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Title:

# Techno-Economic Feasibility Study of a Photovoltaic Grid-Connected System Installation in Algerian Petroleum Institute (IAP)

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# ABSTRACT

With the rapid growth in electricity demand and the depletion of fossil fuel, the Algerian government has given importance to renewable energy to extend fossil fuel reserves lifetime and bring sustainable solutions for combating global climate change, especially greenhouse gas emissions. To minimize these issues, the Algerian government maximizes the utilization of renewable energy resources for power generation. This study presents a techno-economic feasibility evaluation for an installationof a fixed panel, grid-connected photovoltaic energy conversion system to be mounted on the rooftop of the Algerian Petroleum Institute "IAP", Boumerdes, Algeria. By means of calculation and software simulation methods, this study was conducted to evaluate the technical and economic aspects of supplying the institute's electricity needs.

# DEDICATION

I have a great pleasure to dedicate this modest work to my dear father who passed away god bless his soul, my beloved mother for their continuous support and sacrifices. I wouldn't be here without them, to my dear sisters, brothers, to all my friends who have helped me along the way specially C.Dihia, B.Hiba, and H.Zahra.

I also dedicate this work to all with whom I spent wonderful moments.

*Kenza Benamarouche*

# DEDICATION

First and foremost, I dedicate this project to God Almighty, my creator, my strong pillar, my source of inspiration, wisdom, knowledge, and understanding.

This desertion is wholeheartedly dedicated to my beloved parents, from an early age, they instilled in me a desire to learn and made sacrifices so I would have access to a high-quality education. Without their support and guidance, I would not be where I am today.

My work on this study could not have been possible without the support and guidance of my fiancee, sisters, brothers, nieces, nephews and family members, who have been my source of inspiration and gave me the strength to overcome obstacles and who continuously provide their moral, spiritual and emotional support.

Zakia Bouchebbat

# ACKNOWLEDGEMENTS

We are thankful to Allah, the most gracious and the most merciful for helping us finish this modest work. This project is a part of the two years master's program in power engineering. The work is conducted jointly with the Algerian Petroleum Institute (IAP), Boumerdes, Algeria, and the Institute of Electrical and Electronic Engineering, Boumerdes, Algeria. The project's main intention has been to conduct a technico-economic study for the integration of a grid-connected photovoltaic system in IAP.

We would like to express our sincere gratitude to our supervisor and principal lecturer, **Prof. Hamid Bentarzi** for his continued guidance and unwavering encouragement throughout the course of this research for sharing with us his expertise, experience, and providing necessary data and supporting materials that contributed a lot to design the project content and finalizing the project outcomes.

We are greatly indebted to our co-supervisor **Mr. Salim Mekki Boualleg**, manager of the renewable energy department in IAP, who gave us an opportunity to perform the work, outlined the framework, and made his suggestions about which tools should be tested in the case study. Special thanks to **Ms. Ouchane**, **Mr. Kaddour,** and all others working in IAP, for their support and will to share information.

With this project, a stage ends. The end of an enrichment stay as an engineering student at the Institute of Electrical and Electronic Engineering. we would like to express special gratitude to teachers, colleagues, and all the people that strongly contributed to the fulfillment of our education.

On a personal note, we would like to thank our families and friends for their support and belief in us throughout this time. without their support and love, it would have been quite impossible for us to pursue our dreams.

*Thank You All*

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**PV:** Photovoltaic.
**kWh:** Kilowatt-hours.
**IAP:** Algerian Petroleum Institute.
**IEA:** International Energy Agency.
**I-V curve:** A current-voltage curve.
**P-V curve:** A power-voltage curve.
**DC:** Direct Current.
**AC:** Alternative Current.
**kWp:** Kilowatt-peak.
**BOS:** Balance Of System.
**GW:** Gegawatt.
**MPP:** Maximum Power Point.
**Voc:** Output voltage.
**Isc :** Short circuit current.
**NPV:** Net Present Value.
**IRENA:** International Renewable Energy Agency.
**DZD:** Algerian Dinar.
**PBP:** Payback Period.
**LCOE:** Levelized Cost Of Energy.
**YF:** Yield Factor.
**PR:** Performance Ratio (%).
**CF:** Capacity Factor (%).
**STC:** Standard Test Condition (25°C and 1kW/m$^2$ ).
**Poly:** Poly-crystalline solar panel.
**CSP**: Concentrated Solar Power
**FIT**: Feed In Tarif
**O&M:** Operation and Maintenance

# CHAPTER I: GENERAL INTRODUCTION

# 1.1 Introduction:

The global energy revolution towards an efficient and sustainable structure is the composition of modern technical development and the integration of renewable sources. The current global electric power system situation has two main challenges; ensuring a secure supply of power and mitigation of environmental impact from power production. In recent years, electricity is the world's fastest growing energy consumption. The main reason for this significant growing demand is the massive population and economic growth associated with industrialization and extensive technical innovation worldwide. According to International Energy Outlook 2019, the net electricity production will increase by around 70% by 2050 which results in 45 trillion kilowatt-hours (kWh) annual electricity consumption in the world [1].

Fossil fuels such as oil, natural gas, and coal are considered as a major source to meet such massive demand. Around 60% [1] of current global electricity is produced from fossil sources, which has an important contribution to greenhouse emission. This situation imposes to make an efficient trade-off between environmental safety and energy security. Therefore, the main challenge is to make suitable technical solutions and business models to guarantee sustainability in the energy sector.

Renewable energy technologies are promising alternative solutions for future electricity generation. Renewable resources such as solar, wind, hydro, and geothermal are the fastest growing energy sources for electricity production containing 9% [1] average annual growth. The solar energy is considered as an important future potential energy source output compared to other types of renewable energy (RE) sources for three reasons. First, it is the most abundant resource of power in the form of heat and light from the sun. Next, solar energy can provide concrete module output efficiency which helps to make an accurate estimation of production. However, solar irradiation depends on weather conditions, but it has the flexibility to be designed based on consumer needs such as distributed generation or grid connected large scale production [2].

The PV based energy technology is one of the most sustainable solutions, the productivity of a PV system varies significantly with the implemented technologies, the system design, and the prevailing weather conditions [3]. The grid-connected solar PV system is designed to operate alongside the utility power grid, one of the best advantages of rooftop solar PV systems is that it can be granted and installed faster than other types of renewable energy sources. It is a cost-saving, a secure investment, increasing access to energy, supporting from government, reducing carbon footprints, and needs low maintenance costs.

Algeria has enormous renewable energy potential. It possesses high solar potential, with more than 3000 hours of sunshine per year [4],[5]. However, fossil fuels remain the main source of electricity production in Algeria. In fact, Algeria is considered to be one of the most energy-consuming countries, with the contribution of fossil fuels in electricity production at more than 98.75% in 2016. Moreover, energy consumption and its evolution over time are the principal factors explaining the global $CO_2$ emission growth [6] – [9]. Furthermore, Algeria is particularly vulnerable to climate change. Solar photovoltaic (PV) systems are a good alternative and feasible solution for generating electricity in Algeria, especially for grid-connected systems.

## 1.2 Overview of similar projects:

With respect to grid-connected solar energy systems modeling and the feasibility issues, numerous studies have been conducted so far and have been implemented in different countries.

System design and techno-economic evaluation of a grid-connected PV system in Adam city, Oman [10] with a size of 1 MW. The numerical simulation was made using MATLAB developed code. The system was considered feasible and shows great promise for the city of Adam.

The author analyzed the solar radiation aspects, the performance, and the cost-effectiveness of designing a proposed utility-scale, grid-connected PV power plant of 4 MW capacity to enhance the energy demand at the AL-Mahmudiyah region in Iraq [11]. The performance ratio (PR) 79.2%, the final yield (Yf) ranged from 3.53 to 5.45 kWh/kWp/day with an annual capacity factor of 19.4%, the array yield (Yr) with an average value of 4.7 kWh/kWp/day, and the AC output power of 3.162 MW at an average system efficiency of 15.5%. The power losses were calculated and displayed in a diagram loss.

A techno-economic feasibility assessment of grid-connected PV systems for residential buildings, a case study in Saudi Arabia is carried out [12], The size of the PV system for a typical Saudi Arabian apartment is estimated to be 12.25 kW. Results have shown that the proposed system can generate 87% of the electricity needs of an apartment. The technical analysis showed that the capacity factor and the performance ratio were 22% and 78% respectively.

Performance analysis of a 20 MW grid-connected photovoltaic installation in Adrar, South of Algeria [13], the results were monitored over a period of 1 year, from January 2018 to December 2018. The total yearly energy delivered to the grid was 35892.22 MWh, and the monthly average reference and final yields of the system are in the range of 5.92 to 8.1 (h/day) and 4.39 to 5.56 (h/day) respectively. Furthermore, the annual average daily PV system efficiency, performance ratio, capacity factor, and total losses were 10.82%, 71.71%, 20.76%, and 2.04 h/day respectively.

## 1.3 Aim of the project:

The Algerian strategy to mitigate global climate change was built on the balance between sustainable development and international climate commitments. The government action program has given priority to promoting RE in the electricity sector, with a view of reaching an adequate energy mix.

The aim of this project is to design a 237 kW fixed panel, grid-connected photovoltaic system in the Algerian Petroleum Institute “IAP”, Boumerdes, Algeria, that will be mounted on the rooftops of the institute’s buildings that will meet the energy demand. The optimum case is further investigated to evaluate the technical and economic feasibility of the system for a period of twenty-five years. By means of the calculation methodology, technical parameters, and performance indicators are evaluated to determine the productivity of a solar PV system. Furthermore, economic indicators and environmental effects are determined to ensure the profitability of the project, evaluated parameters are validated by means of specialized software packages. The feasibility analysis results are used to convince and attract solar energy investors to invest in solar energy projects in the institute.

## 1.4 Organization of the report:

This report is compiled into six chapters, including this introduction and followed by the references used in this work.

Chapter one provides an introduction to the project work.

In chapter two, an overall background about solar energy and photovoltaic cells is presented. Following this, the photovoltaic system itself is introduced describing the characteristics of grid-connected PV system such as components losses and scenarios. Ending this chapter, we had an overview of the Photovoltaic market in Africa thus including Algeria.

In Chapter three, a sizing of the system is conducted. Its core objective is the determination of the optimal configuration on the system according to the IAP meteorological and load data provided. A simulation by PVsyst software is realized to confirm the sizing results obtained by the calculation methodology and to acquire detailed technical indicators to validate the system productivity.

In chapter four, an economic analysis is conducted for the grid-connected system installed in IAP Boumerdes, by means of calculation, the capital cost of the project is estimated, cash inflows and cash outflows are studied. This economic study is conducted based on the Net Present Value (NPV) and the Payback Period to determine the profitability and viability of the project. Additionally, economic indicators are validated using the RETScreen software.

In Chapter five a feasibility analysis is carried with the help of PVsyst software to show and discuss the technical, economic, and environmental analysis results of a grid-connected PV system. The IEA standard (International Energy Agency) guidelines were used to compare the performance of the system with similar projects.

Chapter six concludes the project with some remarks and suggestions for future work.

Finally, the report terminates with an extensive list of references for additional information on the subject and some appendices to provide additional details on the different components used in the system design including supporting information.

# CHAPTER II: PHOTOVOLTAIC OVERVIEW

# 2.1 Introduction:

Photovoltaic (often shortened as PV) gets its name from the process of converting light (photons) to electricity (voltage), which is called the photovoltaic effect. This phenomenon was first exploited in 1954 by scientists at Bell Laboratories who created a working solar cell made from silicon that generated an electric current when exposed to sunlight. Solar cells were soon being used to power space satellites and smaller items such as calculators and watches. Today, electricity from solar cells has become cost competitive in many regions and photovoltaic systems are being deployed at large scales to help in the powering of the electric grid.

# 2.2 Solar radiation:

The basic processes behind the photovoltaic effect, on which the operation of solar cells is based, is generation of the electron-hole pairs due to absorption of visible or other electromagnetic radiation by a semiconductor material. Today we accept that electromagnetic radiation can be described in terms of waves, which are characterized by the wavelength (λ) and frequency (ν), or in terms of discrete particles, photons, which are characterized by energy ( h*ν ) expressed in electron volts. The following formulas show the relations between these quantities:

$$\nu = c/\lambda \tag{1}$$

$$h\nu = \frac{hc}{\lambda} \tag{2}$$

Where c is the speed of light in a vacuum ($2.998 \times 10^{8}$ m/s), and h is Planck's constant ($6.625 \times 10^{-34}$ Js).
Only photons of appropriate energy can be absorbed and generate the electron-hole pairs in the semiconductor material, more specifically only photons that have energy equal or greater than the bandgap energy of the electron are able to make that latter free and create the electron-hole pair. Therefore, it is important to know the spectral distribution of solar radiation [14].

# 2.3 Solar cell:

The basic building block of PV technology is the photovoltaic cell. Different materials are used to produce PV cells, but silicon is the main ingredient since it is mainly extracted from sand, which by itself is widely available.
A solar cell is basically a p-n junction diode. It utilizes the photovoltaic effect to convert light energy into electrical energy.

## 2.3.1 Working principle of solar cell:

When light reaches the p-n junction, the light photons can easily enter the junction, through a very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The free electrons in the depletion region can quickly come to the n-type side of the junction. Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side and the created holes come to the p-type side, they can not further cross the junction because of the barrier potential of the junction. As the concentration of electrons in one side and holes on the other side becomes higher, the p-n junction will behave like a small battery cell.

A voltage is produced known as photovoltage. If we connect a small load across the junction, there will be a tiny current flowing through it [15].

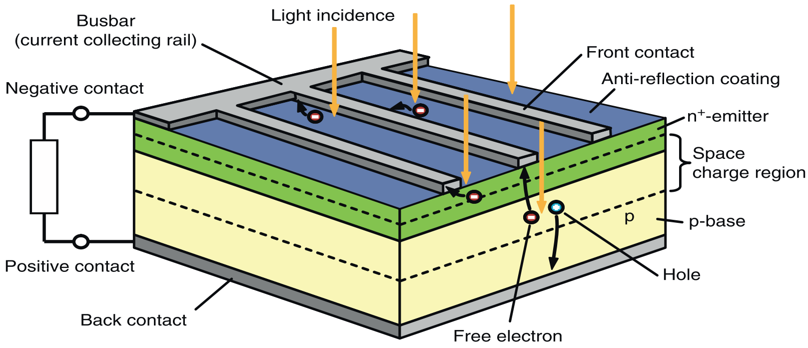



Figure 2.1 Typical solar cell [15]

## 2.3.2 Equivalent circuit:

The standard model, also called the single-diode model goes deeper into electrical losses in the solar cell. The series resistance $R_S$ describes especially the ohmic losses in the front contacts of the solar cell and at the metal-semiconductor interface. In contrast, leak currents at the edges of the solar cell as well as at any point short circuit of the p-n junction are modeled by the shunt resistance $R_{SH}$, in Figure 2.2, $I_P$ is the shunt current, $I_D$ is the diode current and $I_{ph}$ is the photocurrent.

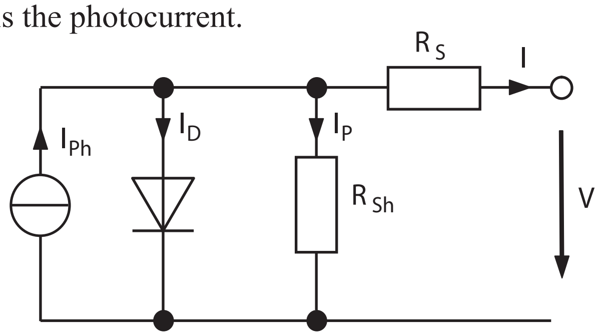



Figure 2.2 Equivalent model [15]

## 2.3.3 Types of solar photovoltaic cell:

The main types of a solar cell are:

• Monocrystalline, conversion efficiency for this type of cell ranges from 15% to 20% and the expected lifespan of these cells is typically 25-30 years.

• Polycrystalline, it has less efficient from 13% to 17% compared to monocrystalline, the lifespan is expected to be between 20 and 25 years.

• Thin-film technology, lower efficiency ranges from 5% to 13% with lifespan around 15-20 years. Although less efficient than mono and polycrystalline silicon, thin-film solar cells offer greater promise for large-scale power generation because of ease of mass-production and lower materials cost [14].

## 2.3.4 PV cell characteristics:

The characteristic curve of a solar cell corresponds to the principle of a photodiode [15]. A typical solar cell characteristic curve is shown in Figure 2.3, where $I_{ph}$ is the photocurrent, $I_s$ is the saturation current, $V_T$ is the thermal voltage, $I_D$ is the diode current and m is the ideality factor.

$$I = I_{\mathrm{Ph}} - I_{\mathrm{D}} = I_{\mathrm{Ph}} - I_{\mathrm{S}} \cdot \left( e^{\frac{V+I.R_s}{m \cdot V_T}} - 1 \right) - \frac{V+I.R_s}{R_{sh}} \tag{3}$$

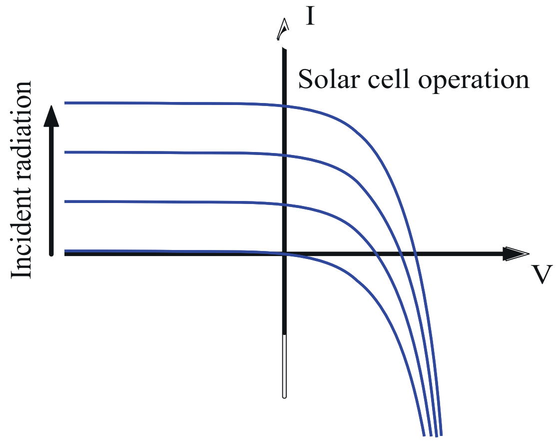



Figure 2.3 Characteristic curve [15]

#### 2.3.4.1 Short circuit current Isc:

The short circuit current Isc is delivered by the solar cells when it is short-circuited at its connections, the short circuit current Isc is equal to the photocurrent Iph[15], where Is is the saturation current.

$$I_{SC} = I(V=0) = I_{Ph} - I_S \cdot \left(e^0 - 1\right) = I_{Ph} \tag{4}$$

#### 2.3.4.2 Open circuit voltage Voc:

The second extreme case, occurs when the current becomes zero. In this case the resulting voltage is called open circuit voltage Voc [15], where m is the ideality factor and Is is the saturation current.

$$V_{OC} = V(I=0) = m \cdot V_T \cdot ln\left(\frac{I_{SC}}{I_S} + 1\right) \tag{5}$$

#### 2.3.4.3 Maximum power point (MPP):

The solar cell provides different capacities depending on the actual working point in which it is operated. The operating point at which the maximum power is provided is called the maximum power point (MPP). The current and voltage values associated with the MPP are called IMPP and VMPP [15].

#### 2.3.4.4 Fill factor FF:

The fill factor FF, describes the relationship of MPP power and the product from the open circuit voltage and short circuit current [15]. The fill factor is a measure of the cell quality.

$$FF = \frac{V_{MPP} \cdot I_{MPP}}{V_{OC} \cdot I_{SC}} = \frac{P_{MPP}}{V_{OC} \cdot I_{SC}} \tag{6}$$

#### 2.3.4.5 Efficiency $\eta$:

The efficiency of a solar cell describes what portion of the optical power Popt incident on the cell is the output as electrical energy PMPP [15], where E is the irradiance and A is the cell area.

$$\eta = \frac{P_{MPP}}{P_{Opt}} = \frac{P_{MPP}}{E \cdot A} = \frac{FF \cdot V_{OC} \cdot I_{SC}}{E \cdot A} \tag{7}$$

### 2.3.5 I-V and P-V curves of a PV device:

A current-voltage (I-V) curve shows the possible combinations of the current and voltage output of a photovoltaic (PV) device. The I-V curve is based on the device being under standard test conditions (1 kW/m², AM 1.5, 25°C Cell Temperature). The main points of the I-V curve characteristics are the short-circuit current (Isc), the open-circuit voltage (Voc) and there is a point on the knee of the curve where the maximum power output is located. The power-voltage (P-V) curve is the product of the current and voltage for each point in the I-V curve. This product represents the output power for that operating condition. The MPP produced by the PV generator is reached at a point on the characteristic where the product I-V is maximum (see Figure 2.4) [16].

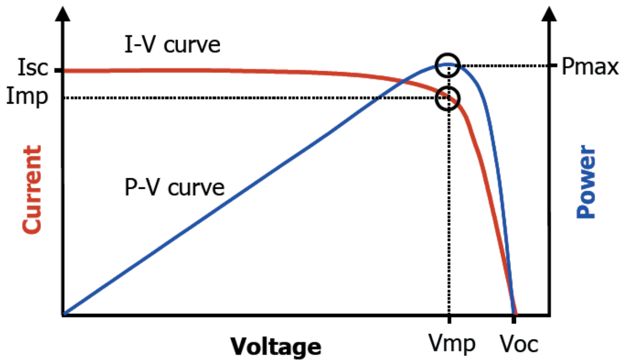



Figure 2.4 Maximum power point [17]

## 2.4 Impacts of temperature and irradiance on the module's performance:

### 2.4.1 Temperature effect:

Solar cells are sensitive to temperature like all other semiconductor devices. The increase in temperature reduces the bandgap of a semiconductor, thereby affecting most of the semiconductor material parameters. The decrease in the bandgap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. For this reason the short circuit current Isc increases slightly with increasing temperature and the open circuit voltage is most affected by an increase in temperature , this change affects the power as well [18]. The impact of increasing temperature is shown in the figure below:

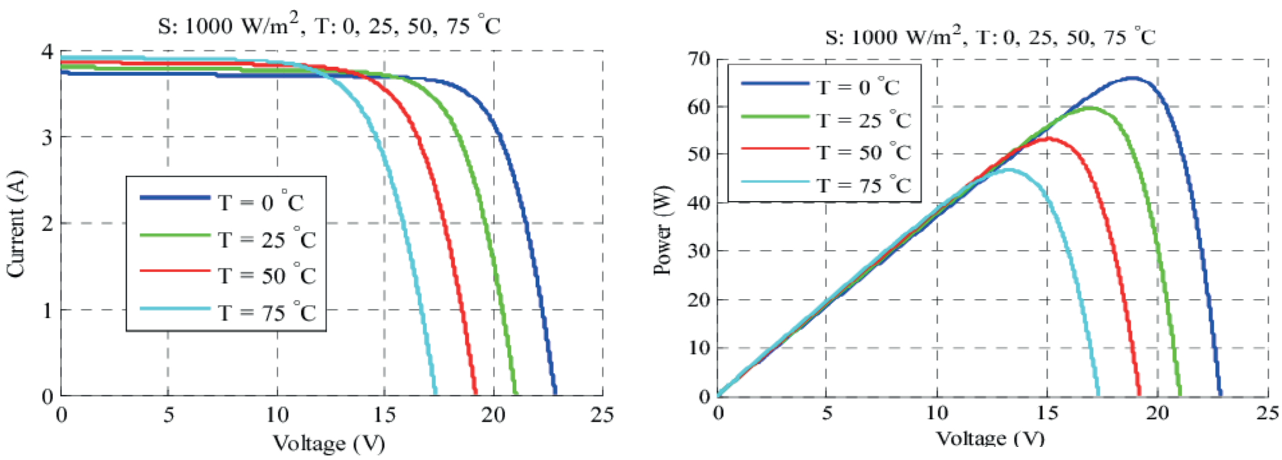



Figure 2.5 Temperature effect on I-V and P-V characteristic curves [19]

### 2.4.2 Irradiation effect:

In a solar cell, the parameter most affected by an increase in irradiation is the short-circuit current and this change affects the power as well, but has a small effect on the PV module's open-circuit voltage. The impact of increasing irradiation is shown in the figures below:

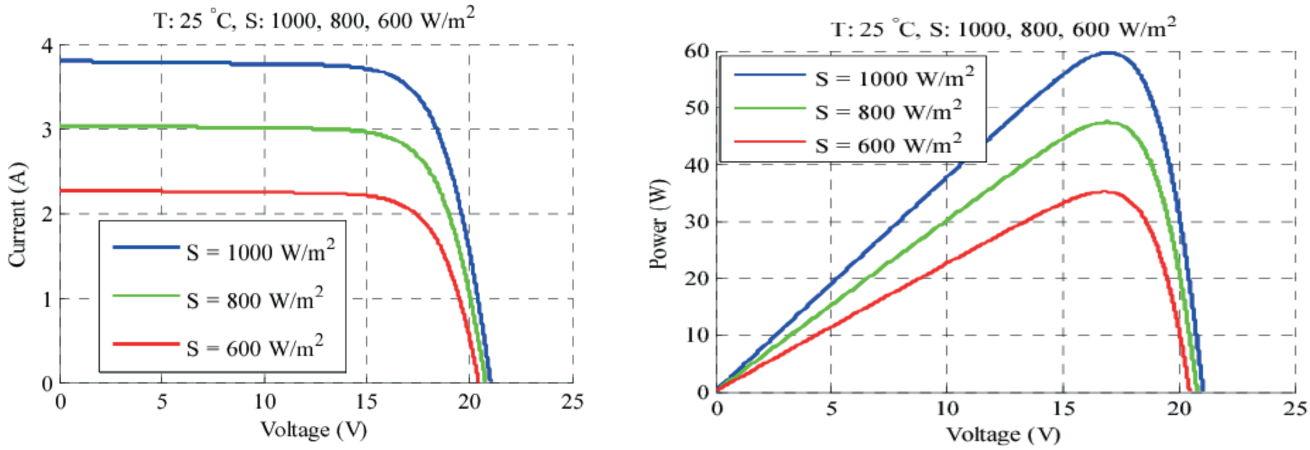



Figure 2.6 Irradiation effect on I-V and P-V characteristic curves [19]

## 2.5 Solar module:

The power produced by a PV cell is very small, for that, many PV cells are connected in series or parallel to form solar modules.

### 2.5.1 Parallel connection of cells:

The parallel connection forces all the cells to have the same voltage. At the same time, the individual currents are added up.

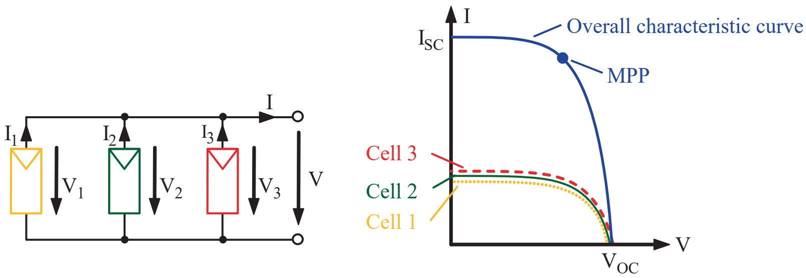



Figure 2.7 Parallel connection of solar cells [15]

### 2.5.2 Series connection of cells:

The current in all cells is the same and the overall voltage is made up of the sum of the individual voltages.

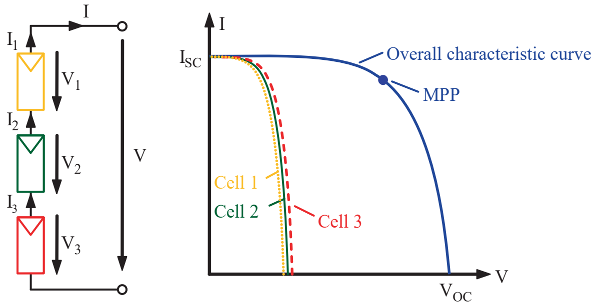



Figure 2.8 Series connection of solar cells [15]

## 2.6 Solar array:

In the photovoltaic system, multiple photovoltaic modules are connected in series to form a photovoltaic string to achieve a required voltage and power output. To achieve even higher power, these photovoltaic strings can be connected in parallel to form a photovoltaic array.

For a large-scale generation of solar electricity, the solar panels are connected together in series and parallel to comprise the solar array according to the demand.

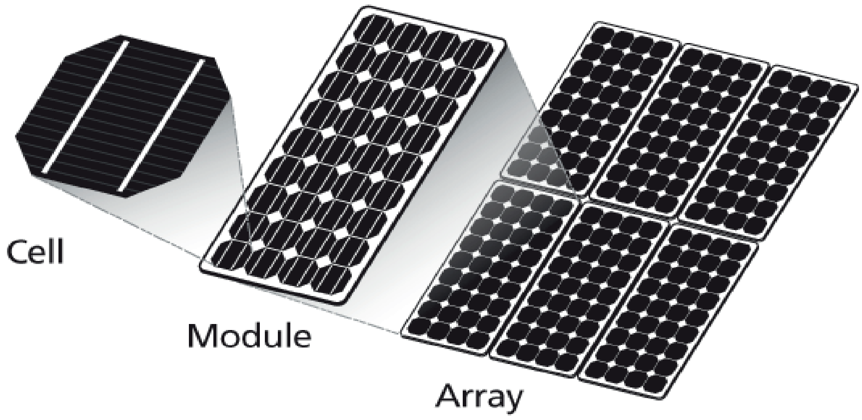



Figure 2.9 Array construction [20]

## 2.7 Shading effect:

Shading can have a huge impact on the performance of solar photovoltaic panels. A common misconception is that partial shading does not affect the output of solar panels. In fact, the solar photovoltaic panels consist of a number of cells that are wired together into a series circuit. Because of this, the performance of the solar panel is significantly reduced even if the smallest section of the panel is in shade. Another possible issue from partial shading is overheating. Because of partial shading, one part of the solar panel generates a lower amount of energy as compared to the other non-shaded part. As the amount of power generated in shaded and non-shaded parts differs, it leads to overheating which in turn reduces the total power output of the solar panel. Setting up the solar panel where there is no shade is the best way to reduce the loss of output. But this is not always possible. Therefore, here are some of the ways in which you can reduce the effects of shading [8].

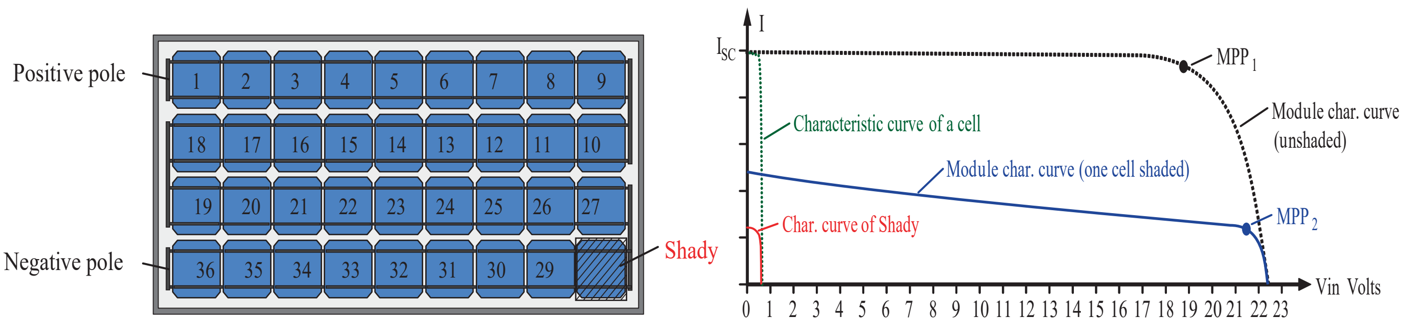



Figure 2.10 Shading effect [15]

### 2.7.1 Bypass diodes:

Bypass diodes can be connected between the cells in the solar panel. This restricts the power loss only from the shaded portion of the solar panel as compared to the entire solar panel. The bypass diodes create an alternate route for the currents from the unshaded part of the panel and avoids passing through the shaded part of the panel. As a result of this process, some amount of power is lost because of the voltage drop, however, the overall output is still higher than the power generated without the diodes. Also, when the solar photovoltaic panel is not shaded, the diode is blocked. This way, the bypass diodes are able to reduce the effects of shading and protect the solar panels as well [21].

### 2.7.2 Micro inverters:

Micro Inverters are the next-generation of solar system technology. Unlike the conventional systems which have only one centralized inverter for the entire solar panel array, the inverter systems couple a micro-inverter with each solar panel. The advantages of using a micro-inverter include greater system power yields, it protect the solar panel against potentially more dangerous outgoing, high-voltage DC electricity, and flexibility to monitor individual solar panel performance [21].

## 2.8 Solar systems:

Photovoltaic (PV) systems are mainly defined based on if the energy generated by the system is stored or it is directly connected to the grid. Thus, there are stand-alone PV systems and grid-connected PV systems.

### 2.8.1 Stand-alone PV systems:

The stand-alone PV systems are the most popular systems used worldwide, especially where the grid electricity was not available or not cost-effective, in relatively remote areas, or in mobile systems, such as cars and solar pumps used mostly for agriculture. The electricity generated in this type of system is going directly for usage when there is a load, however since the load is varying, as well as the energy yielded by the PV system, usually a battery is connected to the PV array's output to store the electricity, where there is a charge controller to monitor the battery when charging in the case there is more energy yielded by the array than needed by the load, and the battery supplying the load to compensate the lack when the array's energy is reduced below the load's demand or when there is absence of production (very low irradiance or at night) [22].

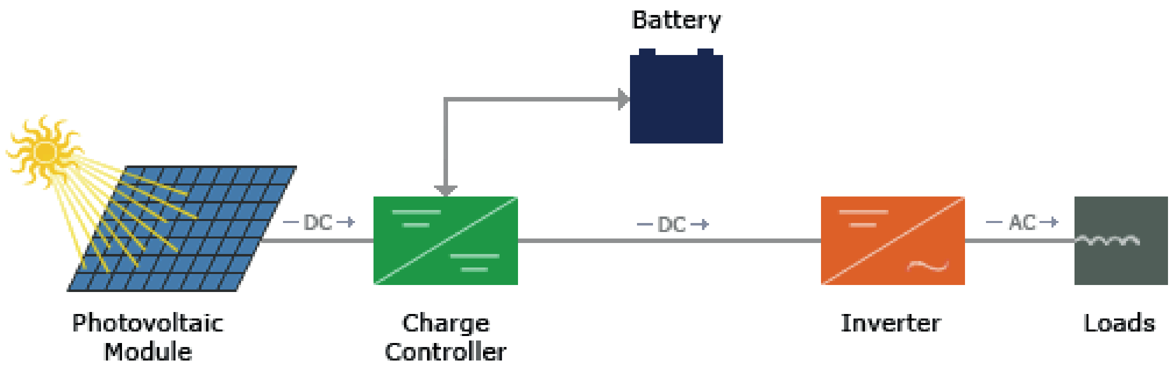



Figure 2.11 Stand alone configuration [22]

A system with more than one source of power is called a hybrid system. It is often desirable to design a system with an additional source of power. The most common type of hybrid system contains gas or diesel-powered engine generator. Another hybrid approach is a PV/Wind system. Adding a wind turbine to a PV system provides complementary power generation.

In a hybrid system, another source(s) of energy, such as wind, biomass or diesel, can be hybridized with the solar PV system to provide the required demand. In such type of system, the main objective is to bring more reliability into the overall system at an affordable way by adding one or more energy source(s) [22].

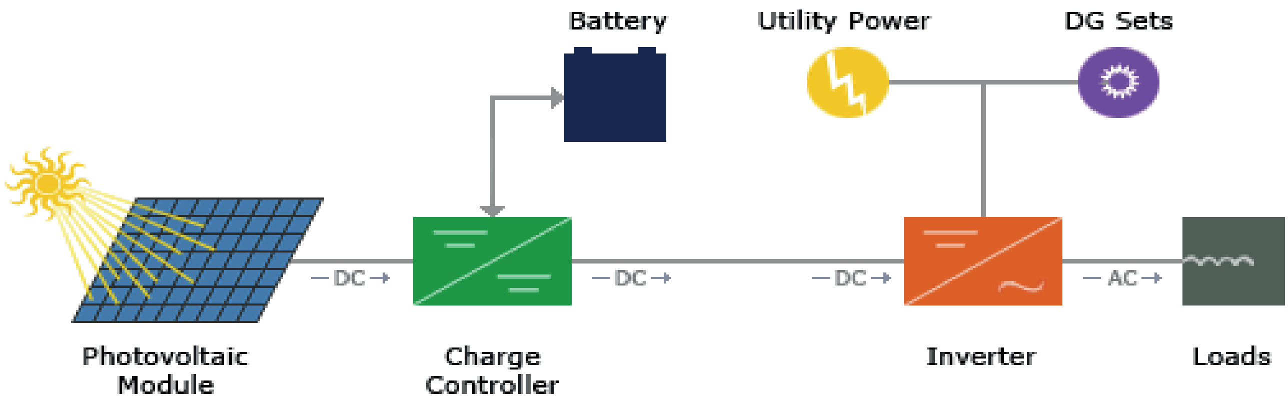



Figure 2.12 Hybrid configuration [22]

## 2.8.2 Grid connected PV systems:

Grid-connected or utility-interactive PV systems are designed to operate in parallel with the electric utility grid. This type of system is becoming more popular lately, especially in the countries where the utility grid is available and the electricity cost is relatively high. Where the stand-alone system is comparatively simpler, the grid-connected system offers several advantages. The fact that some of the electricity is produced from the PV system reduces the demand on the utility, which is important during peak hours [23].

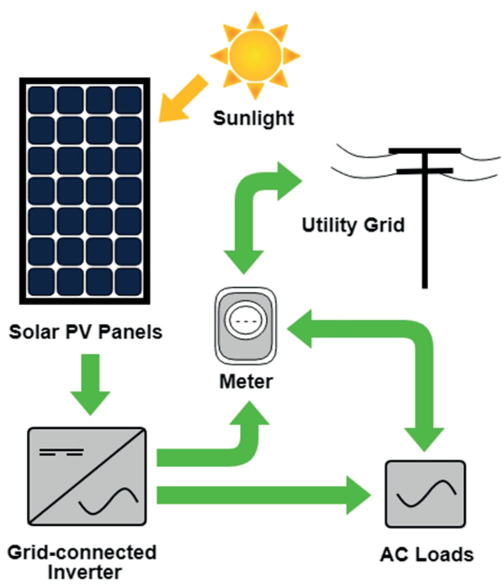



Figure 2.13 Grid connected configuration [23]

Furthermore, some of the countries recently are using what is called the net metering, which is a cost-reduction process, when the PV system is yielding more electricity than needed, it supplies the extra energy to the grid rather than let it go to waste, and the opposite happens when the yield is less than demanded. This means that all the energy produced by the system is benefited from and the amount of grid electricity that will be beneficial and paid for, would be only the difference between the PV electricity supplied to the grid and the amount the latter supplies to the user.

# 2.9 Grid connected PV system components:

The building blocks of a grid-connected PV system are shown in Figure 2.13. Different components of the system are discussed in the following sub-sections.

## 2.9.1 Solar PV panels:

The solar panel is the most expensive component of the PV system. Solar cells are the electrical building blocks for solar arrays. Different types of materials can be used in manufacturing these cells. However, the most widely used cells are made of polycrystalline silicon (54.5% of the world's market share) and monocrystalline silicon (29.36% of the world's market share) [23].

## 2.9.2 Grid connected inverter:

Also known as a grid-tied inverter, it is used in grid-connected systems and many different models are currently available. Inverters are an important part of any solar installation, they are the brain of the system. Although the inverter's main job is to convert the DC power produced by the solar array into usable AC power. The inverter will only function when the grid is present and is working within a specific voltage and frequency range. There are two broad classes of inverters: central inverters and string inverters [23].

### 2.9.2.1 String inverter:

String inverters are used in small systems ranging from 1kWp to 11kWp. String inverters will all have one maximum power point tracker (MPPT) and the DC input voltages could vary from the extra-low voltage (ELV) right up 1000 volts DC. String inverters can be connected in a variety of ways [24].

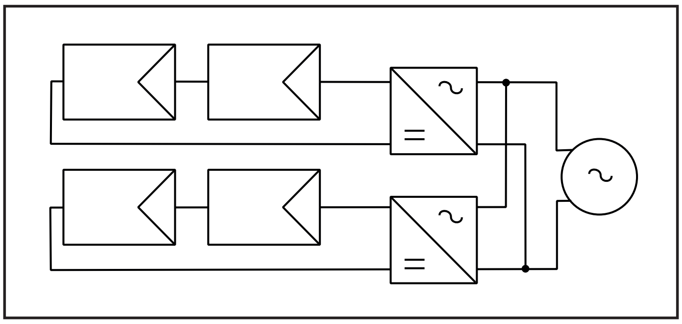


Figure 2.14 String inverter configuration [24]

### 2.9.2.2 Central inverter:

A central inverter is very similar to the string inverter with multiple strings – the difference is that central inverters are generally used for a large system greater than 10kWp. In these systems the array could be divided into a number of subarrays, each comprising a number of strings [24].

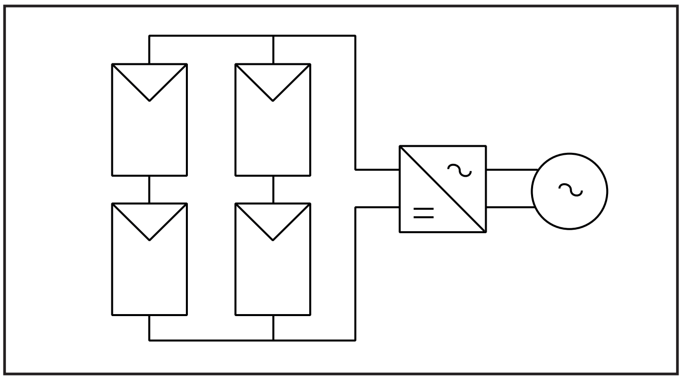



Figure 2.15 Central inverter configuration [24]

### 2.9.3 Balance of system equipment:

In addition to the PV array and inverter, a system requires a variety of other components in order to function. These are known collectively as the balance of system equipment (BOS). The BOS equipment is composed of the components required to connect and protect the PV array and the inverter. This equipment includes cabling, disconnects/Isolators, protection devices, and monitoring equipment [23].

### 2.9.4 Net metering:

A net meter is a device that is used to monitor the inflow and outflow of electricity between the electrical power generating system to the electric utility grid. In photovoltaic systems, if excess energy is generated, it can be sold to the utility [23].

### 2.9.5 Electrical Grid:

It is an electrical power network interconnecting the load centers and energy providers. It is one of the major parts of the electrical power system network acting as an interface between power generation plants, power transmission lines, and distribution lines. It transmits electric power that is generated using any source (renewable or non-renewable) at any place and distributes finally to the consumers [23].

## 2.10 Scenarios for the grid-connected PV system:

It is a matter of fact that the grid interruption periods are time-wise irregular, depending on the situation of the required electricity  chosen by the PV user. We have the following two scenarios [23]:

### 2.10.1 First scenario:

Sufficient energy is being generated by the PV system. Covering the load demand by PV energy will have the priority over using the grid if it is available. Excess PV power if available, will be injected into the grid.

### 2.10.2 Second scenario:

The generated PV power is not sufficient to supply the load. The priority here is to use grid power if it is available.

## 2.11 Grid connected PV system losses:

The discussion about PV system loss is essential to design a PV system and evaluate its technical performance. The actual energy production with a realistic system loss analysis helps to make an accurate technical and economic assessment of a PV system. Different types of PV system losses are discussed below:

### 2.11.1 Soiling loss:

Soiling loss due to seasonal impact or dust on the PV module surface reduces the nominal solar radiation on the system's array, it depends on system location, weather conditions, dust material, size, and the density of dust particles in the environment. The monthly average module efficiency can degrade from 7% to 15% in dry areas. The yearly average value of daily irradiation loss for accumulated dust on a module surface is 4.4%. This loss increases more than 20% during summer and reduces rainfall. The irradiation loss arises from the difference between direct and diffuse beam angle, which is called the irradiance angle; large values lead to increased loss. The main solution is to clean the module with water and to have a proper evaluation of weather data before system implementation [25].

### 2.11.2 Shading loss:

The energy loss of external shading arises from large obstacles, chimneys, trees around the arrays, and cloud shading. On the other hand, internal shading is initiated from one array to another at the large outdoor solar systems. Around 5% -25% annual energy loss is the result of shading loss depending on the site location and weather conditions. Shading on a single module in a string reduces the current output, changes the operating point of all modules and reduces the output power [26].

### 2.11.3 Module loss:

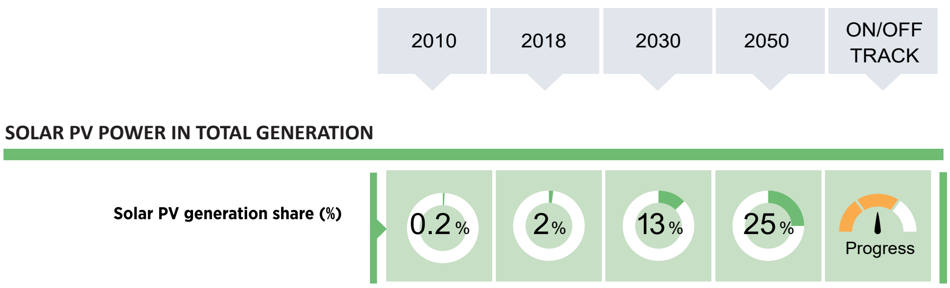
Multiple modules are connected in the array and the current mismatch occurs when each module's performance varies from others. However, string connected modules are also affected by shading which causes module losses. This loss is measured with a comparison of string I-V characteristics and module manufacturer data. The standard module loss is around 2% of total DC energy production [27].

### 2.11.4 DC and AC wiring loss:

DC losses are incurred from system components such as diodes and connectors, DC wiring and any power optimizer at the system's DC side. AC wiring loss is found at the system's AC side. Annual curtailment for maintenance also reduces the system output power. The outdoor temperature increases the wiring loss for internal resistance [28].

## 2.12 PV market:

The evolution of the solar PV industry so far has been remarkable, with several milestones achieved in recent years in terms of installations, cost reductions, and technological advancements, as well as the establishment of key solar energy associations. Solar power will clearly continue to be an essential renewable option in the coming decades.



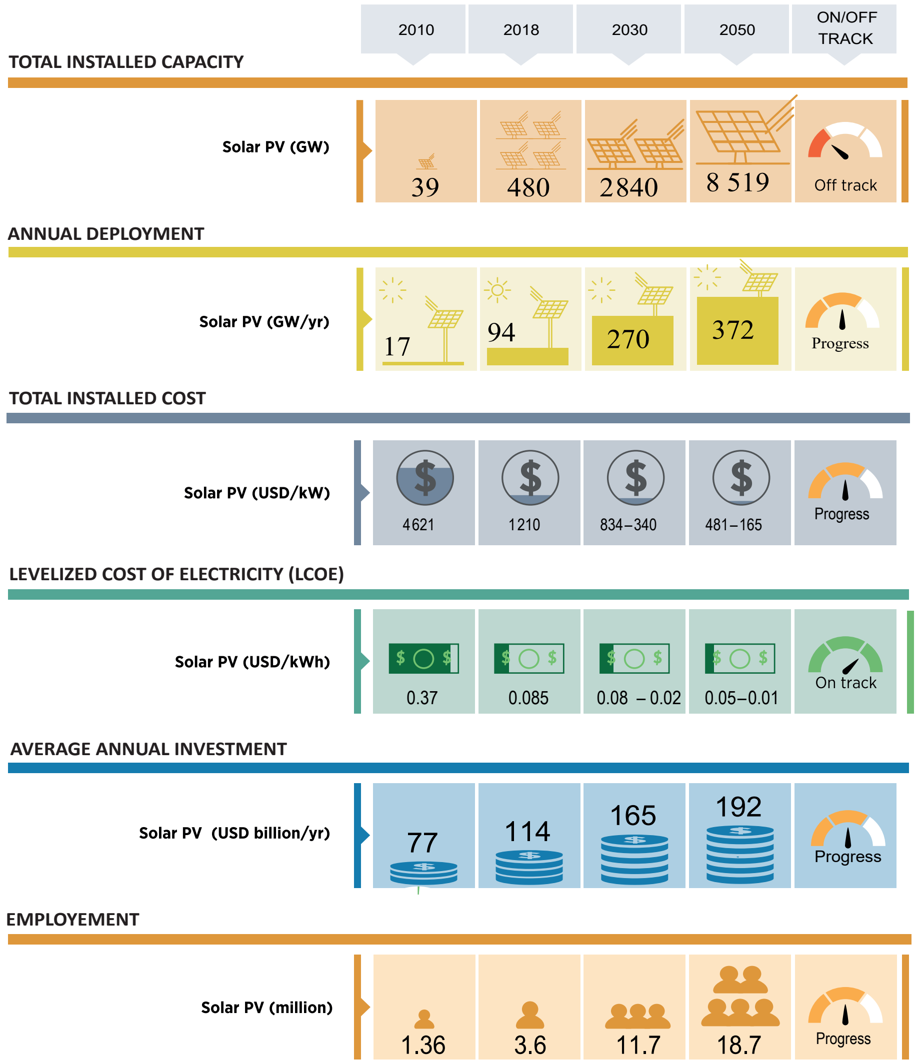



Figure 2.16 Status and future of solar photovoltaics (PV) [29]

## 2.12.1 African PV market:

Despite the growth of the market to around 1.2 GW in 2018, the share of the PV market in Africa remains relatively small compared to other regions of the world. The total solar PV installed capacity at the end of 2018 in Africa reached 5110 MW. This represents 0.7% of the world solar PV capacity. One of the main reasons for this delay is the difficulty for many countries to attract the needed private investments, together with political uncertainty and several cases instability. The first installations were often linked to rural electrification programs. Off-grid hybrid PV and diesel back-up systems also quickly made their way to Africa, especially in remote areas. Although most of the African countries already had some level of installations in 2010, the PV market really took off in 2014 with the first tender in South-Africa and other countries in the following years. Nowadays, solar PV is present under multiple forms in Africa, from a rooftop to utility-scale, but also for some various applications such as street lighting, water pumping, powering hospitals. The medium-scale installation of ground-mounted PVsystem is probably the least represented of the segments [30].

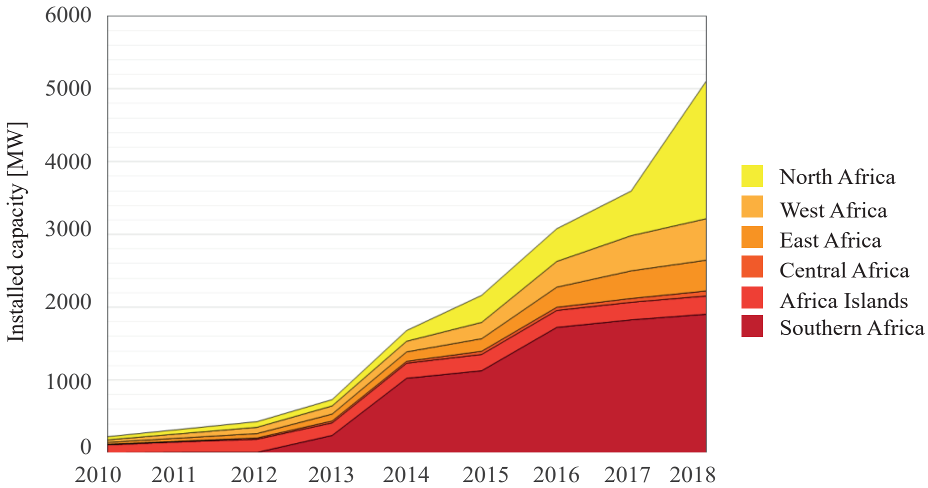



Figure 2.17 Evolution of installed PV capacity per region in Africa [30]

## 2.12.2 Algerian PV market:

With the Sahara Desert representing 75% of its territory, Algeria has the highest solar potential in the region and one of the highest in the world. Measurements of solar radiation reported an average annual global solar radiation of 6.6 kWh/m².

In 2010, Algeria installed one of the world's first hybrid power stations, which combines 25 MW of CSP with a 130 MW combined cycle gas turbine plant. The development of solar PV consistently took off with the increased FiT in 2015, when 48 MW were installed, followed by 180 MW in 2016 and 181 MW in 2017. In 2018, 119 MW were installed, for a total PV installed capacity of 519 MW. A governmental program ended in 2010 which provided solar electricity for 302,795 isolated and off-grid households in the south of the country.

Algeria has several features that favors the development of PV systems. There is a well-developed local PV panel industry, which is still growing, the desert offers plenty of opportunities and the country shares some interconnections with Morocco (1400 MW) and Tunisia (900 MW). In order to enable the growth of distributed PV, the nation should reduce subsidies on conventional electricity retail prices. Over the next five years, there is potential for up to 4.8 GW of PV installation if the country wants to achieve its target [31].

**Total PV installed capacity**
**Top 10 of the African countries**

| | |
|---|---|
| South Africa | 1,815 MW |
| Egypt | 660 MW |
| Morocco | 606 MW |
| Algeria | 519 MW |
| La Réunion | 190 MW |
| Senegal | 134 MW |
| Kenya | 93 MW |
| Mauritania | 86 MW |
| Namibia | 79 MW |
| Ghana | 64 MW |

Figure 2.18 Total PV installed capacity - Top 10 in Africa [31]

## 2.13 Conclusion:

This chapter gave a little introduction to the theme of solar energy. Afterward an overview of how the solar energy production works explained the solar cell and photovoltaic modules parameters and characteristics. Then the I-V curve, Power curve, and maximum power point (MPP) are introduced with the impacts of various factors that may change these indicators. Following this, the photovoltaic (PV) system is introduced presenting the characteristics of the two main types of PV system, stand-alone and grid-connected PV systems. Ending this chapter, we had an overview of the photovoltaic market in Africa including Algeria.

# CHAPTER III: PHOTOVOLTAIC SYSTEM SIZING

# 3.1 Introduction:

PV systems are the one of the major sources of electricity in power systems. Solar resources are being developed by scientists with better technology to maximize as much as possible energy production. The grid-connected PV system that provides electricity straight to the power grid is one of the leading models of this technology. The system developer is accountable for choosing the various parameters: PV modules amount and type, the inverter type and the setup area distribution of the parts. The values of the design parameters are however, indirectly proportional and are a major challenge.

The design of grid-connected photovoltaic system has a significant impact on the overall process of power generation. This chapter demonstrates complete modeling and simulation of a grid-connected and fixed photovoltaic system in the Algerian Petroleum Institute, Boumerdes. The PVsyst software package was used in the simulation part.

# 3.2 Needed data:

To ensure acceptable operation at minimum cost, it is necessary to determine the correct size of the PV system and the appropriate surface needed by taking into account meteorological data, solar radiation, and the exact load profile of consumers over long periods. These factors are discussed in the following sections.

## 3.2.1 Location:

The grid connected PV system study was established on the rooftop of the Algerian Petroleum Institute commonly known as "IAP" Boumerdes, Algeria. GPS coordinates: 36° 45' 29.088" N, 3° 28' 16.176", Latitude: 36.7597°, Longitude: 3.4707°, Altitude: 56m. Figure 2.1 shows a Google Earth™ image of the selected site, the proposed area available for the institute buildings is approximately 8000 $m^2$. Analysing the characteristics of our site location is a crucial component of developing a viable solar PV project regarding its impact on the system performance providing the needed site surfaces and meteorological data, economic, environmental, social aspects, and future infrastructures.


Figure 3.1 Google Earth™ image of the IAP Boumerdes Algeria

### 3.2.2 Load data:

At the beginning, the electrical consumption over the year 2019 have been taken from the paid Institute's electricity bills. As the system is Grid-connected AC system with no battery back-up, we needed to target only the off-peak period (9.00PM to 5.00PM) consumption indicated in kWh that includes the day's sun shining hours. Figure 3.2 shows the off-peak consumption data of year 2019. As noticed, August manifests the largest electricity consumption with 52085 kWh and a monthly energy tariff of 1.8064 DA/ kWh. To obtain a workable and reasonable estimation of the amount of electricity consumption in the building that should be very close to actual consumption, we proposed to work our feasibility study with the average energy consumption, in other words, 33914.6 kWh will be the data used in calculating our PV system size.

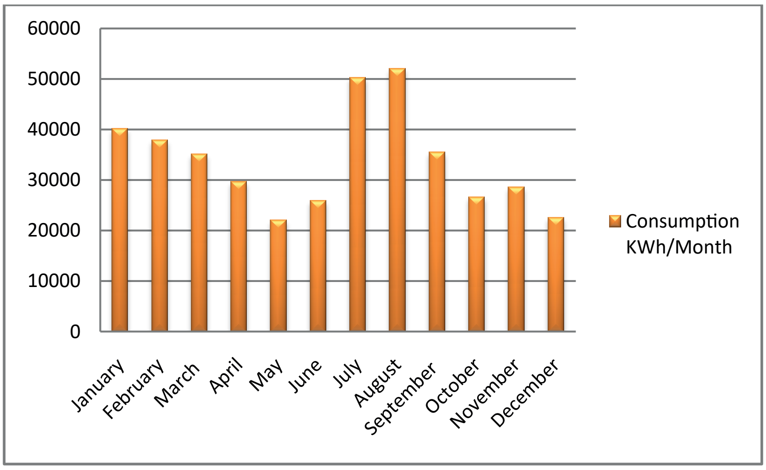



Figure 3.2 Off-peak monthly consumption data of year 2019

### 3.2.3 Climate information:

Solar radiation data is the key point for the planning and sizing of the PV system. Which is extracted through the calculation of the amount of solar radiation for each square meter per day in the selected area. Daily data of solar global irradiance and ambient temperatures are available in Figure 3.3 according to NASA satellite data of our site location « IAP Boumerdes » resulting in a yearly average solar global irradiance and ambient temperature of 4.78 kWh/m².day and 17.8C° respectively, which will be used in the calculation of our PV system orientation parameters.

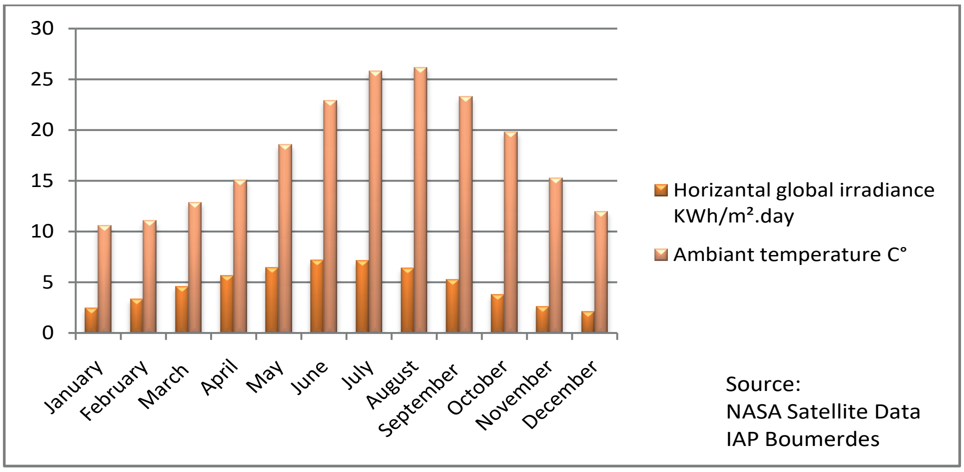



Figure 3.3 NASA satellite data IAP Boumerdes (horizantal global irradiance kWh/m$^2$.day and ambiant temperature)

# 3.3. System sizing methodology:

## 3.3.1 System orientation:

The position of a solar module is fixed and referred to as its orientation. This orientation of the solar array is very important as it affects the amount of sunlight hitting the array and hence the amount of power produced. The orientation generally includes the direction that the solar module is facing which is the south, and the tilt angle, thus it is important for this study to determine the characteristics of our PV system orientation including the optimum tilt angle and the radiation on the tilt surfaces.

### 3.3.1.1 The optimum tilt angle:

-Tilt angle (β) is the angle between the fixed panels and the horizontal plane [32], tilting the system at optimum angle allows considerable energy gains in the system and it is related to the latitude of the system location Ø and the sun declination angle δ by the following equation:

$$\beta = \text{Ø} - \delta \tag{8}$$

- The latitude angle (Ø) : is the angle forming according to the equator center [32]. In our system location it is 36.7597°.
- The declination angle (δ): is the angle between the sun lights and the equator plane [32]. It is computed by the following equation:

$$\delta = 23.45\times\sin\left(360\times\frac{(284+n)}{365}\right) \tag{9}$$

Where n represents the day of the year.

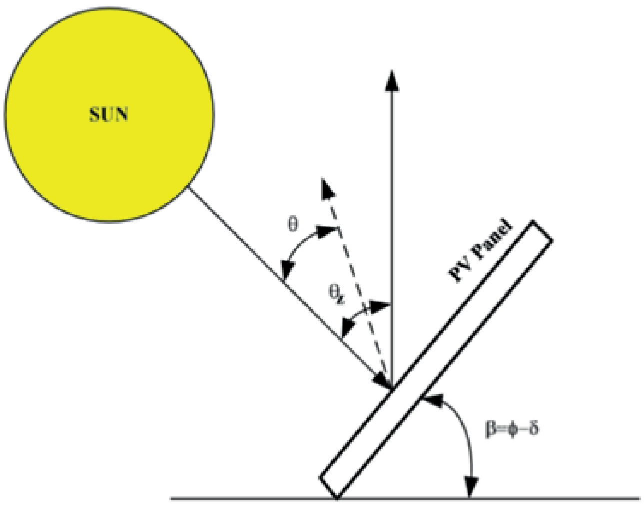



Figure 3.4 Tilt angle of system orientation [32]

Using equations (8) and (9) and according to the site data the tilt angle is found to be around 37°, calculation results are shown in Table 3.1.

| Months | Day numbers "n" | Declination angle δ (°) | Tilt angle β (°) |
|---|---|---|---|
| 1st January | 1 | -23 | 59.7597 |
| 1st February | 32 | -17.52 | 54.2797 |
| 1st March | 60 | -8.29 | 45.0497 |
| 1st April | 91 | 4.02 | 32.7397 |
| 1st May | 121 | 14.9 | 21.8597 |
| 1st June | 152 | 22.04 | 14.7197 |
| 1st July | 182 | 23.12 | 13.6397 |
| 1st August | 213 | 17.91 | 18.8497 |
| 1st September | 244 | 7.72 | 29.0397 |
| 1st October | 274 | -4.21 | 40.9697 |
| 1st November | 305 | -15.36 | 52.1197 |
| 1st December | 335 | -22.12 | 58.8797 |
| Yearly | | | 36.83 ≈ 37 |

Table 3.1 Calculation results of the optimum tilt angle

### 3.3.1.2 Radiation on the tilt surface:

The amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation which is perpendicular to the module surface. The following figure shows how to calculate the radiation incident on a tilted surface ($S_{module}$) given either the solar radiation measured on the horizontal surface ($S_{horiz}$) or the solar radiation measured perpendicular to the sun ($S_{incident}$) [33].

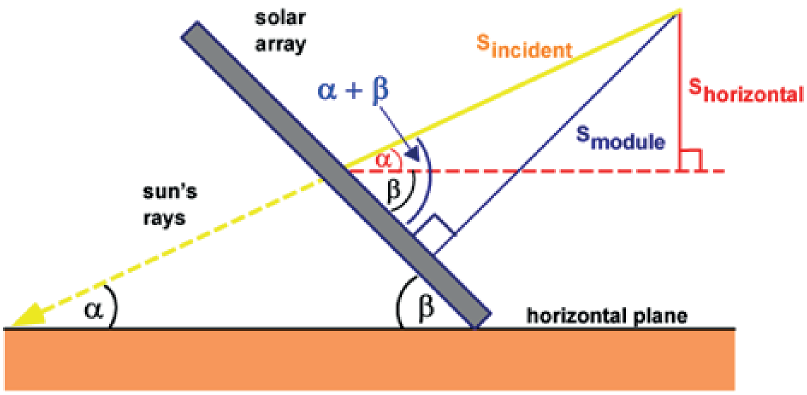



Figure 3.5 Radiation on the tilt surface [33]

The equations relating $S_{module}$, $S_{horiz}$ and $S_{incident}$ are:

$$S_{horiz} = S_{incident} \times \sin\alpha \qquad (10)$$

$$S_{module} = S_{incident} \times \sin(\alpha+\beta) \qquad (11)$$

Where α is the elevation angle and β is the tilt angle of the module measured from the horizontal.

The elevation angle is given as:

$$\alpha = 90 - \beta \qquad (12)$$

From these equations a relationship between $S_{module}$ and $S_{horiz}$ can be determined as:

$$S_{module} = \frac{S_{horiz}}{\sin\alpha} \tag{13}$$

First the annual global irradiation is found 4.78 kWh/m².day that we multiply by 365 days to get the solar radiation on the horizontal surface $S_{horiz}$ :

$$S_{horiz} = 4.78 \times 365$$

$$\boxed{S_{horiz} = 1744.7 \text{ kWh/m}^2}$$

$$S_{module} = \frac{S_{horiz}}{\sin(90-\beta)} = \frac{1744.7}{\sin(90-37)}$$

$$\boxed{S_{module} = 2184.6 \text{ kWh/m}^2}$$

### 3.3.2 System sizing using calculations:

System sizing is the process of evaluating the adequate ratings, sizes and configurations for major components needed to meet the functional requirements and performance objectives of the photovoltaic system. In this design the system is a grid connected solar PV system which consists of a PV panel, inverter, grid and load. This type of system is selected to reduce the cost of the whole system by avoiding battery backup. When the battery backup capacity is excluded, the cost of the whole system decreases by around 40 to 50% [34], depending on the type of batteries used and the capacity required.

#### 3.3.2.1 Plant power calculation:

Sizing the proposed PV system will consider the following stated parameters:

- Annual average solar energy intensity on tilted surface with a tilt angle of 37° in our site location « IAP Boumerdes » is 2184.6 kWh/m²(h/year), which corresponds to average peak sunshine hours $I_d$ = 5.98 h/day.
- From our load data the average monthly consumption is 33914.6 kWh that we divide by the average number of days in the month equal to 30 days to get the daily energy use $E_d$ =1130.5 kWh/day.
- All PV systems have a corresponding derating factor that takes into account the inefficiencies of the overall system, such as soiling of the panels and imperfect electrical connections. According to the National Renewable Energy Laboratory, a typical derate factor is 0.84. For the sake of this calculation, we assume the derate factor to be d = 80%, or 0.8 [35].

$$PV_{capacity} = \frac{Ed}{Id \times d} \tag{14}$$

$$PV_{capacity} = \frac{1130.5}{5.98 \times 0.8}$$

$$\boxed{PV_{capacity} \approx 237 \text{ kW}}$$

A PV generator with a peak power of 237 kW will be selected to secure for continuous power availability during grid outage hours and to compensate for all system electrical losses.

### 3.3.2.2 PV module sizing:

The solar panel is the one of the most important equipment in solar power plants. Solar panel type, supplier number, and configuration selection processes are important decisions that can affect the performance and the structure of the system.

#### 3.3.2.2.1 Module types:

We selected the Polycrystalline modules, due to their greater efficiency and the best performance offered under the influence of temperature and warranty. « STP325 - 24/Vem » will be selected for this system with efficiency up to 16.7%. More details are given in table 3.2:

| | |
|---|---|
| Model | STP325-24/ Vem |
| Manufacturer | SUNTECH China |
| Solar Cell | Polycrystalline silicon |
| No. of Cells | 72 (6 × 12) |
| Dimentions | 1956 × 992 × 40mm |
| Weight | 25.8 kgs |
| Maximum Power at STC (Pmax) | 325 W |
| Optimum Operating Voltage (Vmp) | 31.5V |
| Optimum Operating Current (Imp) | 8.72A |
| Open Circuit Voltage (Voc) | 51.1 V |
| Short Circuit Current (Isc) | 9.26 A |
| Module Efficiency | 16.7% |
| Operating Module Temperature | -40 °C to +85 °C |
| Power Tolerance | 0/+5 W |
| Warranty | 25 years |

Table 3.2 STP325 - 24/Vem Data table

#### 3.3.2.2.2 Number of modules $N_m$:

For a system power capacity $P_{pv}$ of 237 kW and a selected module with a maximum power $P_{module}$ of 325W the number of modules $N_m$ is computed by the following equation [36]:

$$N_m = \frac{P_{pv}}{P_{module}} \tag{15}$$

$$N_m = \frac{363\ kW}{325W}$$

$$\boxed{N_m = 729 \text{ modules}}$$

#### 3.3.2.2.3 Selection of system DC voltage:

The required AC voltage will determine the DC voltage needed from a PV module string. In Algeria power system, a single phase is Vac equal to 220V/phase [36], thus the equivalent DC phase voltage is given by:

$$V_{dc} = \sqrt{2}V_{ac} \tag{16}$$

$$\boxed{V_{dc} = \sqrt{2}\times 220 = 311.13\ V}$$

10% is added to account for the ripples of the specified voltage in the design.

$$V_{dc} = (\sqrt{2}+0.1)V_{ac} \tag{17}$$

$$\boxed{V_{dc} = (\sqrt{2}+0.1)\times 220 = 333.13 \text{ V}}$$

#### 3.3.2.2.4 Number of modules in series $N_s$:

In this design, the system DC-link rated at $V_{dc\text{-}nominal}$ equal to 400V to reduce the output current ripple and regulate the voltage at the DC side of the inverter [36], therefore the number of necessary PV modules in series Ns is obtained by the following equation:

$$N_s = \frac{V_{dc\text{-}nominal}}{V_{mp\text{-}module}} \tag{18}$$

$$N_s = \frac{400}{31.5}$$

$$\boxed{12 < N_s = 12.7 \text{ modules} < 13}$$

Where $V_{mp\text{-}module}$ is the module optimum operating voltage. For the calculations Ns = 13 is the number of modules in series.

#### 3.3.2.2.5 Number of strings in parallel Np:

For the system, the number of modules $N_m$ = 729 and the number of modules in series Ns =13, the number of strings in parallel is computed by the following equation:

$$N_p = \frac{N_m}{N_s} \tag{19}$$

$$N_p = \frac{729}{13}$$

$$\boxed{N_p = 56 \text{ modules}}$$

### 3.3.2.3 Inverter selection:

An inverter is a critical interface component that deploys feed-in function and converts direct current (DC) from the PV array into alternate current (AC) for the system output to be compatible with a local utility grid in terms of voltage and frequency.

Several inverter types are available in the market. However, an appropriate inverter selection depends on three main factors that should be considered, which are its output AC power, the DC-AC conversion efficiency, and the capital cost. For the grid-tied system, the input rating power should be the same as a PV array rating to allow for a safe and efficient operation. For our system inverter, the DC voltage of the system must be in DC voltage range of the selected inverter for a safe operation.

After an intensive research for a proper inverter choice, 70 kW central inverter manufactured by DEYE, seems to be a good candidate, as it has a high efficiency that equal to 98.7%. Several characteristics of this inverter are listed in Table 3.3.

| | |
|---|---|
| Model | SUN-70K-G |
| Manufacturer | DEYE |
| Max recommended PV power | 77 kW |
| Max DC voltage | 1000V |
| Rated MPPT voltage range | 280 – 850 V |
| Max input current | 112A |
| Nominal AC rated power | 70 kW |
| Maximum AC output power | 77 kW |
| Nominal AC line voltage | 400v |
| AC voltage range | 277-460V |
| Ac maximum output current | 106.4A |
| Nominal output frequency | 50Hz |
| Maximum efficiency | 98.7% |
| Number of inverter | 3 |
| Lifetime | 20 years |

Table 3.3 SUN-70K-G characteristics

### 3.3.2.4 Components rating:

In PV systems, the DC cables should be waterproof and be of high temperature rating at least 80C°; and should be installed in such a way to reduce the risk of earth fault or short circuits. The cable should be of the size that will not allow more than 3% of voltage drop between the array and the inverter [37],[38]. In addition, all DC components rating (conductor, disconnector, switches) should have the following voltage and current ratings are:

$$V = V_{oc} \times 1.15 \tag{20}$$

$$I = I_{sc} \times 1.25 \tag{21}$$

$$V = 51.1 \times 1.15 \qquad I = 9.26 \times 1.25$$

$$\boxed{V = 58.765V} \qquad \boxed{I = 11.575A}$$

### 3.3.2.5 Cables sizing:

Wiring is very essential in PV systems, both for safety and effective performance of the PV system. It is necessary that conductors and insulation are rightly sized. If cables are under-sized, it could result in fire hazard and high losses across the cables. There are three major types of cable in PV system: array cable, string cable and AC cable [37],[38]. Voltage and current ratings for the main DC cable are:

$$V = N_S \times V_{oc} \times 1.15 \tag{22}$$

$$I = N_P \times I_{sc} \times 1.25 \tag{23}$$

$$V = 13 \times 51.1 \times 1.15 \qquad I = 56 \times 9.26 \times 1.25$$

$$\boxed{V = 763.945V} \qquad \boxed{I = 648.2A}$$

Voltage and current ratings for the string cable are:

$$V = N_s \times V_{oc} \times 1.15 \quad (24)$$

$$I = (N_p - 1) \times I_{sc} \times 1.25 \quad (25)$$

$$V = 13 \times 51.1 \times 1.15 \qquad I = 55 \times 9.26 \times 1.25$$

$$\boxed{V = 763.945V} \qquad \boxed{I = 636.625A}$$

### 3.3.2.6 Area occupied by the PV modules $S_{array}$:

We compute first the surface area of each PV module with its following parameters Width=1957mm and Length=992m :

$$S_{module} = Length \times Width \quad (26)$$

$$S_{module} = 1956 \times 992 \times 10^{-6}$$

$$\boxed{S_{module} = 1.94\ m^2}$$

For calculating the total area occupied by the PV array $S_{array}$, the following formula is used:

$$S_{array} = S_{module} \times N_s \times N_p \quad (27)$$

$$S_{array} = 1.94 \times 13 \times 56$$

$$\boxed{S_{array} = 1412.32\ m^2}$$

### 3.3.3 Sizing results:

| | |
|---|---|
| **Location** | IAP Boumerdes |
| **Coordinates** | 36° 45' 29.088'' N, 3° 28' 16.176'' |
| **Latitude** | 36.7597° |
| **Longitude** | 3.4707° |
| **Altitude** | 56m |
| **Site available area** | 8000m² |
| **Average load consumption** | 33914.6 kWh |
| **Yearly average solar global irradiance** | 4.78 kWh/m².day |
| **Yearly average ambient temperature** | 17.8C° |
| **Tilt angle** | 37° |
| **Radiation on the tilt surface** | 2184.6 kWh/m² |
| **Plant power** | 1130.5 kWh/day |
| **Pv system capacity** | 237kW |
| **PV module characteristics** | SUNTECH STP325-24/ Vem Polycrystalline silicon 325W |
| **Estimated number of modules** | 729 |
| **Number of modules in series** | 13 |
| **Number of modules in parallel** | 56 |
| **System Inverter** | SUN-70K-G DEYE 70KW |
| **Number of inverters** | 3 |
| **Components ratings** | 58.765V-11.575A |
| **DC cables ratings** | 763.945V-648.2A |
| **Array cables ratings** | 763.945V- 636.625A |
| **Area occupied by the PV modules** | 1412.32m² |

Table 3.4 Sizing result’s table

## 3.4 System sizing using simulation:

For checking the sizing calculation mentioned above, PVsyst software may be used.

### 3.4.1 Introduction to « PVsyst »:

PVsyst is a PC software package for the study, sizing, and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transportation) PV systems, and includes extensive meteo and PV system components database, as well as general solar energy tools. PVsyst software has been selected for its internationally recognized trustworthiness. It is designed and developed in Germany, one of the world’s leading countries in photovoltaic technology and deployment researchers around the world have used it for the sizing and study of photovoltaic system performance. The simulation method used in the program is based on the realization of hourly energy balances throughout a year, by tracking the behavior of the system in order to calculate the appropriate combination for obtaining a system with the maximum amount of energy in function of climatic variables such as global radiation, wind speed, and temperature, taking into account the installed capacity of the photovoltaic system [39].


Figure 3.6 PVsyst interface

## 3.4.2 Simulation results:

### 3.4.2.1 Needed data:

A database associated with the software was used. It contains a variety of parameters and irradiation data collected in numerous parts of the world over the course of a year.

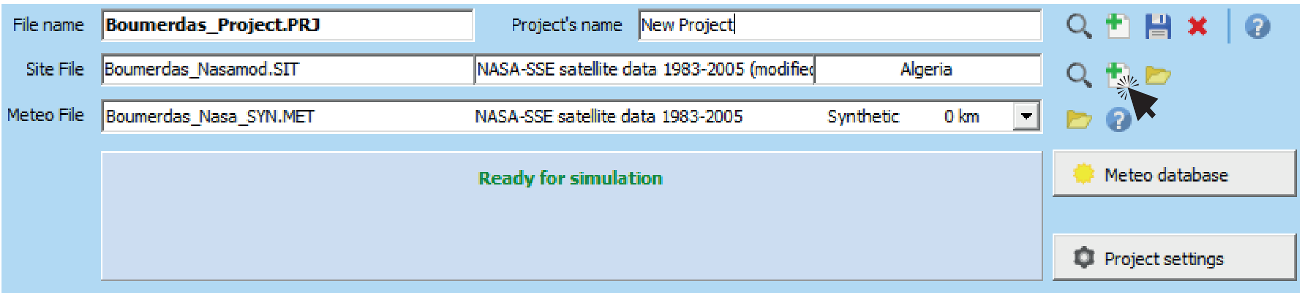



Figure 3.7 Site selection process

#### 3.4.2.1.1 Location:

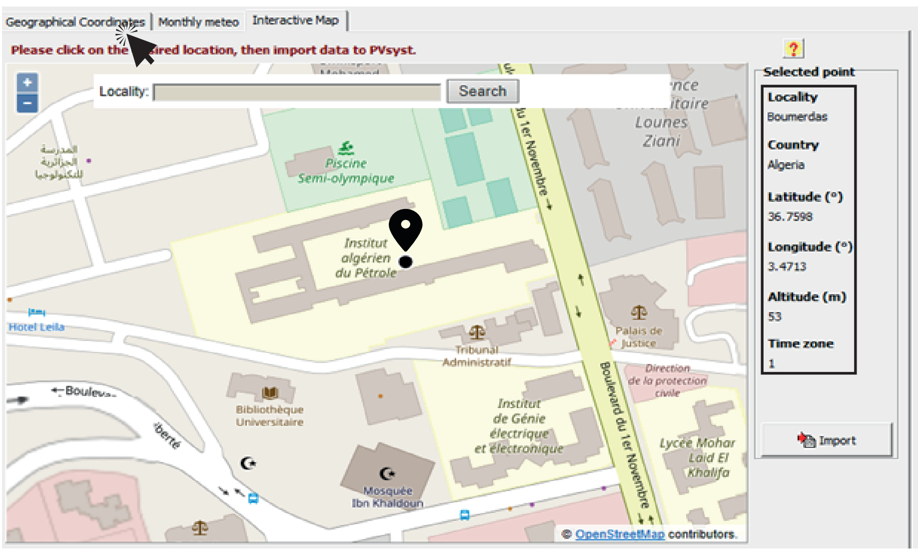
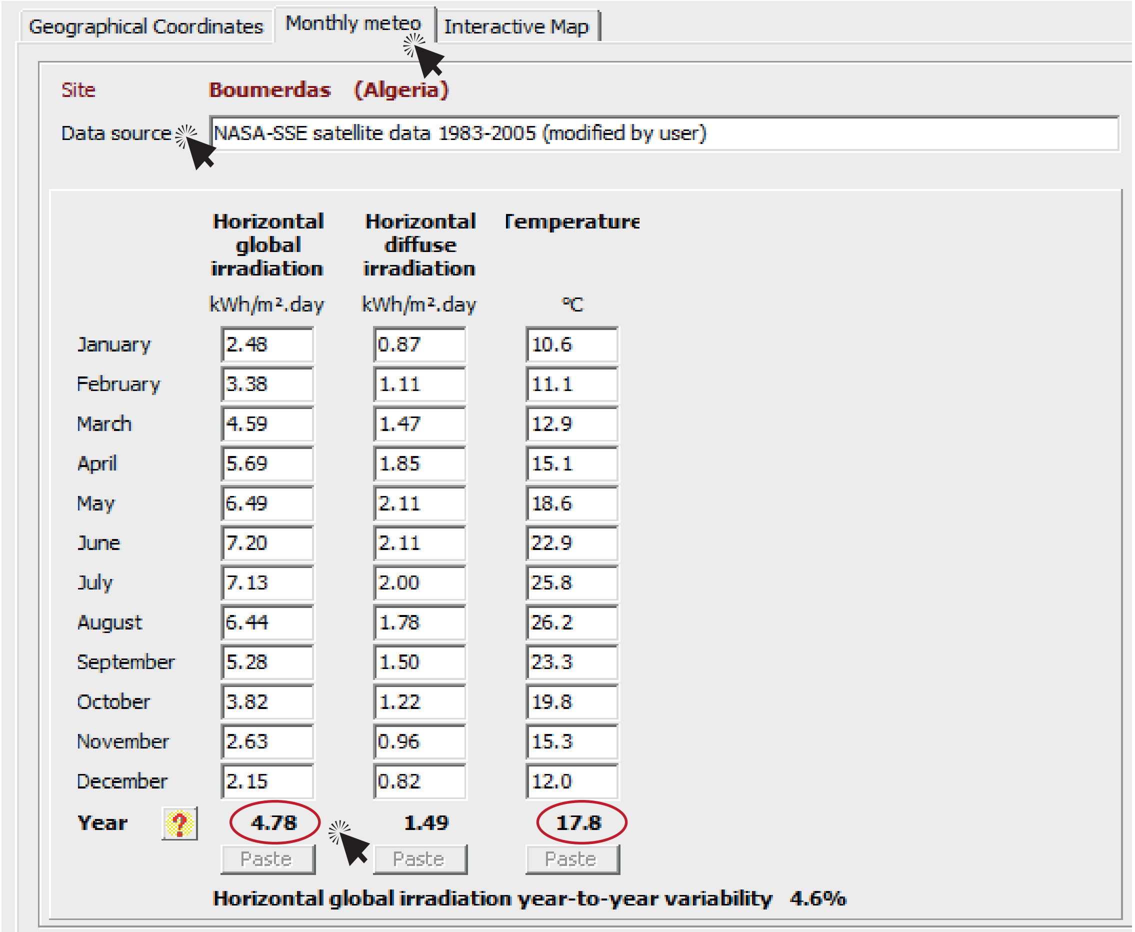



Figure 3.8 Site geographical data

#### 3.4.2.1.2 Climate information:




| | Horizontal global irradiation kWh/m².day | Horizontal diffuse irradiation kWh/m².day | Temperature °C |
|---|---|---|---|
| January | 2.48 | 0.87 | 10.6 |
| February | 3.38 | 1.11 | 11.1 |
| March | 4.59 | 1.47 | 12.9 |
| April | 5.69 | 1.85 | 15.1 |
| May | 6.49 | 2.11 | 18.6 |
| June | 7.20 | 2.11 | 22.9 |
| July | 7.13 | 2.00 | 25.8 |
| August | 6.44 | 1.78 | 26.2 |
| September | 5.28 | 1.50 | 23.3 |
| October | 3.82 | 1.22 | 19.8 |
| November | 2.63 | 0.96 | 15.3 |
| December | 2.15 | 0.82 | 12.0 |
| Year | 4.78 | 1.49 | 17.8 |

Figure 3.9 Site climate data

## 3.4.3 Sizing results:

### 3.4.3.1 System orientation:

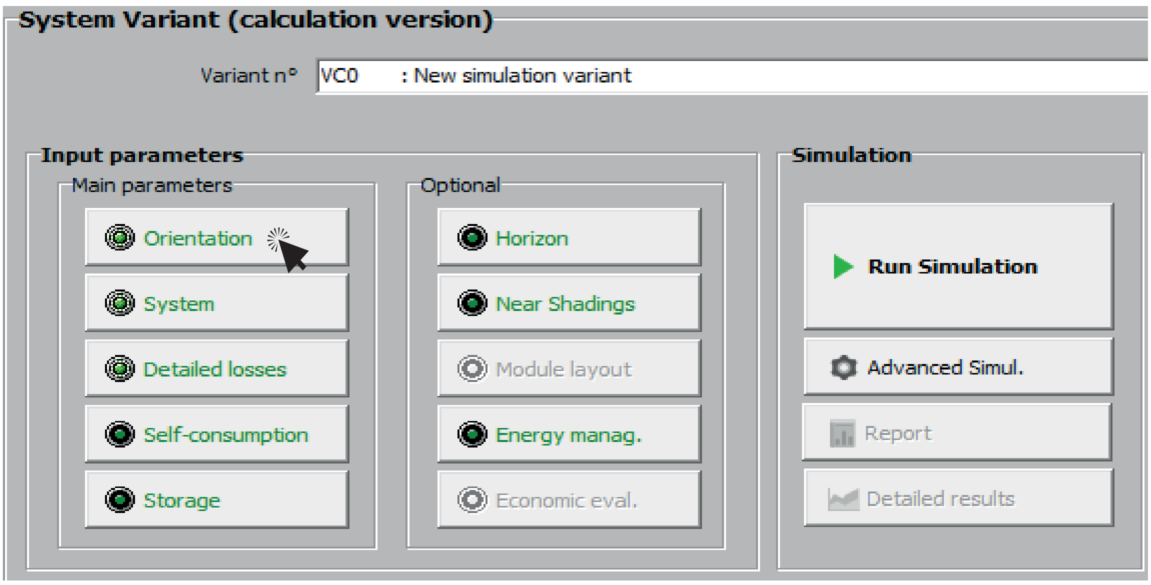



Figure 3.10 System orientation process

### 3.4.3.1.1 The optimum tilt angle:

The tilt angle of the PV array is kept equal to the latitude of the corresponding location to gain maximum solar irradiation. Since the latitude « IAP Boumerdes » is at 36.9°, the modules are oriented south and the solar panels are inclined at an angle of 37° as shown in Figure 3.11.

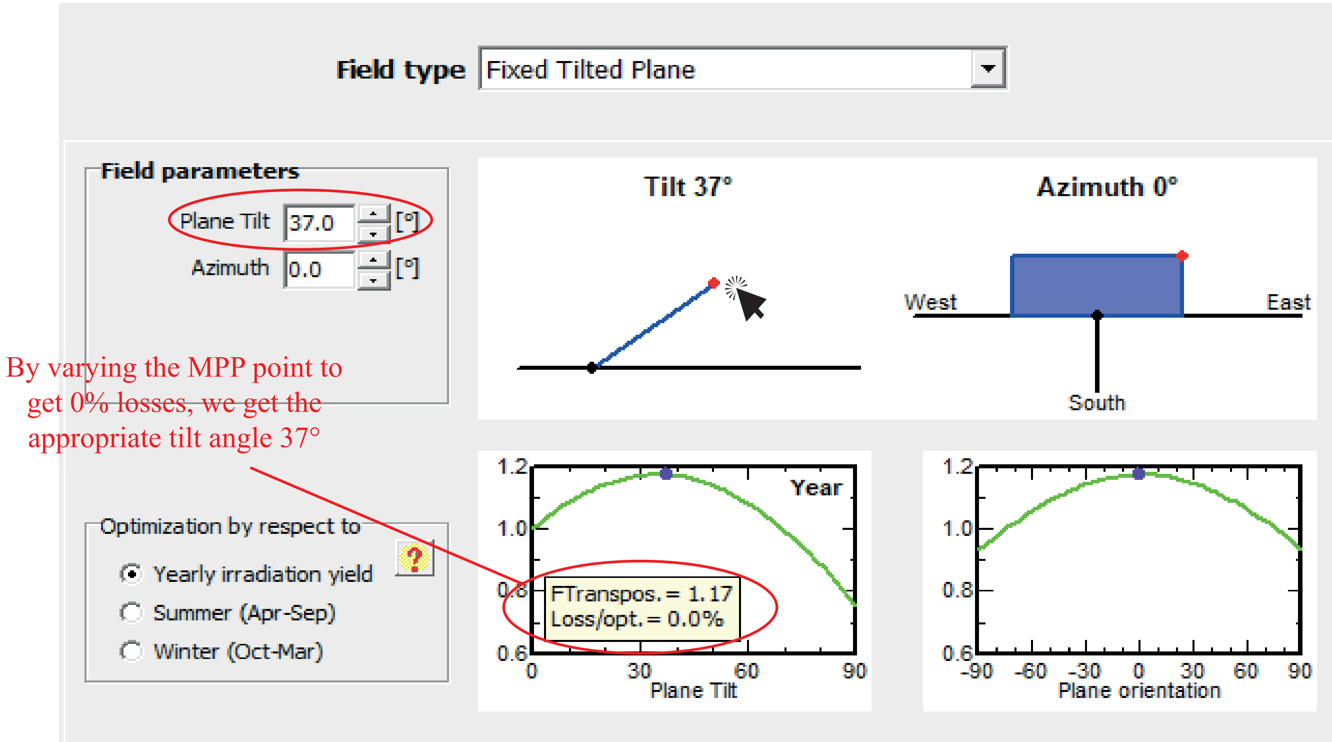



Figure 3.11 System tilt angle settings

### 3.4.3.1.2 Radiation on the tilt surface:

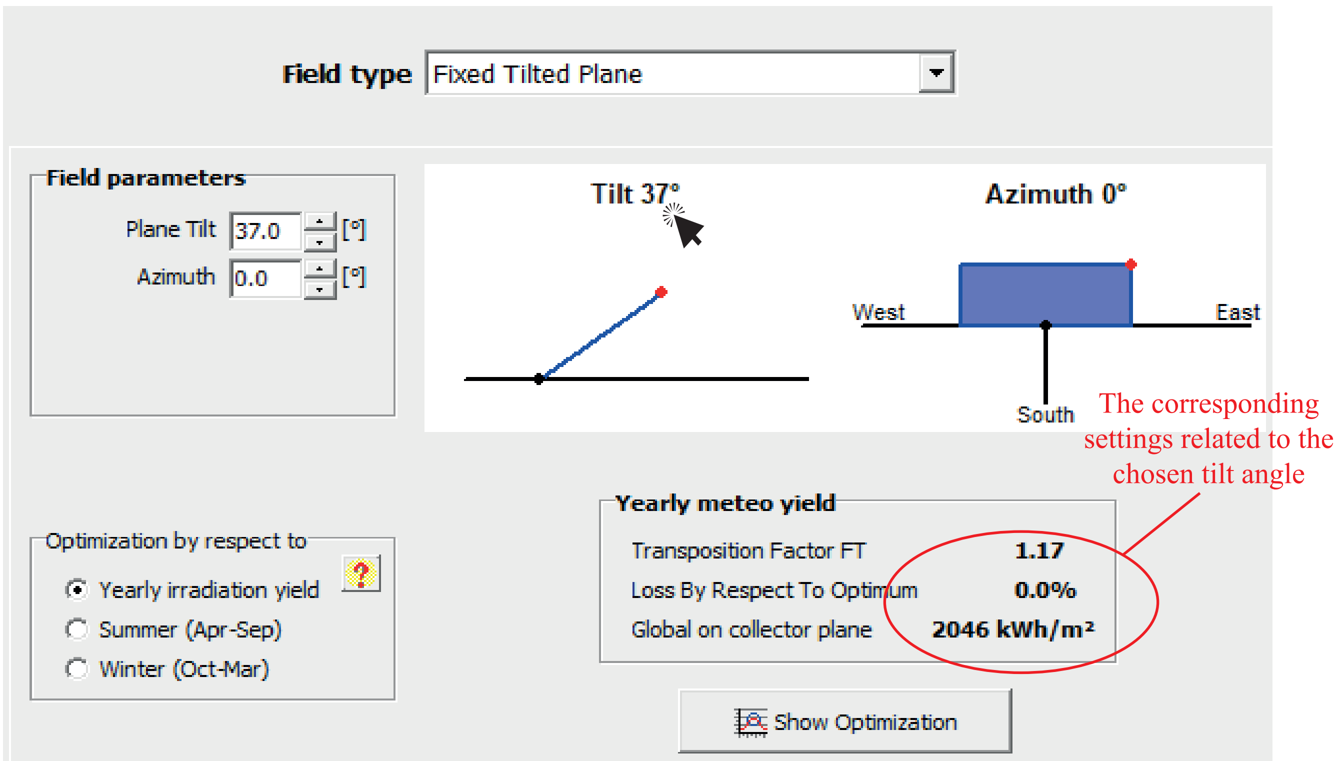



Figure 3.12 System radiation on the tilt surface

### 3.4.3.2 System sizing:

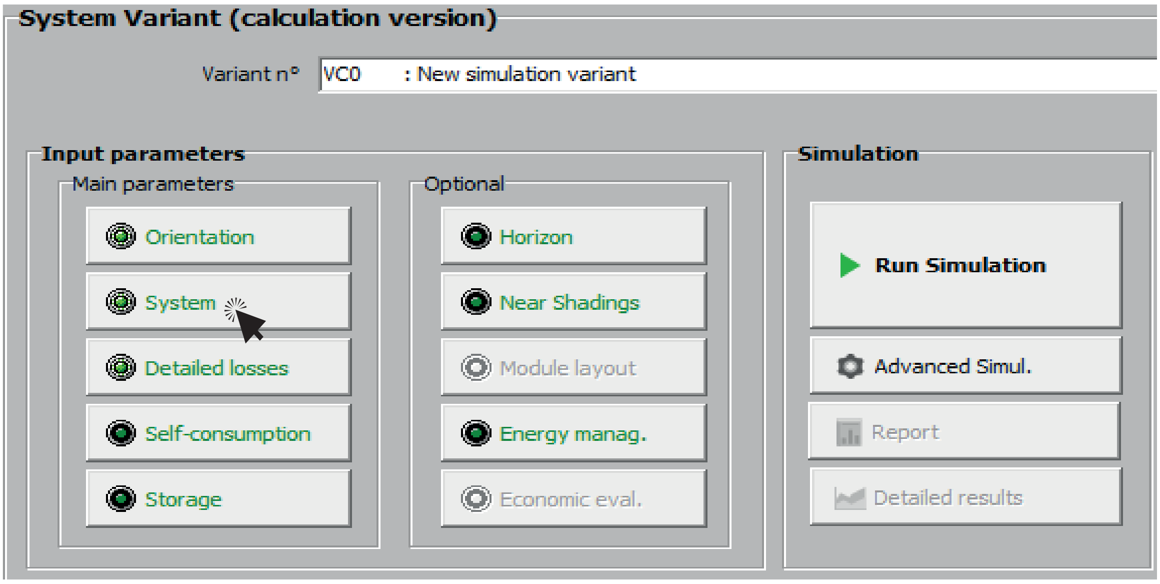



Figure 3.13 System sizing process

#### 3.4.3.2.1 Plant power settings:

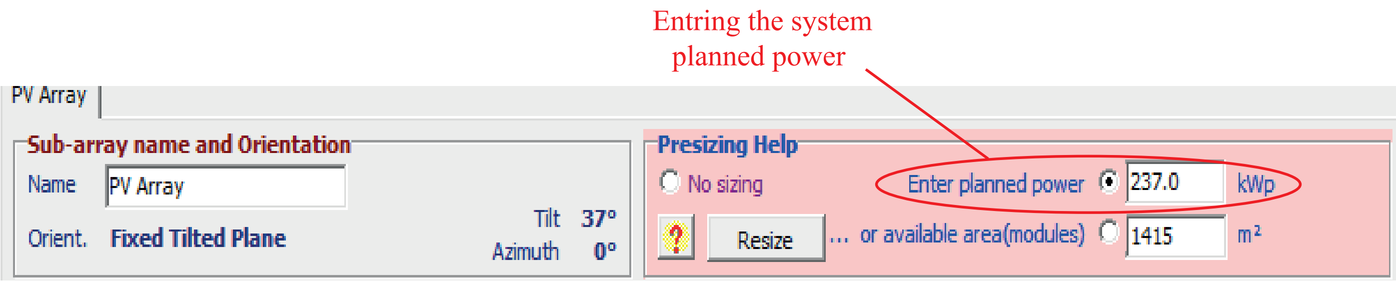



Figure 3.14 PV system power settings

#### 3.4.3.2.2 PV module sizing:

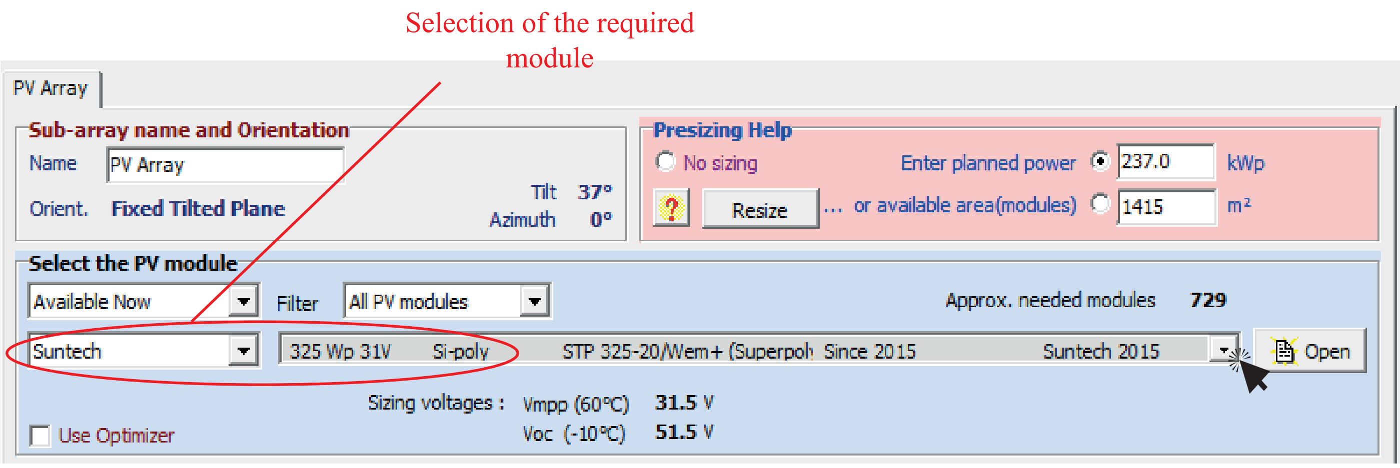



Figure 3.15 Module selection

### 3.4.3.2.3 Inverter selection:

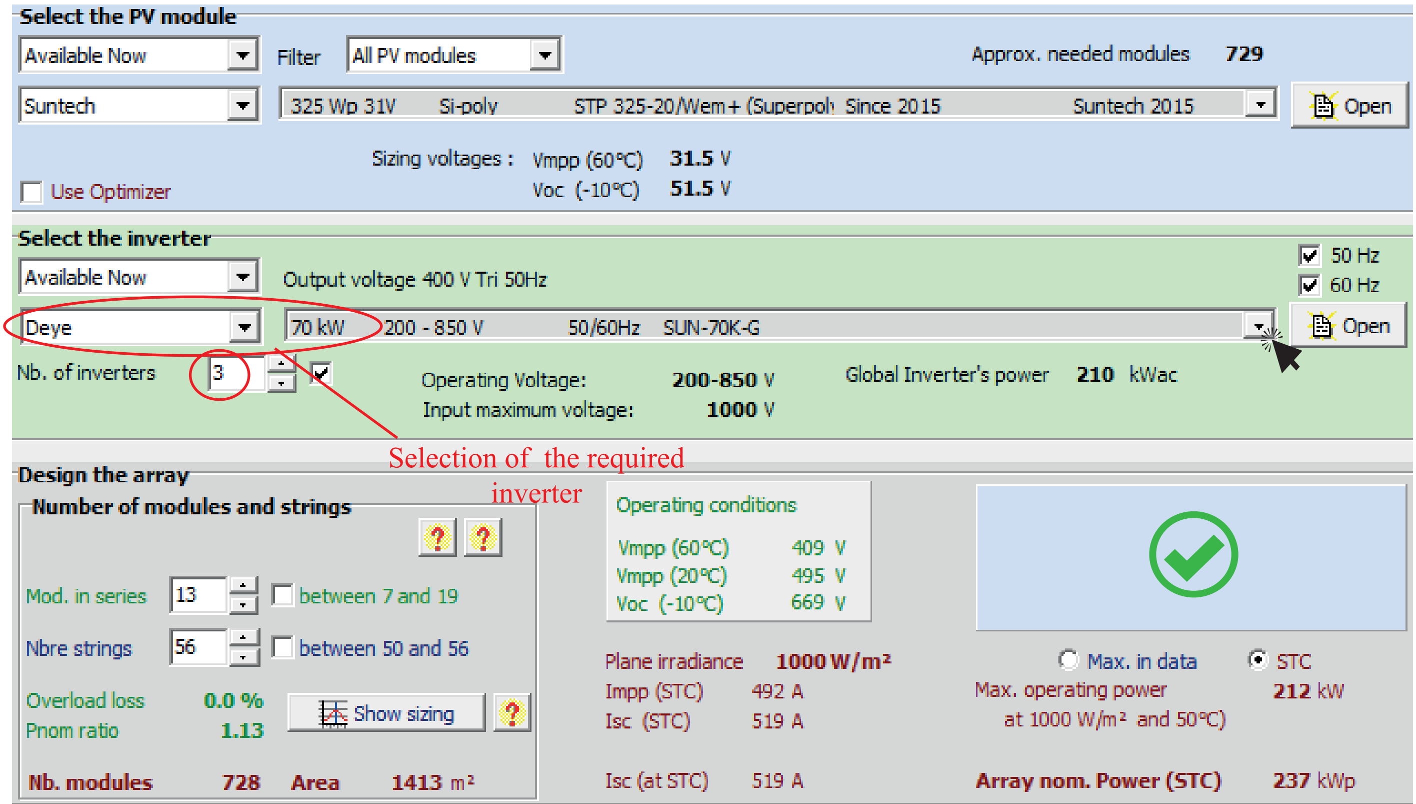



Figure 3.16 Inverter selection

### 3.4.3.2.4 Array configuration:

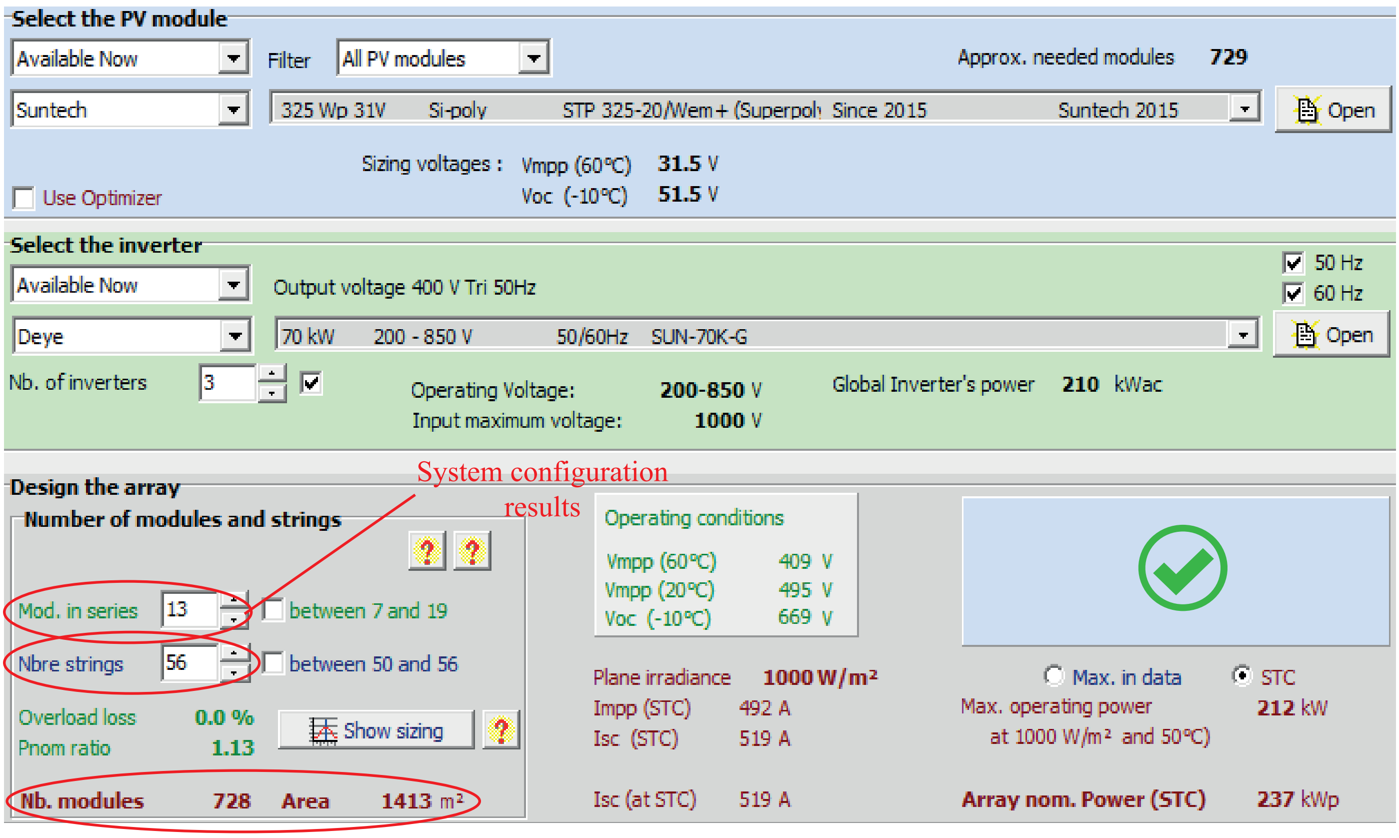



Figure 3.17 Array configuration

## 3.5 Conclusion:

In this chapter a 237 kW photovoltaic grid-connected system located on the site of IAP, was modeled and simulated in PVsyst software to evaluate the different components types and sizes. The results show that the average solar irradiation was achieved at a tilt angle of 37° with a value of 2184.6 kWh/m². Furthermore, the system is composed of 728 poly-crystalline silicon solar modules of 325W and 3 inverters of 70kW. The theoretical sizing calculation results of the system were proved using the simulation in PVsyst software. The economic study of this proposed system will be carried in the next chapter.

# CHAPTER IV: ECONOMICAL ANALYSIS OF PV SYSTEM INSTALLATION

# 4.1 Introduction:

It is well known that the use of photovoltaic systems helps to preserve the environment, produces lower levels of greenhouse gases, and reduces global warming. However, whether it is economically profitable for customers is highly debatable process. For that reason, an economic study of the photovoltaic projects by the PV installer is essential to avoid the risk that may occur from the investment. This chapter discusses the economic analysis of PV installation specifically for the 237 kW grid-connected system installed in IAP Boumerdes. This economic study is conducted based on the Net Present Value (NPV) and the Pay Back Period to determine the profitability and viability of the project using calculation and software simulation using RETscreen software.

# 4.2 Project capital cost:

The capital cost is the initial investment of the PV system including the component cost such as module, inverter, the balance of system (BOS), as well as the engineering and electrical installation costs. The modules are the most expensive items by far, but inverters can still be costly [40]. The economic feasibility of our grid-connected PV systems relies on the project's capital cost, operation and maintenance cost, and running cost. The technology and installation costs were estimated based on the International Renewable Energy Agency IRENA costs database and validated by quotations collected from the Algerian market [41].

## 4.2.1 Module cost:

PV module cost includes the cost of raw material, cell manufacturing, and module assembly. It is the key component of a PV system and around 40% to 60% of total system cost is covered. In recent years, module price has decreased around 80% [42] due to the massive growth and expansion of PV system installation. The cost is varied regarding the technology, module efficiency, and manufacturer market strategy. For the module chosen in this study the « SUNTECH STP325-24/ Vem » polycrystalline silicon 325w with a quantity of 728 modules and a price of 21.8 DZD/Wp from Shenzhen « Topsky Energy CO.,Ltd » company, Guangdong, China; the shipping fees is 2.69 DZD\Wp and the total price is 24.49 DZD/Wp.

## 4.2.2 Inverter cost:

Inverters are the primary power electronic component in a PV system and accounted for 5% to 10% of the total installed cost. Inverter cost depends on the system size; large systems have a lower cost in comparison to the system of less than 100 kW [42]. For the inverter chosen in this project the « Deye SUN-70K-G » central grid inverter 70 kW with a quantity of 3 inverters and a price of 4.76 DZD/W from « Ningbo Deye Inverter Technology Co., Ltd. » Zhejiang, China; the shipping fees of 0.012 DZD/W, the total price is 4.77 DZD/W.

## 4.2.3 Balance of system "BOS":

The BOS installation cost, as the second higher investment cost, accounts for approximately 20% of the total cost and is comprised with the additional components cost [41]. It includes the system mounting, cables, combiner box, site engineering, and grid connection cost to set up a complete system. It depends on the system sizing and installation area. The average BOS cost is 9.8 DZD/W.

### 4.2.4 Installation Cost:

The installation cost of grid-connected solar photovoltaic systems has witnessed a rapid decline in recent years accounting for approximately 18% of the total cost [40]. In this study, the installation cost is 9.06 DZD /W and includes the installation labour, the installer margin, and the engineering cost.

### 4.2.5 Operation and maintenance:

Compared to other power generating technologies, solar PV power plants have low maintenance and servicing requirements. However, proper maintenance of a PV plant is essential to maximize both energy yield and the plant's useful lifetime. Optimal operations must strike a balance between maximizing production and minimizing cost. Solar PV plants encounter costs for successful O&M over their lifetime, the O&M cost for solar PV system mainly comprises regular cleaning of PV modules, monitoring of performance, it is 1.5% of the capital cost [40]. The cost of operation and maintenance in this system is 0.72 DZD/W.

Economic parameters considered in the proposed grid-connected PV system are shown in Table 4.1:

| Items | Price DZD/W(dc) | System size kW(peak) | Total cost (DZD) |
|---|---|---|---|
| **PV module** | 24.49 | 237 | 5 804 130.00 |
| **Inverter** | 4.77 | 70*3 | 1 001 700.00 |
| **Balance of system** | 9.80 | 237 | 2 322 600.00 |
| **Installation** | 9.06 | 237 | 2 147 220.00 |
| **Operation and maintenance** | 0.72 | 237 | 170 640.00 |
| **Capital cost** | | | 11 446 290.00 |

Table 4.1 Cost estimation of the project

## 4.3 Replacement cost:

The only components considered in the design which have to be replaced during the operational lifetime of the PV solar power plant are the inverters. According to inverter's manufacturers, the operational lifetime of central inverters can be 20 years or even more. For the inverter used in this project, the lifetime is a minimum of 20 years. The other components involved in the design of the PV project are assumed to have lifespans above 25 years. In summary, the replacements cost considered in economic calculations are exclusively the ones derived from the cost of the inverters. Sharing the same type of inverter and the number of inverters required, in this project the replacement cost of 1 001 700.00 DZD.

## 4.4 Economic metrics modeling using calculation:

The PV investment return depends on electricity prices and revenue sources. The investment analysis is varied based on the economic metrics which characterize the PV system's economic performance. The financial model analysis period is 25 years according to the lifetime of the photovoltaic modules. The discount rate is a measurement of the future depreciation value of money in the total analysis period. The discount rate is very influential for energy projects as it reflects the detailed economic evaluation and presents the investment risk. The discount in Algeria is 3.5% [43]. The economic parameters which are considered in order to evaluate a PV system are discussed in the section below.

### 4.4.1 Savings from avoided electricity purchases:

The annual electricity bill savings or savings from avoided electricity purchases are used to measure the PV system capacity to reduce the annual electricity bill for end consumers. This annual bill savings or monthly bill savings are normally used to show the PV system cost reduction potential. For this project electricity bill before the photovoltaic system is built, is estimated to be 2 695 591.96 DZD/year, after installing the system the price is 1 674 994.48 DZD/year with net savings of 1 020 597.48 DZD/year.

### 4.4.2 Net present value (NPV):

The Net present value (NPV) is the key economic parameter to evaluate the system investment. It measures the investment profit by calculating the present value of future money by taking the discount rate into account [40]. NPV is calculated by summing up all the cash outflows and inflows of the investment for an analysis period. The cash flow for each year is discounted with a discount rate. The outflows are calculated negative values and inflows are considered positive. The resulting value defines the project's net present value. Positive NPV denotes a profitable investment and negative NPV shows the opposite. The following formula is used to determine the NPV where Cn is the total cash flow in year n, Co is the capital investment, d is the nominal discount rate and N is the project analysis period.

$$NPV = -Co + \sum_{n=1}^{N} \frac{Cn}{(1+d)^{n}} \tag{27}$$

For our project the bill savings of 1 020 597.48 DZD/year during the project analysis period are the cash inflows parameters and are represented as positive values, the capital cost of 11 446 290.00 DZD, the replacement cost of 1 001 700.00 DZD are the cash outflow parameters represented as negative value in Figure 4.1. The parameters needed to compute the Net Present Value NPV are the capital cost, where Co = 11 446 290.00 DZD, the discount rate d= 3.5%, the project analysis period N=25 years and the values of Cn varie yearly according to the Table 4.1.


Figure 4.1 Project cashflows over lifetime

| Year "N" | Discount Rate "d" | Cashflows "CN" | NPVn | Year "N" | Discount Rate "d" | Cashflows "CN" | NPVn |
|---|---|---|---|---|---|---|---|
| 1 | 0.035 | 1 020 597.48 | 986 084.52 | 14 | 0.035 | 1 020 597.48 | 630 506.54 |
| 2 | 0.035 | 1 020 597.48 | 952 738.67 | 15 | 0.035 | 1 020 597.48 | 609 185.06 |
| 3 | 0.035 | 1 020 597.48 | 920 520.45 | 16 | 0.035 | 1 020 597.48 | 588 584.60 |
| 4 | 0.035 | 1 020 597.48 | 889 391.74 | 17 | 0.035 | 1 020 597.48 | 568 680.77 |
| 5 | 0.035 | 1 020 597.48 | 859 315.69 | 18 | 0.035 | 1 020 597.48 | 549 450.02 |
| 6 | 0.035 | 1 020 597.48 | 830 256.71 | 19 | 0.035 | 1 020 597.48 | 530 869.59 |
| 7 | 0.035 | 1 020 597.48 | 802 180.39 | 20 | 0.035 | 18 897.48 | 9 497.23 |
| 8 | 0.035 | 1 020 597.48 | 775 053.52 | 21 | 0.035 | 1 020 597.48 | 495 572.44 |
| 9 | 0.035 | 1 020 597.48 | 748 843.98 | 22 | 0.035 | 1 020 597.48 | 478 813.95 |
| 10 | 0.035 | 1 020 597.48 | 723 520.75 | 23 | 0.035 | 1 020 597.48 | 462 622.18 |
| 11 | 0.035 | 1 020 597.48 | 699 053.87 | 24 | 0.035 | 1 020 597.48 | 446 977.95 |
| 12 | 0.035 | 1 020 597.48 | 675 414.37 | 25 | 0.035 | 1 020 597.48 | 431 862.75 |
| 13 | 0.035 | 1 020 597.48 | 652 574.27 | Capital cost | | | - 11 446 290.00 |
| | | | | Total NPV | | | 4 871 282.01 |

Table 4.2 NPV estimation procedures

Results are positive and indicate the acceptance of the project with a Net Present Value of:

$$\boxed{NPV = 4\ 871\ 282.01\ DZD}$$

## 4.4.3 Payback period (PBP):

The total payback time to return the capital investment is known as payback period, and is an important decision-making indicator for the investment. Usually, shorter payback time is good for the investment. Simple payback and time to net positive cash flow (TNP) are two common methods used to calculate the payback time in PV system. Simple payback period is the time required to return the initial investment cost to net revenues without discounted money [40]. Time to-net-positive-cash-flow (TNP) payback period is a method to calculate the payback time of investment with discounted revenues to exceed the discounted costs. This is highly dependent on the investor’s economic condition, as a longer payback period has a higher risk of money liquidity. The main limitation of payback period is that; it can not measure the system profitability.

$$PBP = \frac{\text{Capital cost}}{\text{Bill savings}} \tag{28}$$

$$PBP = \frac{11\ 446\ 290.00}{1\ 020\ 597.48}$$

$$\boxed{PBP = 11.21\ \text{years}}$$

### 4.4.4 Levelized cost of energy (LCOE):

The Levelized cost of energy (LCOE) is measured from the expected lifetime cost (development, financing, fuel, maintenance, operation, incentives and taxes) and annual energy production [40]. All the cost and benefits are calculated considering inflation and discounted factor to estimate the actual time value of money. This is a valuable metric to compare different generation options to choose the lowest cost of energy production. Although, the initial cost of renewable energy based generation is high, it is compensated by zero fuel cost and low operating cost in comparison with others at the system lifetime. The capital cost is 11 446 290.00 DZD, the peak power is 237 kW and the total energy yield is 1719 kWh/kW, the LCOE can be computed by the following equation:

$$\text{LCOE (DZD/kWh)} = \frac{\text{Total life cycle cost (DZD/W)}}{\text{Total lifetime Energy yield (kWh/W)}} \tag{29}$$

$$\text{LCOE} = \frac{11\ 446\ 290.00}{237000 \times 1.719}$$

$$\boxed{\text{LCOE} = 28.09 \text{ DZD/kWh}}$$

### 4.4.5 Profitability index (PI):

The profitability index is an investment assessment technique which is calculated from the divided value of NPV and the initial investment [40]. This is a modification of the net present value method to evaluate the project. Net present value is an absolute measurement in cash while the profitability index is a relative measurement. It represents the discounted value of return on an investment and the result greater than zero is considered as the profitable investment. To compare several investments with different cost, normalized values are used to rank the relative returns and finalize the selection.

$$\text{PI} = \frac{\text{NPV}}{\text{Capital cost}} \tag{30}$$

$$\text{PI} = \frac{4\ 871\ 282.01}{11\ 446\ 290.00}$$

$$\boxed{\text{PI} = 0.42}$$

# 4.5 Economic Analysis using Simulation:

For checking the economic metrics calculations mentioned above, RETScreen softaware may be used.

## 4.5.1 Introduction to « RETScreen » :

There are several models available for conducting a technical and financial viability analysis of potential energy projects. RETScreen software is a clean energy tool developed by Natural Resources Canada used by professionals, many research centers and universities all over the world, the financial viability of potential renewable energy projects. It accepts input parameters such as project location, loads, renewable energy resources, cost (Initial, annual and periodic) and financial factors (inflation, taxes) [44]. Outputs from these inputs includes annual energy production, fuel savings, electricity export revenue, and financial indicators such as net present value, simple payback. This facilitates an understanding of the viability of the project.

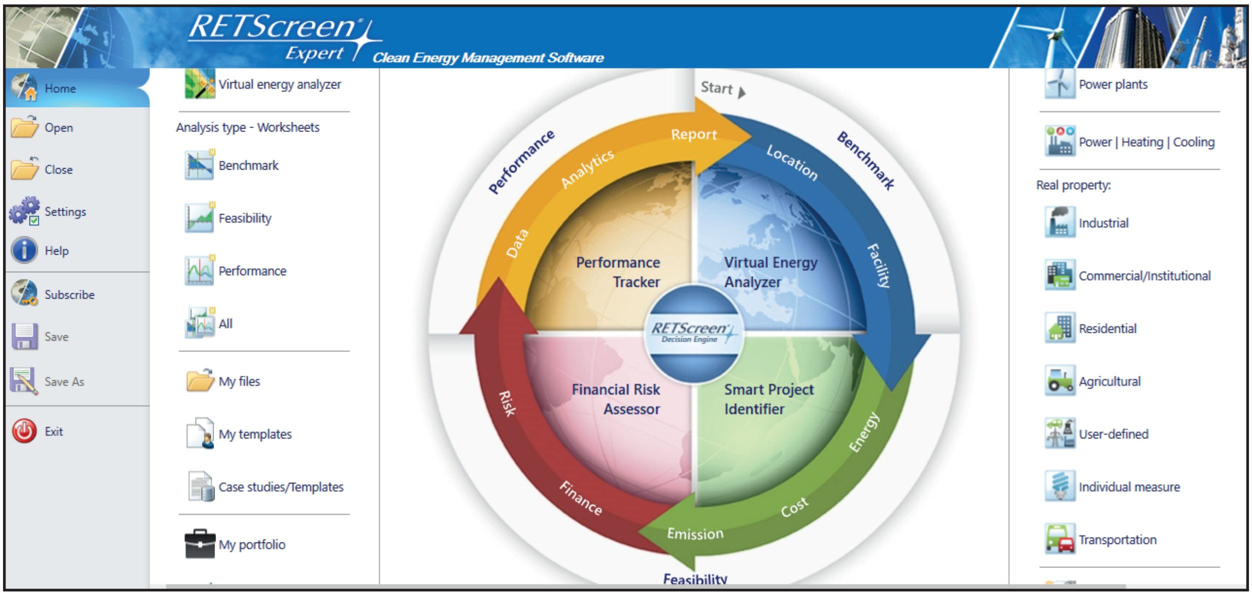



Figure 4.2 RETScreen software interface

## 4.5.2 Simulation results:

The RETScreen software enables us to input various forms of financial data in the financial analysis worksheet of the software, The values used as input variables are standards gotten directly from the software excluding the initial cost, the bill savings, inverter replacement and the operation and maintenance cost that was manually inputted which are automatically calculated to produce key financial feasibility indicators such as simple payback and net present value. Figure 4.3 shows the detailed cost settings for the project.

**RETScreen - Cost Analysis**

| Initial costs (credits) | Unit | Quantity | Unit cost | | Amount | |
|---|---|---|---|---|---|---|
| **Feasibility study** | | | | | | |
| Module | cost | 1 | DZD | 5 804 130 | DZD | 5 804 130 |
| Inverter | cost | 1 | DZD | 1 001 700 | DZD | 1 001 700 |
| Balance of system | cost | 1 | DZD | 2 322 600 | DZD | 2 322 600 |
| Installation | cost | 1 | DZD | 2 147 220 | DZD | 2 147 220 |
| Operation and maintenace | cost | 1 | DZD | 170 640 | DZD | 170 640 |
| Subtotal: | | | | | **DZD** | **11 446 290** |
| **Annual savings** | **Unit** | **Quantity** | **Unit cost** | | **Amount** | |
| Bill savings | cost | 1 | DZD | 1 020 597,48 | DZD | 1 020 597 |
| Subtotal: | | | | | **DZD** | **1 020 597** |
| **Periodic costs (credits)** | **Unit** | **Year** | **Unit cost** | | **Amount** | |
| Inverter Cost | cost | 20 | DZD | 1 001 700 | DZD | 1 001 700 |
| End of project life | cost | | | | DZD | - |
| **Financial parameters** | Discount rate | | % | | | 3,5% |
| **General** | Project life | | yr | | | 25 |

Figure 4.3 Financial parameters settings

The results were carefully analyzed and compared. It can be seen in the figures 4.4 and 4.5 that considering inputted data the simulation confirms our previous calculations using the theoretical analysis.

| Costs \| Savings \| Revenue | | | |
|---|---|---|---|
| **Initial costs** | | | |
| Feasibility study | 100% | DZD | 11 446 290 |
| **Total initial costs** | **100%** | DZD | **11 446 290** |
| **Annual savings and revenue** | | | |
| Bill savings | | DZD | 1 020 597 |
| **Net yearly cash flow - Year 1** | | **DZD** | **1 020 597** |
| **Periodic costs (credits)** | | | |
| Inverter Cost - 20 yrs | | DZD | 1 001 700 |
| Net Present Value (NPV) | | DZD | 4 871 282 |
| Benefit-Cost (B-C) ratio | | | 1,4 |
| Simple payback | | yr | 11,2 |

Figure 4.4 Simulation financial data results

| Yearly cash flows | | |
|---|---|---|
| Year | Pre-tax | Cumulative |
| # | DZD | DZD |
| 0 | -11 446 290 | -11 446 290 |
| 1 | 1 020 597 | -10 425 693 |
| 2 | 1 020 597 | -9 405 095 |
| 3 | 1 020 597 | -8 384 498 |
| 4 | 1 020 597 | -7 363 900 |
| 5 | 1 020 597 | -6 343 303 |
| 6 | 1 020 597 | -5 322 705 |
| 7 | 1 020 597 | -4 302 108 |
| 8 | 1 020 597 | -3 281 510 |
| 9 | 1 020 597 | -2 260 913 |
| 10 | 1 020 597 | -1 240 315 |
| 11 | 1 020 597 | -219 718 |
| 12 | 1 020 597 | 800 880 |
| 13 | 1 020 597 | 1 821 477 |
| 14 | 1 020 597 | 2 842 075 |
| 15 | 1 020 597 | 3 862 672 |
| 16 | 1 020 597 | 4 883 270 |
| 17 | 1 020 597 | 5 903 867 |
| 18 | 1 020 597 | 6 924 465 |
| 19 | 1 020 597 | 7 945 062 |
| 20 | 18 897 | 7 963 960 |
| 21 | 1 020 597 | 8 984 557 |
| 22 | 1 020 597 | 10 005 155 |
| 23 | 1 020 597 | 11 025 752 |
| 24 | 1 020 597 | 12 046 350 |
| 25 | 1 020 597 | 13 066 947 |

Figure 4.5 NPV simulation results

From the cash flow diagram depicted in Figure 4.6 that gives the idea on the breakeven point for the investments made on the project using RETScreen, it can be estimated that it takes around 11 years for cash flow to become positive and that the simple payback period will be 11.2 years. From the financial viability analysis, we get a Net Present Value of 4 871 282.00 DZD. In terms of the project's economics, we can say that the proposed grid-connected system is economic because after 11.2 years the project will start to generate profit and reduce the system's overall costs.

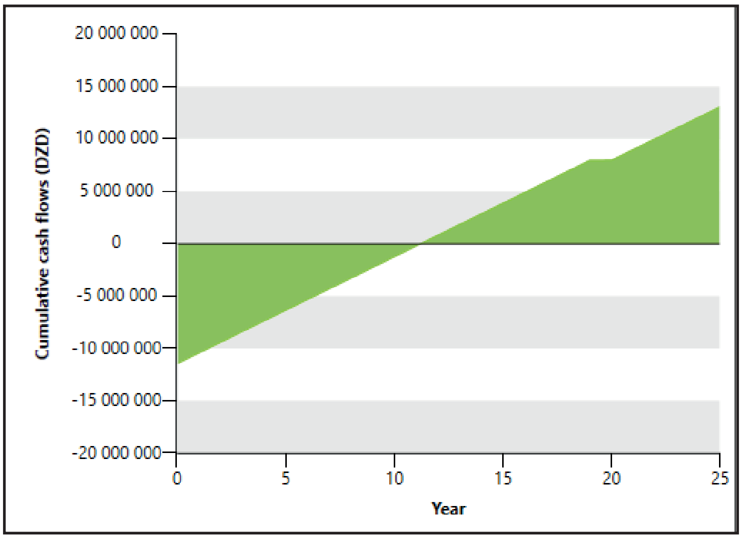



Figure 4.6 Cummulative cashflows (DZD)

# 4.6 Discussion of results:

The economic matrics calculation results of the system were approximately the same as the simulation results obtained using RETScreen software.

The financial analysis is carried out considering the 25 years of project lifetime. At the beginning of the year, the project requires high initial capital of 11 446 290.00 DZD which is contributed mostly by the PV modules. In the following years until the end of project's lifetime, the system gains a revenue of 1 020 597.00DZD per year.

The system cost is a major barrier for the design and installation of PV. However the bill savings analysis revealed that the discounted payback period was decreased to nearly 11 years, while NPV was significantly increased. Hence, it can be inferred that the adoption of the bill savings mechanism brings investors great economic benefit at the same time, it helps in reducing the peak load demand.
LCOE is a good indicator for comparing the cost of PV system energy production in different locations, or with alternative power generation but it is not adequate for measuring financial profitability. For that purpose, the net present value and payback period are measured. Net present value is one of the key concepts that cannot be avoided during grid connected PV system feasibility evaluation. Net present value describes the present worth of future net cashflow over the project’s lifetime.
The estimated net present value of the system over its lifetime is 4 871 282.00 DZD, a positive NPV indicates that the investor is earning money. The simple payback period or the time needed for this system to offset its investment cost is 11.22 years which means that all project cost will be recovered by the first 12 years of the lifetime and the other 13 years it will profit which mean also the project is feasible.

## 4.7 Conclusion:

An economic feasibility study of photovoltaic grid connected system to be installed in IAP, has been presented in this chapter. The analysis used real load data that were estimated based on the International Renewable Energy Agency (IRENA) costs database and validated by quotations collected from Algerian market. RETscreen software was used for the feasibility assessment and determined according to the net present value and the payback time. It is found that the total cost of the PV project will be covered in 12 years only. The estimated net present value of the system over its lifetime is 4 871 282.00 DZD which mean also the project is feasible. The technical analysis of this proposed system will be carried in the next chapter.

# **CHAPTER V:** A FEASIBILITY ANALYSIS FOR INSTALLING A GRID CONNECTED PV SYSTEM IN IAP

# 5.1 Introduction:

The grid-connected solar PV system is designed to operate alongside the utility power grid. However, a techno-economic viability investigation for this system is a substantial process needed to persuade individuals to turn to solar energy. Simulation techniques are commonly used to demonstrate and analyze the performance and feasibility of various components of the PV system before the installation, hence reducing materials and installation costs.

This chapter presents a feasibility analysis that is carried out with the help of PVsyst software to show the technical, economic and environmental analysis and results of the PV system that is expected to demonstrate the advantages and challenges of installing the grid-connected PV system.

# 5.2 Methodology of performance analysis of on-grid PV system:

The International Energy Agency (IEA) photovoltaic power systems program outlines the parameters used to describe energy quantities for PV systems and their components. These parameters include the total energy yield, the yield factor, the performance ratio, and the capacity factor. The performance of a grid-connected PV system is usually examined using the above-selected set of performance indicators, the most important of these indicators are final energy output, final energy yield, and performance ratio. The overall performance of any grid-tied PV system can be evaluated and compared with other systems.

## 5.2.1 Balances and main results:

Balances and main results shown in Table 5.1 includes the variables like global irradiance on horizontal plane, diffuse irradiance on the horizontal plane, ambient average temperature, effective irradiance considering soiling losses. Apart from these variables, DC energy produced by the Si-poly photovoltaic array, energy injected into the grid or to be supplied to AC loads considering the losses in electrical components and performance ratio is also computed. The computed values of each variable mentioned in balances and main results were obtained in terms of monthly and yearly values. For the studied location, annual global irradiance on the horizontal plane is 1744.7 kWh/m², the diffuse irradiance on the horizontal plane is 542.10 kWh/m², the global incident energy on the collector without optical corrections and effective global irradiance after optical losses are 2019.1 kWh/m² and 1965.1 kWh/m² respectively.

### 5.2.1.1 The energy delivered by the array (E-Array):

The energy delivered by the array is the monthly effective energy at the output of the array. The average annual energy produced by this system is 413.21MWh; it varies 25.58 MWh as a lower production in December to 39.78 MWh in July as the most energy productive month.

### 5.2.1.2 The total energy yield (E_Grid):

The total energy yield is the total amount of energy generated by the system and in the case of grid-connected PV systems, the total amount of electricity that is injected into the utility grid or supplied to the load. The result of the simulation shows that, the total energy to be generated by the 237kWp grid-connected solar PV system is estimated at 406.73MWh/year. This is about 79.35% of IAP's annual electricity consumption.

Balances and main results

| | GlobHor kWh/m² | DiffHor kWh/m² | T_Amb °C | GlobInc kWh/m² | GlobEff kWh/m² | EArray MWh | E_Grid MWh | PR |
|---|---|---|---|---|---|---|---|---|
| January | 76.9 | 27.00 | 10.57 | 128.8 | 126.2 | 27.61 | 27.17 | 0.891 |
| February | 94.6 | 31.10 | 11.14 | 141.7 | 138.6 | 30.35 | 29.89 | 0.892 |
| March | 142.3 | 45.60 | 12.92 | 179.3 | 175.0 | 37.65 | 37.06 | 0.873 |
| April | 170.7 | 55.50 | 15.12 | 181.7 | 176.5 | 37.50 | 36.90 | 0.858 |
| May | 201.2 | 65.40 | 18.61 | 188.4 | 182.2 | 38.38 | 37.77 | 0.847 |
| June | 216.0 | 63.30 | 22.91 | 191.7 | 185.2 | 38.22 | 37.61 | 0.829 |
| July | 221.0 | 62.00 | 25.78 | 202.3 | 195.8 | 39.78 | 39.15 | 0.818 |
| August | 199.6 | 55.20 | 26.24 | 204.3 | 198.4 | 39.98 | 39.36 | 0.814 |
| September | 158.4 | 45.00 | 23.31 | 187.4 | 182.8 | 37.14 | 36.57 | 0.825 |
| October | 118.4 | 37.80 | 19.80 | 166.8 | 163.0 | 34.11 | 33.58 | 0.851 |
| November | 78.9 | 28.80 | 15.30 | 128.1 | 125.3 | 26.92 | 26.49 | 0.874 |
| December | 66.7 | 25.40 | 12.02 | 118.7 | 116.1 | 25.58 | 25.18 | 0.896 |
| Year | 1744.7 | 542.10 | 17.85 | 2019.1 | 1965.1 | 413.21 | 406.73 | 0.851 |

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

Table 5.1 Balances and main results of PVsyst report

## 5.2.2 Normalized productions:

Normalized productions such as collection losses, system losses and produced useful energy per installed kWp/day were evaluated from the simulation study; Figure 5.2 shows the normalized productions with the standardized variables for assessing the PV system performance where Lc is the collection losses or the PV array capture losses (0.75 kWh/kWp/day), Ls is the system loss (0.08 kWh/kWp/day), and the Yf is the produced useful energy (4.71 kWh/kWp/day). In comparison, the energy output in November and December (autumn season) and in January and February (winter season) is generally low due to cloudy weather, short sunshine periods and low solar irradiance in winter.

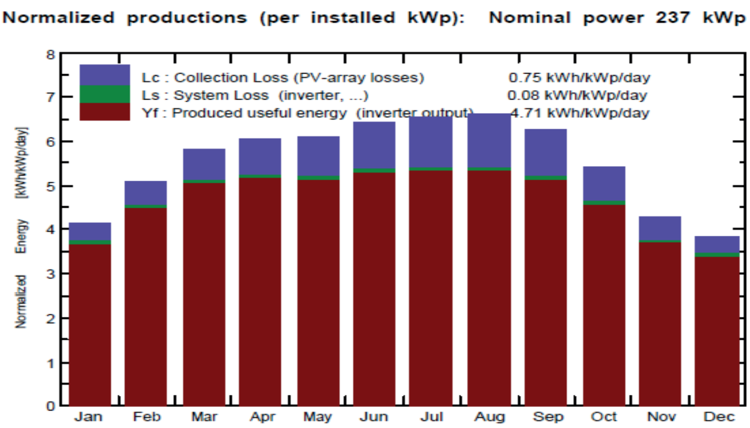



Figure 5.1 Normalized production of PVsyst report

### 5.2.3 Energy injected to grid:

Energy produced by PV array can not be the same as energy injected into the grid or used to supply an AC load. Energy from the PV array is DC which has to be converted into AC energy in order to feed the load. During this, some amount of energy is lost in terms of AC wiring loss. For the designed 237 kWp Si-poly photovoltaic the yearly and daily sum of specific electricity supplied are 1719 kWh/kWp/year and 4.42 kWh/kWp respectively. The detailed information about the AC produced is shown in Figure 5.2.

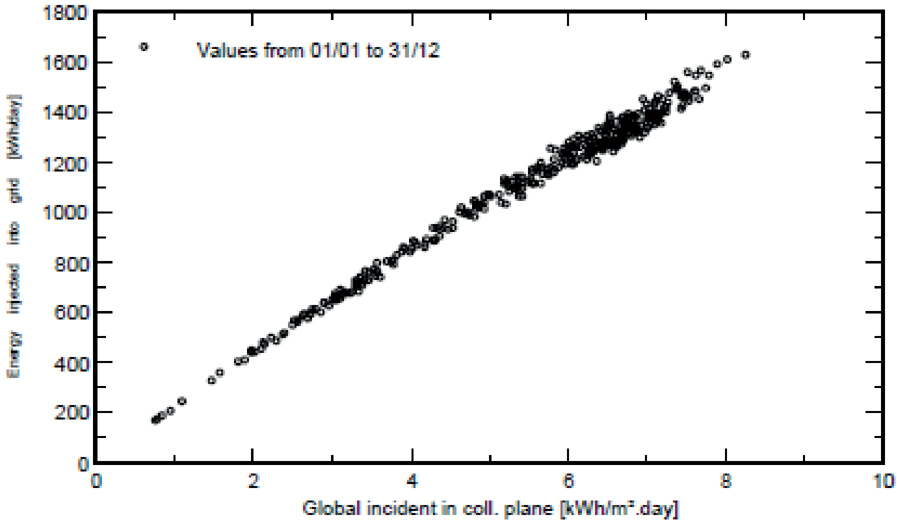



Figure 5.2 Daily output diagram by PVsyst

Assuming annual reduction in the energy yield due to annual degradation of 0.5% in the output of the PV modules. Figure 5.4 shows the annual energy production during the lifetime period.

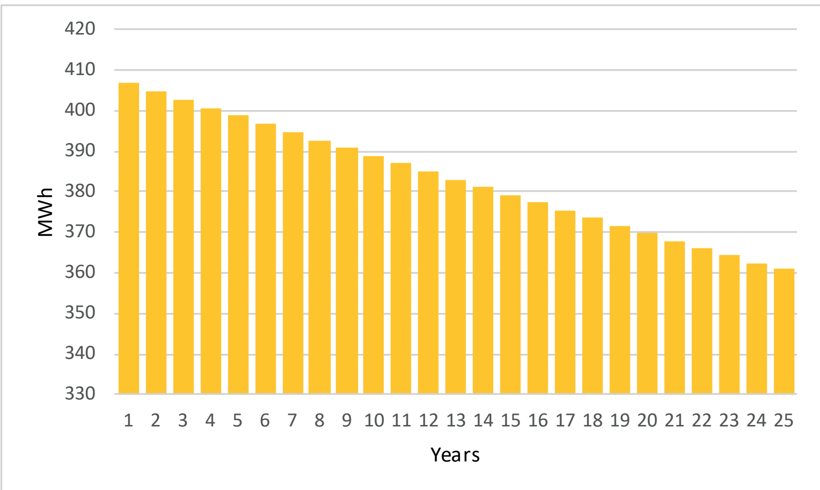



Figure 5.3 Annual energy production during the lifetime period

Figure 5.4 compares the monthly energy production of the proposed solar PV system and the consumption of IAP. Based on this figure, the system is unable to meet the energy demand during few months in winter and summer seasons due to the high demand caused by the excessive use of air conditioners. In the remaining months of the year, excess power generation is fed into the distribution network.

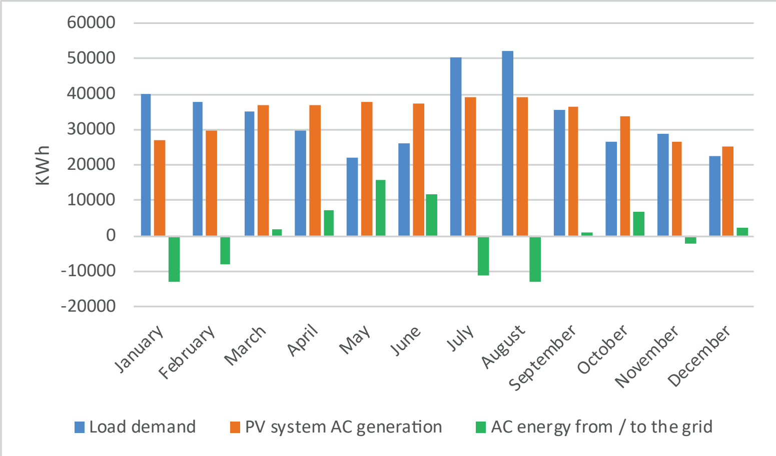



Figure 5.4 Monthly production and load demand.

## 5.2.4 Yield factor (YF):

The yield factor is the ratio of the net AC energy of the system, at standard testing conditions, and the peak power of PV system installed, the net energy can be annualy, monthly or daily evaluated. The yield factor aids the PV array's productivity in some weather scenarios [45]. For this project the yield factor is 1719 kWh/kWp/year. This means that the system needs to operate at its rated power for 1719 hours to provide the generated energy. The comparison of the annual final yield of this system with other systems installed at different locations worldwide shows that IAP PV plant presents a good final yield during the monitoring period with an average of 4.71 kWh/kWp/day.

## 5.2.5 The performance ratio (PR):

The performance ratio is a quality factor that measures the quality of a PV plant. It describes the relationship between the theoretical and actual energy outputs of the PV plant. The PR shows the energy after deduction of energy consumptions and losses. Usually, the Performance ratio is around 80% due to the unavoidable losses during operation. The more the PR is close to 80 %, the more the system will be effective and efficient [46]. Performance ratio (PR) for the simulated 237 kWp Si-poly photovoltaic system is 85.1 %, which is the annual average PR value. There is small variation in PR value on monthly basis, the highest 89.6% PR is recorded in December due to the low module temperature and in August lowest PR is recorded 81.4% due to the high temperature of photovoltaic modules as it can be seen in Figure 5.6 and in the monthly values tabulated in Table 5.1.

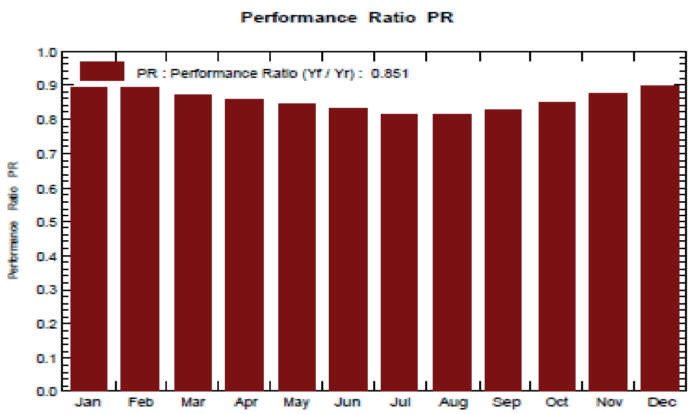



Figure 5.5 Monthly performance Ratio by PVsyst report

### 5.2.6 The capacity factor (CF):

The capacity factor is the actual annual output energy divided by the energy generation of a PV system, this factor is used in assessing the PV array usage [47], Figure 5.7 shows the monthly capacity factor of the PV system. The monthly capacity factor can be seen to vary between 14.28% in December and 22.32% in August. The annual capacity factor is 19.62%, with an overall monthly average of 17.66%. This figure for CF is reasonable compared to similar grid connected system in Algerian regions as in Adrar [48]. The capacity factor of other PV plants based on existing literature: in India [49], it ranged from 15.4% to 20%, Oman from 13% to 20% [50] and 21% [51], and Morocco [52] from 6.55% to 21.42%.

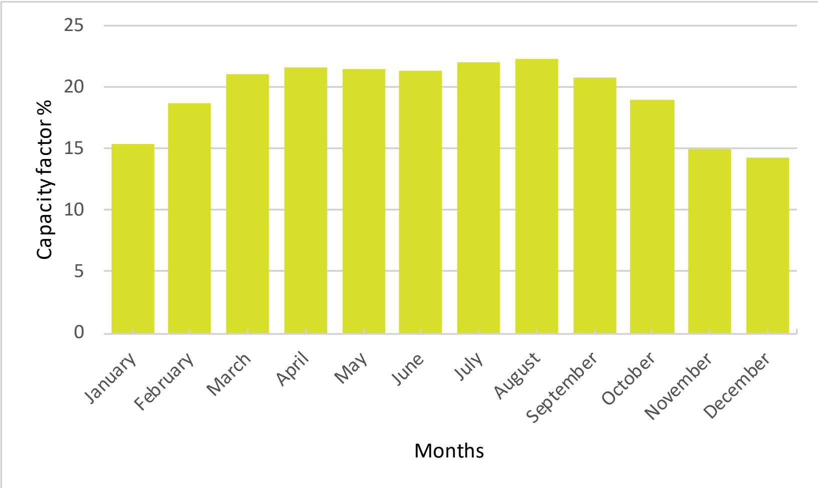



Figure 5.6 Monthly capacity factor

### 5.2.7 System losses:

PV system is not able to convert 100% energy received from the solar radiation because of various losses. Arrow loss diagram is obtained from the simulated studies, which helps in analyzing the various losses that are to be encountered while installing PV plant or constraints to be considered. The loss diagram for the 237kW is illustrated in Figure 5.7 showing that the system Global irradiance on horizontal plane is 1745 kWh/m² and is subjected to optical losses in this case, the global incidence in collector plane (+15.7%) and the IAM (Incidence angle modifier) factor (-2.68%) giving the effective irradiance on collector 1765 kWh/m². After the PV conversion, array nominal energy at standard testing conditions (STC) is 465.3 MWh considering the efficiency of the PV array at STC 16.76 %, when this energy is subjected to the array losses, -0.35 % due to irradiance level, -12.8 % losses due to temperature, +0.75% loss to module quality loss, - 1.1 % loss due to module array mismatch and -1.11 % due to the Ohmic writing losses, it gives the annual array virtual energy at MPP 413.2 MWh. Available energy on annual basis at the inverter output facility is 406.7 MWh. Here three losses , -1.56 % for the inverter loss during inverter operation, -0.01% due to the inverter loss over nominal inverter power and -0.01% inverter losses due to the power threshold. Due to low energy yield of the PV systems, it is essential to transmit the produced energy to the consumers with minimum losses as possible. Therefore, it is necessary to minimize these losses by eliminating the factors that cause the losses occurred in PV systems. PV systems should be installed taking into account the losses and the produced energy should be consumed in local areas where it was produced.

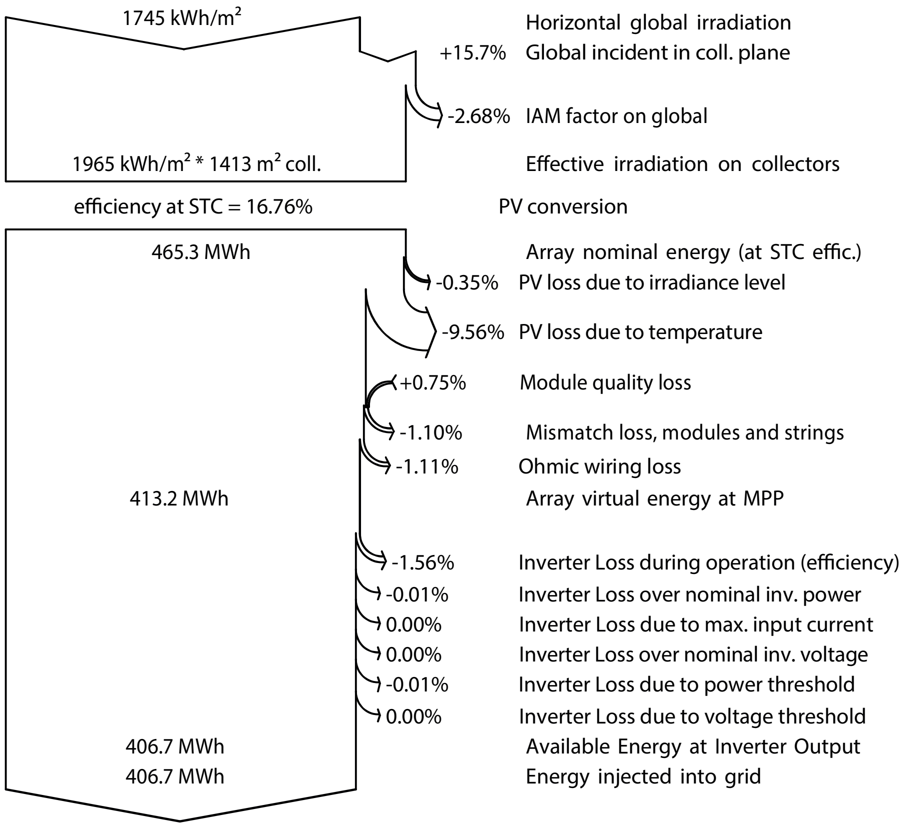



Figure 5.7 Arrow loss diagram by PVsyst

## 5.3 Environmental impact:

Replacing fossil fuel power generation with any kind of renewable energy resources would result in positive impact to the environment. The environmental impacts of PV system regarding the reductions in emission are estimated for one of the four atmospheric emission constituents (CO2) which has the greatest amount from others. After taking into consideration the small amount of CO2 emission during the PV system operation, Figure 5.8 shows the amount of CO2 emission reduction by installing the 237 kW PV for 25 years project lifetime which is estimated to be 4951.675 tons of CO2 that can be avoided from entering the local atmosphere during 25 years.

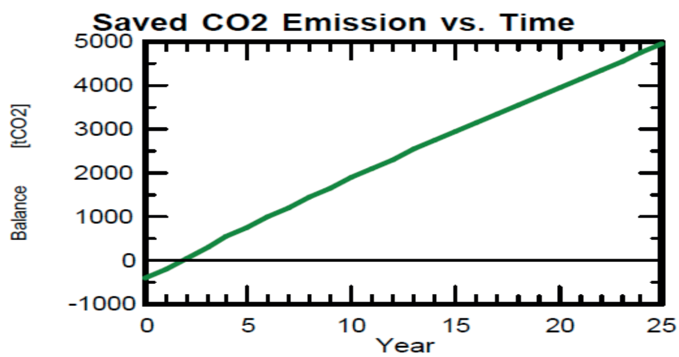



Figure 5.8 Saved CO2 emission verse time

## 5.4 Economic sensitivity:

In locations with a high proportion of direct irradiation, single- or dual-axis tracking systems can be used to increase the average total annual irradiation. In this project fixed panels system is considered especially for the higher financial and operational costs of tracker installations, combined with the decreasing cost of the silicon-based modules has reduced the interest being shown in tracking projects in recent years.

A battery system is a promising technology that can improve monthly bill savings since a battery can store the solar energy and the off-peak grid energy and release it later during the on-peak hours. However, battery capacity loss due to the discharging process will be accumulated day by day which needs to be changed every 5 to 10 years depending on the kind of battery, thus when considering the battery investment cost and the lifetime of the battery, battery degradation cost is a considerable cost in the daily operation cost of the grid connected PV system. In this grid connected PV project, battery backup capacity is excluded, the cost of the whole system decreases by around 40 to 50%.

In general, the increase of system cost reduces the system economic viability. Figure 5.10 shows the different financial contributions to the capital cost. It reveals that, module cost has an important impact on this system, followed by BOS service and installation cost. Also, NPV analysis shows different findings where the increase in electricity cost or for areas with expensive electricity tariffs, high bill savings are more significant to impact positively the economic viability of the project.

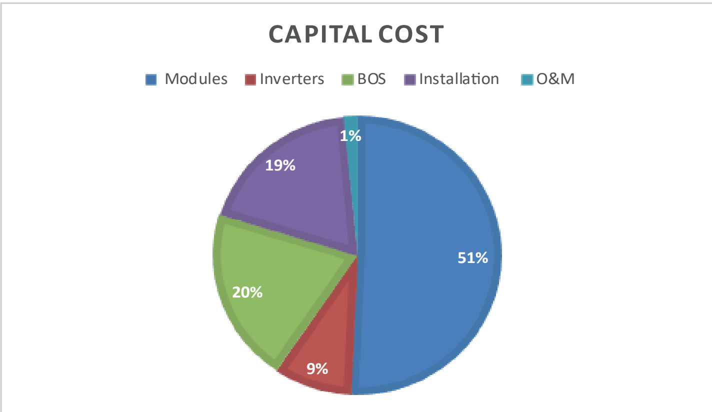



Figure 5.9 Capital cost financial contributions

## 5.5 Conclusion:

The present chapter investigates the performance analysis assessment of fixed panel, grid-connected PV plant in IAP, Boumerdes. The analysis of simulation results show that the project when implemented will supply about 406.73MWh electricity annually, with a performance ratio of 85.1% , an annual capacity factor of 19.62% and an annual yield factor of 1719 kWh/kWp/year.

The reasons for the losses are generally due to dust, ambient temperature and solar radiation. The higher total energy losses were observed in the hot months, May to August (heating of the photovoltaic cells which reduce the power provided by the photovoltaic modules).

The project also stands the chance of reducing about 4951.675 tons of $CO_2$ which would have been emitted by a crude oil fired thermal power plant generating the same amount of electricity.

# CHAPTER VI: GENERAL CONCLUSION

# 6.1 Conclusion:

Algeria has enormous renewable energy potential. However, fossil fuels remain the main electricity production source, with the country being the third-highest CO2 emitter in Africa. Likewise, Algeria is particularly exposed to climate change. Therefore, a set of actions related to the energy, forests, industry, and waste sectors, have been programmed over the period of 2015 to 2030, with the government action program giving priority to promote renewable energy.

Throughout this work, the techno-economic feasibility evaluation of a fixed panel, grid-connected solar PV system mounted on the rooftop of IAP (45' 29.088" N, 3° 28' 16.176") building in Boumerdes, Algeria, is presented and analyzed. Several performance indicators, such as yield factors, performance ratio, net present value (NPV), payback period, and sensitivity analysis of the effects of the techno-economic parameters' variation on system performance were considered for the assessment of the project.

Technically, based on the site's meteorological and load demand data, technical parameters have been evaluated and simulated by PVsyst software. The proposed PV system size is estimated to be 237 kW of 728 Poly-crystalline silicon modules, with a nominal power rating of 325W per module, an efficiency of 16.7%, and a total area occupied of 1413 m² coupled with three inverters using a maximum of 70 kW of AC power. The modules are fixed and oriented to south with 37° as tilt angle and 0° for azimuth angle. The lifetime of the PV modules is set at 25 years. Resulting in an appropriate sizing of components and technical indicators describing the productivity and performance of the project.

The technical results revealed the following:

- The system's total monthly energy production varied between 39036 kWh in August and 20518 kWh in December. The total system energy generated was 407 MWh, with an average energy production of 33916 kWh/month.
- The capacity factor (CF) of this system was found to be 19.62%, which is reasonable regarding similar grid-connected systems in the world, as found in literature. The yearly capacity factor ranges between 15% to 25%.
- The PV system's annual performance ratio (PR) was estimated to be 85.1%. This was found acceptable since the more the PR is close to 80 %, the more the system will be effective and efficient.
- Factors like cloudy weather in autumn and a short sunshine period and low solar irradiance in winter were found to affect the energy output in November and December, as well as in January and February. Furthermore, the higher total energy losses were observed in the hot months. The reasons for the losses are generally due to dust and ambient temperature.

Economically, the selection of modules and inverters was conducted carefully according to the technical adaptability and economical viability, an extensive research related to prices was established regarding their significant contribution to the capital investment cost of the project which includes additionally the balance of system cost, installation cost and the maintenance and operation cost, by means of calculations economic indicators were evaluated and validated by simulation in RETScreen Software.

The economic analysis resulted in the following findings:

- The capital cost of the project is estimated to be 11 446 290.00 DZD, the replacement cost is 1 001 700 DZD, and saving from avoided electricity purchase for IAP is 1 020 597.48 DZD/year. These three parameters were the key values for determining the economic metrics and indicators of the project.
- The estimated NPV of the system over its lifetime is 4 871 282.013 DZD, and its PBP is 11.21 years. Since the NPV is positive, and the PBP is significantly smaller than the lifetime period, it reveals that the project is economically feasible.

This project will be able to reduce CO2 emissions by approximately 4951.675 tons over 25 years. The study proved that the proposed system is more reliable and cost-effective and also more environmentally friendly.

## 6.2 Futur work:

This study can serve as a reference for similar solar energy projects, taking into account the differences in legislation and economic indicators for different countries. In addition, it can be noted that the installation cost of grid-connected solar photovoltaic (PV) systems has shown a rapid decline in recent years. Further investigations can be made in the calculation methodology in order to have more accurate results. The following aspects of the PV plant design can be carried out in the future to improve the current project.

Design the configuration of the components inside the PV plant. By knowing the configuration of the components, and in particular, the configuration of the PV modules (optimum inter-row spacing and space for corridors) losses can be obtained in a more accurate manner. Furthermore, by knowing the configuration of the components inside the PV plant, AC and DC cables can be properly sized and their voltage drop calculated.

More detailed information regarding the electrical layout, possible mechanical load, dimensioning for the mounting structure and protection, disconnection switches and metering is needed. An analysis of the ground soiling type may also be required.

Conducting a study more in depth regarding the cost associated to the PV plant analyzed and trying to obtain the cost of the components/services for a PV project located in Algeria, since in this study the cost of modules and inverters representing the expensive part of the project are estimated accurately, the cost of BOS, Installation and O&M is based on assumptions regarding their percentages from the capital cost, on studies carried in the world, in Algeria and more importantly from the International renewable energy agency “IRENA”.

The creation of a comprehensive series of laws and regulations providing the basis for renewable systems feeding into the public network, development of feed-in tariff mechanism and providing good incentive for renewable systems through greenhouse gas abatement.

Improving system-efficiency might be achieved by investigating a new mechanism to keep the sun radiation vertical to solar-panels by using different tilt angle for each season.

It is recommended to develop a future study to investigate the viability of one-axis and two axis PV grid-connected tracking system and compare the result with the result of this study in order to develop a comprehensive picture for the viability of different types of PV systems.

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شركة توزيع الكهرباء و الغاز للوسط
Société de Distribution de l'Electricité et du Gaz du Centre

Fourniture d'Electricité
MOYENNE TENSION

Capital social de 64Milliards de

FACTURE N° 561903000036 Période : Mars 2019

S F F : Saisie des Flux Futurs
KTP N° 444 807
Echéance le : ..........................

Direction Distribution: Dir.Dist.Bou
Adresse : PLACE 1ER NOVEMBRE
N° RC : 35/29-0805455B06 N°IS : 000516019000263
N° RIP : 00799999000038044188 N° RIB : BNA 00100645030030001422

Fax : 024.79.41.72
Tél. : 79 41 87
Dépannage Electricité :

CLIENT

Référence : 35101200370216
N° Poste : 081 N° RC : 00B0013767 N°IS :
N° Client : 5693702
Tél. : 0 00 00 00
Fax : 0 00 00 00
Désignation du lieu de consommation : IAP PVILLON II BOUMERDES
Nom et Adresse du Destinataire de facture : SONATRACH DIRECTION ... SOCILES IAP BOUMERDES R22 35000 BOUMERDES

Tarif : 42 Comptage : Période de consommation du: 27-02-2019 au: 27-03-2019

CONSOMMATION :

| Compteurs | Numéro | Coeff. de lecture | Index Premier cadran Ancien | Index Premier cadran Nouveau | Index Second cadran Ancien | Index Second cadran Nouveau | Index Troisième cadran Ancien | Index Troisième cadran Nouveau |
|---|---|---|---|---|---|---|---|---|
| ACTIF-T-TARIF | 3359 | 1.00 | 958702 | 972400 | 614656 | 623207 | 1537110 | 1557141 |
| REACTIF-S-T | 3359 | 1.00 | 1081721 | 1091659 | | | | |
| IND PUISSANCE | 3359 | 1.00 | | 137.00 | | | | |

| Energies | Consommations Cadran 1 | Cadran 2 | Cadran 3 | Périodes tarifaires H.POINTE | POINTE | |
|---|---|---|---|---|---|---|
| CONSOM. ACTIVE | 13698 | 8551 | 20031 | 35130 | 8858 | |
| P.E.C ACTIVE | 205 | 128 | 300 | | | |
| P.A.V ACTIVE | 336 | 179 | 560 | | | |
| CONSOM. REACTIVE | 9938 | | | 18063 | | |
| P.E.C REACTIVE | 397 | | | | | |
| P.A.V REACTIVE | 7728 | | | | | |

FACTURATION

veuillez regler avant le par :

- Virement au compte CCP ou bancaire sus indique.
- Cheque CCP ou bancaire adresse a notre unite.

Dir.Dist.B,ule 09-04-2019

Le Directeur

D.D. De Boumerdes
D.R.C
SDC

| Energie consommée | Quantité | P.U (cDA) | A déduire | A ajouter |
|---|---|---|---|---|
| H.POINTE | 35130 | 180.64 | | 63458.83 |
| POINTE | 8858 | 872.02 | | 77243.53 |
| Facteur de puissance 41.06% | | | | |
| BONIFICATION | 3931 | 9.110 | 358.11 | |
| Puissance mise à disposition | 500 | 3870.00 | | 19350.00 |
| Puissance maximale atteinte | 137 | 18058.00 | | 24739.46 |
| Primes fixes | | | | 515.65 |
| Montant énergie HT | | | | 185307.47 |
| TVA énergie taux 19 % | | | 68.04 | 35208.42 |
| Location (comptage, transformateur) | | | | |
| Entretien de poste transformateur | | | | |
| Frais de coupure et remise | | | | |
| Montant prestation HT | | | | |
| TVA prestation taux | | | | |
| Taxe d'habitation | | | | 200.00 |
| Taxe sur vente de produits énergétiques | 0.03 | | | 1319.64 |
| Intérêts moratoires | | | | |

MT/1

Contribution aux coûts permanents du système : 329.91 DA

TOTAL FACTURE : 221609.38 DA

Coupon détachable à joindre à votre correspondance

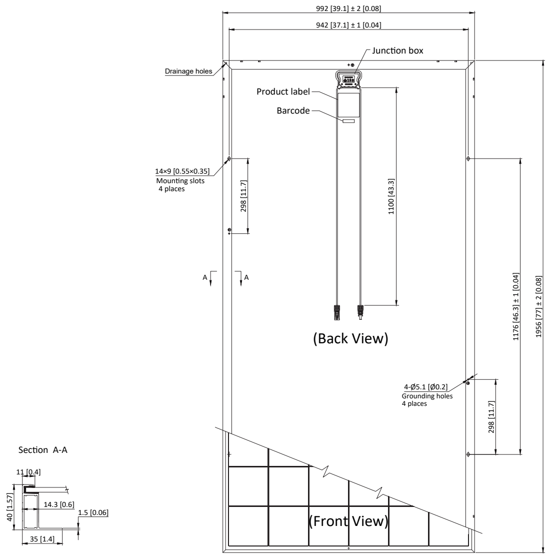
Client n° : 5693702
Facture n° : 561903000036
Référence : 35101200370216
Montant : 221609.38

La présente facture est arrêtée à la somme de :
Deux Cent Vingt et Un Mille Six Cent Neuf Dinars Trente Huit Centime(s)

AVIS : Un délai de paiement de 15 jours à dater de la réception de la présente facture vous est accordé. Passé ce délai, nous serons dans l'obligation d'entamer la procédure de suspension de la fourniture d'énergie.

# STP325 - 24/Vem
# STP320- 24/Vem
# STP315 - 24/Vem

SUNTECH




## Electrical Characteristics

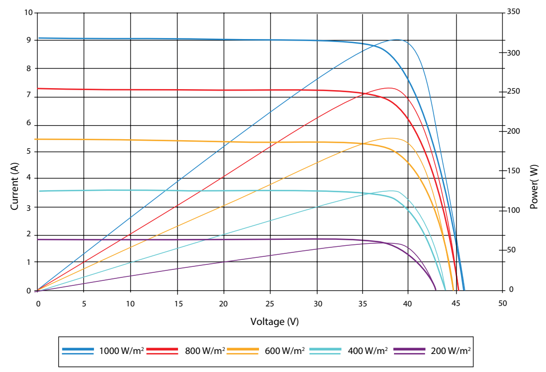
| STC | STP325-24/ Vem | STP320-24/ Vem | STP315-24/ Vem |
|---|---|---|---|
| Maximum Power at STC (Pmax) | 325 W | 320 W | 315 W |
| Optimum Operating Voltage (Vmp) | 37.3 V | 37.1 V | 36.8 V |
| Optimum Operating Current (Imp) | 8.72A | 8.63A | 8.56 A |
| Open Circuit Voltage (Voc) | 45.9 V | 45.6 V | 45.1 V |
| Short Circuit Current (Isc) | 9.26A | 9.14A | 9.02 A |
| Module Efficiency | 16.7% | 16.5% | 16.2% |
| Operating Module Temperature | -40 °C to +85 °C | | |
| Maximum System Voltage | 1500 V DC (IEC) | | |
| Maximum Series Fuse Rating | 20 A | | |
| Power Tolerance | 0/+5 W | | |

STC: Irradiance 1000 W/m², module temperature 25 °C, AM=1.5;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

| NOCT | STP325-24/ Vem | STP320-24/ Vem | STP315-24/ Vem |
|---|---|---|---|
| Maximum Power at NOCT (Pmax) | 240W | 235W | 229 W |
| Optimum Operating Voltage (Vmp) | 34.2V | 33.9V | 33.2 V |
| Optimum Operating Current (Imp) | 6.99 A | 6.94 A | 6.91 A |
| Open Circuit Voltage (Voc) | 42.2V | 41.9V | 41.5 V |
| Short Circuit Current (Isc) | 7.49 A | 7.40 A | 7.30 A |

NOCT: Irradiance 800 W/m², ambient temperature 20 °C, AM=1.5, wind speed 1 m/s;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

## Current-Voltage & Power-Voltage Curve (325-24)




Excellent performance under weak light conditions: at an irradiation intensity of 200 W/m² (AM 1.5, 25 °C), 96.5% or higher of the STC efficiency (1000 W/m²) is achieved

## Temperature Characteristics

| | |
|---|---|
| Nominal Operating Cell Temperature (NOCT) | 45±2°C |
| Temperature Coefficient of Pmax | -0.41 %/°C |
| Temperature Coefficient of Voc | -0.33 %/°C |
| Temperature Coefficient of Isc | 0.067 %/°C |

## Mechanical Characteristics

| | |
|---|---|
| Solar Cell | Polycrystalline silicon 6 inches |
| No. of Cells | 72 (6 × 12) |
| Dimensions | 1956 × 992 × 40mm (77.0 × 39.1 × 1.6 inches) |
| Weight | 25.8 kgs (56.9 lbs.) |
| Front Glass | 4.0 mm (0.16 inches) tempered glass |
| Frame | Anodized aluminium alloy |
| Junction Box | IP68 rated (3 bypass diodes) |
| Output Cables | TUV (2Pfg1169:2007) |
| | 4.0 mm² (0.006 inches²), symmetrical lengths (-) 1100mm (43.3 inches) and (+) 1100 mm (43.3 inches) |
| Connectors | MC4 compatible |

## Dealer information

## Packing Configuration

| Container | 20' GP | 40' GP | 40' HC |
|---|---|---|---|
| Pieces per pallet | 25 | 25 | 25 |
| Pallets per container | 5 | 12 | 24 |
| Pieces per container | 125 | 300 | 600 |

Information on how to install and operate this product is available in the installation instruction. All values indicated in this data sheet are subject to change without prior announcement. The specifications may vary slightly. All specifications are in accordance with standard EN 50380. Color differences of the modules relative to the figures as well as discolorations of/in the modules which do not impair their proper functioning are possible and do not constitute a deviation from the specification.

# APPENDIX C: INVERTER CHARACTERISTICS

| Model | SUN-60K-G | SUN-70K-G | SUN-75K-G | SUN-80K-G |
|---|---|---|---|---|
| Energy source | Grid-connected PV | | | |
| Input Side | | | | |
| Max.DC Power(kW) | 78 | 91 | 97.5 | 96 |
| Max.DC Input Voltage(V) | 1000 | | | |
| Start-up DC Input Voltage(V) | 250 | | | |
| MPPT Operating Range(V) | 200~850 | | | |
| Max.DC Input Current(A) | 30+30+30+30 | 40+40+40+40 | 40+40+40+40 | 40+40+40+40 |
| Number of MPPT/ Strings per MPPT | 4/3 | 4/4 | 4/4 | 4/4 |
| Output Side | | | | |
| Rated Output Power(kW) | 60 | 70 | 75 | 80 |
| Max.Active Power(kW) | 66 | 77 | 82.5 | 88 |
| Rated AC Grid Voltage(V) | 380/400 | | | |
| AC Grid Voltage Range(V) | 277~460 | | | |
| Rated Grid Frequency(Hz) | 50/60 (Optional) | | | |
| Operating Phase | Three phase | | | |
| Rated AC Grid Output Current(A) | 87.8 | 101.5 | 108.7 | 115.9 |
| Max.AC Output Current(A) | 95.7 | 111.6 | 119.6 | 127.5 |
| Output Power Factor | >0.99 | | | |
| Grid Current THD | <3% | | | |
| DC Injection Current(mA) | <0.5% | | | |
| Grid Frequency Range | 47~52 or 57~62(Optional) | | | |
| Efficiency | | | | |
| Max. Efficiency | 98.9% | | | |
| Euro Efficiency | 98.3% | | | |
| MPPT Efficiency | >99% | | | |
| Protection | | | | |
| DC Reverse-Polarity Protection | Yes | | | |
| AC Short Circuit Protection | Yes | | | |
| AC Output Overcurrent Protection | Yes | | | |
| Output Overvoltage Protection | Yes | | | |
| Insulation Resistance Protection | Yes | | | |
| Ground Fault Monitoring | Yes | | | |
| Surge Protection | Yes | | | |
| Islanding Protection | Yes | | | |
| Temperature Protection | Yes | | | |
| Integrated DC Switch | Optional | | | |
| General Data | | | | |
| Size(mm) | 700W×575H×297D | | | |
| Weight(kg) | 60 | | | |
| Topology | Transformerless | | | |
| Internal Consumption | <1W(Night) | | | |
| Running Temperature | -25~60℃ | | | |
| Ingress Protection | IP65 | | | |
| Noise Emission(Typical) | <30 dB | | | |
| Cooling Concept | Intelligent cooling | | | |
| Max. Operating Altitude Without Derating | 2000m | | | |
| Designed Lifetime | >20 years | | | |
| Grid Connection Standard | EN50438,IEC61727,VDE4105,NB/T32004(CQC),IEC62109-1-2 | | | |
| Operating Surroundings Humidity | 0-100% | | | |
| Stafty EMC /Standard | IEC62109-1/-2,AS3100,EN61000-6-1 | | | |
| Features | | | | |
| DC Connection | MC-4 mateable | | | |
| AC Connection | IP65 rated plug | | | |
| Display | LCD 240 × 160 | | | |
| Interface | RS485/RS232 | | | |

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|---|---|---|---|

## Grid-Connected System: Simulation parameters

| | | | | |
|---|---|---|---|---|
| Project : | New Project | | | |
| Geographical Site | Boumerdas | | Country | Algeria |
| Situation | Latitude | 36.76° N | Longitude | 3.47° E |
| Time defined as | Legal Time | Time zone UT+1 | Altitude | 52 m |
| | Albedo | 0.20 | | |
| Meteo data: | Boumerdas | NASA-SSE satellite data 1983-2005 - Synthetic | | |

| | | | | |
|---|---|---|---|---|
| Simulation variant : | New simulation variant | | | |
| | Simulation date | 07/05/20 22h01 | | |

| | | | | |
|---|---|---|---|---|
| Simulation parameters | System type | No 3D scene defined, no shadings | | |
| Collector Plane Orientation | Tilt | 37° | Azimuth | 0° |
| Models used | Transposition | Perez | Diffuse | Perez, Meteonorm |
| Horizon | Free Horizon | | | |
| Near Shadings | No Shadings | | | |
| User's needs : | Unlimited load (grid) | | | |

| | | | | | |
|---|---|---|---|---|---|
| PV Array Characteristics | | | | | |
| PV module | Si-poly | Model | STP 325-20/Wem+ (Superpoly) | | |
| Custom parameters definition | | Manufacturer | Suntech | | |
| Number of PV modules | | In series | 13 modules | In parallel | 56 strings |
| Total number of PV modules | | Nb. modules | 728 | Unit Nom. Power | 325 Wp |
| Array global power | | Nominal (STC) | 237 kWp | At operating cond. | 212 kWp (50°C) |
| Array operating characteristics (50°C) | | U mpp | 431 V | I mpp | 492 A |
| Total area | | Module area | 1413 $m^2$ | Cell area | 1276 $m^2$ |
| Inverter | | Model | SUN-70K-G | | |
| Custom parameters definition | | Manufacturer | Deye | | |
| Characteristics | | Operating Voltage | 200-850 V | Unit Nom. Power | 70.0 kWac |
| Inverter pack | | Nb. of inverters | 3 units | Total Power | 210 kWac |
| | | | | Pnom ratio | 1.13 |

| | | | | |
|---|---|---|---|---|
| PV Array loss factors | | | | |
| Thermal Loss factor | Uc (const) | 20.0 W/$m^2$K | Uv (wind) | 0.0 W/$m^2$K / m/s |
| Wiring Ohmic Loss | Global array res. | 15 mOhm | Loss Fraction | 1.5 % at STC |
| Module Quality Loss | | | Loss Fraction | -0.8 % |
| Module Mismatch Losses | | | Loss Fraction | 1.0 % at MPP |
| Strings Mismatch loss | | | Loss Fraction | 0.10 % |
| Incidence effect, ASHRAE parametrization | IAM = | 1 - bo (1/cos i - 1) | bo Param. | 0.05 |

## Grid-Connected System: Main results

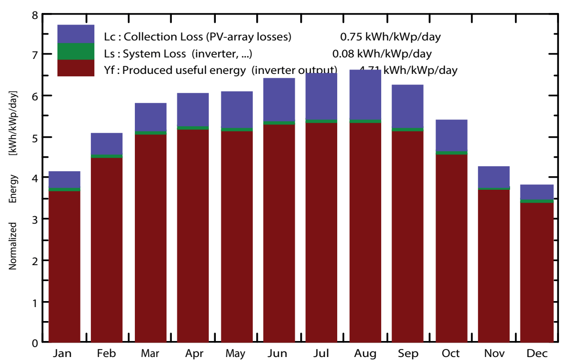
Project : New Project

Simulation variant : New simulation variant

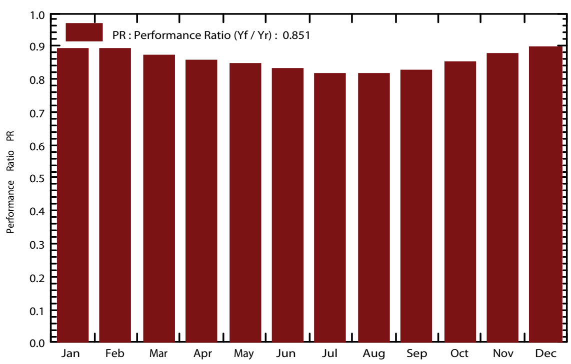
| | | | | |
|---|---|---|---|---|
| Main system parameters | System type | No 3D scene defined, no shadings | | |
| PV Field Orientation | tilt | 37° | azimuth | 0° |
| PV modules | Model | STP 325-20/Wem+ (Superpoly) | | 325 Wp |
| PV Array | Nb. of modules | 728 | Pnom total | 237 kWp |
| Inverter | Model | SUN-70K-G | Pnom | 70.0 kW ac |
| Inverter pack | Nb. of units | 3.0 | Pnom total | 210 kW ac |
| User's needs | Unlimited load (grid) | | | |

| | | | | |
|---|---|---|---|---|
| Main simulation results | | | | |
| System Production | Produced Energy | 406.7 MWh/year | Specific prod. | 1719 kWh/kWp/year |
| | Performance Ratio PR | 85.14 % | | |

Normalized productions (per installed kWp): Nominal power 237 kWp




Performance Ratio PR




New simulation variant

Balances and main results

| | GlobHor kWh/m² | DiffHor kWh/m² | T_Amb °C | GlobInc kWh/m² | GlobEff kWh/m² | EArray MWh | E_Grid MWh | PR |
|---|---|---|---|---|---|---|---|---|
| January | 76.9 | 27.00 | 10.57 | 128.8 | 126.2 | 27.61 | 27.17 | 0.891 |
| February | 94.6 | 31.10 | 11.14 | 141.7 | 138.5 | 30.35 | 29.89 | 0.892 |
| March | 142.3 | 45.60 | 12.92 | 179.3 | 175.0 | 37.65 | 37.06 | 0.873 |
| April | 170.7 | 55.50 | 15.12 | 181.7 | 176.5 | 37.50 | 36.90 | 0.858 |
| May | 201.2 | 65.40 | 18.61 | 188.4 | 182.2 | 38.38 | 37.77 | 0.847 |
| June | 216.0 | 63.30 | 22.91 | 191.7 | 185.2 | 38.22 | 37.61 | 0.829 |
| July | 221.0 | 62.00 | 25.78 | 202.3 | 195.8 | 39.78 | 39.15 | 0.818 |
| August | 199.6 | 55.20 | 26.24 | 204.3 | 198.4 | 39.98 | 39.36 | 0.814 |
| September | 158.4 | 45.00 | 23.31 | 187.4 | 182.8 | 37.14 | 36.57 | 0.825 |
| October | 118.4 | 37.80 | 19.80 | 166.8 | 163.0 | 34.11 | 33.58 | 0.851 |
| November | 78.9 | 28.80 | 15.30 | 128.1 | 125.3 | 26.92 | 26.49 | 0.874 |
| December | 66.7 | 25.40 | 12.02 | 118.7 | 116.1 | 25.58 | 25.18 | 0.896 |
| Year | 1744.7 | 542.10 | 17.85 | 2019.1 | 1965.1 | 413.21 | 406.73 | 0.851 |

Legends:

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

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|---|---|---|---|

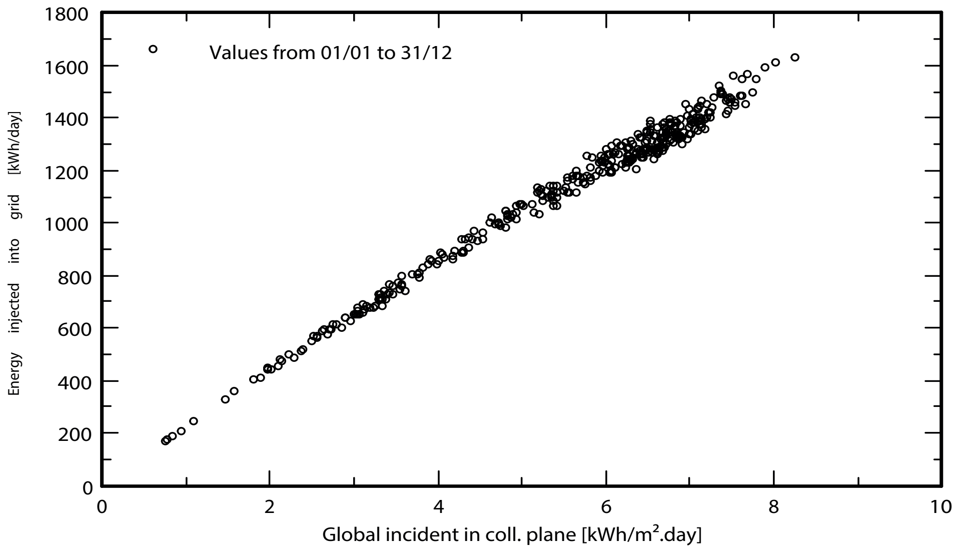
## Grid-Connected System: Special graphs

Project : New Project

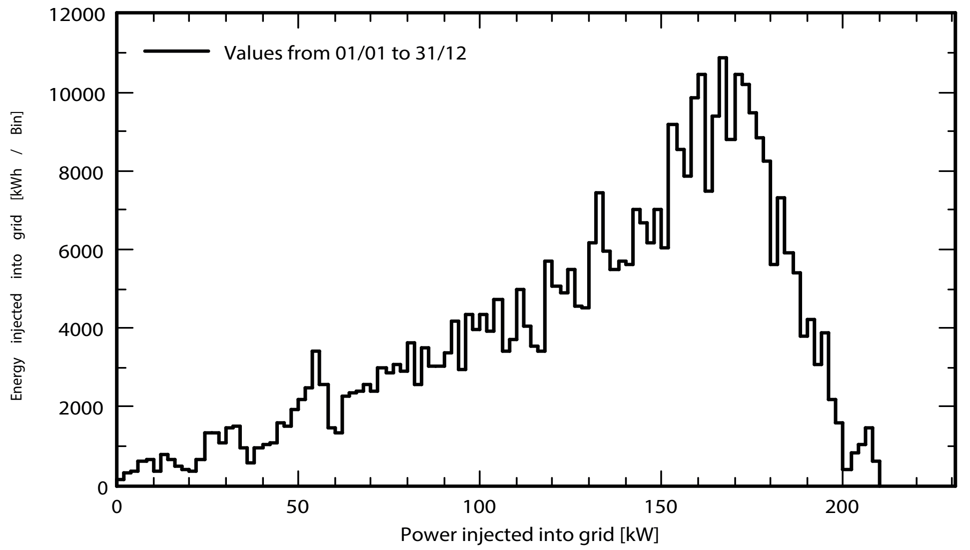
Simulation variant : New simulation variant

| | | | | |
|---|---|---|---|---|
| Main system parameters | System type | No 3D scene defined, no shadings | | |
| PV Field Orientation | tilt | 37° | azimuth | 0° |
| PV modules | Model | STP 325-20/Wem+ (Superpoly) | | 325 Wp |
| PV Array | Nb. of modules | 728 | Pnom total | 237 kWp |
| Inverter | Model | SUN-70K-G | Pnom | 70.0 kW ac |
| Inverter pack | Nb. of units | 3.0 | Pnom total | 210 kW ac |
| User's needs | Unlimited load (grid) | | | |

### Daily Input/Output diagram




### System Output Power Distribution



| | | | |
|---|---|---|---|
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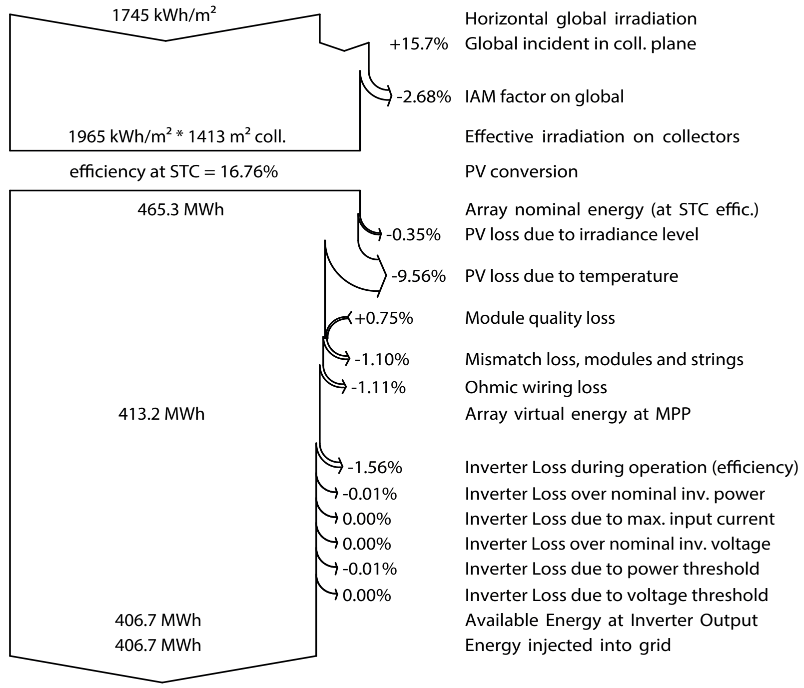
## Grid-Connected System: Loss diagram

Project : New Project

Simulation variant : New simulation variant

| | | | | |
|---|---|---|---|---|
| Main system parameters | System type | No 3D scene defined, no shadings | | |
| PV Field Orientation | tilt | 37° | azimuth | 0° |
| PV modules | Model | STP 325-20/Wem+ (Superpoly) | | 325 Wp |
| PV Array | Nb. of modules | 728 | Pnom total | 237 kWp |
| Inverter | Model | SUN-70K-G | Pnom | 70.0 kW ac |
| Inverter pack | Nb. of units | 3.0 | Pnom total | 210 kW ac |
| User's needs | Unlimited load (grid) | | | |

Loss diagram over the whole year



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|---|---|---|---|

## Grid-Connected System: CO2 Balance

**Project :** **New Project**

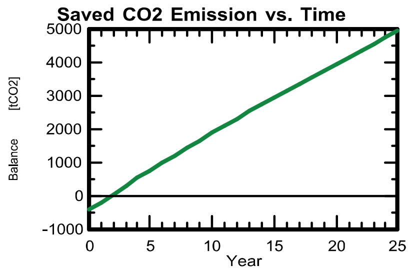
**Simulation variant :** **New simulation variant**

| | | | | |
|---|---|---|---|---|
| **Main system parameters** | System type | **No 3D scene defined, no shadings** | | |
| PV Field Orientation | tilt | 37° | azimuth | 0° |
| PV modules | Model | STP 325-20/Wem+ (Superpoly) | | 325 Wp |
| PV Array | Nb. of modules | 728 | Pnom total | **237 kWp** |
| Inverter | Model | SUN-70K-G | Pnom | 70.0 kW ac |
| Inverter pack | Nb. of units | 3.0 | Pnom total | **210 kW ac** |
| User's needs | Unlimited load (grid) | | | |

| | | | | |
|---|---|---|---|---|
| **Produced Emissions** | **Total:** | **434.17 tCO2** | | |
| | Source: | Detailed calculation from table below | | |
| **Replaced Emissions** | **Total:** | **6060.3 tCO2** | | |
| | System production: | 406.73 MWh/yr | Lifetime: | 25 years |
| | | | Annual Degradation: | 1.0 % |
| | Grid Lifecycle Emissions: | 596 gCO2/kWh | | |
| | Source: | IEA List | Country: | Algeria |
| **CO2 Emission Balance** | **Total:** | **4951.7 tCO2** | | |

**System Lifecycle Emissions Details:**

| Item | Modules | Supports |
|---|---|---|
| LCE | 1713 kgCO2/kWp | 3.98 kgCO2/kg |
| Quantity | 237 kWp | 7280 kg |
| Subtotal [kgCO2] | 405230 | 28940 |



People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research

University M'Hamed BOUGARA - Boumerdes

Institute of Electrical and Electronic Engineering

Department of Power and Control

# Authorization for Final Year Project Defense

Academic year: 2019/2020

The undersigned supervisor: Mr Hamid BENTARZI (Prof.)....................
authorizes the student(s):

Zakia BOUCHEBBAT..................................Option...Power......................................

Kenza BENAMROUCHE...............................Option... Power.........................................

..............................................................................................Option...........................................

to defend ~~his~~ / ~~her~~ / their final year Master program project entitled:

Techno-economic feasibility Study of a Photovoltaic Grid-Connected System Installation

in Algerian Petroleum Institute (IAP).............................................

during the [X] June [ ] September session.

Date: 16 / 06 / 2020

The Supervisor

The Department Head

قسم الإلكتروتقني و الآلية

رئيس قسم الإلكتروتقني والآليـة بالنيابـة
أ. معـــاش