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MEMORY

To obtain the master's degree

MASTER IN ELECTRICAL ENGINEERING

Specialty: renewable energies in electrotechnical

Presented by

SULAIMAN ABUTEIR

EVALUATION AND SIZING OF THE NAAMA PHOTOVOLTAIC POWER PLANT.

Supported on 25/06/2023 before the jury composed of:

President: Mr. Chaouch Abdallah	MCA	University of Mostaganem
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Thanks

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Mr. Bekkouche Benaissa Professor at the University of Mostaganem, Mr. Chaouch Abdallah Professor at the University of Mostaganem, for having done me the honor of agreeing to be the examiners of this dissertation.

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All my respect and my gratitude to all those who have contributed directly or indirectly to the realization of this work.

Dedication

I dedicate this modest work to: To my dear parents, for all their sacrifices, their love, their support and their prayers throughout my studies, thanks to them that I have made it this far today, I hope that one day I will be able to give them at least the minimum because no matter what happens we will never manage to give them everything back.

To my dear brothers and sisters for all the support you have given me.

Thank you for always being by my side.

Abstract:

With the increasing demand for energy in the world in general and in Algeria in particular, renewable energies have emerged as an effective solution in promoting economic growth. At the national and international levels, renewable energies play an important role in the Algerian program dedicated to the advancement and promotion of energy efficiency, and this study concerns a comprehensive assessment of the size of photovoltaic power plant with a capacity of 20 MW located in the city of Naama according to international specifications. Therefore, we explained everything related to photovoltaic energy and the scaling of all elements of the plant, and finally, using the PVSYST software, we simulated the plant and obtained the results of the plant, and these results indicate that the performance index is good and its value is approximately 81.8% and contributed on the one hand to knowing the location of the plant in terms of energy production at the national level, and on the other hand contribute to the development of the construction of other photovoltaic plants programmed by the Algerian government.

Keywords: photovoltaic power plant, performance index, sizing, renewable energies, Algerian program for energy development, PVSYST software.

Résumé:

Avec la demande croissante d'énergie dans le monde en général et l'Algérie en particulier, les énergies renouvelables sont apparues comme un atout efficace pour favoriser la croissance économique. Aux niveaux national et international, les énergies renouvelables jouent un rôle important dans le programme algérien dédié à l'avancement et à la promotion de l'efficacité énergétique, et cette étude concerne un dimensionnement complet de la taille de la centrale photovoltaïque d'une capacité de 20 MW située dans la ville de Naama selon le cahier des charges international. Par conséquent, nous avons expliqué tout ce qui concerne l'énergie photovoltaïque et la mise à l'échelle de tous les éléments de la centrale, et enfin, à l'aide du logiciel PVSYST, nous avons simulé la centrale et obtenu les résultats de la centrale, et ces résultats donne un bon indice de performance de 81,8% est qui a contribué d'une part à connaître l'emplacement de la centrale en termes de production d'énergie au niveau national, et d'autre part au développement de la construction d'autres centrales photovoltaïques programmées par le gouvernement algérien.

Mots-clés: centrales photovoltaïques, indice de performance, dimensionnement, énergies renouvelables, programme algérien de développement énergétique, logiciel PVSYST.

ملخص :

مع تزايد الطلب على الطاقة في العالم بشكل عام وفي الجزائر بشكل خاص ، ظهرت الطاقات المتجددة كحل فعال في تعزيز النمو الاقتصادي. على المستويين الوطني والدولي ، تلعب الطاقات المتجددة دورًا مهمًا في البرنامج الجزائري المخصص للنهوض وتعزيز كفاءة الطاقة ، وتتعلق هذه الدراسة بتقييم شامل لحجم محطة الطاقة الكهروضوئية بقدرة 20 ميجاوات الموجودة في مدينة نعامة طبقا للمواصفات العالمية. لذلك قمنا بشرح كل ما يتعلق بالطاقة الكهروضوئية وتحجيم جميع عناصر المحطة ، وأخيرا باستخدام برنامج PVSYST قمنا بمحاكاة للمحطة و تحصلنا على نتائج المحطة ، وهذه النتائج تشير إلى أن مؤشر الأداء جيد وقيمته تقارب 81.8 ٪ وساهم من جهة في معرفة موقع المحطة من حيث انتاج الطاقة على المستوى الوطني ، ومن جهة أخرى في تطوير إنشاء محطات كهروضوئية أخرى ببرمجة الحكومة الجزائرية.

الكلمات المفتاحية: محطات الطاقة الكهروضوئية ، مؤشر الأداء ، التحجيم ، الطاقات المتجددة ، البرنامج الجزائري لتطوير الطاقة.، برنامج PVSYST.

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General Introduction

Energy production will pose a significant challenge in the upcoming years, as the energy demands of industrialized societies continue to rise. Additionally, developing countries will require increasingly more energy to support their development.

Energy serves as the foundation for all human activities. At present, a considerable portion of global energy production relies on fossil fuels. The consumption of these non-renewable sources leads to greenhouse gas emissions and contributes to pollution. Moreover, overconsumption of natural resources further diminishes the reserves of these energy sources, posing a significant risk for future generations. Consequently, it has become imperative to contemplate and embrace alternative solutions that have been developed and implemented to mitigate the environmental impact of energy consumption.

On a national scale, a horizontal surface of $1m^2$ typically receives around 5 KWh of energy per day. Algeria, in its energy strategy, places a high priority on the advancement of renewable energies and sustainable development. Given its strategic location at the intersection of energy routes, Algeria presents numerous investment opportunities in the field of solar thermal and photovoltaic energy. Because it has one of the largest solar deposits in the world, the duration of insolation on almost the entire national territory exceeds 2000 hours annually and reaches 3900 hours (highlands and Sahara). This energy is considered as an opportunity and a lever for economic and social development.

Currently, Algeria's energy strategy is based on accelerating the development of solar energy. Solar photovoltaics is of particular interest, which is visible by the presence of 23 photovoltaic power plants on the national territory and other projects with a capacity of 200 MW per year should be carried out over the period 2021-2030.

In order to exploit the potential available in Algeria, the Algerian government launched the national renewable energy and energy efficiency program, the latter of which was updated several times recently in 2020. This update will allow the country to produce 15 GW by 2035, 2.3% of which was completed in 2021 (21 photovoltaic power plants, 01 wind farms), accumulating a total power of 354.3 MW (344.1 MW PV, 10.2 MW Wind). [1]

In this work we evaluated and scaled the Naama photovoltaic power plant with a capacity of 20 MW implemented during this program and received in 2015. Therefore we have provided its dimensions and operation using the classical method and software design. Finally, we examined their performance and impact on the environment.

This study consists of three chapters distributed as follows:

- The first chapter is devoted to the types of renewable energies and the principles of their operation.
- The second chapter is devoted to the photovoltaic system, the effect of photovoltaic cells, the principles of their operation, Their Types, the method of their connection, electrical properties, installation, protection and, finally, the scaling of the photovoltaic power plant in Naima.
- The third chapter is devoted to the evaluation and scaling of the Naama photovoltaic power plant using the PV system software and we will process the analysis of the Metrological data of the site, simulate all system parameters, and calculate the performance and CO_2 reduction rate generated by the system.
- Finally, this work is completed with a general conclusion and perspective

Chapter I : Renewable energy

I.1 Introduction

Renewable energy refers to energy that is obtained from sources that are replenished naturally and are not depleted over time. These sources of energy include solar, wind, hydro, geothermal, and biomass. The use of renewables energies has gained widespread attention and importance in recent years due to concerns over climate change, energy security, and the sustainability of our current energy systems.

Renewables energies is often seen as a key solution to the challenges associated with traditional fossil fuels, which are finite and contribute to greenhouse gas emissions and air pollution. The use of renewables energies can also help to reduce dependence on foreign oil and increase energy independence. Additionally, renewables energies can create new jobs and economic opportunities, particularly in rural and underdeveloped countries.

Some of the most common types of renewables energies sources include solar energy, wind energy, hydraulic energy, geothermal energy and biomass energy.

As the world continues to focus on reducing greenhouse gas emissions and transitioning to a more sustainable energy future, the use of renewables energies is likely to become increasingly important.

In 2021 renewable electricity generation rose by almost 7%, a record 522 TWh increase, with wind and solar PV technologies together accounting for almost 90% of this growth. The share of renewables in global electricity generation reached 28.7% in 2021, after modest growth of 0.4 %. The slow growth of renewables’ share was due to global electricity demand reaching its highest level in history, as economic activity rebounded after the Covid-19-related slowdown, and droughts in several regions decreased hydropower generation. [2]

I.2 Types of renewable energies

I.2.1 Solar energy

Solar energy is an energy source that depends on the sun. This energy makes it possible to produce electricity from photovoltaic panels or solar thermal power plants, thanks to sunlight captured by solar panels. [3]

I.2.1.1 Types of solar energy

1. Photovoltaic solar

❖ **Principle of operation**

Photovoltaic solar energy is obtained by the energy of the sun's rays. The principle is to transform the energy carried by the photons hooked on light into electricity. This is why the photovoltaic panels that will collect them are often installed on the roofs, with the best possible orientation.

When the photovoltaic cell made of silicon, exposed to light, it absorbs the energy of light photons. The latter generates a direct electric current which will be converted into alternating current using an inverter. This electricity produced can be used for several applications such as: Residential, commercial buildings, street lighting, powering machinery and water pumping, etc.... [4]

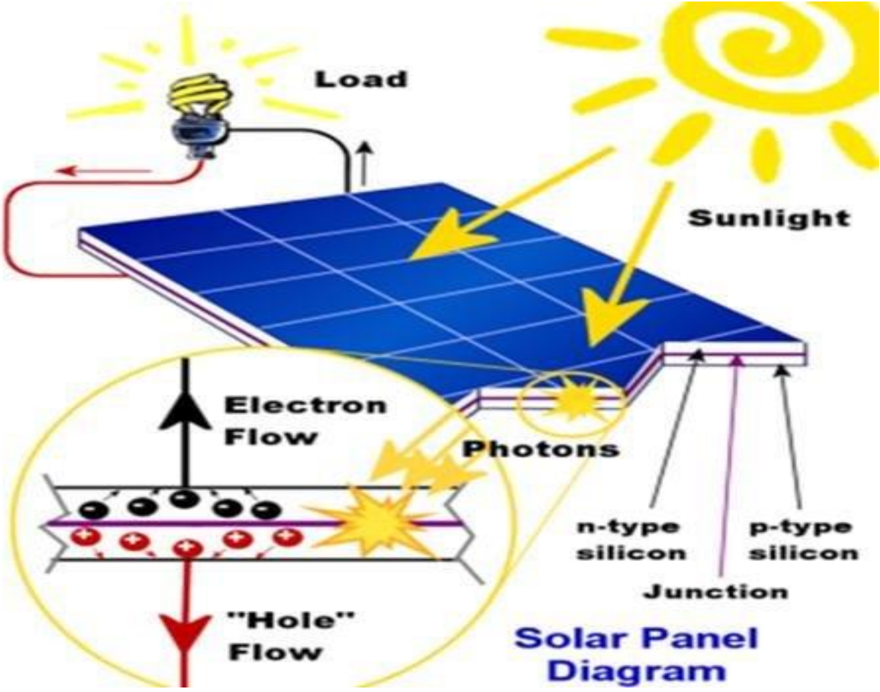


Figure I.1: Principle of operation of a photovoltaic panel [5].

2. Solar thermal

❖ **Principle of operation**

Solar thermal panels contain heat transfer fluids. The principle is heated fluids by the sun. The fluids begin to heat the hot water tank. It can be useful in certain industrial uses as drying, curing, or melting to replace some of the use of fossil energy. [4]

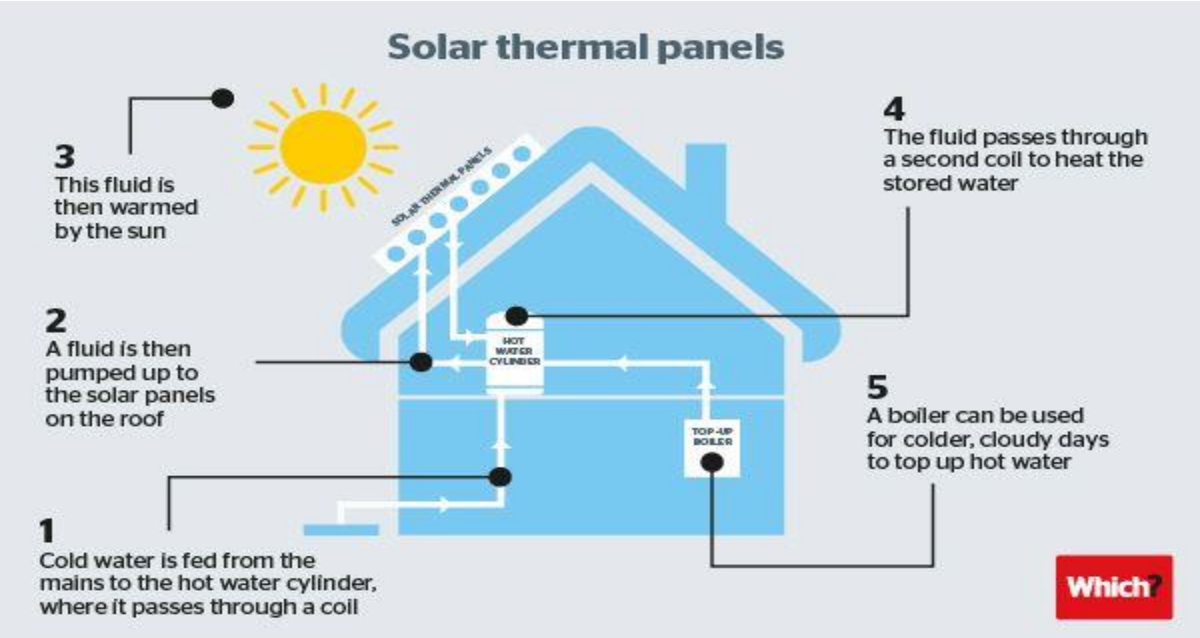


Figure I.2: Principle of operation of solar thermal panel [6].

3. Thermodynamic solar

❖ **Principle of operation**

Thermodynamic solar energy is produced via concentrated solar power plants. It is an assembly of mirrors containing heat transfer fluids, coupled to a solar electricity generator. The principle is the mirrors that transform the energy collected by the sun's rays into heat. This heat has a very high temperature. Much higher than the temperature at which it was collected. It can range from 250° to 800° depending on the technique used.

This heat will be converted into electricity by means of a turbine and an alternator as in a thermal power plant. [4]

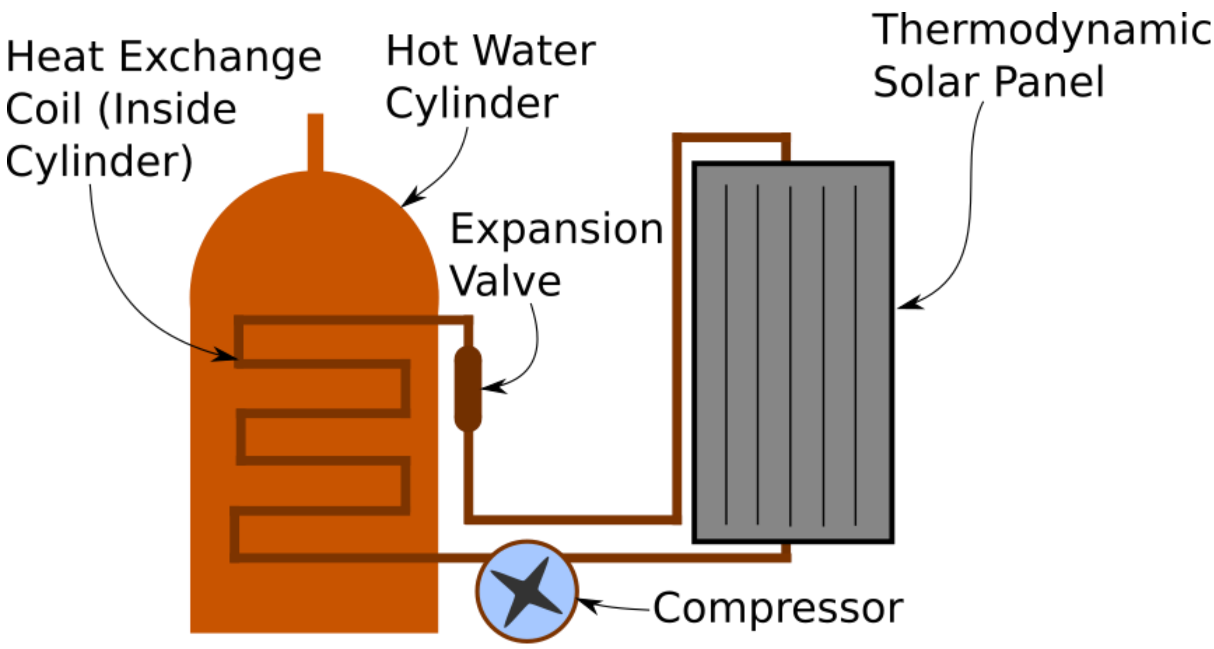


Figure I.3: thermodynamic solar system [7].

I.2.1.2 Solar Coordinates Model

The solar coordinate model is expressed in terms of sun angles. These are interesting factors for calculating solar radiation.

a. Latitude (ϕ)

The angle between the equatorial plane and the direction connecting the location under consideration with the center of the Earth. A positive sign is assigned to latitudes in the northern hemisphere and a negative sign is assigned to latitudes in the southern hemisphere.

b. longitude (λ)

Longitude represents the angle formed by the meridian plane of the location under consideration and the meridian origin plane. The latter passes through Greenwich Observatory and is at 0° longitude. Longitudes east of this meridian are positive, and longitudes west of it are negative.

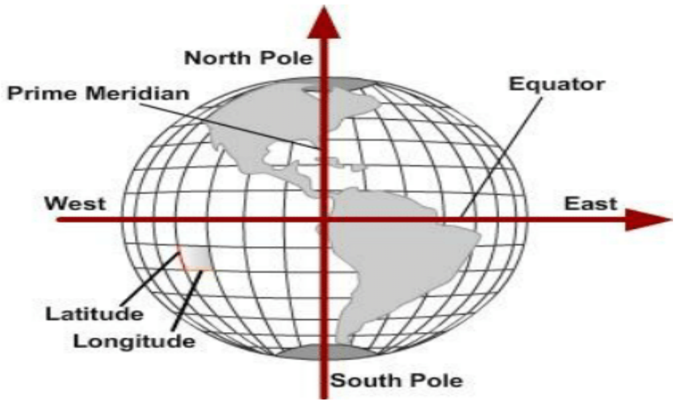


Figure I.4: Longitude and latitude [8].

c. Sun declination (δ)

This is the angle between the direction of the sun and the equatorial plane, reflecting the tilt of the equatorial plane with respect to the ecliptic plane. Its value varies between 23°7 (winter solstice). At +23°7' (summer solstice) and vanishes at the spring and autumn equinoxes.

$$\delta = 23.45° \sin [0.980° (284 + n)] \qquad \textbf{(I.1)}$$

n: is the number of days of the year counted from January 1, it varies from 1 to 365 or 366 Depending on the year:

[Calendar year → n = 365 days and Leap year → n = 366 days].

P: is the North Star;

Z: the zenith.

The angle between the direction of the polar star and the horizon is equal to the latitude of the place.

On the figure, we see that: $90-\varphi=h-\delta$ **and therefore:** $\delta=h+\varphi-90$. **(I.2)**

If we measure h and if we know φ, then we can calculate the declination δ of the Sun.

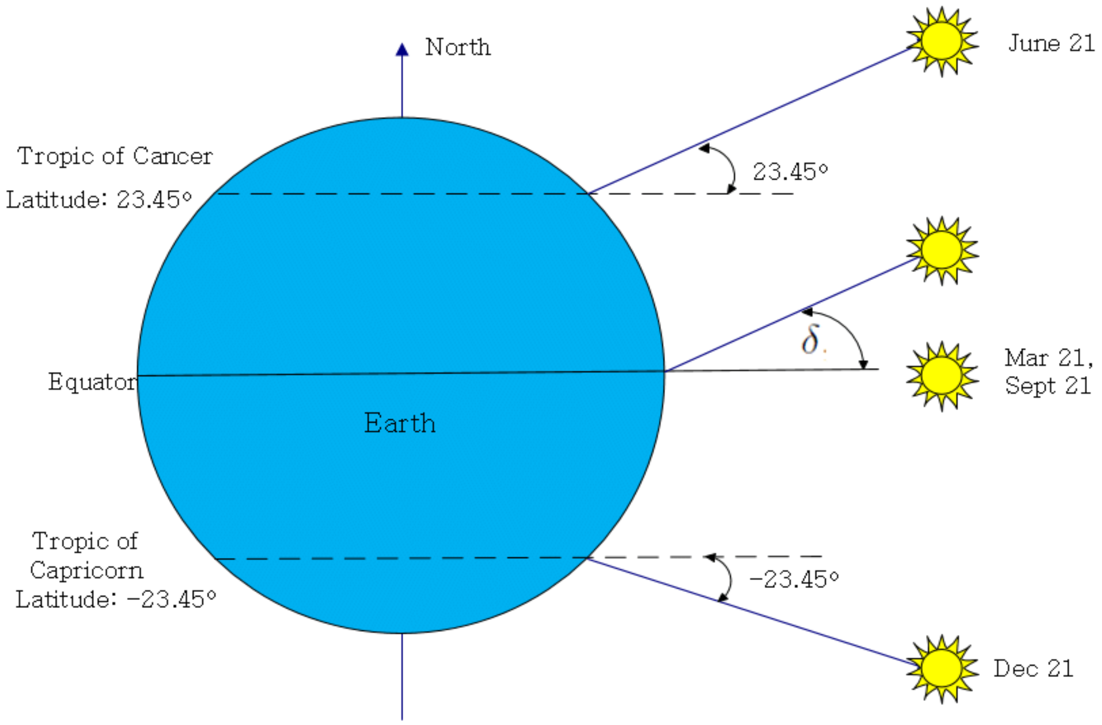


Figure I.5: Sun declination (δ) [9].

d. The hour angle (ω_0) of the sun

It marks the position of the sun in its daily rotation on the aperture cone d. It is the angle between the meridian plane passing through the observer and the meridian plane containing the sun. In principle, a solar day (d varying from -180° to +180°) corresponds to 24 hours:

$$\omega_0 = 15\,[TSV - 12 + \frac{\lambda}{15}] \qquad \text{(I.3)}$$

With TSV is true solar time.

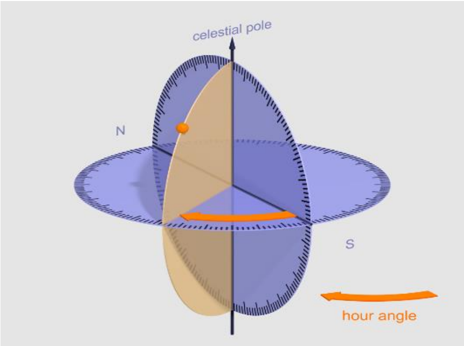


Figure I.6: hour angle ω0 [10].

e. True solar time

Relations relating to the movement of the sun using the true solar time TSV which generally differs from the legal time TL (time of watches) of the place considered. This difference is related to:

-the difference (set by each country) between the legal time TL and the civil time TCF of the time zone in which it is located.

$$C = TL - TCF \qquad \text{(I.4)}$$

The civil time TCF of the time zone is equal to universal time UT (solar time of the meridian of Greenwich) increased by the value of the time difference. “For Algeria Greenwich+1 hour”

-The variation in the speed of the earth on its trajectory around the sun which introduces a corrective term called the equation of time and noted "ET".

$$ET = -\,[0.0002 - 0.4797\cos(\omega' j) + 3.2265\cos(2 * \omega' j) + 0.0903\cos(3 * \omega' j) + 7.3509\sin(\omega' j) + 9.3912\sin(2 * \omega' j) + 0.3361\sin(3 * \omega' j)] \qquad \text{(I.5)}$$

j= day number of the year ;

ω'= 0.984

- The difference in longitude ($L_{ref} - L$) between the place considered and the place serving as a reference for legal time (generally the center of the time zone).

The true solar time TSV is finally calculated by the following formula:

$$TS = TL - C + ET + \frac{(Lref - L)}{15} \qquad \text{(I.6)}$$

f. azimuth (ψ)

It is the angle that the direction of the projection of the sun on the horizontal plane makes with the southern direction, this angle being oriented positively towards the West.

$$\text{Sin } \psi = \frac{\cos\delta * \sin\omega}{\cos\beta} \qquad \text{(I.7)}$$

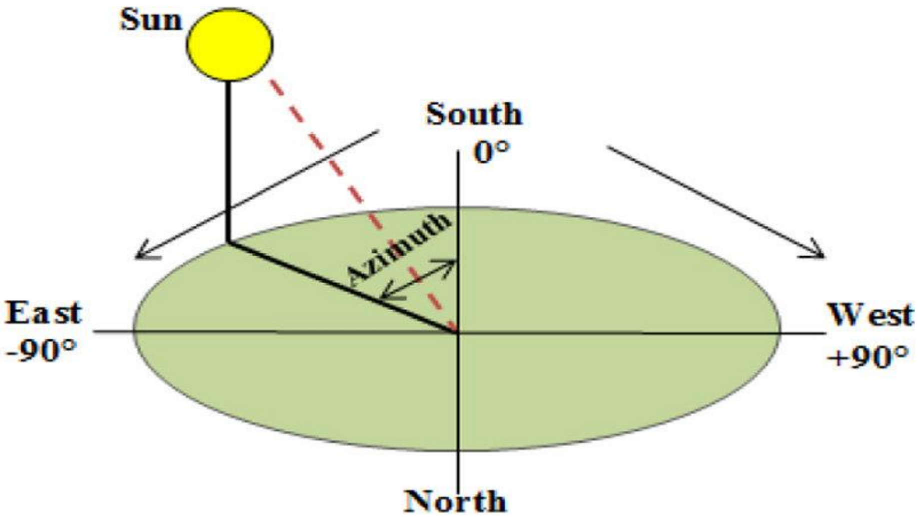


Figure I.7: azimuth (ψ) [11].

g. Angular Height (*β*)

It is the angle that the direction of the sun makes with its projection on a horizontal plane with ε: is the angle of inclination of the plane with respect to the horizontal, ε=0 for a horizontal plane.

$$\sin\beta = \sin(\Phi) * \sin\delta + \cos(\Phi) * \cos\delta * \cos\omega \qquad \text{(I.8)}$$

h. Angle of incidence (θ)

It is proposed to calculate the angle (θ) between a ray arriving directly from the sun and the plane normal to a plane of the PV panel.

A trigonometric relationship makes it possible to determine its value according to the other angles:

$$\cos\theta = \cos\alpha * \sin\beta * \cos(\psi - \gamma) + \sin\gamma\alpha * \cos\beta \qquad \text{(I.9)}$$

i. Orientation (γ)

The orientation of the PV panel with respect to the south, (0° to the south, 180° to the north, + 90° to the west and -90° to the east. In our case +45° to the south. [12]

I.2.2 Wind energy

Wind turbines harvest the wind's kinetic energy and convert it to mechanical energy and finally electrical energy form.

Figure I.8 depicts a general wind turbine design. Wind turbines typically consist of a tower, three rotor blades, a drive train system, and an electrical (asynchronous) generator. Wind speeds tend to increase with increasing altitude, so the tower's height is very tall and typically ranges from 50 to 100 meters.

I.2.2.1 Principle of operation

When the wind blows, the blades feel the wind's force and spin about an axis much like a pinwheel. The blades transfer the wind's energy to a low-speed speed shaft, which turns the larger gear in the drive train system. At this stage in the process, the wind's kinetic energy has been converted to an electrical form. The low-speed shaft and gear transfer the load to the high-speed shaft and gear within the drive train system. The rotational motion of this high-speed shaft drives the electrical generator and transforms the mechanical energy into electrical form. The wind turbine's blades turn when the wind speed direction is roughly parallel with wind rotor and perpendicular to the blades. The blades' axis of rotation is perpendicular to the tower, and the system's generator is stored at the top of the wind turbine tower. The vertical wind turbine's axis of rotation is in-line with the tower and the generator is located at the base of the tower. [13]

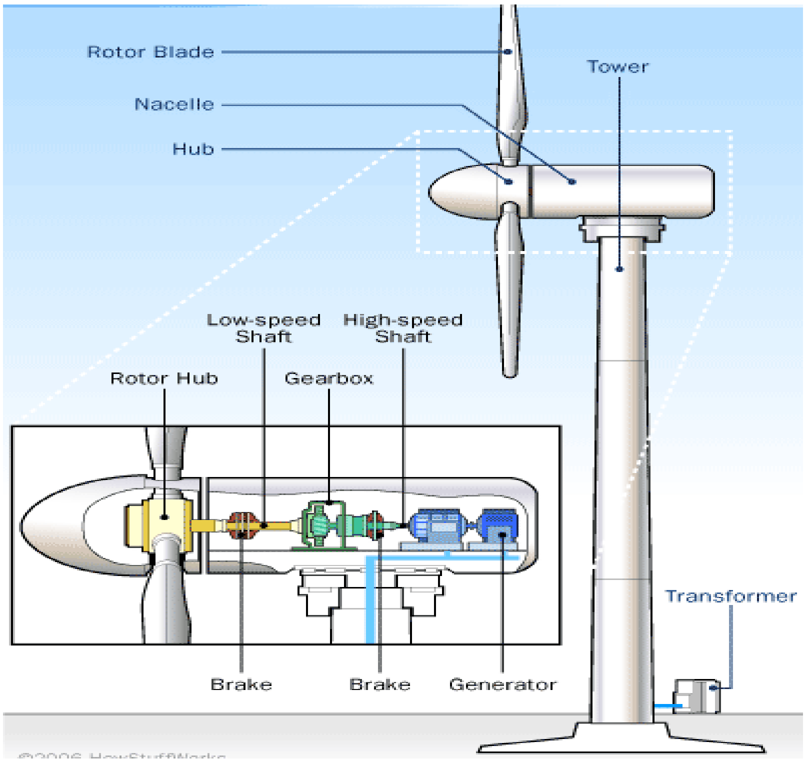


Figure I.8: Wind Turbine Design [14].

I.2.3 Hydraulic energy

Hydraulic energy is the energy provided by all forms of water movement: fall, watercourse, sea current, tide, waves.

Hydraulic energy is actually kinetic energy in the case of ocean currents and rivers, and potential energy in the case of tides, waves, waterfalls and dams.

Hydraulic energy is a renewable energy source with very low greenhouse gas emissions. This renewable energy source harnesses the movement of water driven by the sun and gravity through the water cycle, tides and ocean currents. [15]

I.2.3.1 Principle of operation

The working principle of a hydroelectric power plant is to convert the potential energy (from lifting water out of a canal) and kinetic energy (from water flowing at high speed) into mechanical energy with the help of turbines. Water stored in the reservoir behind the dam or in the fore bay falls through the penstock and hits the turbine blades at high pressure, causing the turbine impeller to turn. The impeller is mounted on a central shaft connected to a generator, which ultimately produces electricity, or electricity. H. The mechanical energy of the turbine is converted into electricity by the generator. The resulting electrical energy is delivered via domestic or industrial power lines after voltage regulation by transformers. The electrical energy produced by a hydroelectric power station is proportional to the water flow rate and the elevation gradient. [16]

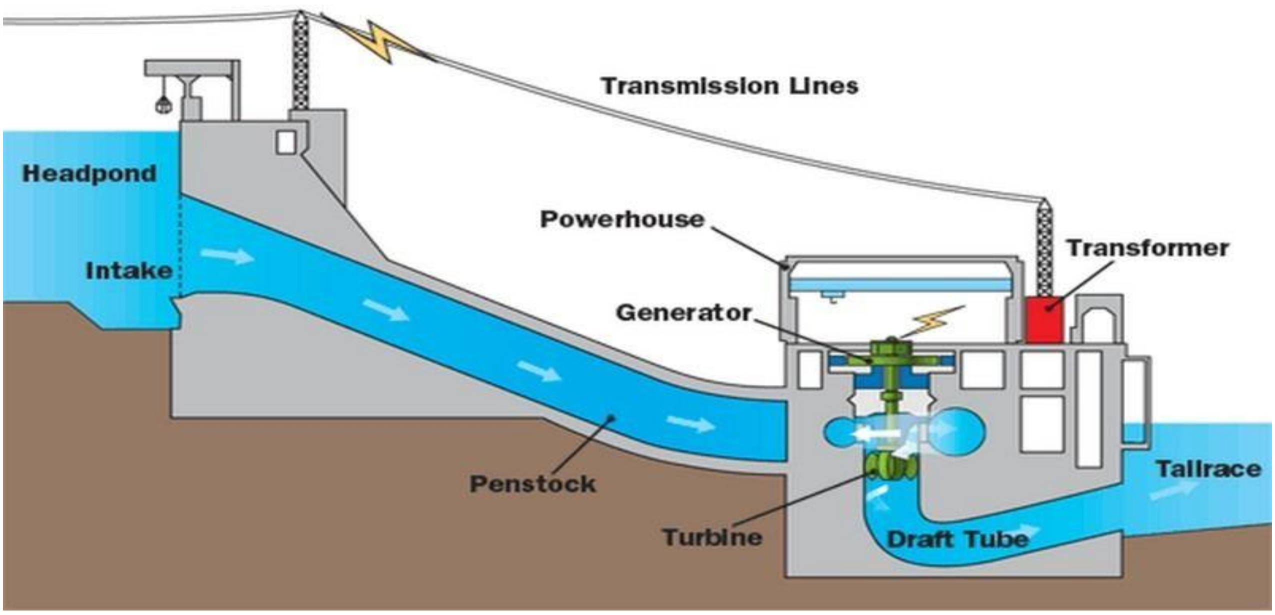


Figure I.9: Principle of operation of hydraulic energy [16].

I.2.4 Geothermal energy

Geothermal energy is heat energy from the Geo (earth) + thermal (heat). Geothermal resources are hydrothermal reservoirs that exist below the earth's surface or are man-made at various temperatures and depths. Wells, feet to kilometers deep, can be drilled into underground reservoirs to extract steam and very hot water that can be brought to the surface for a variety of uses, including power generation, direct use, and heating and cooling**.** [17]

I.2.4.1 Types of geothermal installation

- **Heat pumps:** they use surface geothermal energy for heating.
- **Hydrothermal facilities:** they exploit naturally hot water sources, and are used for heating or electricity production (for deep sources).
- **Petrothermal facilities:** this is the solution that can be used when there is no thermal spring. This is called deep geothermal energy. [18]

I.2.4.2 Principle of operation

1. Hot water is pumped from underground through drilled well at high pressure.
2. When this high-pressure hot water reaches the surface due to the pressure drop it converts into steam.
3. This steam is used to spin a turbine which is connected to a generator that converts the mechanical energy of the turbine into electricity.
4. This steam is then cooled inside the cooling water and due to the condensation turn back into the water.
5. The cooled water is sent back into the earth to continue the same process. [19]

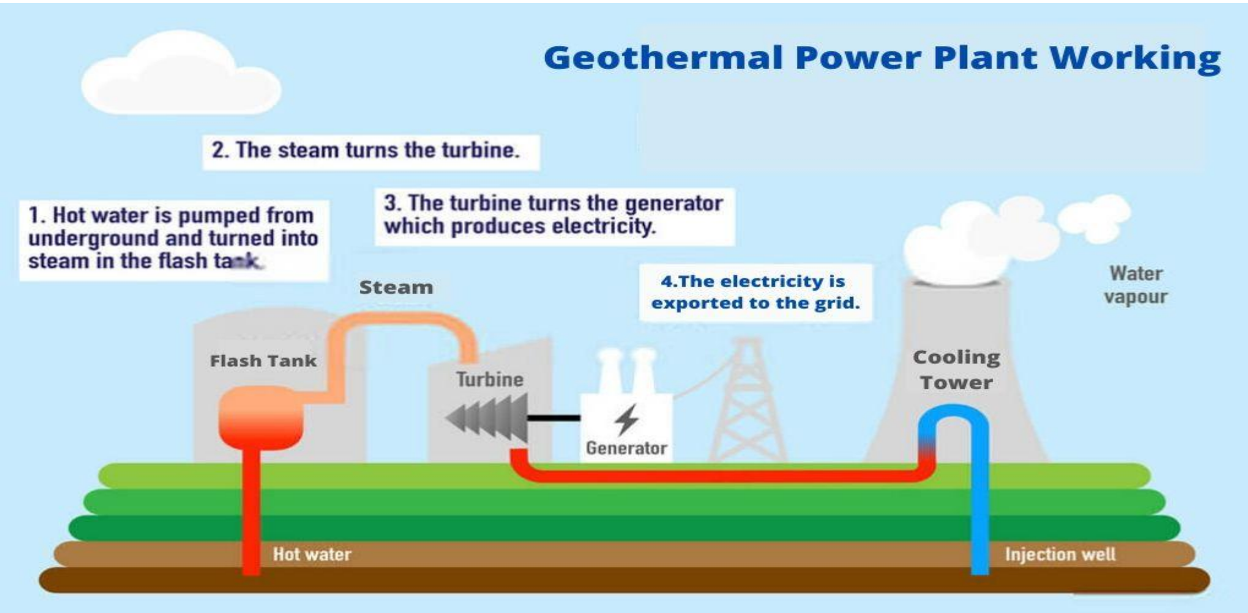


Figure I.10: Principle of operation of geothermal energy [19].

I.2.5 Biomass

Biomass is increasingly known as the leading source of renewable energy on earth. Biomass is the burning of plants and animals to generate electricity and heat. The main interest of this energy production solution is that unlike fossil fuels, the materials used are inexhaustible as long as they are produced in an environmentally friendly manner. [20]

I.2.5.1 Principle of operation

A biomass power plant produces electricity from the steam that is released during the combustion of plant or animal matter in a combustion chamber. This process is done in several steps:

1. Combustion: The biomass is burned in a combustion chamber.

2. Steam production: The biomass releases heat that heats water in a boiler. The water is transformed into steam, which is sent under pressure to turbines.

3. Electricity production: The steam turns a turbine which in turn drives an alternator. Thanks to the energy supplied by the turbine, the alternator produces an alternating electric current. A transformer raises the voltage of the electric current produced by the alternator so that it can be more easily transported in medium and high voltage lines.

4. Recycling: At the exit of the turbine, part of the steam is recovered to be used for heating. This is called cogeneration

The rest of the steam is again transformed into water thanks to a condenser in which cold water from the sea or a river circulates. The water thus obtained is recovered and recirculated in the boiler to start another cycle. [20]

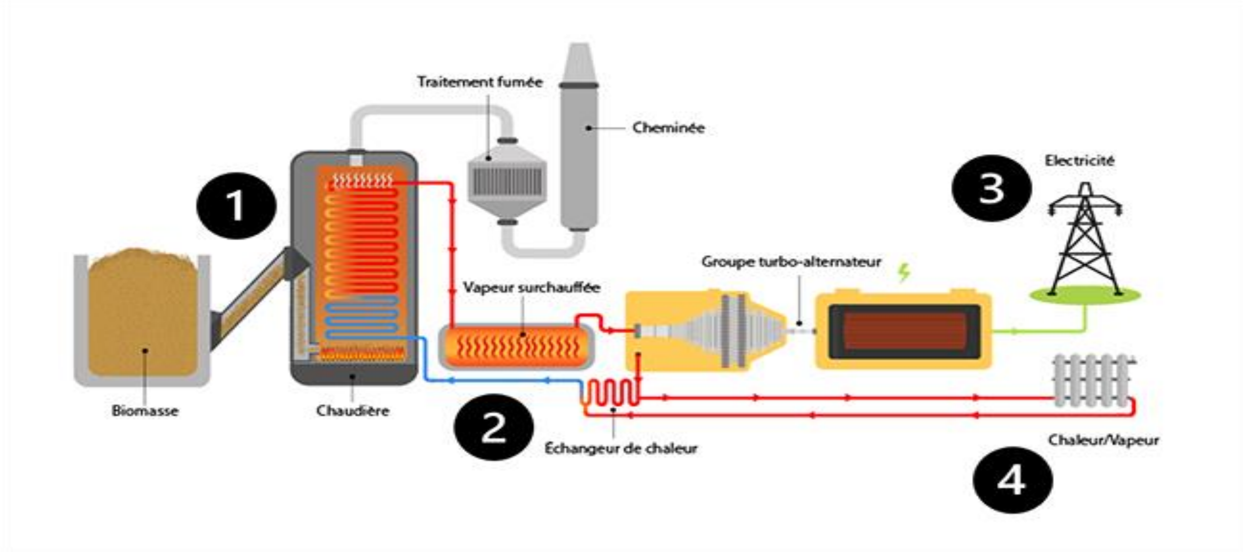


Figure I.11: Principle of operation of biomass power plant [20].

I.3 Conclusion

Renewable energies have emerged as a crucial solution to address the pressing challenges of climate change, energy security, and sustainable development. The rapid advancements in renewable technologies, coupled with increased awareness and policy support, have facilitated the transition towards a cleaner and more sustainable energy future.

Renewable energies, such as solar, wind, hydro, geothermal, and biomass, offer numerous benefits. Firstly, they are abundant and widely available, reducing our dependence on finite fossil fuel resources and mitigating concerns of resource depletion. Secondly, renewables produce minimal to no greenhouse gas emissions during operation, contributing significantly to mitigating climate change and reducing air pollution.

Renewables have proven to be a game-changer in the energy sector, offering a clean, sustainable, and economically viable alternative to fossil fuels. The continued expansion and integration of renewable energy sources into our energy systems will be crucial in achieving a more sustainable and resilient future for generations to come. With ongoing technological advancements, supportive policies, and collaborative efforts, the global transition to renewables is within reach, paving the way for a greener and more sustainable planet.

Chapter II : Photovoltaic energy

II.1 Introduction

Photovoltaic energy is produced by converting part of the solar radiation directly into electrical energy. This energy conversion is done by what is known as a photovoltaic (PV) cell. It is based on a physical phenomenon called the photovoltaic effect, which generates an electromotive force when the surface of this cell is exposed to light. The voltage produced depends on the material used to manufacture the cell. Connecting multiple PV cells in series/parallel results in photovoltaics (GPV) with a nonlinear current-voltage (I-V) characteristic representing the maximum power point. [21]

The discovery of the photovoltaic effect dates back to 1839, the year in which the French physicist Alexandre Edmond Bequeret discovered the possibility of producing electricity using light and the presence of semiconductor materials such as silicon.

After 1913, the first photovoltaic cells were born, but it was not until 1916 that Robert Millikan managed to produce direct current.

In 1954, Bell Laboratories announced the first solar cell with an energy efficiency of around 6%, then in 1958 it reached around 9%. It was not until 1980 that the University of Delaware built the first house powered by photovoltaic cells.

After all these advances, it was only between 1995 and 2001 that photovoltaic panels were put on sale commercially. [22]

II.2 Solar resource

II.2.1 Solar spectrum

The spectrum of the sun is a division into wavelengths or colors. In fact, sunlight consists of all kinds of radiation in different colors, characterized by a range of wavelengths. Photons, or particles of light, make up this electromagnetic radiation. Louis de Broglie in 1924 confirmed both the corpuscular and wave nature of light: presence of corpuscles (photons) and propagation of waves with a vibration frequency and a wavelength.

The radiation emitted by the Sun corresponds to that of a blackbody with a temperature of 6000°C. The irradiance above the atmosphere is 1.35 kW/m^2, with a spectrum centered at λ=0.48 μm. At the surface, the power density is only 0.9 kW/m^2, mainly due to absorption by ozone, water and carbon dioxide. Furthermore, the spectrum is no longer continuous, but has absorption bands.

To measure the effect of the atmosphere, we use the air mass, defined by AM=1/cosα where α represents the angle that the direction of the sun makes with the vertical. AM0 is used to specify conditions in the atmosphere. AM 1.5 being that reaches the ground in clear weather (surface of one square meter making an angle of 48° with the equator). In addition, the AM1.5D and AM1.5 G spectra are distinguished, which correspond respectively to the direct flux and to the global flux (direct + diffuse). These spectra are given in figure II.1, on which are also indicated some semiconductors used for photovoltaic applications and their gap energies Eg. [23]

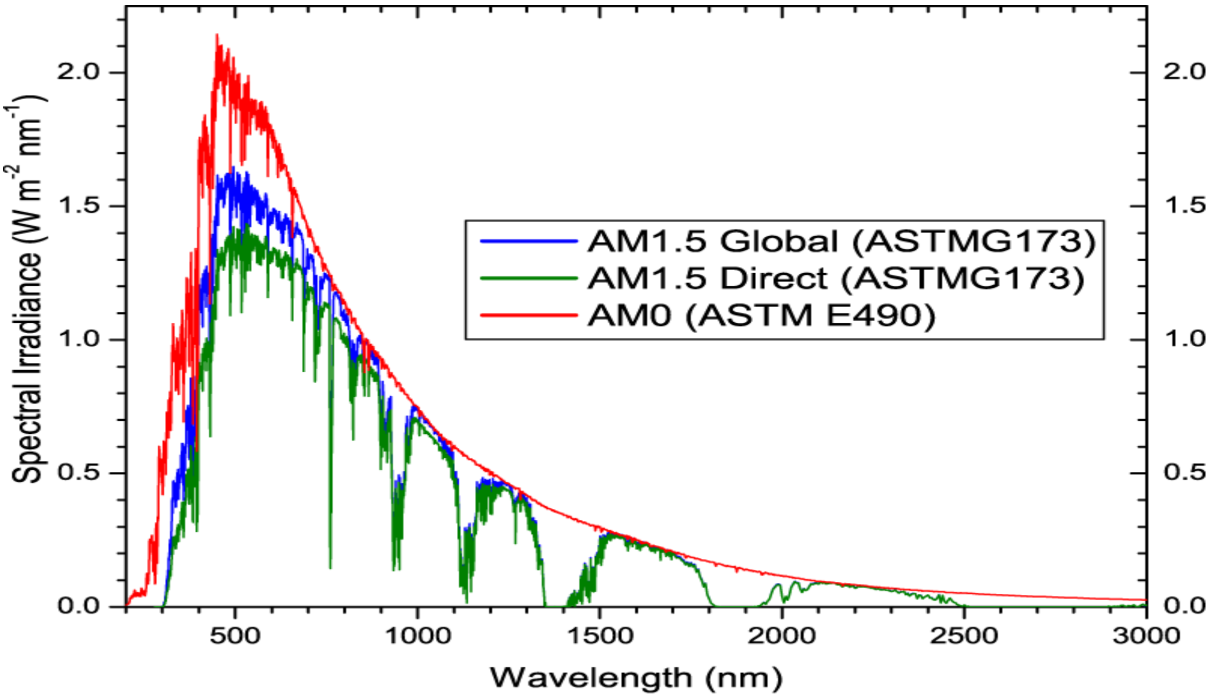


Figure II.1: Solar spectrum at the surface of the Earth's atmosphere (AM0) and at the ground (AM1.5D and AM1.5G). [24]

II.2.2 Radiation

- **Irradiation**

Solar irradiation represents energy. The solar irradiation received by an object depends on its exposure. A horizontal surface will not receive the same amount of solar energy as a vertical surface. Thus, it is always necessary to specify the configuration of the receiver when speaking of irradiation received.

Irradiation is expressed in kWh or in kWh/m² or in kWh/m²/year, its symbol H. [25]

- **Illumination**

Direct illumination from the sun varies from 0 to 1000 W/m² during the day. [25]

II.2.3 Solar radiation

- **Direct radiation**

Solar flux in the form of parallel rays coming from the sun disk without having been dispersed by the atmosphere. [26]

- **Diffuse radiation**

It is the part of the radiation coming from the sun, having undergone multiple reflections (dispersions), in the atmosphere. [26]

- **Reflected radiation**

It is the part of the solar illumination reflected by the ground, this radiation depends directly on the nature of the ground (cloud, sand, etc.). It is characterized by a coefficient specific to the nature of the bond called Albedo (ε) $0 \leq \varepsilon \leq 1$. [26]

- **Global radiation**

A plane receives from the ground a global radiation which is the result of the superposition of the three compositions direct, diffuse and reflected. [26]

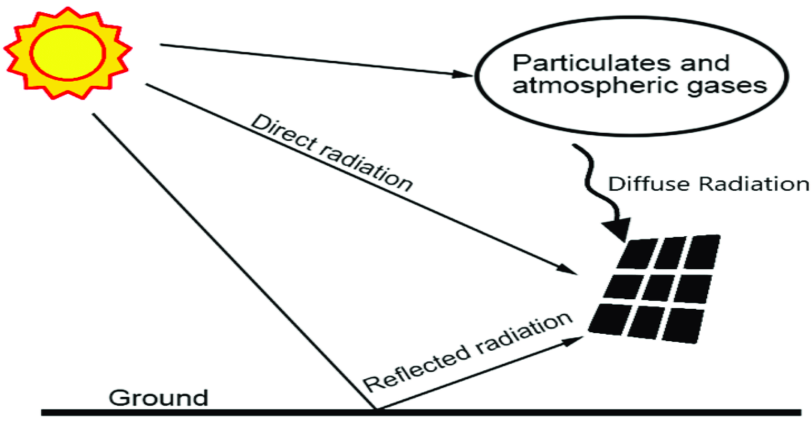


Figure II.2: Types of solar radiation (Direct, Diffuse and Reflected). [27]

II.3 Photovoltaic cells

The PV cell or solar cell is the smallest element of a photovoltaic installation. It is made of semiconductor materials and directly converts light energy into electrical energy. Photovoltaic cells consist of:

-A thin semiconductor layer (material with a band gap, which acts as an energy barrier that electrons cannot cross without external excitation, and whose electronic properties can be varied) such as silicon, which is a material with relatively good electrical conductivity,

- An anti-reflection layer allowing maximum penetration of the sun's rays,

-A conductive grid on the top (cathode) and a conductive metal on the bottom (anode),

-The newer ones even have a new combination of reflective multi-layers just below the semiconductor, allowing light to bounce around it longer to improve performance.

A photovoltaic cell is based on the physical phenomenon called the photovoltaic effect which consists in establishing an electromotive force when the surface of this cell is exposed to light. The voltage generated can vary between 0.3 V and 0.7 V depending on the material used and its layout as well as the temperature and aging of the cell. [28]

II.4 Photovoltaic effect

The photovoltaic cell based on silicon consists of two thin layers of semiconductor, which are doped differently, see Figure II.3. Where the sun's radiation fall on, the upper layer (2) is negatively doped with phosphorous, while the other lower layer (3) is positively doped with boron. [29]

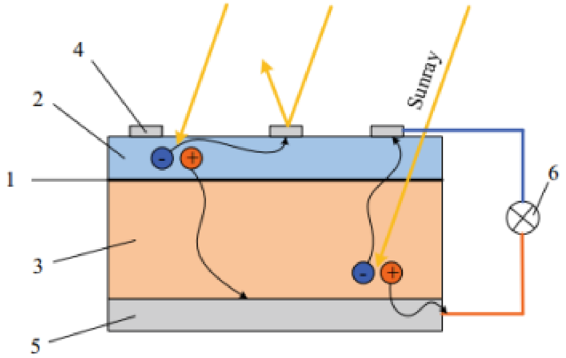


Figure II.3: Component and operational principle of PV cells [29].

Then, in the part between them, it knows as a p-n junction (1), where some electrical charges combine that where an opposite electrical field is created.

Where: (1) is p-n junction, (2) is the negatively doped layer, (3) is the positively doped layer, (4) is the negative electrode, (5) is the positive electrode, (6) is load. [29]

II.5 Principle Operation of a photovoltaic cell

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

- Absorption of photons (whose energy is greater than the gap) by the material constituting the device;

-Conversion of photon energy into electrical energy, which corresponds to the creation of electron/hole pairs in the semiconductor material;

-Collection of particles generated in the device.

The material constituting the photovoltaic cell must therefore have two energy levels and be sufficiently conductive to allow the flow of current, hence the interest of semiconductors for the photovoltaic industry.

In order to collect the generated particles, an electric field allowing to dissociate the created electron/hole pairs is necessary. For this, a PN junction is most often used. [30]

The operation of photovoltaic cells is illustrated in Figure II.4:

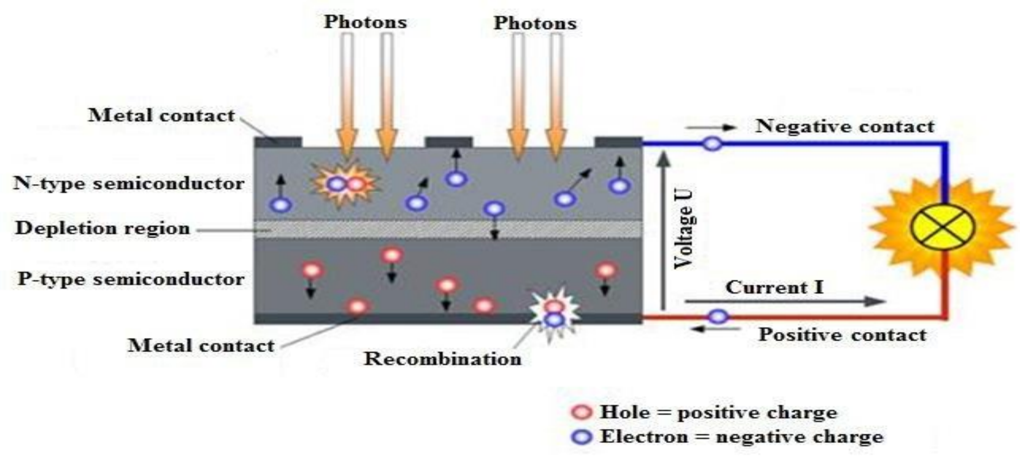


Figure II.4: Principle Operation of a photovoltaic cell. [31]

The incident photons create carriers in the N and P regions and in the space charge region. The photo-carriers will behave differently depending on the region:

-In the N or P zone, the minority carriers that reach the space charge zone are “sent” by the electric field to the P zone (for holes) or to the N zone (for electrons) where they will be majority. We will have a current broadcast photo,

-In the space charge zone, the electron/hole pairs created by the incident photons are dissociated by the electric field: the electrons will go to the N region, the holes to the P region. We will have a photo generation current.

These two contributions add up to give a resultant photocurrent Iph. It is a stream of minority carriers. It is proportional to the light intensity. [30]

II.6 Different types of solar cells

There are different types of solar cells or photovoltaic cells. Each type of cell is characterized by its own efficiency and cost. However, whatever the type, the efficiency remains quite low: between 8 % and 23% of the energy that the cells receive. [32]

Currently, there are three main types of cells.

II.6.1 Monocrystalline cells

Monocrystalline cells are the first generation solar cells, they are made from a block of crystallized silicon in a single crystal (See Figure (II.5). Its manufacturing process is long and energy-intensive; more expensive, however, it is more efficient than polycrystalline silicon. Raw silicon is melted to create a bar. When the cooling of the silicon is slow and controlled, a single crystal is obtained.

A wafer (slice of silicon) is then cut out of the silicon bar. After various treatments (surface treatment with acid, doping and creation of the P-N junction, deposition of an anti-reflection layer, installation of collectors), the Wafer becomes a cell. The cells are round or almost square, and when viewed up close they have a uniform color. They have a yield of 15% to 22%, but the production method is laborious. [32]

II.6.2 Polycrystalline cells

Polycrystalline cells are composed of an agglomerate of crystals. They also come from the sawing of blocks of crystals, but these blocks are cast and heterogeneous.

Polycrystalline cells are characterized by:

-Lower production cost.

- Less energy-intensive process.
- Yield of 13% and up to 20% in the lab [32]

II.6.3 Amorphous cells

Amorphous silicon appeared in 1976. Its atomic structure is disordered, not crystallized, but it has an absorption coefficient higher than that of crystalline silicon. However, what it gains in absorption power, it loses in mobility of electrical charges (low conversion efficiency).

- Much lower production cost.
- Yield of only 6% per module and 14% in the lab.
- Works in very low light.

Thanks to the technology of new materials cadmium telluride ($CdTe$), gallium arsenide ($GaAS$) as well as copper and indium di-selenide (CIS) have made it possible to obtain photocells with 38% yields in the laboratory. [32]

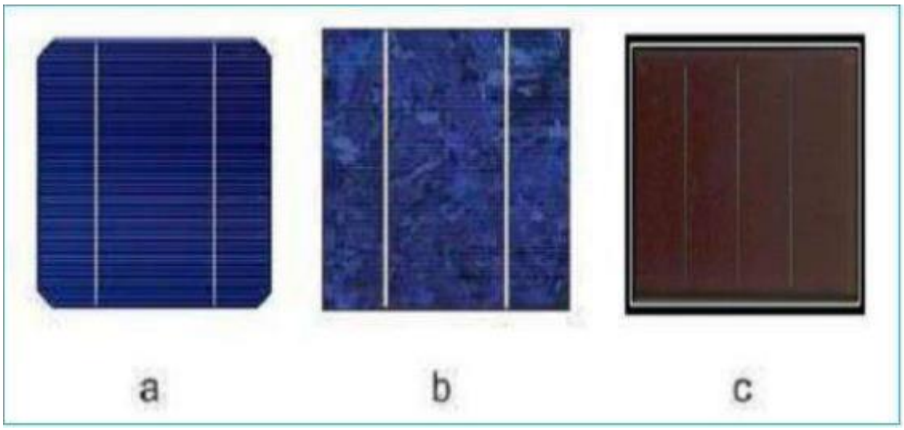


Figure II.5: Types of photovoltaic cells: (a) monocrystalline, (b) polycrystalline, (c) amorphous. [32]

II.7 Association of photovoltaic cells

The power available at the terminals of a cell is very low. It is therefore necessary to combine such cells in series and in parallel, in order to obtain power modules compatible with the usual electrical equipment. The powers of the modules available on the market range between a few watts-peak (W_C) and a few tens of watts-peak (W_C).

Represents the maximum electrical power delivered under the following conditions called standard conditions, solar irradiation of 1000 W/m^2, Junction temperature of 25°C, optimum load [33].

II.7.1 Serial association

An association of (Ns) cells in series shown in figure (II.6) makes it possible to increase the voltage of the photovoltaic generator. The cells are then traversed by the same current and the characteristic resulting from the series grouping is obtained by adding the elementary voltages of each cell.

The equation summarizes the electrical characteristics of a series Association of (Ns) cells [33].

$$\mathbf{V_{OCNs} = N_S * V_{OC}} \qquad \textbf{(II.1)}$$

$$\mathbf{I_{SC} = I_C} \qquad \textbf{(II.2)}$$

V_{OC} .N_S: The sum of the open circuit voltages of Ns cells in series;

I_{SC} .N_S: Short-circuit current of Ns cells in series;

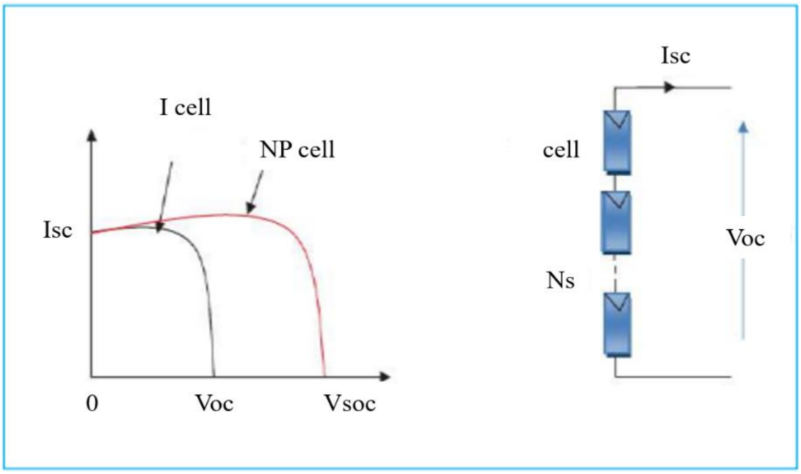


Figure II.6: Current-voltage characteristic of Ns cell in series [33]

II.7.2 Pairing in parallel

The properties of parallel grouping of cells are dual to those of series grouping. Thus, in a group of cells connected in parallel, the cells are subjected to the same voltage and the resulting group characteristic is obtained by adding the currents at a given voltage. Figure (II.7) shows the resulting characteristic obtained by associating in parallel identical cells [33].

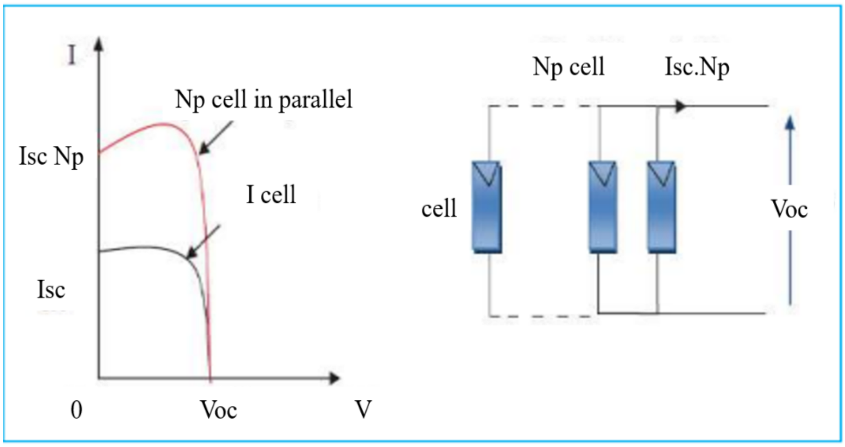


Figure II.7: Current-voltage characteristic of (NP) cell in parallel [33]

II.7.3 Mixed connection

If for a given application it is necessary to increase the current and the voltage delivered by the solar cells, a mixed group or series-parallel group is produced. We will speak in this case of module and solar panels. A solar panel is by definition a set of modules grouped together in a mixed assembly, the module being in turn composed of a set of cells generally mounted in series. It is possible to use an assembly of NC identical cells in series on a module, NSP number of branches (placed in parallel) and NMS number of modules per branch figure (II.8) [33].

The total available power PT, under these conditions, is equal

$$P_T = N_{MS} * N_{SP} * P_M \qquad \text{(II.3)}$$

The optimum resistance is given by

$$R_{OP} = \left(\frac{Nms}{Nsp}\right) * P_M \qquad \text{(II.4)}$$

Where R_{optm} is the optimum resistance of the modulus under the same conditions.

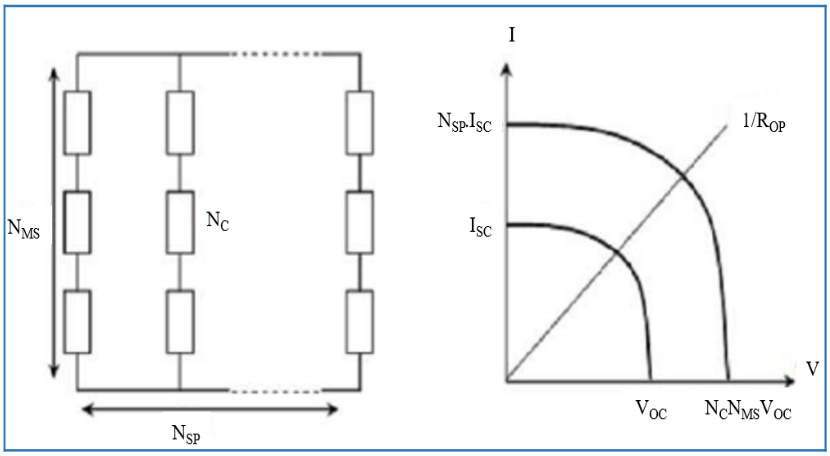


Figure II.8: Mixed association of NSP branches and NMS modules composed of N_C identical solar cells [33]

II.8 Photovoltaic panel

The solar panel or (solar field) consists of photovoltaic modules interconnected in series and/or in parallel in order to produce the required power. These modules are mounted on a metal frame that supports the solar field with a specific angle of inclination. [34]

Figure II.9: Photovoltaic panel. [35]

For each panel, you can have as many outputs as modules, which means that you will need a junction box that groups them all together. Then this junction box fixed on a structure of the assembly has the role of making the connections between the modules to obtain optimum output power.

Figure II.10: Junction box. [36]

The junction box is also composed of a printed circuit on which are located:

- Series schottky diodes, placed on a radiator, on each input, which prevent the batteries from discharging in the panels.
- Protection fuses which will prevent the batteries from discharging in the modules in the event of the destruction of the antiparallel diodes.
- Light diodes, in parallel on each protection fuse. These diodes make it possible to individually control each branch of modules. For example, a box with 4 inputs of 24 Volts will consist of two branches of two modules, there will therefore be two diodes which will make it possible to observe the operation of each branch.
- Surge protection at the outlet of the box.

The wiring of these boxes makes it possible to have a 12.24 or 48 volt output depending on the modules, they are equipped with two to twelve inputs, depending on the output voltages. The amount of electricity in all the components of the PV panels depends on:

- Electricity needs.
- The size of the panel.
- The sunshine of the place of use.
- The season of use.

The power delivered by a panel is important in the hours of maximum sunshine, which requires a storage element. [34]

II.9 Electrical characteristics of photovoltaic panel

The current delivered to a load by an illuminated photovoltaic cell is written:

$$I(V) = I_{ph} - I_{obsc}(V) \qquad (II.5)$$

With: I_{ph}: photogenerated current density and I_{obsc}: dark current density.

For an ideal photovoltaic cell, the equation (2.1) can be written in the following form:

$$I(V) = I_{ph} - I_s(\exp(qV / kT) - 1) \qquad (II.6)$$

With:

I_s: diode saturation current,

q: elementary charge,

k: Boltzmann constant,

T: temperature.

Thus, in a photovoltaic cell, two currents oppose each other: the illumination current and a diode current called the dark current which results from the polarization of the component. The characteristic of a cell under darkness is identical to that of a diode. Under illumination, the characteristic looks as shown in figure II.11.

From the I(V) characteristic of the photovoltaic cell, the electrical parameters specific to the cell are deduced and in particular:

I_{CC}: short-circuit current (obtained for V=0);

V_{CO}: open circuit voltage (obtained for I=0);

I_m: current at the maximum operating power of the photovoltaic cell;

V_m: voltage at the maximum operating power of the photovoltaic cell;

η: conversion efficiency;

FF: form factor.

η = (Maximum electrical power delivered) / (Incident solar power):

$$\eta = \frac{VmIm}{PiS} = \frac{FFVcoIcc}{PiS} \qquad \textbf{(II.7)}$$

With **Pi**: power of illumination received per unit area; **S**: surface of the photovoltaic cell.

FF = (Maximum power delivered to the load) / (V_{co}*I_{sc}):

$$\textbf{FF} = \frac{VmIm}{VcoVcc} \qquad \textbf{(II.8)} \qquad \textbf{[30]}$$

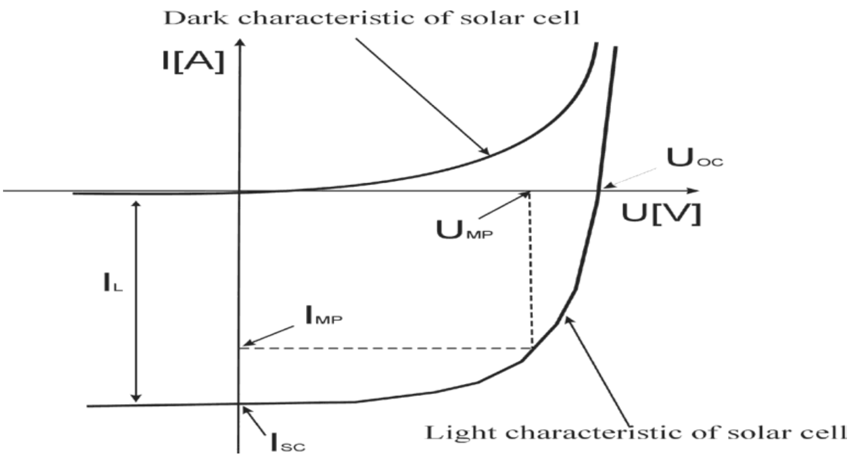


Figure II.11: characteristics I=f(V) under darkness and under illumination of a PV cell. [37]

II.10 Installation and protection

II.10.1 Site selection

The panels must be placed in such a way that no shade (tree, buildings) can cover them during the day, whatever the inclination of the sun during the seasons. The modules will be spaced out from the surface that supports them in order to promote natural convection and limit their heating. [38]

II.10.2 Inclination

The module will be tilted on the basis of the value of the latitude, which constitutes a good summer/winter compromise for annual production.

The angle formed by the sun's rays and the solar panel is called the angle of incidence (denoted α). The production is maximum if the sun's rays reach the surface of the panel perpendicularly at noon (solar time).

Inclination of 90° in relation to the sun's rays (in the center) = optimal production. [38]

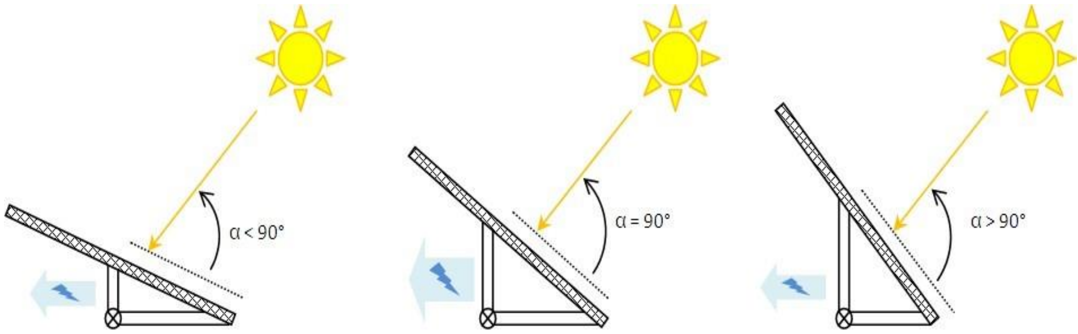


Figure II.12: Tilt of solar panel. [38]

II.10.3 Directions

The panels must be perpendicular to the sun's rays at the time when they are strongest (variable according to region and season). The panels must be oriented due south to capture maximum sunlight and for better performance.

If not, it can be considered up to 30° S-E or 30° S-W. [34]

	Orientation from North						
	W			S			E
Tilt	270°	240°	210°	180°	150°	120°	90°
0°	84	84	84	84	84	84	84
10°	84	87	90	91	90	87	84
20°	82	89	94	96	94	89	82
30°	81	90	97	100	97	90	81
40°	78	89	97	100	97	89	78
50°	74	87	95	98	95	87	74
60°	69	82	92	95	92	82	69
70°	64	77	86	89	86	77	64
80°	57	69	78	81	78	69	57
90°	50	61	68	71	68	61	50

Table II.1The tilt and orientation of photovoltaic solar panels. [39]

II.10.4 Solar installations

-The photovoltaic panels produce a direct electric current. ;

-The regulator optimizes the charging and discharging of the battery according to its capacity and ensures its protection. ;

- The inverter transforms direct current into alternating current to supply the AC receivers;

-The batteries are charged by day to be able to supply power at night or on bad weather days;

- Specific DC receivers can be used. These devices are particularly economical. [38]

II.10.4.1 Connection to the regulator

After marking the location of the battery, regulator and panel according to the cable lengths and advice above, the system components should be connected to the regulator in the following order after Grounding: [38]

a. Battery

First remove the fuse on the + cable

Connect the cables to the controller: red on the + terminal, black on the - terminal.

Connect the other end of the red cable to the + terminal, black to the - terminal of the battery, following the diagram below (red cable and black cable at each end of the system in parallel).

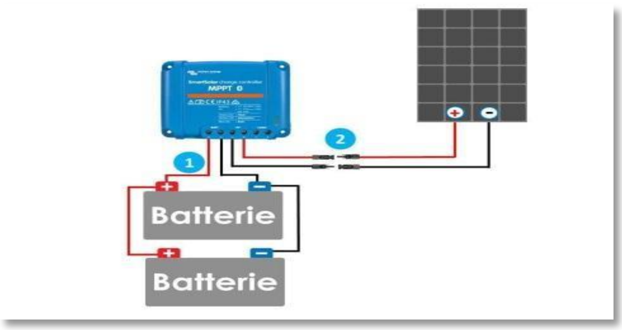


Figure II.13: Connection to the regulator. [38]

b. Panel

Cover the panel with protection to prevent any production of electricity. Connect the cables back to the panel.

Red on red and black on…blue.

Connect the other end of these cables to the regulator: terminals + and -.

c. Consumers

The energy produced supplies one or more consumer appliances (lighting, refrigeration, pumping, etc.).

- Put all consumers in the off position;

- Connect the cables from the distribution box to the regulator;

-Then check all the polarities, the quality of the connections;

- Now install the fuse on the battery cable and on the regulator;

-Remove the protective cover on the solar panel;

-Turn on the consumers.

II.10.5 Lightning protection and grounding

❖ **Protection against lightning**

A surge protector is necessary to protect installations from high voltage transients. Placed between the panel fuse and the regulator, it will be connected to the ground in order to evacuate the lightning potentially attracted by the metal structure of the modules (itself connected to the ground). When using a corrugated local network, an AC surge protector will also be used at the head of the installation.

❖ **Grounding**

Grounding will ensure the protection of people and equipment: the structure of the modules, the surge arresters, and the inverter will be connected to the ground. [38]

II.11 Types of PV system:

II.11.1 Stand-alone system

The role of stand-alone systems is to supply one or more consumers located in an area isolated from the electrical network. As can be seen in figure II.14, which represents an example of an autonomous PV system: It is made up of a storage system, associated with PV generators to ensure power at all times and for several days despite the intermittency of production. This storage system represents a very large part of the cost of the installation, and these operating conditions are very restrictive. Therefore, energy management systems have been developed to optimize the lifetime of the storage system and reduce operating costs. [40]

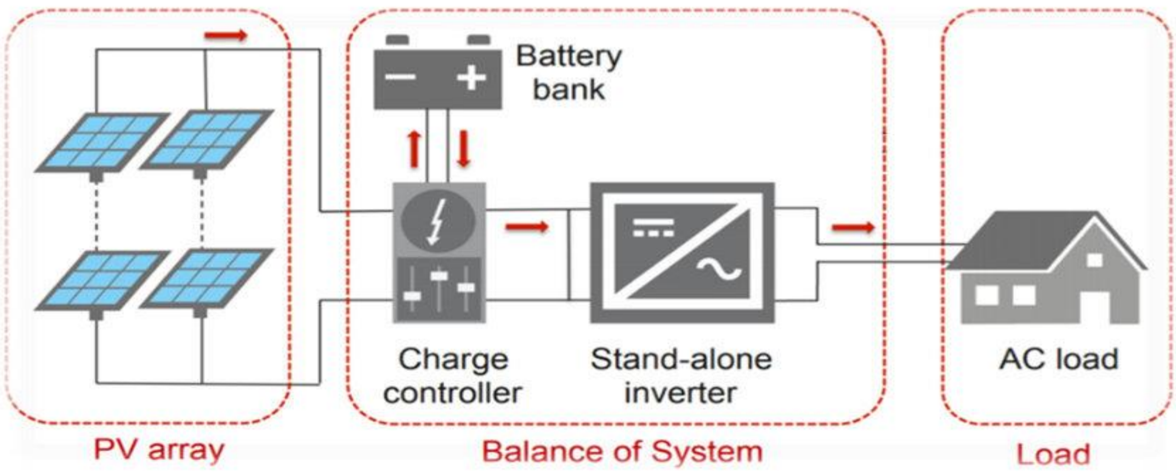


Figure II.14 :Stand-alone system [41]

II.11.2 Hybrid system

Hybrid systems receive part of their energy from one or more additional sources, which are also independent of the electricity distribution networks. In practice, the photovoltaic generator is combined with a wind turbine or a fuel generator, or both at the same time with energy storage accumulators. Such a system is a good choice for applications that require a fairly high power continuous supply. [40]

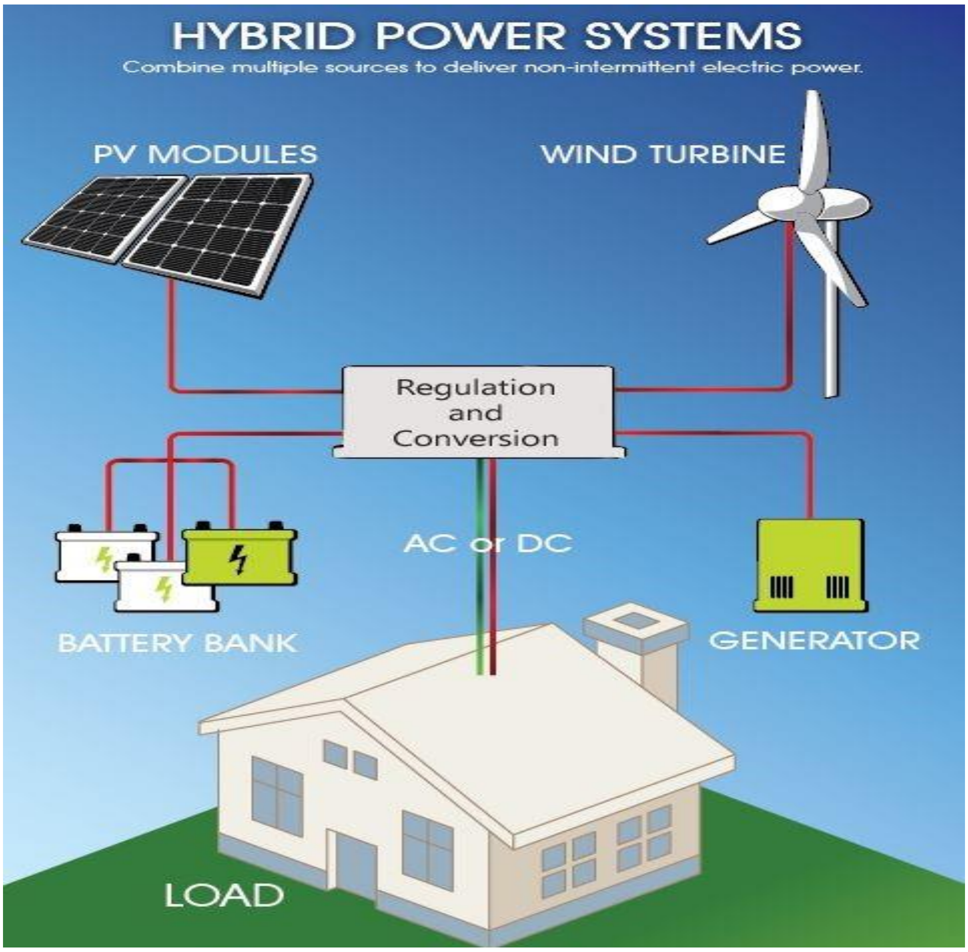


Figure II.15: Hybrid system [42]

II.11.3 Grid connected PV system

A PV installation can be connected in parallel with the electricity grid. The solar panels are connected in series to form "strings", themselves connected to an inverter. The task of the inverter is to transform the direct current coming out of the panels into alternating current. Each inverter is chosen according to the power of the panels and can accommodate one or more strings.

If local consumption is greater than the production of the PV installation, the back-up is provided by the network. Otherwise, the energy is supplied to the public network and is used to supply consumers. [40]

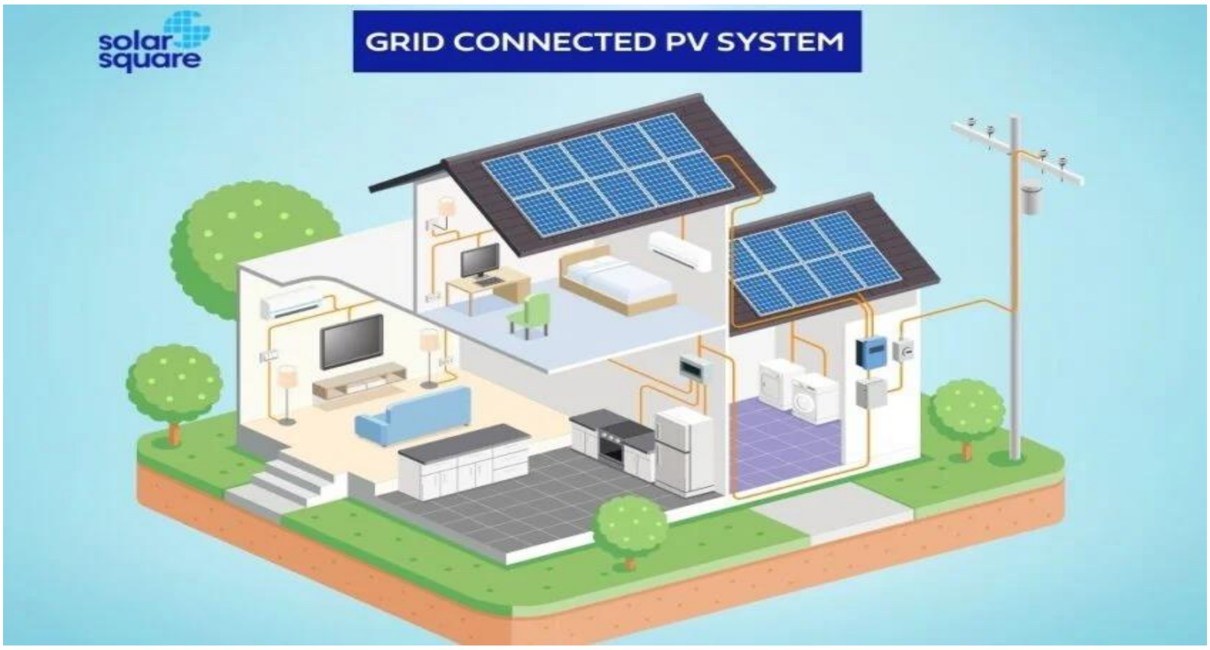


Figure II.16: Grid connected PV system [43]

II.12 MPPT Command

The MPPT control (Maximum Power Point Tracking) is an electronic assembly at the level of the regulator which makes it possible to extract the maximum amount of energy from a photovoltaic solar installation.

II.13 Classification of MPPT commands:

We can broadly classify MPPT commands according to the type of electronic implementation: analog, digital or mixed. However, it is more interesting to classify them according to the type of research they perform and according to the input parameters of the MPPT command.

II.13.1 Indirect MPPT

This type of MPPT commands use the existing link between the measured variables (Isc or Voc), which can be easily determined, and the approximate position of the MPP.

II.13.2 Direct MPPT

This type of MPPT control determines the optimum operating point (MPP) from the currents, voltages or powers measured in the system. It can therefore react to unpredictable changes in the operation of the GPV.

II.14 Sizing of a photovoltaic power plant

The sizing of a photovoltaic system is a measurement step where it requires taking into consideration the technical, meteorological, economic and strategic criteria of a project. The choice of its parameters depends on the size of the photovoltaic field, itself determined by the power consumption.

In this chapter consists of working out the size of the installation of the power station, taking into consideration all the parameters, also keeping the same choice of the company with regard to the types of equipment.

II.14.1 The steps for sizing a PV power plant

The methodology for sizing a photovoltaic system depends on the following steps [44]:

- **Step 1:** Presentation and determination of the geographical coordinates and the site.
- **Step 2:** Determination of the user's needs: voltage, power of the devices and durations of use.
- **Step 3:** Adaptation of photovoltaic modules technology, voltage, current and power.
- **Step 4:** Determination of SKID
  - Adaptation of the inverter: technology, voltage, current and power.
  - Central Box.
  - Sensor Box.
  - A transformer.
  - RMU.
- **Step 5:** Wiring diagram: determination of wiring accessories and cable sections.

The Naama Photovoltaic plant represents a system of production of electrical energy connected to the network to inject a power of 20 MW during the day. In order to improve the quality of service of the central electricity distribution network and to cover the insufficient energy needs of the region. So it is noted that the photovoltaic field works without storage.

II.14.1.1 Step 01: Presentation and determination of the geographical coordinates and the site.

Determine the geographical and astronomical coordinates of the Naama power station site as shown in Table II.2.

Site presentation	Data
City	Naama
Latitude	33,27372° or 33° 16' 25'' north
Longitude	-0.37196° or 0° 22' 19'' west
Altitude	1172 meters
Albedo	0.20

Table II.2: Geographical data from Naama site

Figure II.17: General scheme of Naama photovoltaic power plant by RETScreen

- **Orientation and inclination of the modules.**

In order to maximize the electricity production of a photovoltaic system, it is necessary to orient the modules optimally in order to capture the maximum amount of solar radiation. In order to achieve its maximum performance, a photovoltaic module must ideally have a flat collector that is perpendicular to the sun's rays [44]. As shown in (Figure II.18).

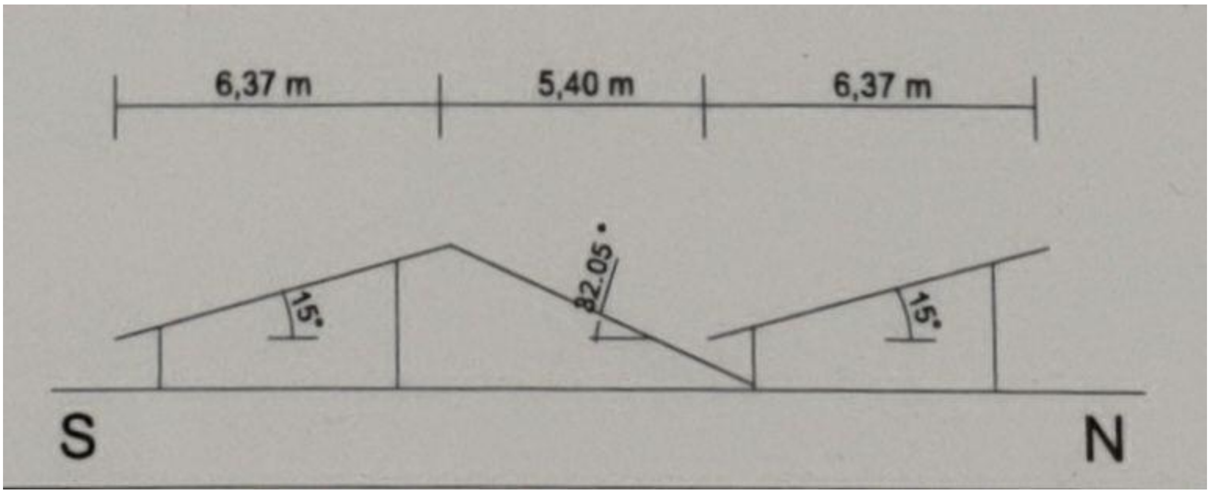


Figure II.18: Angle of inclination of the photovoltaic modules. [45]

In the case of our project the chosen installation and fixed type inclined by 15 ° due south this choice is based on the following considerations:

- The inclination of 15 ° will have an almost optimal production during the summer period because it is in summer that the sunshine is maximum.
- Fixed installations require low maintenance due to the absence of motors and pivoting devices;
- The fixing elements of the modules and their own structure are mounted so as not to create shading zones on the modules. The distance between chains is equal to 6 m. [46]

II.14.1.2 Step 02: Determination of the user's needs.

The planned capacity is determined by the government as part of the Algerian national renewable energy development project. The project includes the construction of various power plants to generate electricity from renewable energy sources, connected to the Sonalgaz network. The role of these systems is to generate additional energy to improve quality and fill energy shortages in some areas of the country. Under this project, the envisaged capacity of for the wilaya of Naama is 20 MW.

It is therefore not necessary to collect a sample of the energy requirements or the receiver types or operating modes of the consumers.

II.14.1.3 Step 03: Determination of photovoltaic modules.

The module chosen is a module of the Canadian Solar CS6P-250P polycrystalline silicon type with an optimal power of 250Wc, for economic reasons, it is chosen essentially for its price, the table (annex01) shows more details of these characteristics.

Imp = 8.30A / Isc = 8.87A

Vmp = 30.1V/ Voc = 37.2V

- **Electrical production of a module in one day.**

A photovoltaic module is characterized above all by its peak power Pp (W), power under STC conditions (1000 W/m^2) at 25 °C). If the module is exposed under these conditions STC, it will produce at a given instant an electrical power equal to this peak power, and if it lasts N hours, it will have produced during this time an electrical energy Eprod equal to the product of the peak power by the elapsed time :

$$E_{prod} = N \times Pp \qquad (II.9)$$

-**E_{prod}:** Electrical energy produced (Wh)
-**N:** Number of hours of exposure to the STC condition
-**Pp:** Peak Power (W)

However, due to the fluctuating radiation throughout the day, this law is not necessarily applicable. The number of hour's equivalent to receiving lighting with a power of 1000 W/m2 for a certain number of hours is given. This number corresponds to the energy that the photovoltaic module produces on a sunny day that has a specific energy profile.

Thanks to the reference irradiation value (1000 W/m^2), the number of equivalent hours is numerically equal to the integrated solar energy, expressed in kWh/m^2/day.

$$Esol = Ne \times 1000 \qquad (II.10)$$

Esol: Daily solar energy per unit area (Wh/m^2/d)
Ne: Number of equivalent hours (h/d)
1000 W/m^2: power under STC conditions

- **Electrical losses.**

The photovoltaic system contains several losses, the designer must identify them case by case in order to be able to encrypt them. Then we must take all the sources of loss of the system and take them into account in the calculation of the modules because they must supply all the energy consumed, even that which is lost.

- **Types of losses.**

a) Losses due to soiling of the panel or by a coating placed in front, which modify its charging current, the voltage not being affected;

b) Losses by voltage drop at the terminals of the series diodes;

c) Losses by voltage drop at the terminals of the cables according to their length, their cross-section and the amperage transported:

d) Another loss directly affects the voltage of the panel, it is the drop in voltage when the temperature rises, the peak power being given at 25°C;

e) On the other hand, there may be a discrepancy between reality and calculation because it assumes that the power of photovoltaic panel is proportional to the illumination and it is in fact the current that is, so sometimes it is necessary to consider the loss of the beginning and end of the day when the illumination is low;

f) Finally, there is a loss related to the actual power of the panel which may be lower than that announced in the manufacturer's documentation. We do not consider this loss in our calculations, because it is far from being the general case, but we must know that it happens.

- **Evaluation of the loss coefficient Cl.**

Generally the loss rate is mentioned with the technical characteristics of each device for photovoltaic installations these losses are calculated as follows:

- Inverter losses 10%;
- Temperature losses 10%:
- Cable and connection losses 3%;
- Losses For "soiling" 10%;
- Low illumination losses 4%;
- Losses due to the quality of module 3%

Ales the current loss coefficient is:

Cl=0.9x0.9x0.97x0.90x0.96x0.97=0.65=65% either 100% - 65% = 35% total losses

Composition of the photovoltaic field.

The size of the photoelectric field depends mainly on its maximum strength, the connection of modules in series is limited by the input voltage of the inverter, and on the other hand, their connection in parallel depends on the current of the inverter.

- **Total number of panels :**

We remind you that the chosen module has a power of 250W under 30.1V so the total number of Nt modules is expressed as follows:

$$\textbf{Nt} = \frac{Pp}{Unit\ peak\ power\ of\ the\ module} \qquad \textbf{(II.11)}$$

$$\textbf{Pp} = \frac{Pu}{Ns.Cl} = \frac{20000000}{1.545x0.65} = 19920000W \qquad \textbf{(II.12)}$$

Nt: the total number of modules

Pp: peak power

Pu: Useful Power

Ns: number of hours of sunshine

Cl: Loss coefficient

Which implies that the number of the modules is:

$$\textbf{Nt} = \frac{19920000}{250} = \textbf{79680 modules.} \qquad \textbf{(II.13)}$$

On the one hand for a sustainable operation of the power plant and to ensure a good isolation of the parts of the power plant in case of failure. On the other hand following the proportionalities between the price, the quality and the power of the inverters in the international market. The power plant has been divided into several 1MW power sub-plants each sub-plant is connected to an inverter which gives a total of 20 inverters.

- **The dimensioning of 1 MW is adopted:**

So our work is limited to the dimensioning of a central sub which will be the other zones. The peak power:

$$\textbf{Ppc} = \frac{Total\ daily\ consumption}{Ns \times Cl} = \frac{1000}{1.545 \times 0.65} = \textbf{996 KW} \qquad \textbf{(II.14)}$$

Which implies that the number of modules per 1 MW inverter is:

$$\textbf{Ntc} = \frac{996000}{250} = \textbf{3984 panel.} \qquad \textbf{(II.15)}$$

With:

Ppc: the peak power of the central unit;

Ntc: Total number of modules for a central unit.

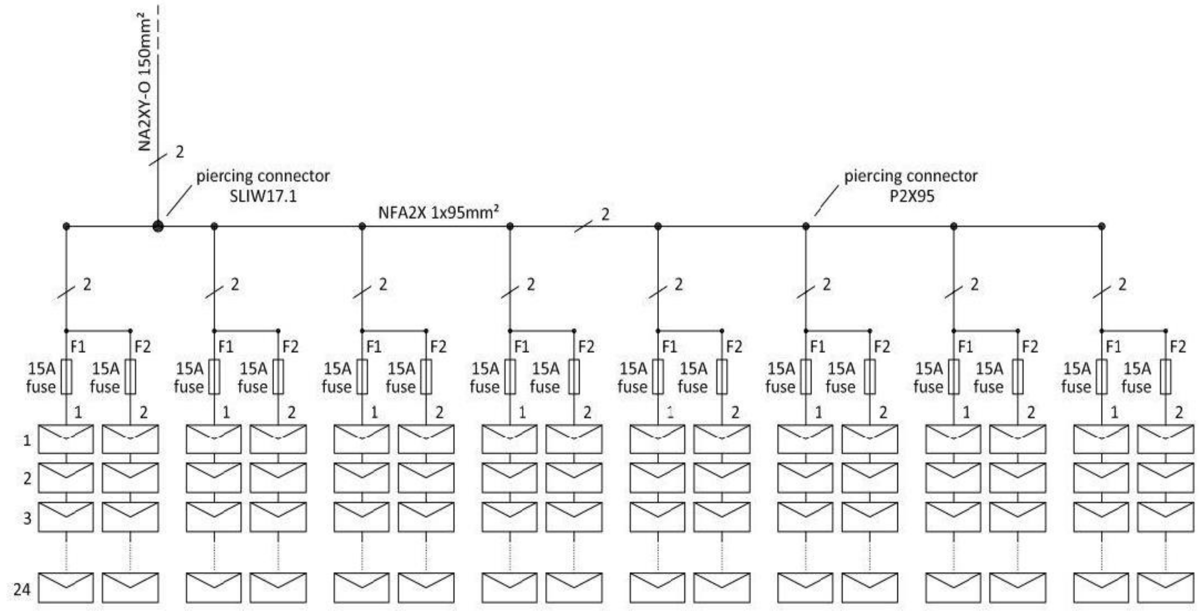


Figure II.19 : Single Line Diagram 996 KW. [47]

II.14.1.4 Step 4: Determination of SKID

The SKID is the set of equipment allowing to group the energy produced by photovoltaic fields and convert it from direct to alternating, each skid pilot 2 MW. Composed of:

- Four Central Boxes;
- Two inverters ;
- Sensor Box;
- A transformer;
- RMU.

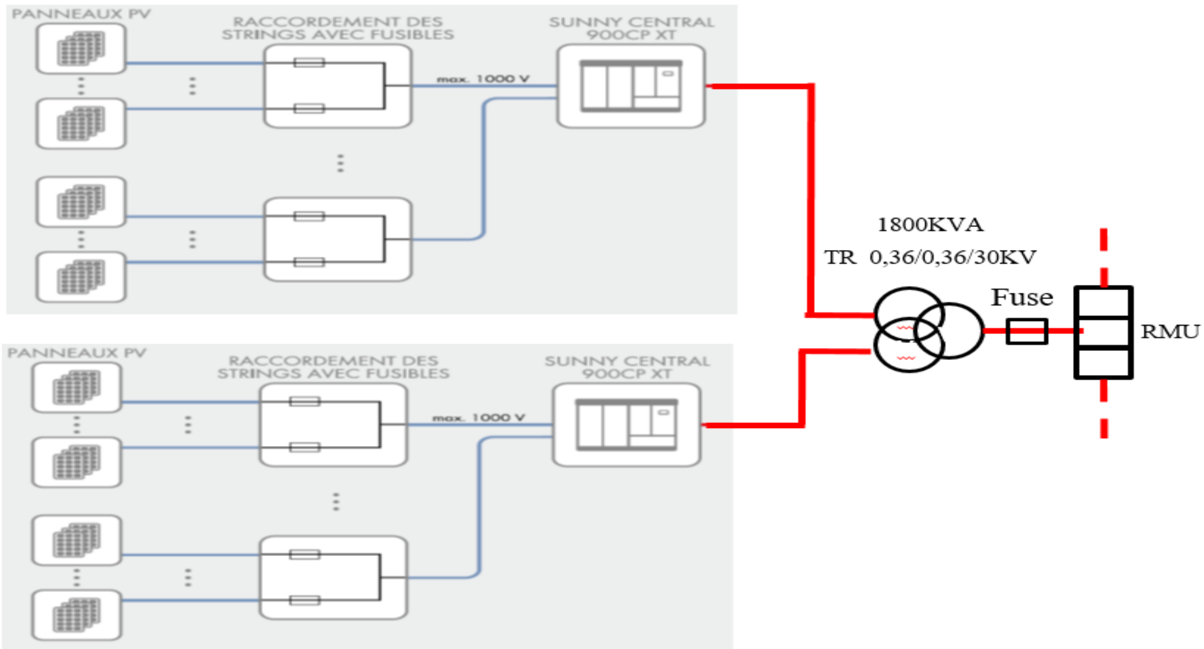


Figure II.20 : SKID Diagram. [47]

❖ **Adaptation of the inverter.**

For a grid-connected installation, the dimensioning of the inverter is carried out according to the characteristics of the modules and the electrical network. The characteristics of the output voltage of the inverter must be synchronized with that of the electrical network. Inverters are characterized by a limited input voltage range. The latter must be compatible with the voltage of the modules in series, regardless of the temperature, the number of modules in series and the technology. Its dimensioning consists in ensuring that the voltage range of the photovoltaic generator remains included in the input voltage range of the inverter and regardless of the temperature of the modules since, in cold weather (-10 ° C.) and in the presence of too high a number of modules, the field voltage can exceed the upper limit of the input range of the inverter and cause the destruction of the latter. In addition, in hot weather and in the presence of few modules, the voltage can become too low and significantly reduce the efficiency until the system stops.

❖ **Rated power.**

The inverter delivers almost the same power as that of the photovoltaic generator with a difference, due either to the technology of the panels, or to the effect of the temperature or the efficiency of the inverter. The determination of the configuration << photovoltaic field / inverter "> makes it possible to propose for each power considered, an installation that makes the best use of its energy production. It is indeed important to respect the relationship admitting the fact that the inverter power is between 0.7 times and 1.2 times the peak power of the field. However, the choice fell on the Sunny central 800CP type inverter, with characteristics present in the au technical data sheet (annex02). A check of the previous condition confirms our choice as shown below:

$$\frac{Pmax}{Pp} = \frac{898}{996} = 0.9 \qquad 0.7 \leq 0.9 \leq 1.2 \qquad \textbf{(II.16)}$$

Pmax: Maximum power of the inverter (see Annex 02):

Pp: Peak power of central unit.

❖ **The maximum number of modules in series.**

$$Nsc = \frac{Uinv\ max}{UocPv} = \frac{1000}{41} = 24.39 = 24 \text{ modules in series} \qquad \textbf{(II.17)}$$

So:

$$U_{DC\ branch} = 24 \times 41 = 984 < Uinv\ max; \qquad \textbf{(II.18)}$$

So the final number of serial modules per branch is Nsc =24 modules.

- **Number of parallel modules (chains).**

$$\mathbf{Npc} = \frac{Ntc}{Nsc} = \frac{3984}{24} = 166\ Chains\ of\ PV\ in\ parallel \qquad \textbf{(II.19)}$$

So:

Imax= (Npc × Iscpv) = 166×8.87=1472.42 A. It exceeds the maximum current of the inverter 1400 A.

With:

Ntc: total number of modules in the central.

Nsc: Real number of modules in series in the central

Npc: real number of modules in parallel in the central

Uinv.max: max voltage of the inverter

Uocpv: Open circuit voltage of the module.

Imax: max current of the channels

lscpv: the short-circuit current of the photovoltaic panel.

- **Interpretation of results obtained.**

However, the total number of modules of the power plant is:

$Nt' = Npc \times Nsc \times Ninv$

$$\mathbf{Nt'=166 \times 24 \times 20 = 79680\ panels.} \qquad \textbf{(II.20)}$$

Nt=Nt'→79680=79680

We have found that the installation that has been done by the company is based on standardization, it consists of distributing 24 modules in series with a voltage that is 1.6% lower compared to the maximum voltage supported by the inverter.

- **Central Box.**

The main DC cables are grouped in central boxes. According to their polarity, the main DC cables are distributed on Central Boxes. We have two central Negative Box grouping the Negative DC cables and the other two positive ones grouping the positive DC cables.

- **Sensor Box.**

- It performs the following functions:
- Real-time measurement of DC and AC current & voltage values;
- Measurement of the system's weather parameters;
- Input of signals per second and intermediate storage;

- **A transformer.**

Each Skid includes a transformer. Its function is to convert the alternating current and voltage system into another system of voltage and current with generally different values, with the aim of transmitting electrical energy.

The type of transformer chosen is DNTG 1800 H/30, and the Electrical characteristics as in the figure II.21:

Figure II.21: Electrical characteristics of the transformer type DNTG 1800 H/30. [45]

- **RMU.**

All the skids are looped via the medium voltage cells called ring main unit "RMU" to ensure continuity of service by the artery cut-off technique. The RMU consists of named MT cells:

- Cell arrived;
- Departure cell;
- Transformer protection cell;
- Arrival and departure cell;
- Modular cell with arrival or departure function, equipped with a three-position disconnecting switch (open, closed or grounded). Allowing communication with the busbar and the set of cells.

II.14.1.5 Step 5: The wiring.

The cables are considered as the core of an electrical installation, in addition an oversizing generates additional costs in the realization of the project, on the other hand an under sizing can generate heating and cause a malfunction of the electrical installation, hence the need for an optimal dimensioning for this the determination of the sections of the cables will minimize the losses during the transmission of electricity. To make this dimensioning, we need to know the intensity of the current flowing in these cables, including the operating current and the allowable current.

a) The current of employment.

The operating current IB is the current corresponding to the greatest power transported by the circuit in normal operation, it is determined from the absorbed current and corrected according to several factors.

b) The permissible current.

The permissible current Iz of a conductor is the current capable of passing under normal conditions without prejudice to malfunction or degradation of the cable. In practice Iz is calculated from the current IB taking into account the constraints of the medium where the pipes are laid. The employment current (IB) is related to the permissible current by the relation:

$$\mathbf{Iz} > \frac{\mathbf{IB}}{\mathbf{K1 \times K2 \times K3}} \qquad \textbf{(II.21)}$$

With:

•The correction factor K1 takes into account the laying mode;

•The correction factor K2 takes into account the mutual influence of the circuits placed side by side;

•The correction factor K3 takes into account the ambient temperature and the nature of the insulation.

- **Solar chain DC cable**

This is the cable that connects the two solar chains, each chain consisting of 24 modules with the following characteristics: Impp = 8.30 A, Isc = 8.87 A.

The coefficient 1.25 against overloads on the DC side.

Number of chains = 2.

Which implies that the current flowing in a chain is:

$$\mathbf{Ic = 8.3 \times 1.25 \times 2 = 20.75\ A.} \qquad \textbf{(II.22)}$$

a) The current of employment IB.

$$\mathbf{IB = 8.87 \times 1.25 \times 2 = 22.18 A} \qquad \textbf{(II.23)}$$

b) The permissible current Iz.

$$Iz > \frac{IB}{K1 \times K2 \times K3} \quad \text{(II.24)}$$

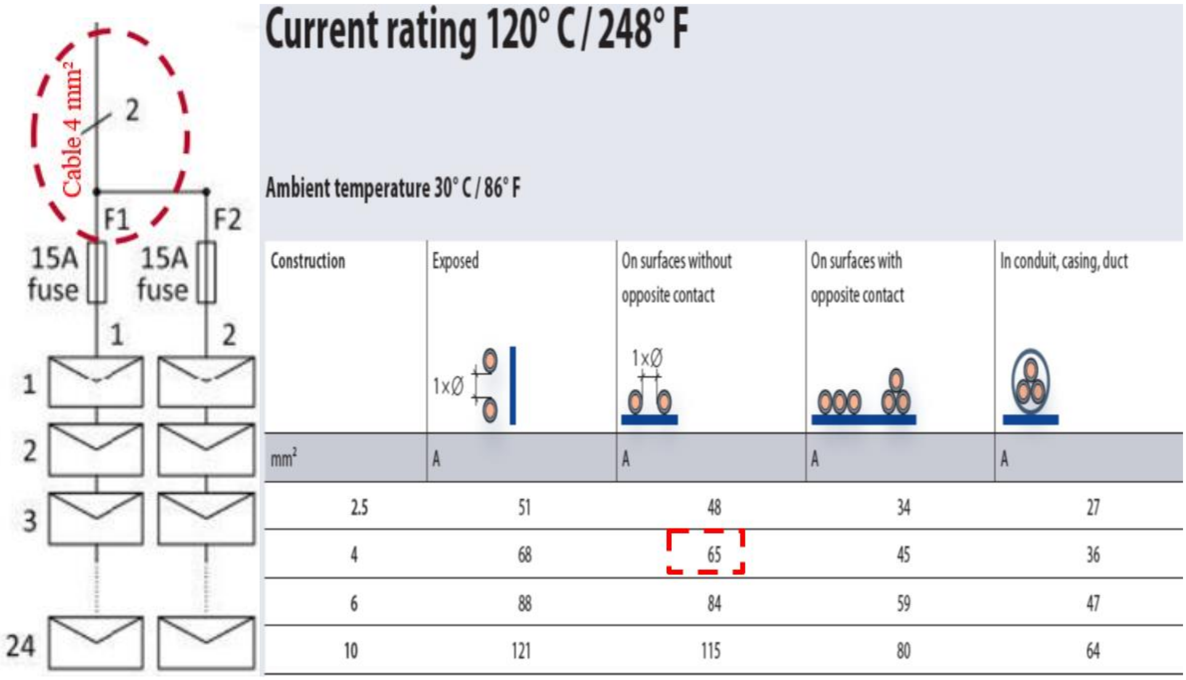
According to the tables (Annex 03) the values of K1, K2 and K3 are:

K1=0.95, K2=0.8, K3=0.5.

So:

$$Iz > \frac{22.18}{0.95 \times 0.8 \times 0.5} = 58.37A \quad \text{(II.25)}$$

To find the section of the cable which corresponds to our current which is 58.37 A, refer to figure II.22 which presents a reference table between the admissible current and the section of the cable according to the installation, View that the value of our current which is not on the board Select the nearest higher value which equals 65 A, for cables laid on a surface with no contact between them, a section of 4 mm² is obtained.



Current rating 120° C / 248° F

Ambient temperature 30° C / 86° F

Construction	Exposed	On surfaces without opposite contact	On surfaces with opposite contact	In conduit, casing, duct
mm²	A	A	A	A
2.5	51	48	34	27
4	68	65	45	36
6	88	84	59	47
10	121	115	80	64

Figure II.22: Cables with a cross-section of 4 mm2 connecting two solar chains. [47]

❖ **Collector electric cable**

The collector electric cable is a cable that groups the current of several tables, each table consists of two chains, the grouping of 8 tables which constitute 16 chains is considered as a photovoltaic generator.

Calculation of the currents IB and IZ of the collector electric cable:

a) The current of employment IB for 16 strings:

$$IB = 8.87 \times 16 \times 1.25 = 177.4A \quad \text{(II.26)}$$

b) The permissible current Iz for 16 strings:

According to the tables (Annex 03) the values of K1, K2 and K3 are:

K1=0.90, K2=0.88, K3=0.87.

$$Iz > \frac{177.4}{0.90*0.88*0.87} = 257.45\text{A}. \quad \text{(II.27)}$$

From figure II.23 which normalizes the section according to the admissible current and the installation method, the value of the current closest to 257.45 A is equal to 241 A, which corresponds to a section of 95 mm².

Section nominale des conducteurs mm²	Méthodes de référence du Tableau B.52.1						
	Câbles multiconducteurs		Câbles monoconducteurs				
					Trois conducteurs chargés en nappe		
						Non jointifs	
	Deux conducteurs chargés	Trois conducteurs chargés	Deux conducteurs chargés jointifs	Trois conducteurs en trèfle chargés	Jointifs	Horizontaux	Verticaux
	Méthode E	Méthode E	Méthode F	Méthode F	Méthode F	Méthode G	Méthode G
1	2	3	4	5	6	7	8
2,5	23	19,5	–	–	–	–	–
4	31	26	–	–	–	–	–
6	39	33	–	–	–	–	–
10	54	46	–	–	–	–	–
16	73	61	–	–	–	–	–
25	89	78	98	84	87	112	99
35	111	96	122	105	109	139	124
50	135	117	149	128	133	169	152
70	173	150	192	166	173	217	196
95	210	183	235	203	212	265	241
120	244	212	273	237	247	308	282

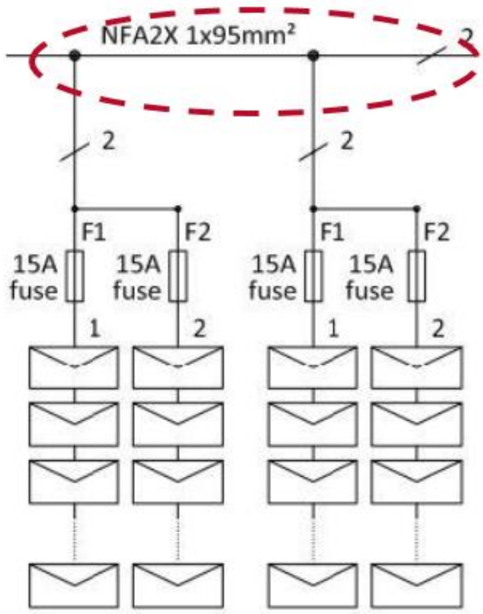


Figure II.23: Electrical collector cable type NFA2X (95 mm²). [47]

- **Main DC cable.**

The power of the photovoltaic generators will be transmitted to the central box thanks to 11 cables (main DC) which will then be grouped with a busbar.

Since the same current flows in the previous section (95mm^2), will flow in this new cable which will connect the collector cable with the central box because the same power produced, but this cable will have another laying mode, since it will be buried (Figure II.24).

Conclusion: The Company has chosen to increase the cable size by 150mm^2 with a permissible current of 261A.

Section nominale des conducteurs mm^2	Méthodes de référence du Tableau B.52.1						
	A1	A2	B1	B2	C	D1	D2
Aluminium							
2,5	20	19,5	25	23	26	26	
4	27	26	33	31	35	33	
6	35	33	43	40	45	42	
.10	48	45	59	54	62	55	
16	64	60	79	72	84	71	76
25	84	78	105	94	101	90	98
35	103	96	130	115	126	108	117
50	125	115	157	138	154	128	139
70	158	145	200	175	198	158	170
95	191	175	242	210	241	186	204
120	220	201	281	242	280	211	233
150	253	230	307	261	324	238	261
185	288	262	351	300	371	267	296
240	338	307	412	358	439	307	343
300	387	352	471	415	508	346	386

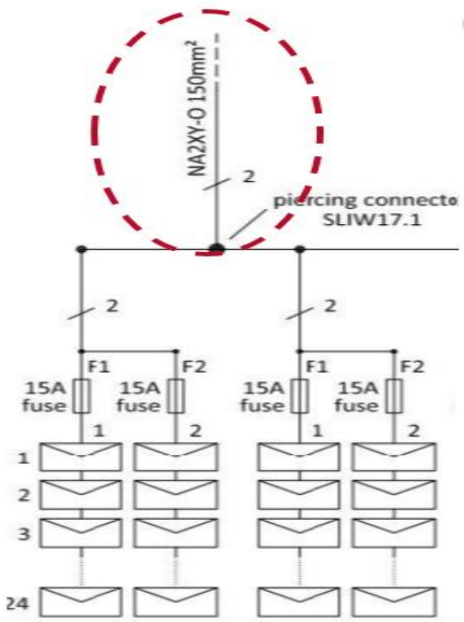


Figure II.24 : Main DC cable with a section of 150mm². [47]

- **DC central box transmission cable to the inverter.**

a) The current of employment IB.

$$\mathbf{IB = 166.31 \times 11 = 1829.41A.} \quad \textbf{(II.28)}$$

b) The permissible current Iz.

According to the tables (Annex 03) the values of K1, K2 and K3 are:

K1=1, K2=1, K3=0.87.

So:

$$Iz > \frac{IB}{K1 \times K2 \times K3} = \frac{1829.41}{1*1*0.97} = 2102.77\ \text{A.} \quad \textbf{(II.29)}$$

Since our current is very high, we will carry it on two parallel cables, which implies that:

$$\text{Iz} = \frac{2102.77}{2} = 1051.39\ \text{A}. \quad \textbf{(II.30)}$$

To find the section of the cable which corresponds to our current which is 1051.39 A by referring to figure II.25, then we obtain a section of 300 mm².

mm²		mm	mm	mm	mm	mm	mm	mm	kg	A	kA	kJ/m
SIENOPYR(120)	(N)HXSGAFHXOE	EN50264-3-1	1800 V	...		FM			ohne Schirm /	*without screen*		
1,5	5DB7 501	1,5	-	5,5	6,4	23	58	46	48	36	0,189	624
2,5	5DB7 502	2,0	-	6,0	6,9	25	63	50	61	49	0,315	700
4	5DB7 503	2,4	-	6,4	7,3	27	67	54	78	65	0,504	777
6	5DB7 504	2,9	-	6,9	7,8	29	72	58	99	82	0,756	862
10	5DB7 505	3,9	-	8,3	9,2	34	86	69	150	116	1,26	1165
16	5DB7 506	5,6	-	10,3	11,5	43	107	86	227	156	2,02	1647
25	5DB7 507	6,7	-	12,4	13,6	64	128	102	342	206	3,15	2357
35	5DB7 508	7,9	-	13,6	14,8	70	140	112	442	256	4,41	2647
50	5DB7 509	9,4	-	15,0	16,5	78	155	124	587	323	6,30	3009
70	5DB7 510	10,9	-	16,5	18,0	85	170	136	774	407	8,82	3371
95	5DB7 511	12,6	-	19,0	20,5	98	195	156	1039	486	12,0	4384
120	5DB7 512	14,3	-	20,7	22,2	106	212	170	1273	571	15,1	4848
150	5DB7 513	16,2	-	23,0	24,5	118	235	188	1573	659	18,9	5740
185	5DB7 514	17,6	-	24,5	26,9	127	253	202	1909	750	23,3	6540
240	5DB7 515	20,8	-	27,7	30,1	143	285	228	2421	900	30,2	7515
300	5DB7 516	23,1	-	30,0	32,4	154	308	246	2959	1041	37,8	8216
400	5DB7 517	26,8	-	34,1	37,7	177	353	282	3917	1250	50,4	10453

Figure II.25: Reference of DC central box transmission cable to the inverter. [47]

- **Skid transformer cable and RMU cell :**

Each SKID with two inverters, the maximum allowed voltage drop is 10% of the allowed nominal voltage is therefore 27KV.√3

a) The current of employment IB.skid:

$$\text{IB.skid} = \frac{2 \times 880 \times 10^3}{\sqrt{3} \times 27 \times 10^3} = 37.64\text{A}. \quad \textbf{(II.31)}$$

6 hours/days of PV production are assumed on average, so the maximum power of the Skid per day is as follows:

Ipv.daily =6 x ISKID=6 x 37.64= 225.84 A/days. **(II.32)**

b) The permissible current Iz.

The values of K1, K2 and K3 are:

K=0.95, K2=0.82, K3=0.71.

$$Iz > \frac{IB}{K1 \times K2 \times K3} = \frac{225.84}{0.95 * 0.82 * 0.71} = 408.32 \text{ A.} \qquad \textbf{(II.33)}$$

Pour trouver la section du câble qui correspond à notre courant qui est de 408.32 A en se réfère au figure II.26, Alors on obtient une section de 240 mm² correspond à un courant admissible de 422 A.

Nombre de fils et section transversale nominale Number of cores and cross-section	Courant de court-circuit admissible, conducteur Conductor short-circuit current	Courant de court-circuit admissible, écran Screen short- circuit current	Constante de temps de chauffage (en triangle) * Time heating constant (trefoil)*	Constante de temps de chauffage (à plat) * Time heating constant (flat)*	Capacité dans l'air (en triangle) * Current ratings of cable in air (trefoil)* A	Capacité dans l'air (à plat) * Current ratings of cable in air (flat)* A	Capacité en état enterré (en triangle)* Current ratings of cable in ground (trefoil)* A	Capacité de charge : en état enterré (à plat) * Current ratings of cable in ground (flat)* A
mm²	kA	kA	s	s				
1x50/16	4.7	3.2	263	202	187	219	174	195
1x70/16	6.6	3.2	337	258	232	273	213	238
1x95/16	9.0	3.2	425	327	282	331	254	283
1x120/16	11.3	3.2	510	395	325	382	289	321
1x150/25	14.2	5.0	632	504	367	429	322	354
1x185/25	17.5	5.0	735	594	421	492	364	399
1x240/25	22.7	5.0	897	737	496	578	422	458

Figure II.26: Reference of the Transmission Cable MT. [47]

- **Loop connection:**

The current flowing through the cable is the current injected by the 5skids, so:

a) The current of employment IB. loop:

IB.loop =5x 37.64= 188.2 A **(II.34)**

b) The permissible current Iz.loop.

According to the tables (Annex 03) the values of K1, K2 and K3 are:

K=0.90, K2=0.88, K3=0.71.

$$Iz > \frac{IB}{K1 \times K2 \times K3} = \frac{188.2}{0.90 * 0.88 * 0.71} = 334.68 \text{ A} \qquad \textbf{(II.35)}$$

To find the section of the cable that corresponds to our current which is 334.68 A with reference to Figure II.26, Then we obtain a section of 240 mm^2 corresponds to a permissible current of 422 A.

❖ **Connection to the delivery station:**

The current flowing in the cable is the current injected by the 10 skids, with the same calculation method we obtain:

a) The current employment IB. loop:

IB.loop =5 x 37.64= 188.2 A . **(II.36)**

b)) The permissible current Iz.

According to the tables (Annex 03) the values of K1, K2 and K3 are:

K=0.95, K2=0.73, K3=0.79.

$$\boldsymbol{Iz} > \frac{\boldsymbol{IB}}{\boldsymbol{K1 \times K2 \times K3}} = \frac{\mathbf{188.2}}{\mathbf{0.95 * 0.73 * 0.79}} = \mathbf{343.52}\ \text{A} \quad \text{(II.37)}$$

To find the cable section that corresponds to our current, refer to Figure II.26, then a cross-section of 240mm^2 is obtained corresponding to a permissible current of 422 A.

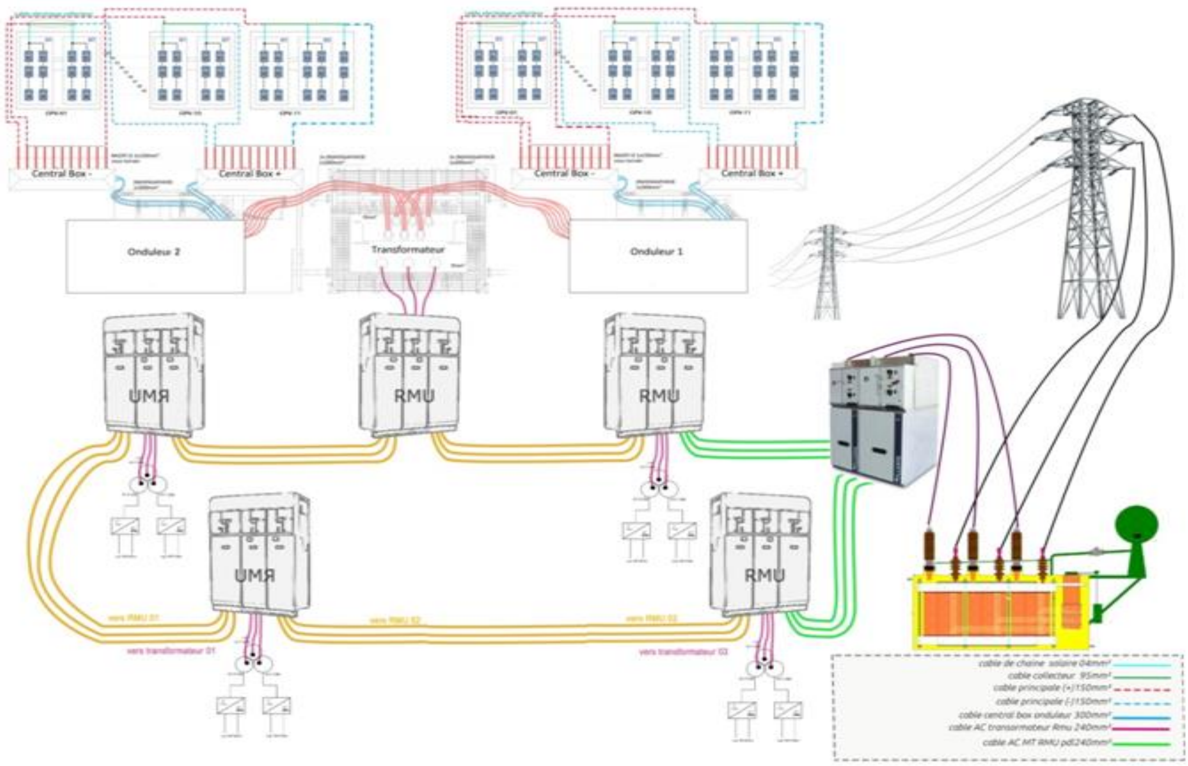


Figure II.27: diagram of the cable paths from the panel to the electrical network. [47]

II.15 Conclusion

In this chapter, we have demonstrated the mode of operation of the photovoltaic solar cell from its absorption of the solar spectrum to the production of electricity. We have described in this chapter the generalities of the solar system and we have defined the three PV systems, electrical characteristics of photovoltaic panel and the type of photovoltaic cell. We then did the installation, the protection, the classification of the PV systems, classification of MPPT commands and we finished this chapter by sizing the photovoltaic system with a capacity of 20 MW.

Chapter III : Simulation of the operation of the Naama photovoltaic power plant.

III.1 Introduction

All models for studying photovoltaic systems aimed at understanding all steps of PV energy conversion, from light to electricity. This is usually done by tracking the conversion and energy loss at each of these steps. For large PV systems, simulation software is usually used to check the performance. This software is used during the development stage of a photovoltaic project to estimate expected performance parameters over the lifetime of the system. Evaluating the performance of a photovoltaic system allows us to predict energy production while observing possible degradation over a period of time. Several performance parameters have been specified by the International Energy Agency (IEA) and described according to the standard IEC 61724 (International Electrotechnical Commission) in order to be able to carry out a complete analysis of the performance of photovoltaic systems. Therefore, this chapter provides a complete analysis of the performance of the Naama photovoltaic power plant, according to the international standardized standard IEC 61724 in order to understand the production cycle of the PV power plant and all the factors that impact on the latter since its launch in order to consider an improvement and prevent damage to the system [48]

III.2 Definition of PV system software

PVSYST software is designed to be used by architects, engineers and researchers, but also a very useful educational tool. It includes in-depth contextual help, which explains in detail the procedure and the models used and offers a cost-effective approach with a guide in the development of a project. PVSYST allows you to import weather data from a dozen different sources. [49]

III.3 Simulation of PV Power plant using PVSYST software.

An important step in the evaluation of photovoltaic systems is to calculate the expected performance parameters of photovoltaic plants already in the design stage. In addition to the dimensions of the PV system and the technical specifications of the components, accurate estimation of these parameters requires the use of various information such as local meteorological data (solar radiation, temperature, wind speed, humidity). There is several researchers have demonstrated the importance of tools for evaluating the performance of solar power plants. Several simulation tools exist to fully analyze the performance of solar power plants. In this case, PVsyst, SAM, PVGIS, and SolarGis were used for forecasting and modeling large-scale PV systems. We chose PVsyst as the simulation software to evaluate the sizing of the Naama PV plant. This choice was not accidental, but because the PVsyst software is widely accepted and easy to use, especially for large PV plants. [50]

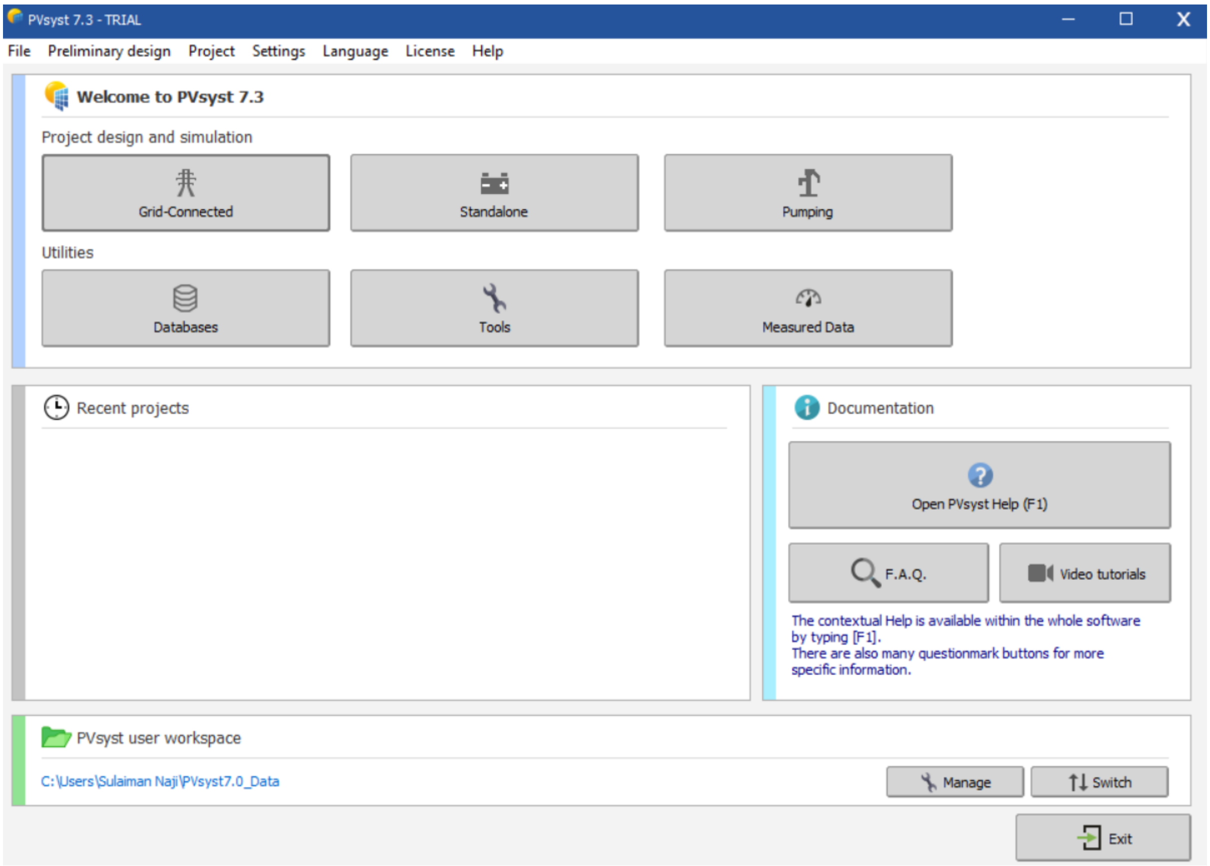


Figure III.1: The PVsyst interface.

III.3.1 Characteristics of the site

III.3.1.1 Geographical data

The geographical location of the city of Naama, it is given in the form of the following Table (III.1):

Site presentation	Data
City	Naama
Latitude	33° 16’ 25’’ north or 33,27372°
Longitude	0° 22’ 19’’ west or -0.37196°
Altitude	1172 meters
Albedo	0.20

Table III.1: Geographical data from Naama site.

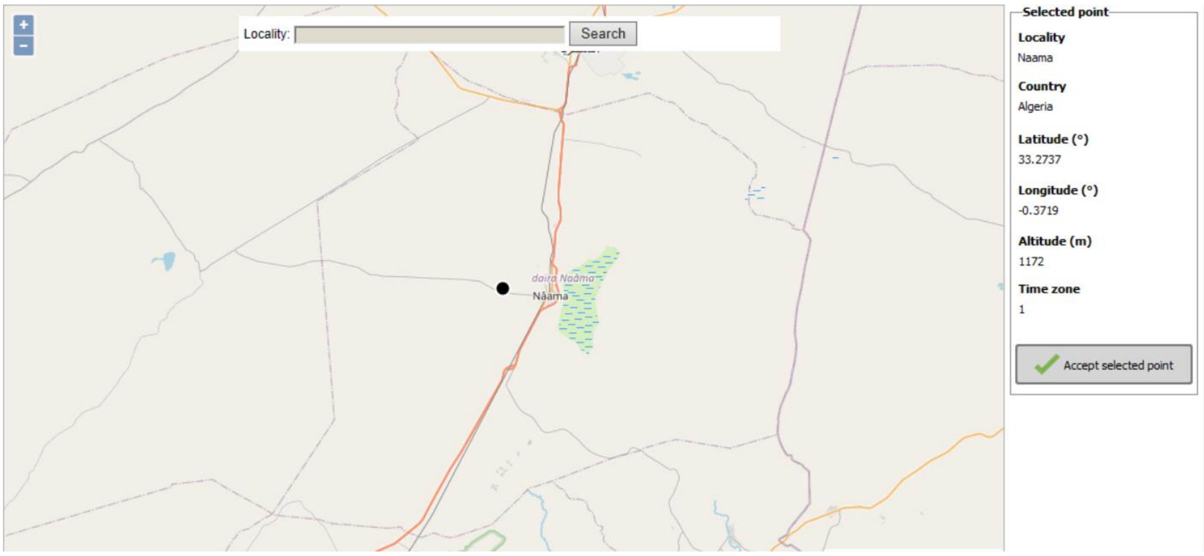
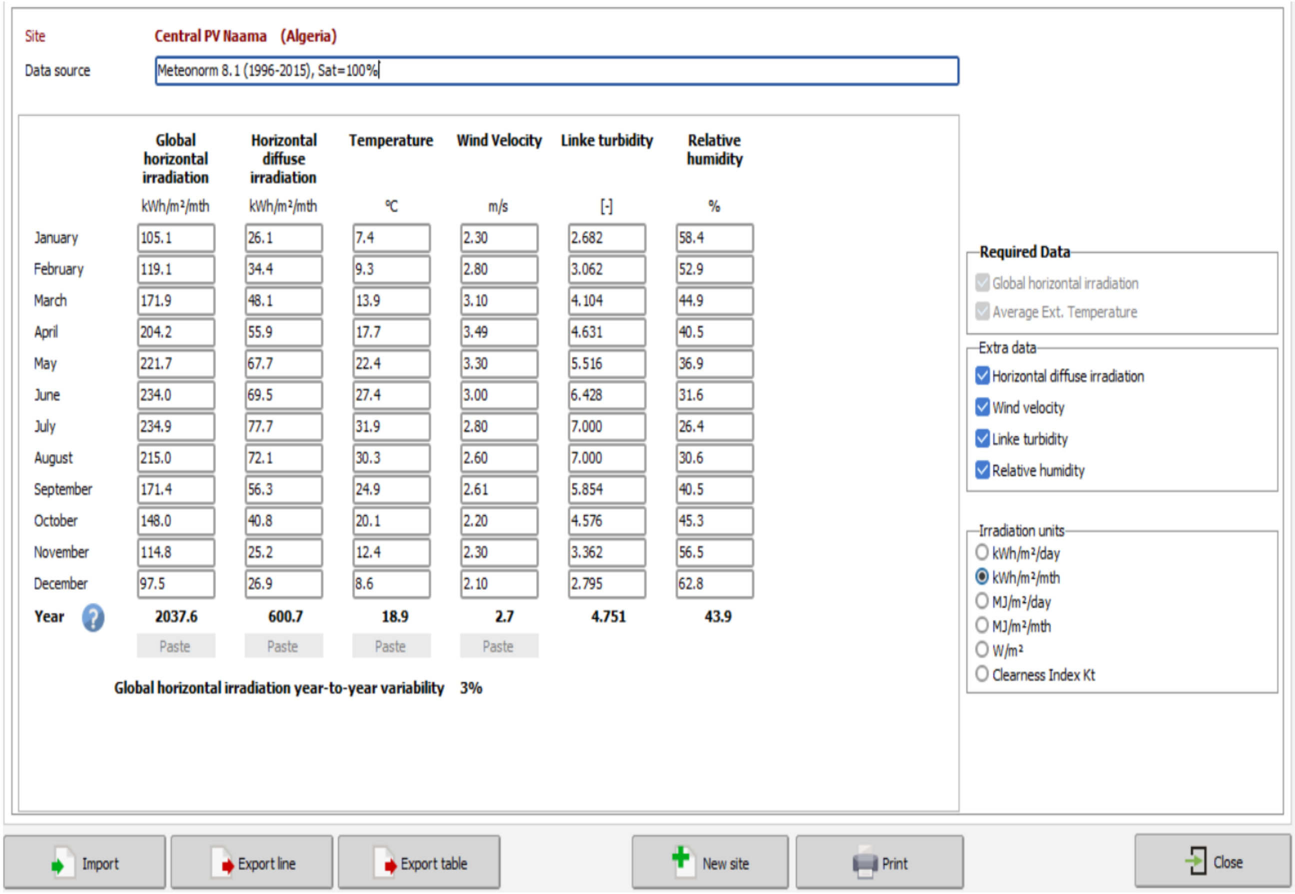


Figure III.2: Presentation site of Nâama photovoltaic solar power plant by PVSYST website

III.3.1.2 Meteorological data

The climatic characteristics of the site given by PVsyst software are illustrated in the figure III.3


Site: Central PV Naama (Algeria)

Data source: Meteonorm 8.1 (1996-2015), Sat=100%

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/mth	kWh/m²/mth	°C	m/s	[-]	%
January	105.1	26.1	7.4	2.30	2.682	58.4
February	119.1	34.4	9.3	2.80	3.062	52.9
March	171.9	48.1	13.9	3.10	4.104	44.9
April	204.2	55.9	17.7	3.49	4.631	40.5
May	221.7	67.7	22.4	3.30	5.516	36.9
June	234.0	69.5	27.4	3.00	6.428	31.6
July	234.9	77.7	31.9	2.80	7.000	26.4
August	215.0	72.1	30.3	2.60	7.000	30.6
September	171.4	56.3	24.9	2.61	5.854	40.5
October	148.0	40.8	20.1	2.20	4.576	45.3
November	114.8	25.2	12.4	2.30	3.362	56.5
December	97.5	26.9	8.6	2.10	2.795	62.8
Year	2037.6	600.7	18.9	2.7	4.751	43.9

Figure III.3: Meteorological data from Naama site

III.3.2 The path of sun.

Looking more precisely, the value of the azimuth at different times of the year, we see that the expression "the Sun rises in the east and sets in the west" is not accurate. Indeed, in December, it rises in the south-east to set in the south-west, while it practically rises in the north-east to set in the north-west. This gives a maximum of 7 hours of sunshine: these are the two times of the solstices of the year. It is only at the spring and autumn equinoxes that the duration of the day is equal to that of the night (Figure III.4).

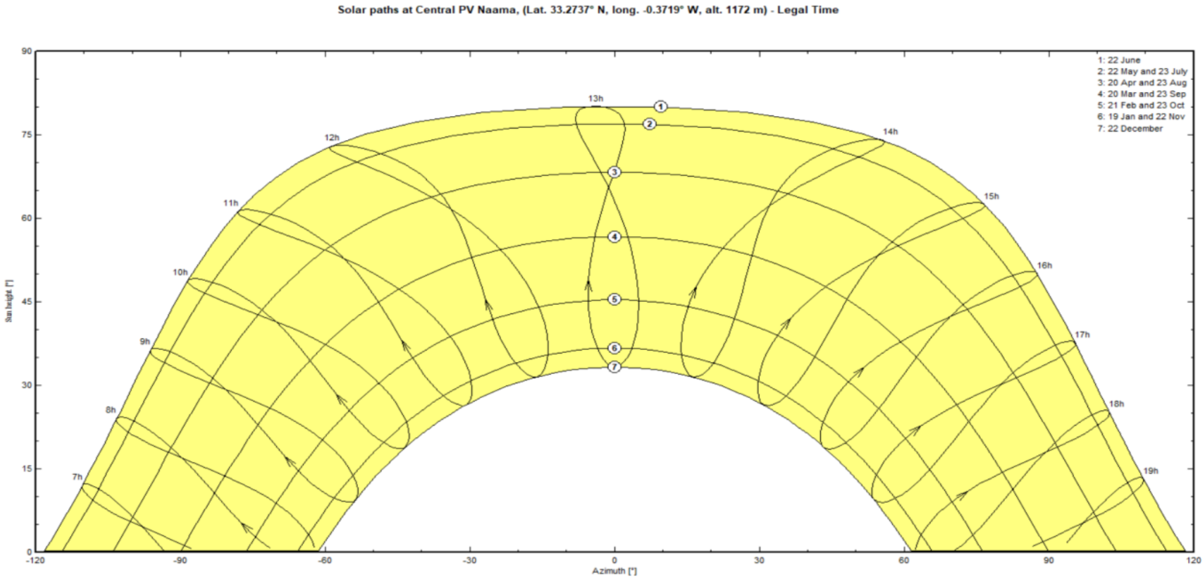


Figure III.4: The path of sun in Naama

III.3.3 Orientation of the PV modules.

For a good dimensioning of the photovoltaic power plant, you must choose the orientation and the inclination favoring the energy production. For the simulation, the SKTM Company chose a fixed plane with a slope of 15° (relative to the horizontal). This choice will be justified later when we examine the influence of the propensity on the efficiency of the photovoltaic field. Figure III.5 illustrates the optimal slope given by PVsyst.

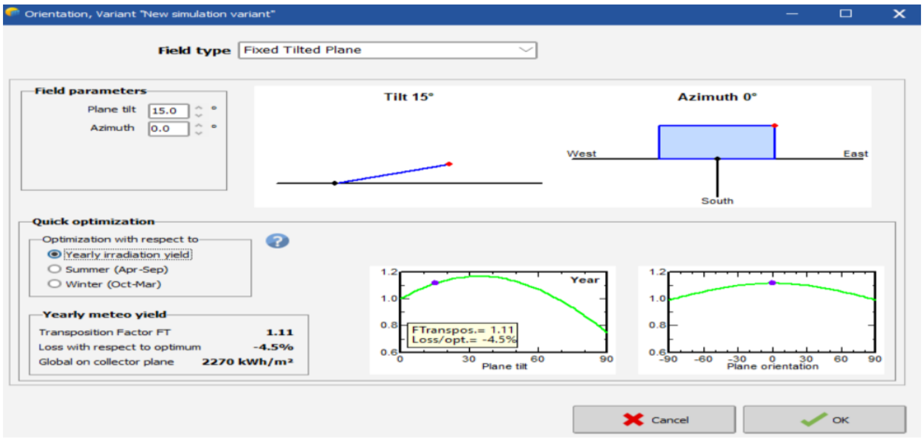


Figure III.5: Orientation and inclination of the PV panel system (Fixed Tilted Plane).

III.3.4 Component of the PV system connected to the grid.

III.3.4.1 Characteristic of the Panels.

The software must define the type of panels to be used. The photovoltaic panels used in the choice of the power plant are polycrystalline silicon panels, composed of 60 cells with a peak power of 250 watts. The type of the photovoltaic panel is CS6P - 250 P supplied by Canadian Solar company .And, the electrical characteristics of the photovoltaic which are as follows:

Module Type	unit	CS6P-250P
Nominal Maximum Power (Pmax)	W	250
Optimum Operating Voltage (Vmp)	V	30.1
Optimum Operating Current (Imp)	A	8.30
Open Circuit Voltage (Voc)	V	37.2
Short Circuit Current (Isc)	A	8.87
Maximum System Voltage	V	1000
Maximum Series Fuse Rating	A	15

Table III.2: Electrical characteristics of the photovoltaic module CS6P-250P

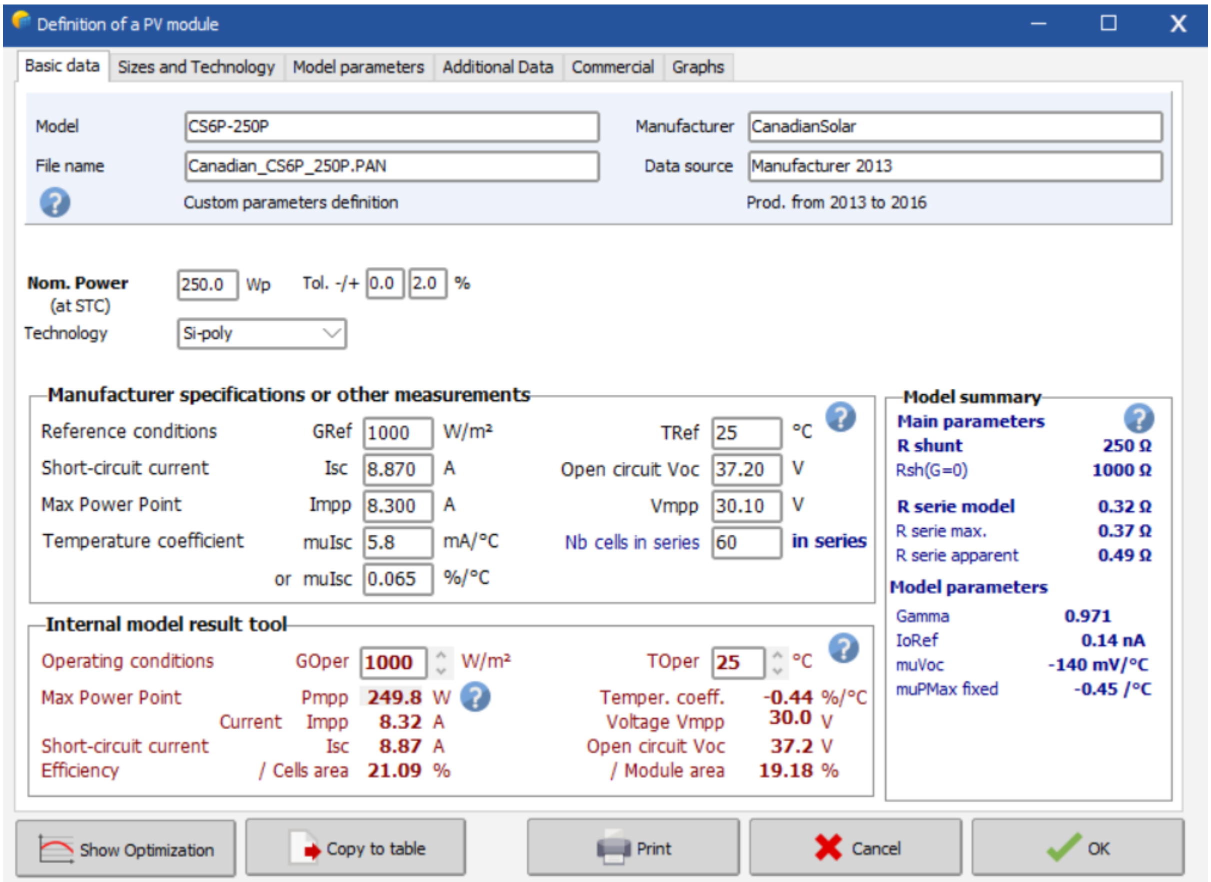


Figure III.6: Characteristic of panels type CS6P-250P supplied by Canadian Solar Company.

The figure III.7 shows influence of irradiation and temperature on the performance factor of PV module, such as current, voltage, power, efficiency and incident global.

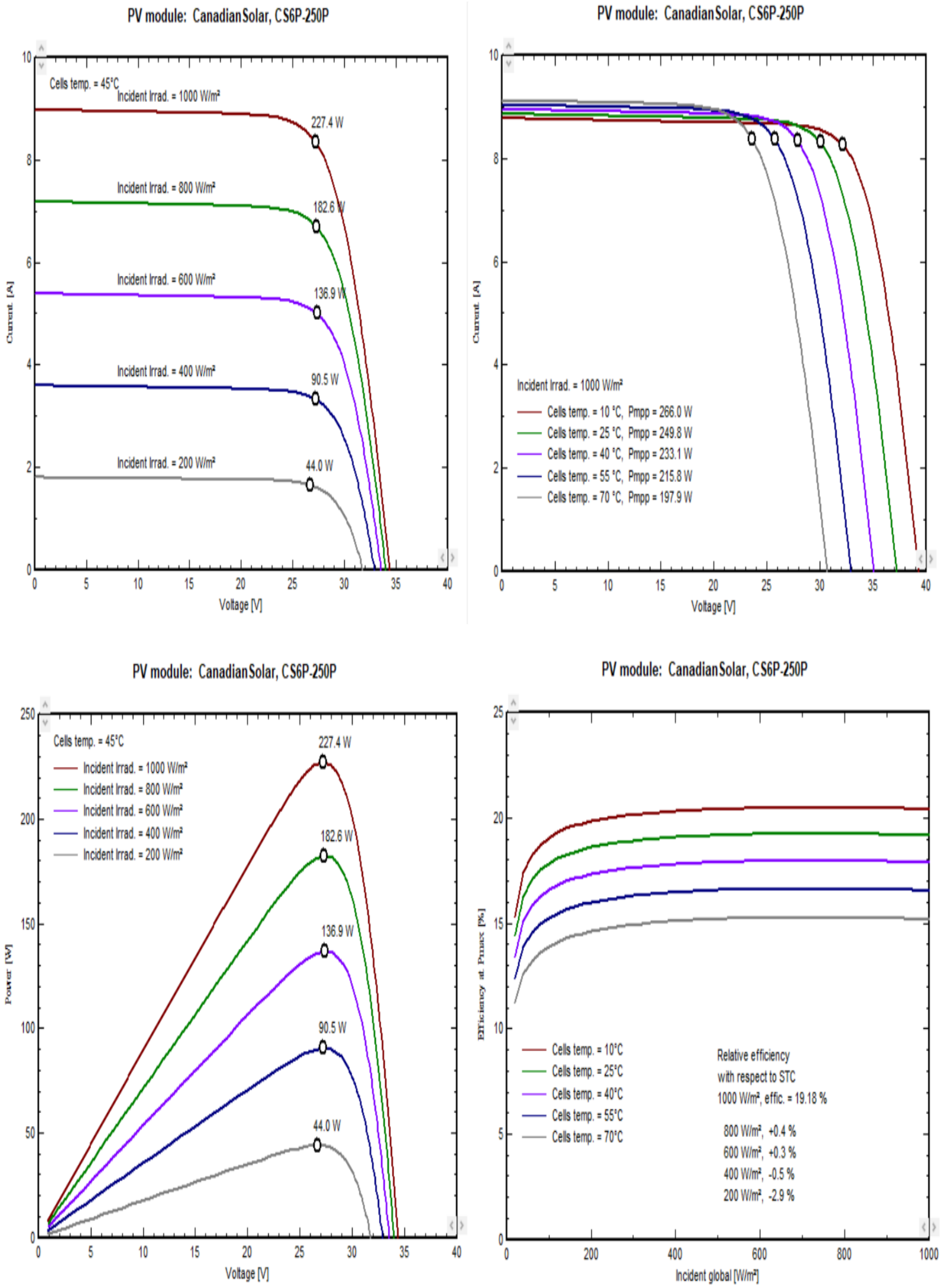


Figure III.7: Characteristic of the PV module

III.3.4.2 Characteristics of the PV inverter.

The inverter chooses for the dimensioning of our solar station and type SUNNY CENTRAL 800CP XT from the manufacturer SMA. This inverter has the following characteristics:

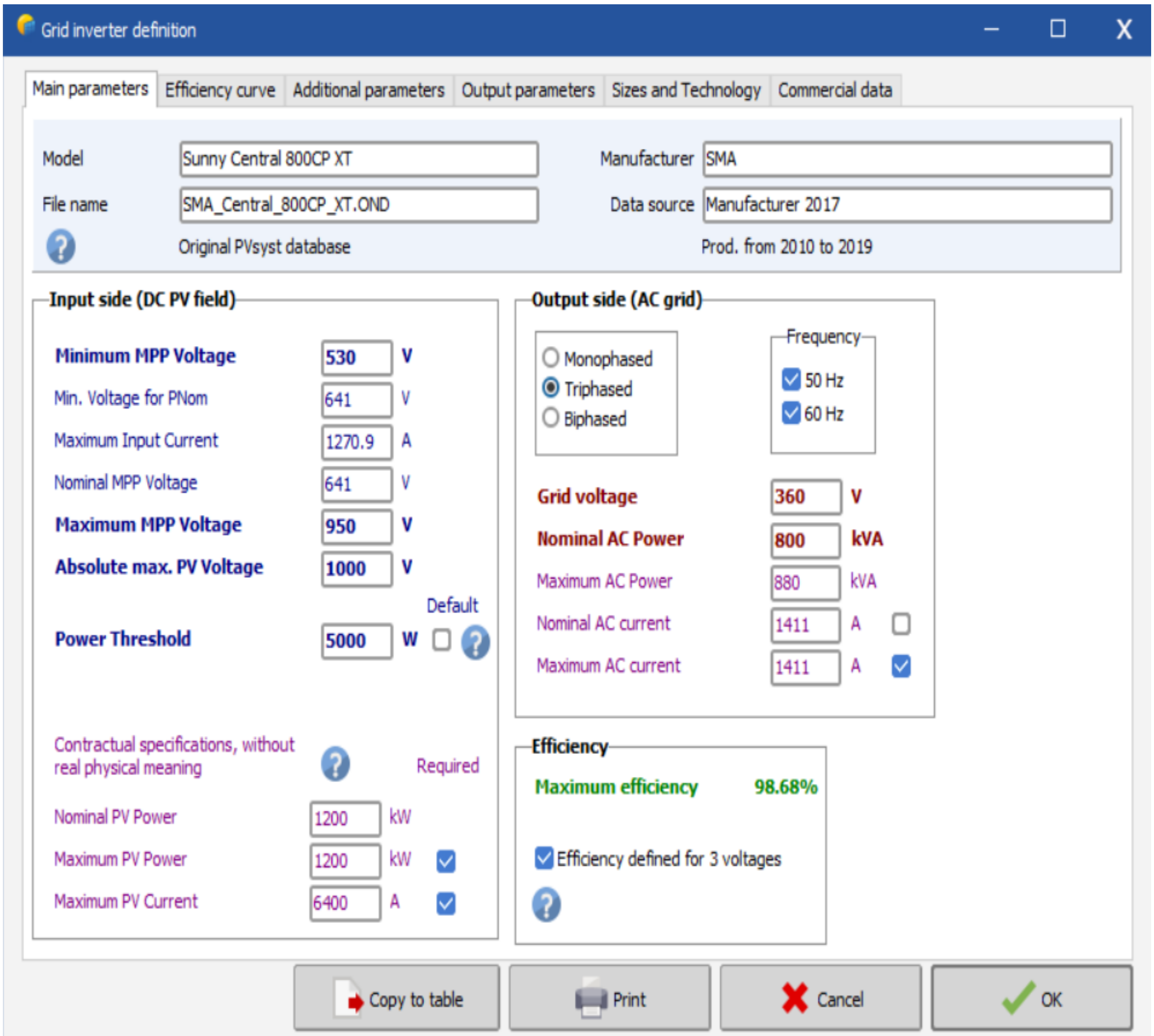


Figure III.8: Characteristic of the inverter SUNNY CENTRAL 800CP XT from the manufacturer SMA.

III.4 Result of the simulation.

In this section, we present the simulation results of the PV power plant. We used the PVsyst software to then evaluate their results.

III.4.1 Report of the simulation results.

After the introduction of all the simulation parameters of the PV field for a power of 20 MW, the PVsyst software provided us with the results shown in Fig. III.9 below (annex04):

Project: Central PV Naama

Variant: Central PV Naama

PVsyst V7.3.4
VC0, Simulation date:
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with v7.3.4

Project summary

Geographical Site	Situation		Project settings	
Central PV Naama	Latitude	33.27 °N	Albedo	0.20
Algeria	Longitude	-0.37 °W		
	Altitude	1172 m		
	Time zone	UTC+1		

Meteo data
Central PV Naama
Meteonorm 8.1 (1996-2015), Sat=100% (Modified by user) - Synthetic

System summary

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation		Near Shadings	User's needs
Fixed plane		No Shadings	Unlimited load (grid)
Tilt/Azimuth	15 / 0 °		

System information

PV Array		**Inverters**	
Nb. of modules	79680 units	Nb. of units	20 units
Pnom total	19.92 MWp	Pnom total	16.00 MWac
		Pnom ratio	1.245

Results summary

Produced Energy	36782523 kWh/year	Specific production	1847 kWh/kWp/year	Perf. Ratio PR	81.75 %

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Variant: Central PV Naama

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General parameters

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation

Orientation		Sheds configuration	Models used	
Fixed plane		No 3D scene defined	Transposition	Perez
Tilt/Azimuth	15 / 0 °		Diffuse	Perez, Meteonorm
			Circumsolar	separate

Horizon	Near Shadings	User's needs
Free Horizon	No Shadings	Unlimited load (grid)

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	CS6P-250P	Model	Sunny Central 800CP XT
(Custom parameters definition)		(Original PVsyst database)	
Unit Nom. Power	250 Wp	Unit Nom. Power	800 kWac
Number of PV modules	79680 units	Number of inverters	20 units
Nominal (STC)	19.92 MWp	Total power	16000 kWac

Array #1 - Station #1

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #2 - Station #2

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #3 - Station #3

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #4 - Station #4

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

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VC0, Simulation date:
17/05/23 10:51
with v7.3.4

Project: Central PV Naama

Variant: Central PV Naama

PV Array Characteristics

Array #5 - Station #5

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #6 - Sub-array #6

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #7 - Station #7

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #8 - Station #8

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #9 - Station #9

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #10 - Station #10

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

PV Array Characteristics

Array #11 - Station #11

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #12 - Station #12

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #13 - Station #13

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #14 - Station #14

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #15 - Station #15

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #16 - Station #16

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

PV Array Characteristics

Array #17 - Station #17

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #18 - Station #18

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #19 - Station #19

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Array #20 - Station #20

Number of PV modules	3984 units	Number of inverters	1 unit
Nominal (STC)	996 kWp	Total power	800 kWac
Modules	166 Strings x 24 In series		
At operating cond. (45°C)		Operating voltage	530-950 V
Pmpp	906 kWp	Max. power (=>25°C)	880 kWac
U mpp	653 V	Pnom ratio (DC:AC)	1.25
I mpp	1388 A		

Total PV power		**Total inverter power**	
Nominal (STC)	19920 kWp	Total power	16000 kWac
Total	79680 modules	Max. power	17600 kWac
Module area	103808 m²	Number of inverters	20 units
		Pnom ratio	1.25

Array losses

Thermal Loss factor
Module temperature according to irradiance

Uc (const)	20.0 W/m²K
Uv (wind)	0.0 W/m²K/m/s

DC wiring losses

Global array res.	7.8 mΩ
Global wiring resistance	0.39 mΩ
Loss Fraction	1.5 % at STC

Module Quality Loss

Loss Fraction	-0.5 %

Module mismatch losses

Loss Fraction	2.0 % at MPP

Strings Mismatch loss

Loss Fraction	0.2 %

IAM loss factor
ASHRAE Param.: IAM = 1 - bo (1/cosi -1)

bo Param.	0.05

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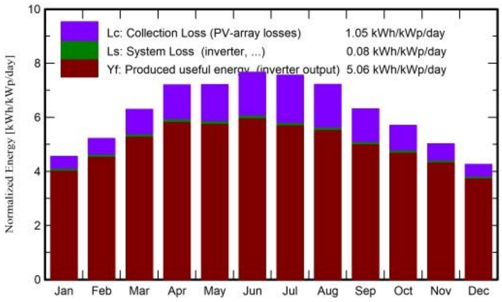
Variant: Central PV Naama

Main results

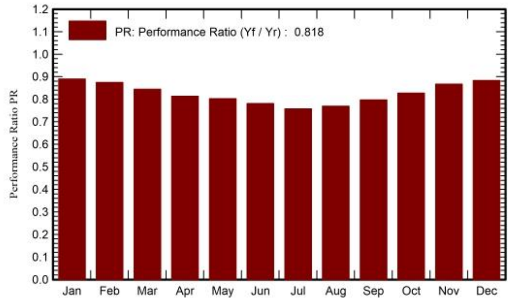
System Production

Produced Energy	36782523 kWh/year	Specific production	1847 kWh/kWp/year
		Perf. Ratio PR	81.75 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	ratio
January	105.1	26.10	7.40	141.2	136.3	2545370	2502889	0.890
February	119.1	34.40	9.28	146.1	141.9	2588312	2545451	0.875
March	171.9	48.10	13.92	195.0	189.9	3334294	3279380	0.844
April	204.2	55.90	17.66	216.1	210.7	3557452	3500394	0.813
May	221.7	67.70	22.42	223.5	218.3	3633092	3572019	0.802
June	234.0	69.50	27.41	229.9	224.5	3635927	3577286	0.781
July	234.9	77.70	31.93	234.3	229.0	3593709	3535801	0.758
August	215.0	72.10	30.34	223.8	218.8	3484993	3429939	0.769
September	171.4	56.30	24.93	189.3	184.4	3052508	3003843	0.797
October	148.0	40.80	20.07	176.8	172.1	2959833	2912065	0.827
November	114.8	25.20	12.35	150.7	145.8	2643913	2601286	0.867
December	97.5	26.90	8.60	132.0	127.3	2363436	2322172	0.883
Year	2037.6	600.70	18.92	2258.6	2199.1	37392838	36782523	0.818

Legends

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

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Figure III.9: Report of the simulation

In this report we find the essential parameters confirmed by the software among these data we find:

- The geographical and astronomical location of the site as well as the source of the meteorological data used and the orientation of the modules;
- The general description of the power plant which includes the types and number of modules and inverters as well as the peak power of the power plant;
- The software has calculated the nominal powers (STC condition) and the powers at the output of the system by taking into consideration the factors of losses due to the PV field and losses due to the inverters.
- We also have the annual energy produced which is 36782523 KWh / year simulated from the irradiation data of the site and the characteristics of the system and the modules, the same energy but specific production that is to say divided by the installed power which is 1847 kWh / kWp / year this value corresponds to the number of annual hours where the system functions at its nominal power.
- The performance index (PR) of 81.75% is a measure of the general quality of the system and presents the overall efficiency as a function of the installed power. with a diagram that summarizes the monthly variation of the performance index during a year
- A review of the results detailing the variations of all the parameters acting on the system from the irradiation received from the sun to the energy at the system output.

III.4.2 Graphs resulting from the simulation.

To better understand the results of the report, we resorted to the software function which makes it possible to draw graphs from the data obtained from the simulation.

From Figure III.10 we can deduce the impact of the inclination of the panels on the amount of energy and radiation received by the field and on the annual distribution.

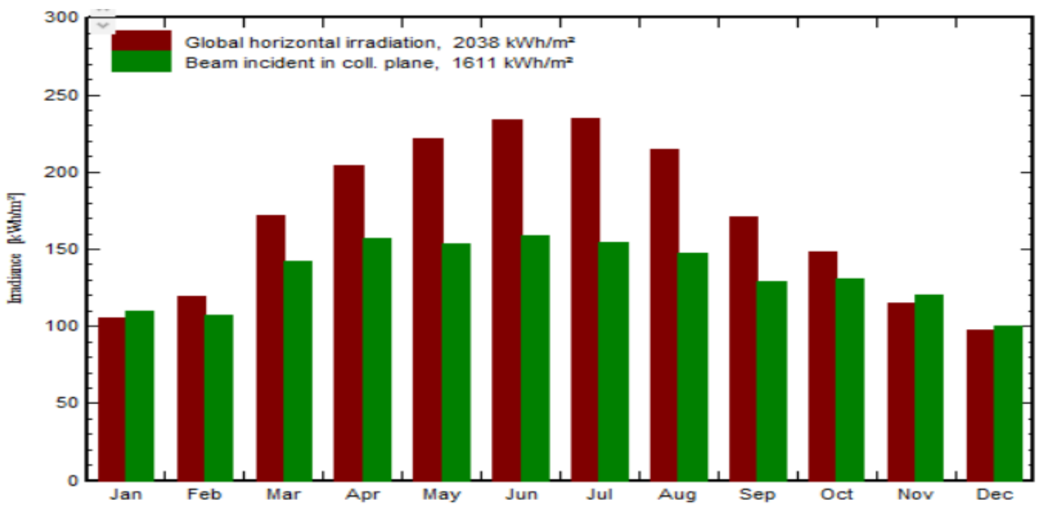

Figure III.10: Global horizontal irradiation and Beam Incident in the collector plane

Figure III.11 shows us the average monthly temperature for the location of the power plant, as it is noted that the summer temperatures are equal to 32°C, which is very high compared to other seasons, which will have an impact on production rates in view of the losses caused by the temperature.

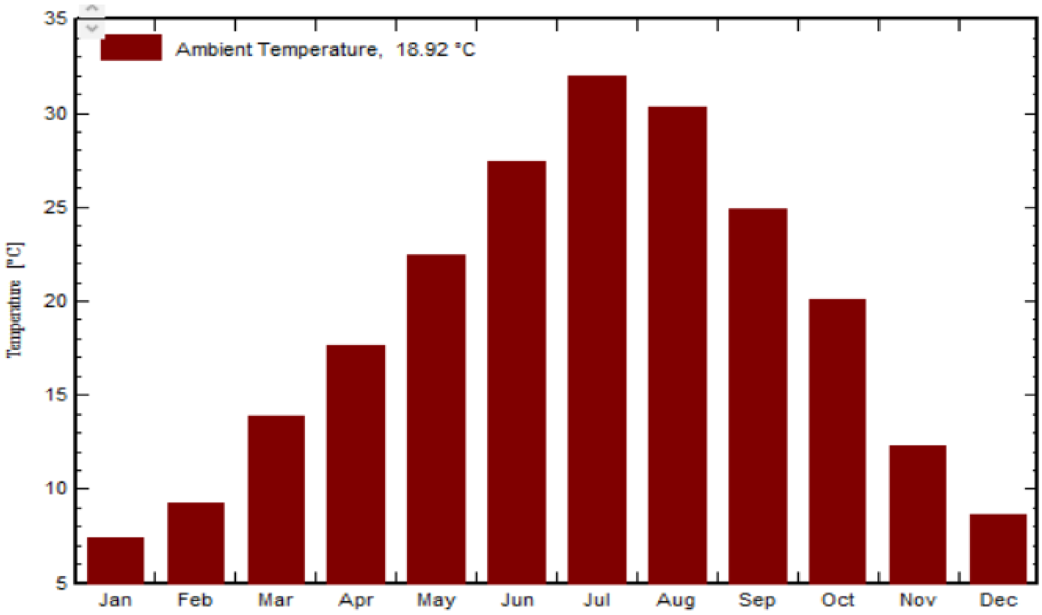

Figure III.11Monthly average temperature at the plant site.

The figure III.12 represents the different energy values respectively of the nominal field and the effective energy output from the field. It can be seen that the variation of the two curves is proportional over the year, the values of the two energies are very important in the summer season. The difference in power value is between array nominal energy (at STC efficacy) and effective energy at the output of the array because of solar cell efficiency, temperature effects, shading, obstructions, aging, degradation and system losses.

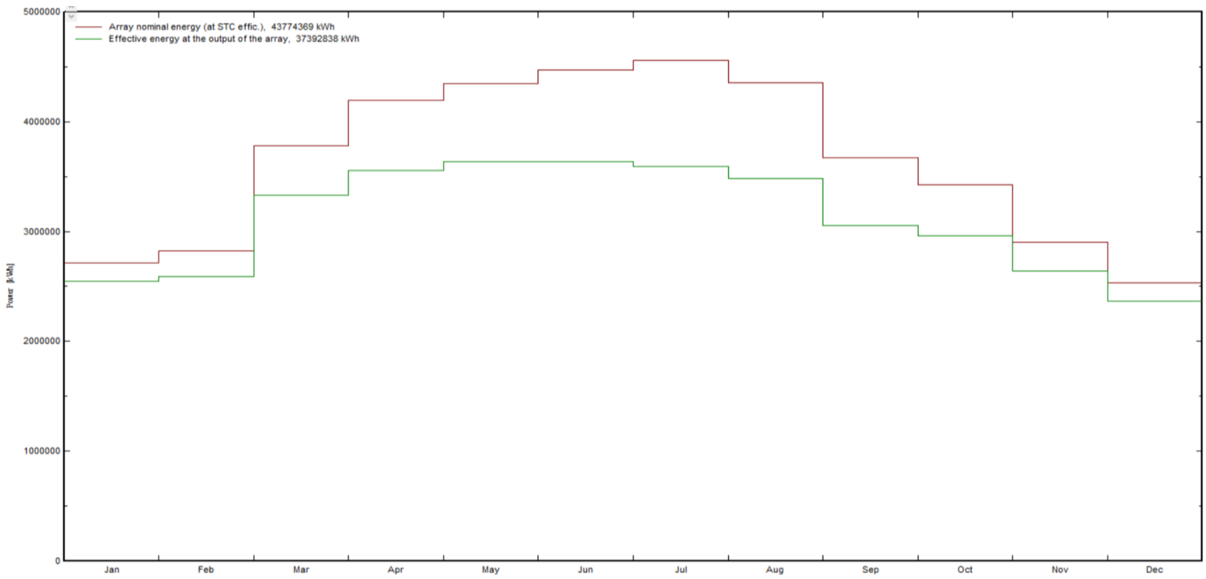

Figure III.12: Energy at the STC condition and the energy of the field output

This figure III.13 shows the current and voltage curves at the output of a solar array, but keep in mind that these two parameters vary from month to month. These bending changes reflect the appearance of radiation. In the summer, power reaches a maximum in ampere-hours due to daylight hours. This gives good operating figures for PV generators, see in Figure 3.14.

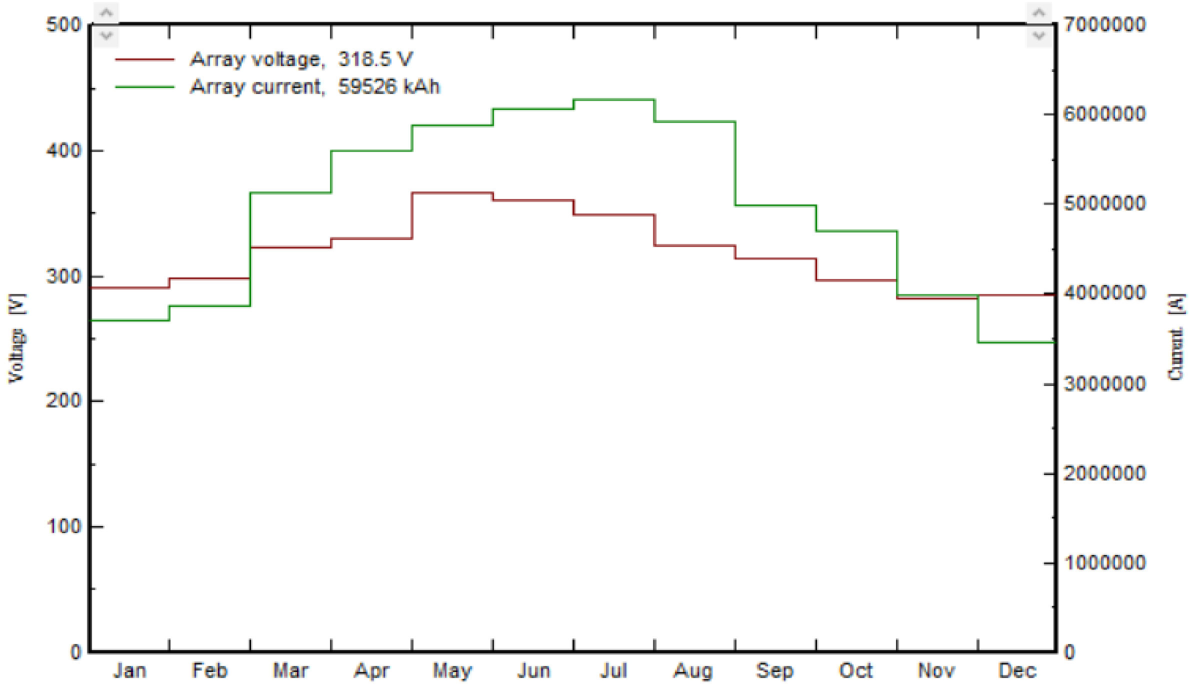

Figure III.13: DC current and voltage at the output of the PV field

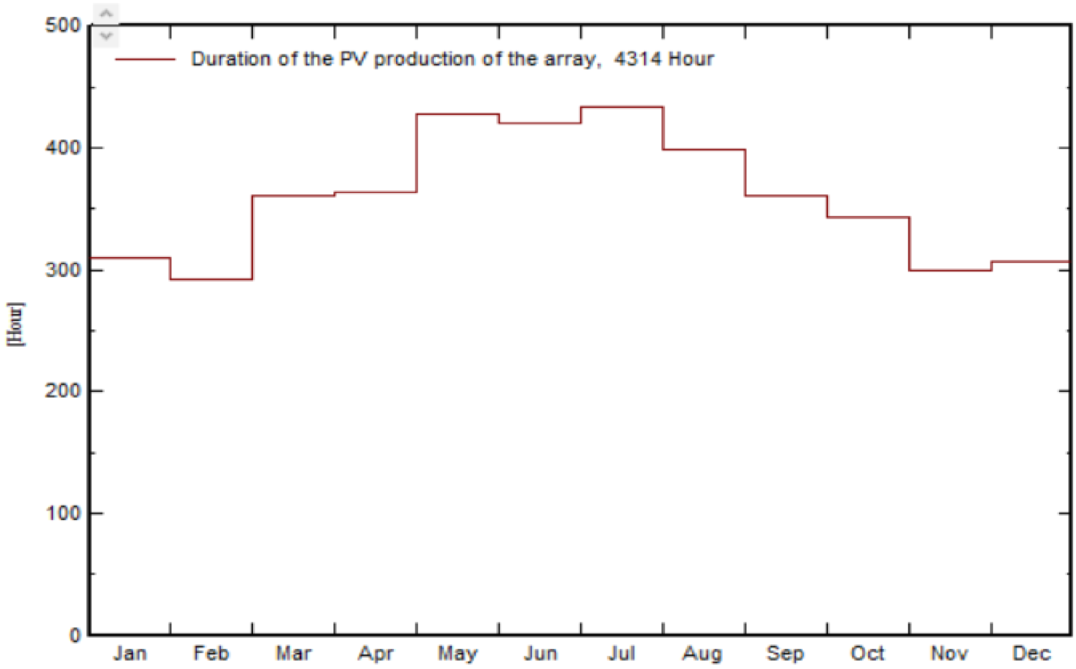

Figure III.14: The number of hours of monthly sunshine

The figure III.15 shows the daily Input / Output diagram. We give the Energy injected into the network according to the global incident daily Irradiation in [MWh/day] throughout the year in the region studied. We will see that the energy produced injected into the electrical network increases according to the overall incident radiation on the surface of the photovoltaic panels. So for the purpose of better sizing, it should be approximately a slightly saturated straight line for large values of irradiation. This slight curvature is a temperature effect. If some points (days) deviate at high radiation, this indicates overload conditions, such as grid injected system.

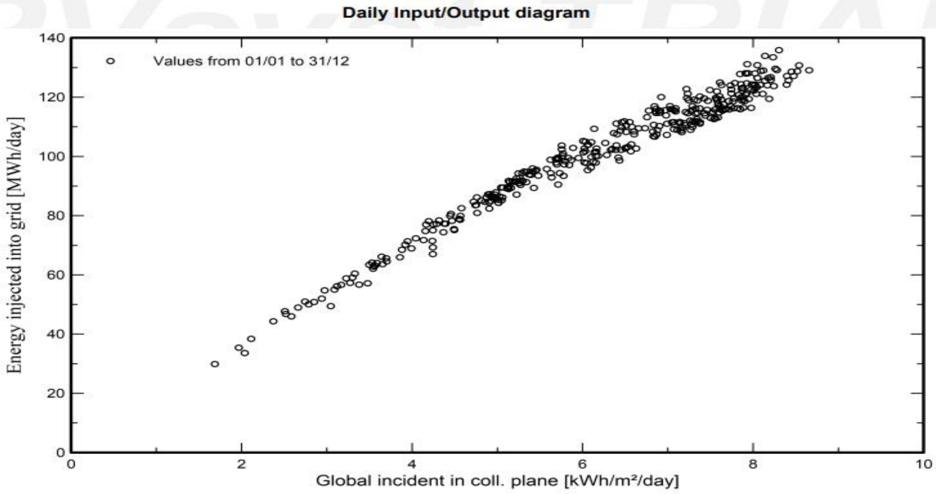

Figure III.15: Daily Input / Output diagram

The figure III.16 summarizes the losses influencing the production of the PV system, namely: the ohmic losses of the wiring, incidence effects, losses due to the temperature of the field, losses due to the quality of the modules, etc. Among these, we notice that the most important contribution is that of the inverter, hence the importance of taking into consideration the efficiency of the inverter. Indeed, the energy produced by the field (EArray estimated at 37514.97 MWh is reduced to 36782.523 MWh at the output of the inverter.

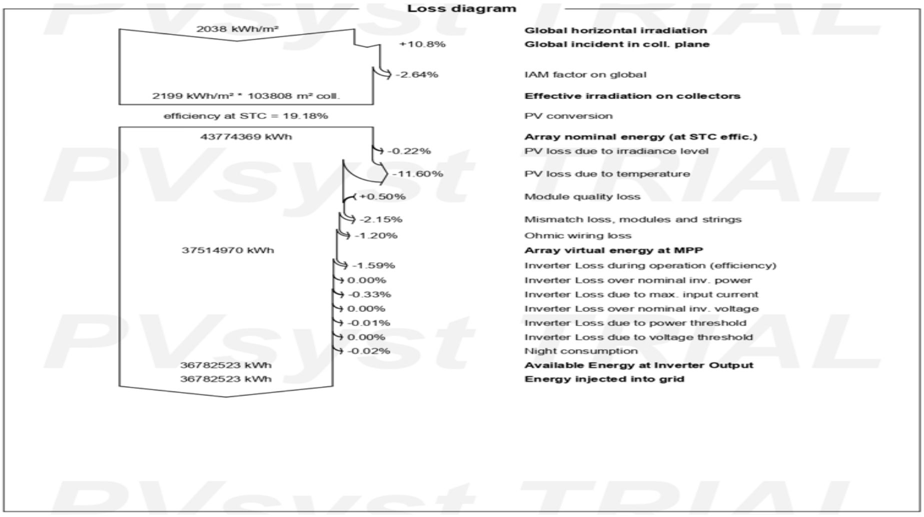

Figure III.16: Diagram of losses in the PV system over the entire year.

Figure III.17 shows the IAM loss due to reflection since the radiation transmitted to the panel is not the incident radiation because part of it is returned by reflection. Thus, losses increase when the rays are not perpendicular to the sensor and following their curve notice a considerable increase in these losses in summer compared to other seasons.

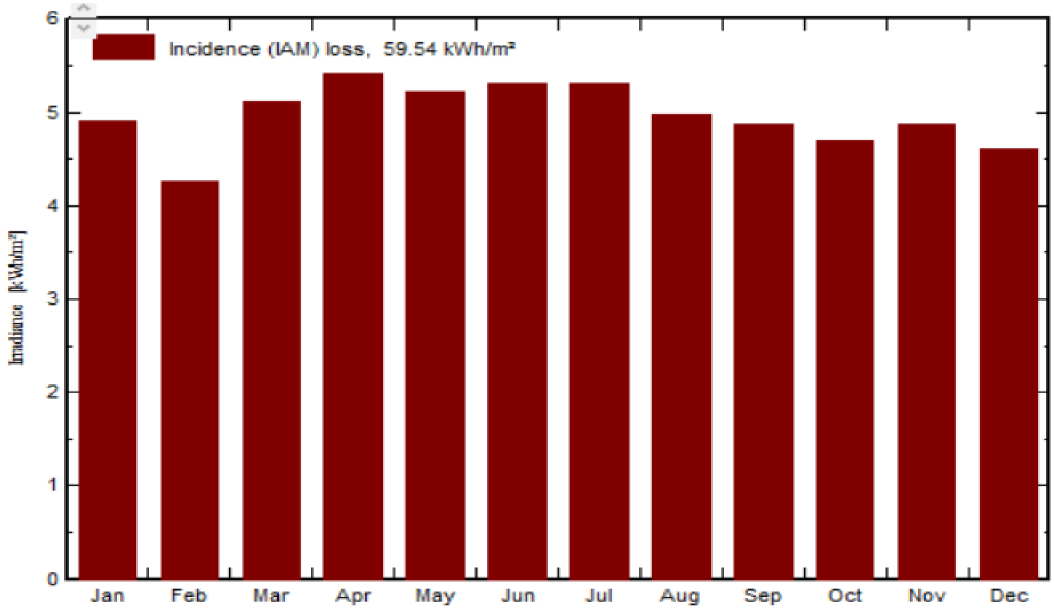

Figure III.17: Monthly losses IAM

Figure III.18 shows the energy produced by the photovoltaic installation during a year for each month. In this figure we notice that the maximum energy is produced during the summer period (June-August). The minimum energy is produced during the month of December. The losses Lc, Ls are the losses corresponding to the PV field. Note that these loss values equal to 1.05 (KWh/kWp/day).

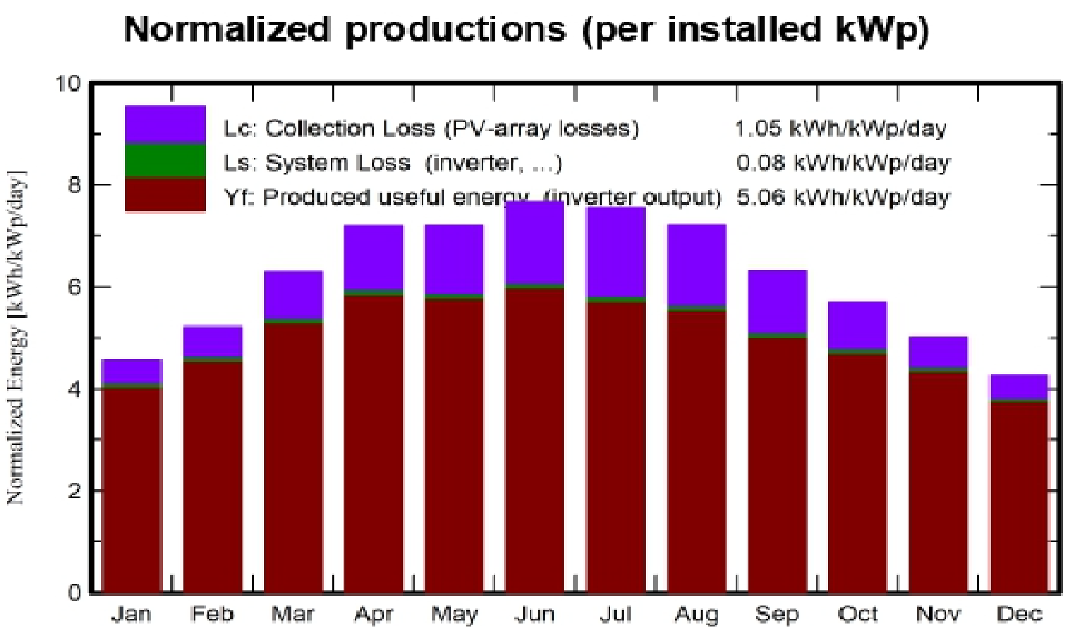

Figure III.18Collective losses in relation to the energy produced.

The figure III.19 shows the most important main loss of the energy produced before it is injected into the network, which is the resistance of the cables used, which will generate ohmic losses, whether on the continuous side or in the alternatives, as their value increases in proportion to the temperature. We also note that the ohmic losses in the DC cables are more than the AC cables due to the high currents that circulate in the DC cables, and there are other losses resulting from the passage of energy in the transformers, and through all types of previous losses, the value of the losses remains low in relation to the total energy produced by the photovoltaic field, as in the figure III.20

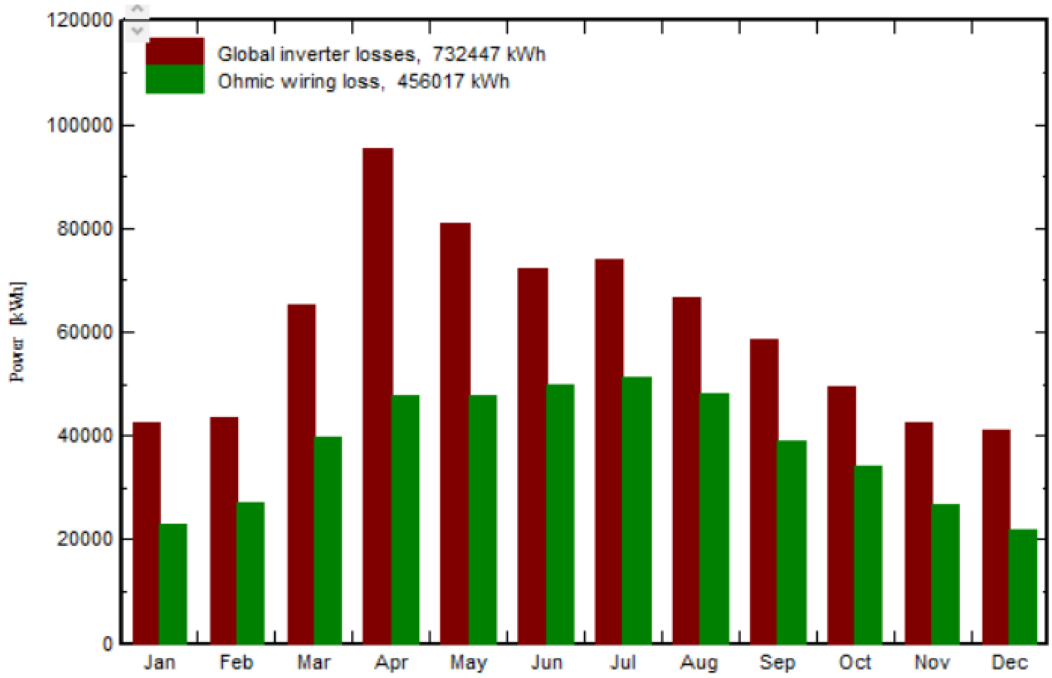

Figure III.19: Ohmic wiring losses and global inverter losses

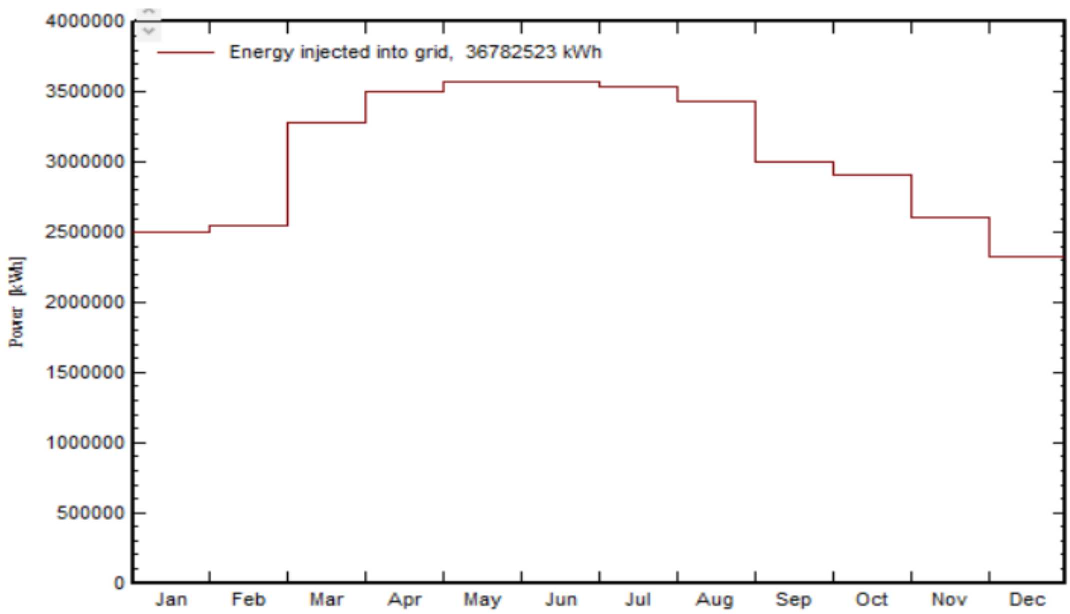

Figure III.20: Energy injected into grid

Figure III.21 shows the main difficulty in generating electricity using solar power plants due to disturbances. Note that stochastic phenomena are more frequent and intense during winter, fall, and spring, in contrast to summer, when meteorological factors lead to steady production and shift to consistently high levels of radiation dose. This highlights our tendency to choose in favor of maximum and stable production during the summer.

Disturbances in energy injected into the grid from solar energy are caused by factors such as solar irradiance variations, shading and soiling effects, panel degradation, inverter issues, and voltage/frequency regulation challenges. These factors affect the overall energy production and performance of the solar PV system, leading to fluctuations and disruptions in the injected energy.

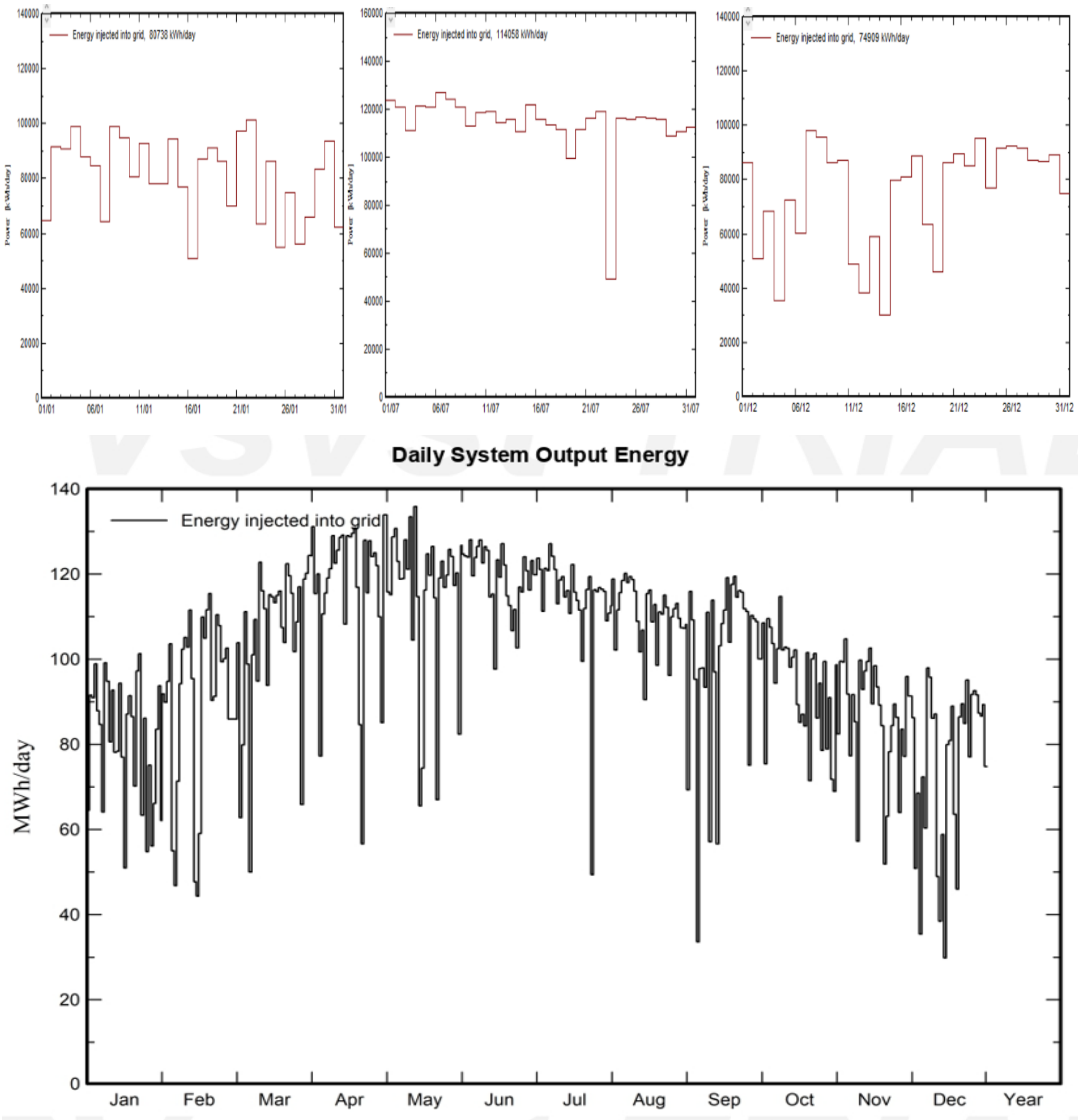

Figure III.21: The daily energy produced by the system output

- **Performance report.**

The PR performance report indicates the overall effect of losses on the energy production of the rows of a PV system. The PR values indicate how close a PV system approaches the ideal performance under real operating conditions.

PR is defined by the ratio between the final yield and the reference yield, it is a dimensionless quantity. The monthly performance index is expressed by:

$$\mathbf{PR} = \frac{Yf}{Yr} \qquad \textbf{(III.1)}$$

The monthly evolution of the performance index of the Naama solar power plant during the year is illustrated in Figure III.22. It varies from 75.8% in July to 89% in January.

It should be noted that a performance index is greater than 80% corresponds to a system whose performance approaches the ideal performance under STC conditions. On the other hand for the months of June, July and August this decrease in the index is due to the effect of the temperature.

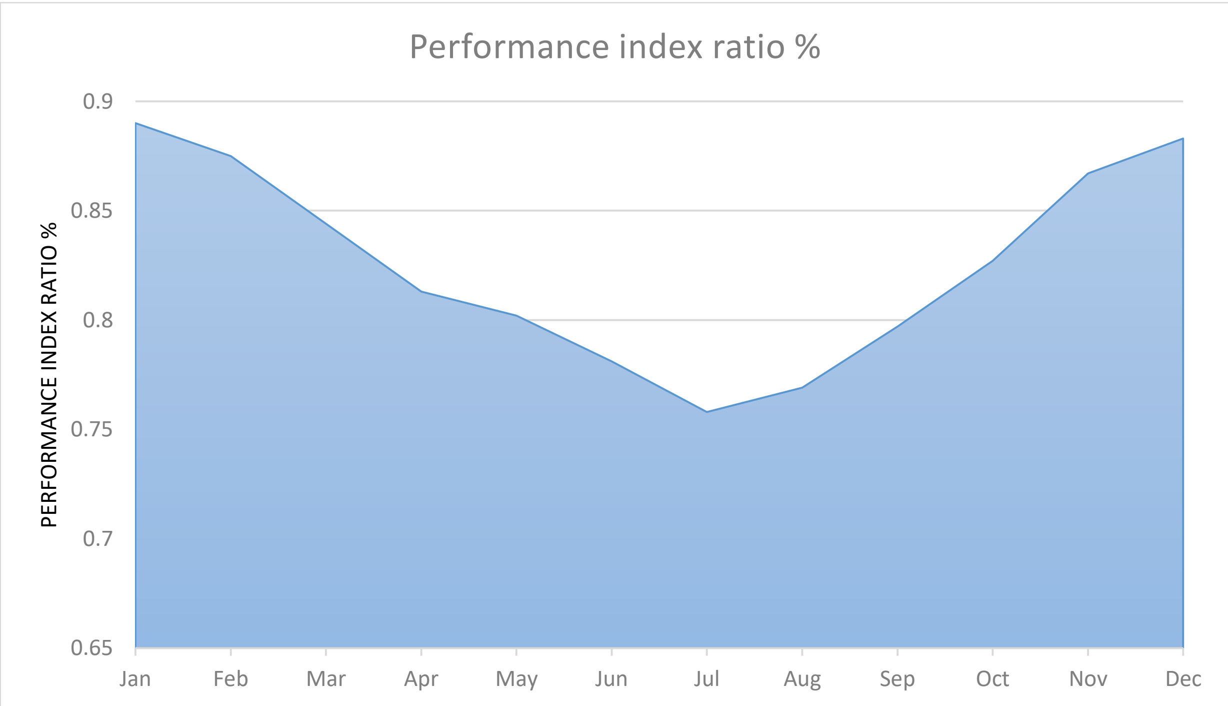

Figure III.22: Performance index for the Naama power plant.

The figure III.23 shows the impact of the module temperature on the performance ratio. The monthly average temperature of the module displays a linear relationship with the ambient temperature, it varies from 8.6 °C in December month to 31.9 °C in July month. The graph indicates a certain correlation between the average temperature of the module during the day and the performance ratio, with a correlation coefficient of 0.97.

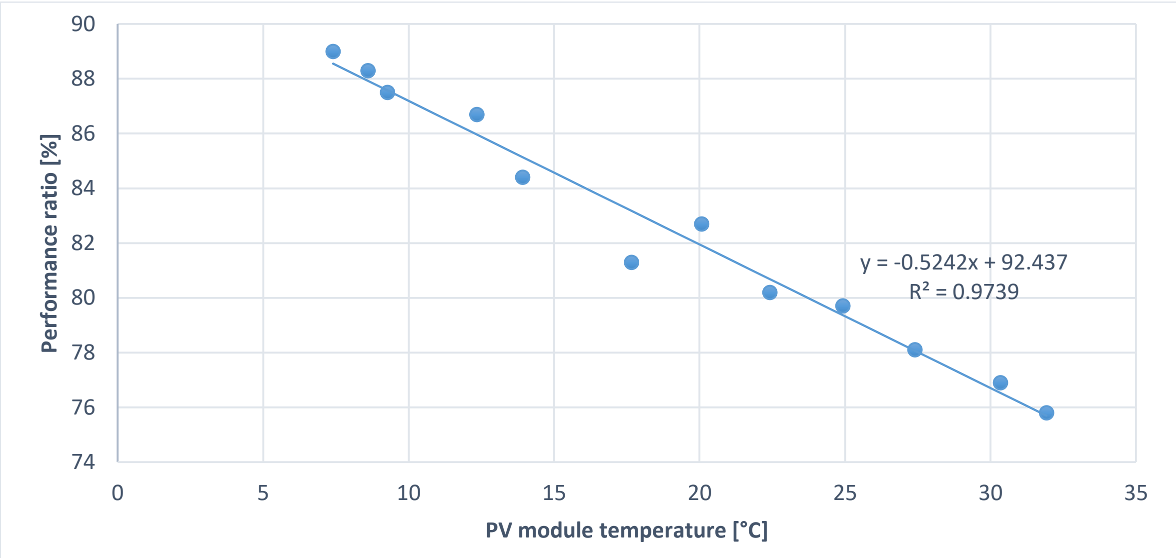

Figure III.23: Impact of module temperature on performance ratio

The figure III.24 shows the monthly evolution of module efficiencies of Naama PV plant. The monthly efficiency of the field (or module) varies between 14.54% noted in the month of July and 17.07% noted in the month of January. This due to the temperature effect in the summer season.

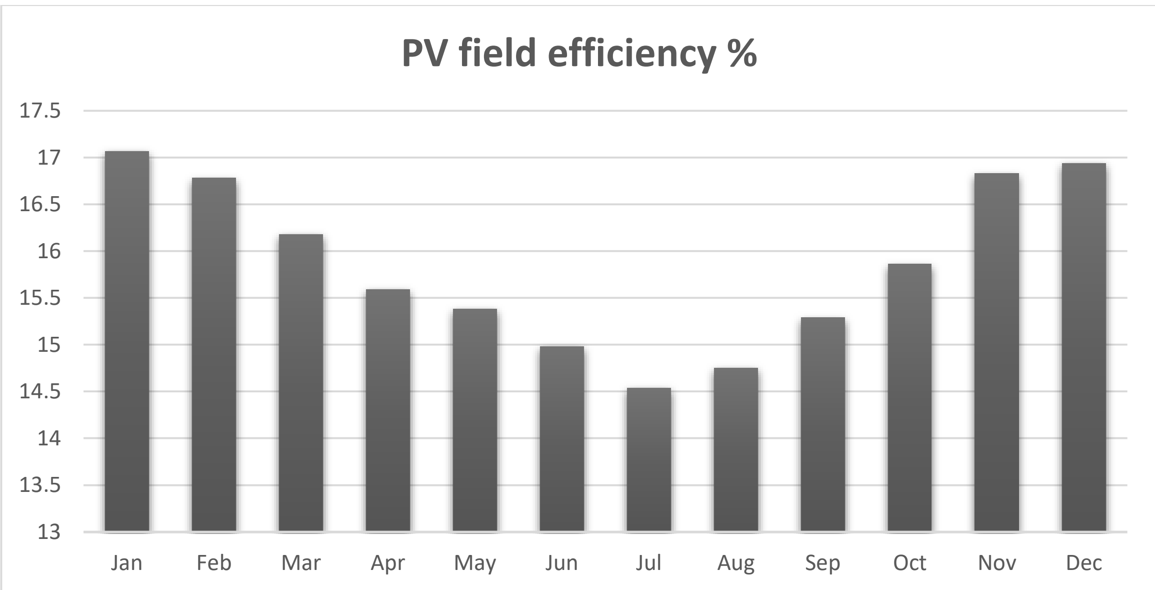

Figure III.24: PV field efficiency.

The figure III.25 presents the monthly evolution of the efficiency of the inverters at the Naama PV plant. It varies between a minimum of 98.3% noted for the month of December and a maximum of 98.5% noted for the month of July. What we agree with the results of the monthly losses of the system by conversion.

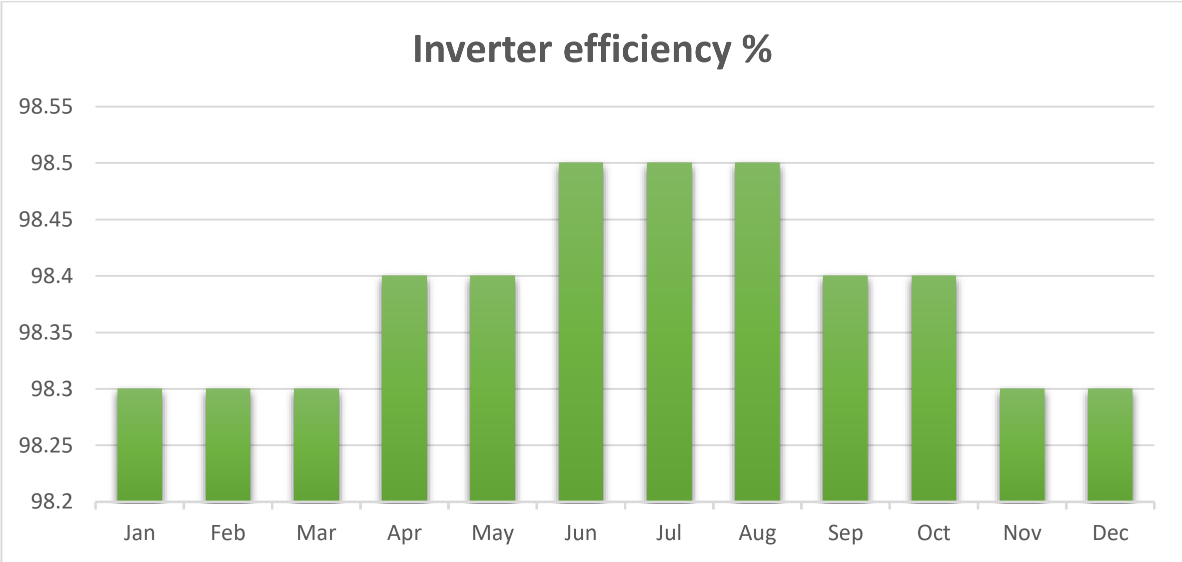

Figure III.25 Inverter efficiency.

The figure III.26 represents the performance index which is defined by the ratio of the production of the system by the reference incident energy. In other words, it represents the overall efficiency of the system compared to what could be expected according to the installed power and can reach 81.8 % in figure "III.26" which presents the performance index obtained for our site, we note that this coefficient varies during the year. we note that this coefficient varies during the year. Remember that the power supplied by a PV array decreases with temperature.

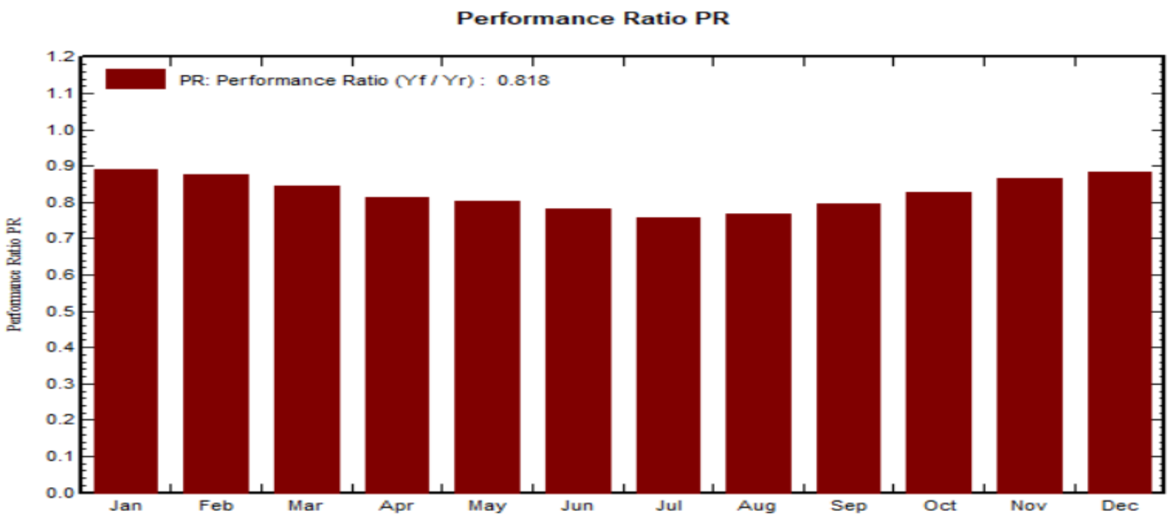

Figure III.26: Performance Ratio of the PV system.

III.5 Estimation of the project income.

III.5.1 Estimation of the construction cost of the power plant.

According to what we read on the website of the Ministry of Renewable Energy, we found that the cost of the solar power plant in the state of Naama, which has a capacity of 20 MW, is 4 billion DZD, or approximately 17.81 million euros.

III.5.2 Income from the power plant.

❖ **Estimation of the income from the energy injected annually into the network.**

- The simulation results show that the annual power injected into the network by the photovoltaic power plant
  36782 MWh/year => E_{prod}=36782523 KWh/year.
- According to the Algerian regulations, the selling price of the KWh of electrical energy of renewable origin is 12 DA for installations with a power greater than 5 MW.

So to calculate the annual income from the energy injected into the network by the central office, we multiply the amount of energy in Kw injected into the network by the defined price of KW.

RE = $E_{prod} \times P_{sell}$ = 36782523KWh/years × 12DZD = 441 390 276 DZD/Years

RE: income from energy injected into the grid in DZD;

E_{prod}: the amount of energy injected by the power plant into the network;

P_{sell}: the selling price defined in DZD per KWh.

❖ **Estimation of the depreciation period of the power plant.**

To calculate the amortization duration of the Project in years (DY), we convert the construction cost of the project (CC) by the annual income from the energy injected into the network (RE).

$$DY = \frac{CC}{RE} = \frac{4000000000}{441390276} = 9.06 \text{ years}$$

- **Estimated profit reported by the power plant.**

  Since the service life of the panels and equipment of the power plant is estimated at 30 years, then to calculate the reported profit of the power plant (BR), we calculate the income from the energy injected into the network annually for the rest of the life of the power plant from the time it is amortized (9.06 years) which makes us 30-9.06=20.94 years. **BR= 20.94 Years × 441 390 276 DZD/Years= 9 242 712 379 DZD.**

So the power plant will bring us after depreciation **9 242 712 379 DZD** of profit Note that all the calculations made previously were made without taking into consideration the charges and maintenance costs of the power plant.

In addition to financial gains, the power plant allows us to save 657671.5 tons for 30 years resignation of CO_2 according to the PVSYST software.

III.6 Carbon emission balance.

We call carbon return time, the time necessary for a photovoltaic installation, by substituting the electricity produced to the local grid, to avoid the GHS emissions that were necessary for its manufacture, installation, maintenance and end of life, so it is very important to take it into consideration to make our assessment. In Algeria electricity is produced mainly from natural gas which has a CO_2 emission rate per kWh of 883g (883g /kWh).As for photovoltaics, it produces 100g/kWh. [51]

So the production of our power plant for its entire lifespan which is estimated at 30 years we will have an estimated production of:

$\mathbf{EP_{total} = 30\times E_{prod} = 30\times 36782523\ KWh}$

$\mathbf{EP_{total} = 1\ 103\ 475\ 690\ KWh}$

$\mathbf{EP_{total}}$: the total energy produced by the power plant

$\mathbf{E_{Prod}}$: the amount of energy injected by the power plant into the network.

III.6.1 Estimation of co₂ emissions due to the PV plant.

$\mathbf{PVco_2}$ = $EP_{total} \times 100(g/kWh)$ = 110 347 569 000 g CO_2 = 110347,569 tonne of co_2

$\mathbf{PVco_2}$: the quantity of CO_2 released due to the plant during its life cycle.

III.6.2 Estimation of the CO_2 emissions avoided thanks to the PV plant.

For that makes the equivalence of our total PV production in a production with natural gas which has a higher CO_2 emission rate then subtracts the $PVCO_2$ which represents a carbon payback time for the plant

$\mathbf{EVco_2}$ = [EP 883(g/kWh)]-PV CO_2= [1 103 475 690 x 883] - 110 347 569 000

$\mathbf{EVco_2}$= 864 021 465 270 CO_2 = 864021,465270 tonne of CO_2

EVco2: the quantity of co_2 avoided thanks to the PV plant

III.7 Conclusion

The Naama Solar Power Plant has a capacity of 20 MW and is part of the National Program for Power Generation from Renewable Energy. In this chapter, we started with a PV array system simulation to better understand the behavior of the PV array system.

The most important results that we obtained are the performance index 81.8%, the age of the station 30 years, the amount of CO_2 produced by the station 110347,57 t of CO_2 in 30 years and the amount of CO_2 that the power plant in relation to natural gas is 864021,47 t of CO_2 in 30 years.

It was concluded that the system was well implemented given the site and all selected parameters, which serve to inject an energy value which is 36782.5 MWh / year. Therefore, it was found that the project could improve the power grid, leading to an increase in energy levels and the economy.

General Conclusion

This work is in line with those which contribute to the realization of the National Program of Renewable Energies and Energy Efficiency set up in 2012. Updated in 2020, this new update forecasts the production of 15 GW by 2035 in Algeria. The country has an important energy potential, whether in fossil energy or renewable energies. As part of its energy strategy, it gives priority to the development of renewable energies. Our country occupies a strategic position at the heart of an energy crossroads and offers many investment opportunities in the solar photovoltaic sector.

In this work, the evaluation and sizing of the Naama photovoltaic power plant, as well as an analysis of its performance and the CO_2 reduction rate generated by the system.

This photovoltaic power plant in Naama has a capacity of 20 MW, it spreads over an area of 40 ha with 79,680 panel's photovoltaic of a type CS6P-250P (polycrystalline silicon). It also includes 40 junction boxes, 20 inverters of a type Sunny Central 800CP XT, a load communication cabinet and a control room. In addition to a mini station for the measurement of meteorological data.

In the first chapter, we provided information about the types of renewable energies and their mode of operation. This part allowed us to consolidate our theoretical knowledge about the types of renewable energies and their mode of operation.

In the second chapter, we provided information about photovoltaic power, as well as the size of the photovoltaic power station in Naama by the classical method, and we decided that all the indicators are good compared to the indicators in the station, and that its size is acceptable and its operation is standard.

In the third chapter, we started a simulation of the PV plant system in order to confirm and better understand its operation by PVSYST program. We have come to the conclusion that the plant has been well implemented with regard to the location and all the selected parameters, which pumps an energy of 36782.5 MW/year with gives a good performance index of 81.8 %. So we found that this project has added an improvement to the electricity grid that can give an increase in the level of energy and the national economy program.

After that, we obtained the results, the most important of which are the amount of energy produced(36782,523 MWh/year), the performance index(81.8%), the age of the power plant (30 years), and the amount of CO_2 produced by the power plant(37292.79 t CO_2).

Finally, In light of the interruption of photovoltaic power at night and its lack in winter, we propose to the Algerian government to build a wind power station to achieve integration between the two systems (photovoltaic - wind).

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Annex 01 :

Maker	Canadian Solar
Module Type	CS6P-250P
Nominal Maximum Power (Pmax)	250 W
Optimum Operating Voltage (Vmp)	30.1 V
Optimum Operating Current (Imp)	8.30 A
Open Circuit Voltage (Voc)	37.2 V
Short Circuit Current (Isc)	8.87 A
Operating temperature	-40 C°~+85C°
Maximum System Voltage	1000 V
Maximum Series Fuse Rating	15 A
Classification of applications	Class A
Power tolerance	0 ~ +5W
Cell type	Polycrystalline silicon
Cell arrangement	20 (2×10)
Dimensions	1638×982×40mm
Weight	20Kg
Front Cover	Tempered glass
Frame Material	Anodized aluminum alloy
Cell temperature	25°C
Cell yield	15.54%

Characteristic of the photovoltaic module at T-25°C and E=1000W/m^2.

Annex 02 :

Technical Data	Sunny Central 800CP XT
Input (DC)	
Max. DC power (at cos φ =1)	898 kW
Max. input voltage	1000 V
V_{MPP_min} at I_{MPP} < I_{DCmax}	530 V
MPP voltage range (at 25°C / at 50°C at 50 Hz)[1) 2)]	641 V to 850 V[3)] / 583 to 850 V[3)]
MPP voltage range (at 25°C / at 50°C at 60 Hz)[1) 2)]	641 V to 850 V[3)] / 583 to 850 V[3)]
Rated input voltage	641 V
Max. input current	1400 A
Max. DC short-circuit current	2500 A
Number of independent MPP inputs	1
Number of DC inputs	9
Output (AC)	
Rated power (at 25°C) / nominal AC power (at 50°C)	880 kVA / 800 kVA
Nominal AC voltage / nominal AC voltage range	360 V / 324 V to 414 V
AC power frequency / range	50 Hz, 60 Hz / 47 Hz to 63 Hz
Rated power frequency / rated grid voltage	50 Hz / 360 V
Max. Output current / max. total harmonic distortion	1411 A / 0.03
Power factor at rated power / displacement power factor adjustable	1 / 0.9 leading to 0.9 lagging
Feed-in phases / connection phases	3 / 3
Efficiency[4)]	
Max. efficiency / European efficiency / CEC efficiency	98.6% / 98.4% / 98.5%
Protective devices	
Input-side disconnection device	Motor-driven load-break switch
Output-side disconnection device	AC circuit breaker
DC overvoltage protection	Type I surge arrester
Lightning protection (according to IEC 62305-1)	Lightning Protection Level III
Stand-alone grid detection active / passive	● / —
Grid monitoring	●
Ground fault monitoring / remote-controlled ground fault monitoring	○ / ○
Insulation monitoring	○
Surge arrester for auxiliary power supply	●
Protection class (according to IEC 62109-1) / overvoltage category (according to IEC 60664-1)	I / III
General data	
Dimensions (W / H / D)	2562 / 2272 / 956 mm (101 / 89 / 38 inches)
Weight in kg	1900 kg / 4200 lb
Operating temperature range	−25°C to +62°C / −13°F to +144°F
Extended operating temperature range	○ (−40°C to 62°C / −40°F to 144°F)
Noise emission[5)]	64 dB(A)
Max. self-consumption (operation)[6)] / self-consumption (night)	1950 W / < 100 W
External auxiliary supply voltage	230 V / 400 V (3 / N / PE)
Cooling concept	OptiCool
Degree of protection: electronics / connection area (according to IEC 60529) / according to IEC 60721-3-4	IP54 / IP43 / 4C2, 4S2
Application in unprotected outdoor environments / indoor	● / ○
Maximum permissible value for relative humidity (non-condensing)	15% to 95%
Maximum operating altitude above MSL 2000 m / 4000 m	● / ○
Fresh air consumption (inverter)	3000 m^3/h
DC connection / AC connection	Ring terminal lug / ring terminal lug
Display	HMI touch display
Communication / protocols	Ethernet (optical fiber optional), Modbus
DC current monitoring (Zone monitoring / String monitoring)	○ / ○
SC-COM / Plant monitoring	● / ○ (via Sunny Portal)
Color enclosure / door / base / roof	RAL 9016 / 9016 / 7004 / 7004
Guarantee: 5 / 10 / 15 / 20 years	● / ○ / ○ / ○
Configurable grid management functions	Power reduction, reactive power setpoint, dynamic grid support (e.g. LVRT)
Certificates and approvals (more available on request) ● Standard features ○ Optional features — Not available	EN 61000-6-2, EN 61000-6-4, EMC conformity, CE conformity, BDEW-MSRL / FGW / TR8, Arrêté du 23/04/08, R.D. 1663 / 2000, R.D. 661 / 2007, P.O. 12.3 / IEEE 1547[7)]
Type designation	SC 800CP-10

Annex 03 :

Correction factor K1

Selection letter	Installation case	K1
B	**Cables in conduits embedded directly in thermally insulating materials.**	0.70
	Ducts embedded in thermally insulating materials.	0.77
	Multicore cables	0.90
	Building voids and gutters	0.95
C	**Installation under ceiling**	0.95
B, C, E, F	**Other cases**	1

Correction factor K2

Selection letter	arrangement of contiguous cables	Correction factor K2 number of circuits or multi-conductor cables											
		1	2	3	4	5	6	7	8	9	12	16	20
B, C, F	**recessed or embedded in the walls**	1	0.8	0.7	0.65	0.6	0.55	0.55	0.5	0.5	0.45	0.4	0.4
C	**single layer on walls or floors or non-perforated shelves**	1	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.7	No additional reduction factor for more than 9 cables.		
	single layer ceiling	1	0.85	0.76	0.72	0.69	0.67	0.66	0.65	0.64			
E, F	**single layer on perforated horizontal shelves or on vertical shelves**	1	0.88	0.82	0.77	0.75	0.73	0.73	0.72	0.72			
	single layer on cable ladders, corbels, etc.	1	0.88	0.82	0.8	0.8	0.79	0.79	0.78	0.78			

When the cables are arranged in several layers, apply in addition a correction factor of:

0.80 For two coats

0.73 For three layers

0.70 For four or five coats.

Correction factor K3

ambient temperature (°C)	insulation		
	elastomer (rubber)	polyvinyl chloride (PVC)	cross-linked polyethylene (RP) butyl, ethylene, propylene (EPR)
10	1.29	1.22	1.15
15	1.22	1.17	1.12
20	1.15	1.12	1.08
25	1.07	1.06	1.04
30	1	1	1
35	0.93	0.94	0.96
40	0.82	0.87	0.91
45	0.71	0.79	0.87
50	0.58	0.71	0.82
55	-	0.61	0.76
60	-	0.5	0.71

Annex04 :

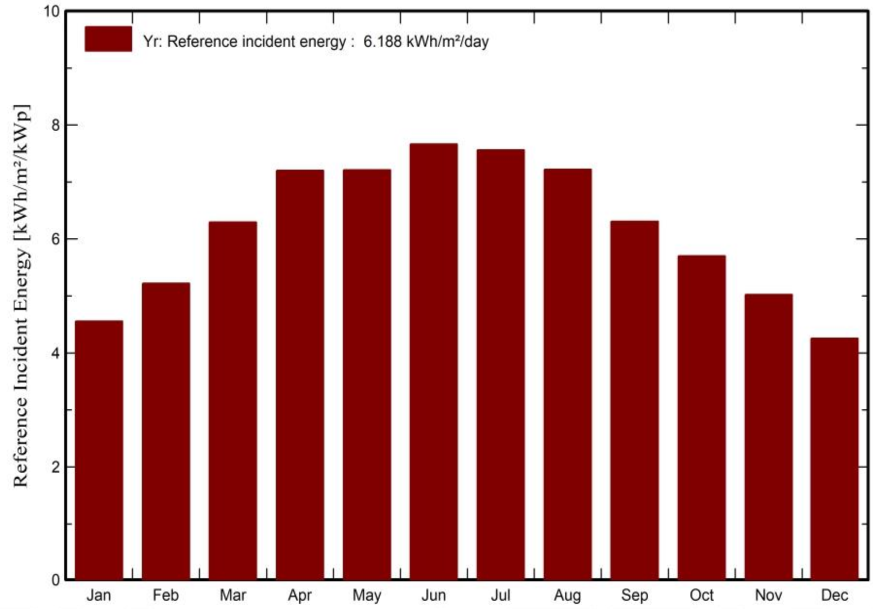
Project: Central PV Naama

Variant: Central PV Naama

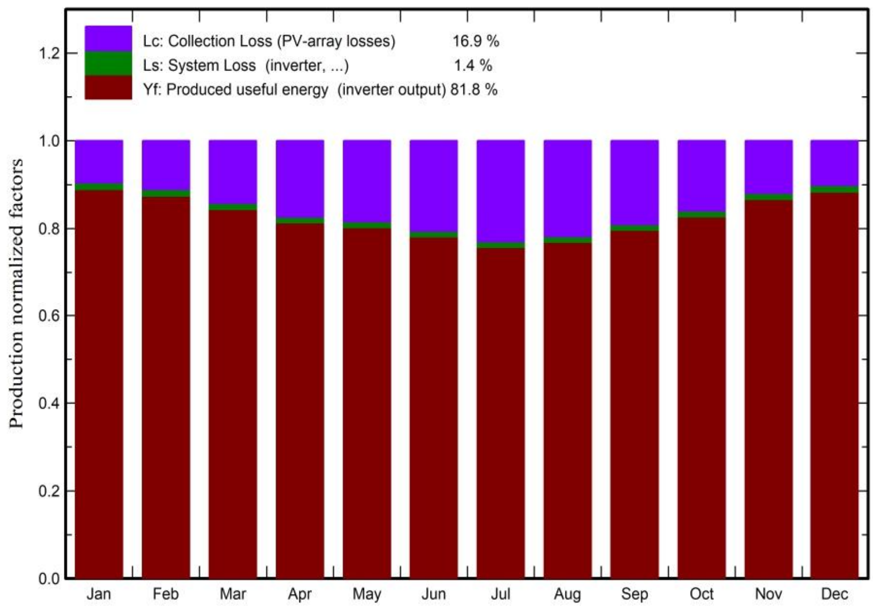
PVsyst V7.3.4
VC0, Simulation date:
17/05/23 10:51
with v7.3.4

Predef. graphs

Reference Incident Energy in Collector Plane



Normalized Production and Loss Factors



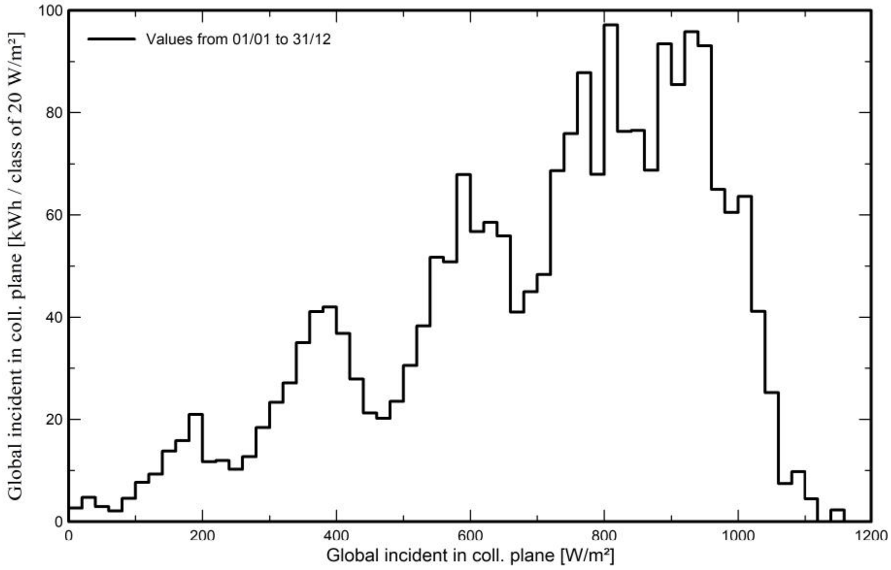
Project: Central PV Naama

Variant: Central PV Naama

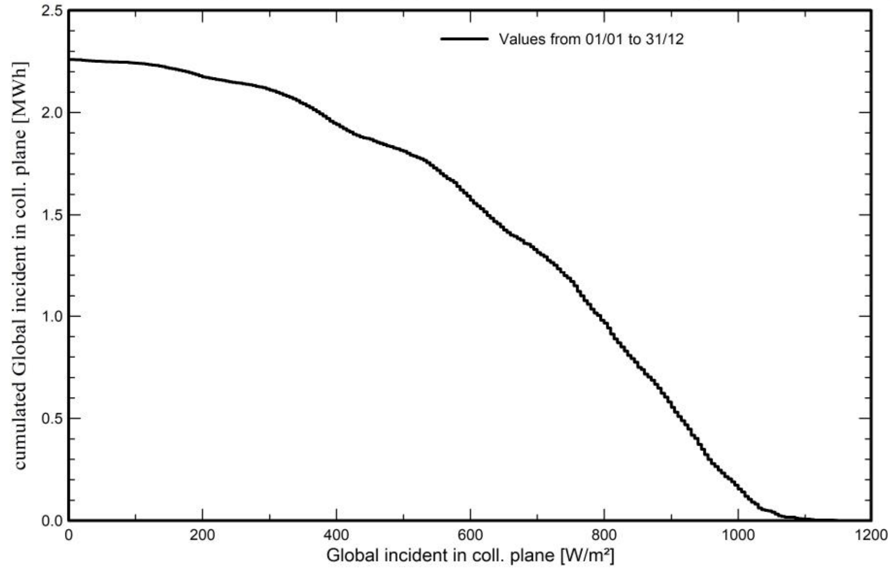
PVsyst V7.3.4
VC0, Simulation date:
17/05/23 10:51
with v7.3.4

Predef. graphs

Incident Irradiation Distribution



Incident Irradiation cumulative distribution



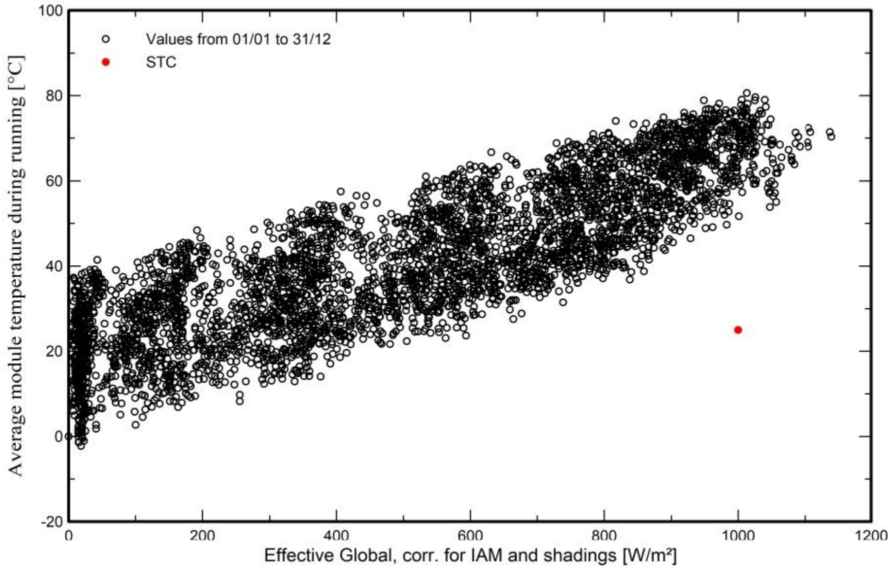
Project: Central PV Naama

Variant: Central PV Naama

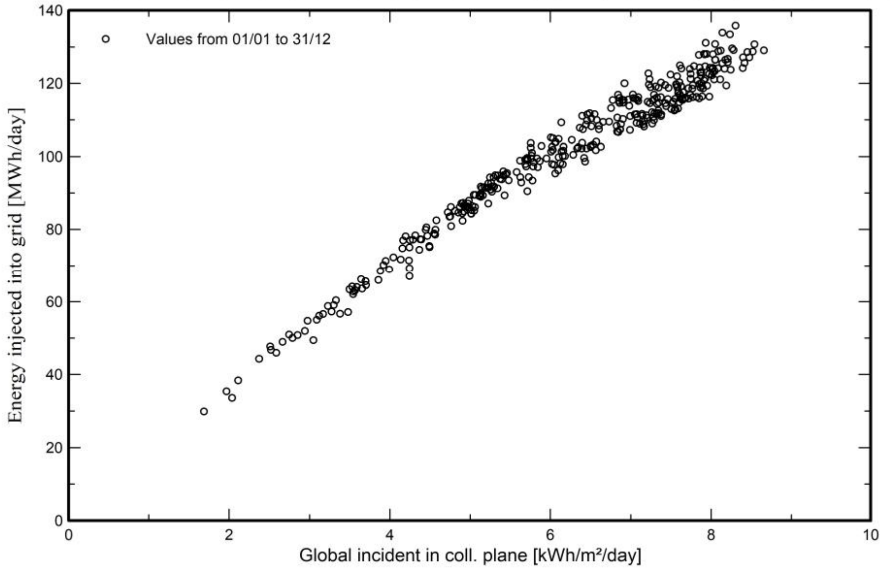
PVsyst V7.3.4
VC0, Simulation date:
17/05/23 10:51
with v7.3.4

Predef. graphs

Array Temperature vs. Effective Irradiance

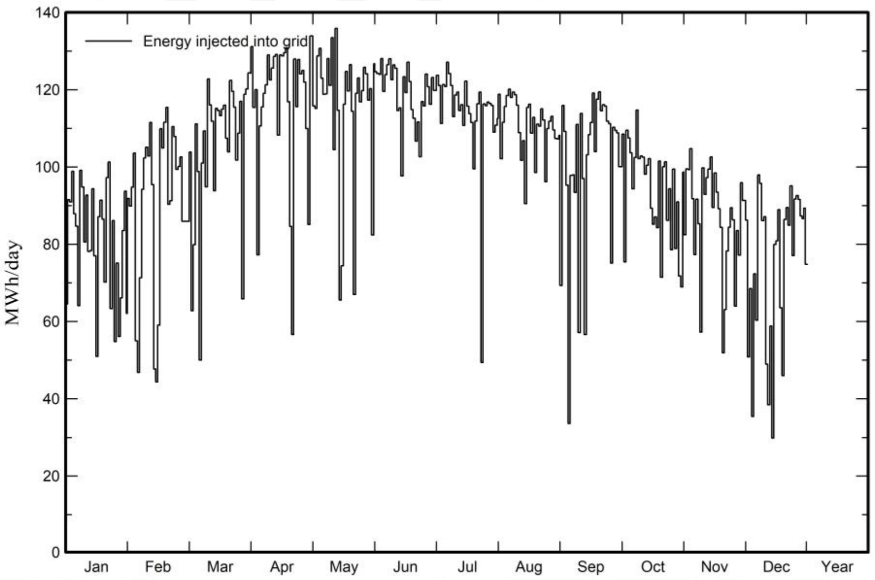


Daily Input/Output diagram

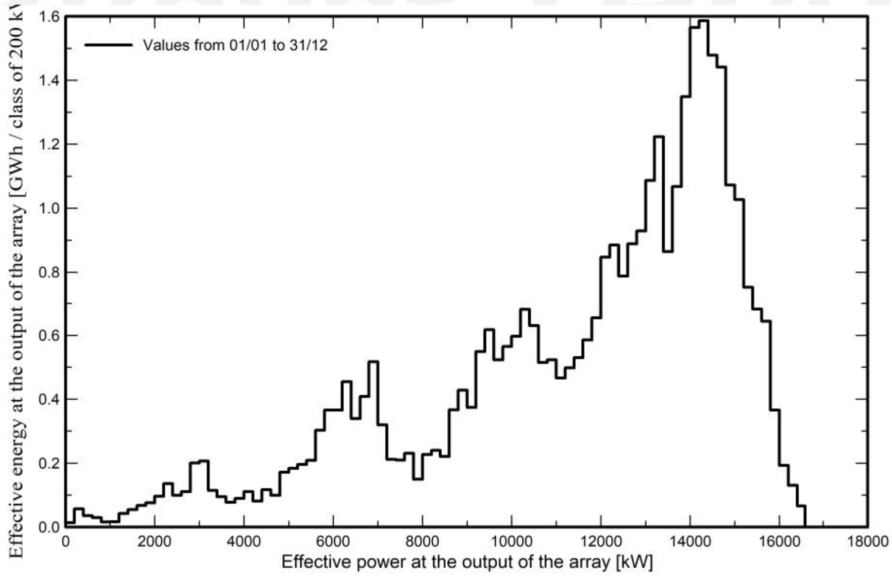


Predef. graphs

Daily System Output Energy



Array Power Distribution



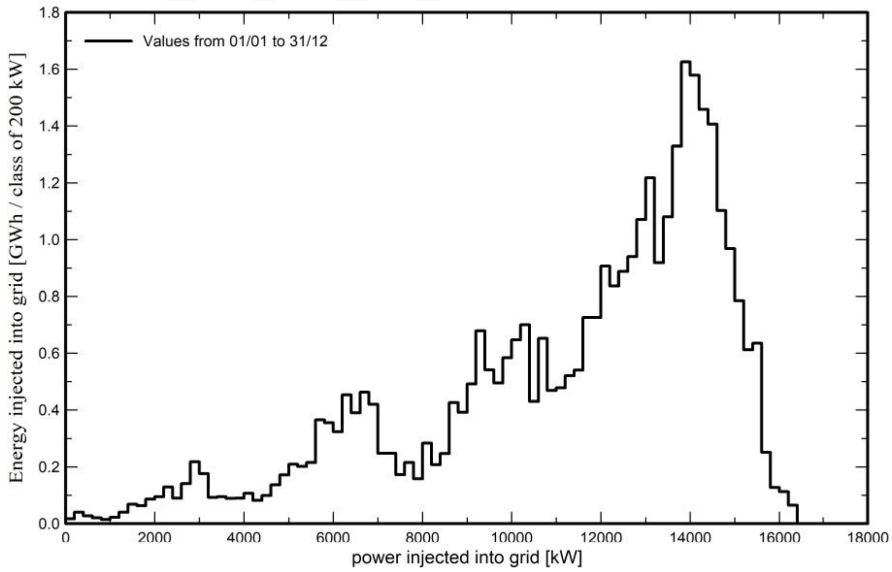
PVsyst V7.3.4
VC0, Simulation date:
17/05/23 10:51
with v7.3.4

Project: Central PV Naama

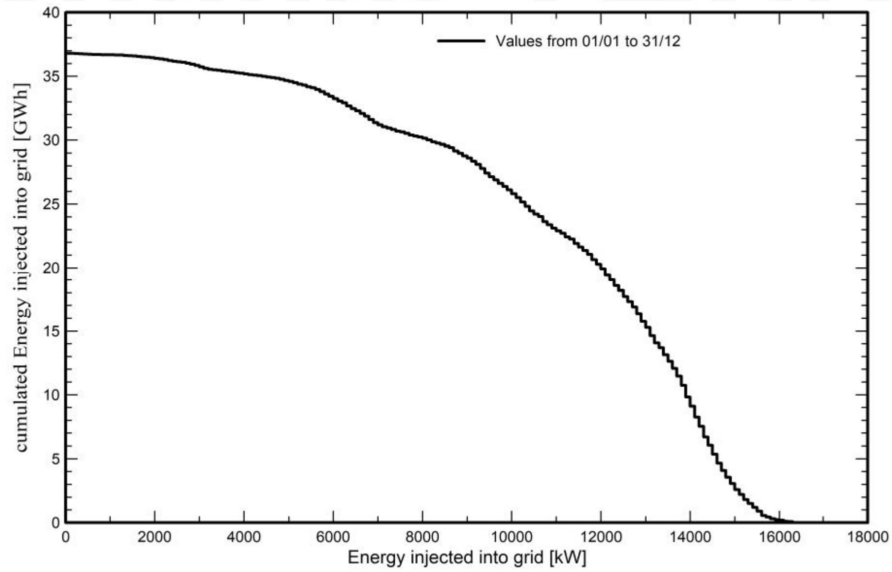
Variant: Central PV Naama

Predef. graphs

System Output Power Distribution



System Output Power cumulative distribution



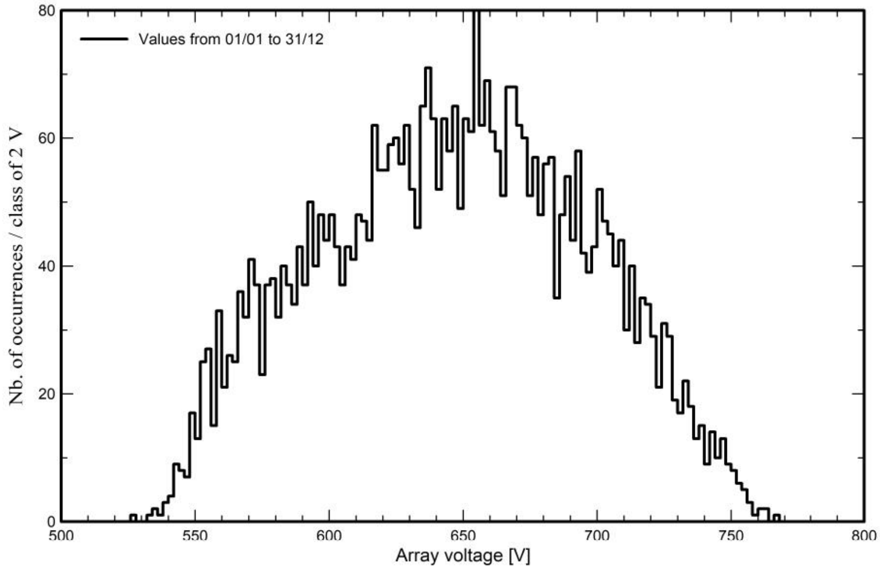
Project: Central PV Naama

Variant: Central PV Naama

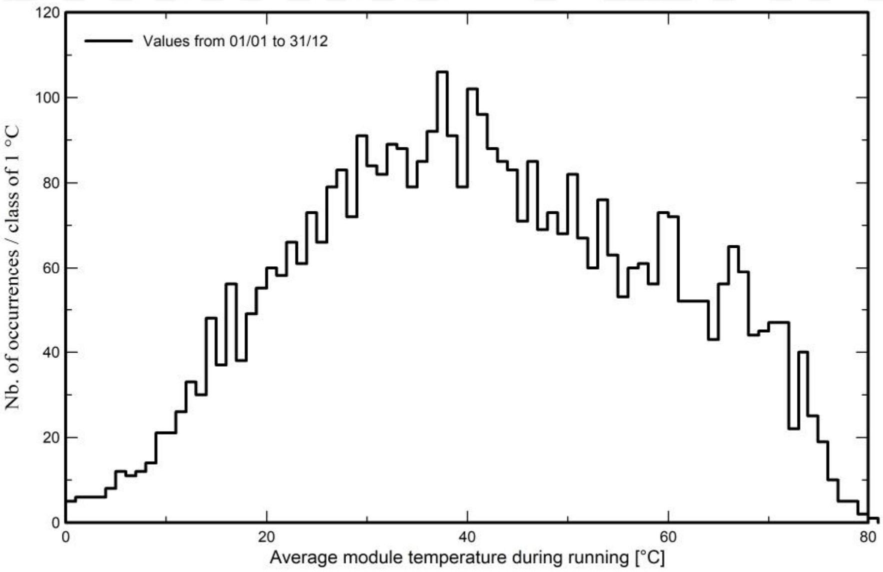
PVsyst V7.3.4
VC0, Simulation date:
17/05/23 10:51
with v7.3.4

Predef. graphs

Array Voltage Distribution



Array Temperature Distribution during running



PVsyst V7.3.4
VC0, Simulation date:
17/05/23 10:51
with v7.3.4

Project: Central PV Naama

Variant: Central PV Naama

P50 - P90 evaluation

Meteo data

Source	Meteonorm 8.1 (1996-2015), Sat=100% (Modified by user)
Kind	Monthly averages
Synthetic - Multi-year average	
Year-to-year variability(Variance)	3.0 %
Specified Deviation	
Climate change	0.0 %

Simulation and parameters uncertainties

PV module modelling/parameters	1.0 %
Inverter efficiency uncertainty	0.5 %
Soiling and mismatch uncertainties	1.0 %
Degradation uncertainty	1.0 %

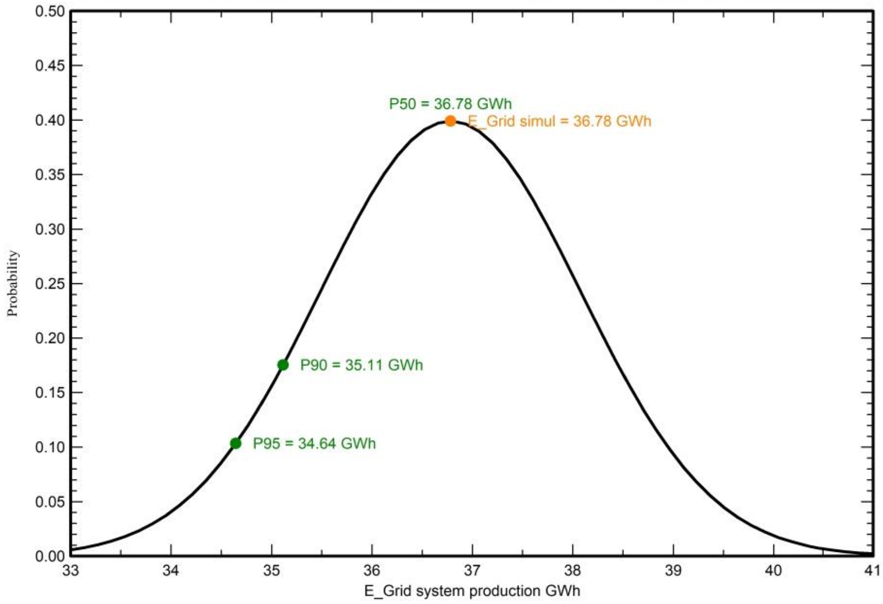
Global variability (meteo + system)

Variability (Quadratic sum)	3.5 %

Annual production probability

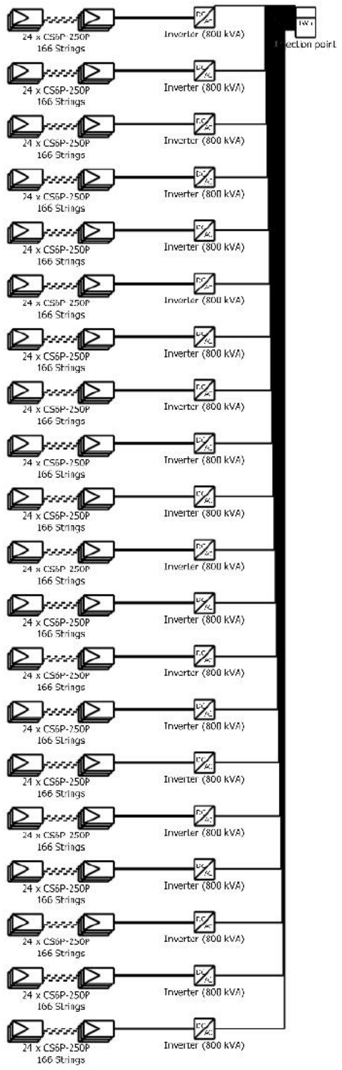
Variability	1.30 GWh
P50	36.78 GWh
P90	35.11 GWh
P95	34.64 GWh

Probability distribution



PVsyst V7.3.4
VC0, Simulation date:
17/05/23 10:51
with v7.3.4

Single-line diagram



PV module	CS6P-250P
Inverter	Sunny Central 800CP XT
String	24 x CS6P-250P

Central PV Naama	
VC0 : Central PV Naama	17/05/23

CO_2 Emission Balance

Total: 533346.0 tCO_2

Generated emissions

Total: 37292.79 tCO_2

Source: Detailed calculation from table below

Replaced Emissions

Total: 657671.5 tCO_2

System production: 36782.52 MWh/yr

Grid Lifecycle Emissions: 596 gCO_2/kWh

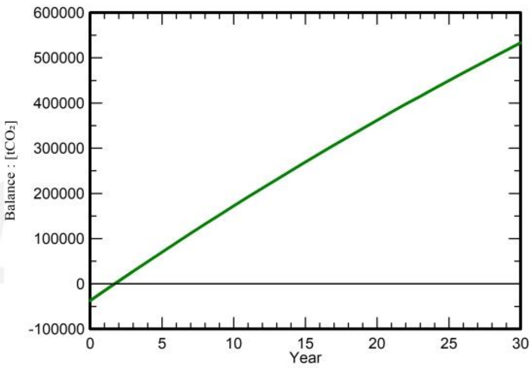
Source: IEA List

Country: Algeria

Lifetime: 30 years

Annual degradation: 1.0 %

Saved CO_2 Emission vs. Time



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	19920 kWp	34117382
Supports	3.98 kgCO2/kg	796800 kg	3167535
Inverters	394 kgCO2/	20.0	7877