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Optimal sizing of renewable energy system using iHOGA simulator

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ABSTRACT

Traditional electrical energy generation approaches which rely on oil and its derivatives, produce different kinds of pollution in addition of being expensive to be implemented and maintained. Renewable energy is a term for clean sustainable energy that is derived from naturally regenerating sources. The sun is an unlimited source for humanity around the world and a competitive one with strong potential, specially in the southern zone of Algeria, where high magnitudes of solar radiation are present and represent an important parameter in sizing the PV systems.

This study presents a techno-economic feasibility evaluation for the installation of a stand-alone PV system which covers the electrical demand of 20 houses in Tindouf by selecting the right components and compare the results of the simulation between the two control strategies load following and cycle charging using the hybrid simulator iHOGA , which include the net total cost, CO_2 emissions and their impact on the environment.

CONTENTS

LIST OF FIGURES

List of Tables

LIST OF ABBREVIATION

PV :	Photovoltaic.
KWh :	Kilowatt-hours
I-V curve:	A current-voltage curve.
P-V curve:	A power-voltage curve.
MPP:	Maximum Power Point.
Voc:	Open Circuit Voltage.
STC:	Standard Test Conditions.
Pn :	Nominal Power.
MPPT:	Maximum Power Point tracking
SOC:	State of Charge.
DOD :	Depth of Discharge.
Rs :	Series Resistance.
Rp:	Parralel Resistance
AC:	Alternating Current
DC:	direct Current
Ns:	Number of series modules.
Np :	Number of parallel strings.
NPC:	Net present cost
NPV:	Net present value
OPZV :	Ortsfest (stationary) PanZerplatte (tubular plate) Verschlossen (closed)
OPZS:	Ortsfest (stationary) PanZerplatte (tubular plate) Flüssig (flooded)

1

SMART GRIDS AND PHOTOVOLTAIC SYSTEMS

1.1 INTRODUCTION

Renewable energy is the energy which is derived from a limitless source. Proper utilization of energy resources is a hot debate going these days. It is very essential to choose which source of energy must be used and why [1].

Majority of factors such as cleanliness, cost, stability, efficiency and environmental effects must be taken into account. It is a bitter fact that many industries around the world are still dependent on fossil fuels for electricity generation. No doubt, these fuels are very effective as far as power production quality is concerned, but in the long run they are not advantageous. Fossil fuels will deplete one day and the industries must turn to renewable sources as soon as possible. Moreover, these fossil fuels pose a huge threat to environmental balance and are a cause of many ecological hazards[1].

Proper use of energy is very vital in catering the need for energy demand. Experts all over the world are of the opinion to utilize renewable energy sources for power generation. Moreover, people can setup small solar panels over their homes to tackle their own load demands. These sources of energy are not hazardous to the environment since they do not require any sort of mining and drilling and produce nearly no pollution. Most importantly, they are much more economical than fossil fuels and do not cause adverse mishaps[1].

1.2 THE SMART GRID

A smart grid is an electricity network based on digital technology that is used to supply electricity to consumers via two-way digital communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the energy supply chain. The smart grid was introduced with the aim of overcoming the weaknesses of conventional electrical grids by using smart net meters [2].

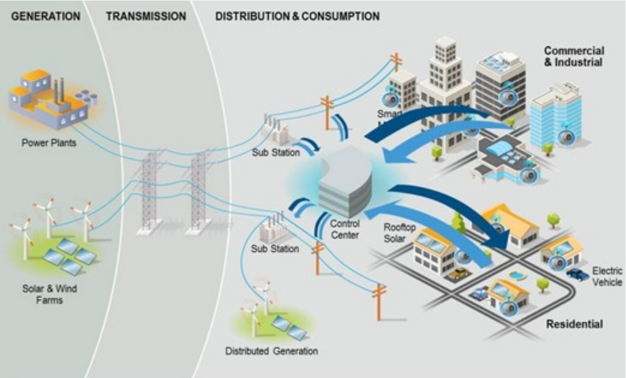


Figure 1.1 – *Smart grid architecture*

1.2.1 Smart grid architecture model

The number of smart objects in Smart Grid networks is extremely high. Smart Grid networks are made of a number of networks including power generation to substation automation and control, smart metering, an building/home energy management.

a. Smart power generation

Smart Power Generation enables the complete power system to operate in the most cost efficient way with the lowest possible carbon emissions, and the maximum utilisation of wind and solar power. In addition, Smart Power Generation secures the electricity supply by balancing the system even during extreme wind variations and contingency situations [3].

b.Smart substation

Smart substations play a significant role in the smart grid, which is one of the basic platforms to promote a new round of energy revolution and technology innovation. With the development of advanced, reliable, integrated, and environmental-friendly intelligent electronic devices, the smart substations are based on the whole station information digitalization, communication platform networking, and information-sharing standardization. Automatically completing the basic functions of information collection, measurement, control, protection, computation, and monitoring, the smart substations also support advanced functions, such as real-time automatic control of the smart grid, intelligent regulation, online analysis and decision, and interaction with adjacent substations and power dispatching [4].

c.Smart meter

A smart meter is a device that can read the consumption of electricity, gas or water in a building and reports it directly, using the internet, to the supplier. They can track how much is consumed at which point in time and report any unusual activities. Additionally, there is no need to estimate prices anymore for consumption, as real-time data is available from the smart meters. The smart meter includes a device that is connected to the sources where it measures the energy consumption itself. A display that can track the data and visualize it is often also included or can be bought later on[5].

d.Energy Management in Smart Grid

The integration of highly fluctuated distributed generations (such as PVs, wind turbines, electric vehicles, and energy storage systems) threatens the stability of the power and distribution systems. The main cause is that the power ratio between the supply and demand may not be balanced. An excess/shortage in the generation or consumption of power may perturb the network and create severe problems such as voltage drop/rise and in severe conditions, blackouts. To increase the balance between the supply and the demand in an efficient way, and to reduce the peak load during unexpected periods, energy management systems are utilized. Energy management can be divided into two main categories. The first one is on the side of the supplier such as electric utility, in which some generators are turned ON or OFF to follow the fluctuation of the load demand. The second category is on the consumer side and it is called demand-side management.[6] The main goal of using energy management is to reduce the cost of operation and consumption, reduce the energy losses and increase the reliability of the network. Energy management has many barriers and limitations. However, it has a prominent future in which most of the current research is focused on developing sophisticated algorithms and models to better manage the energy on the grid [6].

1.3 THE RENEWABLE ENERGIES

1.3.1 wind energy

Wind power or wind energy describes the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water), or can be converted into electricity by a generator.[7] Wind energy is the second largest source of global renewable energy production, surpassed only by hydroelectric power. Wind energy is a widely available source of renewable energy. Onshore wind turbines are located on land, while offshore are set up in water bodies such as oceans and seas. An ideal location is based on wind patterns, speed, and the availability of space. Evaluation of the benefits of onshore and offshore wind farms pros and cons is key to understanding the best source to supply reliable, efficient electricity [7].

Figure 1.2 – *wind farm*

1.3.2 biomass energy

Biomass is an organic material that comes from living organisms, such as plants and animals. The most common biomass materials used for energy are plants, wood, and waste products. Biomass is one of the renewable energy sources. The energy from these organisms can be transformed into usable energy through direct and indirect means. Biomass can be burned to create heat (direct), or processed into biofuel (indirect). Different types of energy are created through several ways such as: direct firing, co-firing, pyrolysis, gasification, and anaerobic decomposition. All these ways involve thermal conversion. Thermal conversion involves heating the biomass feedstock in order to burn, dehydrate, or stabilize it.and before burning the biomass, it must be dried [8].

Figure 1.3 – *generation of electricity using biomass renewable energy*

1.3.3 Hydraulic energy

Also called water energy, it is a type of energy that takes advantage of the movement of water. It enables us to obtain electricity by the kinetic and potential energy from currents and waterfalls. Nowadays, the most frequent use of hydraulic energy is to produce electricity.

A hydroelectric power station basically works by using a turbine that rotates when it is driven by a current or a waterfall [9].

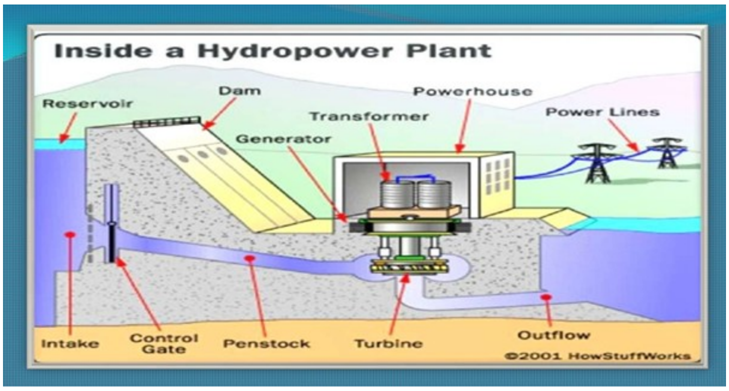


Figure 1.4 – *generation of electricity using hydraulic renewable energy*

1.3.4 Solar Energy

Solar energy is a renewable energy resource that is more affordable now than ever before and is used to produce electricity for a wide variety of residential and commercial uses. Electricity produced from sunlight will be a key part of our journey toward sustainable energy in the future.[10]

a. Photovoltaic energy statistics

The sun is an unlimited source of energy for humanity around the world and a competitive energy with strong potential. It could reach 16% of total electricity production in 2050. Every year solar energy produces more than 20 times the world's energy needs, and yet, it still represents only 1% of global electricity production capacity [10]. In addition to that Algeria plays an important role as a major exporter of oil and natural gas, It was the fourth largest crude producer in Africa, and the sixth largest natural gas producer in the world, Algeria started an interesting efforts in exploiting renewable energies with the creation of the solar energy institute as soon as 1962, studies of indigenous solar resources performed by the CDER during recent years, show that the climatic conditions in Algeria are favourable for solar energy utilisation that can exceed 6 m/s in the South.[10] The assessed economic potentials, by the German Space Centre (DLR), of renewable energy sources in Algeria are :

- Thermal solar: 169 440 TWh/year
- Photovoltaic: 13.9 TWh/year [10]

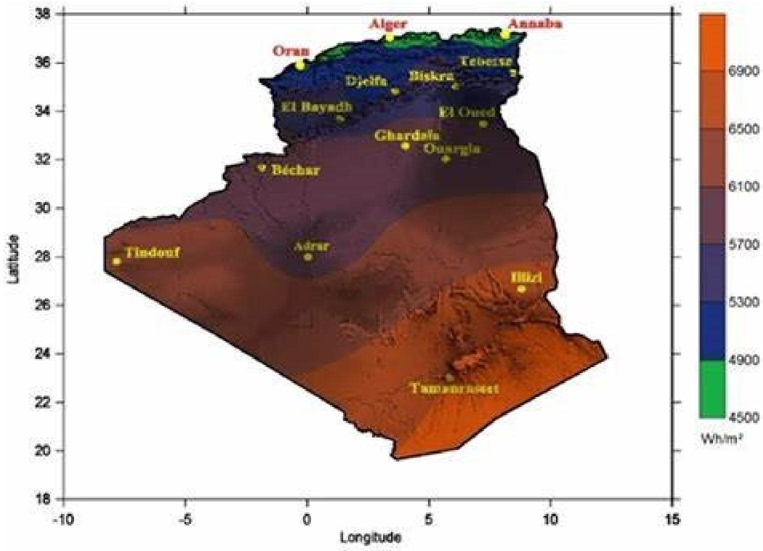


Figure 1.5 – *annual average irradiation received on a horizental surface in Algeria during the period 1992-2002 [11]*

Algeria has high sun radiation level and is one of the largest markets for solar power in Africa. The country occupies 75% of the Sahara desert territory. The northern part of the country has high insolation rates of 2650 KWh per m2. In 2016, the country's total solar installed capacity was more than 240 MW. Under the National Development Plan for Renewable Energies, the country aims to install renewable generation capacity of 22 GW by 2030, with solar accounting for almost 60% of the capacity. As a result, the demand for solar energy is expected to grow in the country during the forecast period [11].

Table 1.1 – *Algeria sun capacity [11]*

Region	Coastal regions	Highlands	Sahara
Area	4	10	86
Average duration of sun exposure (h/year)	2650	3000	3500
Average energy received (Kwh/$m^2/year$)	1700	1900	2650

b. Solar energy and environment

The use of photovoltaics reduces the amount of energy consumed to produce electricity, what is called embodied energy in comparison to other production methods. It is now estimated that a solar panel produced in a few years (4 to 6 depending on the technologies) the energy that was needed to manufacture it. The manufacture of solar panels uses largely recyclable materials or upgraded. Silicon often comes from scrap electronics.

The production of electricity by a photovoltaic generator does not emit greenhouse gases and does not generate pollution comparable to that of traditional production methods. In 2030, according to EPIA, the European photovoltaic association, solar photovoltaics will reduce global co2 emissions by 1.6 billion tonnes per year, i.e. the equivalent of 450 coal-fired power plants with an average power of 750 MW [12].

It is reliable and sustainable energy: photovoltaic generators are modular, easy to implement and maintain. They have very little intrinsic wear. Their lifespan is 20 to 30 years [12].

1.4 PHOTOVOLTAIC SYSTEMS TECHNOLOGIES

A photovoltaic (PV) system is composed of one or more solar panels combined with an inverter and other electrical and mechanical hardware that use energy from the Sun to generate electricity. PV systems can vary greatly in size from small rooftop or portable systems to massive utility-scale generation plants.

According to the use of solar photovoltaic system, they can be classified into two different types: grid-connected solar PV system and stand-alone solar PV system. The other general subtypes are described and classified in the figure below .
The significant difference between the two types is that in a stand-alone system the photovoltaic energy and load demand are in phase but in a grid-connected one they are not in phase. Grid-connected systems are divided into direct and indirect systems; stand-alone systems are divided into with storage, without storage and hybrid system. In stand-alone systems, batteries are used for storage mostly; hybrid systems use other power sources like wind or diesel generator in combination with photovoltaic system [13].

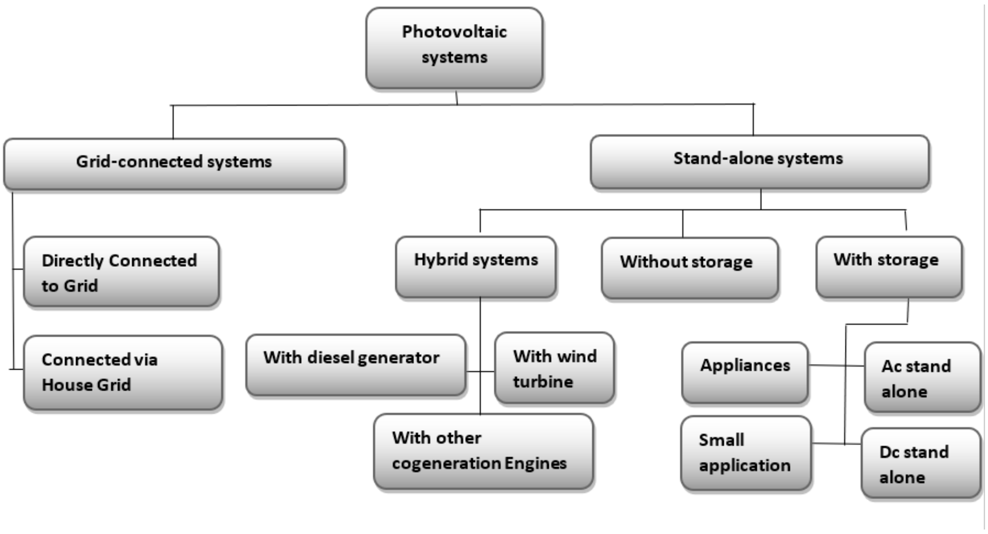


Figure 1.6 – *photovoltaic systems classification: grid-connected and stand-alone systems [13]*

1.4.1 Direct coupled PV system

In a direct-coupled PV system, the PV array is connected directly to the load. The powered device will only work in the presence of light and as soon as the illumination is sufficient to reach the requested power[14]. This is interesting for all applications that do not need to work in obscurity, and for which the need for energy coincides with the presence of light. If there is light, it works, otherwise it stops [14].
A typical application of this type of system is for water pumping where the pump is connected directly to the solar panels via a regulator or converter. The flow of water inlet in the tank is therefore variable, directly depending on the solar radiation[14]

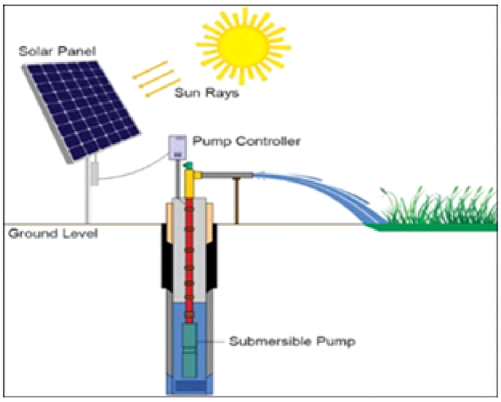


Figure 1.7 – *block diagram of Direct coupled PV system*

1.4.2 Standalone system

Stand-alone PV systems are used in areas that are not easily accessible or have no access to an electric grid. A stand-alone system is independent of the electricity grid, with the energy produced normally being stored in batteries. A typical stand-alone system would consist of a PV module or modules, batteries, and a charge controller. An inverter may also be included in the system to convert the direct current generated by the PV modules to the alternating current form required by normal appliances [14].

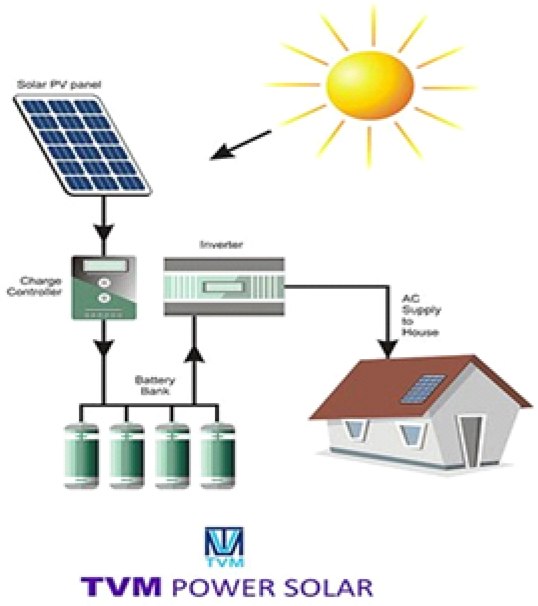


Figure 1.8 – *block diagram of stand alone PV system*

1.4.3 Grid connected system (no battery)

Grid-connected PV system is an electricity generating solar PV power system that is connected to the utility grid. It consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment.

During the day, the electricity generated by the PV system can either be used immediately (for systems installed in offices) or be sold to one of the electricity supply companies when solar panels produce more solar electricity than house's demand.

In the evening, when the solar system is unable to provide the electricity required, power can be bought back from the network. In effect, the grid is acting as an energy storage system, which means the PV system does not need to include battery storage [15].

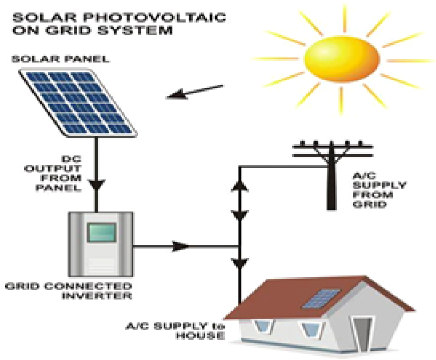


Figure 1.9 – *block diagram of Grid connected system (no battery)*

1.4.4 Hybrid connected system

A Hybrid Solar Photovoltaic (PV) System is a combination of both the On-Grid and Off-Grid Solar PV Systems, where more than one type of electricity generator is employed. The second type of electricity generator can be renewable, such as a wind turbine, or conventional, such as a diesel engine generator or the utility grid. in this system, both DC and AC loads can be satisfied simultaneously [16].

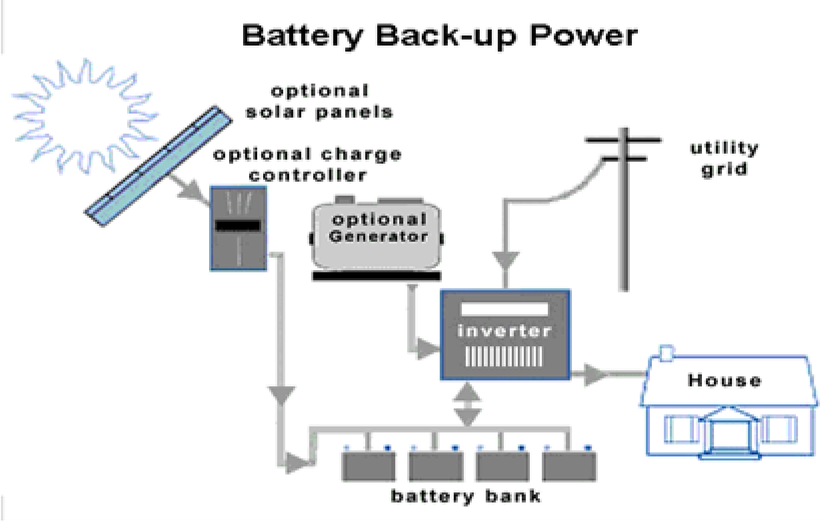


Figure 1.10 – *block diagram of hybrid connected PV system*

1.5 STRUCTURE OF A PV SYSTEM

Solar photovoltaic (PV) energy systems are made up of different components. Each component has a specific role. The type of component in the system depends on the system type, site location, applications and the purpose. These components include the pv genertor, inverters, batteries, battery chargers, diesel engine generator, wiring, surge protectors, switches and mechanical mounting components. They are what distributes and stores electricity safely and efficiently and can account of up to half the cost of the total cost of a photovoltaic system.[17]

1.5.1 PV generator

The photovoltaic generator is a generator that uses the photovoltaic effect to convert sunlight into electricity and it is represented by the PV array in a PV system.. The majority of solar modules available on the market and used for residential and commercial solar systems are silicon_crystalline. These modules consist of multiple strings of solar cells, wired in series (positive to negative), and are mounted in an aluminum frame where ach solar cell is capable of producing 0.5 volts [17].

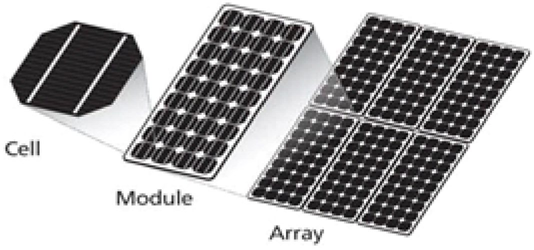


Figure 1.11 – *Solar photovoltaic cel, module and array*

PV cells are made using silicon crystalline wafers similar to the wafers used to make computer processors. The silicon wafers can be either **polycrystalline** or **monocrystalline** and are produced using several different manufacturing methods. The most efficient type is **monocrystalline (mono)** which are manufactured using the well known **Czochralski process**.

This process is more energy-intensive compared to polycrystalline (poly) and therefore more expensive to produce[17]. The Mono crystalline silicon cell is produced from pure silicon (single crystal). Since the Mono crystalline silicon is pure and defect free, the efficiency of cell is higher. Efficiency of this type of solar cell is 14-17%[17].

Polycrystalline solar cells use liquid silicon as raw material. Since the polycrystalline silicon involves solidification process the materials contain various crystalline sizes. Hence, the efficiency of this type of cell is less than Mono crystalline solar cell. Efficiency of this type of solar cell is 13-15%[17].

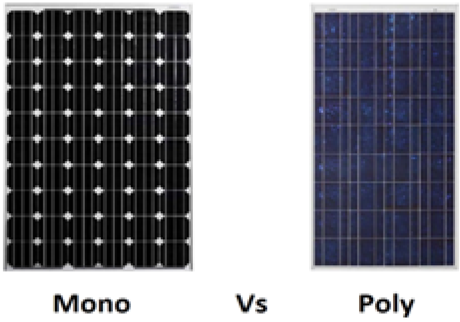


Figure 1.12 – *Types of silicon wafers: polycrystalline and monocrystalline*

Most residential solar panels contain 36, 54, 60 mono or polycrystalline cells linked together via busbars in series to generate a voltage between 30-40 volts, depending on the type of cell used. Larger solar panels used for commercial systems and utility scale solar farms contain 72 or more cells and in turn operate at a higher voltage. The electrical contacts which interconnect the cells are known as busbars and allow the current to flow through all the cells in a circuit[17].

1.5.2 Construction of pv generator

Solar panels are made using the six main components described below and assembled in advanced manufacturing facilities with extreme accuracy. We will focus on panels made using crystalline silicon solar cells since these are by far the most common and best performing solar technology available today.There are other solar PV technologies available such as thin film and screen printed cells, but we will not be discussing these as they have limited use or are still in development[17].

The components are:

- a. Solar photovoltaic cells
- b. Toughened Glass - 3 to 3.5mm thick
- c. Extruded Aluminium frame
- d. Encapsulation - EVA film layers
- e. Polymer rear back-sheet

- f. Junction box - diodes and connectors

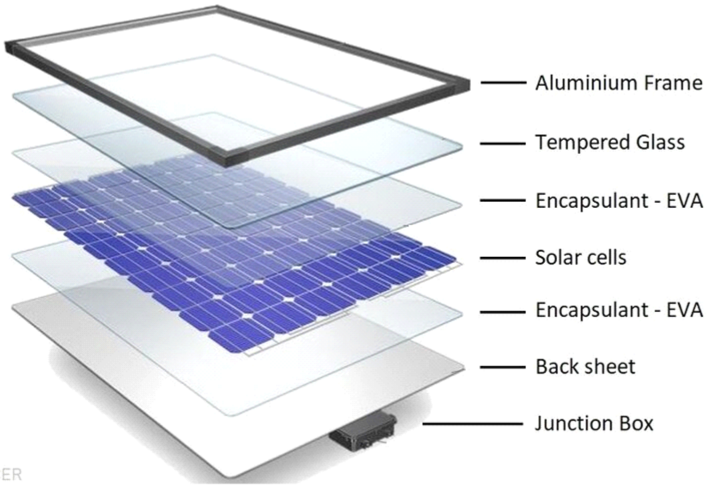


Figure 1.13 – *TConstruction of PV generator [17].*

a - Solar photovoltaic cells :

Solar photovoltaic cells or PV cells convert sunlight directly into DC electrical energy. The performance of the solar panel is determined by the cell type and characteristics of the silicon used, with the two main types being monocrystalline and polycrystalline silicon. The base of the PV cell is a very thin wafer, typically 0.1mm thick, and is made from either a positive p-type silicon or negative n-type silicon. There are many different cell sizes and configurations available which offer different levels of efficiency and performance including half-cut or split cells, multi-busbar (MBB) cells, and more recently shingled cells using thin overlapping wafer strips[17] .

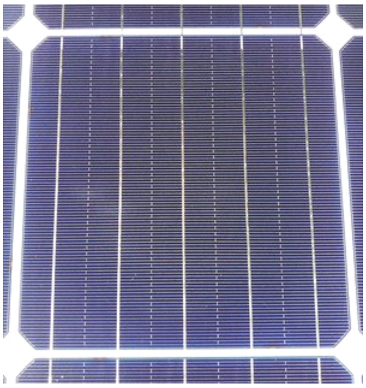


Figure 1.14 – *Solar photovoltaic cell [17].*

Most residential solar panels contain 60 mono or polycrystalline cells linked together via busbars in series to generate a voltage between 30-40 volts, depending on the type of cell used. Larger solar panels used for commercial systems and utility scale solar farms contain 72 or more cells and in turn operate at a higher voltage. The electrical contacts which interconnect the cells are known as busbars and allow the current to flow through all the cells in a circuit[17].

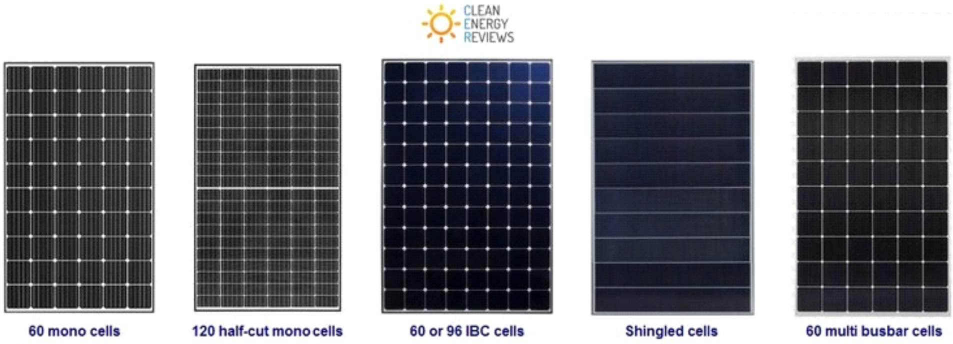


Figure 1.15 – *Number of cells in different PV panels[17]*

b- Glass:

The front glass sheet protects the PV cells from the weather and impact from hail or airborne debris. The glass is typically high strength tempered glass which is 3.0 to 4.0mm thick and is designed resist mechanical loads and extreme temperature changes. The IEC minimum standard impact test requires solar panels to withstand an impact of hail stones of 1 inch (25 mm) diameter traveling up to 60 mph (27 m/s). In the event of an accident or severe impact tempered glass is also much safer than standard glass as it shatters into tiny fragments rather than sharp jagged sections [17].

Figure 1.16 – *Front glass of PV generator*

To improve efficiency and performance **high transmissive glass** is used by most manufacturers which has a very low iron content and an anti-reflective coating on the rear side to reduce losses and improve light transmission.

c - Aluminium Frame:

The aluminium frame plays a critical role by both protecting the edge of the laminate section housing the cells and providing a solid structure to mount the solar panel in position. The extruded aluminium sections are designed to be extremely lightweight, stiff and able to withstand extreme stress and loading from high wind and external forces.
The aluminium frame can be silver or anodised black and depending on the panel manufacturer the corner sections can either be screwed, pressed or clamped together providing different levels of strength and stiffness[17].

d - EVA Film:

EVA stands for 'ethylene vinyl acetate' which is a specially designed polymer highly transparent (plastic) layer used to encapsulate the cells and hold them in position during manufacture. The EVA material must be extremely durable and tolerant of extreme temperature and humidity, it plays an important part in the long term performance by preventing moisture and dirt ingress.[17]
The lamination either side of the PV cells provides some shock absorption and helps protect the cells and interconnecting wires from vibrations and sudden impact from hail stones and other objects. A high quality EVA film with a high degree of what is known as 'cross-linking' can be the difference between a long life or a panel failure due to water ingress. During manufacture the cells are first encapsulated with the EVA before being assembled within the glass and back sheet [17].

e - Backsheet :

The backsheet is the rear most layer of common solar panels which as acts as a moisture barrier and final external skin to provide both mechanical protection and electrical insulation. The backsheet material is made of various polymers or plastics including PP, PET and PVF which offer different levels of protection, thermal stability and long term UV resistance. The backsheet layer is typically white in colour but is also available as clear or black depending on the manufacturer and module.
Dual glass panels - Some panels such as bifacial and frameless panels use a rear glass panel instead of a polymer backsheet. The rear side glass is more durable and longer lasting than most backsheet materials and so some manufacturers offer a 30 year performance warranty on dual glass panels [17].

f - Junction Box And Connectors:

The junction box is a small weatherproof enclosure located on the rear side of the panel. It is needed to securely attach the cables required to interconnect the panels. The junction box is important as it is the central point where all the cells sets interconnect and must be protected from moisture and dirt.[17]

Figure 1.17 – *Junction Box And Connectors*

f.1 Bypass diodes: The junction box also houses the bypass diodes which are needed to prevent back current which occurs when cells are shaded or dirty. Diodes only allow current to flow in one direction and a typical 60-cell panel is divided into 3 groups of 20 PV cells, each with a bypass diode for preventing reverse current. Unfortunately, bypass diodes can fail over time and may need to be replaced, so the cover of the junction box is usually able to be removed for servicing, although many modern solar panels now use more advanced long-lasting diodes and non-serviceable junction boxes [17].

f.2 Solar MC4 Connectors: Almost all solar panels are connected together using special weather-resistant plugs and sockets called MC4 connectors. The term MC4 stands for multi-contact 4mm diameter connector. Due to the extreme weather conditions, the connectors must be very robust, secure, UV resistant and maintain a good connection with minimal resistance at both low and high voltages up to 1000V. The connectors are designed to be used with the standard 4mm or 6mm double insulated solar DC cable with tinned copper multi-strand core for minimum resistance and increased durability. To correctly assemble the connectors a special crimping tool is used to crimp the multi-strand cable to the inner terminal which is then inserted and snapped into the MC4 housing [17].

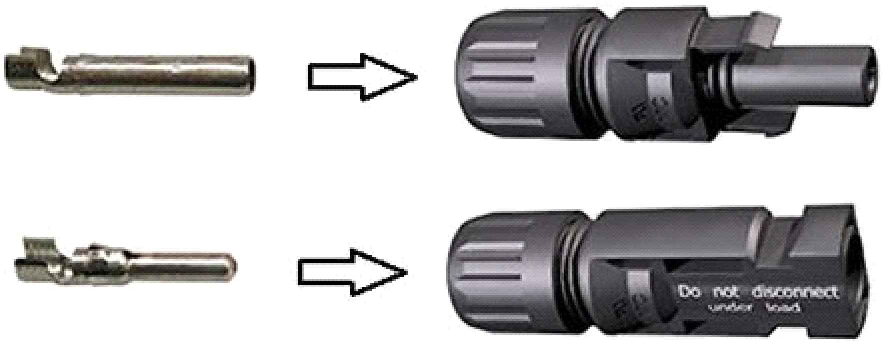


Figure 1.18 – *Solar MC4 Connectors [17].*

1.5.3 Battery

In stand-alone photovoltaic systems, the electrical energy produced by the PV array can't always be used when it is produced. Because of the demand for the energy does not always coincide with its production. During the night, or during a period of low solar irradiation, energy is supplied to the load from the battery and during the hours of sunshine, the PV system is directly feeding the load[18]. The primary functions of a storage battery in a PV system are to:

1. **Energy Storage Capacity and Autonomy:** to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand.

2. **Voltage and Current Stabilization:** to supply power to electrical loads at stable voltages and currents, by suppressing or 'smoothing out' transients that may occur in PV systems .
3. **Supply Surge Currents:** to supply surge or high peak operating currents to electrical loads or appliances [18].

Battery types and classifications

Many types and classifications of batteries are manufactured today, each with specific design and performance characteristics suited for particular applications. Each battery type or design has its individual strengths and weaknesses [18].

Some super useful concepts related to batteries are briefly explained below:

- **State of Charge (SOC)** is the available battery capacity.
- **Capacity (Cb)** is a mount of electrical energy the battery contains, measured in ampere hours (AH):

$$Cb = Ampers \times Hours$$

- **Depth of Discharge (DOD)** is the energy drawn from the battery [18].
- **Efficiency** which represents the output energy over the input one (typically 80-85%) [18]

In general, electrical storage batteries can be devided into two major categories, Primary and secondary batteries. Primary batteries can store and deliver electrical energy, but can not be recharged, so can't be used in PV systems and will be replaced by Secondary batteries which can be recharged by passing a current through it in an opposite direction to the discharge current.

There exists many types of secondary batteries based on their electrolyte structure:

- Lead-acid batteries: they use Lead and an acid electrolyte as major components hence the name. These batteries can be classified or distinguished by the electrolyte and their construction into 2 types:
  - Floaded lead acid (FLA): Flooded Lead Acid batteries are the most commonly found lead acid battery type and are widely used in the automotive industry. They provide the most cost effective solution, as the least cost per amp hour, of any lead acid battery type [19].

Normal flooded batteries require extra care and regular maintenance in the form of watering, equalising charges and keeping the terminals clean. They are also called OPZS .

- Sealed Lead-Acid Batteries (SLA) Or Valve-Regulated Batteries (VRLA): They were developped to avoid maintenance and eliminate emissions of CO2, they ae denoted by OPZV. The AGM is short for Absorbent Glass Mat, which refers to the battery technology used [19].

  Developed in the early 80s, absorbed glass mat batteries were designed as an alternative to NiCad (NiCd) batteries which were very costly.

  Today, we find this sealed battery in all manner of applications from marine to aviation and even off-grid power systems like wind and solar. They're also well-suited to advanced cars with start-stop technology and significant power demands.

  The Gel cell batteries are very similar to a traditional lead-acid battery with the addition of silica to the electrolyte to create the gel like substance.

- Lithium batteries: Lithium batteries, including both lithium-hydride and lithium-ion batteries, have become popular for consumer electronic devices because of their low weight, high energy density, and relatively long lifetimes. Lithium is extremely reactive and can burst into flames if exposed to water, but modern lithium cells use lithium bound chemically so that it cannot react easily.The types of Lithium batteries are : Lithium Cobalt Oxide, Lithium Manganese Oxide, Lithium Nickel Manganese Cobalt Oxide, Lithium Iron Phosphate, Lithium Nickel Cobalt Aluminum Oxide and Lithium Titanate [20].

The next table shows the difference between these 2 types of batteries [21].:

Table 1.2 – *difference between lead-acid and lithium batteries [21].*

Type of the battery	**Lead-acid**	**Lithium**
Efficiency	80-85	More than 95
Charge Rate	Slower (otherwise they overheat)	refill much faster
Density of Energy	Low energy density (require high number of batteries)	high energy density (require low number of batteries)
Depth of Discharge	Can't resist more than 50% (otherwise it affects lifetime of the battery)	Resist till 80%
Weight	$\approx 30kg$	$\approx 13kg$
Charge time	6-12hours	1-3 hours
Maintenance	High/low/none	none

1.5.4 The inverter

A photovoltaic inverter is a device that converts direct current into alternating current. Since the solar cell and battery are DC power sources, and the load is an AC load, an inverter is essential. According to the operation mode, photovoltaic inverters can be divided into:

- independently operating photovoltaic inverters : are used in independently operating solar cell power generation systems to provide power for independent loads and the inverter has only one entrance DC. This type of systems are called : PV-Battery-Diesel or PV-Battery systems [22].
- Grid-connected inverters : they are used in grid-connected solar cell power generation systems which works with the local utility grid so that when solar panels produce more solar electricity than the load is using the surplus power is fed into the grid. Or when the load requires more power than what the solar panels are producing then the balance of your electricity is supplied by the utility grid. The grid-connected inverter is provided with 2 entrances :AC and DC [22].

The new generation inverters contain batteries and MPPT in there structure to simplify the PV installation, the selection depends on the peak load demand meausred in KW.

1.5.5 Backup generator

The main purpose for backup power generation (that is, equipment that is normally off and in standby mode) is to improve power reliability. Backup systems quickly restore and keep parts of or all of the facility or campus powered up for minutes, hours, or days if (when) normal utility power fails for more than a few seconds [23].

The natural gas, propane, or diesel generator is the most widely used alternative source of power in facilities today. Its ability to provide continuous power as long as it has a supply of fuel makes it well-suited for providing both long- and short-term backup power[23].

Most generator-based systems are designed to automatically provide power to designated loads in the event of an interruption in service. When power is lost, the generator automatically starts. Once the generator comes up to speed, a switch automatically transfers the load from utility power to the output of the generator. Depending on the size of the generator, this transfer typically takes place in 30 seconds or less[23].

Diesel Generators are the most reliable form of emergency back-up power. Today's diesel generators emit 26 times less particulate matter than those manufactured just 10 years ago, making them an environment-friendly choice. [23]. Some of the many other benefits of selecting a new diesel power generator are:

- The engine has a dedicated fuel tank and does not rely on a pipeline or any other form to get the fuel .

- Longer lifespan, diesel burns cooler than gasoline
- Resilient under tough conditions

The next table shows the difference between the diesel and natural gas generators :

Table 1.3 – *the difference between diesel and natural gas generators [24].*

	Diesel generator set	**Natural gas generator set**
Fuel	+	-
Quick start-up	+	-
Installation costs	++	–
Emissions	–	++
simpliity	++	–
Transient capability	++	–
High load reliability	=	=

1.5.6 PV charge controller

A PV charge controller is an important part of power system that charges batteries. The purpose of the controller is usually to ensure that the batteries are properly fed and therefore safe for long-term use, where It blocks reverse current and prevents batteries from overcharging. Certain controllers will also prevent batteries from discharging and protect them from electrical overload [25].

There are various types of charge controllers xhich include shunt type charge controllers; series type charge controllers; pulse-width modulation charge controllers and MPPT charge controllers[25].

The widely used type is the MPPT charge controller with special algorithms to get the most power out of PV arrays and maintain the highest battery charge. This charge controller allows for a PV array with a much higher voltage than the battery bank's voltage and will automatically and efficiently convert the higher voltage down to the lower voltage so panels, battery bank and PV charge controller can all be equal in voltage[25].

Sizing of the charge controller is performed after the design of the PV array in order to safely handle and control the array's incoming power to prevent over- charging the batteries bank. This is achieved by selecting a charge controller based on maximum array watts and nominal battery voltage. Charge controllers are rated and sized by the solar panel array current and system voltage. They are either 12-, 24-, and 48-V controllers with amperage ratings normally from 1 to 60 amps[25].

2

Solar PV Cell Characteristics and modeling of the panel

The basic unit of an electrical energy production system using solar energy is termed as solar cell. It is a device or a structure that converts the solar energy i.e. the energy obtained from the sun, directly into the electrical energy. The basic principle behind the function of solar cell is based on photovoltaic effect.[13]

Mainly Solar cell is constructed using the crystalline Silicon which is the most important and used semiconductor and presently, it is dominating the PV market. It is preferred over others due to its simple structure and it is a good example of a typical solar cell structure. Table (2.1) shows the physical properties of the c-Si solar cells.[13]

Table 2.1 – *the physical properties of the c-Si solar cells [13]*

Name	**Description**	**Unit**
Doping Type	p-type	N/A
Thickness	300	[m]
Area	10 × 10 or 12.5 × 12.5	[cm2]
Top side doping	n + type	N/A
Back side doping	p + type	N/A
Reduced thickness	250	$[\mu m]$
Reduced Area	20 × 20	[cm2]

2.1 Basic parameters of solar PV cell

The cell parameters are given by manufacturers at the STC (Standard Test Condition). Under STC the corresponding solar radiation is equal to 1000 W/m2 and the cell operating temperature is equal to 25C. The solar cell parameters are as follows:

2.1.1 Short Circuit Current (Isc):

Short circuit current is the maximum current produced by the solar cell. This case occurs by connecting the positive and negative terminals together . The short circuit current is directly proportional to the available sunlight. The equation for the short-circuit current can be approximated as[26]

$$Isc = q \times G(Ln + Lp) \times A = Jsc \times A \tag{2.1}$$

Where,

- $Jsc[mA/cm^2]$: the short-circuit current density
- G: is the generation rate
- Ln [cm]: the electron diffusion length
- Lp [cm]: the hole diffusion length
- q [C]: elementary charge
- $A[cm^2]$: the cell area [26]

2.1.2 Open Circuit Voltage (VOC)

Open circuit voltage is the maximum voltage that the cell can produce under open-circuit conditions, where the short circuit current is equal to zero. It occurs when a high impedance load is connected to the circuit or in the of no-load[27]

$$VOC = \frac{AkT}{q} \ln(IL/Is + 1) \tag{2.2}$$

where

- A: ideality factor
- Is[A]: Dark saturation current
- K [J/K] : Boltzmann's constant (1.3805×10^{-23})
- T[K]: Temperature in kelvin

2.1.3 Maximum Power Point (MPP)

Maximum power point represents the maximum power that a solar cell can produce at the STC (i.e. solar radiance of 1000 W/m^2 and cell operating temperature of 25°C). It is measured in WPeak or simply WP. [28]

In the case of short circuit or an open circuit operating points, no power is generated. As a result, the operating point should fall into the range of maximum power output of PV cell. This operating point is determined by choosing the correct value of the connected load.[28]

The maximum power output is defined as the product of the voltage and the current at the MPP (maximum operating point)

$$Pmpp = Vmpp \times Impp \tag{2.3}$$

2.1.4 Fill factor

The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points, the power from the solar cell is zero. The "fill factor", more commonly known by its abbreviation "FF", is a parameter which, in conjunction with Voc and Isc, determines the maximum power from a solar cell.[29] The FF is defined as the ratio of the maximum power from the solar cell to the product of Voc and Isc, it is indicator of the quality of the PV cell.

$$FF = \frac{(Vmpp \times Impp)}{(Voc \times Isc)} \tag{2.4}$$

The maximum value of the fill factor is theoretically unity, and the practical one is 0.88 [29] [**?**].

2.1.5 Efficiency of solar cell

Solar cell efficiency refers to the portion of energy in the form of sunlight that can be converted via photovoltaics into electricity by the solar cell. Improving this conversion efficiency is a key goal of research and helps make PV technologies cost-competitive with conventional sources of energy.[30] The equation of solar cell power conversion efficiency is:

$$\eta = \frac{Pmax}{Pin} = \frac{(Vmpp \times Impp)}{(G \times A)} \tag{2.5}$$

where

- G: Incodent solar radiation
- $A[m^2]$: area of solar cell

2.2 PV CELL MODELING

A PV module consists of several PV cells. The physical model of a PV cell can be made equivalent to an electrical circuit in order to predict its behavior and estimate the parameters values. There are different equivalent circuits like the single diode PV cell model or the four-parameter model, the single diode detailed model or the single-exponential five-parameter model and the double diode PV cell model or double-exponential model.[31]

2.2.1 The ideal model of solar cell

The ideal model shown in figure 2.1 is PV cell equivalent circuit that consists of an ideal current source in parallel with an ideal diode. In this model, the current source represented in the figure is the current generated by the cell due to the impinging photons and is called the photocurrent Iph which flows in the opposite direction of the forward dark current[32] [**?**].

This is considered the most simplified form of a PV equivalent circuit as it does not take account of the effect of internal electrical series resistances and parallel resistance as well. The ideal mathematical model for current that derives from an individual PV cell can be expressed based on Queisser and Shockley diode equation as

$$I_{\text{cell}} = I_{Ph-}I_D = I_{Ph-}I_s\left(e^{\left(\frac{\text{qV}_{\text{cell}}+\text{qRsI}_{\text{cell}}}{\text{ATk}}\right)}-1\right) \tag{2.6}$$

where Iph is the photo current denoted in the figure 2.1 by I_L:

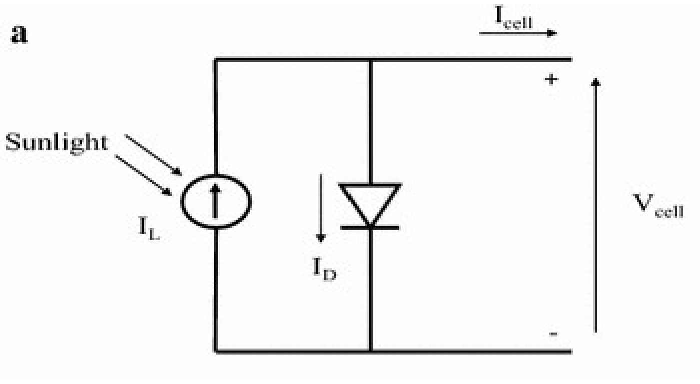


Figure 2.1 – *Ideal model of PV cell equivalent circuit[33]*

2.2.2 The Single Diode Simple Model

A second PV cell equivalent electrical circuit can be illustrated by the figure 2.2. This is called the single diode simple model or four-parameter model. It consists of a constant current source and a diode in parallel. The accuracy can be increased by adding a resistance in series; the parallel resistance is considered infinite, its effect is not taken into account.[33]

This model accounts the losses due to the contact and interconnections between cells and modules. It also considers the losses due to the module internal series resistance.

The four-parameter mathematical model describes the I-V characteristics of a PV cell and the equation is defined as:

$$I_{cell} = I_{Ph} - I_D = I_{Ph} - I_S\left(e^{\left(\frac{\mathrm{qVcell+qRsIcell}}{\mathrm{ATk}}\right)} - 1\right) \tag{2.7}$$

where,Rs (Ω) is the internal series resistance.

Recent conducted research shows that the ignorance of the shunt resistance effects on four_parameter model is not adequate in experimental I-V and P-V data fitting in the current-source operation. This work also demonstrates that it does not satisfactorily reflect the effect of high temperature on the current. In comparison with five-parameter model it is found that in the four-parameter model has less accuracy prediction of current[33].

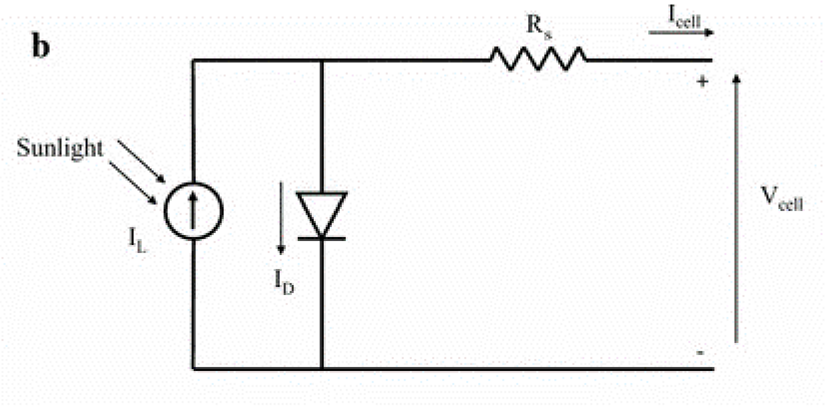


Figure 2.2 – *Four-parameter model of PV cell equivalent circuit[33]*

2.2.3 The Single Diode Full Model (Five-parameter model)

The single diode full model is known as single diode detailed model or single-exponential five_parameter model. A parallel resistance is used in this model in order to improve the accuracy. It also takes account the losses due to the leakage current in the junction and within the cell due to crystal imperfections and impurities.The electrical equivalent circuit of PV cell single diode full model is shown in figure 2.3. This model is considered one of the most complex models.

The five-parameter model is based on Iph , Id, A and the two resistances Rs and Rp [33].

The mathematical model of the five-parameter model can be defined as

$$I_{\text{cell}} = I_{Ph} - I_D = I_{Ph} - I_s \left(e^{\left(\frac{q \ \text{Vcell+lcellqRs}}{\text{ATK}} \right)} - 1 \right) - \frac{\text{V}_{\text{cell}} + \text{I}_{\text{cell}}\text{Rs}}{\text{Rp}} \tag{2.8}$$

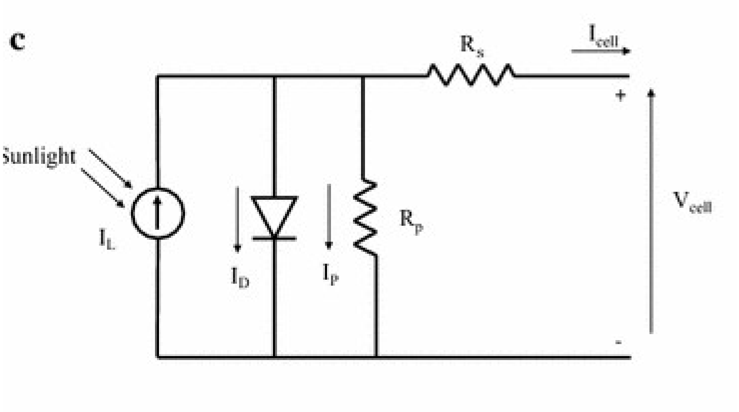


Figure 2.3 – *Five-parameter model of PV cell equivalent circuit[33].*

2.2.4 The Double Diode Model

The double diode model is the known as double-exponential model as well. It is nothing but an addition of the diode to the single diode full model
In the single diode full model it predicts that there is no effect of the recombination loss in the depletion region. But, this recombination loss must be taken into consideration in a practical solar cell. That's the reason introducing the double diode model [33] .
This model is characterized by its high accuracy though it is relatively complex and suffers from low computational speed. Specifically at the low irradiation level it has been shown that the double diode model has more accuracy in representing the behaviour of a PV module when compared with the single diode model.[33]
The basic equation of this model is given by the following equation :

$$I_{\text{cell}} = I_{Ph} - I_{D1} - I_{D2}$$

$$I_{D1} = I_{s1}\left(e^{\left(\frac{\mathrm{qV+I_{cell}qRs}}{\mathrm{A1\times Tk}}\right)} - 1\right)$$

$$I_{D2} = I_{s2}\left(e^{\left(\frac{\mathrm{qV+I_{cell}qRs}}{\mathrm{A2\times Tk}}\right)} - 1\right)$$

$$I_{\text{cell}} = I_{Ph} - I_{s1}\left(e^{\left(\frac{\mathrm{qV+I_{cell}qRss}}{\mathrm{A\times Tk}}\right)} - 1\right) - I_{s2}\left(e^{\left(\frac{\mathrm{qV+I_{cell}qRs}}{\mathrm{A2\times Tk}}\right)} - 1\right) - \frac{\mathrm{V + I_{cell}Rs}}{\mathrm{Rp}} \tag{2.9}$$

Both diode reverse saturation current can be defined as follows:

- I_{s1} : the reverse saturation current for first diode.
- I_{s2} : the reverse saturation current for second diode.
- A1: the diode ideality factor for first diode.
- A2: the diode ideality factor for second diode.
- The main challenge of the double diode model is to estimate the values for all the model parameters within a reasonable simulation time.[33]

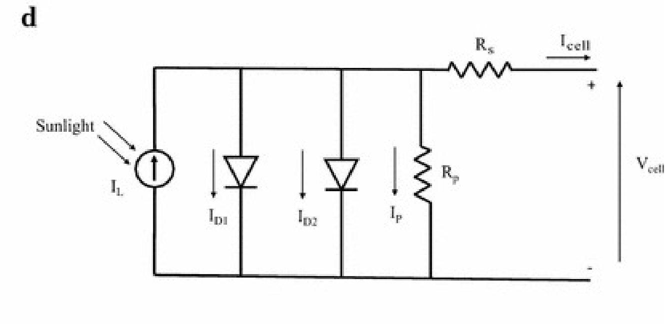


Figure 2.4 – *Double Diode model of PV cell equivalent circuit*

2.3 PHOTOVOLTAIC MODULE AND ARRAY MODELING

Each silicon PV cell generates less than 1 volt DC current. The PV cells are connected in series or in parallel (in series to increase the voltage capabilities, and in parallel to increase the current capabilities). Thirty six (36) cells in series will provide a large enough voltage to charge a 12 VDC battery, and 72 cells would be suitable for 24 VDC battery. The modules can be connected to form a PV array. The larger the array the more power is generated and more appliances can be operated.[33]

The PV efficiency is sensitive to small change in Rs, but insensitive to variation in Rp. The equivalent circuit for the solar module arranged in Np parallel and Ns series is shown in figure 2.5.

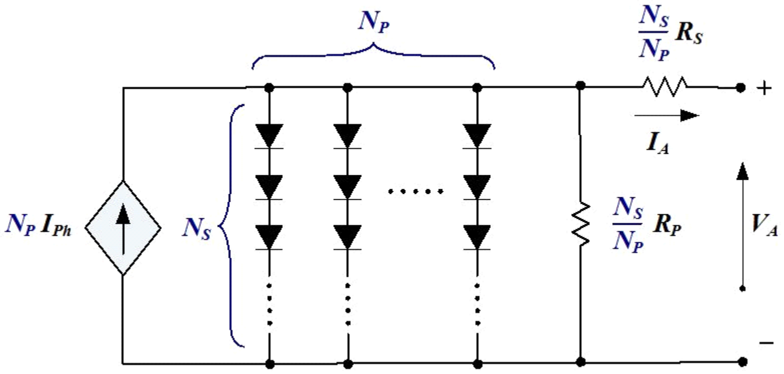


Figure 2.5 – *Photovoltaic Module and Array equivalent circuit*

In order to describe the I-V characteristic of PV panel, we have just defined and developed a model on the panel photovoltaic, we must borrow the basic equations taken from the theory of semiconductors.

2.3.1 Photo Current (Iph)

The current generation in a solar cell is known as 'light-generated current' or solar photo current and it has two main processes. The photo current usually relies on the cell temperature (T) and solar irradiance (G).[13] It is shown by the following equation:

$$Iph = [Iph, n + [Ki(T - \text{ Tref })]] \times \left[\frac{G}{\text{Gref}}\right] \tag{2.10}$$

Where

- $Iph_, n[\text{ A}]$: Nominal photonic current under nominal conditions.
- $Ki[\text{ A/K}]$: Temperature coefficient of the short-circuit current.
- T[K] : Room temperature.
- Tref [K] : Reference temperature $(298, 15\text{ K})$.
- $\text{G}\left[\text{W/m}^2\right]$: Irradiation.
- $\text{Gref}\left[\text{W/m}^2\right]$: Reference irradiation $\left(1000\text{ W/m}^2\right)$

2.3.2 Saturation Current of Diode (Is)

The dependency of diode saturation current on cell temperature can be defined by the following equation:[13]

$$Is = Is_{\iota}, n \times \left(\frac{\text{T}}{\text{Tref}}\right)^3 \times e^{\left[\left(\frac{\left(\frac{9\ \text{EB}}{\text{AXk}}\right.}{}\right)\left(\frac{1}{\text{Trof}} - \frac{1}{T}\right)\right]} \tag{2.11}$$

$$Is = [Is_, n + Ki(T - \text{ Tref })] \times \left(\frac{G}{\text{Gref}}\right) \tag{2.12}$$

where $Is, n[\text{ A}]$: nominal saturation current given by the following equation:

$$\text{Is}, n = \frac{\text{Isc,n}}{e^{\frac{V_{0c,n}}{AVt,n}} - 1} \tag{2.13}$$

- Is,n $[A]$: Nominal short-circuit current under standard conditions $\left(\text{G} = 1000\text{w/m}^2 \text{ and T} = 25\ ^\circ\text{C }\right)$.
- Eg[eV] : Semiconductor gap energy
- Voc, [V] : Panel open circuit voltage (given by the manufacturer)
  $Vt, n = \frac{\text{Ns}\times\text{kT}}{\text{q}}[\text{V}]_i$ is the thermal voltage with Ns cells connected in series
- q[C] : the electron charge $\left(1.602 \times 10^{-19}\text{C}\right)$

- Ns: Number of cells connected in series
- A: ideality constant of the PN junction
- K[J/K]: Boltzmann constant $\left(1.3805 \times 10^{-23}\right)$

2.3.3 Series Resistance (Rs) and Shunt Resistance (Rp)

There are another two parameters in the PV system: the series resistance and the shunt resistance. The shunt resistance is also known as parallel leakage resistance. The approximation of shunt resistance given by:[13]

$$\mathrm{Rp} > 10 \times \frac{\mathrm{Voc}}{Isc}$$

the series resistance has no dependency on irradiation and temperature in all conditions, so it can be defined as

$$\mathrm{Rs} < 0.1 \times \frac{\mathrm{Voc}}{Isc}$$

where Isc represents the short-circuit current and Voc represents the open circuit voltage in the system.[13]

$$Rs = Rs, ref$$

The above equation states that the series resistance in referred condition is equal to the series resistance in the circuit.
the practical significance of parallel resistance is related to partial shading. However, the practical significance of series resistance is in impedance matching. It is important to consider the value of the series resistance for regulating the impedance of the load circuit for biasing the solar cell on maximum power point. Based on maximum power transfer theory, the internal resistance of the power source's Thevenin equivalent circuit should be equal to the load resistance for working the PV on maximum power point.[13]

2.3.4 Ideality Factor (A)

There are many moving carriers across the junction. Ideality factor of a diode is responsible for different operations of the moving carriers. The value of the diode ideality factor varies in accordance with its characteristics: if the movement technique is purely diffusion then the value of n is 1; if it has the primary recombination in the depletion region then the value for A is approximately 2. [34]
In a PV system the ideality factor is considered one of the unknown parameters while in the extraction process, but it can be found if the other parameters value is known. The value of ideality factor does not depend on the operating conditions; it is equal to the value of the referred ideality factor at standard reference conditions.[34]

There are several methods that allow us to identify this value, which is also totally pragmatic, for this it is mandatory to base on real values that are given by the manufacturer in order to converge towards the right value, however it can be chosen arbitrarily because its variation only improves the model accuracy.

$$A = \frac{\left(\mathrm{Kv} - \frac{\mathrm{Voc,n}}{\mathrm{Tref}}\right)}{\left(\mathrm{Ns} \times \mathrm{Vtn} \times \left(\frac{\mathrm{Ki}}{\mathrm{Iphn}} - \frac{3}{\mathrm{Tn}} - \frac{\mathrm{Egap}}{\mathrm{K}\times\ \mathrm{Tref}^{2}}\right)\right)} \tag{2.14}$$

Where

Kv[A/K] :Temperature coefficient of the open circuit voltage.

$$I_A = NpI_L - NpI_o\left(e^{\left(\frac{\mathrm{q}\left(\frac{\mathrm{VA}}{\mathrm{Ns}}\right)}{\mathrm{ATk}} + \frac{\mathrm{q}\left(\frac{\mathrm{I_{cell}}Rs}{\mathrm{Np}}\right)}{\mathrm{Np}}\right)} - 1\right) - \frac{\frac{\mathrm{Np}}{\mathrm{Ns}}VA + I_{cell}Rs}{\mathrm{ATk}} \tag{2.15}$$

- IA : panel output current
- Ns: number of cells in series
- VA: the equivalent voltage across the panel
- Np: number of cells in parallel
- I_s : the saturation current from a single solar cell

2.4 PARAMETERS EXTRACTION OF A PV CELL

The determination of the parameters of the photovoltaic generator in our case study is the **JAM72S30-540/MR** , it is based on the data presented by the manufacturer under the standard conditions $(25°\mathrm{C}, 1000\ \mathrm{W/m^2})$ in the following data sheet:

Table 2.2 – *Data sheet of the JAM72S30-540/MR panel*

Max power Pmax,e	540 W
Voltage at max power (Vmp)	41.64 V
current at max power (Imp)	12.97 A
Open circuit voltage (Voc)	49.60 V
Short circuit current (Isc)	13.86 A
Cell type &Ns Monocrystalline	144
Voltage temperature coefficient Ky	$-0.275\%/°\mathrm{C}$
Current temperature coefficients Ki	$0.045\%/°\mathrm{C}$

The aim of this work is to present a new five-parameter estimation method for the single-diode model (Rp-model) of the photovoltaic multi-crystalline panel by calculating the five unknown parameters: Ipv Io, Rs, Rp, and A.
The proposed fixe-parameters estimation method consists of two steps:

Step 1: Estimation of A and Rs, Parameters:

In the first step, the Rs-model is used without considering the Rp resis- tance, so the equation (2.8) becomes

$$I_{\text{cell}} = I_{Ph} - I_s \left(e^{\left(\frac{\mathrm{V+IRs}}{\mathrm{Vt}} \right)} - 1 \right) \tag{2.16}$$

By imposing the short circuit condition with = Isc and = 0 we get:

$$I_{\text{cell}} = I_{ph} - I_s \left(e^{\left(\frac{\mathrm{(Rs}}{\mathrm{Vt}} \right)} - 1 \right) \tag{2.17}$$

by imposing the open circuit condition with = 0 and V = Voc, the equation (2.16) becomes:

$$0 = I_{Ph} - I_s \left(e^{\left(\frac{\mathrm{V}_{oc}}{\mathrm{v_t}} \right)} - 1 \right) \tag{2.18}$$

So the photo current is equal to:

$$I_{Ph} = I_s \left(e^{\left(\frac{v_{oc}}{v_t} \right)} - 1 \right) \tag{2.19}$$

Therefore, the equation to calculate Io is found replacing the photocurrent equation 2.19 in the equation 2.17 and the inverse current of the diode is equal to:

$$I_s = \frac{I_{sc}}{e^{\left(\frac{Voc}{Vt} \right)} - e^{\left(\frac{NS15c}{Vt} \right)}} \tag{2.20}$$

The equation of the resistance Rs is obtained by imposing that in the maximum power point, the derivative of the power with respect to V is zero, and by replacing Ipv and Is with Equations 2.19 and 2.20 the final expression of Rs is:

$$Rs = \frac{Voc}{\mathrm{Imp}} + \frac{V_t}{\mathrm{Imp}} \ln \left(\frac{\mathrm{Vt}}{\mathrm{Vt} + \mathrm{Vmp}} \right) - \frac{\mathrm{Vmp}}{\mathrm{Imp}} \tag{2.21}$$

Step 2: Estimation of Rp **Parameters**

Unfortunately, the Rs-model is not accurate, and the maximum power point found with the new values of A and Rs does not match with that reported by the manufacturer. For this reason, the Rp resistance is introduced using the Rp-model with Equation 2.22

The procedure is the same as in step 1 with iterations, but this time, the iterated parameter is Rp. Rp is. extracted which is worth:

$$Rp = \frac{Vmp(Vmp + RsImp)}{Vmplpv - Vmplo \left(e \left(\frac{(mp+RsImp}{Vt} \right) - 1 \right) - P\max} \tag{2.22}$$

The proposed estimation method has been implemented in Matlab environment using a single diode Equation giving us the following parameters.

Table 2.3 – *Photovoltaic cell parameters*

Iph	13.86 A
Io	2.090700e-05 A
Rs	0.027153 Ω
Rp	1117.750316 Ω
A	1

2.5 ESTABLISHMENT OF THE SIMULATION MODEL IN MATLAB/SIMULINK:

From what preceded, we base ourselves on the equations that govern the system and we equip ourselves of the calculated parameters, one can construct the following Simulink scheme which describes the phenomena phetexoltaic conversion with irradiation and temperature and at the output we harvest the different electrical quantities namely the current, the voltage and power:

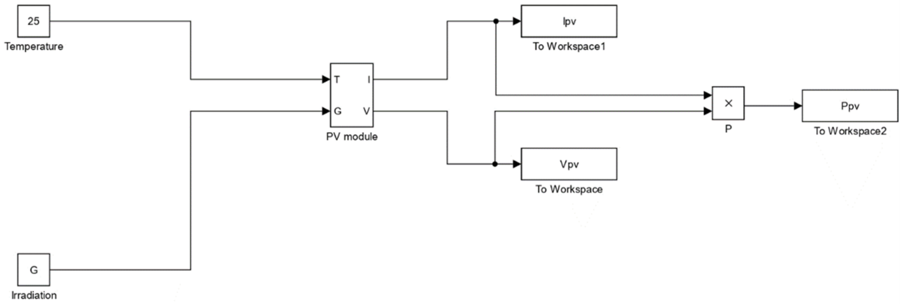


Figure 2.6 – *Photovoltaic panel model*

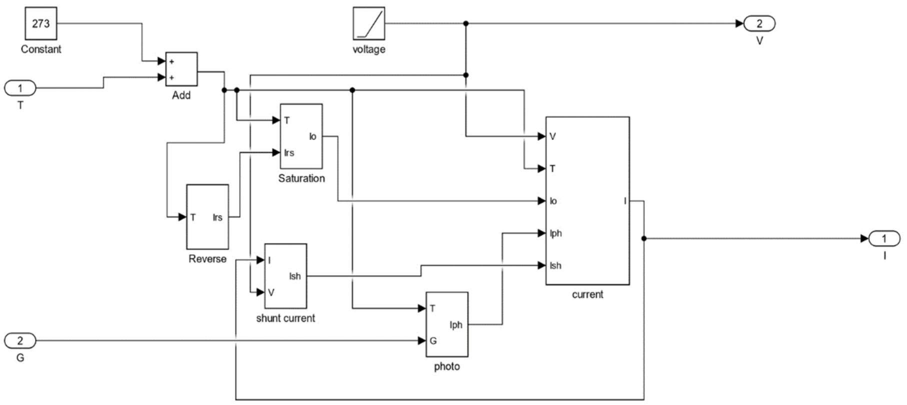


Figure 2.7 – *Photovoltaic panel subsystem*

2.5.1 Simulation result

a. I-V (Current-Voltage) and P-V (Power-Voltage) curves of a PV Cell under Solar Radiation Variation Effects

Building the model in MATLAB/Simulink allowed us to perform simulations ,as the solar radiation is not uniform in all the places of the Earth, the behaviours of a PV cell varies with the place its placed on.

Figure (2.8)and Figure (2.9) present the results of the simulation of the PV module on different irradiation values G (1000 W/m^2 ,800 W/m^2 ,600 W/m^2 ,400 W/m^2, 200 W/m^2) with the maintenance of a constant temperature at 25°C.

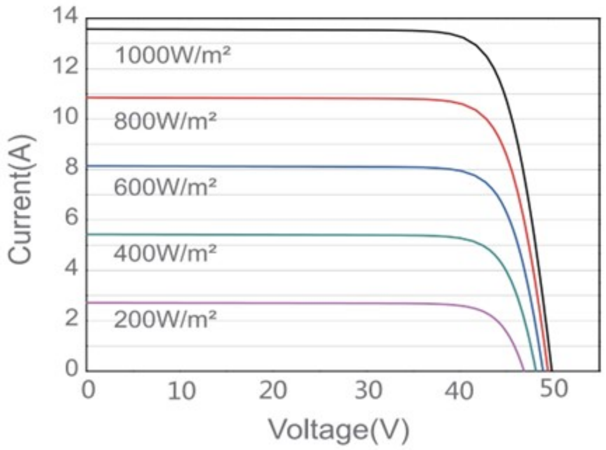


Figure 2.8 – *Current-Voltage characteristic under different illuminations at a temperature T=25°C*

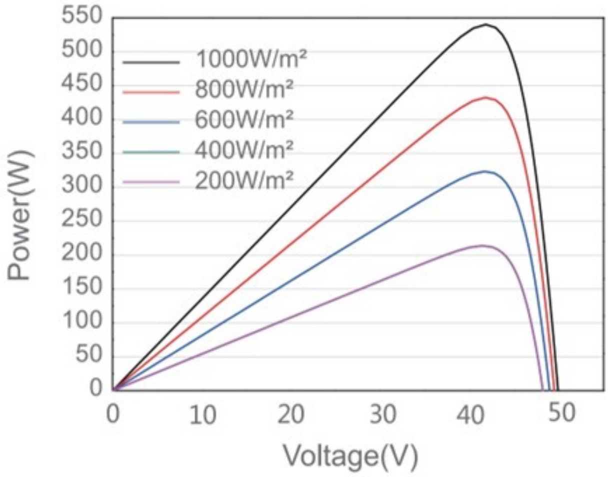


Figure 2.9 – *Power-Voltage characteristic under different illuminations at a temperature T=25°C*

We see that:

- with the increase of irradiance the cell short circuit current (Isc) and cell open circuit voltage (Voc) both increases, but the increment in short circuit is much higher
- while we increase the solar radiation there is also an increase in the P-V curve.

b. I-V (Current-Voltage) curve of a PV Cell under Temperature Variation Effects The temperature has an effect on the efficiency of a solar cell as the voltage is highly dependent on the cell and ambient temperature.

Figures (2.10) present simulation curve showing the temperature variation effect at T=(10°C, 25°C ,40°C ,55°C, 70°C) on the I-V and P-V curves of a PV cell for constant solar irradiation G= 1000 W/m^2.

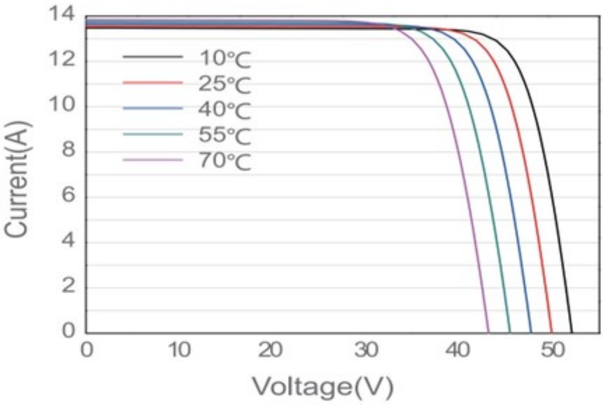


Figure 2.10 – *Current-Voltage characteristic for different temperature values under an illumination of 1000 W/m*^{2}

We note that:

- The increase of the cell temperatures causes the decrease of the cell open circuit voltage and short circuit current decreases slightly too.

PHOTOVOLTAIC SYSTEM SIZING USING SIMULATOR iHOGA

3

3.1 INTRODUCTION TO « iHOGA »

iHOGA (Improved Hybrid Optimization by Genetic Algorithms) is a software developed in C++ by researchers of the University of Zaragoza (Spain) for the simulation and optimization of Electric Power Generation Systems based on Renewable Energies , off-grid (stand-alone systems) or grid-connected systems.

The software can model systems with electrical energy consumption load (DC and/or AC) and/or Hydrogen, as well as consumption of water from tank or reservoir previously pumped.

It can include different components: photovoltaic generator (included bifacial and CPV), wind turbines, hydroelectric turbine (with or without pumped hydro storage), auxiliary generator (diesel, gasoline . . .), inverter or inverter-charger, batteries (lead-acid or li-ion), charger and batteries charge controller as well as components of hydrogen (electrolyzer, hydrogen tank and fuel cell) [35].

The program can simulate and optimize **off-grid systems** of any size up to 5 MW. The iHOGA PRO version includes all the program following features:

- Buy/sell electricity to the AC grid.
- High and low power projects
- Multiperiod simulation and optimization
- PV generator divided in two zones at different slope and azimuth
- PV solar tracking (1 or 2 axis)
- Battery charge / discharge control on systems connected to the AC grid
- Multiple AC generators in parallel

- Obtain optimal PV modules slope / optimize panel slope together with all other variables to be optimized
- Battery cycle number dependence on temperature

3.2 Types of systems

Two different kinds of projects can be simulated and optimized: low power or high power systems.

3.2.1 Low power systems

They include off-grid or grid-connected systems, where the load is not too high and we want to cover the electrical demand at the minimum cost. The system can be DC or AC coupled. Power is measured in W, monthly or annual energy in kWh and costs in the monetary unit (Euro, Dollar or any other).

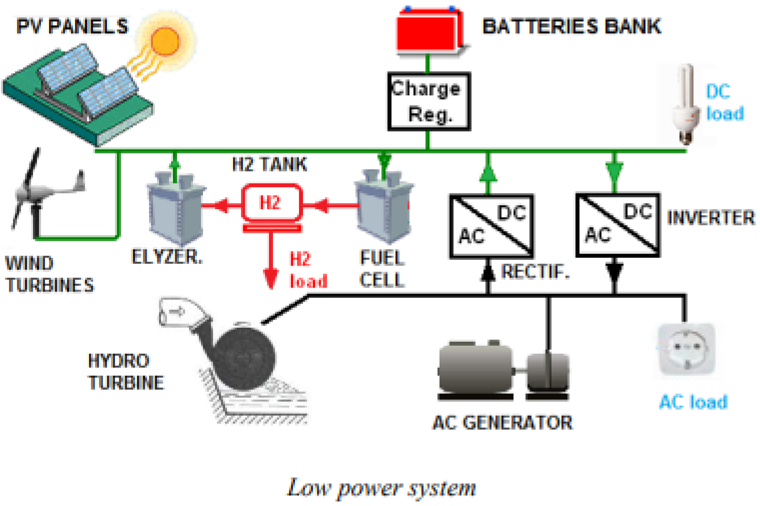


Figure 3.1 – *Low power systems diagram[35]*

3.2.2 High power systems

They include grid-connected systems, where a high load must be covered (big farm or a village), where we want to cover the demand at the minimum cost, or generator systems (without any load) where we want to maximize the benefits of selling electricity to the grid. The system is AC coupled. Power is measured in kW, monthly or annual energy in MWh and costs in kilo monetary units (k€, k$ or any other).[35]

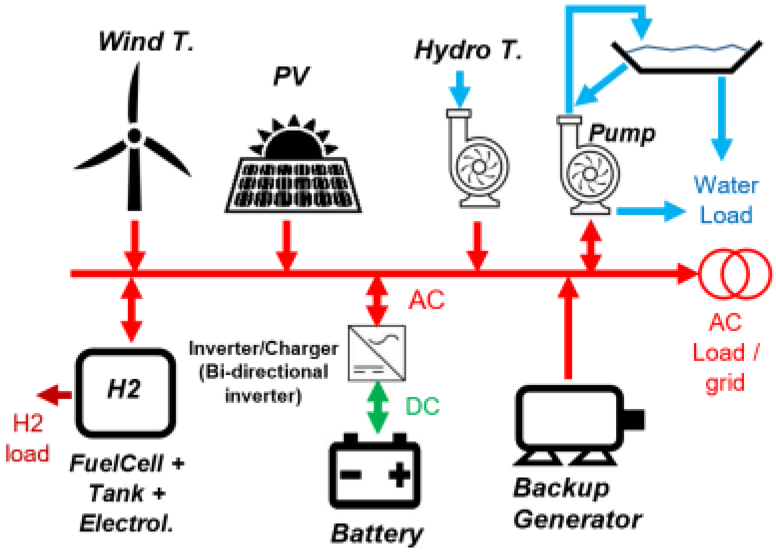


Figure 3.2 – *High power systems diagram*

Our project will be based on low power systems : off-grid type.

3.3 OPTIMIZATION

the software allows for multi-objective optimization depending on the type of the system: High power system: In generating systems, where all or almost all the electricity is sold to the AC grid, optimization is achieved by maximizing the total incomes during the system lifetime **(Net Present Value, NPV).**

Low power system: there is the financial optimization where we try to cover the load demand, by minimizing total system costs throughout the whole of the useful lifespan of the system, where those costs are referred to or updated for the initial investment **(Net Present Cost, NPC).[35]**

Additional variables may also be minimized like the total equivalent CO2 emissions generated by the AC generator fuel (diesel or gasoline), as well as those generated in the manufacture, transportation. Unmet load (energy not served), the Human Development Index (HDI) and job creation (these two objectives are maximization), optimizing temporary installations over a period of time by minimizing the associated cost (transport + operation and maintenance + degradation) or the weight to be transported.

The program can optimize the combination of elements and also the control stratetgy (which determines when batteries or diesel genset must supply the load, to what level the batteries should be charged.

The program includes **multiperiod simulation and optimization** (considering the **increase in load** and the **decrease of electricity production from the renewable sources** during the years of the system lifetime), multi-objective optimization, simulation in time steps from 1 minute to 1 hour, sensitivity analysis, probability analysis (Monte Carlo simulation), etc ...

3.4 Loads

Different system loads are possible:

- Electric AC loads: electric devices using AC electric energy
- Electric DC loads: electric devices using DC electric energy.
- Hydrogen loads (production of H2 for external consumption, e.g., electricity-powered fuel-cell vehicles). Only in PRO+ version
- Water pumping load[35]

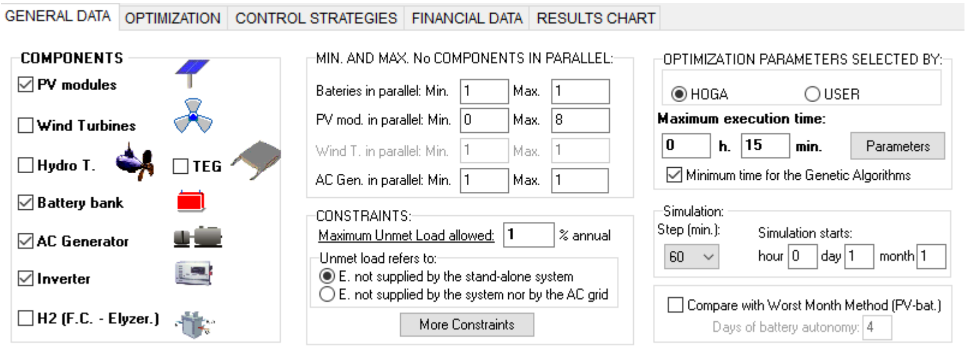
3.5 Energy storage

It is usually carried out using batteries:

1. Lead-acid batteries :they are divided into two types:
    - the classical OGi batteries (flat-plate with a flooded electrolyte)
    - tubular batteries :they are most suitable for solar systems, and include the OPZS (flooded electrolyte) and the OPZV (gel, maintenance free).
2. Lithium batteries : (the most common LiFePO4) can be an economical alternative because they support many more cycles than lead-acid.

3.6 Main screen tabs

On the main screen of the software there are 5 tabs where data must be entered (in the 5th tab we can see the results of the optimization as a graph):



COMPONENTS

☑ PV modules
☐ Wind Turbines
☐ Hydro T.
☐ TEG
☑ Battery bank
☑ AC Generator
☑ Inverter
☐ H2 (F.C. - Elyzer.)

MIN. AND MAX. No COMPONENTS IN PARALLEL:

Bateries in parallel: Min. 1 Max. 1
PV mod. in parallel: Min. 0 Max. 8
Wind T. in parallel: Min. 1 Max. 1
AC Gen. in parallel: Min. 1 Max. 1

CONSTRAINTS:

Maximum Unmet Load allowed: 1 % annual
Unmet load refers to:
● E. not supplied by the stand-alone system
○ E. not supplied by the system nor by the AC grid

OPTIMIZATION PARAMETERS SELECTED BY:

● HOGA ○ USER
Maximum execution time: 0 h. 15 min.
☑ Minimum time for the Genetic Algorithms

Simulation:
Step (min.): 60
Simulation starts: hour 0 day 1 month 1

☐ Compare with Worst Month Method (PV-bat.)
Days of battery autonomy: 4

Figure 3.3 – *Main screen tabs of the software*

3.6.1 GENERAL DATA

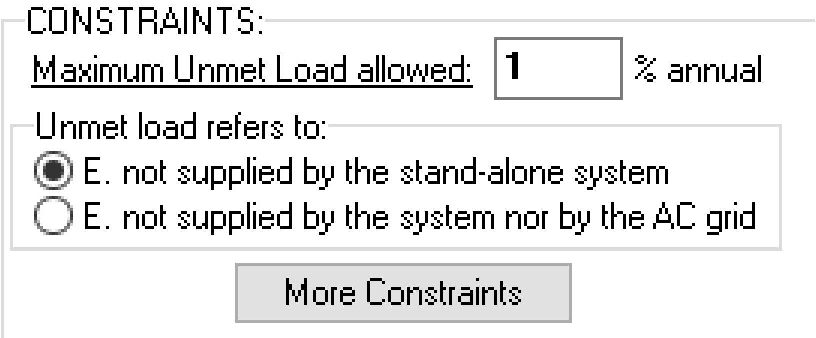
In this tab we must enter the most important data

1. **Components :** Which components can be included in the system (PV generator, AC generator, H2 tank. . . .)

2. **Minimum and maximum number of cmponents in parrallel:** Minimum and maximum number allowed for batteries, PV modules, wind turbines and AC generators parallel must be provided (given by the simulator)
Remark: The parallel connection of more than two batteries is often problematic, so the maximum number allowed in parallel battery should be 1 or exceptionally 2.

3. **Constraints :** The user must determine maximum percentage of annual Unmet Load of energy required by the system refered as :

   - Energy not supplied by the stand-alone system including the renewable sources, the batteries, the AC generator and the fuel cell. It will be possible to purchase energy from the AC grid by seecting the max energy to be purshased.
   - Energy not supplied by the stand-alone system nor by the AC grid, it can't be covered by any means.



CONSTRAINTS:

Maximum Unmet Load allowed: 1 % annual

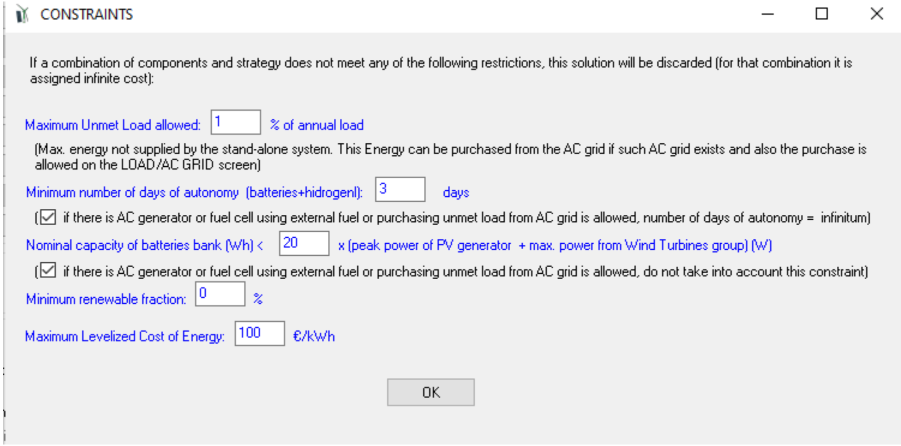
Unmet load refers to:

● E. not supplied by the stand-alone system

○ E. not supplied by the system nor by the AC grid

Figure 3.4 – *Constraint of maximun unmet load*

Remark: we avoid putting 0% , it is preferable to put 0.01%
More constraints are present in the next figure:



If a combination of components and strategy does not meet any of the following restrictions, this solution will be discarded (for that combination it is assigned infinite cost):

Maximum Unmet Load allowed: 1 % of annual load

(Max. energy not supplied by the stand-alone system. This Energy can be purchased from the AC grid if such AC grid exists and also the purchase is allowed on the LOAD/AC GRID screen)

Minimum number of days of autonomy (batteries+hidrogenl): 3 days

(☑ if there is AC generator or fuel cell using external fuel or purchasing unmet load from AC grid is allowed, number of days of autonomy = infinitum)

Nominal capacity of batteries bank (Wh) < 20 x (peak power of PV generator + max. power from Wind Turbines group) (W)

(☑ if there is AC generator or fuel cell using external fuel or purchasing unmet load from AC grid is allowed, do not take into account this constraint)

Minimum renewable fraction: 0 %

Maximum Levelized Cost of Energy: 100 €/kWh

Figure 3.5 – *Extra constraints*

The minimum number of days of autonomy and nominal capacity of batteries are neglected in the presence of AC generator.

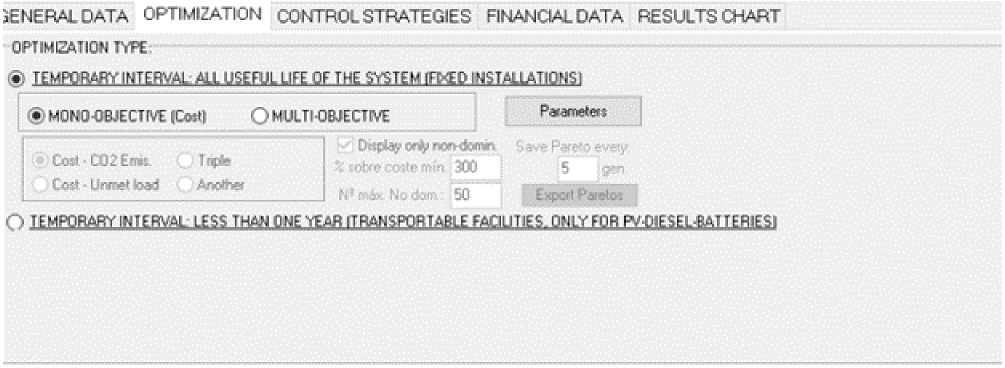
3.6.2 OPTIMIZATION TAB

In this tab the TEMPORARY INTERVAL must be chosen first:

- Fixed installations (the entire useful life of the system is considered) : the optimization can be :
  (a) mono-objective: where the program will seek the most economical solution (lower total cost over the lifetime, NPC)

(b) multi-objective: there will be double or triple multiobjective optimizations to be selected in addition to the minimization of total cost, like reduction of CO2 emisions, unmet load . Solutions are better when they are “dominated” by fewer alternative solutions in our case, better solutions offer a lower NPC, and lower levels of CO2 emissions or unmet load or higher HDI or higher job creation.

It is advisable to let iHOGA select the parameters of the optimization by entering the maximum execution time (15min), and if the time allowed by us is lower than the time needed for the enumerative method, iHOGA will use the genetic algorithms to optimize the system.



OPTIMIZATION TYPE:

● TEMPORARY INTERVAL: ALL USEFUL LIFE OF THE SYSTEM (FIXED INSTALLATIONS)

● MONO-OBJECTIVE (Cost) ○ MULTI-OBJECTIVE

● Cost - CO2 Emis. ○ Triple

○ Cost - Unmet load ○ Another

☑ Display only non-domin.

% sobre coste min: 300

Nº máx. No dom.: 50

Save Pareto every: 5 gen.

○ TEMPORARY INTERVAL: LESS THAN ONE YEAR (TRANSPORTABLE FACILITIES, ONLY FOR PV-DIESEL-BATTERIES)

Figure 3.6 – *Types of optimization*

- Temporary installations for transportable systems that are transported from one place to another in less than one year(transportable facilities, only for PV-DIESEL-BATTERIES) : the main objectives are to:

1. **Minimize the weight to be transported (round trip)** where the following data must be set: time when the temporary installation begins, the number of days that it works, the distance to which the installation is to be transported, the diesel density (kg/m3) with the minimum amount of litres of fuel we want to set, the transport cost in the monetary unit per ton and km, as well as the extra ageing (degradation) of the PV modules, batteries, AC generator and inverter in percentage.

2. **Minimize the total cost of transport**

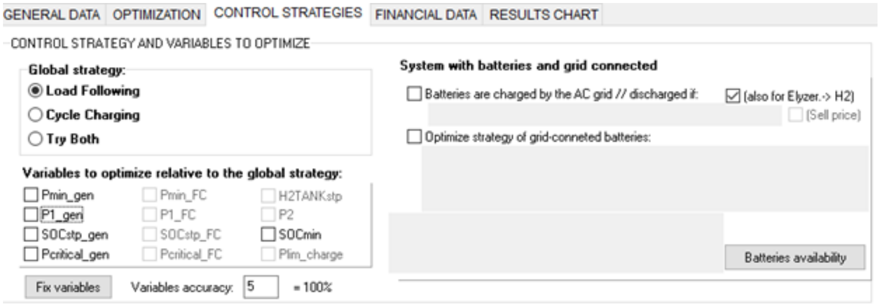
- Optimization parameters : can be selected by iHOGA or the user. For the user, the type of optimization must be specified (are the parametrs) :

1. **Optimization of components** in the main algorithim by selecting the optimization method :evaluate all algorithims (enumerative method) or genetic algorithms, the second one includes some parameters to be fixed like generations, population... . We are allowed to work only with the enumerative method.
2. **Optimization of strategy** in the secondary algorithm which has the same parameters as the previous one.

3.6.3 CONTROL STRATEGIES TAB

This tab defines the overall control strategy ,the variables to be optimized and batteries in grid-connected systems .

1. **The overall control strategy :** it is important for systems with load (off-grid systems or grid-connected systems with high load), where we have batteries and backup generator and/or hydrogen storage. Global strategy and its variables are not used for systems without load consumption (grid-connected generating systems). We can choose between two global control strategies:
    - **Load following strategy :** In this strategy, in systems that include batteries and generator (diesel, gasoline ...), when energy from renewable sources is not enough to meet the whole load, the rest energy is covered by the battery bank. If the batteries cannot meet the whole demand, the generator will run to cover the rest of the load.
    - **Cycle charging :** The difference with the previous strategy is that when the generator must run because load cannot be met by the batteries, it will run at its rated power, so that the extra power will be used to charge the batteries. If " Continue up to $SOC_{stp-gen}$" is activated, the generator will run at rated power until the State Of Charge (SOC) of the batteries reach the value of the variable $SOC_{stp-gen}$, which by default is 100%.
    - **Try both :** If we select "Try both", the software will consider the two strategies. However, in this case, some variables may not be optimized $P_{critical-gen}$ and $P_{critical-FC}$



Global strategy:
● **Load Following**
○ **Cycle Charging**
○ **Try Both**

Variables to optimize relative to the global strategy:
☐ Pmin_gen ☐ Pmin_FC ☐ H2TANKstp
☐ P1_gen ☐ P1_FC ☐ P2
☐ SOCstp_gen ☐ SOCstp_FC ☐ SOCmin
☐ Pcritical_gen ☐ Pcritical_FC ☐ Plim_charge

Variables accuracy: 5 = 100%

System with batteries and grid connected
☐ Batteries are charged by the AC grid // discharged if: ☑ (also for Elyzer.-> H2)
☐ (Sell price)
☐ Optimize strategy of grid-conneted batteries:

Figure 3.7 – *control strategy and variables to optimize*

2. **The variables to be optimized :** The variables to be optimized must be selected with a maximum number of 12, and the exact number depends upon the system elements selected. In the case of stand-alone system the following variables are selected :

    - In the load following strategy the $P_{critical-gen}$ variable is set to $0W$. That is, the generator never work at rated power to try to charge the batteries and the $SOC_{stp-gen}$ is equal to SOC_{min}.

      To optimize these variables , if the software has provided some values as an exemple $P_{critical-gen} = 1000W$

      and $SOC_{stp-gen} = 75\%$ than if :

      - 0 < $P_{loaddemand} < P_{critical-gen}$: the AC generator will run at rated power to supply the load and charge the batteries for one hour till 75% of SOC and the strategy really will be "cycle charging" without continue up to $SOC_{stp-gen}$ (SOCstp is the max)

      $P_{loaddemand} > P_{critical-gen}$: the AC generator will supply the load demand only "load following" .

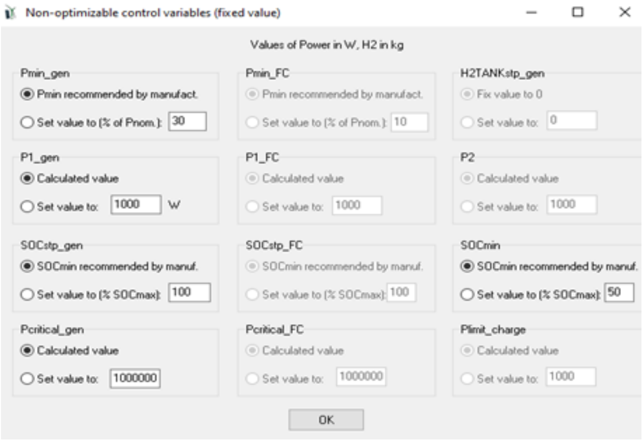
    - In the cycle charging strategy the $Pcrtical - gen$ variable is set to a high value $(10)^{10}W$ so that the generator will run, when batteries can not meet the load, at rated power, not only to meet the demand, but also trying to charge the batteries for the next hours until SOCstp if the checkbox Continue up to $SOC_{stp-gen}$ is selected (SOCstp is 100%)

      To optimize these variables , if the software has provided some values as an exemple $P_{critical-gen} = 1000W$ and $SOC_{stp-gen} = 75\%$ than if :

      $0 < P_{loaddemand} < P_{critical-gen}$: the AC generator will run at rated power to supply the load and charge the batteries for one hour till 75% of SOC if the checkbox Continue up to $SOC_{stp-gen}$ was not selected, otherwise it continue for the next hours.till 75% and the strategy really will be "cycle charging" without or without continue up to $SOC_{setpoint-gen}$ (SOCstp is the max) $P_{loaddemand} > P_{critical-gen}$: the AC generator will supply the load demand only "load following"

3. **The variables not to be optimized (Fix variables)** :

   The “Fix Variables” button allow the user to set the values of the variables not to be optimized, either by giving a value or can be calculated by the programme.



Non-optimizable control variables (fixed value)

Values of Power in W, H2 in kg

Pmin_gen
● Pmin recommended by manufact.
○ Set value to (% of Pnom.): 30

Pmin_FC
● Pmin recommended by manufact.
○ Set value to (% of Pnom.): 10

H2TANKstp_gen
● Fix value to 0
○ Set value to: 0

P1_gen
● Calculated value
○ Set value to: 1000 W

P1_FC
● Calculated value
○ Set value to: 1000

P2
● Calculated value
○ Set value to: 1000

SOCstp_gen
● SOCmin recommended by manuf.
○ Set value to (% SOCmax): 100

SOCstp_FC
● SOCmin recommended by manuf.
○ Set value to (% SOCmax): 100

SOCmin
● SOCmin recommended by manuf.
○ Set value to (% SOCmax): 50

Pcritical_gen
● Calculated value
○ Set value to: 1000000

Pcritical_FC
● Calculated value
○ Set value to: 1000000

Plimit_charge
● Calculated value
○ Set value to: 1000

Figure 3.8 – *Fixed variables*

4. **Variable accuracy** :

   It is the number of possible values that each variable can have. If it is a small number, the precision will be low, while if it is high, it will have great precision, but the optimization can be lengthened.

5. **Management of the charge / discharge of the batteries in the case of systems with batteries and AC grid connection** :

   In case the system has batteries and an AC grid connection (purchase or sell of electricity to the AC grid) defined in the "PURCHASE / SELL E" tab, the management of the charging / discharging of batteries can be selected and we can define two options :

   - Charge / discharge of batteries during the hours when the electricity price is lower / higher than certain fixed values.
   - Optimize the management (SPECIAL FOR GRID-CONNECTED SYSTEMS)

These options of grid-connected batteries management are only suitable for:

- Generating systems (without any load consumption)
- Systems with load consumption where the option of purchasing electricity to the AC grid is selected because the load consumption will not be correctly supplied by the batterie and the backup generator

5.1 Charge / discharge of batteries during the hours when the electricity price is lower / higher than certain fixed values : We activate the box "Batteries are charged by the AC grid / discharged if:" and set he maximum and minimum prices for the charging / discharging of the batteries

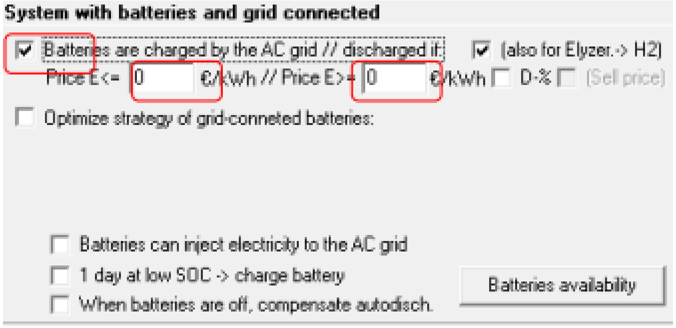
5.1.1 Purshasing:

a- Using prices:

In low power projetcs , we enter the price of electricity for different periods in the "PURCHASE / SELL E" tab : P1 (peak), P2 ,P3 (valley) all in €/kWh ,than the values of the minimum/ maximum purchasing price of charging/ discharging ($P_{chargecost-limit}$, $P_{dischargecost-limit}$) in the selected checkbox Batteries are charged by the AC grid / discharged such that :

- During the hours where : **Electricity price** $< P_{chargeprice-limit}$: the batteries are charged from the renewable energy (after supplying the load) and from the **AC grid**
- During the hours where : **Electricity price** $> P_{dischargeprice-limit}$: the batteries are discharged to supply the load instead of using the AC grid

This method is valid for all days but in one day the prices differ



System with batteries and grid connected

☑ Batteries are charged by the AC grid // discharged if: ☑ (also for Elyzer.-> H2)

Price E<= 0 €/kWh // Price E>= 0 €/kWh ☐ D-% ☐ (Sell price)

☐ Optimize strategy of grid-conneted batteries:

☐ Batteries can inject electricity to the AC grid

☐ 1 day at low SOC -> charge battery

☐ When batteries are off, compensate autodisch.

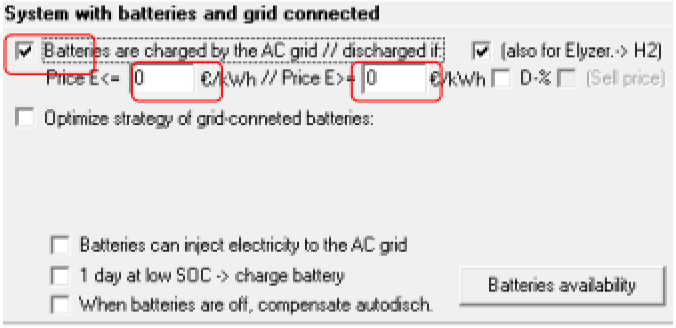
Figure 3.9 – *Charging and discharging the battery using the price comparison method*

b- Using difference and percentage instead of prices:

Instead of using the values of maximum/ minimum price to charge/ discharge, we can use other values: **minimum difference in electricity price** defined as **‘day dif’** which is the maximum minus minimum price of the day) in €/kWh by selecting the checkbox “D-%”, so that the control strategy can be applied, and the % around, in %.

We have two possibilites :

- For price diffrence < **day dif** : the battery won’t be charged or discharged .
- For price diffrence > **day dif** : the battery is charged for electricity price less than day diff minus the specified percentage, and discharged for electricity price greater than day diff minus the specified percentage.



System with batteries and grid connected

☑ Batteries are charged by the AC grid // discharged if: ☑ (also for Elyzer.-> H2)

Price E<= 0 €/kWh // Price E>= 0 €/kWh ☐ D-% ☐ (Sell price)

☐ Optimize strategy of grid-conneted batteries:

☐ Batteries can inject electricity to the AC grid

☐ 1 day at low SOC -> charge battery

☐ When batteries are off, compensate autodisch.

Figure 3.10 – *Charging and discharging the battery using the difference method*

5.1.2 selling: (There is no AC grid to charge the batteries)

By selecting the checkbox “ Batteries can inject electricity to the AC grid” with checking the checkbox “(Sell price)”, we can select that the maximum and minimum sell prices for the charging / discharging of the batteries, such that :

- For Electricity price < $S_{chargeprice-limit}$ (determined by the control strategy) :the batteries will be charged by the renewable sources .
- For Electricity price >$S_{dischargeprice-limit}$ (determined by the control strategy) : the batteries are discharged supplying the load but also injecting the maximum possible of energy to the AC grid (if the injection is allowed to the AC grid in the "PURCHASE / SELL E "tab)

5.1.3 Other options

- If the box **"1 day at low SOC => charge battery "** is selected, for SOC of batteries at minimum , batteries are automatically charged by the AC grid because renewable souces were enable to cover it.
- If the box **"when batteries are off, compensate autodis"** is selected, for batteries are not charging nor discharging, the self-discharge is compensated.

5.1.4 BATTERIES AVAILABILITY

By clicking on the button "BATTERIES AVAILABILITY" the following window appears, where we can deselect the hours when we do not want the batteries to be charged from the AC grid or discharged

The hours that **the CHARGE** is NOT marked, the batteries will not be charged from the AC grid, even if the price of the electricity in the network is low.

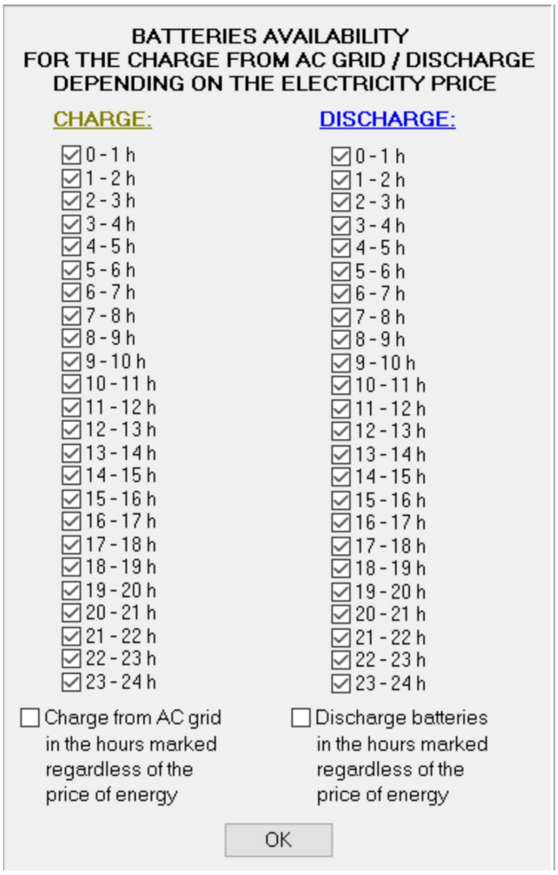
The hours DISCHARGE is NOT marked:

- If the priority to supply the load not covered by the renewables is the AC Grid (Purchase/Sell): the batteries will not supply the demand not covered by the renewables, although the price of the AC grid electricity is high, this demand will be covered by the AC grid.
- If the priority to supply the demand not covered by the renewables is Storage / AC Gen.: the demand not covered by the renewables is primarily provided by the batteries or the AC generator or the fuel cell, depending on the control strategy, so that the batteries can supply the demand.

  If we check the box **"Charge from AC grid in the hours marked..."** , the batteries will be charged with the AC grid at the scheduled times, regardless of the price of electricity.

  If we check the box **"Discharge batteries in the hours marked..."** , the batteries will be discharged (providing load and, if permitted, selling energy to the AC grid) at the scheduled times, regardless of the price of electricity.

  If a certain hour is both marked for charging and discharging and the two previous boxes are marked, forcing at that time both charging and discharging, the priority is the discharge, that is, batteries will be discharged during that hour.



BATTERIES AVAILABILITY
FOR THE CHARGE FROM AC GRID / DISCHARGE
DEPENDING ON THE ELECTRICITY PRICE

CHARGE:

☑ 0 - 1 h
☑ 1 - 2 h
☑ 2 - 3 h
☑ 3 - 4 h
☑ 4 - 5 h
☑ 5 - 6 h
☑ 6 - 7 h
☑ 7 - 8 h
☑ 8 - 9 h
☑ 9 - 10 h
☑ 10 - 11 h
☑ 11 - 12 h
☑ 12 - 13 h
☑ 13 - 14 h
☑ 14 - 15 h
☑ 15 - 16 h
☑ 16 - 17 h
☑ 17 - 18 h
☑ 18 - 19 h
☑ 19 - 20 h
☑ 20 - 21 h
☑ 21 - 22 h
☑ 22 - 23 h
☑ 23 - 24 h

☐ Charge from AC grid in the hours marked regardless of the price of energy

DISCHARGE:

☑ 0 - 1 h
☑ 1 - 2 h
☑ 2 - 3 h
☑ 3 - 4 h
☑ 4 - 5 h
☑ 5 - 6 h
☑ 6 - 7 h
☑ 7 - 8 h
☑ 8 - 9 h
☑ 9 - 10 h
☑ 10 - 11 h
☑ 11 - 12 h
☑ 12 - 13 h
☑ 13 - 14 h
☑ 14 - 15 h
☑ 15 - 16 h
☑ 16 - 17 h
☑ 17 - 18 h
☑ 18 - 19 h
☑ 19 - 20 h
☑ 20 - 21 h
☑ 21 - 22 h
☑ 22 - 23 h
☑ 23 - 24 h

☐ Discharge batteries in the hours marked regardless of the price of energy

Figure 3.11 – *Hours when batteries can be charged or discharged*

3.6.4 FINANCIAL DATA TAB

1. (a)-The economical data :

   Data for economic and financial calculations must be provided which includes:

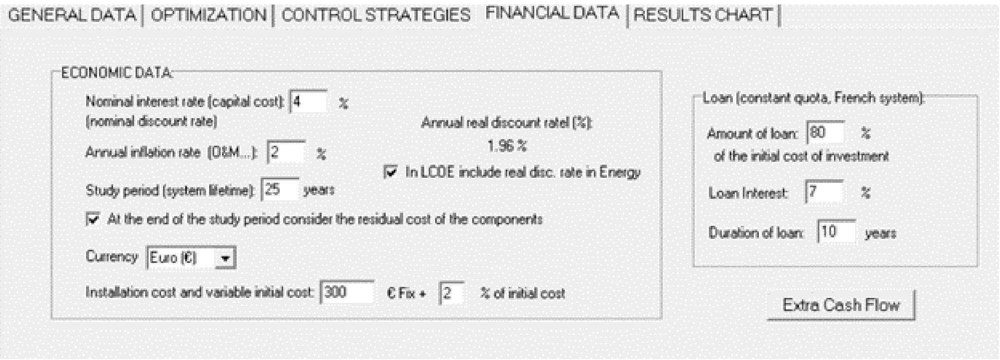
- Lifetime of the system or period of study (usually the same as the lifecycle for the PV modules, 25 or 30 years)
- Installation costs and variable initial cost (fix cost + percentage of initial cost)
- The nominal interest rate(the nominal capital cost) I : which refers to the interest rate before taking inflation into account.
- The annual inflation rate (Inf_{gen}): is the general annual expected inflation rate which idemonstrates the health of a country's economy and tells us how quickly prices are changing.

- The annual real discount rate (real discount rate or real capital cost) (will be reduced copmpared to I) : is used to convert between one-time costs and annualized costs, which depends on the inflataion rate. It can be calculaed using the equation :

$$RealDiscountRate(\%) = \frac{I - \mathrm{Inf_{gen}}}{\left(1 + \frac{\mathrm{Inf_{gen}}}{100}\right)} \tag{3.1}$$

  This value will be used to update the different costs affected by the general inflation rate which include: the operation and maintenance costs $(Cost_{O\&M-j})$, as well as the cost of replacing the elements (NPC_{rep-j}) which do not have a specific inflation rate throughout the whole of the study period, as referred to the initial time of investment NPC.

  The real discount rate for other costs like the fuel .... will be calculated considering their own inflation.



ECONOMIC DATA:

Nominal interest rate (capital cost): 4 %
(nominal discount rate)

Annual inflation rate (O&M...): 2 %

Study period (system lifetime): 25 years

Annual real discount ratel (%):
1.96 %

☑ In LCOE include real disc. rate in Energy

☑ At the end of the study period consider the residual cost of the components

Currency Euro (€)

Installation cost and variable initial cost: 300 € Fix + 2 % of initial cost

Loan (constant quota, French system):

Amount of loan: 80 %
of the initial cost of investment

Loan Interest: 7 %

Duration of loan: 10 years

Figure 3.12 – *The financial data tab*

(a).1 LCOE: levelized cost of energy (electricity)

It the total present cost divided the total supplied energy during system lifetime, including in the energy the real discount rate which contains the costs incurred in the construction, operation and maintenance. It is used for investment planning and to compare different methods of electricity generation on a consistent basis.

In minimizing the NPC,the LCOE can be calculated using the following equation:

$$LCOE_{\mathrm{i,k}} = \frac{\mathrm{NPC_{i,k}}}{\sum_{y=1}^{\mathrm{life_{HS}}} \mathrm{E_{Load_y}} \frac{\left(1+\mathrm{Inf_{gen}}\right)^2}{(1+I)^2}} \tag{3.2}$$

Where

$\mathrm{NPC}_{\mathrm{i,k}}$ (Net Present Cost): In stand-alone systems, NPC of each combination of components i and control strategy k is calculated using the formula :

$$\mathrm{NPC}_{\mathrm{i,k}} = \sum_{j} \left(\mathrm{Cost}_{\mathrm{j}} + \mathrm{NPC}_{\mathrm{rep-j}} + \sum_{y=1}^{\mathrm{Life\ HS}} \left(\mathrm{Cost}_{\mathrm{O\&M-j}} \frac{\left(1 + \mathrm{Inf}_{\mathrm{gen})^{y}}^{(1+I)^{y}}\right)}{(1)} \right) + \right.$$

$$\left. \sum_{y=1}^{\mathrm{Life\ HS}} \left(\frac{\mathrm{Cost}_{\mathrm{\ F-y}}}{(1+I)^{y}} \right) + \ \mathrm{Cost}_{\mathrm{\ INST}} \right.$$

Where

- Life $_{\mathrm{HS}}$: number of years.
- Cost $_{j}$:the acquisition cost of component j (year 0)
- $\mathrm{NPC}_{\mathrm{rep\text{-} j}}$: the sum of the replacement costs of component
- j during the system lifetime converted to the initial moment of the system (year 0)
- $\mathrm{Cost}_{\mathrm{O\&}M-j}$:the annual O&M cost of component j in year 0
- Cost $_{\mathrm{F-y}}$: is the cost of the fuel used by the fossil fuel generator (backup generator) during year y
- $\mathrm{Cost}_{\mathrm{INST}}$: the installation cost.
- y: refers to the year, y $= 0$ the start of the plant construction
- $\mathrm{E}_{\mathrm{Load}\ y} [KWh]$ the electricity generation in year y

  If the checkbox is checked, it is considered that the residual cost of the different components is obtained when the useful life of the system ends (each component would be sold at a price proportional to its remaining useful life)

  (a).2 The currency :

  The currency used in this project is the EUR (€), it can be changed by multiplying it with the commulative conversion factor, where all the costs calculated by this software will be changed .

(b). The loan:

The loan to finance our investement is represented in the right, and represent a percentage of the total initial investment cost .The loan interest and number of years to return should be indicated and must be on constant quota, French system (every year to pay the same amount).

The annual quota (a) is calculated as:

$$a = \left(C_0 \frac{\mathrm{i}}{1-(1+i)^{-n}} \right)$$

Where C_0 is the total financed cost, i is the interest rate of the loan and n is the number of years to return.

Remark: Algerian banks don't provide loans for generating phovoltaic systems projetcs.

(c). Extra cash flow:

By clicking the button "Extra cash flow", a window appears where we can add extra cash flow to be added to the NPC or NPV of the project. Positive values in the table are considered costs.

3.6.5 System DC and AC Voltage

System DC and AC voltage may be introduced on the main screen (bottom left). The DC voltage is common to be a multiple of 12 V, choosing 12 V for systems with very little power consumption and increasing the DC voltage as the system consumption increases.

PHOTOVOLTAIC SYSTEM SIZING OF A STAND-ALONE PV SYSTEM AND SIMULATION RESULTS

4

4.1 INTRODUCTION

Sizing a photovoltaic system for a stand-alone photovoltaic power system involves a five step process which will allow the photovoltaic system designer or user to accurately size a system based on users projected needs, goals and budget. These steps are:

1. Location
2. Climate information (tilt angle, azimuth)
3. The estimated Electric Load
4. Sizing and Specifying An Inverter
5. Sizing and Specifying Batteries
6. Sizing and Specifying An Array
7. choosing the backup generator

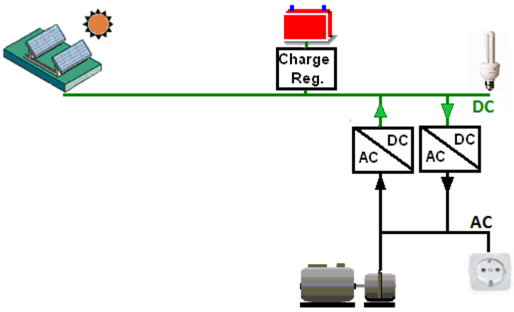


Figure 4.1 – *diagram of stand alone photovoltaic system*

4.2 LOCATION

The Off-grid PV system study was established on the rooftop of 20 houses in Tindouf, Algeria, the GPS coordinates are as follows 27°36′56 N 8°11′09W

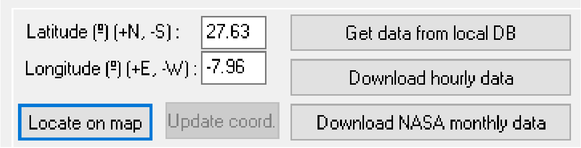
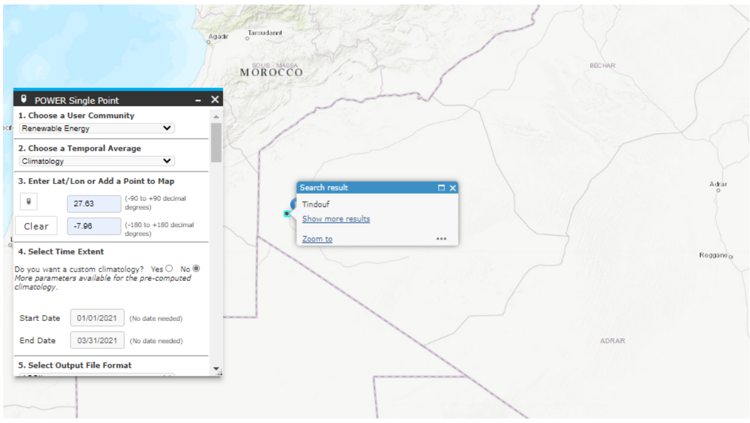

Latitude (º) (+N, -S) : 27.63
Longitude (º) (+E, -W) : -7.96

Figure 4.2 – *latitude and longitude of Tindouf*

We locate the corresponding coordinates on the map to get the climate characteristics of this region


POWER Single Point

1. Choose a User Community: Renewable Energy
2. Choose a Temporal Average: Climatology
3. Enter Lat/Lon or Add a Point to Map: 27.63 (-90 to +90 decimal degrees); -7.96 (-180 to +180 decimal degrees)
4. Select Time Extent

Do you want a custom climatology? Yes ○ No ●
More parameters available for the pre-computed climatology.

Start Date 01/01/2021 (No date needed)
End Date 03/31/2021 (No date needed)

5. Select Output File Format

Search result
Tindouf

Figure 4.3 – *The latitude and longitude of Tindouf provided by NASA*

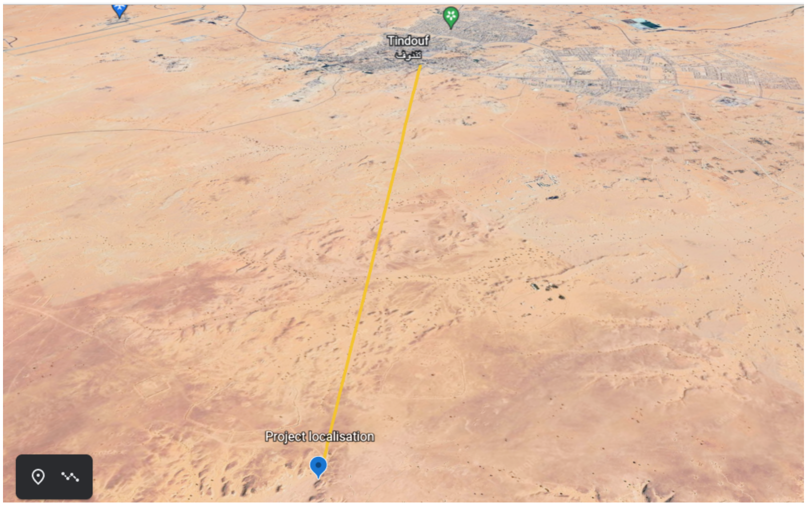


Figure 4.4 – *The localisation of our project on Google earth*

4.3 CLIMATE INFORMATION

4.3.1 System orientation

- **Solar Panel Orientation:** refers to our azimuth setting. Most of the energy coming from the sun arrives in straight line. A solar panel or solar array will capture more energy if it is facing directly at the sun, perpendicular to the straight line between the position of the panel's installation and the sun. Then, we need to have the solar panel turned towards the terrestrial equator (either facing south in the northern hemisphere, or north in the southern hemisphere) so that during the day its orientation allows the panel to catch the greatest possible amount of solar radiation possible.
- **Tilt angle (β) :** is the angle between the panels and the horizontal plane. This angle is south oriented in the Northern Hemisphere and north oriented in the Southern Hemisphere. Tilt angle varies between 0° and 180°. When a plane is rotated about horizontal east-west axis with a single daily adjustment the tilt angle of the surface will be fixed for each day and is calculated by the following equation: [36]

  $$\beta=\emptyset-\delta$$

  where,

  The latitude angle (Ø): is the angle forming according to the equator center.

  The declination angle (γ): is the angle between the sun lights and the equator plane.

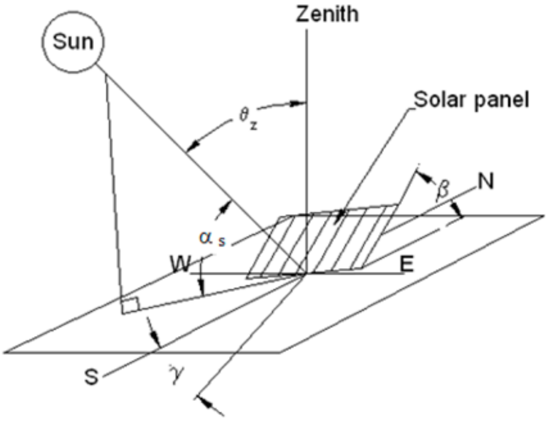


Figure 4.5 – *Tilt angle of system orientation*

According to NASA satellite data of our site location, the tilt angle of each month during a year is:

Jan	Feb	Mar	Apr	May	Jun
54.50°	45.50°	31.00°	15.00°	0.50°	0.00°
Jul	Aug	Sep	Oct	Nov	Dec
0.00°	9.00°	23.00°	39.00°	50.50°	56.00°

The yearly optimum tilt angle is defined as 56° in December since it has the lowest radiation (un unfavorable sunshine) with 6.88 kWh/m2. We enter the specified data in the simulator:

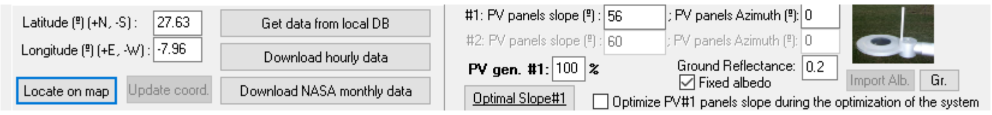
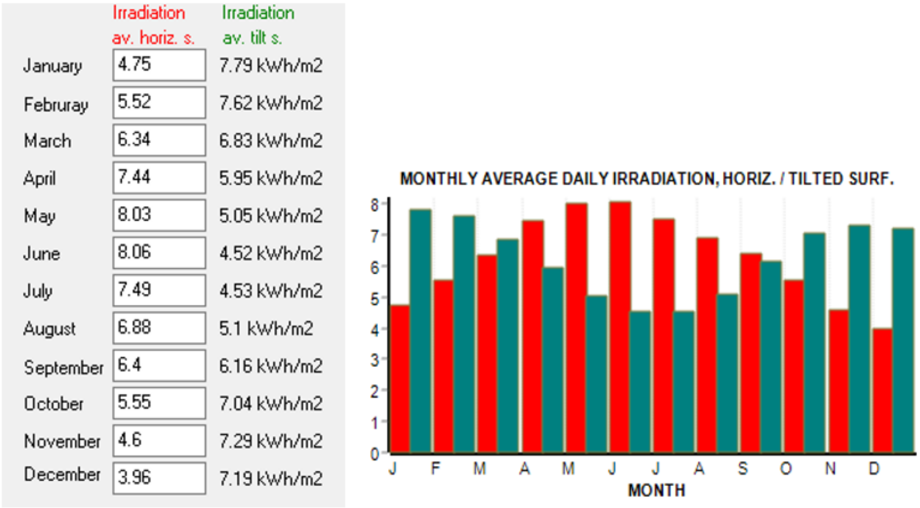

Latitude (º) (+N, -S) : 27.63
Longitude (º) (+E, -W) : -7.96
#1: PV panels slope (º) : 56 ; PV panels Azimuth (º): 0
#2: PV panels slope (º) : 60 ; PV panels Azimuth (º): 0
PV gen. #1: 100 %
Ground Reflectance: 0.2
☑ Fixed albedo
☐ Optimize PV#1 panels slope during the optimization of the system

Figure 4.6 – *the localisation and panel's charachteristics*

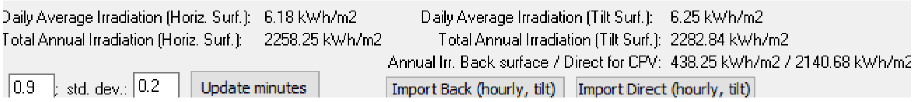
- **Radiation on the horizontal and tilt surface:** Solar radiation data is the key point for the planning and sizing of the PV system .[37] Which is extracted through the calculation of the amount of solar radiation for each square meter per month in the selected area. IHOGA downloaded the average monthly resources data from NASA POWER (https://power.larc.nasa.gov/) for a specific year (2019) for both horizontal and tilt surfaces. Figure shows the resulted solar irradiations:



	Irradiation av. horiz. s.	Irradiation av. tilt s.
January	4.75	7.79 kWh/m2
Februray	5.52	7.62 kWh/m2
March	6.34	6.83 kWh/m2
April	7.44	5.95 kWh/m2
May	8.03	5.05 kWh/m2
June	8.06	4.52 kWh/m2
July	7.49	4.53 kWh/m2
August	6.88	5.1 kWh/m2
September	6.4	6.16 kWh/m2
October	5.55	7.04 kWh/m2
November	4.6	7.29 kWh/m2
December	3.96	7.19 kWh/m2

Figure 4.7 – *the dowloaded average irradiation (Kwh/m²) for both horizontal and tilt surfaces*

According to NASA satellite, the total annual irradiations on both surfaces are represented in figure as :



Daily Average Irradiation (Horiz. Surf.): 6.18 kWh/m2
Total Annual Irradiation (Horiz. Surf.): 2258.25 kWh/m2
Daily Average Irradiation (Tilt Surf.): 6.25 kWh/m2
Total Annual Irradiation (Tilt Surf.): 2282.84 kWh/m2
Annual Irr. Back surface / Direct for CPV: 438.25 kWh/m2 / 2140.68 kWh/m2
0.9 ; std. dev.: 0.2

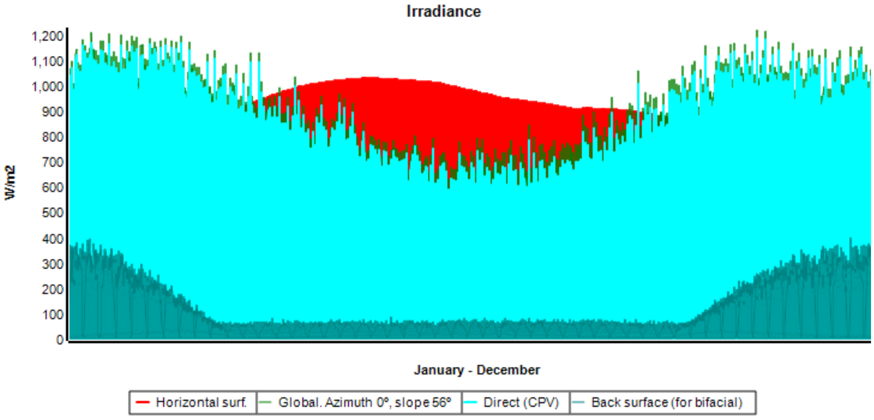


Figure 4.8 – *The total irradiance during one year in W/m^2*

Table 4.1 – *monthly average temperature in °C*

Month	Temperature
Jaruray	10.83
February	13.45
March	19.19
April	21
May	28.4
Jume	26.48
July	31.9
August	34.98
September	30.73
October	25.49
November	18.58
December	13.61

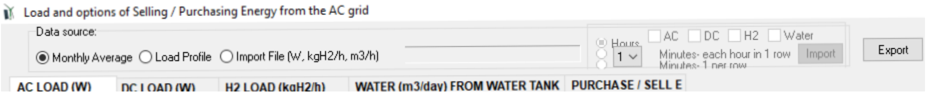
4.4 THE ESTIMATED ELECTRIC LOAD

The objective of this work is to design a PV system which can produce sufficient electrical energy to 20 houses. Therefore, we have to estimate the energy demand of the load by calculating the daily average power consumption of each appliance taking into consideration the winter and summer uses. The results of consumption of for one house are shown in table

Table 4.2 – *The load consumption in kw*

Electrical loads	Number of devices	Consumption kW (for one hour)	Number of hours per day	Days per month	Winter consumption KWh/day (Nov-Feb)	Summer consumption KWh/day (march- Oct)
(combi fridge) of 250L	1	0.150	24	30	3.6	3.6
TV LCD	2	0.150	3	30	0.9	0.9
Washing machine of 7kg with hot watter	2	0.150	3	30	0.9	0.9
Iron	1	1	1	10	1	1
Lamps LED	10	0.008	6	30	0.48	0.48
flat screen Computer	2	0.1	3	12=4*3	0.9	0.9
Phone charger (DC)r	4	0.07	2	30	0.056	0.056
Air conditioner (18000BTU)	1	5.278	12	30	/	63.336
Wifi router (TP-Link)	1	0.009	24	30	0.216	0.216
Water heater	1	1	2	25	2	2
Hair straightner	1	0.016	2	8	0.032	0.032
Vaccum cleaner	1	3.519	24	30	1.4	0.12
Electric stove	1	2	2	30	4	4
Cooling fan	2	0.05	24	30	/	1.2

The are 3 options to introduce data sources on load:

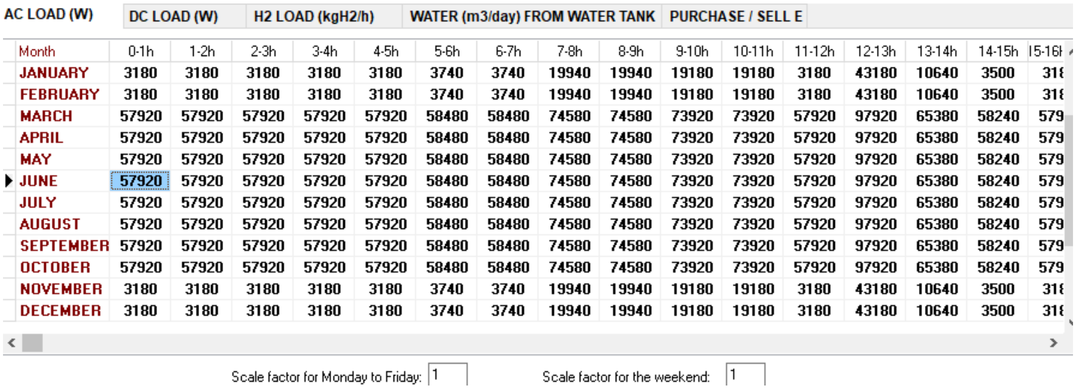

Load and options of Selling / Purchasing Energy from the AC grid

Data source: ● Monthly Average ○ Load Profile ○ Import File (W, kgH2/h, m3/h)

Figure 4.9 – *load data sources*

- Load profil: For loads corresponding to profiles predetermined by the system or created by the user, the default profile is charged
- Import hourly data file : We can import hourly (or in several minutes steps) consumption data for a whole year
- Monthly average :This is adequate in case the expected load is known in monthly average hourly values. Data on load must be introduced on the load tables in watts for AC and DC.

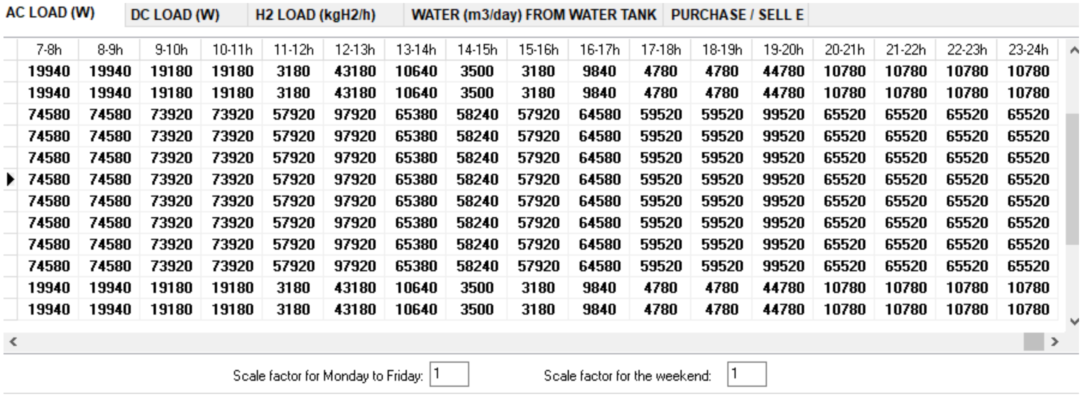
The following table shows the monthly average load consumption of 20 houses from 1am to 12pm:



Month	0-1h	1-2h	2-3h	3-4h	4-5h	5-6h	6-7h	7-8h	8-9h	9-10h	10-11h	11-12h	12-13h	13-14h	14-15h	15-16h
JANUARY	3180	3180	3180	3180	3180	3740	3740	19940	19940	19180	19180	3180	43180	10640	3500	318
FEBRUARY	3180	3180	3180	3180	3180	3740	3740	19940	19940	19180	19180	3180	43180	10640	3500	318
MARCH	57920	57920	57920	57920	57920	58480	58480	74580	74580	73920	73920	57920	97920	65380	58240	579
APRIL	57920	57920	57920	57920	57920	58480	58480	74580	74580	73920	73920	57920	97920	65380	58240	579
MAY	57920	57920	57920	57920	57920	58480	58480	74580	74580	73920	73920	57920	97920	65380	58240	579
JUNE	57920	57920	57920	57920	57920	58480	58480	74580	74580	73920	73920	57920	97920	65380	58240	579
JULY	57920	57920	57920	57920	57920	58480	58480	74580	74580	73920	73920	57920	97920	65380	58240	579
AUGUST	57920	57920	57920	57920	57920	58480	58480	74580	74580	73920	73920	57920	97920	65380	58240	579
SEPTEMBER	57920	57920	57920	57920	57920	58480	58480	74580	74580	73920	73920	57920	97920	65380	58240	579
OCTOBER	57920	57920	57920	57920	57920	58480	58480	74580	74580	73920	73920	57920	97920	65380	58240	579
NOVEMBER	3180	3180	3180	3180	3180	3740	3740	19940	19940	19180	19180	3180	43180	10640	3500	318
DECEMBER	3180	3180	3180	3180	3180	3740	3740	19940	19940	19180	19180	3180	43180	10640	3500	318

Scale factor for Monday to Friday: 1

Scale factor for the weekend: 1



7-8h	8-9h	9-10h	10-11h	11-12h	12-13h	13-14h	14-15h	15-16h	16-17h	17-18h	18-19h	19-20h	20-21h	21-22h	22-23h	23-24h
19940	19940	19180	19180	3180	43180	10640	3500	3180	9840	4780	4780	44780	10780	10780	10780	10780
19940	19940	19180	19180	3180	43180	10640	3500	3180	9840	4780	4780	44780	10780	10780	10780	10780
74580	74580	73920	73920	57920	97920	65380	58240	57920	64580	59520	59520	99520	65520	65520	65520	65520
74580	74580	73920	73920	57920	97920	65380	58240	57920	64580	59520	59520	99520	65520	65520	65520	65520
74580	74580	73920	73920	57920	97920	65380	58240	57920	64580	59520	59520	99520	65520	65520	65520	65520
74580	74580	73920	73920	57920	97920	65380	58240	57920	64580	59520	59520	99520	65520	65520	65520	65520
74580	74580	73920	73920	57920	97920	65380	58240	57920	64580	59520	59520	99520	65520	65520	65520	65520
74580	74580	73920	73920	57920	97920	65380	58240	57920	64580	59520	59520	99520	65520	65520	65520	65520
74580	74580	73920	73920	57920	97920	65380	58240	57920	64580	59520	59520	99520	65520	65520	65520	65520
74580	74580	73920	73920	57920	97920	65380	58240	57920	64580	59520	59520	99520	65520	65520	65520	65520
19940	19940	19180	19180	3180	43180	10640	3500	3180	9840	4780	4780	44780	10780	10780	10780	10780
19940	19940	19180	19180	3180	43180	10640	3500	3180	9840	4780	4780	44780	10780	10780	10780	10780

Scale factor for Monday to Friday: 1
Scale factor for the weekend: 1

Figure 4.10 – *the average monthly load consumption*

The scaling factor must be set for weekdays and another for weekend days, since the expected consumption is equal for all the days of the week, both factors will be 1. Load profiles are shown for each month, we take the exemple of 2 months August(summer period) and December (winter period) to see the difference in the electricity consumption :

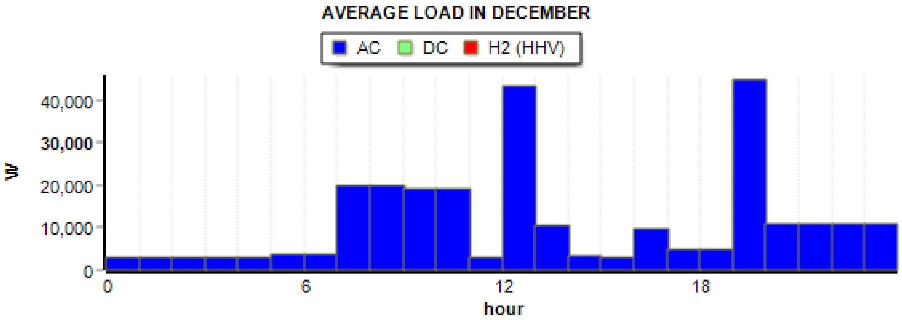


Figure 4.11 – *average load consumption in December*

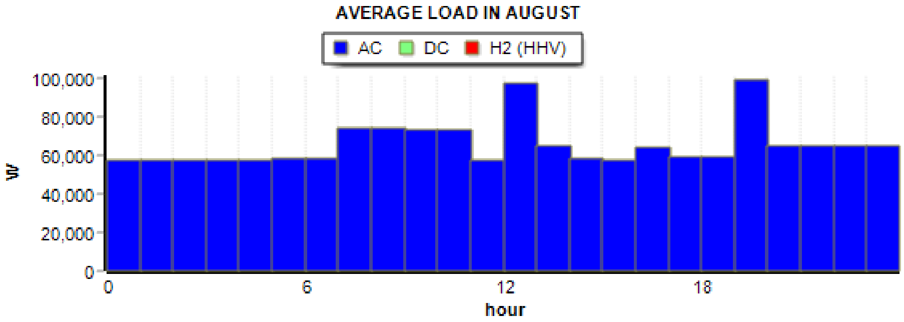
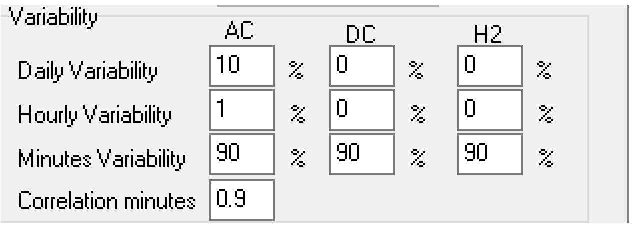


Figure 4.12 – *average load consumption in December average load consumption in august*

Variability: we set the percentage of variability or randomness of AC load both daily and for each hour, and for each minute . The program will randomly calculate the consumption for each hour taking this into account.



Variability

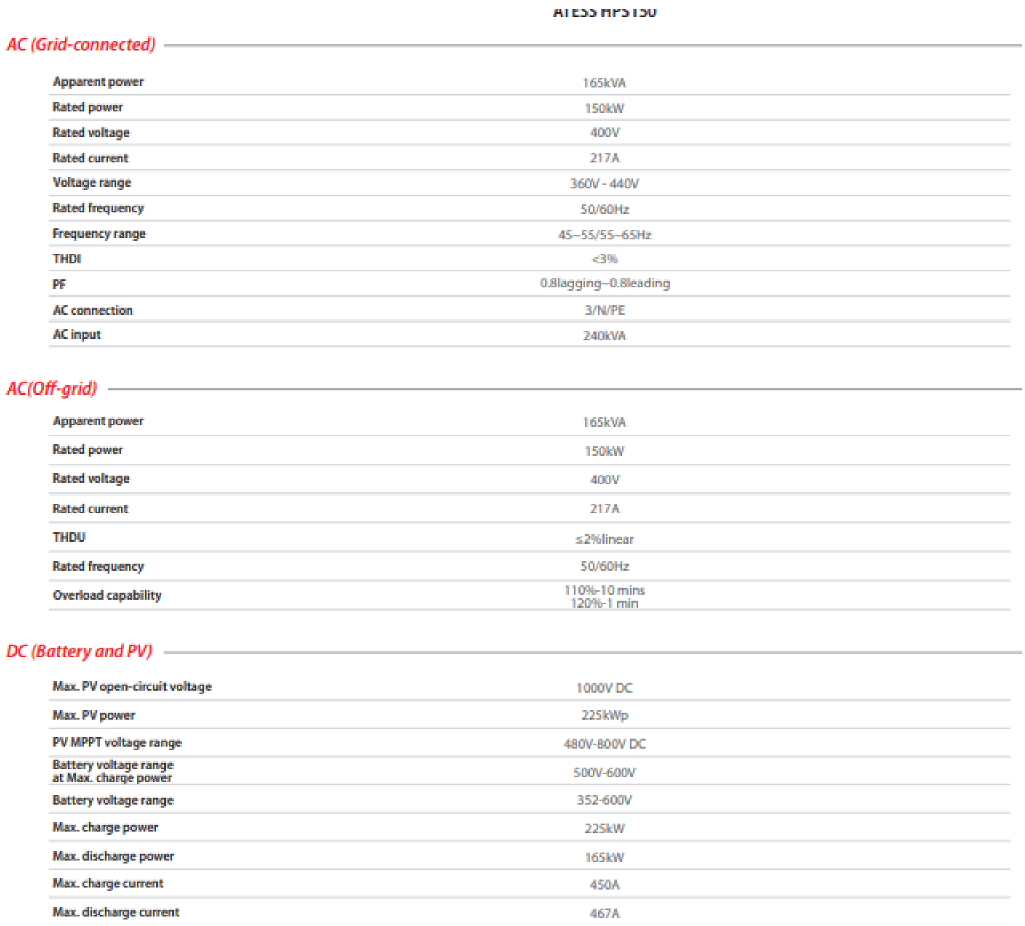
	AC		DC		H2	
Daily Variability	10	%	0	%	0	%
Hourly Variability	1	%	0	%	0	%
Minutes Variability	90	%	90	%	90	%
Correlation minutes	0.9					

Figure 4.13 – *percentage of variability (daily, hourly, minutes)*

Once the hourly and minute load has been generated ,we can add a AC, DC consumption by specifying the day, duration and whether it is repeated during the whole year .

4.5 Sizing and Specifying An Inverter

The selection of the inverter depends on the peak load consumption in watts in one day, since the peak is 124591 W so we select the inverter ATESS HPS150 which can be used in both off-grid and grid-connected systems and has the following parameters:



ATESS HPS150

AC (Grid-connected)

Apparent power	165kVA
Rated power	150kW
Rated voltage	400V
Rated current	217A
Voltage range	360V - 440V
Rated frequency	50/60Hz
Frequency range	45–55/55–65Hz
THDI	<3%
PF	0.8lagging–0.8leading
AC connection	3/N/PE
AC input	240kVA

AC(Off-grid)

Apparent power	165kVA
Rated power	150kW
Rated voltage	400V
Rated current	217A
THDU	≤2%linear
Rated frequency	50/60Hz
Overload capability	110%-10 mins 120%-1 min

DC (Battery and PV)

Max. PV open-circuit voltage	1000V DC
Max. PV power	225kWp
PV MPPT voltage range	480V-800V DC
Battery voltage range at Max. charge power	500V-600V
Battery voltage range	352-600V
Max. charge power	225kW
Max. discharge power	165kW
Max. charge current	450A
Max. discharge current	467A

Figure 4.14 – *Atess HPS150 datasheet*

This type of inverter includes battery charger of type MPPT inside it.

The inverter general data entered in the simulator are described in the following table:

Table 4.3 – *the inverter general data*

Power(W)	150000
Lifespan (year)	10
Aquisition cost (€)	22491(18900 + 19% of the tax)
Battery charger	OK (included)
Efficiency (%)	99.9
Maximum charge current of battery	450
Maximum input power from the photovoltaic generator	225000
Vdcmin/Vdcmax	480/800

4.5.1 The operation

In the off grid mode, when the battery is discharged to the under voltage alarm point, HPS sends a relay signal to start the DG and enter DG mode. The generator will supply power to load; at the same time, HPS stops supplying power to the load and only charges the battery.

1. When PV power is greater than the load power, PV power is only used to charge the battery; the DG only supplies the load.
2. When PV power is less than the charging power, PV supplies priority to battery; DG supplies power to the load and optionally charges the battery.
3. When the battery is charged to "SOC upper limit" or "floating charge current limiting point" (depending on the battery type), the inverter sends a signal to stop the DG and switch to off grid mode.

4.5.2 Cable requirements

The cable diameter requirements depends on the voltage level:

Table 4.4 – *The cable diameter requirements provided by the inverter user manual*

Cable	cable diameter requirements
Pv	120 mm^2
Battery	150 mm^2
Load	95 mm^2
Backup generator	150 mm^2
Earth wire	More than 16 mm^2. Green and yellow is recommended

4.6 SIZING AND SPECIFYING BATTERIES

Our system supply a high load so we selected the battery bank 48v 500ah lifepo4 (lithium) of Cmax batteries which is a combination of 5pcs CMX48100. 5pcs modular connect in parallel total 48v 500Ah and 25Kwh storage system. The System nominal voltage is 51.2v with 16S LiFePo4 cells.

4.6.1 Characteristics of the 48v 500ah lifepo4 (lithium) Cmax battery

The main characteristics of this type of battery are:

- The ups battery 48v 500ah is maintenance free. module is design for easy installation and capacity expansion.
- This battery module with High Capacity Long cycle life. 20 years solar storage battery design supplier

- Lithium ion battery pack Wide working temperature range and high reliability.
- Multiple battery module units can be connected in parallel, suitable for high energy storage applications.
- Compatible with various charge controllers and inverters.
- Widely used for off-grid solar system storage,telecom lithium batteries, ups battery. . . etc.

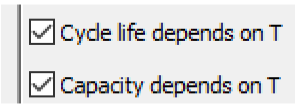
4.6.2 Detail specifications

The details specifications provided by the manufacturer are described in the following table:

Table 4.5 – *specifications of the battery*

Battery type	LiFePO4 battery
Rated voltage (V)	51.2 V
Nominal capacity (Cn) in Ah	500
Nominal voltage (V)	48
Acquisition Cost (€)	4760(4000 + 19% of tax)
Max. Discharge Current (A)	100
Cycle life	$>$ 6000cycles
Weight (kg)	280
Self discharge Coefficient (monthly %)	$<$ 3%
Working temperature	−20C 60C%

The cycle life and capacity depend on temperature by selecting the checkbox



☑ Cycle life depends on T

☑ Capacity depends on T

Figure 4.15 – *cycle life and capacity dependence on temperature*

The annual inflation rate expected for batteries costs is -2%

4.6.3 Lithium batteries lifetime

The calculation of the estimated lifespan of the batteries is very important, since it influences the replacement costs of these and therefore in the total cost of the system. There exist 5 models (methods) in Lithium batteries to estimate the lifetime including the SOC, Imax. . . ., which are:the Equivalent Full Cycle life model, Cycle Counting or (Rainflow) method, Wang, Grot and Saxena methods obtained by testing specific commercial batteries.

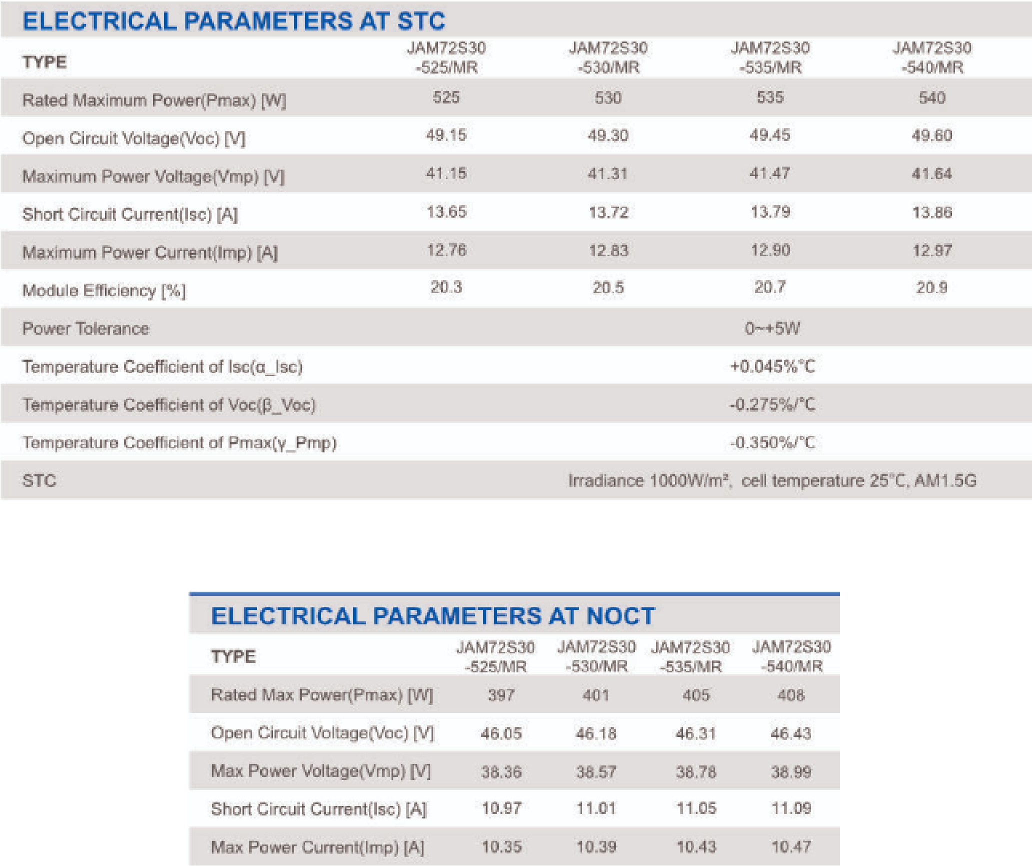
For LiFePo4 batteries we use Wang model where “Rate lower than 1C-> 1C" indicates that charges / discharges at rates lower than 1C will be considered as 1C. Where 1C means the charging or discharging rate such that the battery is fully charged or discharged for 1 hour, i.e. the current in A equals the capacity in Ah.

4.7 Photovoltaic modules

The photovoltaic modules screen may be accessed by selecting “PV modules” in the Data menu. The selected module in our project is **JAM72S30-540/MR** solar panel from **JA Solar Technology.**

4.7.1 PV modules data

The parameters of the **JAM72S30-540** solar panel are:



ELECTRICAL PARAMETERS AT STC

TYPE	JAM72S30 -525/MR	JAM72S30 -530/MR	JAM72S30 -535/MR	JAM72S30 -540/MR
Rated Maximum Power(Pmax) [W]	525	530	535	540
Open Circuit Voltage(Voc) [V]	49.15	49.30	49.45	49.60
Maximum Power Voltage(Vmp) [V]	41.15	41.31	41.47	41.64
Short Circuit Current(Isc) [A]	13.65	13.72	13.79	13.86
Maximum Power Current(Imp) [A]	12.76	12.83	12.90	12.97
Module Efficiency [%]	20.3	20.5	20.7	20.9
Power Tolerance	0~+5W			
Temperature Coefficient of Isc(α_Isc)	+0.045%/°C			
Temperature Coefficient of Voc(β_Voc)	-0.275%/°C			
Temperature Coefficient of Pmax(γ_Pmp)	-0.350%/°C			
STC	Irradiance 1000W/m², cell temperature 25°C, AM1.5G			

ELECTRICAL PARAMETERS AT NOCT

TYPE	JAM72S30 -525/MR	JAM72S30 -530/MR	JAM72S30 -535/MR	JAM72S30 -540/MR
Rated Max Power(Pmax) [W]	397	401	405	408
Open Circuit Voltage(Voc) [V]	46.05	46.18	46.31	46.43
Max Power Voltage(Vmp) [V]	38.36	38.57	38.78	38.99
Short Circuit Current(Isc) [A]	10.97	11.01	11.05	11.09
Max Power Current(Imp) [A]	10.35	10.39	10.43	10.47

Figure 4.16 – *JAM72S30-540 panel's parameters*

The panel considered in the optimization is parameterized in a line of the table in iHOGA as:

- Nominal voltage : The nominal voltage is obtained as a function of the open circuit voltage: since the open circuit voltage is between 40 and 60 V so Vnominal is 24V

- C.OM (€/year) : The unit cost of operation and maintenance (OM) is the cost per panel of the photovoltaic generator, apart from the fixed OM cost for the whole set of modules of the generator is 10% of the panel cost so equals to 2.1 €/year

- Pn (Wp): Peak nominal power under standard test conditions (STC) equals to 540W.

- STC : Standard test conditions are the laboratory conditions under which all PV modules are tested which are :

- An irradiance of 1000 watts per square meter, which simulates peak sunshine on a surface directly facing the sun in a day without clouds.
- Temperature of the cell – 25°C. The temperature of the solar cell itself, not the temperature of the surrounding.
- Mass of the air – 1.5. This number is somewhat misleading as it refers to the amount of light that has to pass through Earth's atmosphere before it can hit Earth's surface, and has to do mostly with the angle of the sun relative to a reference point on the earth. This number is minimized when the sun is directly above as the light has to travel a minimum distance straight down, and increases as the sun goes farther from the reference point and has to go at an angle to hit the same spot.

- NOCT : stands for the Nominal Operating Cell Temperature, it provides a more realistic idea of how solar panels will perform in actual practice. NOCT is reached when the following conditions are met:

- The irradiance is 800 watts per square meter, which takes into account the fact that PV modules don't always face the sun. It also considers atmospheric or geographic conditions what might diminish sunshine.
- Solar panels heat up considerably during operation, so the temperature considered is 45 (+/- 3) °C.
- The light spectrum is the same as for STC.
- A windspeed of 1 m/s is considered, with air at 20°C

NOCT of our panel is equal to 45°C

-Temperature coefficient of Pmax Ct (%/°C) : It is only necessary if we want to consider the effect of temperature in the power, taken -0.350 (%/°C) from the panel datasheet.

4.7.2 Efficiency due to degradation, wires, dirt...

we have selected in the main options of the software the multi-period optimization, this efficiency must not consider the degradation of the modules, as this will be considered in the simulation during the years. Therefore we took the factor equals to 0.99

4.7.3 Maximum Power Point Tracking (MPPT)

We select the MPPT checkbox since the inverter include it ,at each instant the PV modules generate the maximum possible power, depending on the irradiance. The power is calculated as follows, the effect of the ambient temperature is taken into account:

$$P(t) = Pn \times G(t) \times \left(1 + \frac{Ct}{100 \times (\text{ Tcell(} (t) - 25)}\right) \times \text{ Nmodules parallel *Eff}$$

Where Pn is the nominal power (peak power, Wp) of the PV panel. Tcell is the internal cell temperature calculated by:

$$\text{Tcell (t)} = \text{Tambient(t)} + \text{G(t)} \times \frac{(\text{NOCT} - 20)}{0.8}$$

Ct is thr Power Temperature coefficient (%/° C).

4.8 BACKUP GENERATOR

The choosed AC generator is **250Kw diesel generator Caterpillar** which provides double load demand value in order to be sufficient to charge batteries.

1800RPM generators are superior than 3600RPM generators because they are more fuel-efficient but cost quite a bit more up front

Figure 4.17 – *diesel generator caterpillar of 250kw*

4.8.1 AC Generators data

- Rated Apparent Power (kW): 250
- Cost (€): 90000
- and Maintenance Cost (€/h):1
- Lifespan (in hours): 10000
- Recommended Power :which is 30% of nominal power, as an exemple if the required power from the generator is 40% of its capacity, it runs at 40%. If the required power is 15%, it runs at 30%, with the excess power either serving the deferrable load, charging the batteries, or being dumped. If no power is required from the generator, it is turned off.
- Fuel Type : Diesel
- Fuel Price (€/litre): 0.11
- CO2 emissions (kgCO2/litre):3.5
- The annual inflation rate for fuel prices (inf_{gen}) which is an important parameter: 5

- The fuel consumption for the generator selected is:

$$Consumption(fuelunit/h) = Pn(kW)B + P(kW)A$$

Where ,

A and B are the consumption Parameters (litre/kWh) which are fixed, P_n is the nominal power in kVA and P is the output power.

4.8.2 The running of the ac generator

we can either:

- - Force the generator to run all the time to create the AC grid.
- - Turn on an extra generator in each time step to increment spinning reserve ,this extra generator will be connected only if the partial load of all the generators (including the extra one) is higher than the minimum output power.

4.8.3 Time availability AC generator in the hybrid system

We set the time availability of the AC generator to be total (both during the week and on weekends)

AC GENERATOR HOURLY AVAILABILITY:

Monday-Friday:

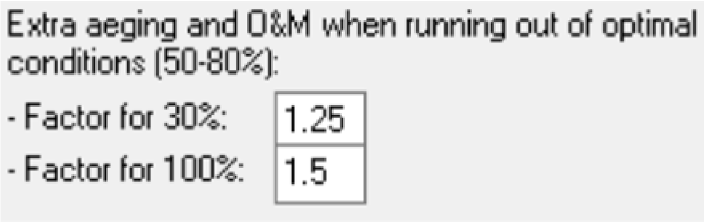
☑ 0 - 1 h
☑ 1 - 2 h
☑ 2 - 3 h
☑ 3 - 4 h
☑ 4 - 5 h
☑ 5 - 6 h
☑ 6 - 7 h
☑ 7 - 8 h
☑ 8 - 9 h
☑ 9 - 10 h
☑ 10 - 11 h
☑ 11 - 12 h
☑ 12 - 13 h
☑ 13 - 14 h
☑ 14 - 15 h
☑ 15 - 16 h
☑ 16 - 17 h
☑ 17 - 18 h
☑ 18 - 19 h
☑ 19 - 20 h
☑ 20 - 21 h
☑ 21 - 22 h
☑ 22 - 23 h
☑ 23 - 24 h

Weekend:

☑ 0 - 1 h
☑ 1 - 2 h
☑ 2 - 3 h
☑ 3 - 4 h
☑ 4 - 5 h
☑ 5 - 6 h
☑ 6 - 7 h
☑ 7 - 8 h
☑ 8 - 9 h
☑ 9 - 10 h
☑ 10 - 11 h
☑ 11 - 12 h
☑ 12 - 13 h
☑ 13 - 14 h
☑ 14 - 15 h
☑ 15 - 16 h
☑ 16 - 17 h
☑ 17 - 18 h
☑ 18 - 19 h
☑ 19 - 20 h
☑ 20 - 21 h
☑ 21 - 22 h
☑ 22 - 23 h
☑ 23 - 24 h

Figure 4.18 – *the AC generator hourly availability*

- Permissible overloads for temporary steps of less than 60 minutes can be indicated .
- We can specify a penalty in the costs of operation and maintenance and extra aging for operating outside the optimal range (50%-80%) for less than 30% or higher than 70% .



Extra aeging and O&M when running out of optimal conditions (50-80%):

- Factor for 30%: 1.25
- Factor for 100%: 1.5

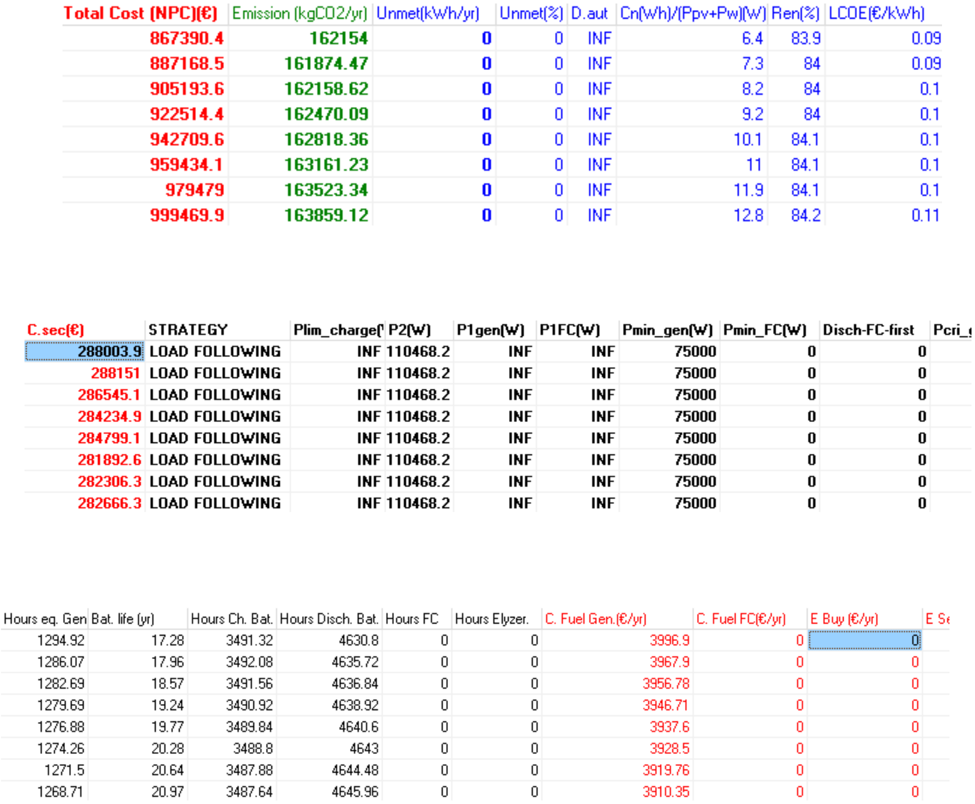
Figure 4.19 – *penalty in OM costs*

4.9 SIMULATION RESULTS

For **a multiperiod simulation** (simulation of the system lifetime 25years), we will see the results for **a multi-objective optimization** which includes **Minimization of Total Cost (NPC), CO2 emissions and unmet load** using two different control strategies : load following and cycle charging.

4.9.1 Using load following method

For Radiation = 6.25KWh/m^2 , interest I= 4% ,inflation g=2%,the simulator has performed 1978 iterations, where it took all cases from the lowest NPC to the highest one, the first 10 iterations are shown in the table:



Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W)	Ren(%)	LCOE(€/kWh)
867390.4	162154	0	0	INF	6.4	83.9	0.09
887168.5	161874.47	0	0	INF	7.3	84	0.09
905193.6	162158.62	0	0	INF	8.2	84	0.1
922514.4	162470.09	0	0	INF	9.2	84	0.1
942709.6	162818.36	0	0	INF	10.1	84.1	0.1
959434.1	163161.23	0	0	INF	11	84.1	0.1
979479	163523.34	0	0	INF	11.9	84.1	0.1
999469.9	163859.12	0	0	INF	12.8	84.2	0.11

C.sec(€)	STRATEGY	Plim_charge(	P2(W)	P1gen(W)	P1FC(W)	Pmin_gen(W)	Pmin_FC(W)	Disch-FC-first	Pcri_
288003.9	LOAD FOLLOWING	INF	110468.2	INF	INF	75000	0	0	
288151	LOAD FOLLOWING	INF	110468.2	INF	INF	75000	0	0	
286545.1	LOAD FOLLOWING	INF	110468.2	INF	INF	75000	0	0	
284234.9	LOAD FOLLOWING	INF	110468.2	INF	INF	75000	0	0	
284799.1	LOAD FOLLOWING	INF	110468.2	INF	INF	75000	0	0	
281892.6	LOAD FOLLOWING	INF	110468.2	INF	INF	75000	0	0	
282306.3	LOAD FOLLOWING	INF	110468.2	INF	INF	75000	0	0	
282666.3	LOAD FOLLOWING	INF	110468.2	INF	INF	75000	0	0	

Hours eq. Gen	Bat. life (yr)	Hours Ch. Bat.	Hours Disch. Bat.	Hours FC	Hours Elyzer.	C. Fuel Gen.(€/yr)	C. Fuel FC(€/yr)	E Buy (€/yr)	E S
1294.92	17.28	3491.32	4630.8	0	0	3996.9	0	0	
1286.07	17.96	3492.08	4635.72	0	0	3967.9	0	0	
1282.69	18.57	3491.56	4636.84	0	0	3956.78	0	0	
1279.69	19.24	3490.92	4638.92	0	0	3946.71	0	0	
1276.88	19.77	3489.84	4640.6	0	0	3937.6	0	0	
1274.26	20.28	3488.8	4643	0	0	3928.5	0	0	
1271.5	20.64	3487.88	4644.48	0	0	3919.76	0	0	
1268.71	20.97	3487.64	4645.96	0	0	3910.35	0	0	

Figure 4.20 – *iterations results*

The results of the first iteration which provides better solutions are shown in the next tables:

- **Components:** the type of components used in this sytem and their numbers are:

Table 4.6 – *components specifications used in our system*

Component	specifications
PV generator JAM72S30-540/MR	24 × 39 × 540Wp
Max number of batteries	12 × 7 × 500Ah
I AC diesel generator Caterpillar	250KW
Inverter ATESS-HPS 150	150KW

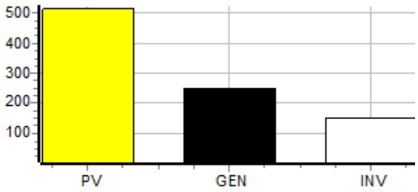


Figure 4.21 – *the power (kw) for each component*

- **Control strategy** :

  1- If the power produced by the renewable sources is higher than load : Charge => The Batteries are charged with the spare power from renewable

  2- If the power produced by the renewable sources is less than load : discharge=> The power not supplied to meet the load will be supplied by the Batteries (if they cannot supply the whole, the rest will be supplied by the AC Generator).

- **Costs:** the different costs in our system are:

Table 4.7 – *type of costs in the system*

Cost type	Price (€)
Initial investment	427846.1
annual quota	**48732.5**
Average year Cost of AC generator fuel	**3996.9**
Total System Costs (NPC)	**867390.4**
Levelized cost of energy	0.09/kWh
PV Generator Costs (NPC)	**250803.6**
Battery bank Costs (NPC)	**148160**
ACGenerator Costs (NPC)	**274411.1**
Inverter Costs (NPC)	**49344**
AC Generator Fuel Costs (NPC)	**78393**
Installation+ financing (NPC):	**66278.2**

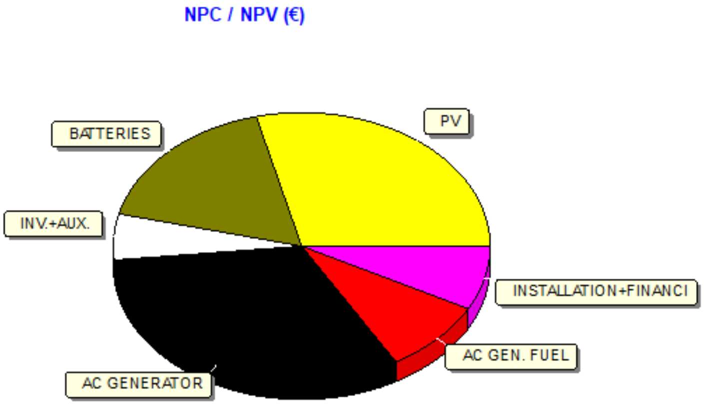


Figure 4.22 – *diagram showing multiple costs in the system*

The different costs for 25 years of each component:

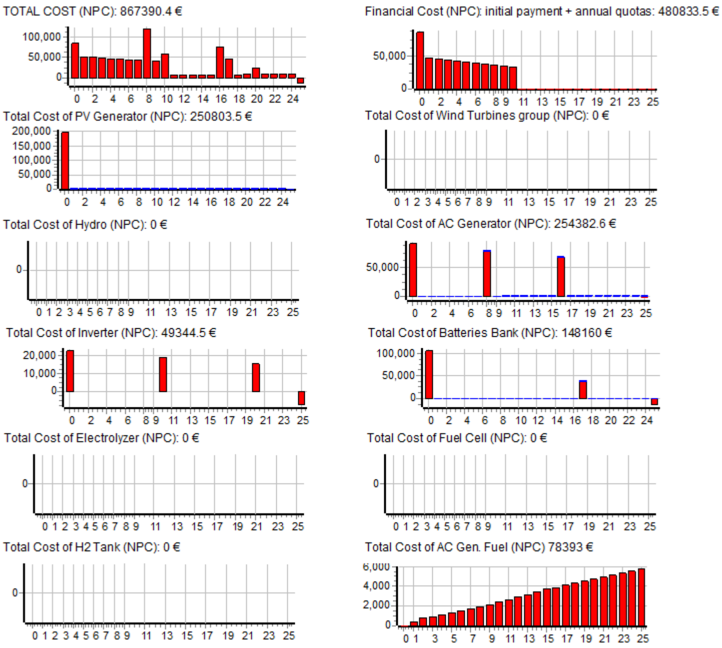


Figure 4.23 – *different costs during the system lifespan*

Other results: the repport attached to the simulation results provided us with the following informations

a) Batteries Lifetime: 17.28 years

b) Equivalent Hours of AC Generator operation: 1294.92h/yr

c) Total CO2 emissions is 162154 kgCO2/yr where, emissions of AC generator (due to consumption of 39741.484 litre/yr) are 139095.2 kgCO2/yr

d) Human Development Index (HDI): 1.0896.

e) Jobs created during system lifetime: 1.5552

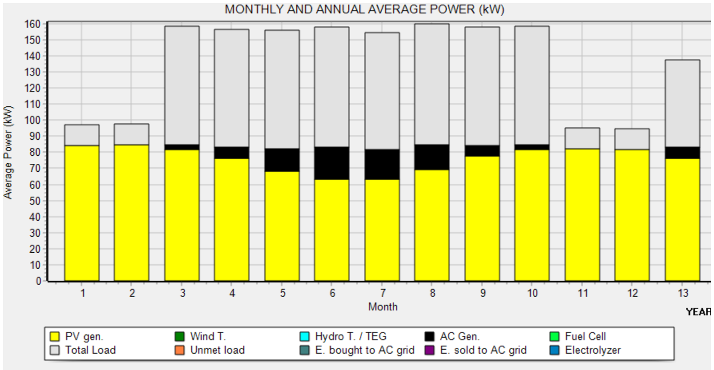


Figure 4.24 – *diagram of the monthly and annual average power*

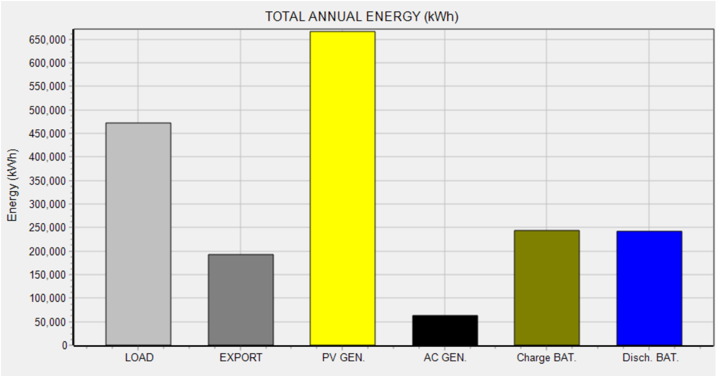


Figure 4.25 – *the total annual energy*

Multiperiod simulation: The energy provided or consumed during the system lifespan is shown in the next graph:

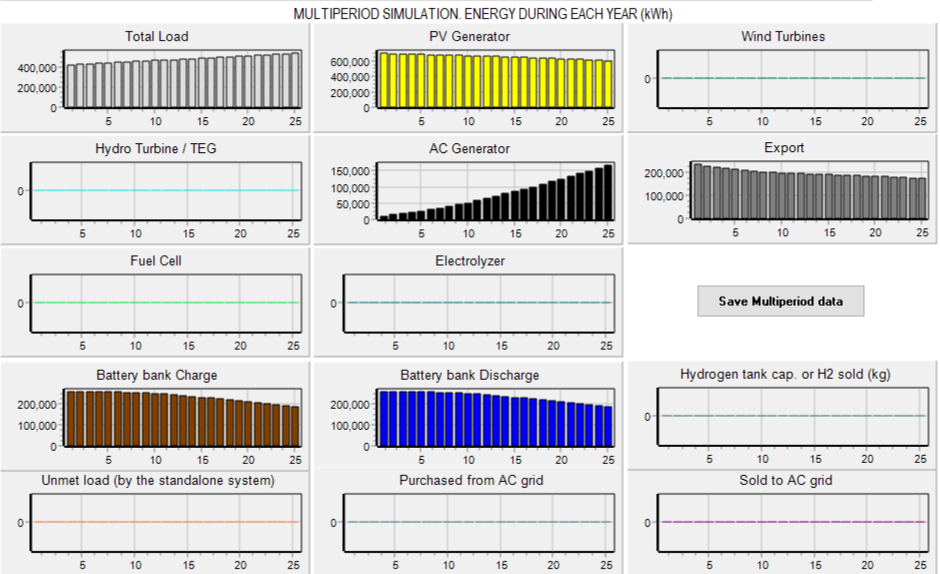
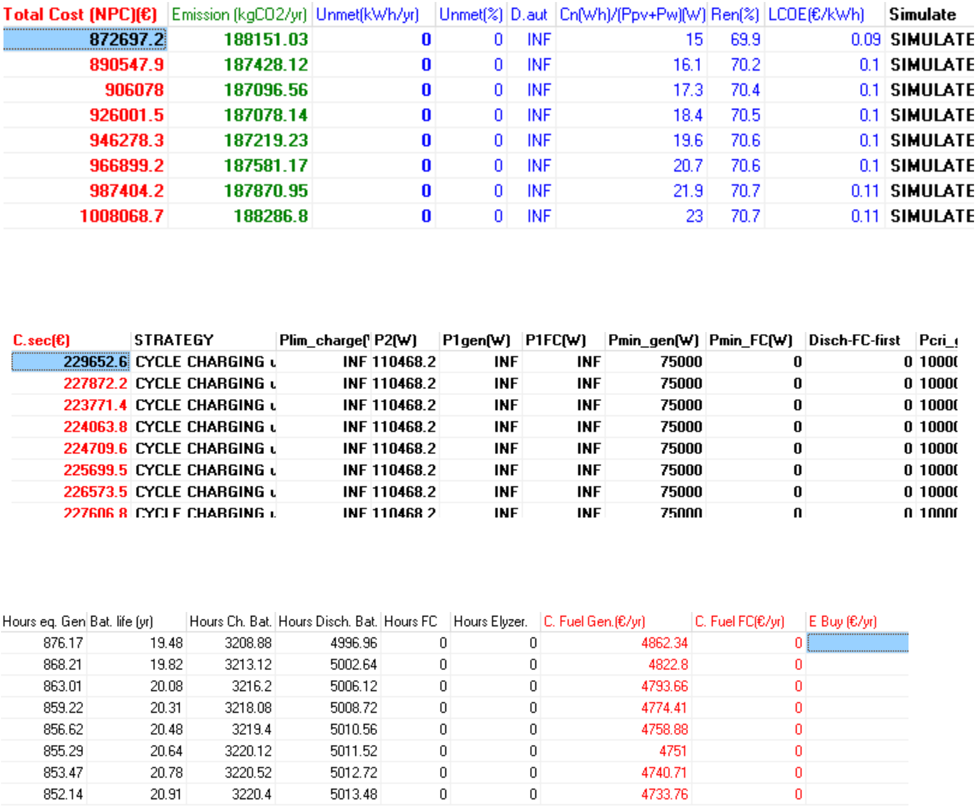


Figure 4.26 – *the energy results (kwh/year) during each year in the system lifespan*

4.9.2 Using cycle charging method

For Radiation = 6.25KWh/m2 , interest I= 4% ,inflation g=2%,the simulator has performed 1978 iterations, where it took all cases from the lowest NPC to the highest one, the first 10 iterations are shown in the table:



Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W)	Ren(%)	LCOE(€/kWh)	Simulate
872697.2	188151.03	0	0	INF	15	69.9	0.09	SIMULATE
890547.9	187428.12	0	0	INF	16.1	70.2	0.1	SIMULATE
906078	187096.56	0	0	INF	17.3	70.4	0.1	SIMULATE
926001.5	187078.14	0	0	INF	18.4	70.5	0.1	SIMULATE
946278.3	187219.23	0	0	INF	19.6	70.6	0.1	SIMULATE
966899.2	187581.17	0	0	INF	20.7	70.6	0.1	SIMULATE
987404.2	187870.95	0	0	INF	21.9	70.7	0.11	SIMULATE
1008068.7	188286.8	0	0	INF	23	70.7	0.11	SIMULATE

C.sec(€)	STRATEGY	Plim_charge(	P2(W)	P1gen(W)	P1FC(W)	Pmin_gen(W)	Pmin_FC(W)	Disch-FC-first	Pcri_
229652.6	CYCLE CHARGING	INF	110468.2	INF	INF	75000	0	0	10000
227872.2	CYCLE CHARGING	INF	110468.2	INF	INF	75000	0	0	10000
223771.4	CYCLE CHARGING	INF	110468.2	INF	INF	75000	0	0	10000
224063.8	CYCLE CHARGING	INF	110468.2	INF	INF	75000	0	0	10000
224709.6	CYCLE CHARGING	INF	110468.2	INF	INF	75000	0	0	10000
225699.5	CYCLE CHARGING	INF	110468.2	INF	INF	75000	0	0	10000
226573.5	CYCLE CHARGING	INF	110468.2	INF	INF	75000	0	0	10000
227606.8	CYCLE CHARGING	INF	110468.2	INF	INF	75000	0	0	10000

Hours eq. Gen	Bat. life (yr)	Hours Ch. Bat.	Hours Disch. Bat.	Hours FC	Hours Elyzer.	C. Fuel Gen.(€/yr)	C. Fuel FC(€/yr)	E Buy (€/yr)
876.17	19.48	3208.88	4996.96	0	0	4862.34	0	
868.21	19.82	3213.12	5002.64	0	0	4822.8	0	
863.01	20.08	3216.2	5006.12	0	0	4793.66	0	
859.22	20.31	3218.08	5008.72	0	0	4774.41	0	
856.62	20.48	3219.4	5010.56	0	0	4758.88	0	
855.29	20.64	3220.12	5011.52	0	0	4751	0	
853.47	20.78	3220.52	5012.72	0	0	4740.71	0	
852.14	20.91	3220.4	5013.48	0	0	4733.76	0	

Figure 4.27 – *iterations results*

The results of the first iteration which provides better solutions are shown in the next tables:

- **Components:** the type of components used in this sytem and their numbers are:

Table 4.8 – *components specifications used in our system*

Component	Specifications
PV generator JAM72S30-550/MR	$24 \times 39 \times 540$Wp
Max number of batteries	$12 \times 7 \times 500$Ah
1 AC diesel generator Caterpillar	250KW
Inverter ATESS-HPS 150	150KW

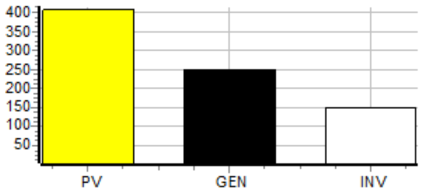


Figure 4.28 – *the power (kw) for each component*

- **Costs:** the diffrent costs in our system are:

Table 4.9 – *type of costs in the system*

Cost type	Price (€)
Initial investment	**478960.3**
annual quota	54554.5
Average year Cost of AC generator fuel	**4862.3**
Total System Costs (NPC)	872697.2
Levelized Cost of energy	0.09/kWh
PV Generator Costs (NPC)	202575.4
Battery bank Costs (NPC)	**259087.6**
ACGenerator Costs (NPC)	192710.5
Inverter Costs (NPC)	49344.5
AC Generator Fuel Costs (NPC)	**95368.4**
Installation+financing (NPC):	**73610.8**

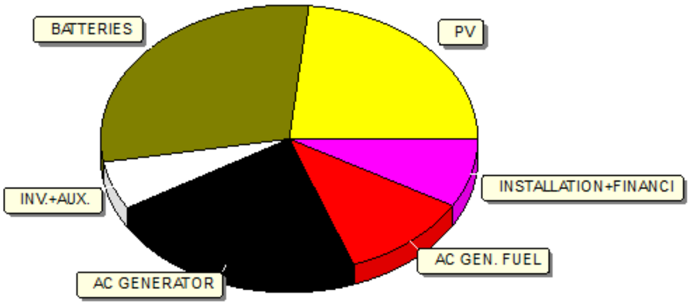
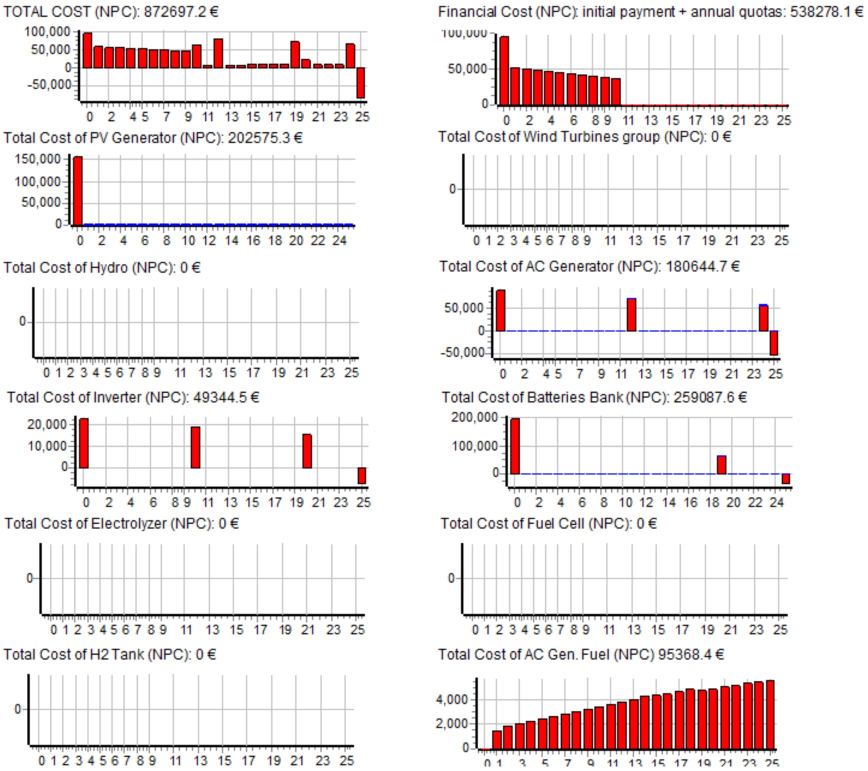


Figure 4.29 – *diagram showing multiple costs in the system*



TOTAL COST (NPC): 872697.2 €

Financial Cost (NPC): initial payment + annual quotas: 538278.1 €

Total Cost of PV Generator (NPC): 202575.3 €

Total Cost of Wind Turbines group (NPC): 0 €

Total Cost of Hydro (NPC): 0 €

Total Cost of AC Generator (NPC): 180644.7 €

Total Cost of Inverter (NPC): 49344.5 €

Total Cost of Batteries Bank (NPC): 259087.6 €

Total Cost of Electrolyzer (NPC): 0 €

Total Cost of Fuel Cell (NPC): 0 €

Total Cost of H2 Tank (NPC): 0 €

Total Cost of AC Gen. Fuel (NPC) 95368.4 €

Figure 4.30 – *different costs during the system lifespan*

- **Other results:**
  - Batteries Lifetime: 19.48 years
  - Equivalent Hours of AC Generator operation: 876.17 h/yr
  - Total CO2 emissions is 188151.03 kgCO2/yr where, emissions of AC generator (due to consumption of 47048.516 litre/yr) are 164669.81 kgCO2/yr
  - Human Development Index (HDI): 1.0896.
  - Jobs created during system lifetime: 1.2477

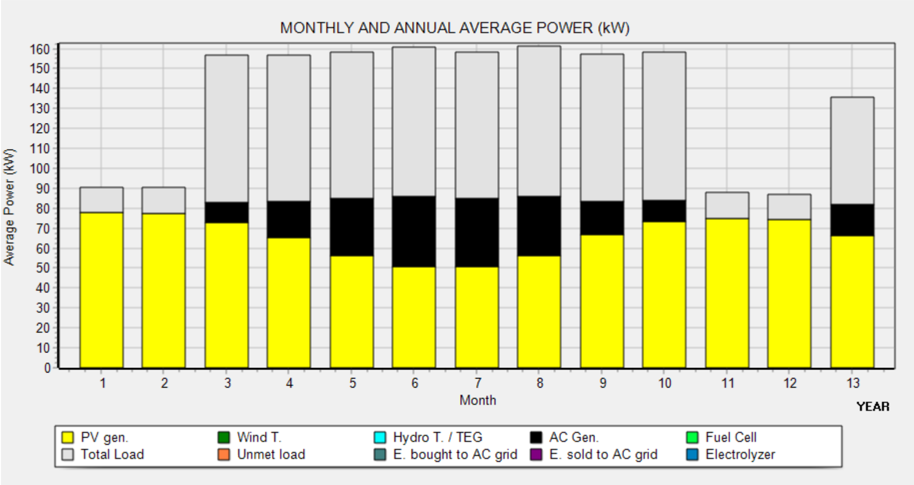


Figure 4.31 – *diagram of the monthly and annual average power*

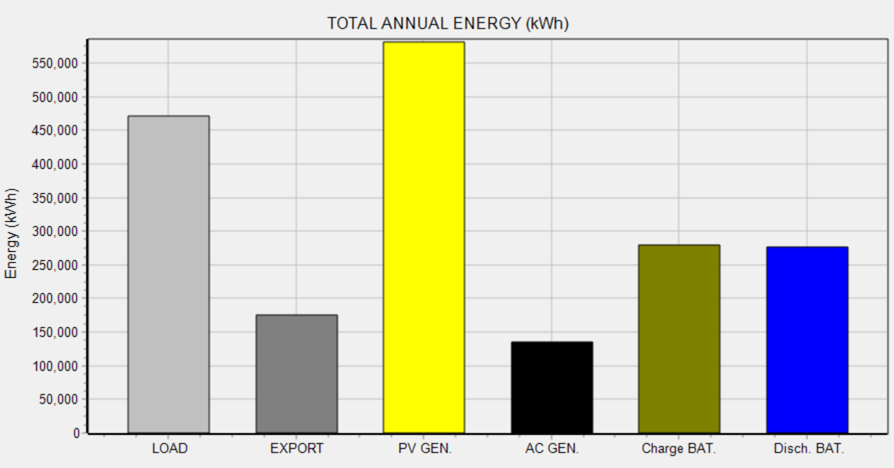


Figure 4.32 – *the total annual energy*

- Multiperiod simulation: energy results (kwh/year) for each year of the study period

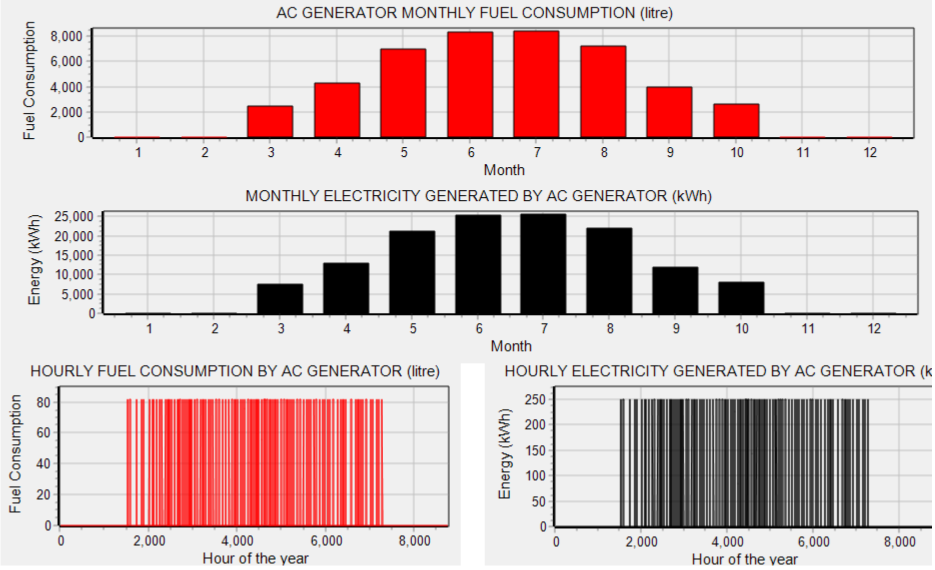


Figure 4.33 – *AC generator monthly fuel consumption*

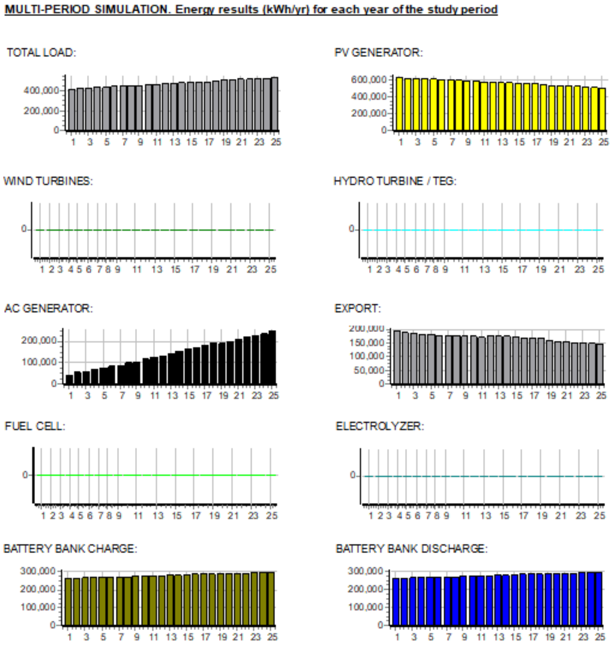


Figure 4.34 – *energy results (kwh/year) for each year during system lifespan*

4.9.3 Discussion

Comparing the two strategies «**load following**» and «**cycle charging**», we see that there is not a big difference in **total costs results (NPC)**. Whereas, for **the CO2 emissions** the cycle charging method has more impact on the environment due to its highest level of gas emissions because of the backup generator's rated power.

In both methods the load demand is well covered by the system components taking into account varriabilities which may happen.

5

GENERAL CONCLUSION

Throughout this work, the techno-economic feasibility evaluation of fixed panels, off-grid solar PV system using batteries and a backup generator mounted in Tindouf is presented, analyzed and simulated using iHoga software. Resulting in an appropriate sizing of components and technical indicators describing the productivity and performance of the project.

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.The study of this project proved that the proposed system is more reliable, cost effective and also more environmentally friendly since it will be able to reduce CO2 emissions in the atmosphere.

The values of input variables of any model are cause to undergo changes due to influence of environmental conditions. These changes can be investigated by conducting the sensitivity analysis of input variables with respect to output variables. Sensitivity analyses relate uncertainty in the PV system output to uncertainty arising from each model. It increases the validity, credibility and assurance of model estimates. The purpose of this study was to identify the most important and sensitive input variables and to prioritize the parameters based on their influence on the model outputs of a standalone photovoltaic (SAPV) system.

Bibliography

[1] "The need for renewable energy sources." [Online]. Available : https ://www.researchgate.net/publication/316691176 The Need For Renewable Energy Sources.[Accessed on 20/02/2022]

[2] "Smart grid."[Online].Available: https://www.techopedia.com/definition/692. [Accessed on 02/03/2022]

[3] "Power generation and smart grid." [Online]. Available : https ://www.ase.org/policy/energy2030/power-generation-and-smart-grid. [Accessed on 20/04/2022]

[4] "Overview of smart substations."[Online]. Available :https ://www.sciencedirect.com/science/article/pii/B978012815158 7000019.[Accessed on 20/04/2022]

[5] "Smart meter." [Online]. Available : https ://smart-cre.com/smart-meter-definition-and-examples/. [Accessed on 20/04/2022]

[6] "Energy management in smart grid." [Online]. Available : https ://smartgrid.ieee.org/bulletins/august-2019/energy-management- in-smart-grid.. [Accessed on 20/02/2022]

[7] "Wind power." [Online]. Available :https ://windexchange.energy.gov/what-is-wind. [Accessed on20 02 2022]

[8] "Biomass energy." [Online]. Available: https ://www.eia.gov/energyexplained/biomass/. [Accessed on 01 02 2022]

[9] "Hydraullic energy." [Online].Available :https ://www.endesa.com/en/blogs/endesa-s- blog/sustainability/hydraulic-energy. [Accessed on 10 05 2022]

[10] "Energy & mines book." [Online]. Available : www.mem-algeria.org. [Accessed on 12 04 2022]

[11] "Cder algeria." [Online]. Available : http ://www.cder.dz. [Accessed on 05 05 2022]

[12] “Epia - european photovoltaic industry association.” [Online]. Available : http ://pr.euractiv.com/pr/how-europe-s-el3ectricity-grid-can-integrate-solar-photovoltaics-epia-presents-new-report-92713. [Accessed on 04 2022]

[13] “Md tofael ahmed.” [Online]. Available : Modelization and Characterization of Photovoltaic Panels” ,ÉVORA university,Portugal. 2017

[14] M. Zeman, “Photovoltaic system,” 2019.

[15] “Grid-connected photovoltaic power system.”[Online].Available : https://en.wikipedia.org/wiki/Grid- connected photovoltaic power system. [Accessed on 15 04 2022]

[16] “Introduction to hybrid systems.” [Online]. Available : https ://link.springer.com/chapter/10.1007/0-8176-4404-0 5_ [Accessed on 09 04 2022]

[17] “Solar panel construction.”[Online].Available : https ://www.cleanenergyreviews.info/blog/solar-panel-components-construction. [Accessed on 14 05 2022]

[18] Kheldoune Aissa, “Renewable energy course,” IGEE, 2020.

[19] “Lead acid battery types.” [Online]. Available: https://batteryguy.com/kb/knowledge-base/what-is-a-lead-acid-battery/. [Accessed on 27 05 2022]

[20] “Lithiumbattery.”[Online].Available:https://www.sciencedirect.com/topics/engineering/lithiumbattery.[Accessed on 14 03 2022]

[21] “Acid battery vs. lithium ion:the detailed comparison.” [Online]. Available : https ://carfromjapan.com/article/car-maintenance/lead-acid-battery-vs-lithium-ion/.[Accessed on 18 02 2022]

[22] “What is the role of photovoltaic inverter in solar power generation ?” [Online]. Available :https ://www.snadisolar.com/photovoltaic-inverter-solar-power-generation/.[Accessed on 18 04 2022]

[23] “Understanding backup power generation system options.” [Online]. Available:https://facilitiesnet.com/mobile/ms/topicDetails/18159.[Accessed on 06 06 2022]

[24] “Natural gas vs. diesel generators : Pros and cons.” [Online]. Available : https ://www.generatorsource.com/Natural_Gas_vs_Diesel_Generators.aspx. [Accessed on 19 03 2022]

[25] “Charge controller.” [Online]. Available : https://alenconsystems.com/learning/pv-charge/.[Accessed on 16 04 2022]

[26] “Short circuit current.” [Online].Available :https ://www.pveducation.org/pvcdrom/solar-cell-operation/short- circuit-current. [Accessed on 25 04 2022]

[27] “Open circuit voltage.”[Online].Available :https ://www.pveducation.org/pvcdrom/solar-cell-operation/open-circuit-voltage. [Accessed on 28 04 2022]

[28] “Maximum power point.” [Online]. Available : https ://www.teachengineering.org/content/cub /lessons/cub pveff/ Attachments/cub_pveff_lesson03_fundamentalsarticle_v11_tedl_dwc.pdf# : :text=maximum%20power%20point[Accessed on 13 05 2022]

[29] “Fill factor.” [Online]. Available :https ://www.pveducation.org/pvcdrom/solar-cell-operation/fill-factor. [Accessed on 28 04 2022]

[30] “Solar cell efficiency.” [Online]. Available : Solar cell efficiency - Wikipediahttps ://en.wikipedia.org/wiki/Solar cell efficiency. [Accessed on 16 03 2022]

[31] “Pv cell modeling.”[Online]. Available :https ://www.researchgate.net/publication/283004040 Single-Diode Pv_Cell Modeling_And_Study Of_Characteristics_Of Single And_Two-Diode _ Equivalent Circuit. [Accessed on 15 03 2022]

[32] “solar cell modeling.”[Online].Available:https ://www.pvresources.com/en/solarcells/solarcells.php. [Accessed on 01 06 2022]

[33] “Equivalent circuit model of a pv cell.” [Online]. Available : https ://www.researchgate.net/figure/A-equivalent-circuit-model-of-a-PV-cell-The-current-of-the-PV-cell-is-given-as fig3 233721009 . [Accessed on 09 06 2022]

[34] “Ideality factor.”[Online]. Available :https ://www.pveducation.org/pvcdrom/solar-cell-operation/ideality-factor. [Accessed on 02 06 2022]

[35] D. R. D. López, “ihoga user’s manual,” Department, University of Zaragoza, Spain.

[36] e. a. Akif Karafil, “of optimum fixed tilt angle of pv panels,” 2020.

[37] “Photovoltaics education website.”[Online].Available : https ://www.pveducation.[Accessed on 03 04 2022]