah:

$$\mathrm{Np} = \frac{77322.8}{400} = 194$$

Total number of batteries

Ns x Np = 4 x 194 = 776 batterie

**NOTE:** This case of study can be reliable in case we have an empty zone of more than 2000 m². So, we will take only the spaces that are non-shaded in order to take the maximum profits and win space.

If we calculate the surface of no shadowed areas it will be estimated around 1118.79m² as we have seen on the previous chapter which means it will powered almost the half of the total power.

### III.4.2 Sizing using PVsys

PVsys software is a simulation software for photovoltaic systems, developed within the framework of the Applied Physics Group (GAP) of the University of Geneva by André Mermoud. PVsys is one of the oldest and most efficient software dedicated to photovoltaic. It offers very advanced functionalities such as its 3D application which simulates the course of the sun and the shadows cast in order to optimize the layout of the panels. (check appendix B)

It presents the results in a complete report, including specific graphs and tables

| PVSYST V6.64 | | | 21/05/20 | Page 1/3 | |
|---|---|---|---|---|---|

**Grid-Connected System: Simulation parameters**

| | | | | | |
|---|---|---|---|---|---|
| **Project :** | **laghouat** | | | | |
| **Geographical Site** | | **Laghouat** | | Country | **Algérie** |
| **Situation** | | Latitude | 33.47° N | Longitude | 2.51° E |
| Time defined as | | Legal Time | Time zone UT+1 | Altitude | 764 m |
| | | Albedo | 0.20 | | |
| **Meteo data:** | | **laghouat** | Meteonorm 7.1 (1986-2005), Sat=100% - Synthétique | | |
| **Simulation variant :** | **sizing** | | | | |
| | | Simulation date | 21/05/20 23h28 | | |
| **Simulation parameters** | | | | | |
| **Collector Plane Orientation** | | Tilt | 30° | Azimuth | 0° |
| **Models used** | | Transposition | Perez | Diffuse | Perez, Meteonorm |
| **Horizon** | | Free Horizon | | | |
| **Near Shadings** | | No Shadings | | | |
| **PV Array Characteristics** | | | | | |
| **PV module** | Si-poly | Model | **Poly 250 Wp 60 cells** | | |
| Original PVsyst database | | Manufacturer | Generic | | |
| Number of PV modules | | In series | 16 modules | In parallel | 46 strings |
| Total number of PV modules | | Nb. modules | 736 | Unit Nom. Power | 250 Wp |
| Array global power | | Nominal (STC) | **184 kWp** | At operating cond. | 165 kWp (50°C) |
| Array operating characteristics (50°C) | | U mpp | 437 V | I mpp | 377 A |
| Total area | | Module area | **1197 m²** | Cell area | 1073 m² |
| **Inverter** | | Model | **12 kWac inverter** | | |
| Original PVsyst database | | Manufacturer | Generic | | |
| Characteristics | | Operating Voltage | 350-600 V | Unit Nom. Power | 12.0 kWac |
| | | | | Max. power (=>25°C) | 14.0 kWac |
| Inverter pack | | Nb. of inverters | 12 units | Total Power | 144 kWac |
| **PV Array loss factors** | | | | | |
| Thermal Loss factor | | Uc (const) | 20.0 W/m²K | Uv (wind) | 0.0 W/m²K / m/s |
| Wiring Ohmic Loss | | Global array res. | 20 mOhm | Loss Fraction | 1.5 % at STC |
| Module Quality Loss | | | | Loss Fraction | -0.8 % |
| Module Mismatch Losses | | | | Loss Fraction | 1.0 % at MPP |
| Strings Mismatch loss | | | | Loss Fraction | 0.10 % |
| Incidence effect, ASHRAE parametrization | | IAM = | 1 - bo (1/cos i - 1) | bo Param. | 0.05 |
| **User's needs :** | | Unlimited load (grid) | | | |

**Figure III.3:** PVsys Report.

## III.4.3 Module Layout

The layout is the positioning of the panels in portrait or landscape. According to the surface on which we will place the panels, it is recommended that we use a portrait layout; however, as we have several surfaces it is necessary to calculate how many panels can be placed on each non shaded surface while respecting the necessary distance.


Périmètre
75,46 m
Zone
322,84 m²
Mesurer une distance
3D


Périmètre
99,03 m
Zone
532,44 m²
Mesurer une distance
3D

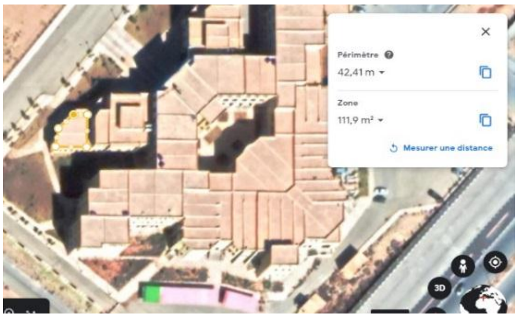

Périmètre
69,38 m
Zone
297,64 m²
Mesurer une distance
3D


Périmètre
51,75 m
Zone
159,14 m²
Mesurer une distance
3D


Périmètre
78,22 m
Zone
373,89 m²
Mesurer une distance
3D


Périmètre
67,3 m
Zone
271,47 m²
Mesurer une distance
3D


Périmètre
125,21 m
Zone
952,21 m²
Mesurer une distance
3D


Périmètre
42,41 m
Zone
111,9 m²
Mesurer une distance
3D


Périmètre
102,04 m
Zone
650,02 m²
Mesurer une distance
3D


Périmètre
45,23 m
Zone
82,98 m²
Mesurer une distance
3D


**Figure III.4:** The pictures represents the calculations of non-shaded areas using GPS

Therefore the total non-shaded available areas is:

75.46+69.38+78.22+125.21+102.04+99.03+51.75+67.3+42.41+45.23+27.42+34.08+33.38+80.27+54.34+33.04+31.98+28.5+39.75 = 1118.79m² = 111879cm²

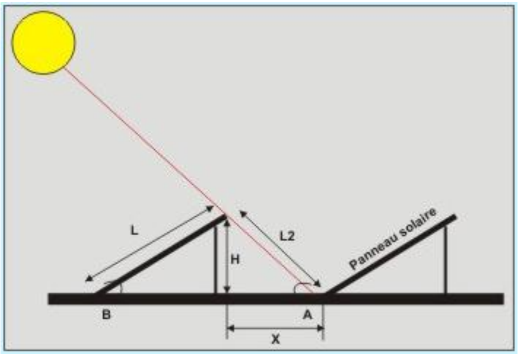



**Figure III.5 :**Minimal distance between panels.

The distance between panel is:

$$BC= \sqrt{(166.6^2 - 95.56^2)} = 136.46 \quad \text{(III.10)}$$

Total distance that should be respected when implanting solar panels

$$BC + X = 136.46 + 142 = 278.5cm$$

Number of panels that can be implanted on total surface

$$111879 / 278.5 = 402 \text{ panel}$$

As an additional option we suppose that we will install a PV system that power only the lights of our department. Using the same brand of panel of 250W and a Battery of 250 Ah, The Results were as follows

<u>Load Estimation:</u>

**Table III.3 :** Load Estimation Light Only

| Appliance Load | Power | Daily use(H) | Daily energy use |
|---|---|---|---|
| 75 Led Lamp | 18W | 12 | 16848Wh |
| 70 Lamp with motion sensor | 12W | When detected | 840Wh |
| Daily AC Energy Demand | | | 17688Wh |
| Peak Load | 2190W | | |

### III.4.4 Cost Estimation

The prices of the equipment to be used in our stand-alone PV installation are given in the following table:

**Table III.4:** The prices of the equipment

| Equipment | Number | Unit price | Price |
|---|---|---|---|
| **Panel (250Wc)** | 20 | 16000DA | 320000DA |
| **Battery (12V/250Ah)** | 8 | 48000DA | 384000DA |
| **Cable** | 15m | 340DA/m | 5100DA |
| **Total** | | | 709 100DA |

## III.5 Conclusion

After seeing the steps of sizing and the cost of installing a stand-alone PV system, we know how to choose our components (panels, batteries, regulators and cables) according to the available place and economical requirements. In the next chapter we will use NN to forecast the next days of PV production using weather data.

# CHAPTER IV

## NEURAL NETWORK FORECAST

## IV.1 Introduction

In this part of the dissertation, we will detail the study and the dimensioning of the autonomous solar station system that has served our study. It has concerned the department of Electronics in pole level of 2000 place in the city of Laghouat which is characterized by a significant sunshine energy. It is therefore interesting to apply the techniques studied on a real calculation to confirm the validity of the chosen method and to draw conclusions from it.

## IV.2 Neural network definition

NN is a series of algorithms that endeavors to recognize underlying relationships in a set of data through a process that mimics the way the human brain operates. In this sense, NN refer to systems of neurons. NN can adapt to changing input; so the network generates the best possible result without needing to redesign the output criteria. The concept of NN, which has its roots in artificial intelligence, is swiftly gaining popularity in the development of trading systems [13].

- Self-Organisation: An NN can generate its own representation of the information that it receives at the time of learning.
- Real Time Operation: NN calculations may be done simultaneously, and some special (hardware) devices are manufactured which take advantage of this capability.
- Adaptive learning: Capability to learn how to solve tasks is based on the data given for training set.

### IV.2.1 Methodology

A typical NN system has three layers; the input layer, the hidden layer(s) and the output layer. These three layers are interconnected and each layer consists of one or more nodes. Neurons in the input layer send data onto the hidden layer, which in turn transmit data to the output layer. NN learn from data examples presented to them and use these data to adjust their weights in an attempt to capture the relationship between the historical set of model inputs and corresponding outputs. (Appendix B)

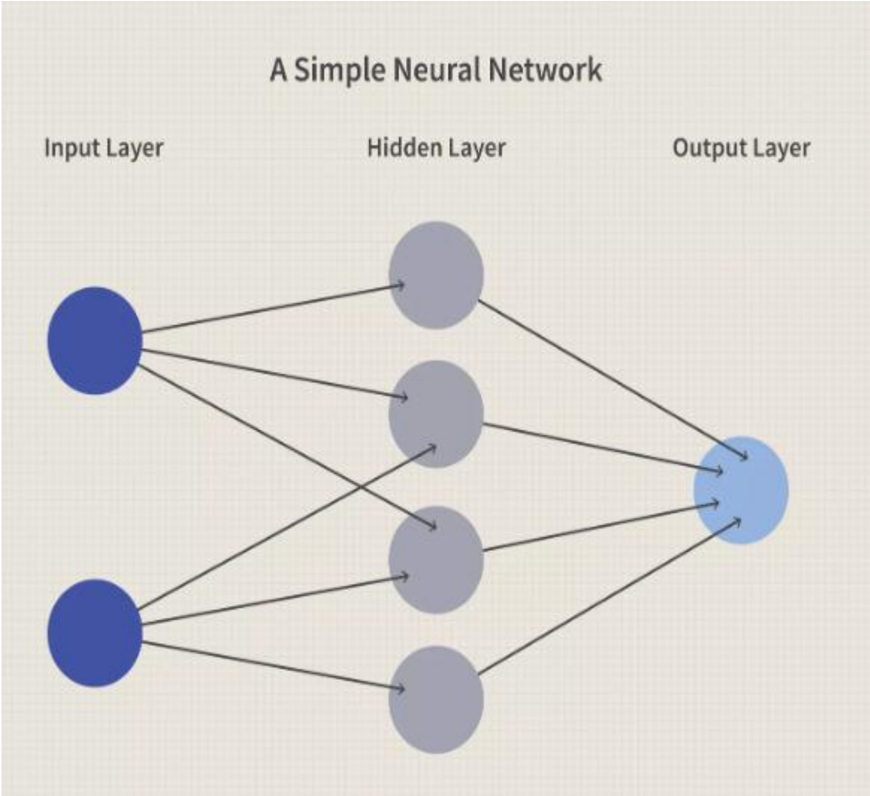



**Figure VI.1:**Neural network chronogram.

**IV.3 Neural Network Production Forecast**

For the forecast of photovoltaic production over a period of 10 months we used as inputs: hours, days of the week, drybulb, dewpoint, irradiation, pressure, speed of wind, humidity, rain, sunset and sunrise, vacation ,prevday , prevweek .The data were treated using MATLAB programs to organize , normalize , draw the graphes .

The choice of inputs was held to their strong affection on PV production. In one hand to see the effects of each one , On the other hand to know which are the most affective datas on a PV production .(check appendix B)

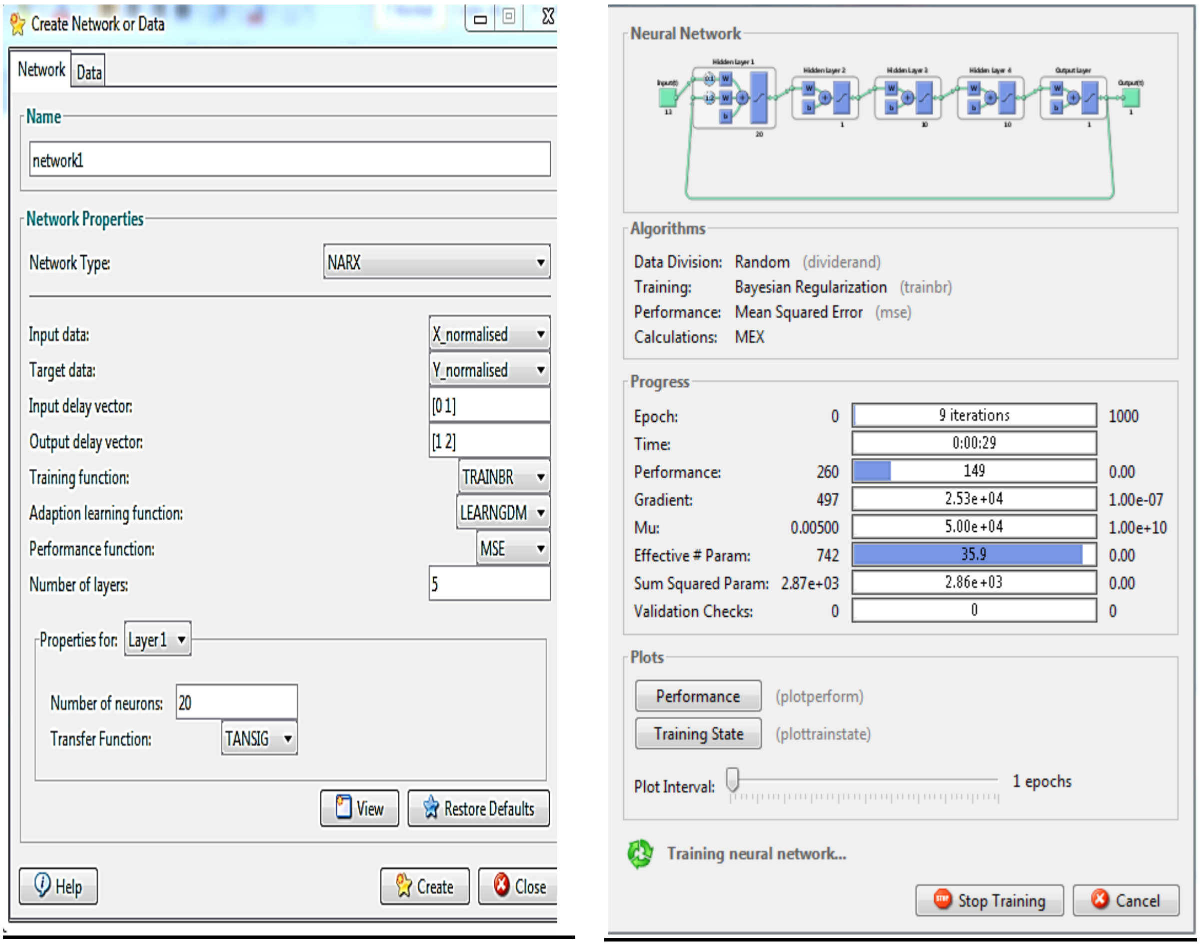



**Figure VI.2:** The steps of creating a network

## <u>Data processing:</u>

The measured data from the NOAA website comes in digital form. They are then processed to correct atmospheric, geometric, and systematic distortions when necessary. If the verification using Excel was positive for the erroneous data (the data values that are not logical), we perform the calibration to correct them.

If the verification with Excel for the missing data was positive, the sensor is damaged and it does not take correct measurements (eg: 99.9 and 999.9), it is corrected by reconstruction using mathematical methods.

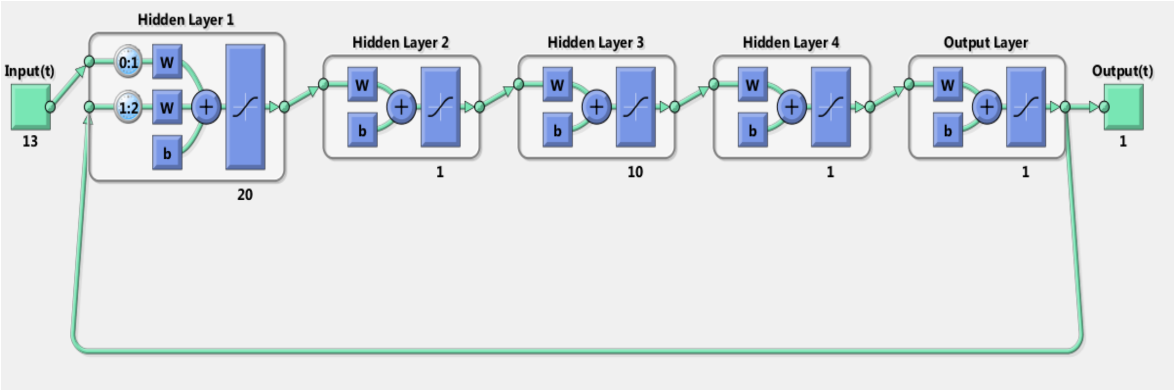



**Figure VI.3:** The number of layers and neurons of the training

For the forecast of the production the results obtained were made by training the network over a period of 10 months.

## IV.4 Neural Network Forecast Results

The comparison between the photovoltaic production obtained by our calculation and the forecasts by neuron network.

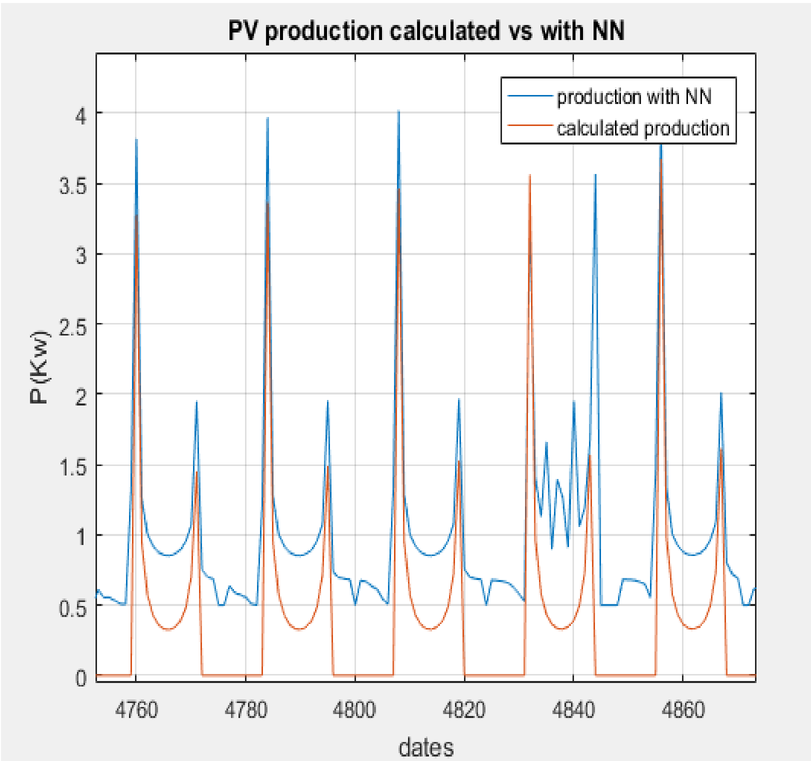



**Figure VI.4:** Comparison of PV production with NN Forecast.

After simulation of the neuron network we obtain good results with a **relative error of 9.79%** for a network made up of 5 layers and 20 neurons for the first layer.

Before we obtain a good results, we made a lot of essays represented in the table down, In which the vector weight of entrance and exit are fixed and we changed number of neurons and layers and we calculate the error rate each time indicated by MAPE

**Table VI.1:** Parameters for the training of the photovoltaic forecast by NN.

| Number of neurons | Vector of weight in entrance | Vector weight in exit | Number of layers | Mape % |
|---|---|---|---|---|
| 10 | [0 1] | [1 2] | 1 | 78% |
| 10 | [0 1] | [1 2] | 2 | 85% |
| 10 | [0 1] | [1 2] | 3 | 95% |
| 20 | [0 1] | [1 2] | 1 | 53.54% |
| 20 | [0 1] | [1 2] | 3 | 21.47% |
| 20 | [0 1] | [1 2] | 5 | 9.79% |

## IV.4 1 production forecast of next 24h

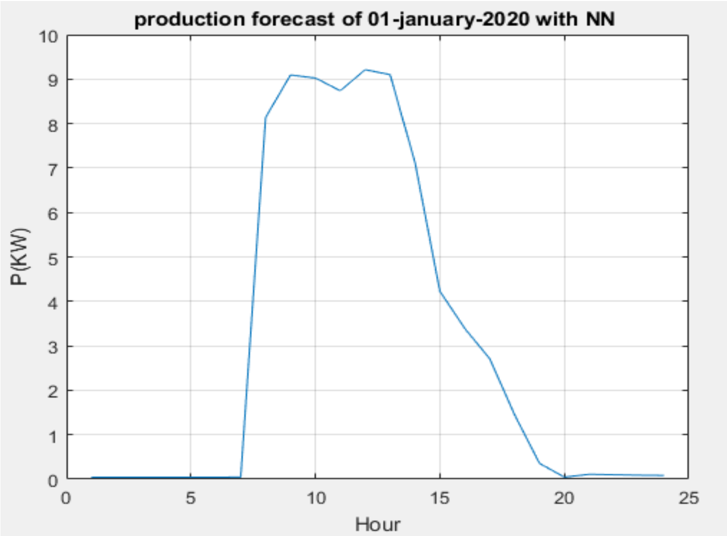



**Figure VI.5:** 24 hours production forecast with NN

The graph above represents a 24 hours forecasting , we notice that the production is 0 in the time [ (1AM-7AM) (7PM-12AM)] and of course due to lack of irradiation ( sun light ) , In other hand the production getting more from (7AM – 2:30PM) by dint of the good lightening . we notice a drop of production in the middle of day and it is because of a cloudy passage .

## IV.4.2 production forecast of next 5 days and 2 week

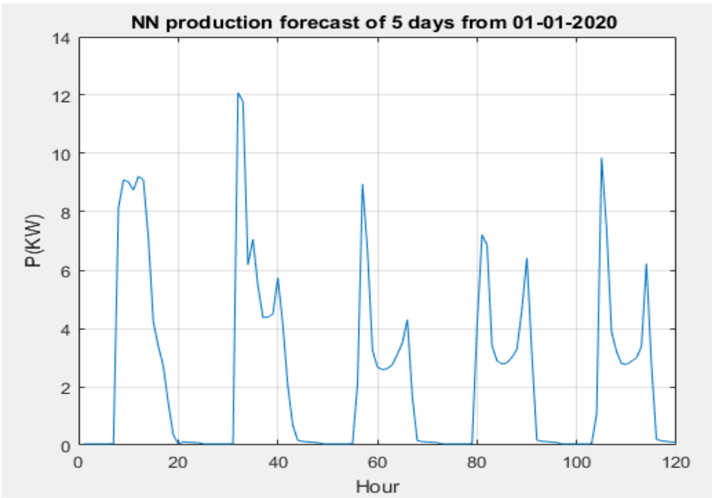



**Figure VI.6:** 5 days production forecast with NN

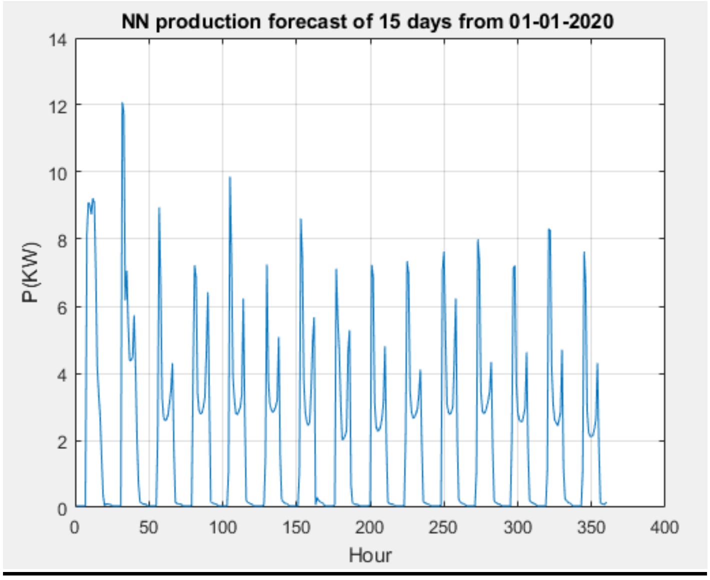



**Figure VI.7:** Production forecast of next 15 days

The graphs above represented a 5 days and two weeks forecasting , we notice that NN has well predicted the production .

### <u>IV.4.3 The affects of weather data on PV production</u>

The length and strength of solar power received are the two most important factors in producing electricity through photovoltaics. As such, regions that receive the most sunshine per day will produce the most energy.

Wind damage to the solar panels is unlikely considering they are specifically designed to withstand wind speed. However, solar PV systems are subject to the same laws of physics as any other electrical circuit. The behavior of the electrical circuit in terms of voltage, resistance and current are governed by other effects, like air temperature and wind speed. Since wind speed influences air temperature, it is a piggy-back factor of how temperature can affect a solar PV system.

Solar panel power production is the most efficient when temperatures are low in sunny environments.

- **High temperatures:** Field and laboratory experiments have revealed a drop of solar energy output for every increase in degree of a home photovoltaic solar panel once the panel reached 42 degrees Celsius, or about 107 degrees Fahrenheit.

- **Low temperatures:** The angle of the sun determines irradiance (brightness) and insolation (strength of sun when it reaches ground) which both determine the amount of energy production photovoltaics. Locations closest to the poles, and/or during winter seasons, the angle of the sun is low and temperatures decrease, causing solar panel energy production to also decrease.

Thin air is ideal for solar power for the simple fact that when the air is thicker, it scatters more sunlight. Typically, the higher the elevation, the thinner the air is. Locations at or below sea level tend to have higher air density.

A thick layer of snow on your solar PV panels will affect the production of energy entirely. However, panels naturally give off heat and are purposely installed at an angle which will prevent the accumulation of thick layers of snow. During rain or snow, the length and strength of the sun is minimal and will decrease energy production as a result.

If you live in an area with dense cloud cover or fog, your solar power output will decrease but the solar PV panels will still produce electricity. Clouds/fog diffuse (spread out) sunlight, so the angle of the sun and/or panels are not as critical. The amount of solar energy produced in these conditions depends on the thickness and duration of the fog or cloud cover. A single cloudy day will not affect the amount of power coming into your home, it is more important on the amount of sun that your panels see on average per year.

## IV.5 Conclusion

Weather can have a significant impact on solar power production. In this chapter we have trained a NN often months data in order to forecast the maximum period we could which is a 15 days . The forecasting has been done successfully with a rate error estimated by 9.79 %. So we can say that the NN forecast a long and short term period

# GENERAL CONCLUSION

# GENERAL CONCLUSION

The generation of energy from solar sources is subjected to very dynamic changes in environmental parameters and asset operating conditions. This is a very relevant issue to be considered when developing reliability studies.

Solar energy generated by sunlight has a non-schedulable nature due to the stochastic environment of meteorological conditions.

To that end, NN models have proven to be a very interesting tool, and there are many relevant and interesting contributions using NN models, with different purposes.

In this dissertation we applied NN model for PV production forecast of a PV off grid structure used at the Department of Electronics, University of Amar Telidji ,Laghouat, Algeria.

To achieve the work objectives, we needed to use a several softwares such as , PVsys , MATLAB and the PVgis .We started from collecting the department energy needs then moved to the topology of the location, Then typed the data manually for a period of 10 months with hourly steps for the forecasting and collected the irradiation of PVgis for the sizing. Also we took into consideration the options we had.

At first we have done a general study that needs more than 2000m² .So we had to calculate the available non-shaded areas to apply the second option of using PV production only to power lights , with its economical features .

The Obtained results confirm that NN can forecast a long and short terms with a fairly low error rate of 9.79% . Besides we confirmed the efficiency of PVsys and how accurate and fast is.

The PV installation can be interconnected to the network.It is interesting to note that our installation becomes profitable in view of the energy saving which is very significant at present contribution to public demand.

Finally, in perspective, we suggest that our study can be completed by using other methods of forecasting.

# Bibliographical references

# Bibliographical references

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# Appendix

**Table A.1 :** the total power consumption of our department

| area | puissance (W) | number | total power (W) | hour of function | Energy per day (KWh) |
|---|---|---|---|---|---|
| class | 520 | 15 | 7800 | 9 | 70200 |
| Coridor 1 | 1280 | 1 | 1280 | 9 | 11520 |
| Coridor 2 | 1520 | 1 | 1520 | 9 | 13680 |
| Coridor 3 | 64 | 1 | 64 | 9 | 576 |
| Coridor 4 | 192 | 1 | 192 | 9 | 1728 |
| bathroom 1 | 96 | 1 | 96 | 9 | 864 |
| bathroom 2 | 96 | 1 | 96 | 9 | 864 |
| Laboratory 1 | 3142 | 1 | 3142 | 9 | 28278 |
| Laboratory 2 | 3142 | 1 | 3142 | 9 | 28278 |
| Laboratory 3 | 3142 | 1 | 3142 | 9 | 28278 |
| Laboratory 4 | 3142 | 1 | 3142 | 9 | 28278 |
| Laboratory 5 | 3142 | 1 | 3142 | 9 | 28278 |
| Amphi 1 | 29152 | 1 | 29152 | 9 | 262368 |
| Amphi 2 | 43792 | 1 | 43792 | 9 | 394128 |
| Amphi 3 | 43792 | 1 | 43792 | 9 | 394128 |
| Amphi 4 | 43792 | 1 | 43792 | 9 | 394128 |
| Amphi 5 | 43792 | 1 | 43792 | 9 | 394128 |
| CC 1 | 2486 | 1 | 2486 | 9 | 22374 |
| CC 2 | 2389 | 1 | 2389 | 9 | 21501 |
| CC 3 | 2195 | 1 | 2195 | 9 | 19755 |
| responsable | 161 | 1 | 161 | 9 | 1449 |
| Labo phy 1 | 2092 | 1 | 2092 | 9 | 18828 |
| Labo phy 2 | 2284 | 1 | 2284 | 9 | 20556 |
| Labo phy 3 | 2686 | 1 | 2686 | 9 | 24174 |
| | | | 245371 | 216 | 2208,339 |

**TableA.2 :** table represents the detailed power consumption of each area

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Corridor 1 | Lamps | 40 | 32 | 1280 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Corridor 2 | Lamps | 40 | 38 | 1520 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Corridor 3 | Lamps | 16 | 12 | 192 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Baths 1,2 | Lamps | 16 | 6 | 96 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Laboratory | Lamps | 40 | 14 | 560 |
| | air-conditioner | 1900 | 1 | 1900 |
| | oscilloscope | 60 | 8 | 480 |
| | Generator | 30 | 6 | 180 |
| | Multimeter | 11 | 2 | 22 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Class | Lamps | 40 | 13 | 520 |

| Area | Components | Power | N° of compo | Total power(w) |
|---|---|---|---|---|
| Amphi1,2,3 | Lamps | 16w | 112 | 7168w |
| | air-conditioner | 14000w | 12 | 168000w |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Amphi 4 | Lamps | 16 | 72 | 1152 |
| | air-conditioner | 14 | 2 | 28000 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| CC 04 | Lamps | 16 | 16 | 256 |
| | air-conditioner | 1900 | 1 | 1900 |
| | PC | 33 | 10 | 330 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| CC 05 | Lamps | 16 | 12 | 192 |
| | air-conditioner | 1900 | 1 | 1900 |
| | PC | 33 | 9 | 297 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| CC 06 | Lamps | 16 | 4 | 64 |
| | air-conditioner | 1900 | 1 | 1900 |
| | PC | 33 | 7 | 231 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Bureau responsable | Lamps | 16 | 8 | 128 |
| | PC | 33 | 1 | 33 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Labo 1 | Lamps | 16 | 12 | 192 |
| | air-conditioner | 1900 | 1 | 1900 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Labo 2 | Lamps | 16 | 24 | 384 |
| | air-conditioner | 1900 | 1 | 1900 |

| Area | Components | Power | N° of compo | Total power |
|---|---|---|---|---|
| Labo 3 | Lamps | 16 | 12 | 192 |
| | air-conditioner | 1900 | 1 | 1900 |

| Area | components | Power | N of comp | Total power |
|---|---|---|---|---|
| foyer | lamp | 18 | 20 | 360 |
| | microwave | 800 | 1 | 800 |
| | printer | 48 | 2 | 96 |
| | Air-conditioner | 48 | 1 | 48 |

**TableA.3:** the peak power of each month

| month | Eb(kw) | Pi(kw/m²) | Ei(kw/m²) | Pr | Pc(kwc) |
|---|---|---|---|---|---|
| january | 245,371 | 1 | 189,82 | 0,65 | 1,98869374 |
| february | 245,371 | 1 | 164,59 | 0,65 | 2,29354059 |
| March | 245,371 | 1 | 193,15 | 0,65 | 1,95440769 |
| april | 245,371 | 1 | 201,26 | 0,65 | 1,87565262 |
| may | 245,371 | 1 | 211,55 | 0,65 | 1,78441903 |
| june | 245,371 | 1 | 214,15 | 0,65 | 1,76275436 |
| july | 245,371 | 1 | 223,83 | 0,65 | 1,68652033 |
| august | 245,371 | 1 | 219,55 | 0,65 | 1,71939807 |
| september | 245,371 | 1 | 184,96 | 0,65 | 2,04094856 |
| october | 245,371 | 1 | 196,53 | 0,65 | 1,92079502 |
| november | 245,371 | 1 | 153,02 | 0,65 | 2,46695756 |
| december | 245,371 | 1 | 133,63 | 0,65 | 2,8249184 |

Détail de l'abonné : 8391724

| | |
|---|---|
| Nom Client | UNIVERSITE AMMAR TELIDJI |
| Adresse client | LAGHOUAT |
| Reference | 039021201724125 |
| Nom abonné | UNIV 2000 PLACE PEDAGOGIQUES |
| Adresse | LAGHOUAT |
| Num Poste | 1609 Détail de GDO MT |
| N° Police | 10/16 |
| N° X 577 | 12582 |

Cadrans | Factures | Créances

Hist. Payement | Hist. Consomation

| | |
|---|---|
| Tarif | E42 |
| Activite économique | V750 LOCAUX ET LABORATOIRES DE L'EN |
| PMD / DMD | 5000 |
| Date Création | 27/09/2017 |
| Loc. Comptage | 0,00 |
| Loc. Transf. | 0,00 |
| Entretien Poste | 0,00 |

## Liste des Factures de l'abonné : 039021201724125

| N° de Facture | Date Facture | Energie Facture (Kwh) | Montant Facture |
|---|---|---|---|
| 831709000836 | 01/10/2017 | 67 918 | 3 260 916,03 |
| 831710000842 | 01/11/2017 | 23 657 | 322 183,06 |
| 831711000841 | 03/12/2017 | 23 065 | 323 582,14 |
| 831712000842 | 01/01/2018 | 27 041 | 341 611,65 |
| 831801000839 | 01/02/2018 | 28 797 | 344 492,06 |
| 831802000845 | 01/03/2018 | 32 959 | 362 603,23 |
| 831803000846 | 01/04/2018 | 29 881 | 352 339,15 |
| 831804000838 | 01/05/2018 | 22 596 | 321 646,55 |
| 831805000022 | 28/05/2018 | 30 546 | 103 465,16 |
| 831805000859 | 03/06/2018 | 16 690 | 298 026,11 |
| 831806000874 | 01/07/2018 | 13 185 | 284 212,54 |
| 831807000853 | 01/08/2018 | 16 738 | 300 627,48 |
| 831808000851 | 02/09/2018 | 38 853 | 434 201,03 |
| 831809000865 | 01/10/2018 | 37 070 | 377 978,85 |
| 831810000867 | 01/11/2018 | 22 985 | 322 467,57 |
| 831811000877 | 02/12/2018 | 25 979 | 335 267,03 |
| 831812000885 | 02/01/2019 | 27 139 | 339 363,53 |
| 831901000885 | 03/02/2019 | 29 797 | 348 457,24 |
| 831902000893 | 03/03/2019 | 26 376 | 337 196,87 |
| 831903000895 | 01/04/2019 | 24 760 | 331 747,29 |
| 831904000892 | 02/05/2019 | 25 989 | 334 306,17 |
| 831905000887 | 02/06/2019 | 26 097 | 355 784,76 |
| 831906000889 | 01/07/2019 | 55 590 | 466 610,01 |
| 831907000886 | 01/08/2019 | 72 939 | 542 844,48 |
| 831908000889 | 01/09/2019 | 59 808 | 477 164,60 |
| 831909000886 | 01/10/2019 | 56 449 | 470 107,77 |
| 831910000887 | 03/11/2019 | 61 994 | 488 524,66 |
| 831911000889 | 01/12/2019 | 72 217 | 522 231,9[illegible] |

**Figure A.1 :** The SNG bills of our department

# Appendix B:Sizing and forecasting results

| PVSYST V6.64 | | 21/05/20 | Page 1/3 |
|---|---|---|---|

## Grid-Connected System: Simulation parameters

**Project :** laghouat

| | | | | |
|---|---|---|---|---|
| **Geographical Site** | **Laghouat** | | Country | **Algérie** |
| **Situation** | Latitude | 33.47° N | Longitude | 2.51° E |
| Time defined as | Legal Time | Time zone UT+1 | Altitude | 764 m |
| | Albedo | 0.20 | | |
| **Meteo data:** | **laghouat** | Meteonorm 7.1 (1986-2005), Sat=100% - Synthétique | | |

**Simulation variant :** sizing

Simulation date 21/05/20 23h28

**Simulation parameters**

| | | | | |
|---|---|---|---|---|
| **Collector Plane Orientation** | Tilt | 30° | Azimuth | 0° |
| **Models used** | Transposition | Perez | Diffuse | Perez, Meteonorm |
| **Horizon** | Free Horizon | | | |
| **Near Shadings** | No Shadings | | | |

**PV Array Characteristics**

| | | | | |
|---|---|---|---|---|
| **PV module** Si-poly | Model | **Poly 250 Wp 60 cells** | | |
| Original PVsyst database | Manufacturer | Generic | | |
| Number of PV modules | In series | 16 modules | In parallel | 46 strings |
| Total number of PV modules | Nb. modules | 736 | Unit Nom. Power | 250 Wp |
| Array global power | Nominal (STC) | **184 kWp** | At operating cond. | 165 kWp (50°C) |
| Array operating characteristics (50°C) | U mpp | 437 V | I mpp | 377 A |
| Total area | Module area | **1197 m²** | Cell area | 1073 m² |

| | | | | |
|---|---|---|---|---|
| **Inverter** | Model | **12 kWac inverter** | | |
| Original PVsyst database | Manufacturer | Generic | | |
| Characteristics | Operating Voltage | 350-600 V | Unit Nom. Power | 12.0 kWac |
| | | | Max. power (=>25°C) | 14.0 kWac |
| Inverter pack | Nb. of inverters | 12 units | Total Power | 144 kWac |

**PV Array loss factors**

| | | | | |
|---|---|---|---|---|
| Thermal Loss factor | Uc (const) | 20.0 W/m²K | Uv (wind) | 0.0 W/m²K / m/s |
| Wiring Ohmic Loss | Global array res. | 20 mOhm | Loss Fraction | 1.5 % at STC |
| Module Quality Loss | | | Loss Fraction | -0.8 % |
| Module Mismatch Losses | | | Loss Fraction | 1.0 % at MPP |
| Strings Mismatch loss | | | Loss Fraction | 0.10 % |
| Incidence effect, ASHRAE parametrization | IAM = | 1 - bo (1/cos i - 1) | bo Param. | 0.05 |

**User's needs :** Unlimited load (grid)

**Figure B.1:** sizing report using PVsys page 1

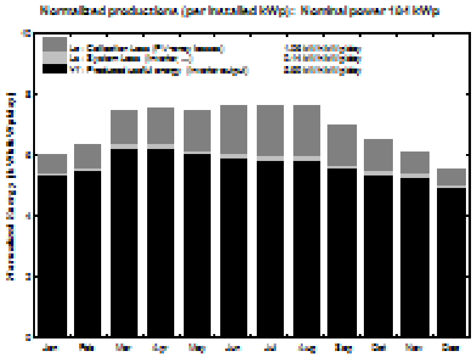
| PVSYST V6.64 | | 21/05/20 | Page 2/3 |
|---|---|---|---|

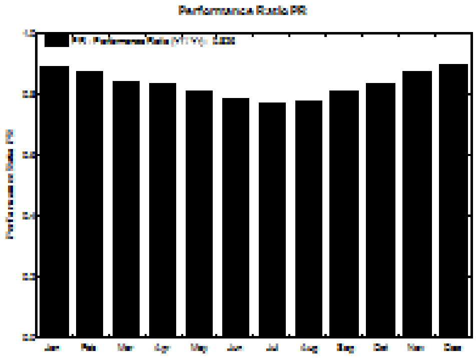
## Grid-Connected System: Main results

**Project :** laghouat
**Simulation variant :** sizing

| | | | | |
|---|---|---|---|---|
| **Main system parameters** | System type | **Grid-Connected** | | |
| PV Field Orientation | tilt | 30° | azimuth | 0° |
| PV modules | Model | Poly 250 Wp 60 cells | Pnom | 250 Wp |
| PV Array | Nb. of modules | 736 | Pnom total | **184 kWp** |
| Inverter | Model | 12 kWac inverter | Pnom | 12.00 kW ac |
| Inverter pack | Nb. of units | 12.0 | Pnom total | **144 kW ac** |
| User's needs | Unlimited load (grid) | | | |

| | | | | |
|---|---|---|---|---|
| **Main simulation results** | | | | |
| System Production | **Produced Energy** | **382082 kWh/year** | Specific prod. | 2077 kWh/kWp/year |
| | Performance Ratio PR | 82.63 % | | |




**sizing**
**Balances and main results**

| | GlobHor kWh/m² | DiffHor kWh/m² | T Amb °C | GlobInc kWh/m² | GlobEff kWh/m² | EArray kWh | E_Grid kWh | PR |
|---|---|---|---|---|---|---|---|---|
| January | 114.8 | 20.22 | 7.02 | 186.5 | 182.4 | 31266 | 30548 | 0.880 |
| February | 125.1 | 27.65 | 9.14 | 176.6 | 172.7 | 29040 | 28376 | 0.873 |
| March | 187.9 | 35.16 | 13.52 | 230.5 | 225.7 | 36548 | 35683 | 0.841 |
| April | 212.8 | 46.44 | 16.20 | 225.5 | 219.3 | 35294 | 34440 | 0.830 |
| May | 243.0 | 54.66 | 21.66 | 231.4 | 224.5 | 35344 | 34515 | 0.811 |
| June | 250.6 | 48.97 | 26.92 | 227.0 | 220.1 | 33655 | 32861 | 0.787 |
| July | 254.2 | 51.55 | 31.38 | 236.6 | 229.9 | 34171 | 33365 | 0.767 |
| August | 230.6 | 51.12 | 29.63 | 234.8 | 226.7 | 34156 | 33361 | 0.772 |
| September | 180.8 | 50.07 | 23.66 | 207.7 | 202.4 | 31516 | 30784 | 0.806 |
| October | 150.3 | 37.45 | 19.60 | 201.5 | 197.0 | 31482 | 30738 | 0.829 |
| November | 116.4 | 22.95 | 11.76 | 183.5 | 179.7 | 29968 | 29274 | 0.867 |
| December | 101.8 | 21.30 | 8.19 | 171.4 | 167.6 | 28779 | 28127 | 0.882 |
| Year | 2170.3 | 468.86 | 18.31 | 2519.0 | 2450.0 | 391173 | 382082 | 0.826 |

| | | | | |
|---|---|---|---|---|
| Legends: | GlobHor | Horizontal global irradiation | GlobEff | Effective Global, corr. for IAM and shadings |
| | DiffHor | Horizontal diffuse irradiation | EArray | Effective energy at the output of the array |
| | T Amb | Ambient Temperature | E_Grid | Energy injected into grid |
| | GlobInc | Global incident in coll. plane | PR | Performance Ratio |

**Figure B.2:** sizing report using PVsys page 2

| PVSYST V6.64 | | 21/05/20 | Page 3/3 |
|---|---|---|---|

## Grid-Connected System: Loss diagram

**Project :** laghouat

**Simulation variant :** sizing

| | | | | | |
|---|---|---|---|---|---|
| **Main system parameters** | System type | **Grid-Connected** | | | |
| PV Field Orientation | tilt | 30° | azimuth | 0° | |
| PV modules | Model | Poly 250 Wp 60 cells | Pnom | 250 Wp | |
| PV Array | Nb. of modules | 736 | Pnom total | **184 kWp** | |
| Inverter | Model | 12 kWac inverter | Pnom | 12.00 kW ac | |
| Inverter pack | Nb. of units | 12.0 | Pnom total | **144 kW ac** | |
| User's needs | Unlimited load (grid) | | | | |

**Loss diagram over the whole year**

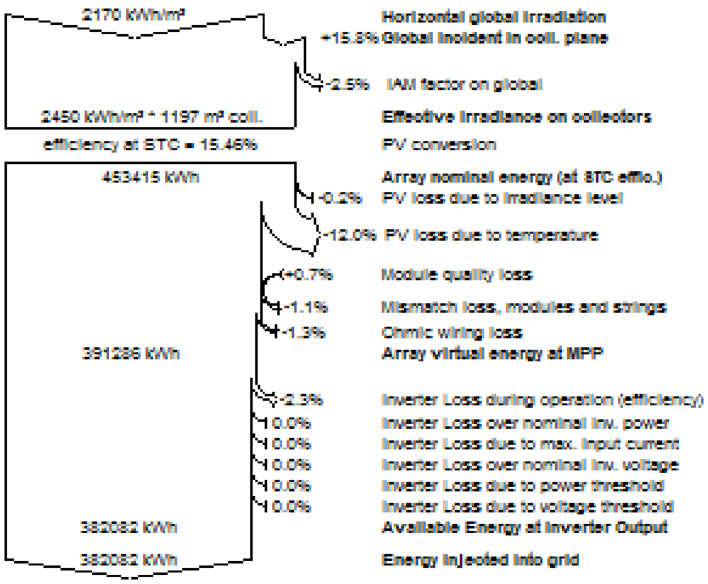
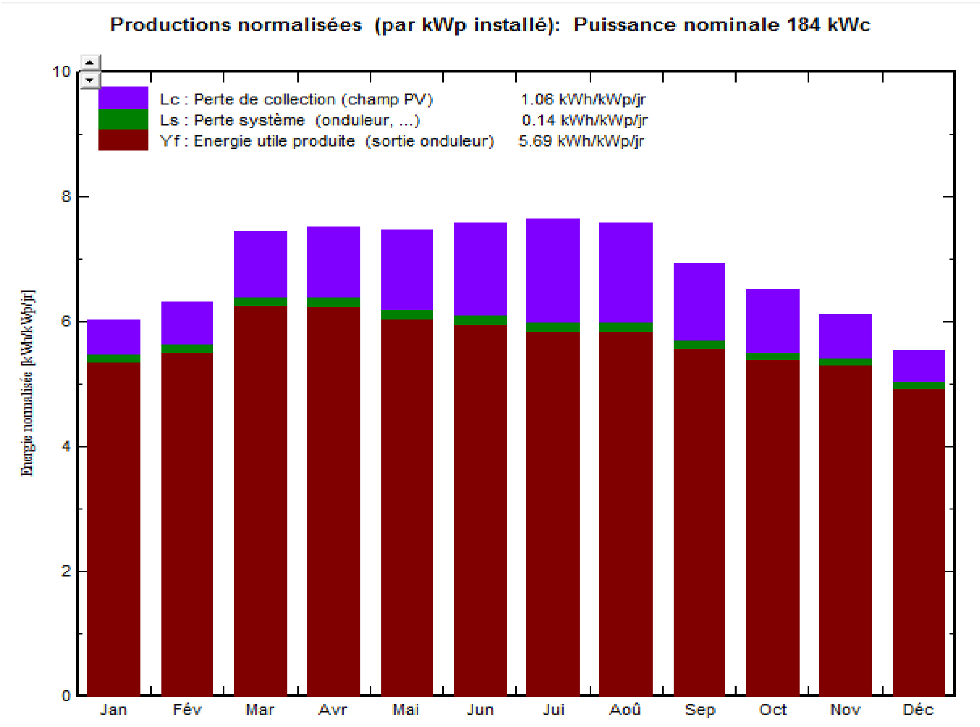



**Figure B.3:** sizing report using PVsys page 3




**FigureB.4**: the loss of PV power

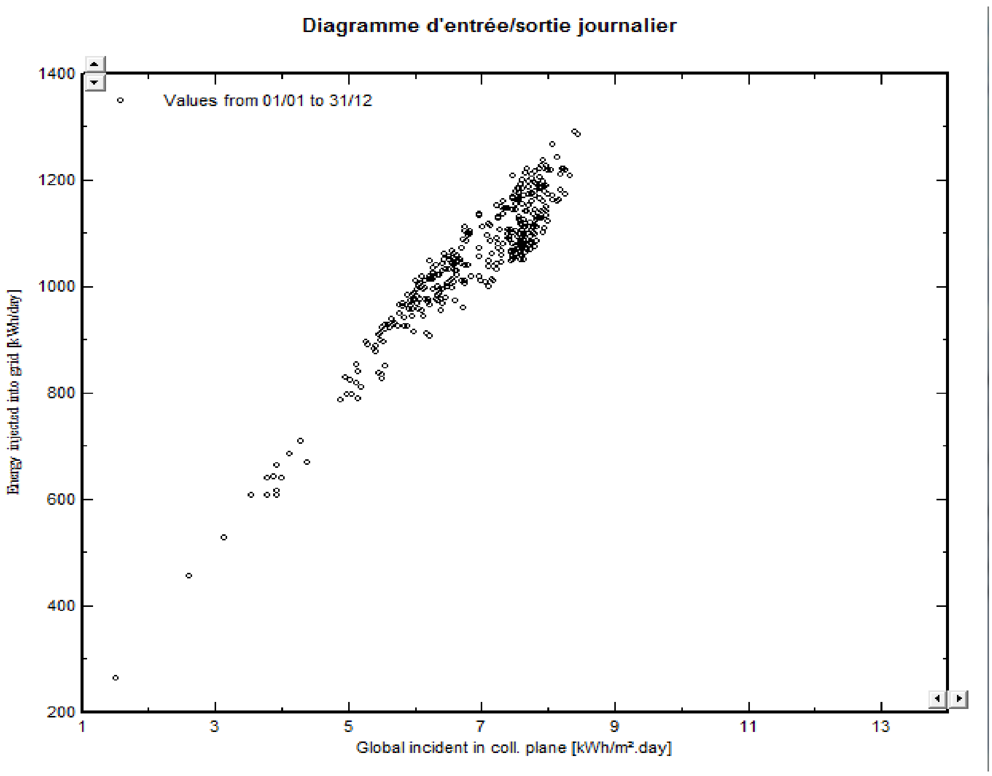



**Figure B.5 :** the energy injected into grid

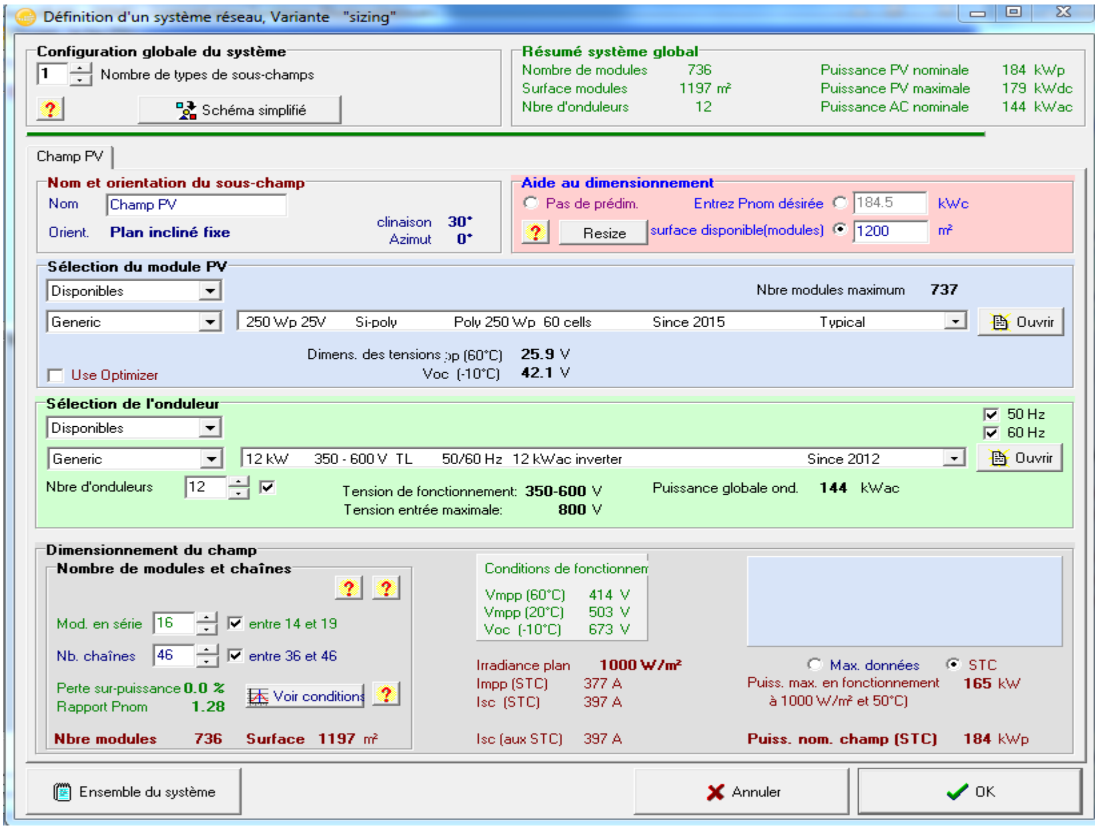



**Figure B.6:** the parameter of PVsys sizing

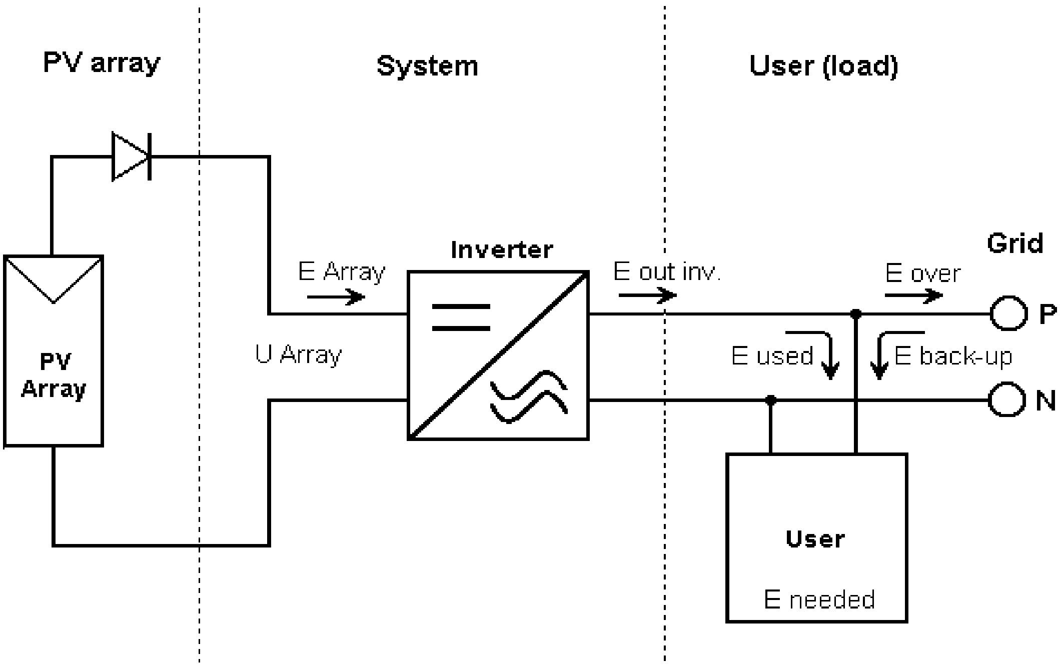


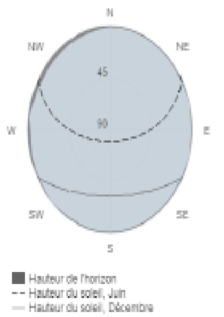

**Figure B.7 :** the PV system scheme

PVGIS-5 base de données géo-temporelles d'irradiation

**Entrées fournies**

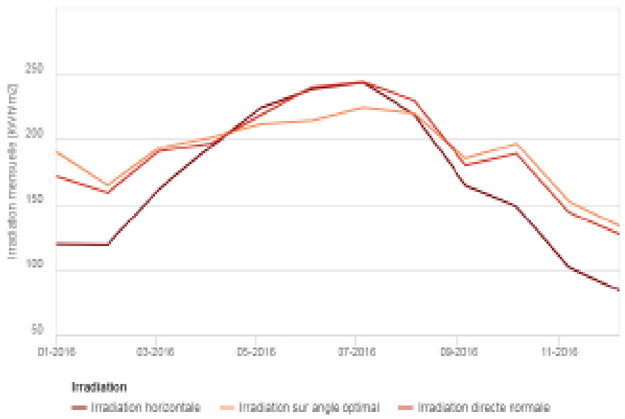
| | |
|---|---|
| Latitude/Longitude: | 33.791, 2.846 |
| Horizon: | Calculé |
| Base de données | PVGIS-SARAH |
| Année de début: | 2016 |
| Année finale: | 2016 |
| Variables inclus dans ce rapport: | |
| Irradiation globale horizontale: | Oui |
| Irradiation directe normale: | Oui |
| Irradiation globale angle optimal: | Oui |
| Irradiation globale pour l'angle * | Non |
| Ratio diffus/global | Non |
| Température moyenne | Non |

**Ligne d'horizon:**




**Irradiation solaire mensuelle**

**Irradiation solaire mensuelle**




| Irradiation globale horizontale | | Irradiation directe normale | | Irradiation globale angle optimal | |
|---|---|---|---|---|---|
| **Mois** | **2016** | **Mois** | **2016** | **Mois** | **2016** |
| Janvier | 119.69 | Janvier | 171.57 | Janvier | 189.82 |
| Février | 119.17 | Février | 158.85 | Février | 164.59 |
| Mars | 161.71 | Mars | 190.64 | Mars | 193.15 |
| Avril | 193.77 | Avril | 196.44 | Avril | 201.26 |
| Mai | 223.9 | Mai | 218.44 | Mai | 211.55 |
| Juin | 237.92 | Juin | 239.42 | Juin | 214.15 |
| Juillet | 242.92 | Juillet | 243.18 | Juillet | 223.83 |
| Août | 218.56 | Août | 229.29 | Août | 219.55 |
| Septembre | 164.48 | Septembre | 179.75 | Septembre | 184.96 |
| Octobre | 148.54 | Octobre | 188.7 | Octobre | 196.53 |
| Novembre | 102.53 | Novembre | 144.68 | Novembre | 153.02 |
| Décembre | 84.34 | Décembre | 126.96 | Décembre | 133.63 |

**Figure B.8:** the PVgis report of monthly irradiation


**Figure B.9 :** surface calculation using Google Earth data

1x1 struct with 12 fields

| Field | Value |
|---|---|
| Date | 7344x1 cell |
| Hour | 7344x1 double |
| DryBulb | 7344x1 double |
| DewPnt | 7344x1 double |
| SYSLoad | 7344x1 double |
| irradiation | 7344x1 double |
| pression | 7344x1 double |
| vitessevent | 7344x1 double |
| pluie | 7344x1 double |
| humidite | 7344x1 double |
| coucheretlever | 7344x1 double |
| holiday | 7344x1 double |

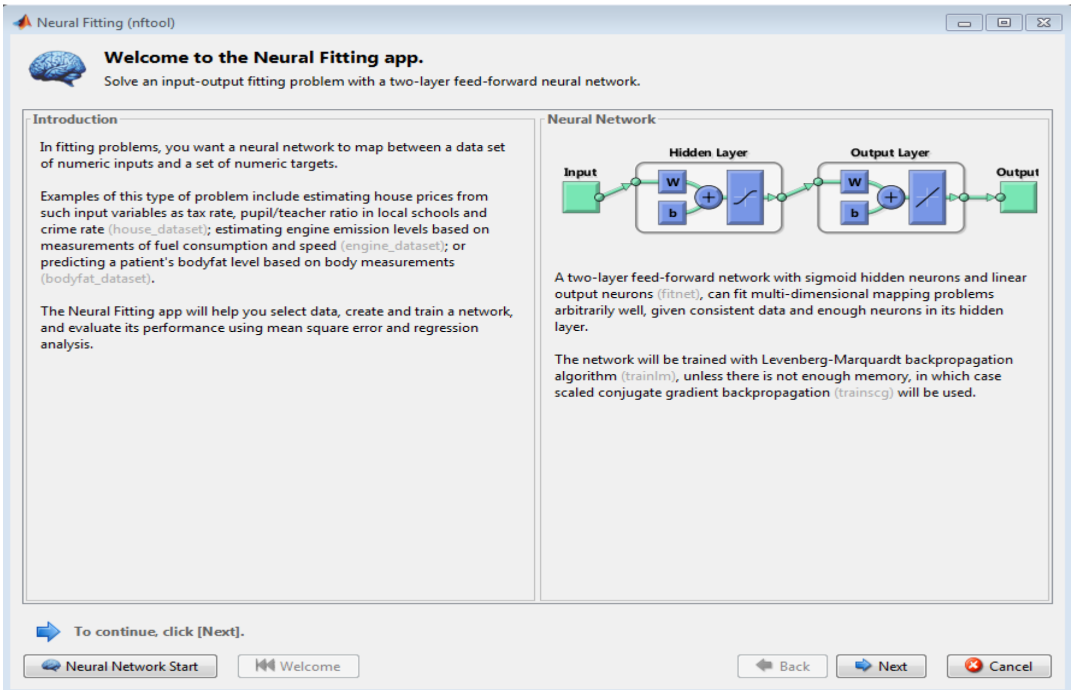
**Figure B.10 :** the different steps of inserting the outputsMATLAB

```
data =

              Date: {7344x1 cell}
              Hour: [7344x1 double]
           DryBulb: [7344x1 double]
            DewPnt: [7344x1 double]
           SYSLoad: [7344x1 double]
           NumDate: [7344x1 double]
       irradiation: [7344x1 double]
          pression: [7344x1 double]
       vitessevent: [7344x1 double]
             pluie: [7344x1 double]
          humidite: [7344x1 double]
    coucheretlever: [7344x1 double]
           holiday: [7344x1 double]

fx >>
```

**Figure B.11 :** adjusting the outputs using a MATLAB code



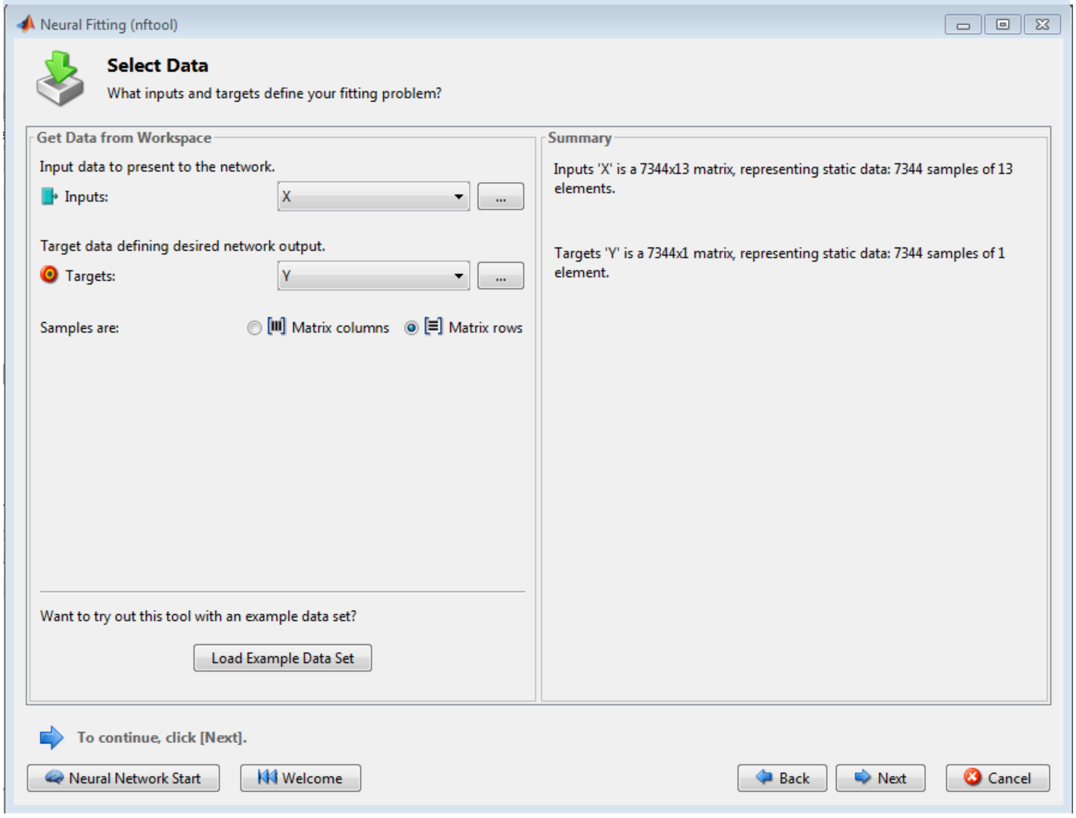




**Figure B.12 :** the different steps of using NN in MATLAB

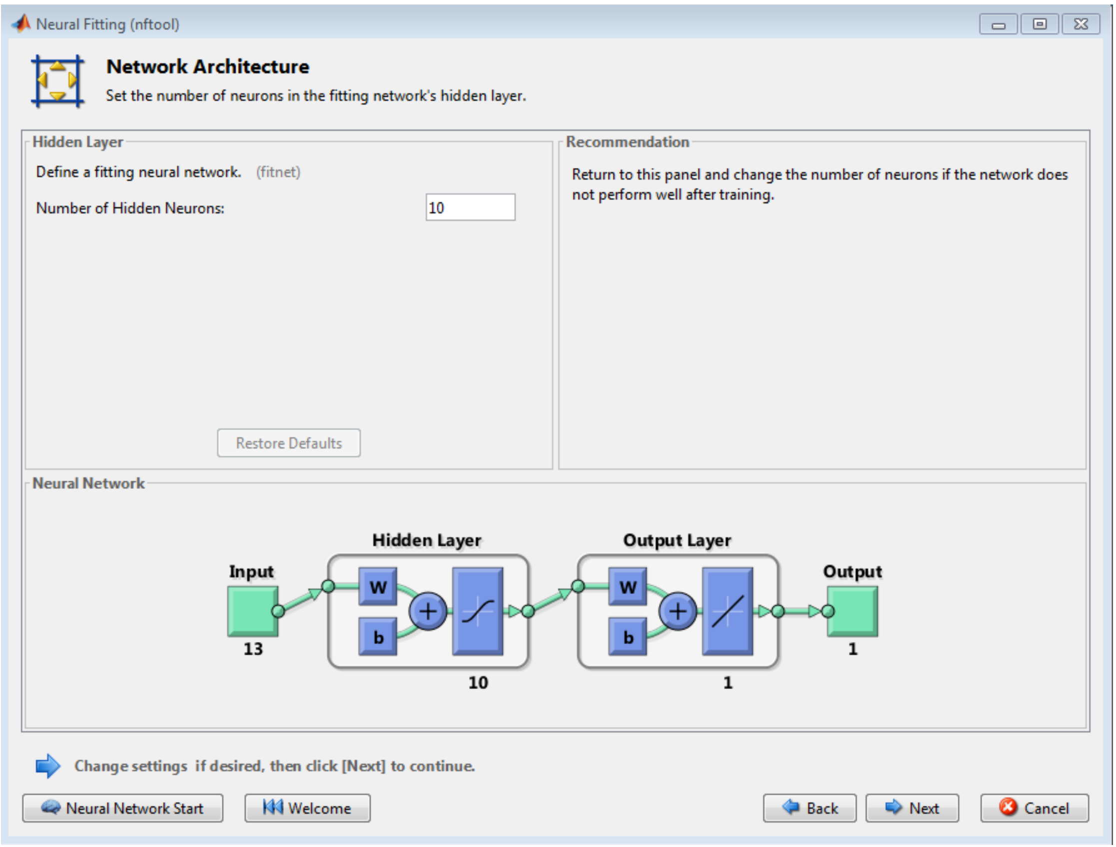
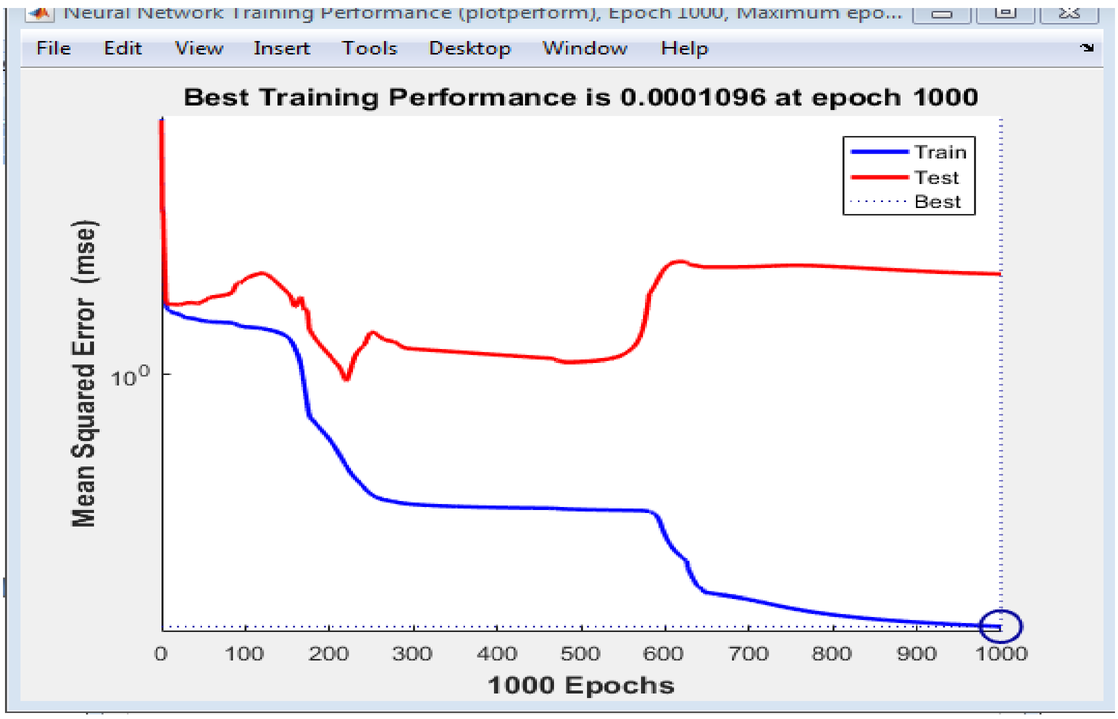



**Figure B.13 :** the architecture of NN in MATLAB




**FigureB.14:** the graph represents the errors

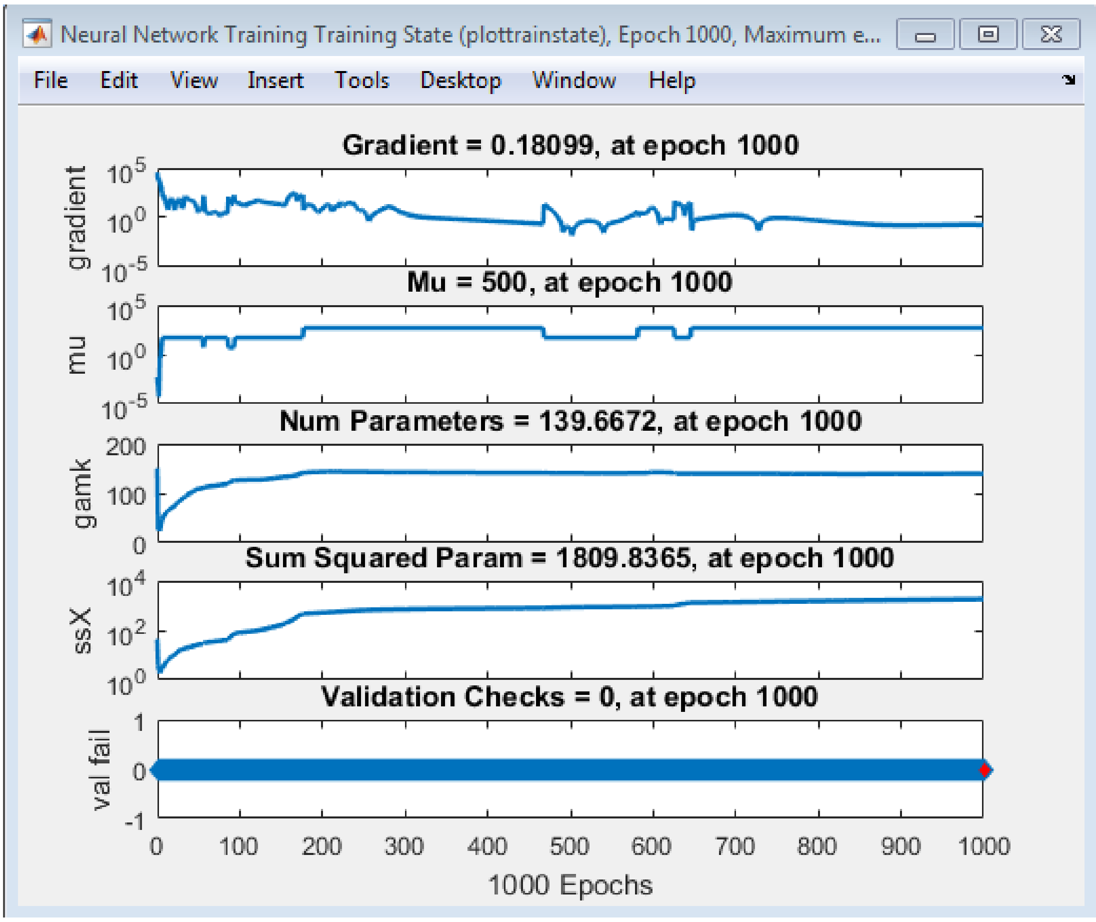



**Figure B.15:** the graphs represents the different results of the training parameters

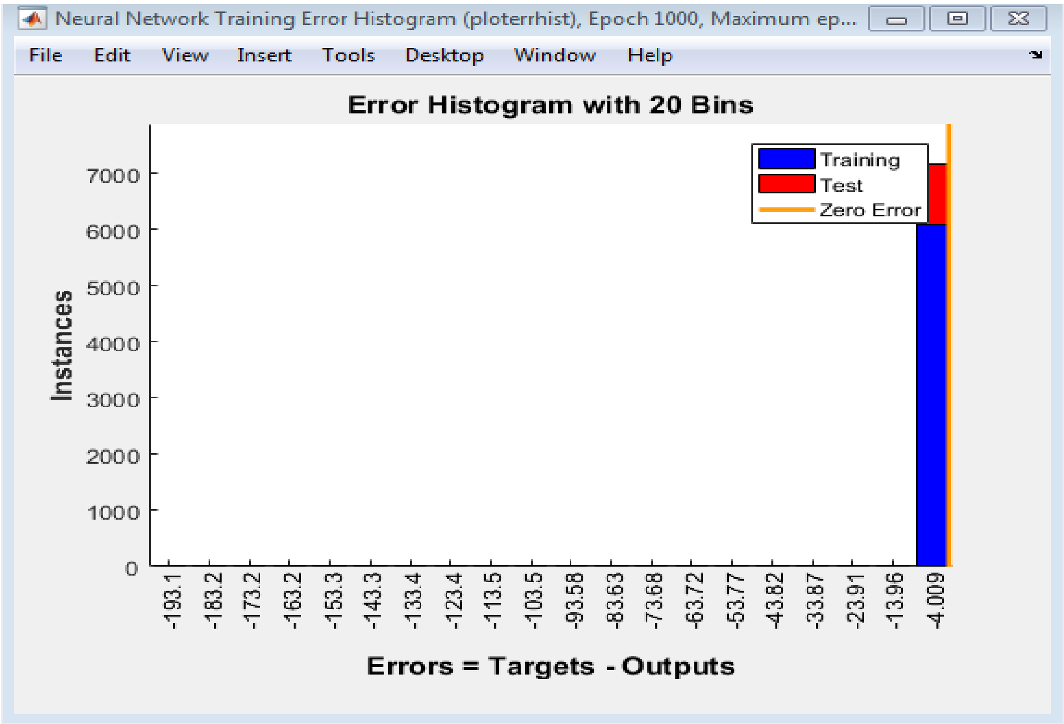



**Figure B.16:** the graph represents the errors histogram

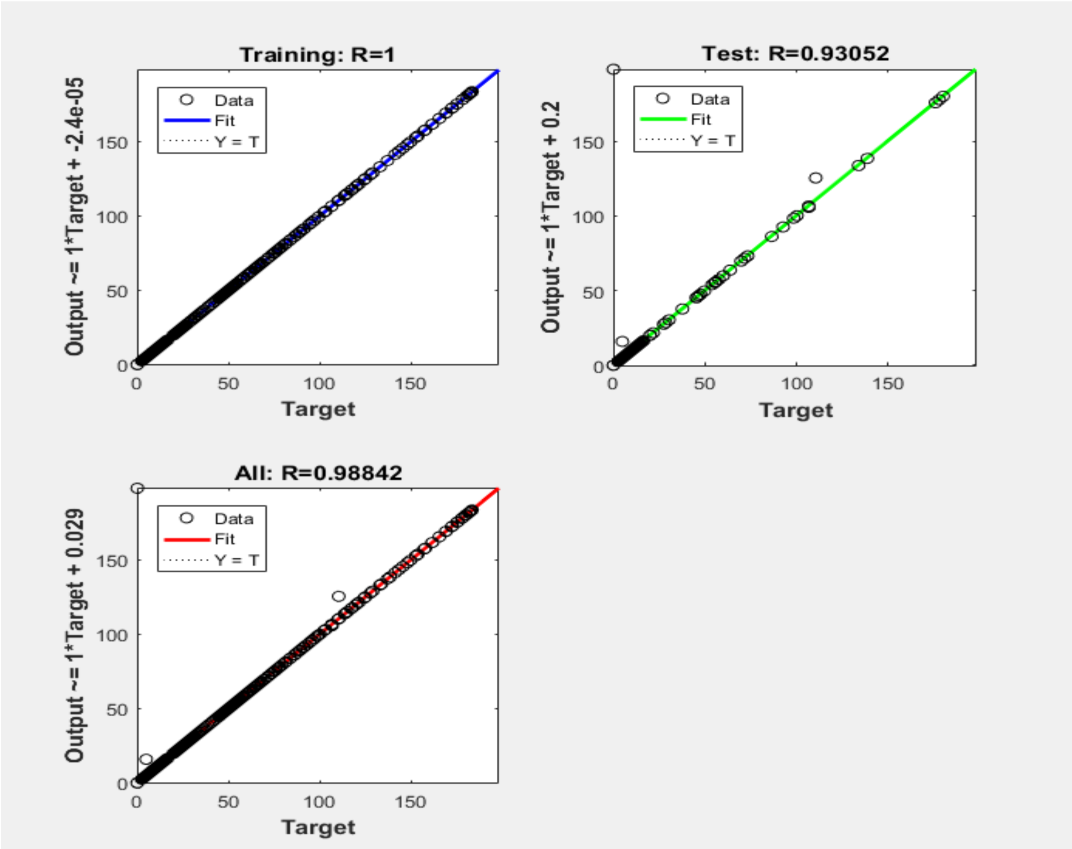



**Figure B.17:** the graph represents the target results vs the inputs

# Appendix C:Data sheets of the equipments

# IFRISOL

Du soleil à la lumière sur mesure

IF-P280-72
IF-P300-72
IF-P310-72
IF-P320-72

## Module photovoltaïque ultra-performant

### 72 cellules / module photovoltaïque polycristallin

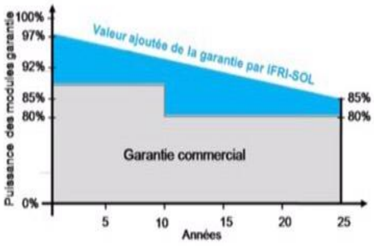

**Caractéristiques principales:**

- 10 ans de garantie sur le produit
- Tolérance de puissance de sortie strictement positive (0 à 5 Wc)
- Excellente performance sous faibles irradiation
- Excellente résistance aux conditions extérieures
- Résistance maximale à l'avant du module 5400 Pa
- Résistance maximale à l' arrière du module 2400 Pa

### Performance linear garantie

10 ans de garantie sur la production de 92% de puissance de sortie[1]

25 ans de garantie sur la production de 85% de puissance de sortie[1]




Système de management certifié selon la norme DIN ISO 9001:2008
**ID 9102077424**

TÜVRheinland CERTIFIED

[1]Selon le certificat de service IFRISOL en vigueur au moment de l'achat

# IF-P280-72
# IF-P300-72
# IF-P310-72
# IF-P320-72

**IFRISOL**
Du soleil à la lumière sur mesure

## Spécifications électriques

| Type module | Puissance nominale Pmpp | Tension au point de puissance maximale Umpp | Courant au point de puissance maximale Impp | Tension en circuit ouvert Uoc | Courant de court circuit Isc | Rendement module |
|---|---|---|---|---|---|---|
| IF-P280-72 | 280 Wc | 35.26V | 7.97A | 44.70V | 8.49A | 14.43% |
| IF-P300-72 | 300 Wc | 36.41V | 8.24A | 45.20V | 8.73A | 16.46% |
| IF-P310-72 | 310 Wc | 37.00V | 8.38A | 45.45V | 8.85A | 15.97% |
| IF-P320-72 | 320 Wc | 37.56V | 8.52A | 45.82V | 9.03A | 16.49% |

Caractéristiques électriques sous les conditions standard de test : irradiation 1000W/m², température de cellule 25°C, masse d'air 1.5g selon EN 60904-3,

## Design

| | |
|---|---|
| Verre | Verre trempé de 3.2mm d'épaisseur / haute transparence / faible teneur en fer |
| Encapsulant | E.V.A |
| Cellule | 72 cellules polycristalline en série / 156mm*156mm |
| Backsheet | Film composite (blanc, noir, ...) |
| Frame | Profilé creux en aluminium anodisé |

## Valeurs limites

| | |
|---|---|
| Tension maximale du système | 1000V CC |
| NOCT | 47±2°C |
| Courant inverse maximal | 12A |
| Température de fonctionnement | de -40°C à 85°C |
| Pression maximale | 2400N/m² |

## Spécification mécanique

| | |
|---|---|
| Dimensions (L×L ×H) | 1956mm × 992mm × 40mm |
| Poids | 23Kg |

## Spécifications thermiques

| | |
|---|---|
| CT de la tension en circuit ouvert | -0.330%/°C |
| CT de courant en court circuit | +0.058%/°C |
| CT de puissance | -0.410%/°C |

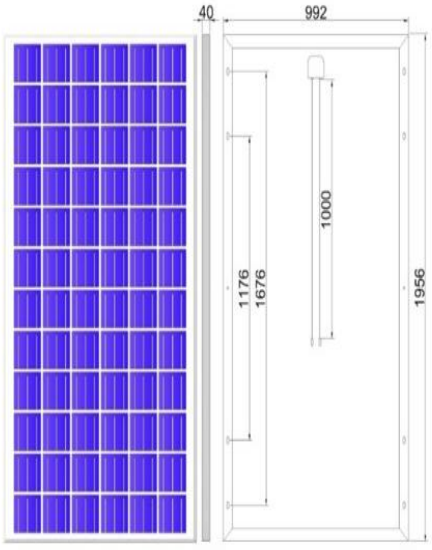
## Connecteurs

| | |
|---|---|
| Boite de Junction | Un boitier avec 3 diodes de dérivation (IP67) |
| Câble solaire | Câble solaire d'une longueur de 1000 mm, 4mm², préfabriqué avec connecteur compatible MC4 (IP67) |
| Application | Classe A (Selon IEC 61730) |

## Conditionnement

| | |
|---|---|
| Dimensions (L×L ×H) | 1970mm × 1065mm × 1140mm |
| Quantité de module / 20' | 260 |
| Quantité de module / 40' | 572 |

## Schéma




Dimensions en mm



**IFRISOL**
Phone +216 73 381 853

## -the datasheet of the inverter:

| Technical data | Sunny Tripower CORE1 (US) | Sunny Tripower CORE1 (IEC) |
|---|---|---|
| **Input (DC)** | | |
| Max. array power | 75000 Wp STC | 75000 Wp STC |
| DC voltage (max) | 1000 V | 1000 V |
| Rated MPP voltage range | 500 V ... 800 V | 500 V ... 800 V |
| MPPT operating voltage range | 150 V ... 1000 V | 150 V ... 1000 V |
| Min. DC voltage / start voltage | 150 V / 188 V | 150 V / 188 V |
| Number of independent MPP trackers / strings per MPP input | 6 / 2 | 6 / 2 |
| Max. operating input current / per MPP tracker | 120 A / 20 A | 120 A / 20 A |
| Max. short circuit current per MPPT / string input | 30 A / 30 A | 30 A / 30 A |
| **Output (AC)** | | |
| AC nominal power | 50000 W | 50000 W |
| Max. AC apparent power | 53000 VA | 50000 VA |
| Output phases / line connections | 3 / 3-(N)-PE | 3 / 3-(N)-PE |
| Nominal AC voltage | 480 V / 277 V WYE | 400 V / 230 V |
| AC voltage range | 244 V ... 305 V | 202 ... 264 V |
| Rated AC grid frequency | 60 Hz | 50 Hz |
| AC grid frequency / range | 50 Hz, 60 Hz / -6 Hz ... +5Hz | 50 Hz, 60 Hz / -6 Hz ... +5Hz |
| Max. output current | 64 A | 72.5 A |
| Power factor at rated power / adjustable displacement | 1 / 0.0 leading ... 0.0 lagging | 1 / 0.0 leading ... 0.0 lagging |
| Harmonics THD | <3 % | <3 % |
| **Efficiency** | | |
| Max. efficiency / CEC efficiency / European efficiency | 98.3 % / 98 % / - | 98.1 % / - / 97.8 % |
| **Protection devices** | | |
| Load rated DC disconnect switch | ● | ● |
| Load rated AC disconnect switch | ● | - |
| DC reverse polarity protection | ● | ● |
| Ground fault monitoring / grid monitoring | ● / ● | ● / ● |
| All-pole sensitive residual current monitoring | ● | ● |
| DC AFCI compliant to UL 1699B | ● | - |
| DC surge arrester (Type II) | ○ | ○ |
| AC short circuit protection | ● | ● |
| AC surge arrester (Type II) | ○ | ○ |
| Protection class / overvoltage category (as per UL840) | I / IV | - |
| Protection class (as per IEC 60664-1) / overvoltage category (as per IEC 60664-1) | - | I / AC: III; DC: II |