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Sizing of PV system supplying the faculty of Science and Technology

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Abstract:

This master's thesis presents a step-by-step methodology for sizing an off-grid photovoltaic system to supply the Faculty of Science and Technology at Ghardaia University. The study focuses on using manual calculations to determine the optimal configuration and capacity of the PV system. The research includes an analysis of solar potential, load power estimation, energy consumption of the faculty, and the cost estimation. The proposed methodology provides a systematic approach for designing off-grid photovoltaic system tailored to the specific requirements of the university. The findings of this study contribute to the field of off-grid solar system design, particularly in the context of educational institutions.

Keywords :

Off-grid , photovoltaic, sizing , load estimation, cost estimation.

ملخص:

تقدم مذكرة الماجستير هذه منهجية تدرجية لتحجيم نظام الطاقة الشمسية الكهروضوئي المستقل عن الشبكة لتغذية كلية العلوم والتكنولوجيا في جامعة غرداية. تركز الدراسة على استخدام حسابات يدوية لتحديد التركيبة المثلى وسعة النظام. تشمل البحث تحليل الإمكانات الشمسية، وتقدير الأحمال، واستهلاك الطاقة للكلية، وتقدير التكاليف. توفر المنهجية المقترحة نهجًا منهجيًا لتصميم نظام الطاقة الشمسية المستقل عن الشبكة وفقًا لمتطلبات الجامعة الخاصة. تساهم نتائج هذه الدراسة في مجال تصميم أنظمة الطاقة الشمسية المستقلة عن الشبكة، خاصة في سياق المؤسسات التعليمية.

كلمات المفتاحية: المستقل عن الشبكة، الكهروضوئي , تحجيم , تقدير الاجمال , تقدير التكاليف

Abbreviation and Nomenclature List :

PV	Photovoltaic
CdTe	Cadmium telluride
CIGS	Copper indium gallium selenide
CAGR	Compound Annual Growth Rate
MTEER	Ministry of Energy Transition and Renewable Energy
ANDI	National Agency for investment Development
APRUE	National Agency for the Promotion and Rationalization of Energy Use
CEREFE	The Renewable Energy and Energy Efficiency Commission
CDER	The Renewable Energies Development Center
CREG	Regulatory Commission for Electricity and Gas
I-V	Current and voltage
P-V	Power and voltage
P	Positive
N	Negative
I_{ph}	photo-current [A]
R_{sh}	shunt resistance
R_s	series resistance
V	voltage across the diode [V]
I_{sc}	short circuit current
V_{oc}	open circuit
MPP	maximum power point
P_{max}	The maximum power
STC	Standard Test Conditions
V_m	maximum voltage
I_m	maximum current

FF	Fill Factor
Ns	Number of modules in series
Np	Number of modules in Parallel
DC	Direct current
AC	Alternative current
C	Capacitor
L	Inductor
K	Switch
D	Diod
MPPT	maximum power point tracker
P&O	Perturb and Observe
IC	method and Incremental Conductance
PWM	Pulse Width Modulation
ΔV	Voltage variation
ΔI	Current variation
Ni-Cd	Nickel-Cadmium
Li-Ion	Lithium-ion
FST	Faculty of science and technology

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General introduction

The field of renewable energy, particularly photovoltaic (PV) systems, has gained significant attention in recent years. The increasing demand for clean and sustainable energy sources has prompted the exploration and implementation of PV technologies worldwide. Photovoltaic systems harness solar energy and convert it into electricity, providing a promising solution for meeting energy needs while reducing carbon emissions.

This study comes in the context of increasing global interest in renewable energy, particularly solar energy. Algeria, with its abundant solar resources, is an ideal location for solar energy development and a transition towards a future energy landscape. Algeria's future vision reflects its commitment to expanding the use of solar energy and relying on renewable energy sources to meet the country's energy needs.

The objective of this research is to size an off-grid photovoltaic system for the Faculty of Science and Technology at the University of Ghardaia . The focus will be on designing and determining the system size based on the faculty's requirements, ensuring sustainable and reliable electrical supply for the Faculty.

The scope of this research focuses on the sizing of an off-grid PV system for the Faculty of Technology. The investigation will include PV technologies and the PV market in Algeria in first Chapter, followed by a discussion of PV cell modeling basics in second Chapter .third Chapter will explore the various components of an off-grid system, and the fourth chapter will present the methodology for sizing the system. Finally, Fifth chapter will apply the sizing principles to the Faculty of Sciences and Technology.

This research aims to contribute to the understanding and implementation of off-grid solar systems, specifically in the Algerian context. By successfully sizing and implementing an off-grid system for the Faculty of Science and Technology, valuable insights and practical knowledge can be gained to inform future off-grid solar projects in Algeria and beyond.

The research will also explore appropriate methodologies for assessing electricity demand, determining the required capacity, and sizing an efficient system.

Through this research, we will have a better understanding of the factors influencing the sizing of an off-grid photovoltaic system and the challenges it may face in the Algerian Context. The findings will contribute to improving the design and implementation of off-grid solar systems, enhancing their efficiency and adoption in Algeria.

Overall, this research is a crucial step towards promoting the use of off-grid solar energy in Algeria and achieving a transition towards a more sustainable and clean future. By applying the results of this research, access to energy can be enhanced, reliance on renewable energy sources can be improved, and the benefits can be realized for society, the environment, and the economy in Algeria.

Chapter I

PV Technologies and PV Market in Algeria

I. Introduction:

Photovoltaic (PV) technologies are rapidly gaining prominence as a sustainable and eco-friendly solution to meet the world's ever-growing energy demands. The conversion of solar energy into electricity using PV cells is becoming increasingly popular due to its ability to generate electricity without producing greenhouse gases or harmful emissions. Algeria, a country in North Africa, is richly endowed with solar resources, and has tremendous potential for the development of photovoltaic. Algeria's energy sector is currently dominated by hydrocarbons, but the government has recognized the need to diversify its energy mix and invest in renewable energy sources, including PV. In this chapter, we will provide an overview of photovoltaic technologies, as well as examine the current state of PV energy in Algeria. We will also discuss the government's initiatives to promote the development of PV in the country.

II. Solar PV technologies:

Photons are tiny particles that carry solar energy and release it when they interact with atoms. This mechanism is responsible for the warmth felt on the skin when exposed to sunlight. To harness this energy, semiconductors like silicon and cadmium telluride use a process called PV conversion, which involves capturing photons from the sun and converting them into electricity. PV cells, which are semiconductors, play a crucial role in this process by generating an electric current from absorbed photons. PV cells are an important component of solar-electric systems, which are increasingly being used as an alternative to conventional electricity sources. Over time, PV cell technology has evolved through different generations of development [1].

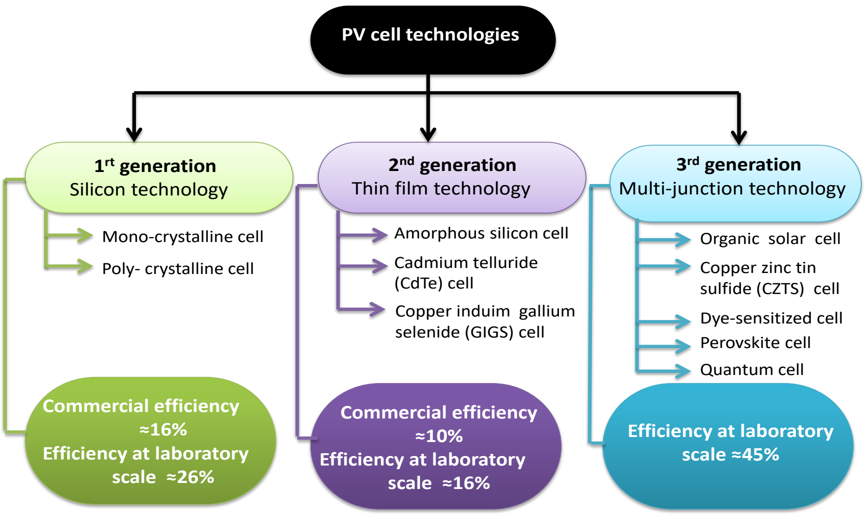


Figure I.1 : Classification of PV technologies

II.1.First generation:

The initial generation of solar cells, known as wafer-based solar cells, primarily utilized crystalline silicon materials, which included polysilicon and monocrystalline silicon [2].

Monocrystalline :

The Czochralski technique is used to produce monocrystalline solar cells by using a single silicon crystal. Large ingots are accurately processed to create silicon crystals. Initially, monocrystalline cells had an efficiency of 16%. However, there have been advancements in multicrystalline silicon solar cells, which now have a higher efficiency of 19.8%. Moreover, there has been a further improvement with monocrystalline cells reaching an efficiency increase of 24.4%. The enhanced efficiency of multicrystalline cells was achieved through an isotropic etching process, which created a symmetrical "honeycomb" surface pattern. Additionally, the surfaces of multicrystalline cells were coated with thermally generated oxides to prevent detrimental electronic processes from occurring [2].

FigureI.2: Monocrystalline panel [3].

A. Polycrystalline:

Polycrystalline silicon production techniques are comparatively simpler. The most commonly employed method in production is the casting method. Similar to monocrystalline silicon, the starting material for polycrystalline silicon is prepared, and the desired level of purity is also required. The high-quality silicon is melted and poured into molds, where it is allowed to cool. Subsequently, the resulting blocks are cut into square shapes [4]. Polycrystalline technologies are with an efficiency of 19.8% [5].

Figure I.3: Polycrystalline panel [6].

II.2. Second generation:

The second generation of solar cells includes three distinct types: cadmium telluride (CdTe), amorphous silicon, and copper indium gallium selenide (CIGS), also known as copper indium selenide (CIS). These solar cells exhibit performance efficiencies ranging from 10% to 15% and have the advantage of not requiring silicon wafers.[7] Flexible thin-film solar cells produced using second-generation technology are more cost-effective compared to those made using first-generation technologies. This is primarily due to their reduced material usage and the efficient, inexpensive production processes involved [1].

A. Cadmium telluride (CdTe):

The initial development of thin-film photovoltaic technology using CdTe solar cells took place during the early 1970s [1]. Currently, CdTe thin-film technology is the only thin-film technology present among the top 10 global manufacturers [2]. The reason for CdTe's dominance among the top global manufacturers is its exceptional durability and chemical stability. Moreover, CdTe can be deposited using various techniques, making it highly suitable for large-scale production across expansive areas [8].

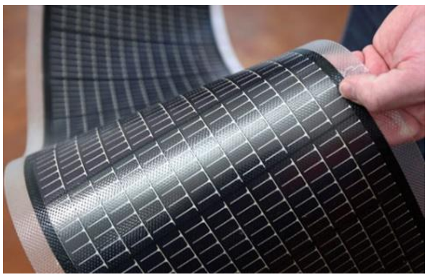


Figure I.4: CdTe thin film photovoltaic technology [9].

B. Amorphous silicon:

Among thin film technologies, this specific type of solar cell has gained significant recognition. To produce amorphous-Si modules, a thin layer of silicon vapor, typically around 1 µm thick, is deposited onto a substrate material such as glass or metal. In this configuration, a transparent conducting oxide is utilized to reduce the series resistance by creating a lateral conducting pathway for the current, as illustrated in Figure I.5 [2].

Figure I.5: amorphous thin film photovoltaic technology [10].

C. Copper indium gallium selenide (CIGS) :

Thin film solar cells based on CIGS (copper indium gallium selenide) have emerged as promising energy conversion technologies for indoor and outdoor applications, and their market share is steadily increasing. CIGS exhibit several favorable characteristics, including a high absorption coefficient, variable band gap, and flexibility. The production of CIGS cells can be achieved through methods such as co-evaporation or depositing a precursor film and subsequently subjecting it to high-temperature annealing [11].

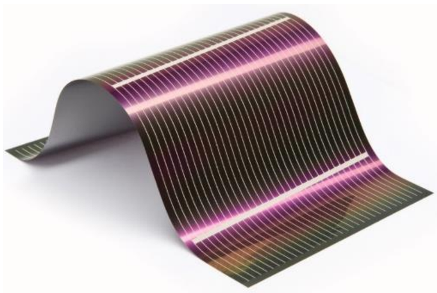


Figure I.6: CIGS thin film photovoltaic technology [12].

II.3.Third Generation:

Some of the materials that are currently being developed and researched for use in the production of PV solar cells are used in the third generation of PV cells. These materials incorporate silicon wires, nanotubes, conductive polymers, organic dyes, and solar inks in addition to more traditional printing press technology. The third generation of PV cells is currently being researched with the aim of enhancing power conversion efficiency , reducing costs so that more solar cells can be deployed, expanding the usage of solar power applications, and enhancing the power density of solar PV panels. However, this study's focus is only on the first and second generations of PV cells. Third-generation PV cells are not included in this list because they are still not widely used commercially and because many PV design and analysis software packages lack databases for them [1].

III.PV in Algeria :

Energy sector overview:

The energy mix of Algeria is predominantly comprised of fossil fuels, with gas accounting for 63% and oil for 36% of the country's total primary energy demand. Between 2000 and 2019, the total energy demand increased from 27 Mtoe to 56 Mtoe, with a Compound Annual Growth Rate (CAGR) of 4%. It is projected that by 2040, the demand will further rise to 73 Mtoe, with a CAGR of 1%. Despite the emergence of renewables, particularly solar energy, their share in the energy mix is expected to only reach 7% by 2040. While the absolute consumption of all fuels is predicted to increase in the future, the proportion of oil will remain constant until 2040. Gas is expected to account for 38% of the market, while electricity is projected to occupy a 17% share [13]. Over the coming years, the power mix is set to undergo diversification, primarily driven by the increasing contribution of solar energy. It is projected that solar power will account for 8% of electricity generation by 2025, and this share is anticipated to rise significantly to 37% by 2040 [13].

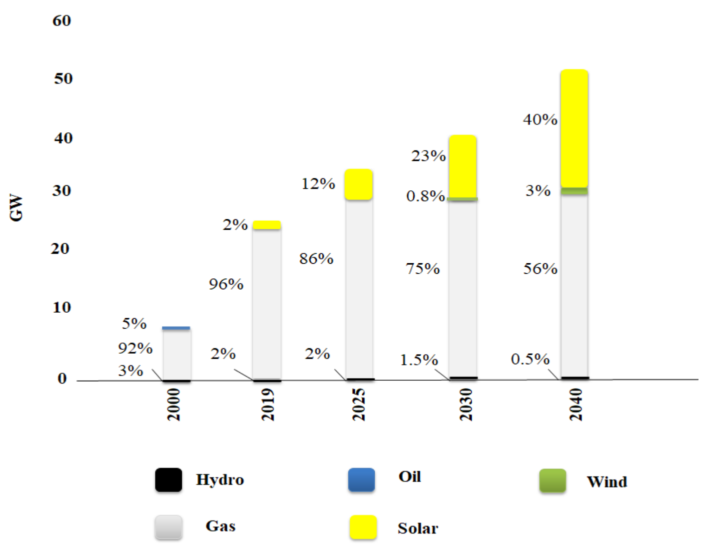


Figure I.7: Power capacity GW in Algeria 2000-2040 [13].

III.1.The development of renewable energy in Algeria:

Algeria took early regulatory steps in 1999 to incorporate renewable energy and energy efficiency into its energy model. In 2011, the country initiated its first program for renewable energy development, which was later revised in 2015. The updated program aimed to install 22 GW of capacity by 2030, with a significant portion of 13.57 GW dedicated to photovoltaic technologies [14].

In Algeria, the government has created the Ministry of Energy Transition and Renewable Energy, which is empowered to oversee and drive the development of projects related to renewable energies and energy transition in the country. This establishment is in accordance with Executive Decree No. 20-322 issued on November 22, 2020 [14].

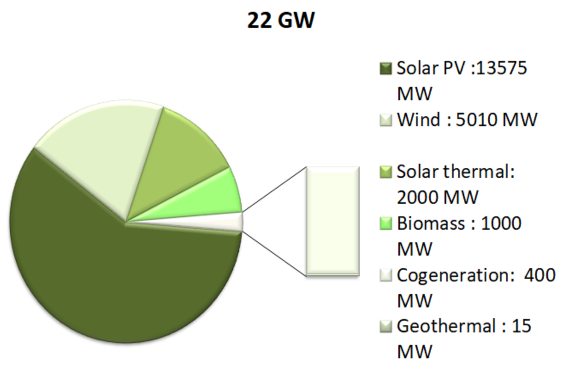


Figure I.8: Algeria's program for renewable energies development by 2030

III.1.2.Laws and legal frameworks for renewable energy:

Legislative texts outlined in the following chart primarily govern projects focused on renewable energy production. The legal foundation was established in 1999 with the enactment of the law on energy management. Additionally, two other laws passed in the early 2000s (in 2002 and 2004) serve as the basis for the development of renewable energy in Algeria. Over time, the regulatory framework has been further enhanced with the addition of several supplementary texts that cover all activities related to renewable energy production projects. This progress ultimately led to the establishment of the Ministry of Energy Transition and Renewable Energy (MTEER) in 2020, dedicated to overseeing energy transition and renewable energy matters. In 2021, the MTEER was granted full authority concerning renewable energy, and the procedures for investor bidding are governed by Executive Decree No. 17-98. These procedures are now regulated by the MTEER under Executive Decree No. 21-431, issued on

November 4, 2021. As a result, the MTEER has become the primary point of contact for renewable energy initiatives in Algeria [14].

III.1.3.Actors of renewable energy in Algeria:

In May 2021, President Abdelmadjid Tebboune reiterated his dedication to initiating projects focused on solar energy and green hydrogen production. When the new Prime Minister, Mr. Aymen Abderrahmane, assumed office in June 2021, he explicitly incorporated the President's commitment into his action plan. It is emphasized that the planned initiatives for the renewable energy sector, including the launch of solar energy production projects, are prioritized as part of the economic recovery and rejuvenation efforts. To accomplish these goals, all stakeholders have been instructed to work towards achieving these objectives [14].

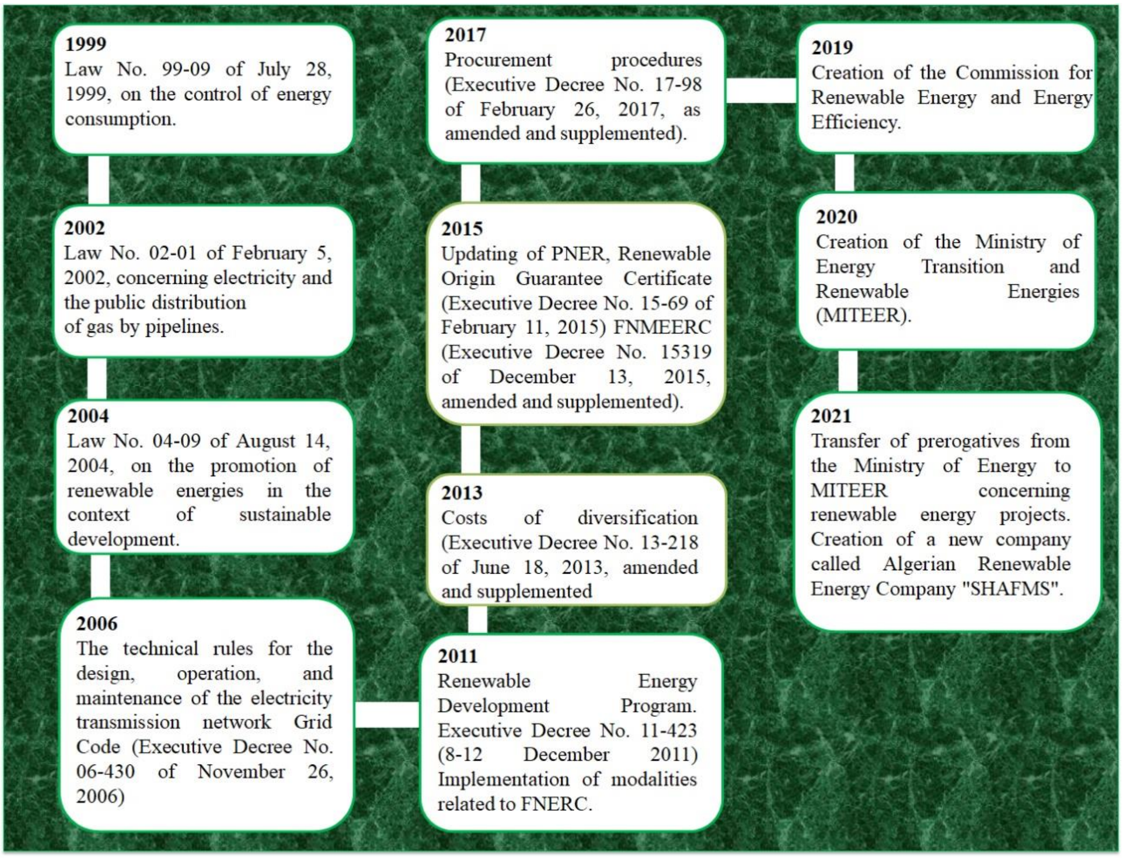


Figure I.9: Evolution of laws related to renewable energies

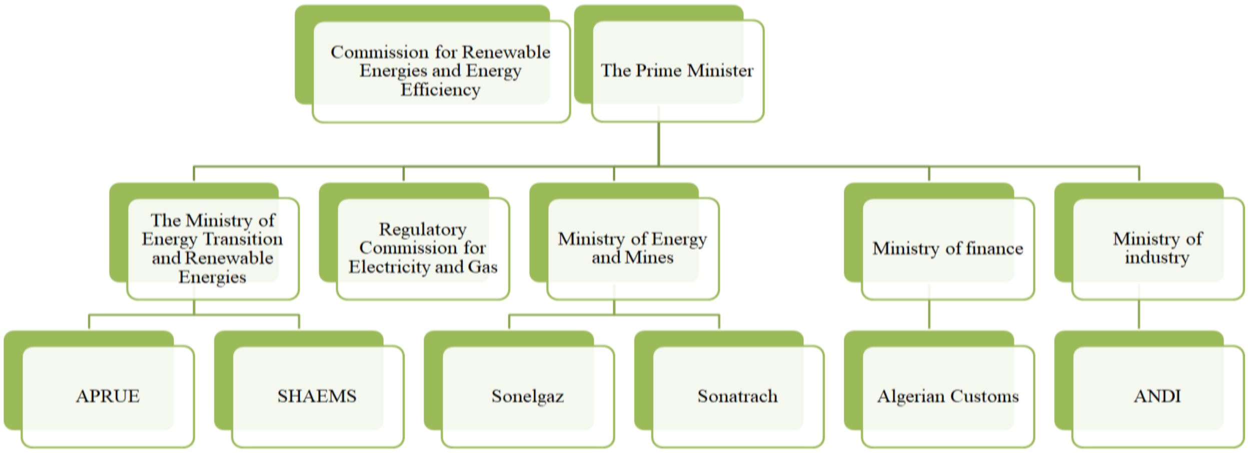


Figure I.10: Actors of renewable energy in Algeria

A. The Prime Minister:

The Prime Minister is responsible for overseeing and coordinating the different institutions involved in sectors related to renewable energy projects. Their role includes ensuring adherence to the action plan approved by the President of the Republic [14].

B. The Ministry of Energy Transition and Renewable Energies (MTEER) :

The Ministry of Energy Transition and Renewable Energies (MTEER) is entrusted with the task of implementing renewable energy projects in Algeria. It holds the responsibility of initiating investor bidding processes for renewable energy production projects. [14]

C. Ministry of Energy and Mines:

The Ministry of Energy and Mines has been a longstanding key player in Algeria's energy sector. It possesses all the necessary infrastructure for energy production, distribution, and transportation [14].

D. Ministry of finance:

The Ministry of Finance is responsible for supervising certain aspects of procedures associated with renewable energy projects, particularly regarding the bidding process for investors. This includes overseeing regulatory provisions and granting tax and customs benefits, among other tasks [14].

E. Ministry of industry:

The Ministry of Industry holds the responsibility for formulating the national industrial policy, developing key elements of the industrial strategy, and revitalizing industrial production [14].

F. National Agency for investment Development (ANDI) :

ANDI, operating under the supervision of the Ministry of Industry, serves as a primary liaison for investors. Its principal objective is to promote and oversee investments by simplifying administrative procedures associated with initiating new business ventures through an efficient single-window system. Moreover, it has the authority to provide tax benefits through official decisions [14].

G. National Agency for the Promotion and Rationalization of Energy Use (APRUE) :

APRUE is responsible for coordinating and promoting energy utilization, collaborating with relevant stakeholders in the private sector (such as industries, buildings, and transportation), and organizing awareness campaigns targeting the general public, professionals, and educational institutions. As of March 2021, the Ministry of Energy Transition and Renewable Energies has been assigned the task of supervising APRUE, as stipulated in Executive Decree No. 21-106 issued on March 17, 2021 [13].

H. The Renewable Energy and Energy Efficiency Commission (CEREFE) :

CEREFE, also known as the Renewable Energy and Energy Efficiency Commission, plays a supportive role in promoting the development of renewable energy and the efficient utilization of energy at both the sectoral and national levels. It is responsible for conducting regular evaluations of national policies aimed at advancing renewable energy sources and energy efficiency [13].

I. The Renewable Energies Development Center (CDER) :

The Renewable Energies Development Center is responsible for devising and implementing research and development initiatives focused on renewable energy sources. Its tasks include establishing pilot projects for renewable energy, conducting feasibility studies, certifying and standardizing equipment, and providing expertise and guidance for projects related to Energy and Natural Resources [13].

J. Regulatory Commission for Electricity and Gas (CREG):

CREG is entrusted with the responsibility of promoting fair competition and open operation within the national electricity and gas markets, with a focus on safeguarding the interests of both consumers and operators [13].

K. Algerian Customs:

Facilitation of customs procedures for national interest projects (green corridor)[13].

L. SHAEMS:

In April 2021, the Ministry of Energy Transition and Renewable Energies established SHAEMS (Algerian Renewable Energy Company) to facilitate the development of renewable energy sources for electricity generation in Algeria. The company, jointly owned by Sonelgaz and Sonatrach, is set to commence operations in the second half of 2021. SHAEMS will play a pivotal role in achieving Algeria's goals in renewable energy expansion [13].

M. Sonatrach:

Sonatrach, the state-owned oil company of Algeria, is involved in all aspects of the hydrocarbon industry, from exploration and extraction to the processing of resources like crude oil and liquefied natural gas. It is vertically integrated and shares ownership of the Algerian Renewable Energy Company (SHAEMS) with Sonelgaz, the national electricity and gas company of Algeria [13].

N. Sonelgaz:

SONELGAZ is a government-owned company responsible for the production, transmission, and distribution of both gas and electricity in Algeria [13].

III.2.Solar potential in Algeria :

As the largest country in Africa, the Mediterranean, and the Arab world, Algeria possesses vast solar potential. It is estimated to have an annual solar energy production capacity of approximately five billion GWh. Certain regions in the country experience an abundance of sunlight, with yearly sunshine durations reaching up to 3600 hours, averaging around 2500 hours. The radiation level is high, and the average daily solar irradiation ranges between 5 and 7 kWh/m^2/day throughout the year [15].

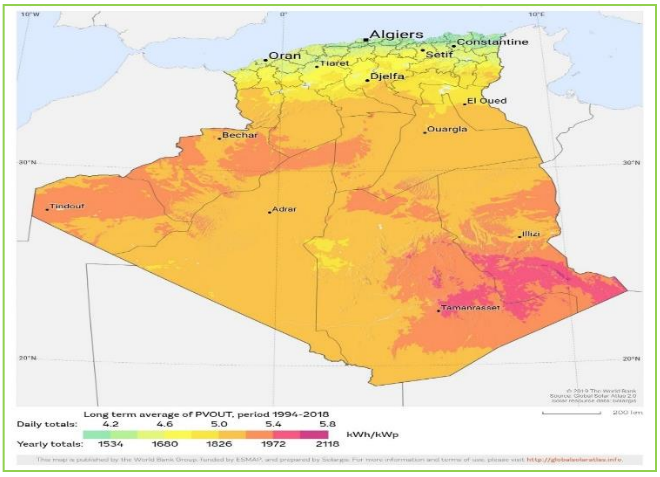


Figure I.11: Algeria photovoltaic power potential.

Algeria possesses immense potential for the expansion of solar energy, particularly in its southern regions where insolation rates can reach up to 2650 kWh per square meter. Additionally, around 75% of Algeria's land is covered by the Sahara Desert. With its abundant solar resources, Algeria aims to harness the high radiation levels and average daily solar irradiation ranging between 5 and 7 kWh/m^2/day throughout the year [15].

III.3.Solar market potential in Algeria:

Algeria offers significant opportunities for the development of large-scale solar initiatives, benefiting from its extensive coverage of the Sahara Desert, which accounts for over 80% of the country's surface area. The region experiences an average daily irradiation of 6.57 kWh/m2, resulting in an annual total ranging from 2,000 kWh/m2 to 2,650 kWh/m2. As of 2019, the combined installed capacity of renewable energy projects connected to the grid reached 686 MW_p, with photovoltaic (PV) installations accounting for 423 MW_p of that capacity [14].

IV .Conclusion:

In conclusion, the photovoltaic market in Algeria has been experiencing rapid growth in recent years, driven by the country's vast solar energy potential and the government's strong support for renewable energy. The implementation of PV has the potential to provide significant benefits to the country, including reducing its dependence on fossil fuels, promoting sustainable economic development, and reducing greenhouse gas emissions. Overall, the future of the PV market in Algeria looks promising, and with the right policies and investments, the country has the potential to become a leader in the deployment of renewable energy technologies in the region

Chapter II

PV Cell Modeling Basic

I. Introduction:

This thesis chapter delves into the fundamental principles and technical aspects of photovoltaic (PV) cells and modules, which are essential components of solar energy systems

The chapter begins with a definition of the PV cell . This is followed by an explanation of the photovoltaic conversion principle, which involves the transformation of solar energy into electrical energy through the use of semiconductor materials.

A mathematical model for PV cells is presented, which allows for the analysis and prediction of the electrical output of a cell under different operating conditions. The I-V and P-V characteristics of solar cells are discussed in detail, including the impact of temperature and irradiance on the performance of the cell. Moving on from individual cells, the focus shifts to PV modules and arrays. The characteristics of a PV module are discussed in detail, including factors such as module efficiency, Maximum Power and fill factors. The role of diodes in a PV array is also explained, along with their function in bypassing current around shaded cells. The final section of the chapter focuses on the wiring of solar panels, both in a series and in parallel.

II.PV cell:

A solar cell, also referred to as a photovoltaic cell, is a technology that harnesses the power of sunlight to generate electrical energy at the atomic level. By utilizing the photovoltaic effect, photons from the sun are directly converted into voltage and current, allowing for the efficient conversion of light energy into usable electricity [16].

II.1.Conversion principle:

Solar cells employ the photovoltaic effect to directly convert sunlight into electrical energy by generating and transmitting positive and negative electric charges within a semiconductor material. This material consists of two regions: one with an excess of electrons (N-type doped) and the other with a deficiency of electrons (P-type doped). When these two regions are brought into contact, the surplus electrons from the N-type material diffuse into the P-type material [17]. As a result of this electron diffusion, the N-doped region becomes positively charged, while the initially P-doped region becomes negatively charged. This creates an electric field between them, which exerts a force pushing the electrons towards the N-doped region and the holes towards the P-doped region. This formation of a junction between the two regions, known as a P-N junction, occurs as a result of these processes [17].

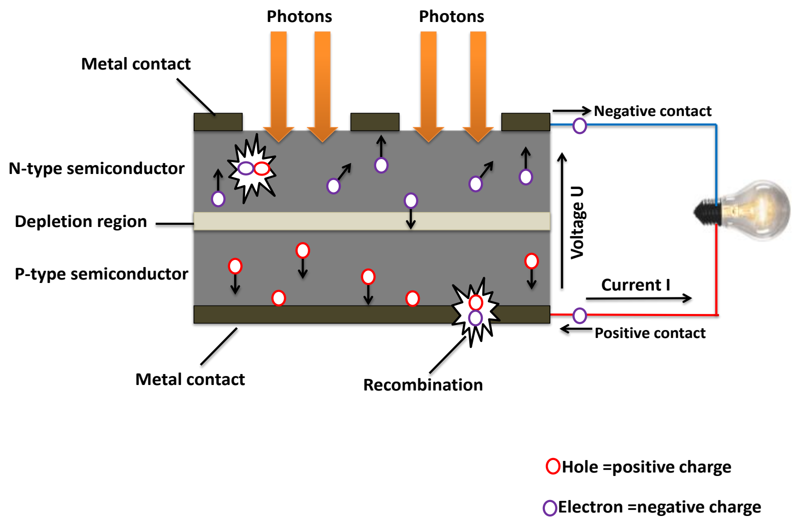


Figure II.1: Working principle of a solar cell

II.2.Mathematical model for photovoltaic cell:

Figure II.2 shows the equivalent circuit of a PV cell. The photo-current of the cell is represented by the current source I_{ph}. The intrinsic shunt resistance R_{sh} and series resistance R_s are also included in the circuit. Typically, R_{sh} has a very large value, and Rs has a very small value, so they can be disregarded to simplify the analysis [18].

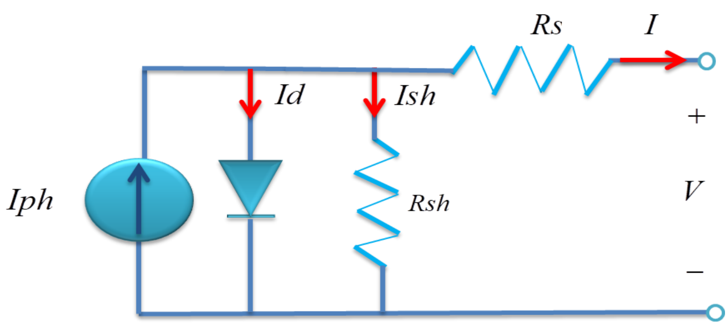


Figure II.2 : PV cell equivalent circuit

The equation that describes the relationship between voltage and current in a solar cell is as follows:

$$I = I_{ph} - I_0 \times \left(exp\left[\frac{q(V+I\times R_s)}{nKT}\right] - 1\right) - \left(\frac{V+I\times R_s}{R_{sh}}\right) \qquad \textbf{(II.1)}$$

Where, I_{ph}: photo-current [A], I_0: saturation current [A] , V : voltage across the diode [V] , T: operating temperature [K] , q: electron charge = 1.6 × 10-19 C , n: the ideality factor of the diode and k: Boltzmann's constant = 1.3805 × 10-23 J/K.

II.3.I-V and P-V characteristics of solar cell:

This section is about the I-V and P-V characteristics curves of solar cell

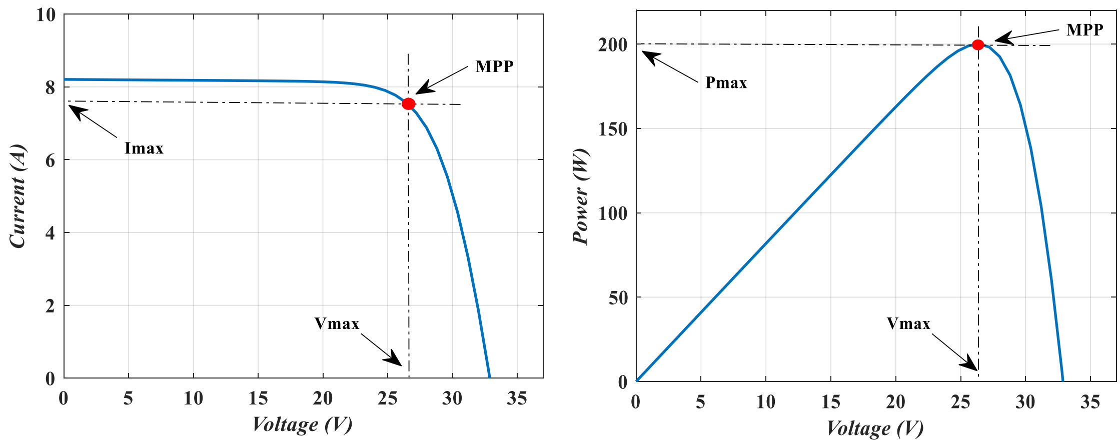


Figure II.2: Characteristic Current = f (Voltage) , power = f (Voltage)of the photovoltaic cell

As depicted in figure II.3 and figure II.4 this characteristics are affected by the irradiation and Temperature

A. Irradiation Influence:

The temperature is constant 25 ° C and different irradiation (200W/m², 500W/m², 1000W/m², 1500W/m²).

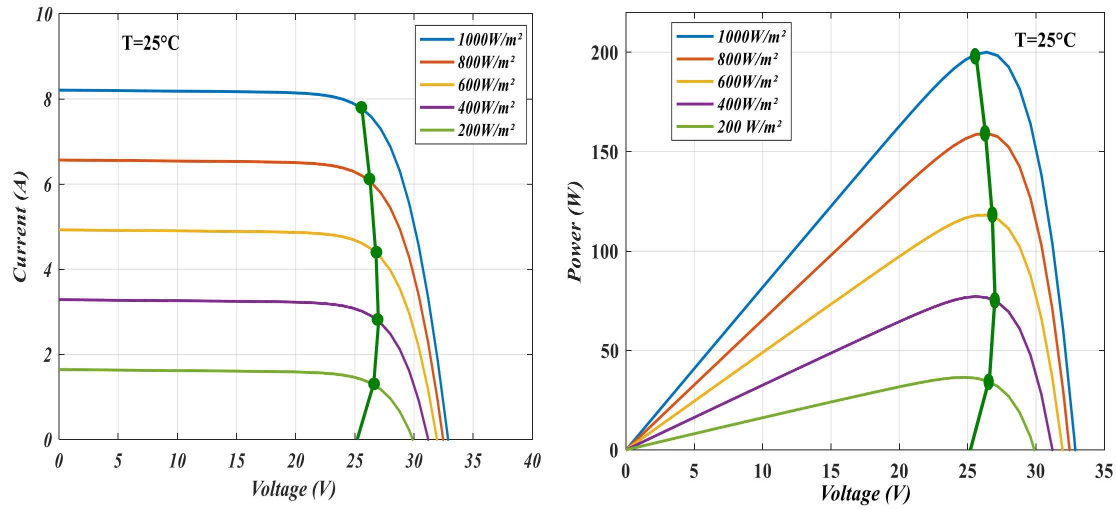


Figure II.3: Influence of the Irradiation

The data presented in Figure II.3 of the Matlab program illustrates the relationship between current and voltage (I-V) as well as power and voltage (P-V) characteristics under specific conditions. The intensity of incident light directly influences the amount of current generated, where higher radiation levels correspond to higher currents. Meanwhile, the voltage remains relatively constant. The impact of radiation on the maximum power point is apparent, as increased radiation levels lead to a higher maximum power point. [19].

B. Temperature Influence :

the irradiation is constant 1000W/m² and different Temperature (25 ° C, 35° C, 50 ° C, 75 ° C)

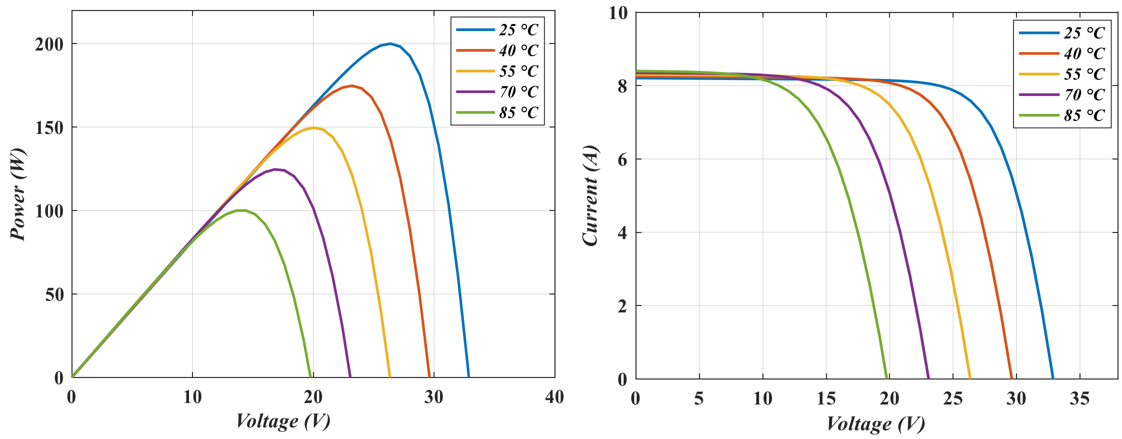


Figure II.4: Influence of the Temperature

Figure II.4 displays the simulation outcomes for the current-voltage (I-V) and power-voltage (P-V) characteristics under the same conditions. The current produced by the incident light remains relatively constant, exhibiting a slight rise as the voltage changes. However, both the voltage and power levels decrease due to the influence of an increase in temperature [19].

III.PV module and PV array:

Solar cells are linked and packaged together to form a photovoltaic (PV) module. When these modules are connected in series, the desired voltage is achieved, whereas connecting them in parallel increases the overall current. By combining series and/or parallel connections of these modules, a PV array is formed. Typically, commercial modules comprise a series connection of 36 solar cells to create a string [20].

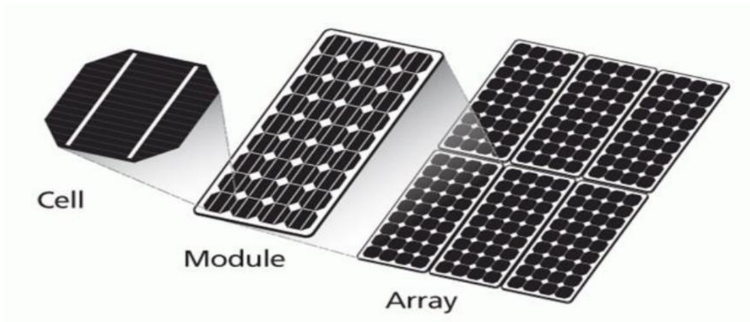


Figure II.5: from cell to array [43].

III.1.Characteristic of PV module:

A. Short Circuit Current:

The short circuit current (I_{sc}) is the highest current generated by a solar PV module when its terminals are shorted. This value can be determined using equation (II.2) [21].

Mostly,

$$I_{sc} = I_L \quad \textbf{(II.2)}$$

Where, I_L is current generated due to light

B. Open Circuit Voltage:

The open circuit voltage (V_{oc}) is the highest voltage achievable from a solar PV module when its terminals are not connected. The equation (II.3) provides the mathematical expression for calculating the open circuit voltage [21].

$$V_{oc} = \frac{KT}{q} Ln\left(\frac{I_L}{I_0} + 1\right) \tag{II.3}$$

C. Maximum Power :

The maximum power (P_{max}) refers to the highest power output that a PV module can generate under STC , which includes a solar radiation of 1000 W/m^2 and a cell temperature of 25˚C. It is calculated by multiplying the maximum voltage (V_m) and the maximum current (I_m). The equation (II.4) provides the formula to determine the maximum power [21].

$$P_m = V_m \times I_m \tag{II.4}$$

D. Fill Factor:

The Fill Factor (FF) is a measure of the "squareness" of the I-V curve of a solar module and is primarily influenced by resistive losses within the module. It represents the ratio of the actual maximum power output to the theoretical maximum power output. In an ideal scenario, the Fill Factor could be 100%, corresponding to a perfectly square I-V curve. However, in practice, it is not possible to achieve a perfectly square I-V curve, and there are always some losses that decrease the value of FF. The equations (II.5) provide the formulas to calculate the Fill Factor [21].

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \ \% \tag{II.5}$$

E. Efficiency:

The module efficiency can be determined using equation (II.6).

$$\eta = \frac{P_m}{P_{in}} \tag{II.6}$$

III.2. Diodes in PV Array:

When there is a difference in electrical performance, damage, or shading in a solar cell within a series, it will generate less current compared to the other cells. It’s important to ensure that the same current flows through all cells. Shading causes the cell to be reverse biased and results in heat losses. This localized heating can lead to a hotspot, potentially causing thermal breakdown and damaging the cell's encapsulation [20]. To prevent these issues, it is common to connect bypass diodes acrosssubsets of solar cells. These diodes allow current to flow around a subset of cells that may have a high resistance or open-circuit condition, allowing the functional subsets to continue providing power. In battery charging systems, blocking diodes can be placed in series with modules to prevent reverse current flow back to the modules [20].

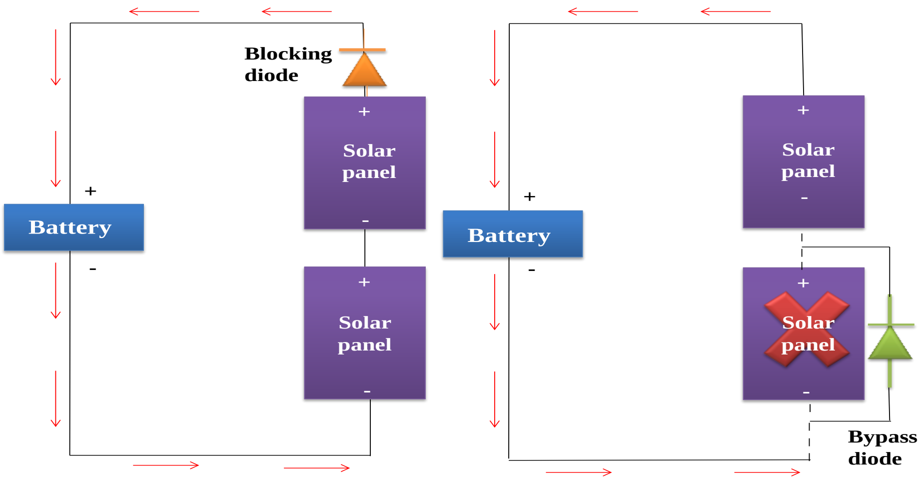


Figure II.6: blocking and bypass diodes in PV array

III.3.Wiring Solar Panels in a Series:

An association of Ns panels in series shown in II.7 makes it possible to increase the voltage of the photovoltaic array [17].

Example : If you had 3 solar panels in a series and each was rated at 14 volts and 6 amps, the entire array would be 42 volts at 6 amps

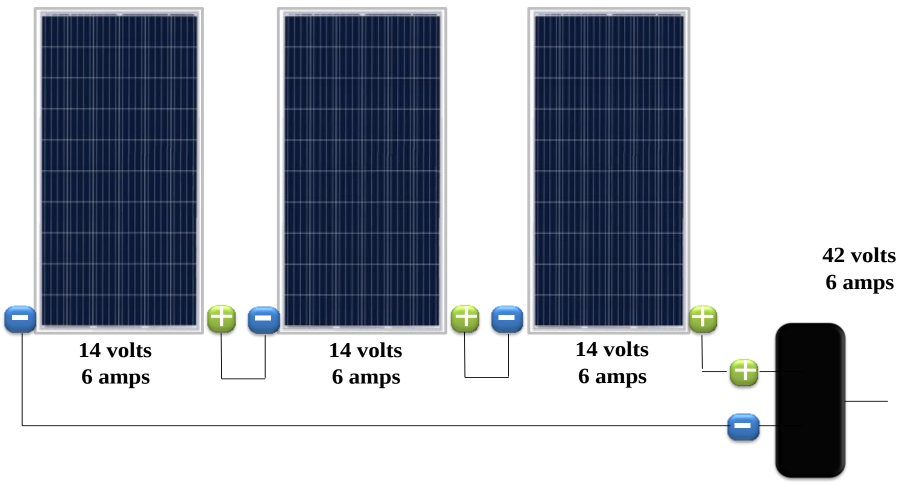


Figure II.7: Three panels wired in series

III.4.Wiring Solar Panels in Parallel:

A parallel association of Np cell figure II.8 is possible and allows to increase the array output current [17]. **Example:** If you had 3 solar panels in parallel and each was rated at 14 volts and 6 amps, the output array would be 14 volts at 18 amps.

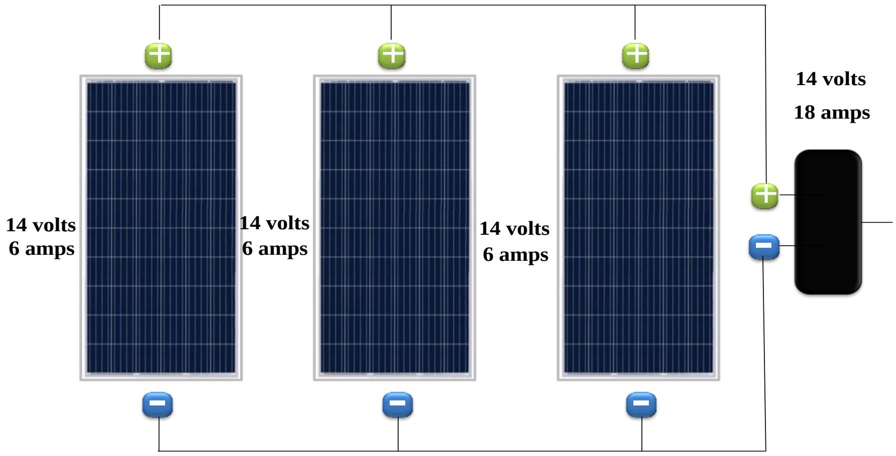


Figure II.8: Three panels wired in parallel

IV. Conclusion:

This thesis chapter provides a comprehensive understanding of the technical aspects of PV cells and modules, which is crucial for the design, operation, and optimization of solar energy systems. The knowledge gained from this chapter can be used to improve the efficiency and performance of PV systems, leading to a more sustainable and reliable source of energy.

Chapter III

PV System Components

I. Introduction:

This chapter aims to provide a comprehensive understanding of the PV chain and its key components, and their roles and utilization. This chapter will delve into the various components of the PV chain, including the solar panel, inverter, charge controller, battery and converters .The chapter will explore the function and operation of each component, as well as their interactions and effects on overall system performance.

II. PV system:

A PV system converts sunlight into electricity; a PV system contains different components, including a photovoltaic generator, electrical connections, mechanical assembly and a way to convert the electrical output. The electricity generated can be stored in a stand-alone system, stored in batteries or can power a larger electrical grid [17].

II.1. types of solar PV system:

Generally, there are two types of solar PV system: grid-connected or (grid-tied) and off-grid or (stand-alone) solar PV systems. :

II.1.1. Off-Grid System:

To ensure continuous power supply for loads during periods when sunlight is unavailable, a system necessitates a reliable and uninterrupted source of energy, like a utility or generator. Another option is to utilize stored energy, such as a battery or other similar means [22].

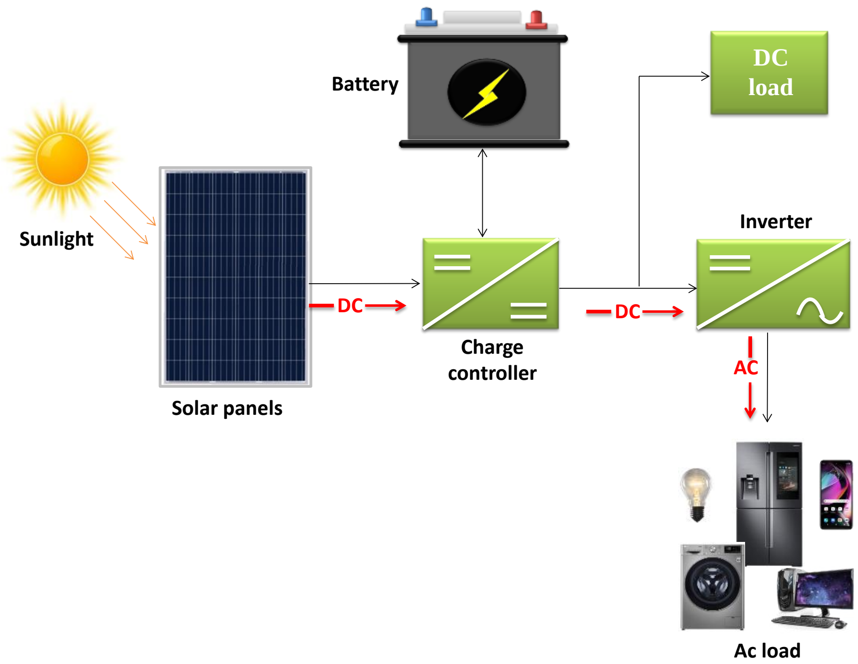


Figure III.1: Off-Grid PV System

II.1.2. Grid-Connect System:

Among the various types of PV systems, the grid-connect system is experiencing rapid expansion. These systems, designed for residential and commercial use, are widely recognized for reducing the reliance on electricity supplied by the local utility. A grid-connect system consists of a solar array, which comprises PV modules connected in series, and an inverter that converts the direct current (DC) electricity generated by the solar array into alternating current (AC) electricity [22].

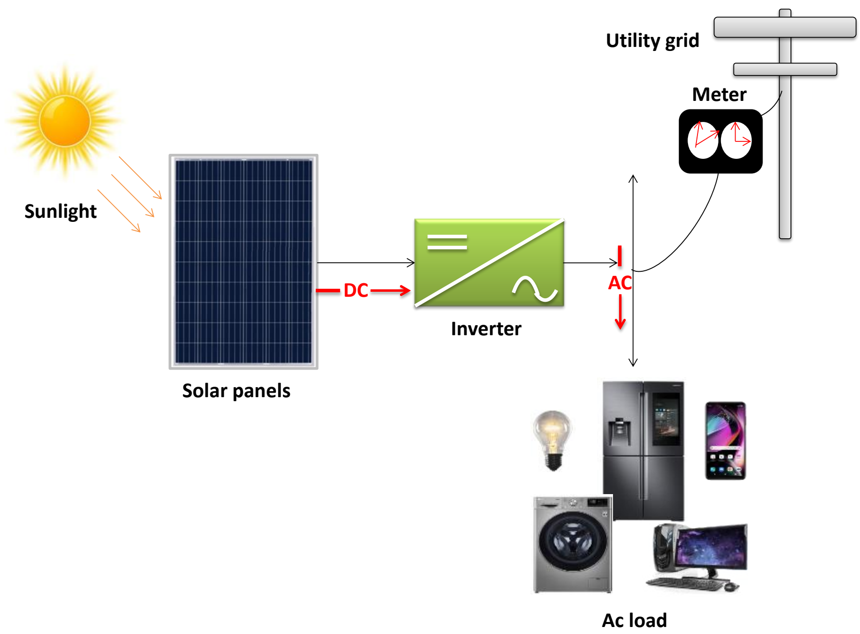


Figure III.2 : Grid-connected PV System

II.2. PV system components:

In a solar PV system, various components need to be carefully chosen based on the system type. For our study, we will specifically examine the components of a stand-alone (off-grid) PV system.:

II.2.1. PV module:

Most of the solar modules available in the market for residential and commercial solar systems are predominantly composed of silicon crystalline material. These modules consist of multiple strings of solar cells, which are arranged in an aluminum frame and connected in series, with positive and negative terminals aligned. Each individual solar cell can generate an output of 0.5 volts, and a 36-cell module can reach a maximum output of 18 volts. For larger modules, typically containing 60 or 72 cells, the frame is designed accordingly. The amperage produced by the cells is determined by their volume or surface area, and larger cells tend to generate higher amperage [23].

II. 2.2.DC DC Converters:

The DC-DC converter plays a crucial role in converting the input DC voltage of a PV system into the desired output DC voltage. The specific electronic converter circuit chosen depends on the system requirements and determines whether the output voltage will be higher or lower than the input voltage. The DC-DC converter consists of essential components such as a switch, diode, inductor, and capacitor. The switch can be implemented using transistors such as BJT, MOSFET, or IGBT, depending on the application and design considerations [24].

Figure III.3: DC-DC converter symbol

A. Buck converter:

A greater input voltage is changed into a stabilized lower output voltage via a step-down or buck converter.

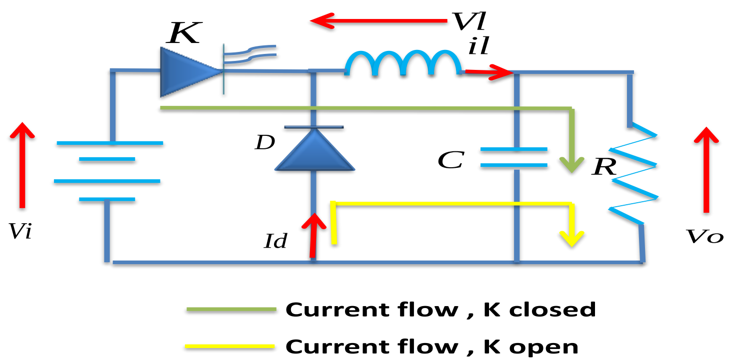


Figure III.4: Buck converter Circuit

One can easily observe the functioning of this circuit by considering the inductor (L) and capacitor (C) as low pass filters. When the switch (K) is closed, the capacitor (C) charges through the inductor (L), resulting in a gradual increase in voltage across the load. Subsequently, when the switch (K) is opened, the energy stored in the magnetic field of the inductor (L) is released. The diode (D) ensures that the inductor is clamped to 0V at the switch end, directing the energy discharge into the capacitor and load. This discharge causes the voltage across the load to gradually decrease or ramp down [25].

B. Boost converter:

The step-up or boost converter, as the name suggests, converts a lower input voltage into a stable, higher output voltage [25].

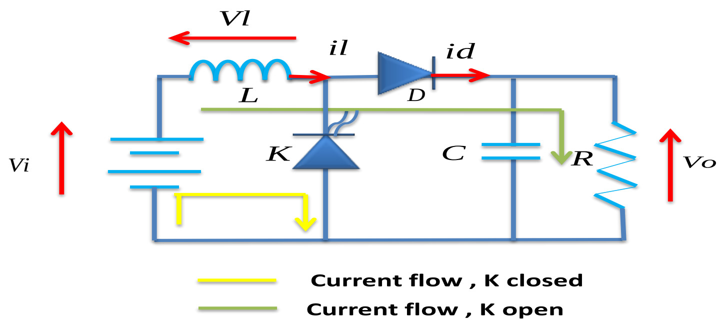


Figure III.5: Boost converter Circuit

If switch K is turned on, a short circuit will be created, leading to an increase in inductor current and stored energy. In this scenario, the load current will be zero, and the input voltage will only be applied across the inductor. Conversely, when switch K is turned off, the load current and inductor current will be equal. To decrease the output voltage, the capacitor is utilized as a filter [24].

C. Buck-Boost (Inverting) Converter:

The inverting flyback converter, also known as a buck-boost converter, generates a regulated negative output voltage from an input voltage that can either be higher or lower than the absolute value of the input voltage [25].

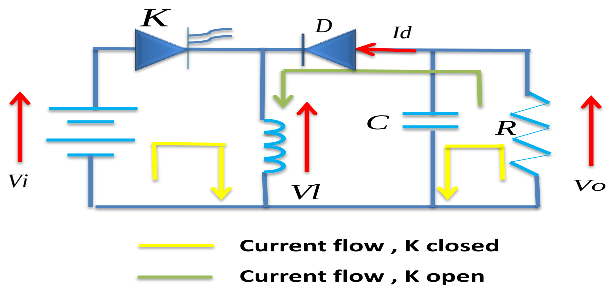


Figure III.6 : Buck-Boost converter Circuit

If switch K is in the "on" state, the input voltage will only be applied across the inductor. As a result, the inductor current and stored energy will increase. At the same time, a capacitor will be present, supplying voltage to the load during the discharge phase with the polarity of the input voltage reversed [24]. On the other hand, if switch K is in the "off" state, the capacitor will charge while the inductor, which was charging during the "on" state, will discharge. This charging and discharging cycle of the inductor and capacitor will continue repeatedly as the switch is alternated between the "on" and "off" positions [24].

II.2.3. MPPT (maximum power point tracker):

MPPT finds applications in PV solar and wind systems to maximize power generation in diverse environments. It is essentially an algorithmic approach that employs a controller to optimize power output from a PV system. The MPPT algorithm identifies the optimal PV module and associated battery with the highest power output, and then adjusts the current to the battery for maximum efficiency. To achieve this, the MPPT is connected to the PV system and can also be advantageous in directly powering DC loads connected to the battery [26].

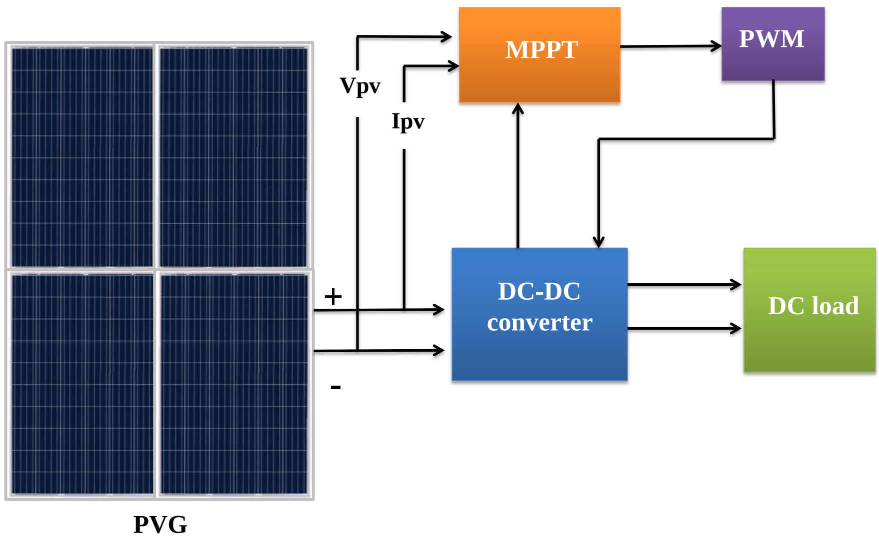


Figure III.7: Synoptic structure of a photovoltaic system with MPPT controller

II.2.3.1. The Different Type of MPPT Techniques for Photovoltaic System :

In this section we study about the two types of MPPT techniques Perturb and Observe (P&O) method and Incremental Conductance (IC).

A. Perturb and Observe Method (P&O) :

This approach involves tracking the Maximum Power Point (MPP) of the PV system. The output power is periodically measured and compared to the previous output power. This comparison helps prevent the Perturb and Observe (P&O) algorithm from moving backward as power levels increase. As the PV module is sensitive to changes in voltage, variations in current result in corresponding changes in power. The P&O algorithm is employed to continuously adjust and fine-tune the PV output, aiming to reach the MPP and achieve the highest power outcome. The P&O algorithm changes its direction based on the concepts of PV voltage increase or decrease. When the voltage increases, the P&O method moves in the same direction, and when the voltage decreases, it moves in the opposite direction. This method provides regular and iterative results [26].

$$d(t+1) = d(t) + (2\,sign - 1)D \quad \textbf{(III.1)}$$

Where sign is given by:

$$sign = ([P(t) - p(t-1)] > 0 \oplus ([V(t) - V(t-1)] > 0) \quad \textbf{(III.2)}$$

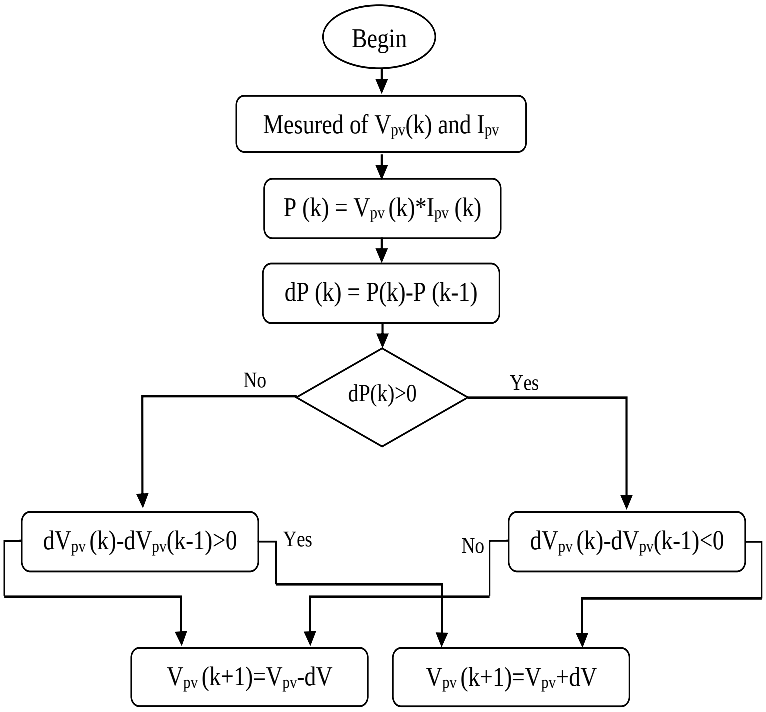


Figure III.8: flow chart of P&O algorithm

B. Incremental Conductance Method (IC) :

The conductance increment algorithm was developed to improve the algorithm (P&O) especially the oscillation problem around the MPP. The generator's voltages and currents are measured so that the controller may calculate the conductance G=I/V and incremental conductance dG= dI/dV and determine its behavior [26].

The derivative of power with respect to voltage is:

$$\frac{dP}{dV} = I + V * \frac{dI}{dV} \tag{III.3}$$

This leads to the following equations:

$$\begin{cases} \frac{dI}{dV} = -\frac{I}{V}, & \frac{dP}{dV} = 0 \qquad (a) \\ \frac{dI}{dV} > -\frac{I}{V}, & \frac{dP}{dV} > 0 \qquad (b) \\ \frac{dI}{dV} < -\frac{I}{V}, & \frac{dP}{dV} < 0 \qquad (c) \end{cases} \tag{III.4}$$

The direction in which a disturbance must occur to move the operating point towards the MPP is determined using equations (III.3) and (III.4). This disruption is repeated until the equation (III.4.a) is satisfied. When the MPP is achieved, the algorithm continues to use that value until the current value changes. The latter is caused by a change in the amount of sunlight. The MPP advances to the right of the working voltage as the insolation increases. The MPPT must boost the operating voltage to compensate for the MPP's movement. In the contrary scenario, as indicated in the image, when the sunshine diminishes, the MPPT must decrease the latter as shown in the figure (III.9).

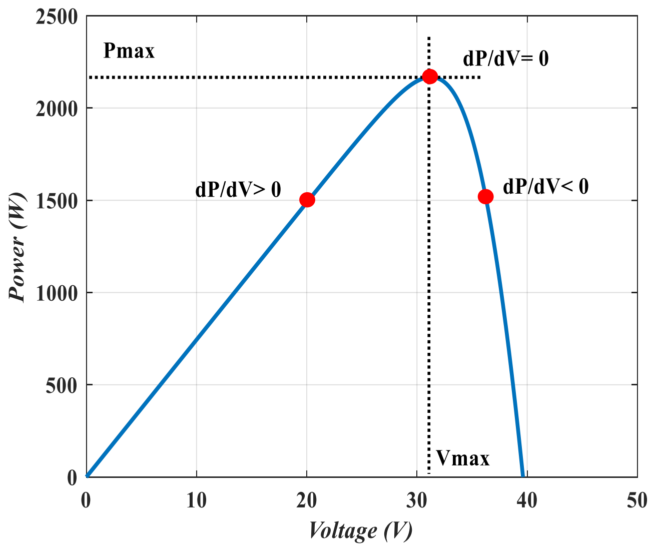


Figure III.9: Variation of dP/dV in the characteristic PV

Figure III.10 shows the algorithm's (INC) flowchart. dI and dV are calculated after measuring the GPV's I_{PV} and V_{PV}. If dV and dI are both 0, the atmospheric conditions have not altered, and the MPPT is remained at MPP. The sunshine has increased if dV=0 and dI>0. In order to regain the MPP, the operating voltage must be increased.

Unlike if dI<0, the insolation has decreased while requiring the algorithm to decrease the operating voltage. If the change in voltage is not zero, the ratios in equations (III.4-b) and (III.4-c) can be used to determine the direction in which the voltage must be changed in order to achieve the MPP. If (dI/dV) > (-I/V) (i.e. the ratio (dP/dV) >0), then the operating point is to the left of the MPP. Thus, the operating voltage must be increased to reach the MPP.

Similarly, if (dI/dV) < (-I/V) (i.e. the ratio (dP/dV) <0), the operating point is to the right of the MPP, meaning that the voltage must be reduced to reach the MPP.

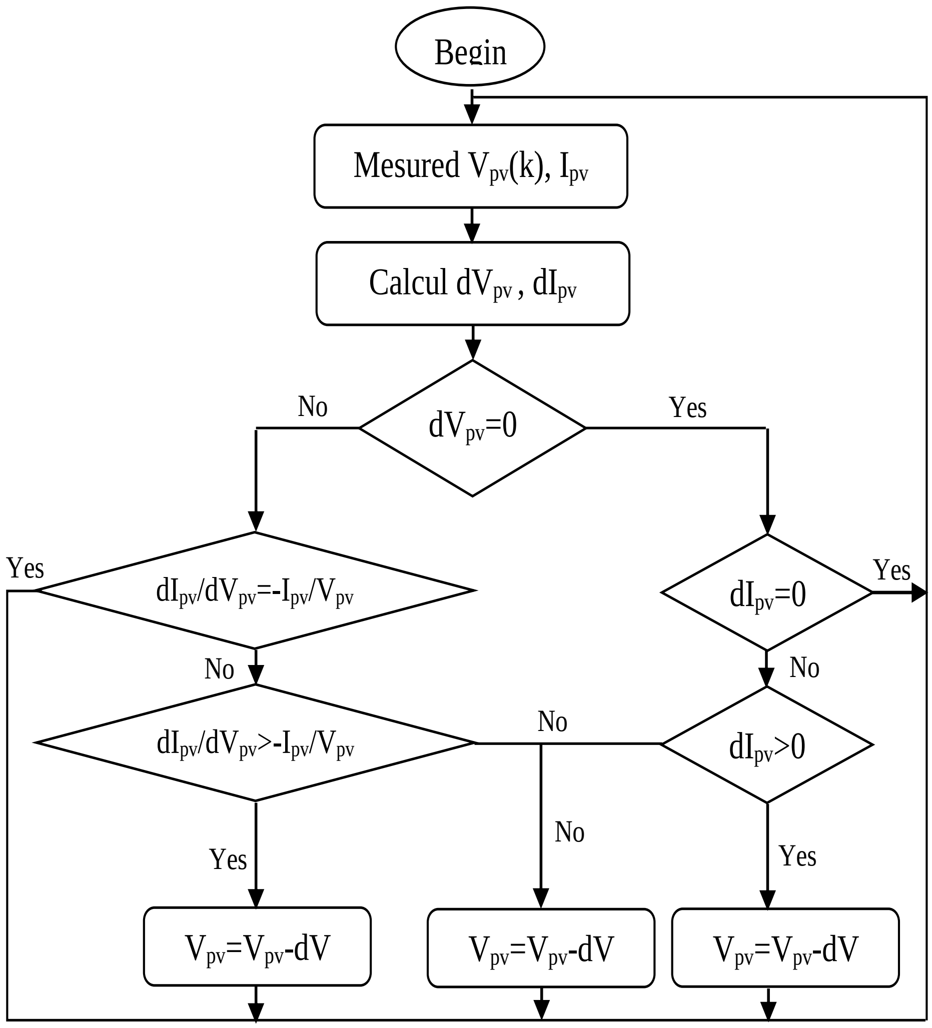


Figure III.10: INC Algorithm Flowchart

II.2.4.Inverter:

An inverter is an electrical device that transforms direct current (DC) into alternating current (AC). By employing suitable transformers, switching mechanisms, and control circuits, the converted AC can be adjusted to the desired voltage and frequency [27].

Figure III.10: Inverter

II.2.4.1. Inverter types and connection topologies :

Solar systems utilize seven different types of inverters: simple inverter, inverter with charger, hybrid inverter, micro inverter, string inverter with power optimizer, string inverter, and central inverter. In the following discussion, we will explore each of these inverter types as well as the various connection topologies in photovoltaic systems.

A. Simple inverter :

This type of inverter specifically converts DC electricity to AC voltage. In order to regulate the charging process, either a PWM or MPPT charge regulator is required. These inverters are typically employed in standalone systems [28].

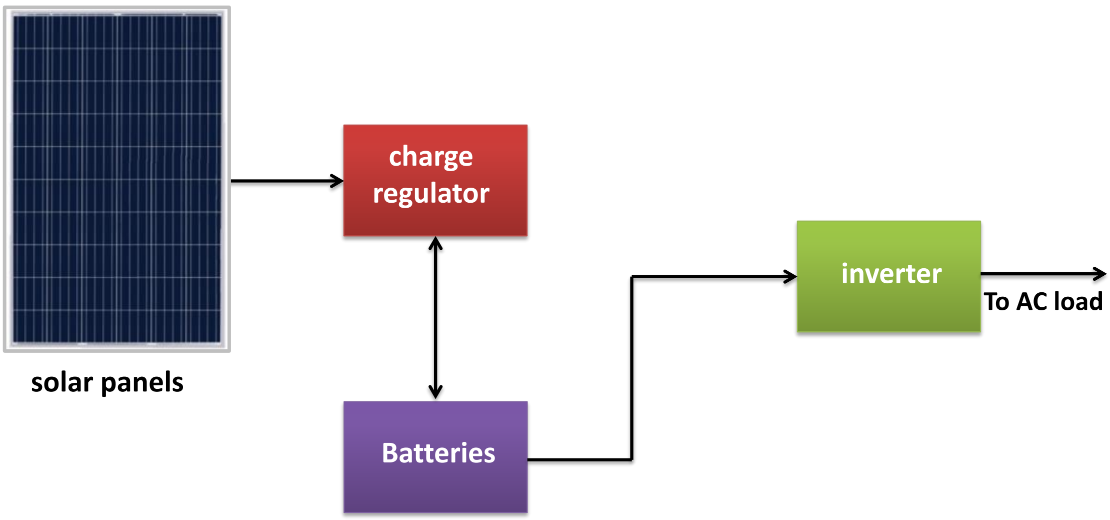


Figure III.11: The connection of the solar system with the simple inverter

B. Inverter with charger regulator(inverter/charger) :

This type of inverter is commonly used in off-grid and stand-alone systems. It performs dual functions of charging batteries and converting DC voltage to AC voltage [28].

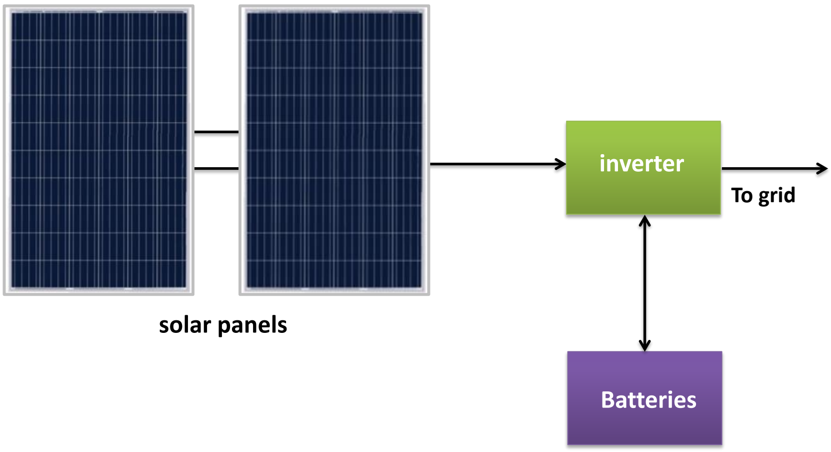


Figure III.12: The connection of the solar system with the inverter/charger

C. Hybrid inverter :

This particular type of inverter combines two distinct energy sources, such as solar panels and batteries. It integrates multiple solar panels and batteries into a single hybrid inverter, which serves multiple purposes simultaneously [28]. The AC voltage is produced by converting the voltage generated by the solar panels, and the solar panels are utilized to charge the batteries.

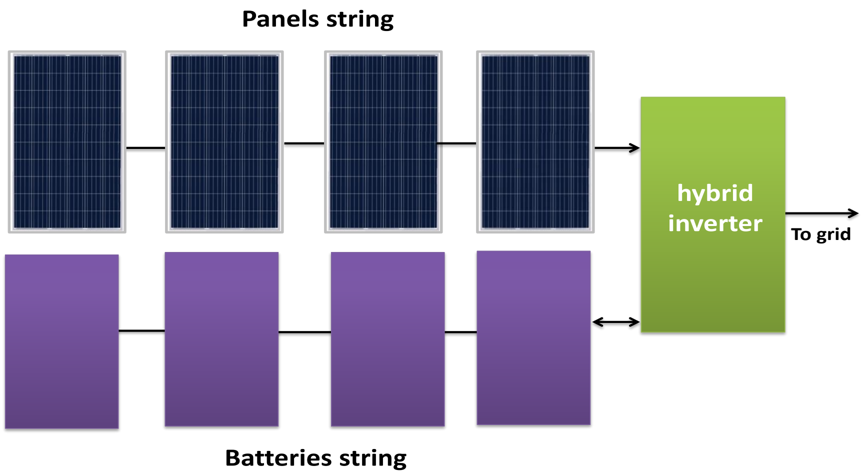


Figure III.13: The connection of the solar system with hybrid inverter

D. Micro inverter :

In this configuration, each panel is connected to a micro-inverter, which converts the DC voltage generated by each panel into AC voltage. This type of inverter is commonly used in small systems that consist of only a few panels [28].

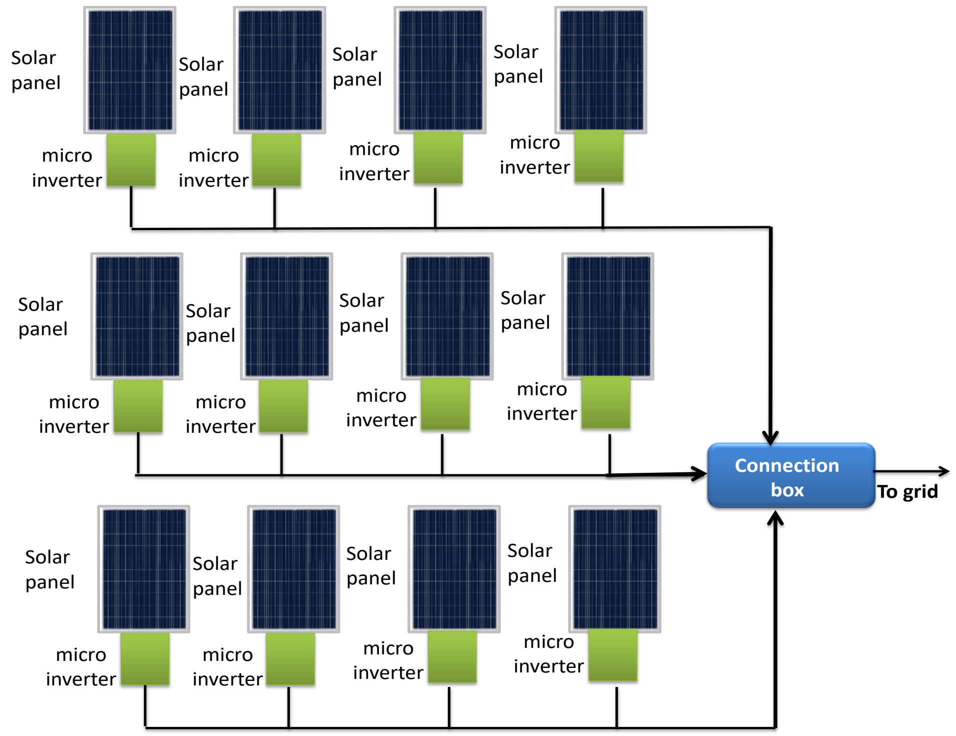


Figure III.14: The connection of the solar system with micro-inverter

E. String inverter with power optimizer :

The power enhancement device, incorporating a system that amplifies the DC voltage generated by the panel, is connected to the panel and utilizes the MPPT technique for operation [28].

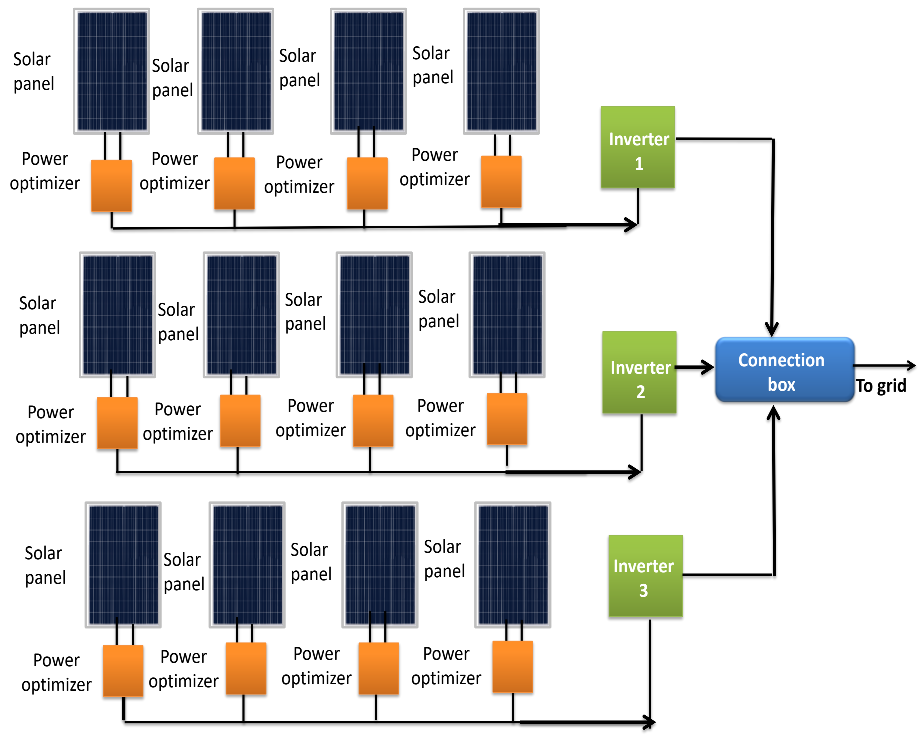


Figure III.15: The connection of the solar system with power optimizer devices

F. String inverter :

In a string topology, individual inverters are connected to separate strings of modules. This arrangement ensures that the total output from all the strings is not controlled by a single centralized inverter [29].

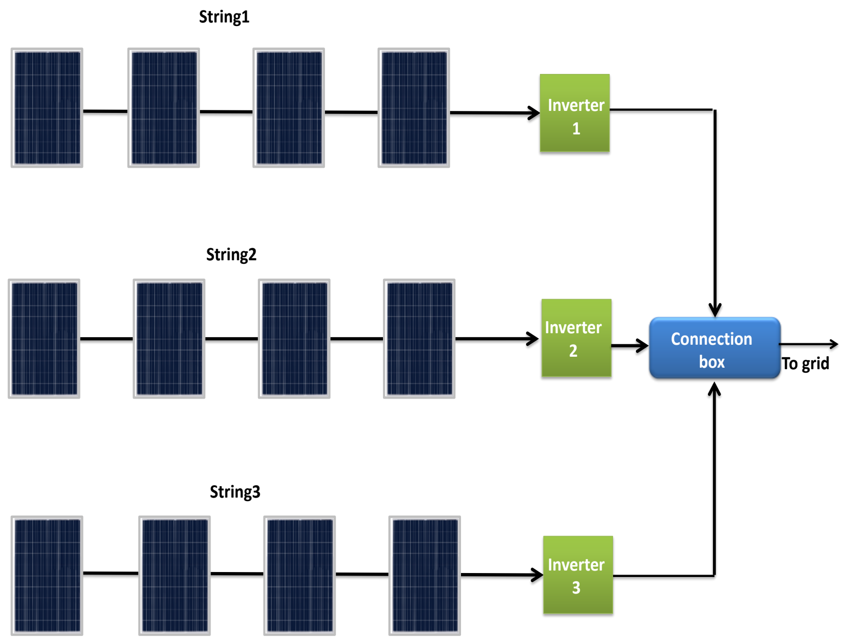


Figure III.16: Solar system connection with the string inverter

G. Central inverter :

In a centralized architecture, a single inverter is responsible for managing the outputs of multiple separate solar arrays that are connected to it. This topology is commonly utilized in high-power solar systems with outputs measured in megawatts (MW) [29].

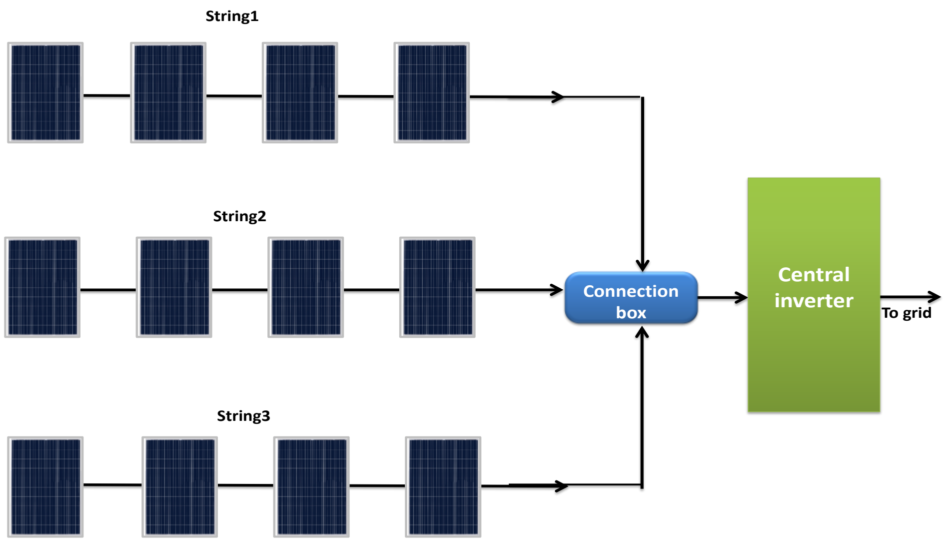


Figure III.17: The connection of the solar panel to the central inverter

In regards to cost and installation convenience, this type of inverter is considered the most favorable choice. However, maintenance can be more demanding compared to other types of inverters [28].

II.2.5.BATTERIES:

In situations where energy storage is required to supply electrical appliances, a battery bank is utilized as a system component. It serves the purpose of providing energy during the night or on days when there is limited sunlight, such as autonomous days, no-sun days, or dark days, when the sun's radiation is insufficient [30].

II..2.5.1.Characteristics of batteries:

A. Capacity:

The Ampere-Hour (Ah) capacity of a battery indicates the amount of electricity it can store and subsequently supply to power electrical equipment during a specified period, particularly during nighttime. To illustrate, a battery with a 20Ah capacity implies that it can hold and deliver a certain amount of electrical energy [31].

Example: a battery has the ability to deliver a current of 20A during one hour or has the ability to deliver a current of 10A during two hour.

B. Efficiency:

Higher battery efficiency allows for the utilization of a greater amount of stored energy. However, the efficiency of the battery is diminished at lower temperatures. Therefore, the efficiency of the battery plays a crucial role in determining the extent to which stored energy can be effectively used [31].

C. Battery life:

The lifespan of a battery is influenced by various factors such as battery type, size, brand, patterns of usage, the number of charging and discharging cycles, and the depth of discharge. Typically, batteries with longer lifespans tend to be more expensive [31].

D. Voltage: is the voltage across the battery terminal [32].

E. Specific energy: which corresponds to the maximum stored energy in relation to mass, expressed in Watt-hour per kilogram (Wh.kg-1) [32].

F. Temperature: which corresponds to the operating temperature range expressed in degrees Celsius [32].

II..2.5.2. Types of batteries:

A. Lead–Acid (PbA) Battery:

The negative electrode in a lead-acid battery consists of porous or spongy lead, which enables easier formation and dissolution of lead. The positive electrode is composed of lead oxide. Both electrodes are submerged in an electrolytic solution of sulfuric acid and water. To prevent direct contact between the electrodes in case of battery movement or changes in electrode thickness, a chemically permeable but electrically insulating membrane is utilized. [33] Lead acid batteries store energy through a reversible chemical reaction, as depicted below [33].

The overall chemical reaction is:

$$PbO_2 + Pb + 2H_2SO_4 \xleftrightarrow[charge]{discharge} 2PbSO_4 + 2H_2O$$

At the negative terminal the charge and discharge reactions are:

$$Pb + SO_4^{2-} \underset{charge}{\overset{discharge}{\longleftrightarrow}} PbSO_4 + 2e^-$$

At the positive terminal the charge and discharge reactions are:

$$PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \underset{charge}{\overset{discharge}{\longleftrightarrow}} PbSO_4 + 2H_2O$$

B. Nickel-Cadmium (Ni-Cd) battery :

The nickel-cadmium battery, also known as Ni-Cd battery, is a rechargeable battery that utilizes potassium hydroxide as the electrolyte and nickel oxide hydroxide as the cathode. The chemical symbols Ni and Cd represent nickel and cadmium, respectively, in this battery [34].

C. Lithium-ion (Li-Ion) battery :

To increase voltage or current in a Li-ion battery, individual Li-ion cells are connected in parallel or series. In a typical Li-ion cell, an electrolyte comes into contact with the cathode (positive electrode) and the anode (negative electrode), both containing lithium ions. The electrodes are separated by a micro porous polymer membrane, known as a separator, which allows the exchange of lithium ions between the electrodes but prevents the flow of electrons [35].

II.2.5.3.Mounting multiple accumulators on the same system:

The principles of calculation for connecting batteries in series and parallel are applicable when assembling them. For instance, when two 100Ah 12V batteries are connected in series, the resulting configuration will provide 100Ah at 24V. Conversely, if they are connected in parallel, the combined capacity will be 200Ah at 12V.

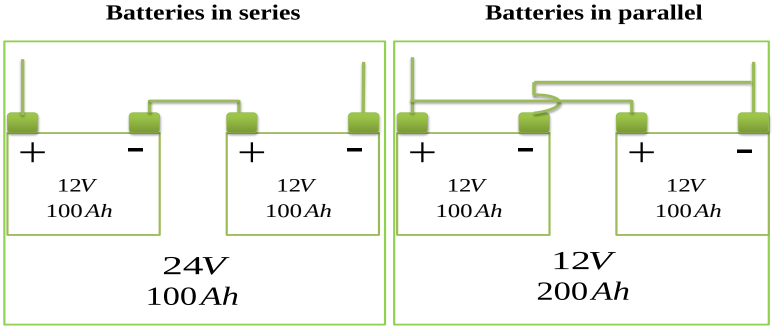


Figure III.18: wiring of batteries in series, in parallel

III 2.2.6.Charge controller:

A charge controller, also known as a charge regulator, is primarily responsible for regulating the voltage and/or current to prevent batteries from overcharging. Its main function is to control the flow of current and voltage from the solar panels to the battery.[36] The main objective of a charge controller is to protect the battery from both deep discharging and overcharging. Its primary function is to ensure that the battery is not excessively discharged or charged, thus safeguarding its health and longevity.

III 2.2.6.1.PWM Charge Controller:

The main role of (PWM) is to control the power devices of a solar system controller by delivering a constant voltage charge to the battery. Modern charge controllers utilize PWM to reduce the power supplied to the batteries when they are nearing full charge, thereby ensuring more efficient charging and preventing overcharging [37]. Essentially, the charge controller acts as an intelligent intermediary between the solar panels and the batteries, effectively controlling the voltage and current flow to the batteries. Its primary function is to regulate and optimize the charging process, ensuring that the batteries receive the appropriate voltage and current for efficient and safe charging [36].

II.2.6.2. MPPT Charge Controllers:

An MPPT charge controller utilizes the MPPT algorithm to maximize the current extracted from the PV module and transferred to the battery. It functions as a DC to DC converter that precisely matches the PV module's output to the battery's requirements. The MPPT charge controller takes the DC input from the PV module, converts it to AC, and then reconverts it to a different DC voltage and current to efficiently charge the battery [36].

III. Conclusion :

In conclusion, the components of a photovoltaic (PV) system play a crucial role in the overall performance and efficiency of the system. A typical PV system consists of several key components including solar panels, inverters, charge controllers and batteries.

Chapter IV

Off-Grid Solar System Sizing Methodology

I. Introduction :

Off-grid solar systems serve an important role in supplying electricity needs in locations without a centralised grid. These systems rely on solar panels to convert direct sunlight into electricity and batteries to store energy for usage during periods of low sunlight or at night.

This chapter provides explanation of steps of off-grid solar system design, as well as how to estimate the appropriate capacity of solar panels and battery storage. We will also go through how to assess solar energy resources at a specific area and estimate the required electrical load to meet energy needs.

II. Sizing:

System sizing is a method of determining the appropriate quantity of electricity required for a solar power system to function correctly and satisfy electricity demands. This procedure entails establishing the appropriate voltage and current for each component of the system, as well as calculating the entire cost of the system from the design phase to when it is completely operational.

III. Off grid system:

Stand-alone systems are those that run independently of the utility grid and are often employed in isolated houses or places where grid connection is not possible. These systems are meant to meet all of the user’s electricity needs and can be of two main sorts, depending on the source of electricity: direct current (DC) or alternating current (AC). To ensure dependable and effective operation, stand-alone systems, which can comprise solar panels, batteries, and inverters, need to be carefully planned and designed [38].

IV. Off grid system sizing steps:

System sizing is a crucial step in designing and building a stand-alone photovoltaic system. It involves evaluating the electrical demand of the facility or residence where the solar power system will be installed, and then selecting components with appropriate voltage and current ratings to meet that demand. This includes choosing solar panels, batteries, charge controllers, inverters, wiring systems etc. all of which must work together seamlessly to provide reliable electricity. In addition to determining component specifications for meeting energy demands at the site location, system sizing also involves calculating total costs associated with purchasing equipment (including shipping), installation labor charges as well as any other expenses related to design phase until fully functional stage.

Overall, it is an important process that requires careful consideration of various factors such as geographical location, load requirements [30].

The approach to follow in sizing a PV system can be summarized as follows :

- Step 01: Determine power consumption demands
- Step 02: Assessment of solar energy resources
- Step 03: The size of PV array
- Step 04: Storage sizing
- Step 05: Inverter sizing
- Step 06: charge controller sizing
- Step 07: Wiring plan: determination of the wiring accessories, sections of the cables to use…
- Step 08: financial cost of the system.

IV.1. Determine power consumption demands (Step 01):

The first step is to collect load information in the load list or table. The load profile is an estimate of the total energy consumed by a power system over a given time period (hours or days). The energy demand (in kilowatt-hours) is estimated based on the load profile's time component.

Figuring out how much power we need is critical for the sizing of energy storage devices, such as batteries. The total amount of energy that the loads will use will determine how much power is required. This calculation is also useful for energy efficiency applications, where it is important to make estimates of the total energy use in a system [39].

IV.1. 1. Load Analysis:

To avoid the system being under- or over-sized to fulfil the load's requirements, it should be examined by detecting the following matters:

- Carful listing of all load

- DC and AC loads
- Wattage rating for each load
- Surge wattage of load
- Time usage for each load

DC and AC load: In the case of an AC load, efficiency losses associated with converting DC current to AC current must be considered. Because there will always be some losses while converting DC to AC, no inverter can transmit 100% of the energy from a battery bank to the loads.

If you have any DC devices you need to account for the power consumption of those loads as well. This consumption can be calculated in the same way as AC loads are. In your tables.
After accounting for efficiency losses, you can add the two values to get the overall power consumption for all loads.

Surge wattage of load: Some devices, such as a refrigerator or motor, have a strong transitory surge in power when they start up. This will assist you in determining the size of the inverter required to manage that power.
The aforementioned matter is identified by reading the device label, and the energy is calculated as follows:
Volts ×amps= Watts
Watts ×hour a day = daily watts hours

IV.1.2. Determining the average daily energy:

To determine the amount of energy consumed by each AC load in kilowatt hours (kWh), you must first know how many watts the load pulls, how long it runs each day, and how many days it is used each week. Certain loads may run only a few times per week, but others may run on a daily basis. By averaging the loads over a week, a consistent pattern of energy consumption can be established [40].

First, we calculated each appliance's unitary power:

$$P_u = V \times I \qquad \textbf{(IV.1)}$$

P_u : The unitary power [W]

V: the voltage [V]

I: the current [A]

Then we calculate the total power taking into account utilization and simultaneity factors :

$$P = N \times P_u \times F \tag{IV.2}$$

$\boldsymbol{P_u}$: Power of appliances [kW]

$\boldsymbol{N}$: Number of appliance

$\boldsymbol{F}$: The multiplication of utilization and simultaneity factors.

Finally, we apply an equation of the average daily energy

$$E = \frac{P \times T \times D}{\eta_{inverter} \times 7} \tag{IV.3}$$

$\boldsymbol{E}$**:** Total energy consumed per day [kWh].

$\boldsymbol{T}$ **:** Hours per day [h].

$\boldsymbol{D}$ **:** The number of days per week.

$\boldsymbol{\eta_{inverter}}$: Inverter efficiency.

- **Inverter efficiency:**

Inverter efficiency refers to how much DC power is converted into AC power by the inverter. A good inverter typically has an efficiency rate of around 95%. Some power may be lost as heat, standby power is also consumed to keep the inverter in powered mode.

IV.2. Assessment of Solar Energy Resources: (step 02)

IV.2.1. Orientation and tilt of PV modules:

Orientation refers to the cardinal point towards which the active face of the panel is turned (south, north, southeast, etc.) in order to extract the maximum power that the panel can generate.

The tilt indicates the angle in degrees that the panel makes with the horizontal plane regarding the choice of orientation, the orientation of a PV module is always towards the equator: south orientation in the Northern Hemisphere and north orientation in th+`e Southern Hemisphere.

As for the tilt, it should be optimized based on the least sunny period of the year or season. The ideal tilt is approximately equal to the latitude of the location + 10° [41].

IV.2.2. Meteorological data:

A surface exposed to the sun receives, at a given moment, instantaneous solar radiation in W/m², which is a flux (power per unit area). This flux varies as clouds pass by and throughout the day. Over the course of a day, this flux results in a daily energy production : integrated solar radiation in Wh/m².day (Wh/m².day = W/m².h/day). The daily energy is obtained by calculating the integral of the radiation curve with respect to time. The integrated radiation in Wh/m².day is available through statistics provided by meteorological stations. This weather data is used for the sizing of PV systems knowing the detailed production of a PV panel hour by hour is only useful for estimating shading losses. The maximum current that a panel or PV array can deliver must be known to size a charge controller.

For an exposure without shadowing, the reasonably accurate sizing of a PV system is done using 12 values of solar radiation: the average daily solar energy values for each month of the year (see data from the nearest weather station to the site).

For a quick sizing, the lowest value of the operating period of the application is considered : we take the value of the lowest integrated radiation, for example, the month of January Meteorological data[41] .

IV.3. The size of PV array: (Step 03)

Panel sizing is the process of estimating how many solar panels are required in a photovoltaic system to match a load's power requirement.

$$P_{pv} = \frac{E \times E_{STC}}{E_{min} \times \eta_{Syst}} \qquad \textbf{(IV.4)}$$

$\boldsymbol{P_{pv}}$ **:** Power of photovoltaic array [kW$_P$]

$\boldsymbol{E}$ **:** Total energy consumed [kWh]

E$_{STC}$: power in STC (E$_{STC}$=1KW/m²)

$\boldsymbol{E_{min}}$ **:** The minimal irradiation [kWh/m²]

$\boldsymbol{\eta_{Syst}}$ **:** System efficiency

IV.3.1. The determination of the loss coefficient:

The losses inherent in any energy conversion process are numerous and must be kept to a minimum. Photovoltaic systems must provide the necessary energy and compensate for foreseeable losses. These losses have several origins and affect certain system parameters. These losses must be included in the calculation of the power to be installed.

Types of losses:

Starting with the energy source, which is the input of solar radiation, the losses are as follows:

a) Losses due to dirt, snow, sand… or even due to a glass placed in front, which affect the panel's charge current. Its voltage is not affected. However, there are voltage drops between the panel's output and the battery input (line losses)

b) Losses at the terminals of the series diode

c) Losses at the terminals of the series regulator of the battery (contains electronic switches in line)

d) Losses at the cable terminals (length, cross-sectional area, and current carried)

e) Losses due to voltage drop when the temperature rises

f) Losses due to the energy efficiency of the battery (ratio between the energy delivered and the energy supplied by the battery, which does not deliver energy at 100%). When the regulator is not an MPPT type, there is a loss due to voltage mismatch

g) In a system with a conventional regulator, the voltage is determined by the battery, which may differ from the maximum power point voltage under STC conditions

h) The loss at the beginning and end of the day must be considered when the sunlight is weak, and the voltage is insufficient to charge the battery

i) Loss related to the actual power, which is lower than the power specified by the PV panel manufacturer (we will not consider this loss in the sizing). To avoid this uncertainty, we will work with the power indicated on the label engraved on the back of the PV panel [41].

These factors can be multiplied together to obtain a single derating factor that represents the overall energy loss in the system. For instance, a derating factor of 0.77 implies that the PV system will retain 77% of the energy and lose 23% due to various factors [38].

Peak Sun Hours (PSH) : is a measure of the amount of solar energy that can be generated by a photovoltaic system in a particular location. It takes into account factors such as the tilt angle of the solar panel and other environmental conditions. PSH is typically between 4 and 6, but it can vary depending on various factors such as weather patterns, latitude, and time of year [38].

IV.3.2.System voltage:

The selection of system voltage in a solar off-grid PV system is a critical decision that depends on the shelter's energy usage and daily load. As a general rule, higher energy usage requires higher voltage, but the system voltage also depends on the available inverters and the type of loads [42].

This voltage is typically in the range of 12 V to 500 VDC (3) (currently up to 1500VDC), depending on the power output of the system.

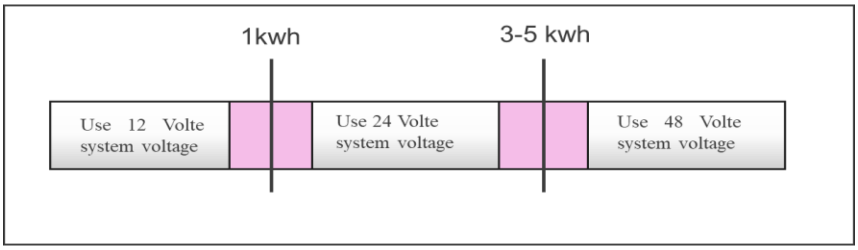


Figure IV.1 : Variations of System Voltage with the Daily Demand.

IV.3.3. Number of PV Modules For The System:

IV.3.3.1. The number of modules in series :

The output power of a PV module is temperature-dependent. The maximum and minimum temperatures can affect the performance of a PV array, so that the voltage of a PV module increases as the temperature decreases due to the inverse relationship between voltage and temperature. To prevent the array's voltage from exceeding the inverter's input value, the modules' STC open circuit voltage value (Voc) must be adjusted for cold temperatures, which is reported on spec sheets. This adjustment is necessary to avoid damaging the inverter's capacitors. On the other hand, the voltage of a PV module decreases as the temperature increases, which can cause the array's voltage to fall below the required level for the inverter to operate. To address this, it is important to consider the maximum power voltage (V_{mp}) and make adjustments accordingly [40].

A. Open circuit voltage Voc :

To accurately calculate a photovoltaic (PV) module's adjusted open circuit voltage, it is necessary to understand the temperature coefficient, which measures how the module's voltage values change with temperature. The base temperature for all PV modules is 25 degrees Celsius, according to STC, any change in temperature must be calculated relative to this value.

Adjusted open circuit voltage can be calculated with theqw following equation :

$$V_{oc} = V_{oc_{STC}}((T_{coff_{Voc}} \times \Delta T) + 1) \quad \textbf{(IV.5)}$$

Δ**T** is the subtraction of the STC temperature, which is 25° from the lowest value of temperature in the location.

To calculate the maximum number of modules that can be connected in a series string without exceeding an inverter's maximum input voltage, divide the inverter's maximum input voltage by the module's maximum adjusted open circuit voltage, which was calculated based on the area's record cold temperature. This computation is critical to ensuring that the inverter is not overloaded and destroyed.

$$N_{smax} = \frac{inverterV_{max}}{V_{OC}} \quad \textbf{(IV.6)}$$

B. maximum power voltage V_{mpp} :

In the same way, the adjusted maximum power voltage V_{mpp} can be calculated with the following equation :

$$V_{mpp} = V_{mpp_{STC}}((T_{coff_{Voc}} \times \Delta T) + 1) \quad \textbf{(IV.7)}$$

Δ**T** is the subtraction of the STC temperature, which is 25° from the highest value of temperature in the location.

To calculate the minimum number of modules that can be connected in a series string without exceeding an inverter's minimum input voltage, divide the inverter's minimum input voltage by the module's maximum adjusted power voltage, which was calculated based on the area's record high temperature. This calculation is critical to ensuring that the inverter is operational and not damaged.

$$N_{smin} = \frac{inverterV_{min}}{V_{mpp}} \quad \textbf{(IV.8)}$$

STC: stands for Standard Test Conditions, which is a set of industry-standard conditions used to measure the performance of photovoltaic (PV) modules. The STC specifies a temperature of 25 degrees Celsius, an irradiance level of 1000 watts per square metre, and an air mass of 1.5. The STC is used as a reference point for comparing the performance of different PV modules and calculating their expected power output under different operating conditions [40].

IV.3.3.2. Number of modules in parallel:

The number of strings in parallel (N_{mp}) is calculated by dividing the designed array output (PPV array) by the selected module output at maximum power point (P_{module} max) and the number of series modules (N_{ms}).

The following equation is used to determine the number of PV modules in parallel :

$$N_{mp} = \frac{P_{PV}}{N_{ms} \times P_{module}} \quad \textbf{(IV.9)}$$

$\boldsymbol{N_{mp}}$ **:** Number of module in parallel

$\boldsymbol{P_{PV}}$ **:** Power of photovoltaic generator [kW]

$\boldsymbol{P_{module}}$: Power of module [kW]

$\boldsymbol{N_{ms}}$ **:** The number of series modules

IV.3.3.3. Total number of modules:

Finally, total number of modules is calculated by multiplying the value of the Number of module in parallel on the value maximum number of module in series

$$N_{module} = N_{Smax} \times N_{mp} \quad \textbf{(IV.10)}$$

Where, N_{module} is the total number of modules needed.

IV.3.4.The system voltage range:

A. minimum voltage :

$$V_{min} = V_{mpp} \times N_{Smin} \quad \textbf{(IV.11)}$$

B. maximum voltage :

$$V_{max} = V_{oc} \times N_{Smax} \quad \textbf{(IV.12)}$$

IV.3.5. PV array area :

The area is calculated by this rule:

For every $1MW_p$ we need $10000m^2$ [46] .

IV.4. Storage sizing: (step04)

Storage batteries are essential components of solar power systems as they store energy for use when the sun is not shining or when the generator is not running.

To determine the appropriate size of a battery bank for a photovoltaic (PV) system, several factors must be considered. These include the daily energy demand, number of days of autonomy, depth of discharge (DOD), ambient temperature of the location, and system bus voltage. Accurately estimating these 53tw hile53s crucial for ensuring that the battery bank can meet the energy demands of the PV system and provide reliable power during periods of low solar output [40].

IV.4.1.The number of days of autonomy:

The « number of days of autonomy » is a critical parameter in designing and sizing photovoltaic (PV) systems. It refers to the number of consecutive days that a user can draw energy from the battery bank without recharging 53tw hile still maintaining an uninterrupted power supply during periods when there isn't enough solar energy available. To understand why this is important, consider that PV systems generate electricity only when sunlight is available. During cloudy or rainy weather conditions or at night, there may not be enough solar radiation to meet the user's demand for electricity. In such cases, batteries are used as backup sources to provide a continuous power supply.

IV.4.2. Temperature effect:

The temperature at which batteries operate affects their capacity, with colder temperatures resulting in less capacity. This is because the efficiency of the chemical reaction inside the battery changes at different temperatures. Battery manufacturers provide data on the effects of temperature on their batteries, which can be used to apply the correct temperature derate factor, a percentage of the battery's capacity that can be expected based on the temperature [40].

IV.4.3. Depth of discharge (DOD):

Is a measure of how much energy a battery can discharge before it needs to be recharged. In the context of solar PV systems, DOD is an important parameter to consider when sizing the battery bank, as it determines the amount of energy that can be stored and used during periods of low solar irradiance. A higher DOD means more energy can be stored, but it can also reduce the battery's lifespan due to increased stress on the battery's electrodes [39].

IV.4.4. The battery bank capacity in Wh:

The calculation of the rough energy storage requirements for a photovoltaic system refers to the minimum amount of energy storage needed to meet the system's needs during periods with little or no sunlight. This includes nighttime and cloudy days and takes into account the influence of temperature. To calculate this rough estimate, multiply the total power demand by the number of autonomy days and the temperature compensation factor.

$$E_{Storage} = E \times N_{\mathrm{d\,a}} \times T_c \qquad \textbf{(IV.13)}$$

To ensure safety, the energy storage required for the battery bank is divided by the maximum allowable level of discharge (DOD). This calculation gives the safe energy storage capacity of the battery bank, which is expressed in terms of the product of the power demand and the number of autonomy days, divided by the DOD**.**

This equation helps determine the appropriate size of the battery bank needed for a photovoltaic system :

$$\frac{\mathrm{E_{Storage}}}{\mathrm{DOD}} \qquad \textbf{(IV.14)}$$

$\boldsymbol{E_{Storage}}$ **:** The total energy storage [Wh].

$\boldsymbol{DOD}$ **:** Depth of discharge.

IV.4.5. The battery bank capacity in Ah:

$$C = \frac{E_{Storage}}{V_{sys}} \qquad \textbf{(IV.15)}$$

$\boldsymbol{C}$ **:** The total capacity [Ah]

$\boldsymbol{E_{Storage}}$ **:** The total energy storage [Wh]

$\boldsymbol{V_{sys}}$ **:** The voltage system in [V]

IV.4.6. The number of batteries in series:

The formula for determining the number of batteries in series is given by dividing the battery voltage (V) by the system voltage (V):

$$N_{bs} = \frac{V_{sys}}{V_b} \tag{IV.16}$$

IV.4.7. Number of batteries in parallel:

The number of batteries in parallel is calculated by dividing the total system rating in ampere-hours (Ah) by the rating of each individual battery in Ah.

$$N_{bp} = \frac{C}{C_b} \tag{IV.17}$$

IV.4.8.Total number of batteries:

The total number of batteries in the battery bank is determined by multiplying the number of batteries in series by the number of batteries in parallel.

$$N_b = N_{bs} \times N_{bp} \tag{IV.18}$$

IV.5. Charge controller sizing: (step05)

When sizing a charge controller, it is important to consider both the voltage and power/current specifications of the PV array. Depending on the type of charge controller, either power or current values from the PV array need to be taken into account. By ensuring that the charge controller is appropriately sized to handle the power or current output of the PV array, the system can operate at maximum efficiency and provide optimal battery charging [40].

The short-circuit current of the modules connected in parallel is multiplied by a safety factor, which gives the rated current of the voltage regulator. A good voltage regulator must be able to handle the maximum current produced by the solar panel array and the maximum load current [30].

$$I = I_{SC} \times N_{mp} \times F_S \tag{IV.19}$$

$\boldsymbol{I}$ **:** Maximum current of the array [A]

$\boldsymbol{I_{SC}}$ **:** Short-circuit current of module [A]

$\boldsymbol{F_S}$ **:** Safety factor

$\boldsymbol{N_{mp}}$ **:** Number of module in parallel

The factor of safety is a measure used to ensure that the voltage regulator can handle the maximum current produced by the solar array, which may exceed the rated value. It also accounts for any additional load current that may be added to the system due to the inclusion of new equipment. In essence, the factor of safety allows for some flexibility in the system's capacity to handle unexpected changes [30].

The number of controllers needed for a photovoltaic system can be determined by dividing the array's short circuit current in amps by the amps required for each controller. This calculation helps ensure that the voltage regulator can handle the maximum current produced by the array and allows for system expansion.

$$N_C = \frac{I}{I_C} \quad \textbf{(IV.20)}$$

Where, N_C is the number of charge controller and I_C is the current of charge controller

We need for charge controller connected in parallel.

IV.6. Inverter sizing: (step06)

Identifying the actual power consumption of the appliances that will be running simultaneously is the first step in sizing the inverter for a photovoltaic system. This is crucial since the inverter must be able to meet the appliances' highest possible power demands. Additionally, you should pick an inverter that can handle the array's power output, the system voltage, and the power spikes that happen when motors like those in refrigerators and washing machines start up. [40]
The power required by an inverter can be calculated using the equation below :

$$P_i = \frac{P_T \times F_S}{\eta_{inverter}} \quad \textbf{(IV.21)}$$

$\boldsymbol{P_i}$ **:** Power needed by inverter [kW]

$\boldsymbol{P_T}$ **:** Total power required per day [kW]

$\boldsymbol{F_S}$ **:** Safety factor

$\boldsymbol{\eta_{inverter}}$: Inverter efficiency

IV.7. Wire sizing: (step07)

Conductor sizing is the process of determining the appropriate size of wires used in a photovoltaic (PV) system to ensure a safe and efficient flow of current. This involves identifying the circuits and pinpointing where the conductors go in the system.

It is important to consider the different requirements for conductors in various parts of the system. The conductors from the PV array to the inverter have different requirements than those from the inverter to the AC main distribution panel. Proper circuit designations and locations are important to understand, including the PV source circuit, PV output circuit, inverter input circuit, and inverter output circuit.

IV.7.1. Calculation of wire section:

The equation allowed us to get the surface of cables:

$$S = \frac{\rho \times 2L}{R} \tag{IV.22}$$

ρ : Resistivity of metal wire [Ω.m].

R : Resistance [Ω].

L : The length between the components.

$$R = \frac{V_{drop}}{I_{max}} \tag{IV.23}$$

V_{drop} **:** The voltage losses [V]

I_{max} **:** The maximum output current [A]

By calculating both the maximum and continuous currents, one can then select a conductor size that can safely handle these currents.

The maximum current refers to the highest expected current that will pass through the conductor under normal operating conditions. It is calculated by multiplying three values: short-circuit current per string, number of modules in parallel, and safety factor.

The continuous current represents the sustained amount of current that will flow through the conductor over an extended period without causing overheating. To determine the continuous current, the maximum current is multiplied by the safety factor of 1.25 again. This additional safety margin ensures that the conductor can handle the sustained current without any problems.

We can determine the total maximum output current as follows:

$$I_{max} = I_{SC} \times N_{mp} \times 1.56 \quad \textbf{(IV.24)}$$

- The safety factor of 1.25 is a safety margin added to the calculation to ensure the conductor can handle any unexpected surges or fluctuations in the electrical current. Specified by NEC

(National Electrical Code), which is a set of safety standards and guidelines for electrical installations in the United States.

- Voltage drop refers to the reduction in voltage that occurs as current flows through a conductor due to the resistance of the conductor. The National Electrical Code (NEC) requires that conductors in a PV system be large enough to safely carry current.

IV.8. Financial cost of the system: (step08)

$$C_{total} = C_{equipment} + C_{maintenance} + C_{civil\ engineering} \quad \textbf{(IV.25)}$$

V.Conclusion:

We conclude that the chapter on sizing off-grid solar systems provides valuable insights into the mehodology used to determine the appropriate system size Sizing plays a critical role in ensuring optimal performance.

By considering factors such as energy demand, solar resource availability, and battery storage capacity and system efficiency, the sizing process enables accurate determination of the required number of solar panels, battery capacity, and inverter specifications.

Overall, the chapter underscores the importance of a systematic and comprehensive approach to sizing off-grid solar systems by following a methodical process and considering all relevant variables.

Chapter V

Sizing of Photovoltaic System Application to the Faculty of Sciences and Technology in Ghardaia University

I. Introduction :

This chapter is reserved of the application of the PV sizing theory in order to power the faculty of sciences and technology in Ghardaia university which is to be indicated as a PV load. We will apply the previously explained method of sizing which is to be treated in detail in order to give the characteristics of each photovoltaic component constituting the whole PV chain system.

II. Sizing method steps applied to our PV load:

II.1. Presentation of the PV load site and solar resources:

II.1.1. Emergence of Ghardaia University:

In the year 2004, the annex of the University of Algiers in Ghardaia was established by virtue of the joint ministerial decision dated 08 Rajab 1425 AH corresponding to 24 August 2004 AD. After that, the higher education sector in the area of Ghardaia witnessed fast development, as according to Executive decree No. 05-302 of August 16, 2005, the University Center was established in Ghardaia. All of this culminated in the center's elevation to the ranks of national universities, according to Executive Decree No. 12/248 of Rajab 14, 1433 , corresponding to June 04, 2012 .

It is located on an area of 30 hectares and accommodates 4,000 pedagogical seats, in addition to 6,000 pedagogical seats [43].The University of Ghardaia is located in the scientific zone of *Noumerat* in Ghardaia, it contains three poles, our study will be about the pole 2, the faculty of sciences and technology [43].

II.1.2. Faculty of Sciences and Technology (FST):

Sciences and technology Faculty in Ghardaia university contains more than 14 bachelor's degree specialties, 10 master's degree specialties and 3 in doctorate degree. All these technical disciplines are hosted in four departments.

Figure V.1 : Science and technology faculty of Ghardaia university

The FST civil engineering building is constituted by four floors. The following tables summarize the pedagogical and administration structures in each floor of the FST building. It is to be note that the whole area of the building is 4319 m² we got it thanks to google earth.

A. FST flours' area

***Table V.1**: Ground floor*

Identification of premises	**Number**	**Area[m²]**	**Horizontal sum Area[m²]**
Administrative Part			
Office	02		25.7
Internet and computer	01	65.78	65.78
Teacher's hostel	01	65.78	65.78
Classrooms Part			
40 seats Classroom	08		502.98
Laboratories Part			
30 seat laboratory	08		613.5
Teaching Part			
Teacher's offices	02		25.7
Student's hostel	01	150.57	150.57
Maintenance workshop	02	123.8	247.60
Internet space	01	150.57	150.57
Amphitheater 300 seats	02	295.38	590.76
Amphitheater 200 seats	02	221.53	443.06
Vertical sum area			**1771.11**

Table V.2 : First floor

Identification of premises	Number	Area[m²]	Horizontal sum Area[m²]
Administrative Part			
Office	04		66.4
Office	14		187.48
Classrooms Part			
40 seats Classroom	08		462.98
Lab Part			
30 seat laboratory	08		610.7
Teacher Part			
Teacher's offices	18		208.56
Library Part			
Loan bank	01	130.20	199.66
Book storage room	02		495.5
Bookbinding workshop	02	92.85	185.7
Manager offices	02	26.96	53.92
Vertical sum area			**1216.97**

Table V.3: Second floor

Identification of premises	Number	Area[m²]	Horizontal sum Area[m²]
Administrative Part			
Offices	04		66.4
Offices	12		158.4
Archives	02	14.54	29.08
Library Part			
Reading room 250 seat	01	576.36	576.36
Periodic exam rooms	02	168.95	337.9
Manger office	02	12.77	25.54
Classroom Part			
Classroom 50 seat	04		307.16
Classroom 40 seat	04		253.92
Lab part			
30 seat laboratory	04		303.54
Teacher Part			
Teacher's office	20		234.8
Vertical sum area			1247.12

Table V.4 : Third floor

Identification of premises	Number	Area[m²]	Horizontal sum Area[m²]

Library part			
Teacher reading room	01	228.10	228.10
Interment and ccomputer area	02	122.62	245.24
Manager office	02	12.77	25.54
Administrative part			
Offices	05		85.82
Meeting room	01		63.95
Vertical sum area			257.85

B. Geographical coordinates :

Geographical location is the main reason for choosing tilt and orientation angle.

Latitude : 32.36 °N	Longitude: 3.81 °E	Time zone: 0 (UTC+0h)	Altitude (amsl): 450m [44]

C. Tilt and:

Table V.5 : tilt angle

	Winter	Spring	Summer	autumn
tilt angle (°)	55.827	32.177	8.950	31.759

We take the average of this values, we got that the tilt angle equal to 32.17°.

D. Meteorological data :

To obtain meteorological data of the FST site, weather data are quoted from the Renewable energy Research Unit in Ghardaia. The following table indicates the annual average irradiation (Wh/m²) and the mean ambient temperature (°C) of Ghardaia.

Table V.6 : Meteorological data of Ghardaia city [44].

Month	Tamb
January	**9.32**
February	**10.74**
March	**18.48**
April	**22.25**
May	**28.8**
June	**32.19**
July	**37.48**
August	**33.98**
September	**28.88**
October	**24.15**
November	**17.43**

December	**11.3**

Where:

Tamb : Mean Ambient Temperature in °C.

II.2. Load demand:

In order to estimate the overall faculty load demand, we need to know three essential aspects: the number of equipment's, the wattage for each device and the operating hours for each device

The purpose of estimating this demand is to obtain the required AC energy for the FST. To calculate the daily energy requirement requested by the faculty, we need to know the individual energy consumption of each device in [kWh] that the faculty contains.

Each electrical equipment contains a wattage label that indicates the essential electrical parameters of the device as indicated in figure V.2 for example, the air conditioner indicated in the figure consumes 500 W under a single phase voltage of 220 volts at a frequency of 50 Hertz. The same for the Laser printer, which consumes what about 660 Watts(220v×3Amps).

Figure V.2: Wattage label example

The power in Watt P_u that consumes each device is called unit power, it is calculated due to equation (V.1)

$$P_u = V \times I \tag{V.1}$$

Where: V is the device voltage (V) and I is the device current (A). these electrical quantities are taken from the nameplate of the device.

For N similar device, the corrected estimated power is then:

$$P = N \times P_u \times F \qquad \textbf{(V.2)}$$

Where: P is power of appliance (kW), N is the number of appliance and F is the multiplication factor, which is the multiplication of the utilization with the simultaneity factors (0.75×0.4 = 0.3) according to NF C -15-100 standard.

Finally, the daily energy in (Wh) that should be consumed by each device is calculate by equation (V.3) as follow:

$$E = \frac{P \times T \times D}{\eta_{inverter} \times 7} \qquad \textbf{(V.3)}$$

Where: E is the daily total energy consumed per day (kWh), T is functioning hours per day (h) , D is the number of days per week (taken 6 days) and $\eta_{inverter}$ is inverter efficiency.

As indicated in Table V.7, the total energy per day is that consumed per the whole devices that disposes the FST. So the required daily load consumption is estimated at E= 1271.415806 kWh/day.

Table V.7 : AC load demand in science and technology faculty

Appliance	**Number**	**Unitary Power (kW)**	**Hours per day**	**F**	**Inverter efficiency**	**Power [kW]**	**Energy per day [kWh]**
Led tube 1	969	0.036	3	0.3	**0.93**	10.4652	28.93603687
led flood	2	0.015	3	0.3	**0.93**	0.009	0.024884793
led tube 2	646	0.072	3	0.3	**0.93**	13.9536	38.58138249
Air conditioner 1	96	1.7	6	0.3	**0.93**	48.96	270.7465438
Air conditioner 2	98	2.3	6	0.3	**0.93**	67.62	373.9354839
Air conditioner 3	3	3.2	6	0.3	**0.93**	2.88	15.92626728
Air conditioner 4	24	9	6	0.3	**0.93**	64.8	358.3410138
Air conditioner 5	2	4.8	6	0.3	**0.93**	2.88	15.92626728
Air conditioner 6	3	7.8	6	0.3	**0.93**	7.02	38.8202765
printer 1	1	0.22	1	0.3	**0.93**	0.066	0.060829493
printer 2	66	0.462	0.25	0.3	**0.93**	9.1476	2.107741935
printer 3	2	0.68	1	0.3	**0.93**	0.408	0.376036866
Photocopier 1	2	1.224	1	0.3	**0.93**	0.7344	0.676866359
Photocopier 2	11	1.512	0.3	0.3	**0.93**	4.9896	1.379612903
Photocopier 3	2	1.56	0.3	0.3	**0.93**	0.936	0.258801843
Computer	227	0.16	0.3	0.3	**0.93**	10.896	3.012718894
Space heater	2	1.5	2	0.3	**0.93**	0.9	1.658986175
Water dispenser	4	0.585	6	0.3	**0.93**	0.702	3.88202765
freezer 1	1	0.156	24	0.3	**0.93**	0.0468	1.035207373
Refrigerator 1	3	0.11	24	0.3	**0.93**	0.099	2.189861751
Refrigerator 2	2	0.5	24	0.3	**0.93**	0.3	6.6359447

Refrigerator 3	2	0.285	24	0.3	**0.93**	0.171	3.782488479
Refrigerator 4	3	0.216	24	0.3	**0.93**	0.1944	4.300092166
Espresso coffee machine	1	4.6	1	0.3	**0.93**	1.38	1.271889401
Shawarma machine	1	3.85	3	0.3	**0.93**	1.155	3.193548387
Data show projector	6	0.296	3	0.3	**0.93**	0.5328	1.473179724
Baffle	22	0.06	0	0.3	**0.93**	0.396	0
Facsimile	5	0.288	0.5	0.3	**0.93**	0.432	0.199078341
Camera	22	0.13	24	0.3	**0.93**	0.858	18.97880184
Exhaust fan	20	0.04	0.5	0.3	**0.93**	0.24	0.110599078
hydrochemistry laboratory	1	0.16	1.5	0.3	**0.93**	0.048	0.066359447
hydraulic laboratory	1	6.879	1.5	0.3	**0.93**	2.0637	2.853041475
chemistry laboratory	1	3.216	1.5	0.3	**0.93**	0.9648	1.333824885
Civil Eng laboratory	1	7.89055	1.5	0.3	**0.93**	2.367165	3.272578341
process Eng laboratory 1	1	24.454	1.5	0.3	**0.93**	7.3362	10.14221198
process Eng laboratory 2	1	112.625	1.5	0.3	**0.93**	33.7875	46.71082949
process Eng laboratory 3	1	1.1625	1.5	0.3	**0.93**	0.34875	0.482142857
process Eng laboratory 4	1	5.154	1.5	0.3	**0.93**	1.5462	2.137603687
electrical Eng laboratory	1	2.254	1.5	0.3	**0.93**	0.6762	0.93483871
automatic laboratory	1	7.995	1.5	0.3	**0.93**	2.3985	3.315898618
renewable energy laboratory	1	1.677	1.5	0.3	**0.93**	0.5031	0.696
physical laboratory	1	3.97466	1.5	0.3	**0.93**	1.192398	1.649
					Total	**306.40491**	**1271.42**

II.3. PV array sizing :

To calculate the minimum size of the PV generator we need, we take the watt-hours we calculated from the power balance, divide them by the most unfavorable irradiation level during the year, and then divide by the system efficiency. The relative irradiation level during the least sunny month is considered to be 3500Wh/m². The system efficiency is taken at 65%.

$$P_{pv} = \frac{E \times E_{STC}}{E_{min} * \eta_{Syst}} \quad \textbf{(V.4)}$$

Where: P_{pv} is photovoltaic array power (kW_p), E is the total energy consumed (kWh), E_{STC} is power in STC (E_{STC}=1KW/m²) , E_{min} is the minimal irradiation level (kWh/m²) and η_{syst} is the system efficiency.

$$\boldsymbol{P_{pv}} = \frac{1271.4158}{3.5 \times 0.65} = 558.864 \text{ kW}_p$$

The daily required photovoltaic PV array power is **558.864 kW$_p$**

II.3.1. Selecting solar panel and module number:

There are several options for choosing the solar panel to be used in our PV panel array, all of which are related to the unit power and voltage. For our system, we have chosen a 270Wp polycrystalline PV panel from ***Yingli*** Solar with a rated voltage of 30.7 V, manufactured in China. Its characteristics are indicated in figure V.3.

YGE 60 CELL SERIES

ELECTRICAL PERFORMANCE

Electrical parameters at Standard Test Conditions (STC)					
Module type			YL270P-29b	YL265P-29b	YL260P-29b
Power output	P_{max}	W	270	265	260
Power output tolerances	ΔP_{max}	%			0 / +3
Module efficiency	η_m	%	16.6	16.3	16.0
Voltage at P_{max}	V_{mpp}	V	30.7	30.5	30.3
Current at P_{max}	I_{mpp}	A	8.80	8.70	8.59
Open-circuit voltage	V_{oc}	V	37.9	37.8	37.7
Short-circuit current	I_{sc}	A	9.27	9.18	9.09

STC: 1000W/m² irradiance, 25°C cell temperature, AM 1.5G spectrum according to EN 60904-3.

Electrical parameters at Nominal Operating Cell Temperature (NOCT)					
Power output	P_{max}	W	196.9	193.3	189.7
Voltage at P_{max}	V_{mpp}	V	28.0	27.8	27.6
Current at P_{max}	I_{mpp}	A	7.04	6.96	6.87
Open-circuit voltage	V_{oc}	V	35.0	34.9	34.8
Short-circuit current	I_{sc}	A	7.49	7.42	7.35

NOCT: open-circuit module operation temperature at 800W/m² irradiance, 20°C ambient temperature, 1m/s wind speed.

Figure V.3: Electrical performance of YINGLI solar panel

II.3.2. The number of modules in each series string:

In order to know the number of modules in series we need to find the corrected module voltage for minimum and maximum temperature. The corrected module voltage is calculated as follow:

C. Open circuit voltage V_{oc} :

$$V_{oc} = V_{oc_{STC}}((T_{coff_{Voc}} \times \Delta T) + 1) \tag{V.5}$$

Where: $T_{coffVoc}$ is the temperature coefficient of V_{oc} (which is $T_{coff_{Voc}} = -0.3\ \%/°C$ from the datasheet) , $V_{oc\ STC}$ is the open circuit voltage at the STC taken from the datasheet and ΔT is the subtraction of the STC temperature which is 25° from the lowest value of temperature in the location.

In our case ΔT is equal to :

$$\Delta T = 9.32 - 25 = -15.68°$$

So, Open circuit voltage is:

$$V_{oc} = (-0.0032 \times 37.9 \times -15.68) + 37.9 = 39.80V$$

D. The voltage at maximum power V_{mpp} :

The voltage at the MPP is calculated according to the equation:

$$V_{mpp} = V_{mpp_{STC}}((T_{coff_{Voc}} \times \Delta T) + 1) \tag{V.6}$$

In this formula, ΔT is the subtraction of the STC temperature which is 25° from the highest value of temperature in the location.

In our case ΔT is equal to :

$$\Delta T = 37.48 - 25 = 12.48°$$

The voltage at maximum power V_{mpp} is :

$$V_{mpp} = (-0.0045 \times 30.7 \times 12.48) + 30.7 = 32.42V$$

After calculating the corrected voltage, one can get the minimum and maximum number of PV modules which will be connected in series to form one PV string. In the purpose of getting the minimum number of module in series, we divided the minimum voltage of inverter by the voltage at maximum power V_{mpp} :

$$N_{smin} = \frac{inverterV_{min}}{V_{mpp}} \quad \textbf{(V.7)}$$

Which gives us: **17 modules in series**

To get the maximum number of module in series we divided the maximum voltage of inverter by the Open circuit voltage Voc:

$$N_{smax} = \frac{inverterV_{max}}{V_{OC}} \quad \textbf{(V.8)}$$

Which gives us: **21 modules in series**

This system will be able to consist at least an 17 PV modules in series and at most 21 modules in series.

II.3.4. Number of PV strings in parallel :

$$N_{mp} = \frac{P_{PV}}{N_{\mathrm{m\,s}} \times P_{mod\,ule}} \quad \textbf{(V.9)}$$

Where: N_{mp} is the number of PV strings in parallel, P_{pv} is power of photovoltaic generator (kW) and P_{module} is the power of module (kW).

$\boldsymbol{N_{mp}}$ = 98.56 ≈ 99 strings in parallel

II.3.5. Total number of PV modules to compose the PV array:

The total PV module needed to compose the PV array is given by:

$$N_{mod\,ule} = N_{Smax} \times N_{mp} \quad \textbf{(V.10)}$$

$\boldsymbol{N_{mod\,ule} = 21 \times 99 = 2079}$ PV modules

So, our PV array or even named PV generator is composed of 1449 of the selected PV module.

II.4. Determination of system voltage :

We multiply the corrected voltages that we find it in earlier section by the number of modules in series to get the system voltage range

A. minimum voltage :

$$V_{min} = V_{mpp} \times N_{Smin} \tag{V.11}$$

Which gives us :

$$\boldsymbol{V_{min} = 551.20\ V}$$

B. maximum voltage :

$$V_{max} = V_{oc} \times N_{Smax} \tag{V.12}$$

$$\boldsymbol{V_{min} = 835.83\ V}$$

The system voltage range is within the inverter voltage range, so we choose a system voltage of 600V.

II.5. Battery bank sizing :

A. The capacity of battery bank capacity in kWh:

The following equation (V.13) allows us to calculate total capacity of the batteries bank:

$$E_{Storage} = \frac{E \times N_{d\,a} \times T_c}{DOD} \tag{V.13}$$

Where: $E_{storage}$ is the total energy storage in (kWh), E is the total energy consumed (kWh), N_{da} is the number of days of battery autonomy , T_c is then the temperature compensation factor and DOD is the depth of discharge

We select the AGM battery of **3000Ah/2V** as depicted in figure V.4. To obtain the total energy storage needed by the batteries bank, we assume the number of days of battery autonomy to 2 days, the depth of discharge is taken at 50% and the temperature compensation factor is taken of 1.09 in temperature of 50° .

Thus, the total energy storage, according to equation (V.13) is to be:

$\boldsymbol{E_{Storage}}$ **= 1732,3 kWh**

OPzS2-3000 (2V3000Ah)

Ritar OPzS series is a flooded Lead Acid battery that adopts Tubular Plate technology to offer high reliability and performance. The Battery is designed and manufactured according to DIN40736-2/IEC60896-11 standards and with die-casting positive spine and patent formula of active material.OPzS series exceeds DIN40736-2/IEC60896-11 standard values with more than 20 years floating design life at 25℃ and is even more suitable for cyclic use(PV/solar,traction etc) under extreme operating conditions.

Specification

Voltage Per Unit	2V
Capacity	3000Ah@10hr-rate to 1.85V per cell @25°C
Approx Weight	Without Electrolyte 166.7 kg With Electrolyte 226.8 kg
Max. Discharge Current	10000 A (5 sec)
Internal Resistance	Approx. 0.11 mΩ
Operating Temperature Range	Discharge: -15°C~50℃ Charge: 0°C~40°C Storage: -15°C~50℃
Optimal Operating Temperature Range	25°C±5℃

Capacity factors vs temperature (OPzS series)											
Temperature	-30°C	-20°C	-10°C	0°C	10°C	20°C	25°C	30°C	40°C	45°C	50°C
Capacity	60%	75%	83%	89%	92%	99%	100%	103%	105%	107%	109%

Figure V.4: technical specifications of battery

B. The batteries bank capacity in kAh:

By dividing the total capacity in kWh by system voltage we get the capacity of the batteries bank in kAh is given according to the following equation:

$$C = \frac{E_{Storage}}{V_{sys}} \qquad \textbf{(V.14)}$$

Where: C is the total capacity in kAh, $E_{storage}$ is the total energy storage in kWh and V_{sys} is the voltage system in V.

So, C =**2.88717kAh**

C. The number of batteries in series :

The number of batteries in series is calculated by the division of the system voltage to the single battery voltage according to this equation:

$$N_{bs} = \frac{V_{sys}}{V_b} \qquad \textbf{(V.15)}$$

$N_{bs} = \frac{600}{2} = 300\ batteries\ in\ series.$

Where: N_{bs} is the number of batteries in series, V_b is the rated voltage of unit battery (V) and V_{sys} is voltage system (V).

D. number of batteries in parallel :

In the batteries bank, the number of branches of batteries that should be mounted in parallel is given by:

$$N_{bp} = \frac{C}{C_b} \tag{V.16}$$

So the batteries bank is composed by $N_{bp} = 0.96 \approx 1$ braches in parallel.

Where: N_{bp} is the number of batteries in parallel, C is the total capacity of batteries bank in kAh and C_b is the capacity of unit battery (kAh).

E. total number of batteries :

The total number of unit batteries to be inserted in the battery bank, N_b, is nothing other than:

$$N_b = N_{bs} \times N_{bp} \tag{V.17}$$

Which gives us: $N_b = 300 \times 1 = 300$ batteries.

II.6.Charge controller sizing:

The charge controller is a device that manage the energy flow between the batteries bank and the load. But is very important to the batteries healthy. It should be chosen due to the load specifications and its low price coast. In our study we choose a PWM charge controller since it is widely disponible in the markets and so on for its coast compared to the MPPT controller.

We calculate the maximum current of the array by the equation (V.18):

$$I = I_{SC} \times N_{mp} \times F_S \tag{V.18}$$

Which gives : $I = 9.27 \times 99 \times 1.56 = 1431.65A$

Where: $\boldsymbol{I}$ is maximum current of the PV array (A), I_{SC} refers to the short-circuit current of PV module (A) and F_S is the NEC's safety factor equal 1.56.

So the maximum current of PV array is $1431.65A$. According to the selected charge controller, SANDI 600V and 300A, the number of these charge controllers is calculated by , equation (V.19), dividing the maximum current of the PV array to the current of unit charge controller:

$$N_C = \frac{I}{I_C} \tag{V.19}$$

we obtain: $\boldsymbol{N_C} = \frac{1431.65A}{300} = 4.77 \approx 5$

Where: N_C is the number of charge controller and I_C is the current of charge controller

We need **four** (4) charge controller of the selected one, connected in parallel with PV array.

II.7. Inverter sizing:

Since the total power of our application is **306.404913 kW** as we determined in table V.7, the power that must be handle by the inverter can calculated as following:

$$P_i = \frac{P_T \times F_S}{\eta_{inverter}} \tag{V.20}$$

Where: $\mathbf{P_i}$ is the power of the used inverter (kW), $\mathbf{P_T}$ is the total power required per day (kW), $\mathbf{F_S}$ is the safety factor equal to 1.1 and $\boldsymbol{\eta}_{inverter}$ is the inverter efficiency. Thereby applying the equation (V.20) we get that the inverter must handle **362.414413kW.** We choose SANDI off grid inverter, SDP-500KW within specifications indicated in figure V.5.

Technical Parameter

Model	SDP-500KW
Isolation mode	Low Frequency Transformer
DC Input	
Rated voltage (Vdc)	600V
Rated current (A)	833A
Input voltage range (Vdc)	540~850V
AC Output	
Rated power (Kw)	500KW
Rated voltage	380V±3%
Number of phases	3 phase 4 wire
Rated current (A)	757.5A
Rated output voltage range (V)	220/230/240/380/400/415/440/480VAC (optional)
Output frequency	50Hz or 60Hz ±0.05 (Can set)
Waveform	Pure sine wave
Waveform distortion rate (THD)	Linear load≤2%
Dynamic Response time (Load 0←→100%)	5%, ≤50ms
Power Factor (PF)	0.99
Inverter Efficiency	>93%
Electrical insulation properties	2000Vac、1 Minute

Figure V.5: Technical parameter of the selected inverter.

II.8. PV Array arrangement:

In order to avoid the shading, we should calculate the inter row spacing between PV panels that should be installed.

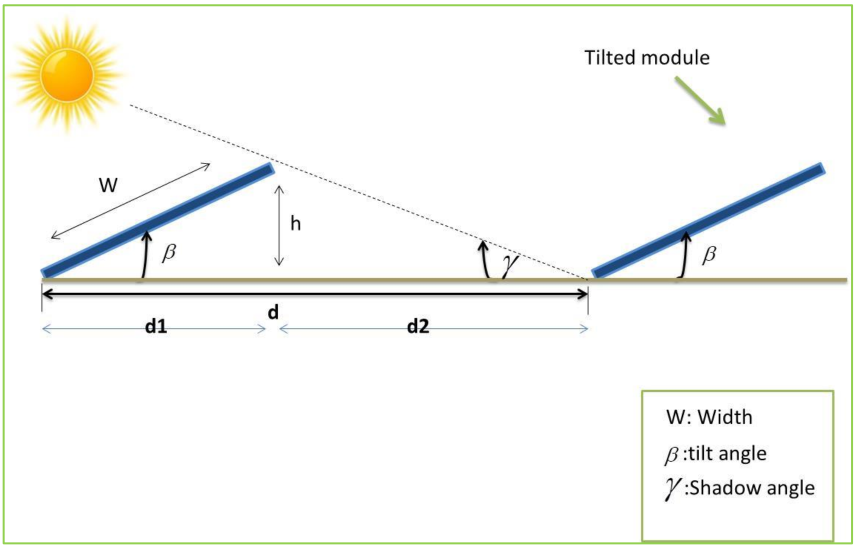


Figure V.6: Inter row spacing between panels

A. inter row spacing between PV panels :

By the following simple equation, we get the value of shadow angle:

$$Shadow\ Angle = 90 - Lattitude - Earth\ Axix\ Tilt \quad \textbf{(V.21)}$$

So the shadow angle is **34.14°**

Where: earth axis tilt equal to 23.5°.

We calculated the distance between PV panels symbolized by d in the upper figure V.6. The following table presented the steps to get this distance.

Table V.8 : Inter row spacing between panels

Latitude	32.36°
tilt angle β	32.17°
Module Length	1.65m
Module Width	0.99m
h=W×sin(β)	0,52710877m
d1=W×cos(β)	0,83800728 m
Shadow angle	34.14°
d2=h×Tan(Shadow angle)	0,35741612m
d=d1+d2	1.1954234m

From the table we got that the inter row spacing between panels should be equal or more than 1.183 m 1,1954234

B. PV Generator Area :

Enough area for this system 5000m².

II.9. Wire sizing, over current protection devices and wiring diagram:

A. Calculation of wire section :

The equation allowed us to get the surface of cables is given by:

$$S = \frac{\rho \times 2L}{R} \quad \textbf{(V.22)}$$

Where: ρ is resistivity of metal wire (for copper equal to $1.7\times10^{-8)}$ in (Ω.m), R is resistance of the wire in (Ω) and L is its length.

The resistor of such conductor is to be calculated as:

$$R = \frac{V_{drop}}{I_{max}} \quad \textbf{(V.23)}$$

Where: V_{drop} is the voltage losses which represents 3% from the voltage system equal to 18 V $(600 \times 0.03 = 8\ V)$ and I_{max} is the maximum output current.

Using these last formulas, sections of several parts are summarized from the table V.9 to table V.12.

Table V.9: Cable surface between PV array and combiner box

PVG - combiner box	
$I_{max} = I_{sc} \times N_{mp} \times 1.56$	997.8 A
V	600 V
V_{drop}	18 V
L	6 m
ρ_{copper}	1.7×10^{-8} [Ω.m]
R	0.017247327 [Ω]
section	11.30 [mm²]

Since there is no copper section of 11.30 mm² so we select the section of 16 mm²

Table V.10: Cable surface between combiner box and charge controller

Combiner box-charge controller	
$I_{max} = I_{sc} \times N_{mp}$ (23) ×1.56	332.60 A
V	600 V
V_{drop}	18 V
L	500 m
ρ_{copper}	1.7×10^{-8} [Ω.m]
R	0.068081553[Ω]
Section	314.12 [mm²]

In this case the suitable copper section is 400 mm²

Table V.11: cable surface between battery and inverter

Battery-inverter	
$I_{max} = P_{inveter}/\eta_{inveter} \times$ VDC	995.619275 A
V	600 V
V_{drop}	18 V
L	6m
ρ_{copper}	1.7×10^{-8} [Ω.m]
R	0.0180792[Ω]
section	11.28368512[mm²]

The copper section is 16 mm²

Table V.12: Cable surface between inverter and load

Inverter-load	
$I_{max} = P_{inveter}/\eta_{inveter} \times$ VAC	2443.79277 A
V	600 V
V_{drop}	18 V
L	6m
ρ_{copper}	1.7×10^{-8} [Ω.m]
R	0.0073656 [Ω]
section	27.69631802[mm²]

The copper section is 35 mm²

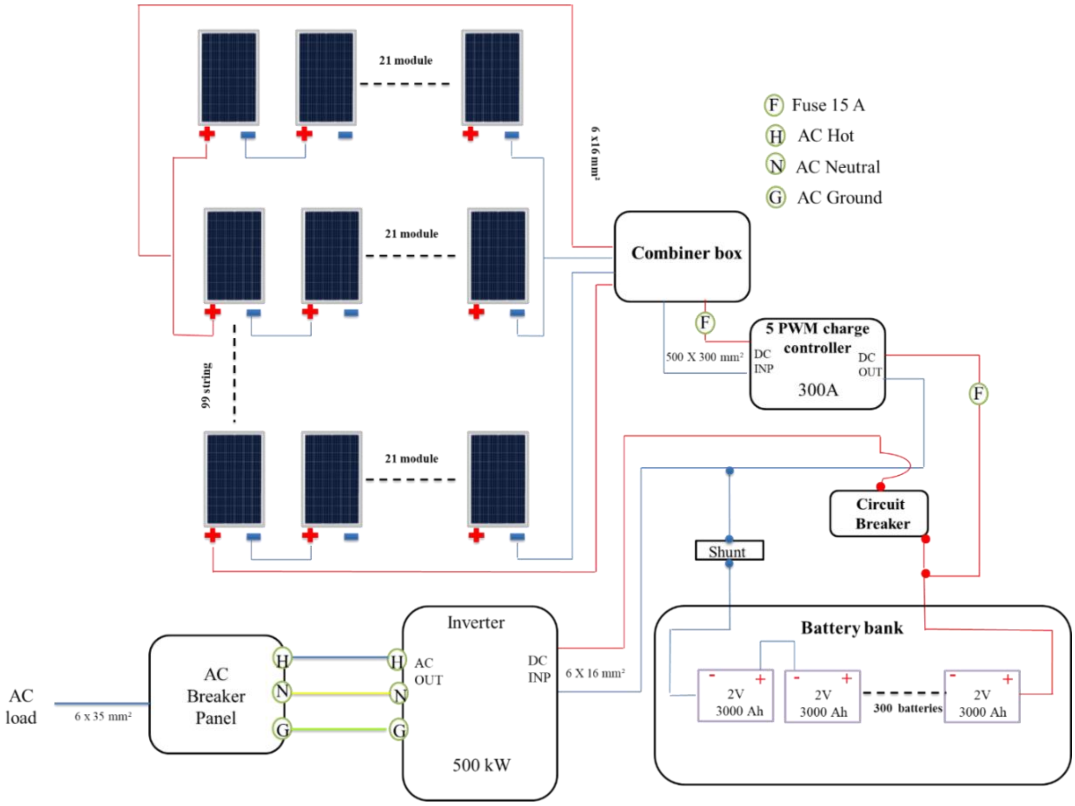
B. Over current protection devices calculation OCPDs:

The OCPDs is given by:

$$\text{OCPDs} = F_S \times I_{SC} \quad \textbf{(V.24)}$$

$\text{OCPDs} = 1.56 \times 8.92 = 13.91A.$

C. Wiring diagram :



FigureV.7 : Wiring diagram of PV system

II.9. Cost estimation :

Then we calculate the total cost by the formula **(IV.25)** in previous chapter where, the cost of equipment is 224803487,675 we take that the cost of maintenance is 25 % from The cost of equipment and the cost of mounting is 10 % and for civil engineering is 20 %

we get that C_{Total} is around **274260254,9635 DA .**

V. Conclusion:

In this chapter, we used the sizing method explained in the previous chapter for a complete stand-alone photovoltaic system. Through the utilization of various formulas and equations, this study has determined that the optimal size of the photovoltaic system for the faculty of sciences and technology in Ghardaia university is 558.86 kW_p. The proposed photovoltaic system comprises 2079 solar panel, inverter of 500kW and a 300 battery.

General Conclusion

The main objective of this study is to evaluate and size an off-grid system for the Faculty of Science and Technology, aiming to meet the electricity needs of the college in a sustainable and efficient manner. The study relied on a comprehensive methodology that includes data collection, analysis, and proposing appropriate solutions. This objective was achieved through analyzing the energy consumption in the Faculty and assessing the available potentials for renewable electricity generation, the study shed light on various aspects of off-grid solar energy systems, including design, implementation, and performance.

Furthermore, this thesis has significant implications for further research on the effectiveness of off-grid solar energy systems in Algeria and the potential for their application in developing regions. It serves as a foundation for conducting comprehensive feasibility studies that encompass technical and financial aspects of off-grid solar energy projects. Additionally, it opens doors for entrepreneurship opportunities and the establishment of a program focused on sizing solar energy systems.

Algeria, with its abundant solar resources, stands as a promising country for harnessing off-grid solar energy and benefiting from renewable electricity. This aligns perfectly with Algeria's energy transition policy, emphasizing the importance of sustainable and clean energy sources for the nation's future.

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