PEOPLES DEMOCRATIC REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

UNIVERSITY SAAD DAHLEB BLIDA 1

Faculty of Technology

Renewable Energies Department

Graduation Project

To obtain master's degree in Renewable Energies

Photovoltaic conversion

Study of PV installation to supply electricity to a cold storage facility

By: NAILI Abdelmoumene

Presented to the jury composed of:

-Dr Khoudja Fouad	MCB	USDB1	Reviewer
-Dr Amrouche Badia	MCA	USDB1	President
- Dr Mazouz Halima	MCA	USDB1	Supervisor

Acknowledgments

At this precious moment when I have the opportunity to present my thesis, I would like to express my deep gratitude to all those who played an essential role in the completion of this work.

First and foremost, I would like to express our gratitude to Allah for granting us the strength, perseverance, and wisdom needed to successfully complete this project. His guidance and benevolent presence have been a source of inspiration and comfort throughout this academic journey.

I would like to extend my sincere thanks to my supervisor, Dr. Mazouz. Her expertise, availability, and kindness have been invaluable to the success of my thesis. Her enlightened guidance and continuous encouragement have nurtured my thinking and pushed our intellectual boundaries.

A heartfelt thank you also goes to the members of the jury, for agreeing to evaluate my work with attention and rigor. Their constructive comments and wise recommendations have allowed me to refine the thesis and deepen my knowledge in the field of renewable energy.

I would like to express our gratitude to the professors and staff of the Renewable Energy Department in Blida for their dedication and academic support, as well as their essential contribution in facilitating my research and progress in this field.

Finally, I would like to thank all the individuals who, directly or indirectly, have contributed to my academic journey. Whether through enriching discussions, warm encouragement, or technical assistance, your support has been invaluable and has fueled my motivation throughout this adventure.

We are aware that my words are not enough to express my full gratitude to each and every one of you, but I sincerely hope that this message conveys my deep appreciation.

DEDICATION

I would like to dedicate this work to my beloved family, whose unwavering love, support, and sacrifices have propelled me forward on my journey. Your encouragement and belief in my abilities have been a constant source of inspiration and motivation. I am immensely grateful for the countless sacrifices you have made to ensure my success, and i dedicate this achievement to each and every one of you.

To my dear friends, you have been my pillars of strength throughout this endeavor. Your companionship, laughter, and shared experiences have enriched my live in immeasurable ways. Together, we have faced challenges, celebrated victories, and grown as individuals. Your unwavering support and friendship have made this journey all the more memorable and meaningful.

With deepest appreciation and love,

NAILI Abdelmoumene.

Contents

Figures list

Tables list

ABBREVIATION LIST

Area: the area of the solar panel (m²).

I_{sc} : short-circuit current. (I)

I: is the current flowing through the cable in amperes.

L: is the length of the cable in meters.

N_{SPp} : Number of solar panels in parallel

N_{sp}: Number of solar panels.

N_{sps} :Rnumber of solar panels in series.

$Pmax_{sp}$: Solar panel maximum power.

PV: Photovoltaic.

Pmax: solar panel peak power (Watts).

PR: Performance ratio.

S : Cable section.

V_F : Branch fuse voltage. (V)

$V_{dc\ Max}$: Maximum system voltage (V).

V_{oc}: Open-Circuit Voltage (V).

V_A: is the voltage at the starting point of the cable in volts.

ŋ $inverter$: Inverter efficiency.

ε: is the voltage drop in volts.

ρ: the resistivity of the cable in Ω.m.

ملخص

هذه المذكرة تغوص حول دمج الانظمة الكهروضوئية كحل مستدام لتقليل استهلاك الطاقة او الكهرباء في مرافق مخازن التبريد . تركز الدراسة على حالات مرافق "Frigomedit" في الوادي و بليدة و وهران، بهدف تقييم جدوى و فعالية تطبيق نظام الطاقة الشمسية. من خلال تحليل عوامل مثل استهلاك الكهرباء و اختيار مكونات النظام الكروضوئي و وضع الدراسات التقنية و الاقتصادية محل اعتبار ، و كذلك نتائج المحاكات، يوفر البحث رؤى قيمة حول الفوائد و التحديات المحتملة لدمج الانظمة الكهروضوئية في عمليات مخازن التبريد.

Abstract

This thesis explores the integration of photovoltaic systems as a sustainable solution for reducing energy consumption in cold storage facilities. The study focuses on the cases of Frigomedit facilities in El-Oued, Blida, and Oran, aiming to assess the viability and effectiveness of PV system implementation. By analyzing factors such as electric consumption, component selection, techno-economic considerations, and simulation results, the research provides valuable insights into the potential benefits and challenges of integrating PV systems in cold storage operations.

Résumé

Cette thèse explore l'intégration de systèmes photovoltaïques en tant que solution durable pour réduire la consommation d'énergie dans les installations de stockage frigorifique. L'étude se concentre sur les cas des installations de Frigomedit à El-Oued, Blida et Oran, dans le but d'évaluer la viabilité et l'efficacité de la mise en œuvre de systèmes PV. En analysant des facteurs tels que la consommation d'électricité, la sélection des composants, les considérations technico-économiques et les résultats de simulation, la recherche offre des aperçus précieux sur les avantages potentiels et les défis de l'intégration de systèmes PV dans les opérations de stockage frigorifique.

GENERAL INTRODUCTION

General introduction

Cold storage facilities play a crucial role in maintaining the quality and safety of perishable goods, such as food and pharmaceuticals, throughout the supply chain. These facilities provide controlled environments with low temperatures to slow down the growth of microorganisms, preserve freshness, and extend the shelf life of products. As a result, they contribute significantly to reducing food waste, ensuring product availability, and supporting the global food industry.

However, cold storage facilities are known to be energy-intensive due to the continuous operation of cooling systems, ventilation, and other equipment necessary to maintain the desired temperature levels. This high energy consumption not only poses financial challenges but also leads to a significant carbon footprint. Consequently, finding sustainable and efficient solutions to power these facilities becomes imperative.

In the pursuit of environmentally friendly alternatives, renewable energy sources have emerged as promising options for powering various sectors, including cold storage facilities. Among these renewable sources, photovoltaic systems have gained widespread recognition for their ability to convert sunlight into electricity, offering clean and abundant energy. Integrating PV systems into cold storage facilities presents an opportunity to reduce dependency on conventional energy sources, decrease greenhouse gas emissions, and achieve cost savings.

The focus of this thesis is to explore the renewable energy potential, particularly in terms of PV systems, for integration into the Frigomedit cold storage complexes located in El-Oued, Blida, and Oran. Using various equations and tools like HOMER Pro and PVsyst for simulation and optimization.

Additionally, this study involved the application of relevant equations, models, and software tools to assess the performance and economic feasibility of different PV system configurations. By comparing and analyzing the obtained results, valuable insights can be gained regarding the optimal PV system setup for the Frigomedit cold storage complexes.

In conclusion, and by investigating the importance of cold storage facilities, their high energy consumption, and the benefits of integrating renewable energy solutions, this study aims to provide valuable insights into designing sustainable and efficient PV systems that can power these facilities effectively.

CHAPTER I

CHAPTER I

Introduction

Electricity consumption is one of the most important aspects for any country, it is needed to power various sectors such as industry, residential areas, and commercial establishments. In Algeria, as in many other countries, the demand for electricity continues to rise with population growth and economic development. However, so the need to transition towards sustainable and renewable energy sources is suggested to ensure long-term energy security and mitigate environmental impacts. In this chapter we are going to do a general study on renewable energies and photovoltaic systems specially in Algeria. we aim to provide an overview of the electricity consumption in the country. Also, we are going to define the different components and technologies that we need to make a feasible in PV systems.

I.1 General study of the electricity consumption in Algeria

in Algeria, the natural gas accounts for 96 percent of the country’s 21,400 megawatts (MW) of installed capacity, and the remaining 4 percent comprising a combination of oil, solar, hydro, and wind technologies. By 2028, however, the Commission for Energy and Gas Regulation (CREG), Algeria’s energy regulator, projects total installed capacity will increase by nearly 45 percent to 36,000 MW. According to the proposed plan, the proportion of natural gas would decrease to 84%, whereas the usage of solar technologies would rise to 15% of the overall installed generation capacity. Although it may not fulfill the country's renewable energy objectives entirely, this situation would mark a significant transformation towards integrating significant renewable energy generation into the national power grid. [1]

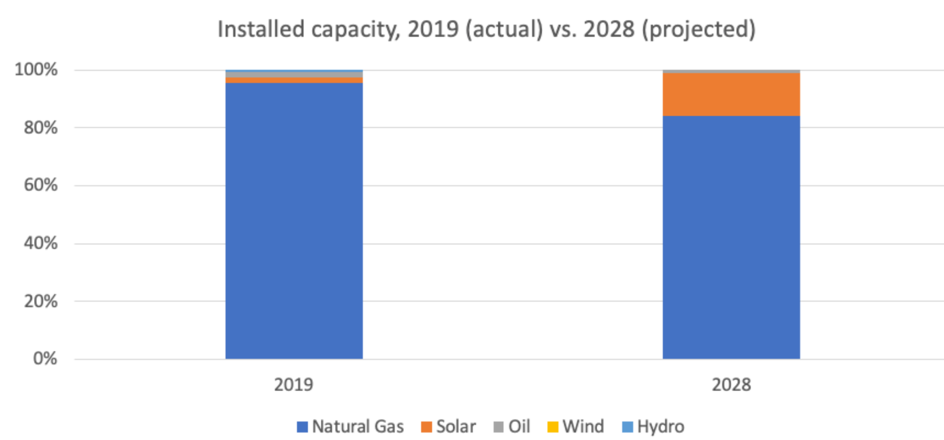


Figure I.1: The installed capacity in 2019 and the projected in 2028 [1]

I.2 Renewable energies potential in Algeria

Algeria has rich natural resources, so it is turning to renewable energy to meet energy needs and reduce reliance on fossil fuels. The country benefits from its favorable location, allowing for the harnessing of various renewable energy sources:

I.2.1 Solar energy

Algeria holds one of the highest solar potentials in the world which is estimated at 13.9 TWh per year. The country receives annual sunshine exposure equivalent to 2,500 KWh/m^2. Daily solar energy potential varies from 4.66 kWh/m^2 in the north to 7.26 kWh/m^2 in the south. The high solar potentials can help a lot especially with lots of environmentally-friendly products and services such as LED lighting, electricity production and car title loans.[2]

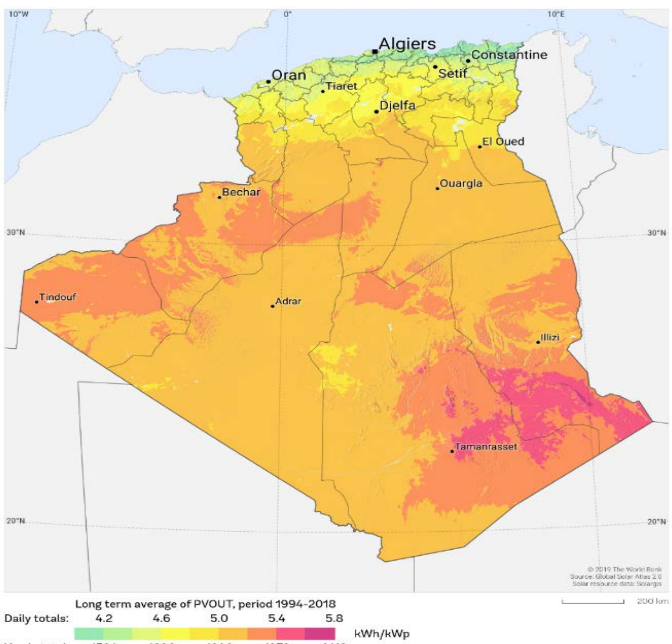


Figure I.2 : Solar resource maps of Algeria [14]

I.2.2 Wind energy

Algeria has promising wind energy potential of about 35 TWh/year. Almost half of the country experience significant wind speed. Studies will be led to detect suitable sites to realize the projects during the period 2016-2030 for a power of about 1700 MW.[2]

an ambitious strategy for encouraging and developing renewable energy production is being implemented, where the wind energy constitutes the second axis of development, with an electricity production expected to reach about 5 GW in 2030.[5]

I.2.3 Hydroelectric energy

The global quantities falling on the Algerian territory are important and estimated at 65 billion m3, but finally benefit little to the country: reduced number of days of precipitation, concentration on limited spaces, strong evaporation, rapid evacuation towards the sea. Schematically, the surface resources decrease from north to south. The useful and renewable resources are currently estimated at about 25 billion m3, of which about 2/3 are surface resources.[3]

I.2.4 Biomass energy

Algeria has good biomass energy potential in the form of solid wastes, date palm biomass, crop wastes and forestry residues. This type of waste is the best source of biomass potential in all of the country. According to the National Cadastre for Generation of Solid Waste in Algeria, annual generation of municipal wastes is more than 10 million tons. Solid wastes are usually disposed in open dumps or burnt wantonly. In recent time, they are starting to use recycled jute bags to minimize the impact of solid wastes. [6]

I.2.5 Geothermal energy

Geothermal energy represents one of the most significant sources of renewable energies in the case of Algeria. Algeria has a large geothermic capacity, estimated in terms of electricity production, at 700MW. More than 200 heat sources have been identified to the north of the country, of which almost 1/3 (33%) have a temperature higher than 45°C. Some sources have temperatures which can reach 96°C at Hammam Meskhoutine. Further south, the country possesses a vast geothermic reservoir which extends across several thousand km2. This reservoir is known as the "Albian Water Table" and has an average temperature of 57°C. [3]

Further long, the target of renewable energies in Algeria is showed in figure I.3.

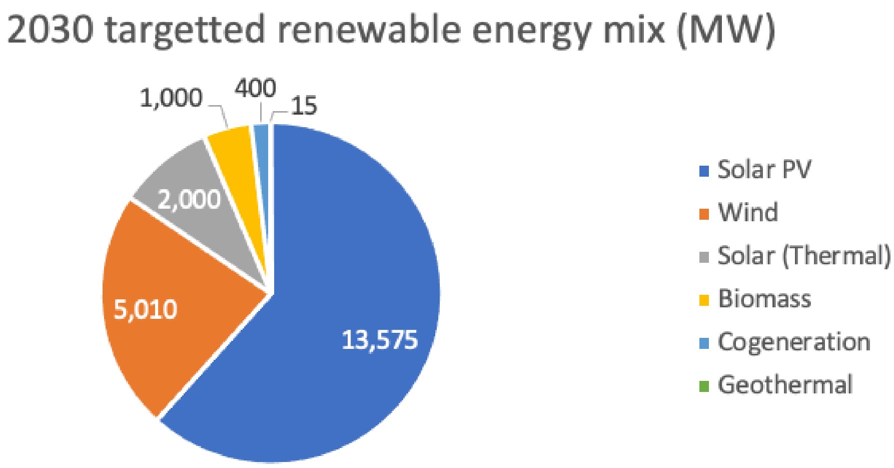


Figure I.3 : 2030 renewable energies target In Algeria [11]

I.3 Solar Photovoltaic energy potential

The PV power output (PVOUT) shows the specific yield, works as a quantitative measure to clarify a potential of a PV system over the long term, and it is measured in kilowatt-hours per installed kilowatt-peak of the system capacity (kWh/kWp).

As we see in figure I.4, the African countries have a better solar potential than the rest of the world.

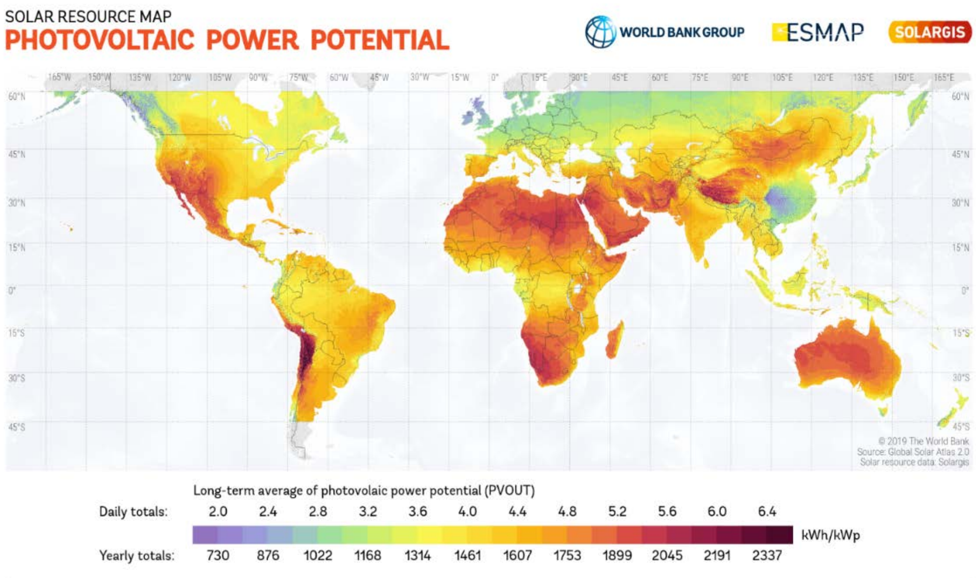


Figure I.4 : Photovoltaic energy potential [14]

I.4 Photovoltaic systems

A photovoltaic system uses solar panels to convert solar energy into usable electricity. It is made up of several interconnected components to ensure the production, conversion, storage and distribution of solar energy

I.4.1 Photovoltaic effect

The photovoltaic effect is a process that generates electricity when photovoltaic cells are exposed to light. Solar cells are composed of semiconductors with a p-n junction, which involves a semiconductor with a p-junction and a semiconductor with an n-junction. By joining these two types together, an electric field is created at the interface between them when the electrons move to the positive p-side and holes move to the negative n-side, this movement of charged particles generates an electric current. After that, A metal contact on the top and the bottom of the cell, that collects the created current for an external use (electrical load, battery…).

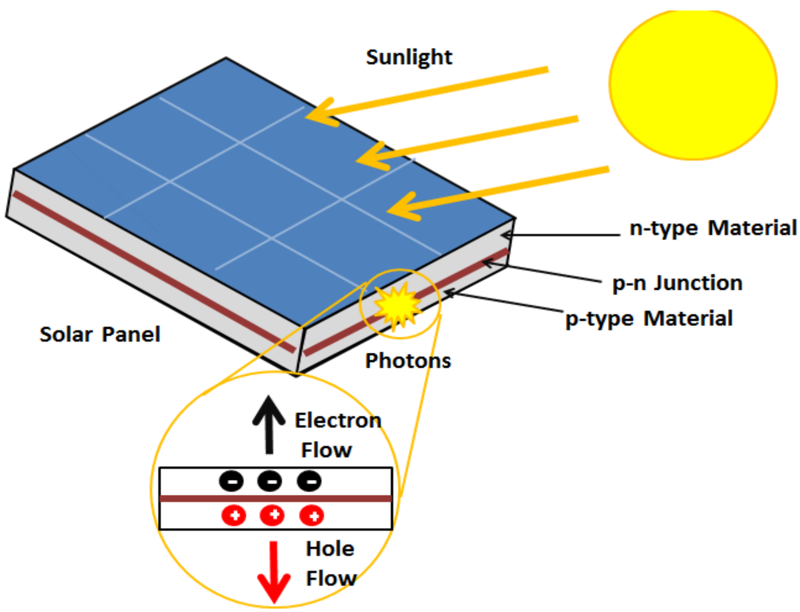


Figure I.5 : A diagram showing the photovoltaic effect.[11]

I.4.2 Photovoltaic system types

Photovoltaic system is composed of multiple components to power individual homes or businesses, we can integrate it into larger electrical grid. The main types of photovoltaic systems are classified as the figure. The main two classification in these types of systems are stand-alone systems and the grid-connected systems.

Each type of the types in figure I.9 has its own installation methods and requirements can vary depending on factors such as the specific PV technology used, system size, site conditions, and local regulations.

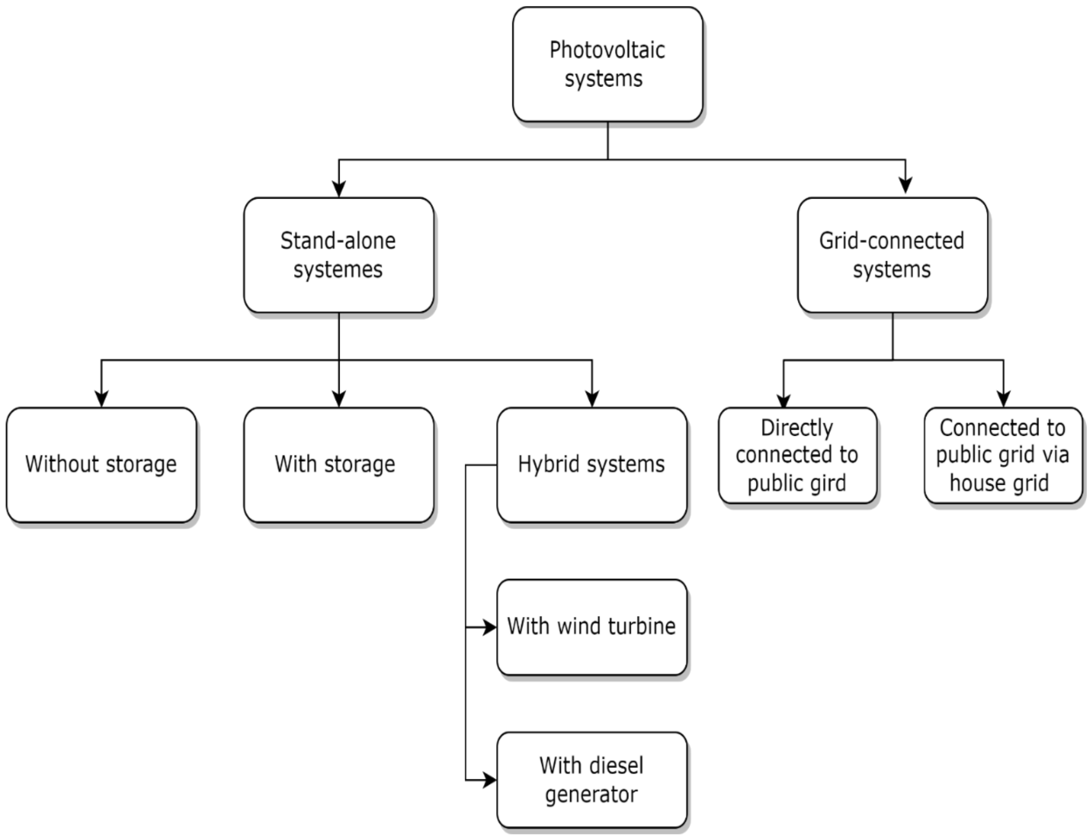


Figure I.6 : Classification of PV systems

I.4.2.1 Stand-alone systems

Stand-alone PV systems or off-grid systems, rely on solar power as their energy source. This type of systems can run with just PV modules and a load, or they can include batteries.

For energy storage. But when using batteries, charge controllers are included to ensure optimal battery performance. They disconnect the batteries from the PV modules once they are fully charged, and may disconnect the load to prevent the batteries from being discharged below a certain limit. [20]

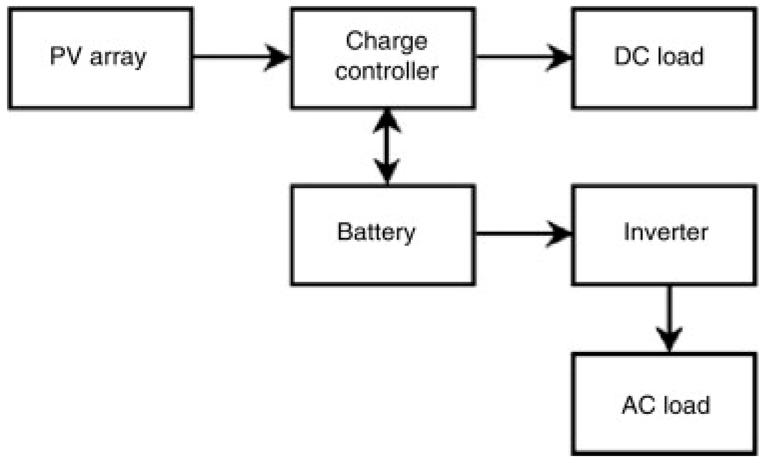


Figure I.7 : Simplest type of stand-alone PV system [25]

I.4.2.2 Grid-connected systems

Grid-connected photovoltaic systems are designed to generate electricity from solar power and directly feed it to the grid, the PV modules are connected to the grid through inverters that convert the DC power generated by the PV panels into AC electricity. These systems do not require batteries, since they are connected to the grid, which acts as a buffer into which an oversupply of PV electricity is transported. [20]

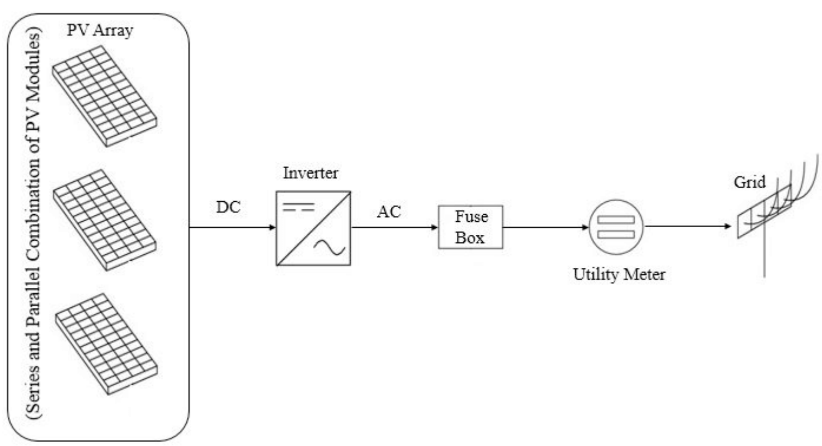


Figure I.8 : Layout of grid connected photovoltaic system [26]

I.4.3 Main PV system components

I.4.3.1 The PV arrays

The PV array is a set of multiple solar panels (each consists Photovoltaic cells) connected together to form a larger unit. We can connect them in series to increase voltages, and in parallel for higher currents.

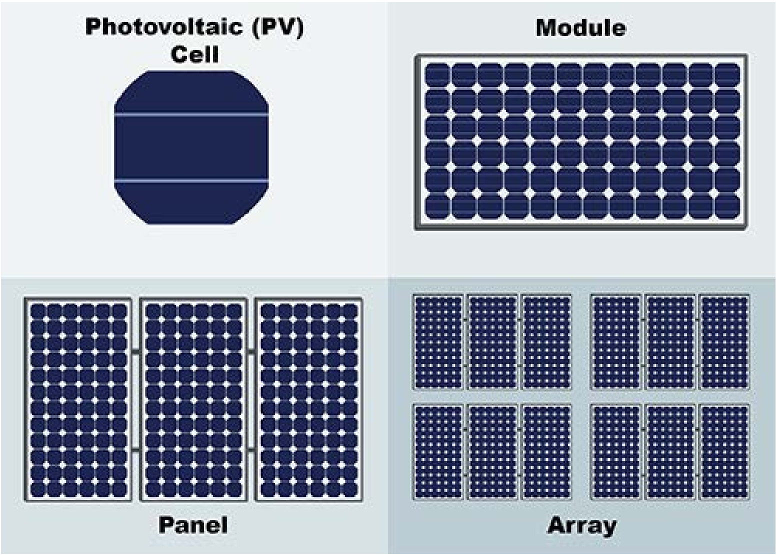


Figure I.9 : Photovoltaic cell, module, panel and array

I.4.3.2 Photovoltaic panels wiring

We can find solar panels wired in three types

- **In series** to increase the voltage output of the system but the current rests the same (constant).
- **In parallel** to increase the current output of the system but voltage rests the same (constant).
- **In series-parallel** to achieve the desired voltage and current levels necessary to power a particular application.

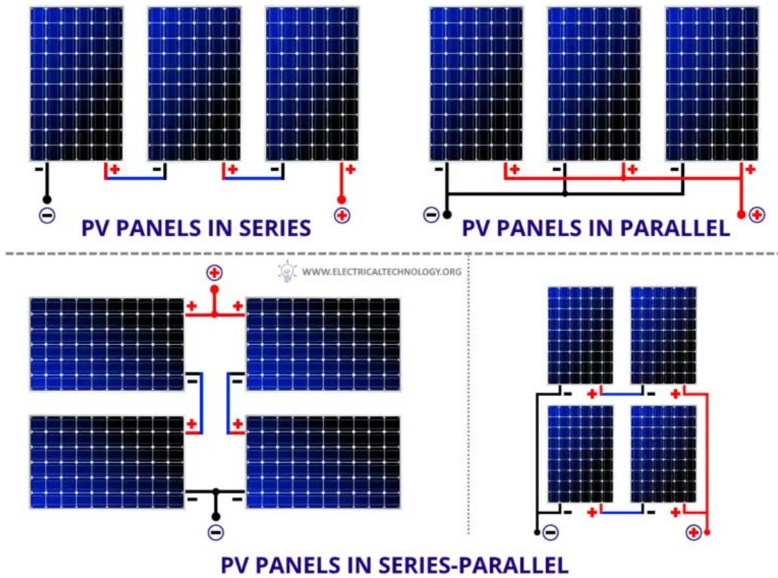


Figure I.10 : PV panels wiring types [13]

I.4.3.3 Inverters

In addition to the PV array, we need an inverter to convert the direct current (DC) generated from the PV array to an alternative current (AC) to make it suitable to use in homes, businesses…

There are two main types of inverters, grid-connected and stand-alone inverters.

a) **Grid-connected inverters:** or grid-tie inverters, this type is designed for photovoltaic systems that are connected to the grid. These inverters convert the DC current electricity produced by the PV modules into AC current electricity that can be fed into the grid. [25]

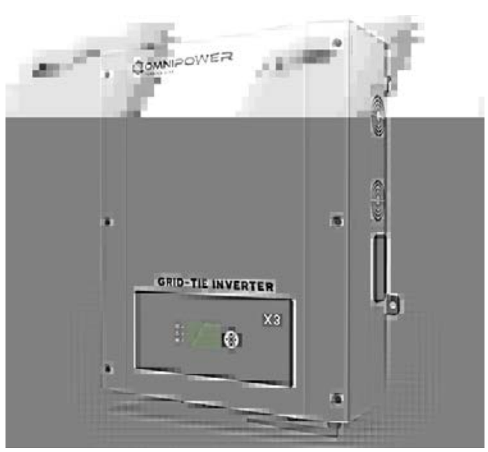


Figure I.11 : Grid-tie inverter [24]

b) **stand-alone inverters:** A stand-alone inverter provides a voltage with either a fixed or adjustable frequency. It doesn't always require an electrical grid to function. [25]

Figure I.12 : Phoenix 12/1200 inverter [9]

I.4.3.4 Charge controllers

Is an important component in PV systems with battery storage, it works by shutting down the PV array when the batteries are full and shuts down the load when the battery reaches the determined state of discharge. The controller should be adjustable to guarantee the best performance of the battery system under the various charge, discharge and temperature conditions. The main types of controllers are on figure I.13, Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT).

Figure I.13 : PWM and MPPT controllers [12]

I.4.3.5 Solar batteries

Solar batteries are used to store the energy produced by the PV array, typically in off-grid PV systems. This stored energy is used when the PV array is not generating sufficient energy to power the electrical loads in the wanted application. The type of battery used varies depending on the application.

I.4.3.6 Protection systems [26]

To protect our system, we need to use several protection systems, we can define the main components as:

a. Fuse for branch protection: this can be placed at the output of each parallel branch, to protect the branch from overcurrent and short-circuit.

b. Fuse for general protection: it is installed to provide protection against overcurrent or short-circuit conditions in the system as a whole.

c. Disconnect switch: it's better to place this component between the solar panel array and the inverter to easily shut off the system when needed.

Figure I.14 : Disconnect switch [16]

d. Surge protector: The surge protector helps protect against the risks of potential overvoltage in the installation. To prevent surges caused by lightning, it is important to have protection against the risks of induced overvoltage in both the alternating voltage circuit and the direct voltage circuit of the installation.

Figure I.15 : Surge protectors [27]

e. Grounding: Grounding is a protection against any potential electrical accident on a person in contact with a device exhibiting an electrical fault, and also provides protection for the equipment installed in the system.

Figure I.16 : Grounding system on a roof [18]

I.4.3.7 Smart meter

A smart meter is an upgraded electric meter that has additional features. The component could be part of smart grid technology to modernize grid infrastructure. Smart meters can transmit data to and from utility companies and monitor energy consumption in real time, and remote meter reading can also offer detailed information about the patterns of energy consumption. Smart meters can be integrated with other devices and technologies in the home, such as smart thermostats or energy management systems. This integration allows for greater control and optimization of home energy consumption.

Figure I.17 : Smart meter [19]

I.4.3.8 Solar cables and wiring

Solar wires are used to connect the components of a photovoltaic system, it connects four components: the solar panel, the inverter, the charge controller and the batteries. This type of cables must be resistant to weather condition, UV, and temperature. They come in 2 types, solar DC cable (They can either be module cables or string cables) and solar AC cable. [21]

Selecting the right type of wire for a photovoltaic system is crucial to ensure an optimal performance and efficiency.

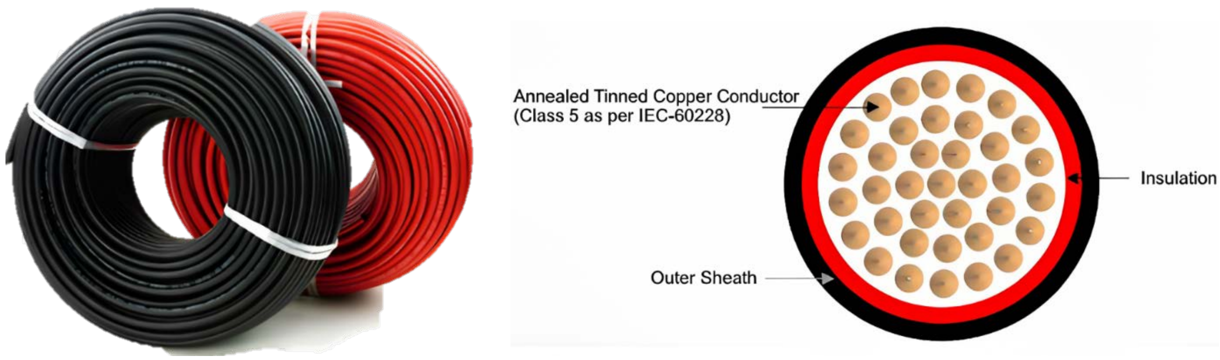


Figure I.18 : Solar cables and inside materials

Conclusion

Our study on the renewable energies available in Algeria, especially, the photovoltaic energy, we made an overview of the PV systems types and the main component needed to make a feasible system for the wanted cold storage facility.

CHAPTER II

Introduction

Refrigeration technology has become a necessary part of our modern lives, to preserve all kind of food, pharmaceuticals and the perishable goods. Over the years, the refrigeration technology has evolved to the point that we can nowadays store and transport the food on any distance and any environment. However, despite of all of its benefits and like all of other technologies it has some disadvantages or challenges, like environmental impact, high energy consumption. So, in the recent years, engineers have tried the integration of renewable energy sources, particularly photovoltaic (PV) systems, into cold storage facilities, and that has emerged as a promising solution to reduce both environmental impact, high energy consumption. In this chapter am going to talk about the photovoltaic systems and its implementation on the cold storages.

II.1 Definition of cold storages

cold storages, which are also referred to as cool stores, are refrigerated rooms designed to store goods in an environment that is maintained at a specified temperature and humidity. These refrigerated rooms, buildings, or units are commonly powered using diesel generators or electricity from non-renewable sources. However, there is a growing trend towards using renewable energy sources.

II.2 History of cold storages

Figure II.1 : A cold room

Simple cold storage can be traced back to thousands of years when the ice was collected to be stored to preserve a variety of food products. In the 1700s, the increasing adoption of industrial and mechanical technology led to several advancements in the cold storage industry.

Different studies suggest that Scottish medical doctor William Cullen was the first person to perform the experiment and solve home cold storage-related issues. He developed a small refrigeration machine in 1755. However, it did not function as per the expectations. Later this machine was thoroughly studied by experts.

Various other developments took place during this era. Benjamin Franklin and John Hadley were involved in the research of using evaporation to cool items in 1758. However, it was not until the late 1800s when the compression refrigeration system was invented and brought a major change in the development of cold storage solutions.

In 1820, Michael Faraday started liquefying the gasses by using high and low pressures. It ultimately led to the invention of the first vapor-compression refrigeration system in 1834. After this period, refrigeration systems started to become common, especially in the meat industry, so that the frozen products can easily be transported abroad.

Such systems were also implemented in rail cars and delivery trucks to keep the frozen products preserved during transportation. At the same time, there was a lot of resistance to these refrigeration systems because they were extremely expensive and even considered dangerous. The introduction of a gas-powered refrigerator made the process much safer. Shortly afterwards, electric refrigerators were developed that used Freon as the primary cooling agent.[7]

II.3 Cold storage types [15]

Cold storage types are usually divided into 4 types: high temperature, medium temperature, low temperature and ultra-low temperature.

II.3.1 High Temperature Cold Storage Facilities

This type’s temperature is usually above 0°C like:

- Refrigerated Warehouses: These facilities are used for storing perishable goods such as fruits, vegetables, and dairy products that require slightly cooler temperatures but not freezing.

II.3.2 Medium Temperature Cold Storage Facilities

The temperature in this type is usually within -18 such as cold rooms and refrigeration containers.

- Cold Rooms: Making them suitable for storing products like meats, seafood, and certain fruits and vegetables that require colder temperatures than refrigerated warehouses.
- Refrigerated Containers: These portable units can maintain temperatures between -30°C to -10°C and are often used for transporting temperature-sensitive goods.

II.3.3 Low Temperature Cold Storage Facilities:

The storage temperature is about -20°C~-30°C, and the food is frozen by air coolers or special freezing equipment.

- Blast Freezers: These facilities are capable of rapidly freezing large quantities of food. They are used for products like frozen meats, fish, and poultry that require deep freezing for preservation.
- Refrigerated Trucks: These mobile cold storage units are specifically designed for transporting frozen goods over long distances.

II.3.4 Ultra-Low Temperature Cold Storage Facilities:

The ultra-low facility has a cold storage temperature of ≤ -30℃.

- Ultra-Low Temperature Freezers:

These specialized freezers are capable of maintaining extremely low temperatures, typically ranging from -80°C to -150°C. They are used for long-term storage of biological samples, vaccines, and certain medical products that require ultra-low temperatures.

II.4 The component of a refrigeration system

The refrigeration system is a system contains a group of components and involves the use of a thermodynamic cycle (reversed Carnot cycle). The most important components are compressor, condenser, expansion valve, and the evaporator.

II.4.1 The compressor:

Which compresses the refrigerant gas and increases its temperature and pressure, and sends it to the condenser.

II.4.2 The condenser:

The cold condenser (air-cooled water-cooled…) absorbs the heat from the refrigerant and completely change its phase from a high-temperature, high-pressure vapor refrigerant into a liquid state.

II.4.3 Expansion valve:

Expands the high-pressure, high-temperature liquid coming from the condenser, so the pressure between the molecules decreases, thus the temperature falls. at this point, the refrigerant coming out from the valve is a low-pressure, low temperature liquid + vapor.

II.4.4 Evaporator:

Is where the main cooling effect happens. The low-pressure and cold refrigerant enters into the evaporator coils, where it absorbs all the heat in the surface where the evaporator is installed. As a result, the liquid refrigerant turns into low-pressure vapor and leaves back to the compressor.

All the components are connected by pipes.

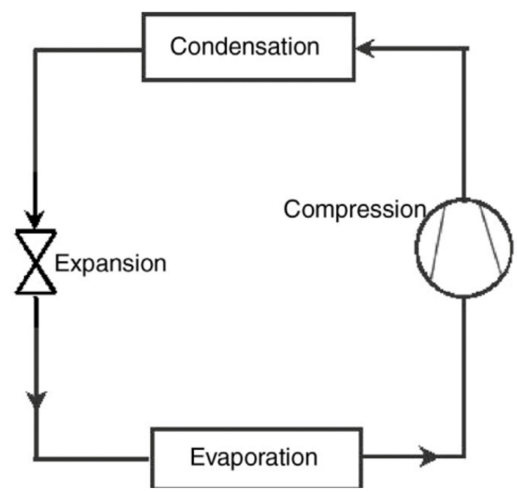


Figure II.2 : The ideal reversed Carnot cycle (refrigeration system) [17]

II.5 Refrigerants

II.5.1 The different categories of refrigerants

a) **CFCs (chlorofluorocarbons):** They are molecules composed of carbon, chlorine and fluorine. Commonly used in refrigeration systems in the past but now mostly reduced its use because it contributes to the destruction of the ozone layer.

b) **HCFC (hydro chlorofluorocarbon):** They are molecules composed of carbon, chlorine, fluorine and hydrogen. Not as harmful as the CFCs to the ozone layer, but still contributes to the ozone depletion. These are called transitional substances.

c) **HFC (hydrofluorocarbons):** They are molecules composed of carbon, fluorine and hydrogen. They do not contribute in the ozone depletion because they don't contain chlorine, but they have a high global warming potential and contribute to climate change.

d) **Ammonia (NH3) R-717:** fluid inorganic, it is an excellent refrigerant for evaporation temperature between 35°C +2°C. it has a low global warming potential and zero ozone depletion but it is a fluid dangerous and toxic.

e) **Hydrocarbons (HC) as R-290 R-600a:** they have good thermodynamic properties, but they are flammable and requires safety precautions.

f) **Carbon dioxide (CO2):** is a natural refrigerant, non-toxic, non-flammable, but it is not efficient thermodynamically. it needs the use of high pressure and a special compressor.[10]

II.6 Photovoltaic-powered cold storage

Solar-powered cold storage is an innovative and eco-friendly system, which uses solar panels to power the refrigeration system, which is a traditional system with modification to integrate the PV system to it.

The first photovoltaic-powered cold store has been developed to store 10 tons of frozen fish at -15°C. It consists of a photovoltaic array (4 kW peak), a battery bank (96 V DC, 180 AH), a vapor compression refrigeration system (1 ton), electronic controls for automatic operation of plant and an insulated cold chamber. Experiments were conducted on the system to evaluate its performance with no heat load (frozen fish at-15°C) and with different heat loads. It is observed that the system can be operated with a maximum heat load of 2350W to maintain the walk-in-cooler temperature below the freezing point of fish (-2°C). The performance studies conducted on these subsystems viz., photovoltaic array and battery bank showed that their output has deteriorated in 5 years.[4]

These types of systems can be used in rural areas with limited electricity sources or any other place, because it can reduce the use of the grid electricity so it will save energy cost over time.

The photovoltaic system needs an available space or the roof of the facility to be installed as the system shown in the figureI.3, and the need of a thoroughly analyze of the energetic balance to choose the right and the needed component.

Figure II.3 : Frigomundo Coldstore in THE NETHERLANDS, Zouterwoude [12]

II.7 Integrating photovoltaic systems in cold stores through research

In 2016, Dipankar N. Basu et al made a conceptual design of a potato cold storage using water–lithium bromide absorption system; the proposed system utilizes both solar thermal and photovoltaic generated electrical energy for its operation. They found that the proposed system offers a net surplus of about 36 MW h energy over a calendar year. In addition, after the economic analysis it was cleared that both the thermal and photovoltaic components have payback periods of less than four years. [28]

In 2019 Ishaq Sider et al, studied using the software TRANSYS, two different scenarios for energy Consumption Evaluation of Air-Cooled Chiller with Cold Storage System Powered by Photovoltaic Modules. In the first scenario, they supplied an air-cooled chiller using a photovoltaic system integrated with the grid and they found that there is a reduction in consumed energy by 81%, reduction in CO2 emissions by 72% and the payback period is estimated to be 9 years. Meanwhile, in the second scenario, they integrated a photovoltaic system to the grid as a thermal storage tank, so they found that there is a reduction in consumed energy by 75.6%, reduction in CO2 emissions by 68% and the payback period is estimated to be 12.4 years. It is obviously that the first scenario is the better solution for a faster payback and better for environmental effect. [29]

In 2021, **"**Wenping du et al" proposed a new method for constructing a distributed solar PV direct-drive cold storage system (vapor compression refrigeration cycle is directly driven by a PV array), and to store the energy they used ice thermal energy instead of batteries. And they studied the key factors affecting system performance. The vapor compression refrigeration cycle system efficiency decreases by 2.28%-2.62% as the solar radiation increased by about 100 W/m². The average daily deviation of the simulation results compared with the experimental results is approximately 2.8%-3.2% on clear days and 4.4%-5.1% on cloudy days. The cold energy during a sunny and partly cloudy weather are 128.83 and 122.00MJ, and the average solar-cold energy conversion efficiencies are 0.30 and 0.31, respectively. [30]

In 2020, P.sarafoji et al studied the performance of phase change material in the prototype solar cold storage system. They made 5 different experiments and they found that 16 kg of phase change material charged 75-90 min able to maintain the temperature for average of 150 min that means the Prototype Solar Cold Storage system maintains the set temperature 35% longer than the conventional cold storage system. PCM is a promising material for cold thermal energy storage applications. The integrating of the PV system with the PCM can replace 16% of the total power consumption. .[31]

In 2021, for a techno-economic evaluation of a solar PV integrated refrigeration system for a cold storage facility, “Hamid Ikram et al” focused on the optimization of a solar PV integrated conventional refrigeration system for cold storage facility based on the conventional vapor compression system for banana fruit. The research was conducted in two stages. In the first stage, they analyzed thoroughly the conventional system using mathematical modeling to determine the sizes of the condenser, evaporator, and air-conditioning compressor. They found that the condenser is oversized, meanwhile the evaporator was undersized, and the air-conditioning compressor was also found to be oversized by approximately 12 kW. The system using refrigerant anhydrous ammonia (R-717) for the refrigeration capacity of 35 kW and a target temperature of 15◦C and the store area can accommodate about 70 tons of banana. .[32]

In the second stage, they integrated a solar PV field and the system was accomplished in PV*SOL tool, the simulation has shown that with 170 m² the production of solar installation is 15,819 kWh against the total consumption of 27,240 kWh and the PV hybrid system can achieve 58.1% solar fraction at a performance ratio of 59.2%, and the economic payback was measured to be in 5.2 years. Before the installation of the PV system, the average consumption cost was around 1701.3 USD per year. However, after the installation of the PV system under optimum conditions, the consumption cost reduced significantly to approximately 713.54 USD per year. .[32]

Conclusion

The integration of PV systems into cold storage facilities offers a promising solution to the challenges of refrigeration technology. By harnessing renewable energy, PV-powered cold storage facilities can reduce environmental impact and energy consumption. The thesis emphasizes the importance of sustainable alternatives and highlights the benefits of PV systems in addressing these concerns. Additionally, it discusses the significance of cold storages in preserving perishable goods. The integration of PV systems in cold storages contributes to energy efficiency and environmental sustainability.

CHAPTER III

Introduction

In our work's simulation, we are focusing on two software tools to help us in the simulation and the optimization of the PV system that we are planning to install, which are HOMER Pro and PVsyst. Despite of these tools, we are going to mention the relations and the equations that we are going to use to calculate and estimate the necessary components for the PV system. These equations will make us able to determinate parameters such as solar panel output, inverter specifications, and the environmental effect on the system, which are so important for a successful implementation of the PV system.

III.1 HOMER, the software description

First of all, HOMER or "Hybrid Optimization of Multiple Electric Renewables" is a simulation model allows you to simulate applicable system for all of the possible combinations of the equipment that we are planning to use, and can simulate a lot of systems depends on the problem we set. HOMER can examine the needed combinations of system types in one run; also, it can give us a detailed modeling of various energy sources and loads or even optimization of system performance and cost. HOMER can also help us to compare a lot of possibilities in a single run. This allows us to see the impact of variables that are beyond of our control, such as wind speed, fuel costs, etc.

The software can be customized to lot of modules to meet the needed specific modeling: Biomass, Hydro, Combined Heat & Power, Advanced Load, Advanced Grid, Hydrogen, Advanced Storage, Multi-Year, MATLAB Link.[12]

Using HOMER, we need to provide the inputs such as component, component costs, and resource availability. To use the software properly we need:

- The PV panels and all of the other component's properties.
- The electric load and the energy demand of the system.
- The solar sources data of the targeted place.
- All of the technical data and cost of component.
- All of the financial data.
- Inverter, controller… settings.
- The required grid data, the voltage, frequency, and capacity of the grid. This data is used to model the interaction between the PV system and the grid.

Figure III.1 : The software "HOMER Pro" [12]

III.1.1 HOMER Pro steps

The first step after entering to the software HOMER is going to the design interface, which we will fill the project information.

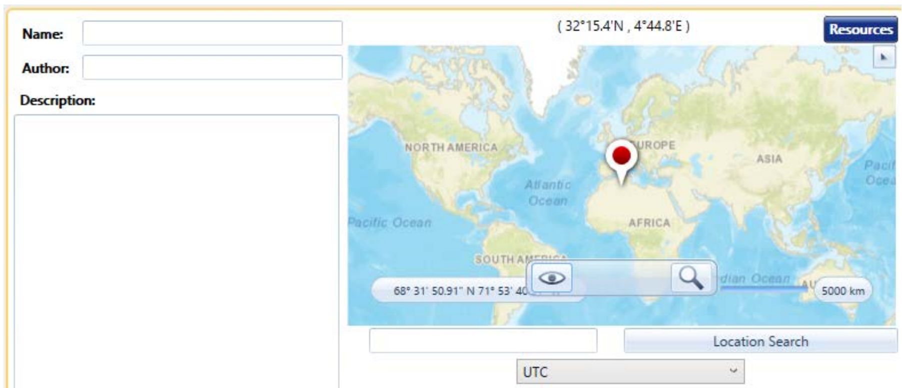


Figure III.2 : Location and project's information.

After that we need to define the system's specifications such as load profile, model of components, weather data of the targeted location such as GHI resource, wind speed etc. also we need to insert all of the economic aspects of the system. After that, we need to include technical specifications (type of photovoltaic modules, battery type, converter, etc.), and their capital, replacement costs, and operation and maintenance to calculate the economic specifications.

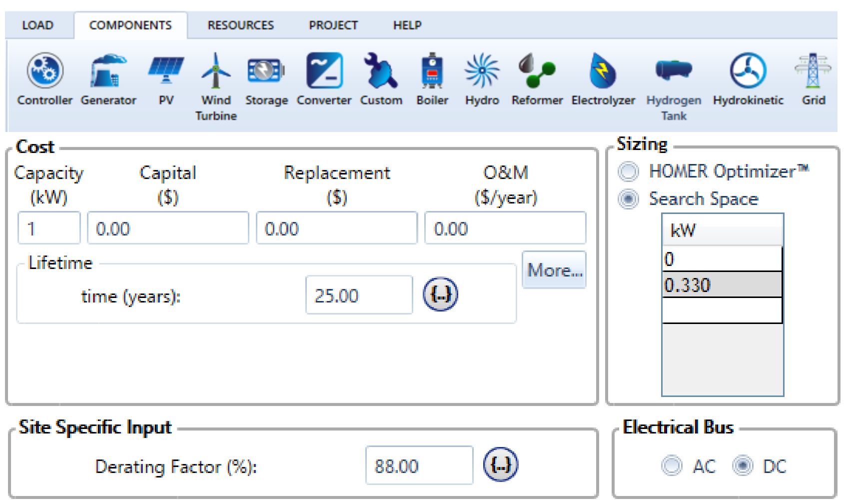


Figure III.3 : Financial details

As a final step, and after running the HOMER model, optimized results will be calculated, and will perform the optimization.

III.2 What is PVsyst?

PVsyst is a software package specializing in the modeling and simulation of photovoltaic systems. It is used to evaluate the energy performance of a solar system, taking into account numerous factors such as geography, climate, orientation and inclination of solar panels, conversion losses, shadows, cables, etc. PVsyst takes into account the specific characteristics of the photovoltaic modules used, as well as local weather data, to estimate expected energy production and carry out detailed analyses such as inverter sizing, profitability assessment and system optimization.

PVsyst is a widely used software tool for the simulation, design, and optimization of photovoltaic (PV) systems. It is known for its extensive capabilities in modeling the performance and behavior of solar power systems. Here are some key features and functionalities of PVsyst:

System Design: PVsyst allows us users to design PV systems by specifying system components such as solar panels, inverters, and batteries. It offers a vast database of PV module and inverter models, making it easy to select specific products from different manufacturers.

Performance Simulation: PVsyst employs mathematical models and algorithms to simulate the energy production of PV systems. It takes into account factors such as solar irradiance, temperature, shading effects, module characteristics, and electrical losses. By considering these parameters, PVsyst accurately estimates the system's energy output over time.

Weather Data: PVsyst incorporates a comprehensive weather database with historical and typical meteorological data for different locations around the world. Users can input their project's geographic coordinates or select a specific city to retrieve weather data relevant to their simulation. This helps in accurately modeling the system's performance based on local weather conditions.

Shading Analysis: PVsyst provides advanced shading analysis capabilities, allowing users to assess the impact of shading on the system's energy production. It enables the modeling of shading from nearby objects, such as buildings or trees, and helps optimize the system's layout and positioning to minimize shading losses.

System Optimization: PVsyst offers optimization features to find the most efficient configuration for a PV system. It allows users to compare different module orientations, tilts, and system sizes to maximize energy production or financial returns. PVsyst's optimization capabilities assist in determining the optimal design parameters for a given project.

Reporting and Visualization: PVsyst provides comprehensive reports and visualizations of the simulated PV system. It generates detailed graphs, tables, and charts that illustrate the system's energy production, losses, and financial metrics. These reports are useful for project documentation, presentations, and sharing information with stakeholders. [13]

Figure III.4 : The software PVsyst [13]

III.2.1 PVsyst steps

We start with choosing the targeted type of system, grid connected, stand-alone and the other PV system types, as it is on figure III.5, in our case we are going to choose the grid connected type.

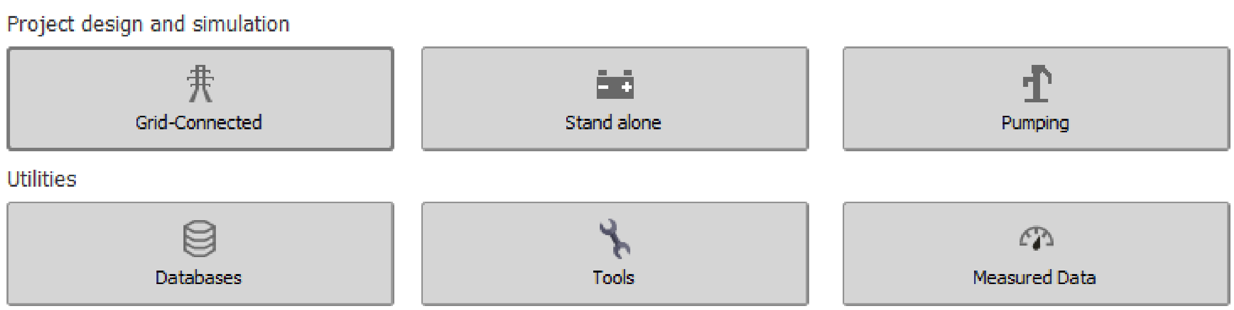


Figure III.5 : The interface of the software PVsyst

After that, we select the location of the facility and import the meteo data (Meteonorm 8.0, NASA-SSE…)

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity
	kWh/m²/mth	kWh/m²/mth	°C	m/s
January	86.0	35.9	10.5	2.40
February	97.3	43.8	12.6	2.79
March	138.2	74.0	17.6	3.19
April	171.7	84.2	21.8	3.70
May	198.2	99.2	26.9	3.88
June	203.0	102.0	31.4	3.60
July	212.2	100.2	35.2	3.30
August	196.4	92.0	34.2	3.10
September	156.6	76.3	29.2	2.90
October	128.0	60.0	24.1	2.31
November	97.5	38.9	16.1	2.19
December	81.0	36.9	11.3	2.20
Year	**1766.1**	**843.3**	**22.6**	**3.0**
	Paste	Paste	Paste	Paste

Global horizontal irradiation year-to-year variability 3.8%

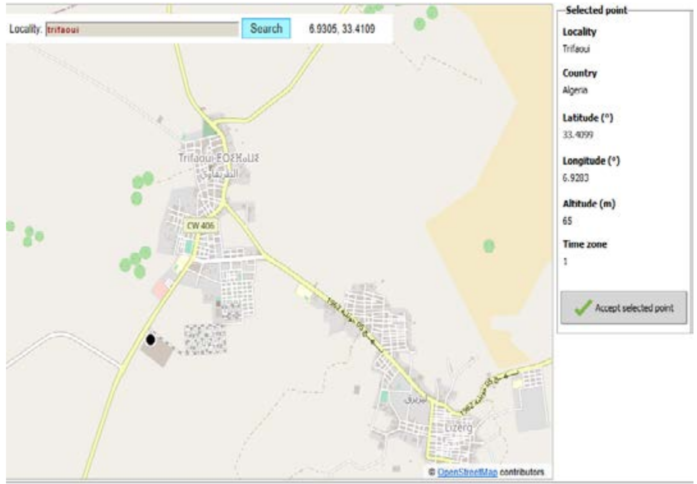


Figure III.6 : The coordination and the meteology data

After saving the active project, we set the orientation for the PV panels (Tilt and azimuth) to get the minimum loss.

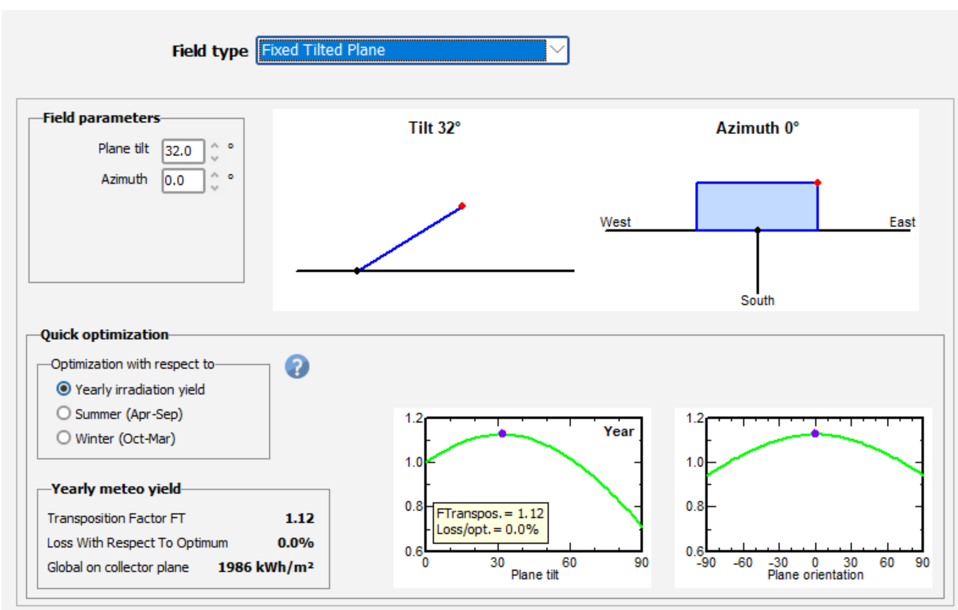


Figure III.7 : The orientation interface

To finish our project, we have to choose the component, basically we choose from the software's data base, and we can change the components characteristics based on what is on the market. We can use the pre-sizing help to help us on how much solar panels we can install on the desired space, at the same time, we need to select the PV module that we need. After that, we move to selecting the inverter and its characteristics. Exactly under "select the inverter" on that interface we find "design the array" where we can modify the number of modules and strings (the software PVsyst suggest the number of the components and how much modules we can install in series and strings). We can find all of the previous on the figure III.9.

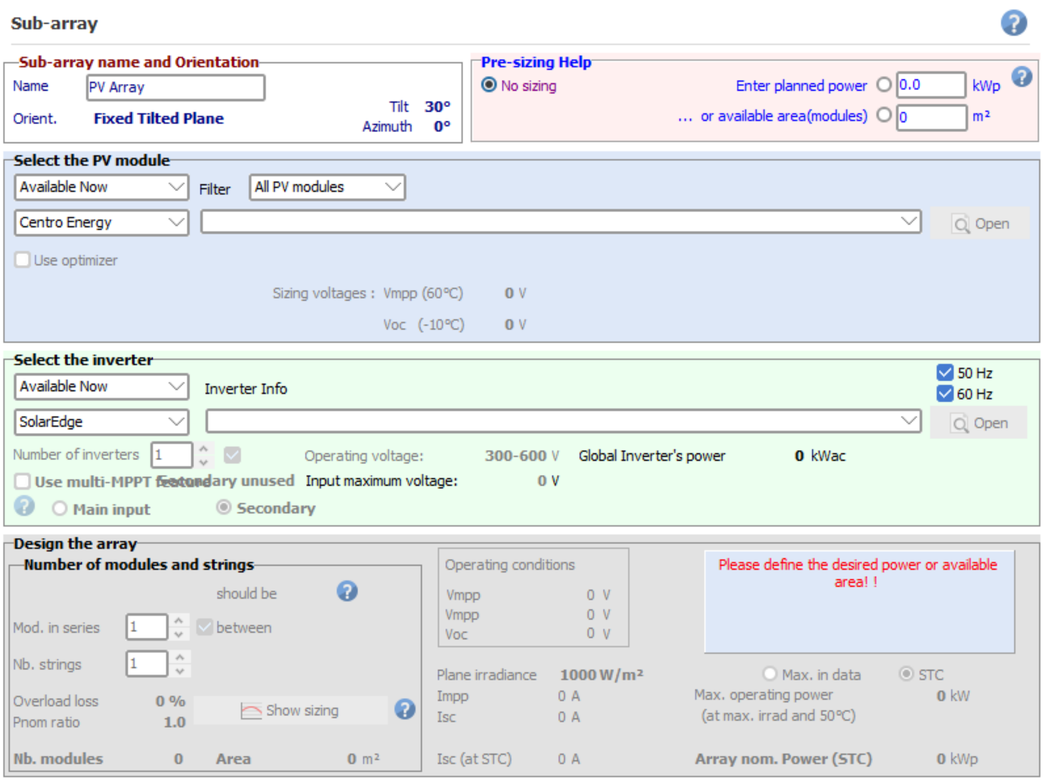


Figure III.8 : The sub-array information and characteristics

As a last step, we run the simulation to get our results as graphs, tables, and diagrams.

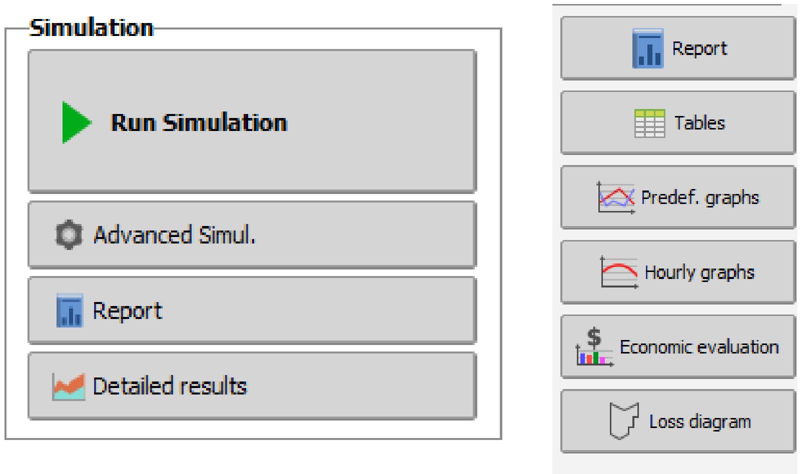
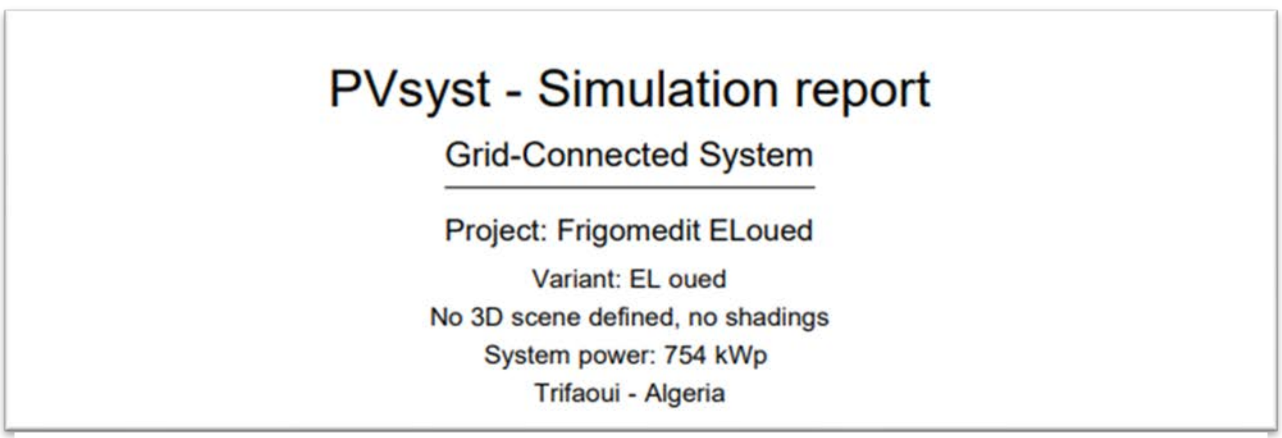


Figure III.9 : Where to run the simulation and to get the results

Finally, we need to thoroughly analyze the results especially the report, because there is where we can find the main and the most important results in our simulation.


PVsyst - Simulation report

Grid-Connected System

Project: Frigomedit ELoued

Variant: EL oued

No 3D scene defined, no shadings

System power: 754 kWp

Trifaoui - Algeria

Figure III.10 : The first page of the report

III.3 PV system sizing

Sizing a photovoltaic (PV) system involves determining the optimum size of system components, such as solar panels, inverters and batteries (if used), based on specific energy requirements and installation conditions. We follow the steps for sizing a PV system:

III.3.1 The efficiency of solar panel

Solar panel efficiency is influenced by various parameters, such as the quantity of sunlight captured, panel orientation, temperature, and other variables. The simplest way to determine the efficiency of a solar panel is to look at the product specifications (solar panel's data sheet). However, we are going to check it by ourselves and compare the results. To calculate the efficiency, we are going to use the formula below:

$$\boldsymbol{Efficiency}\ (\%) = \frac{\frac{\boldsymbol{Pmax}}{\boldsymbol{Area}}}{\mathbf{1000}} * \mathbf{100}\% \qquad \textbf{(III.1)}$$

- Pmax: solar panel peak power (Watts).
- Area: the area of the solar panel (m²).
- 1000: STC (Standers Test Condition) irradiance (Watts/m²).

We used this theoretical method in our study due to its simplicity and the minimal number of parameters it requires. The results are expected to be reliable.

III.3.2 The number of solar panels

After the comparison of the efficiency of the selected solar panel, we are going to estimate the number of solar panels that can be installed on the roof of the facility. We attend to measure the available area on the facility's roof by using the tool "ruler" on "Google earth".

The estimated number of solar panels would be:

$$N_{SPp} = \frac{Useful\ area\ of\ the\ roof}{Area\ of\ the\ solar\ panel} \qquad \textbf{(III.2)}$$

The problem here is that we need to measure the useful area of the roof, to do that we need to calculate:

III.3.2.1 The inclination angle (Tilt angle)

Generally, we use the latitude of the place where we want to plant the system as a tilt angle for the solar panel installation, generally we can get it from the tool "google earth".

III.3.2.2 The minimal distance between solar panels

It is so important to install the PV system in way that the shadow of the previous row does not obscure the next row. To calculate that distance, we are going to use the tool "Easysolar shade calculator", which is a tool uses calculations for the angle of incidence of solar radiation for December 23, when the sun is lowest above the horizon. For that, we only need to know:

- The height of the solar panel "h".
- The angel of the panel "α".
- Latitude "Φ".

The tool will calculate:

- "z" the distance between rows (m).

- "β" the angle of incidence of sunlight on the winter solstice.

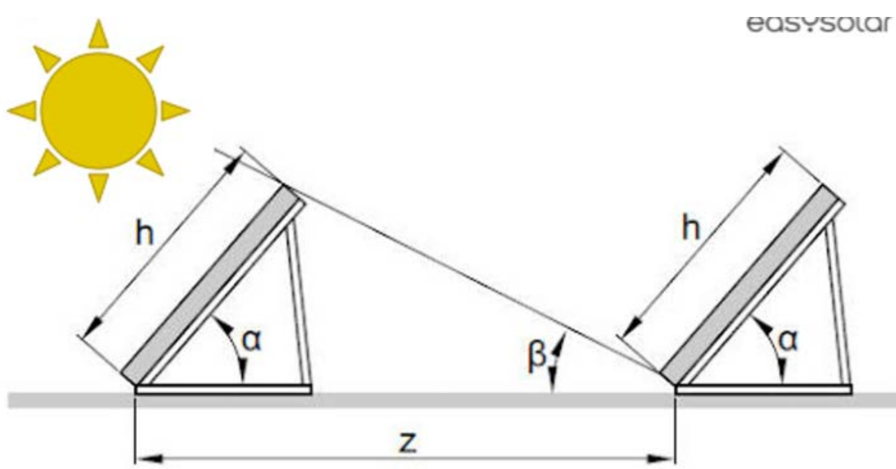


Figure III.11 : The distancing between solar panels [33]

III.3.3 The maintenance team distancing

We need also to leave a space for the maintenance team to walk freely on the roof after installing the system, we are going to estimate the distance by 2 m on each site.

III.3.4 The output of the solar system

To calculate the output of the PV system we need to:

$$System\ output = N_{sp} * Pmax_{sp} \qquad \textbf{(III.3)}$$

III.3.5 PV system protection

Protecting the photovoltaic system is essential for safe, reliable operation. It's important to comply with local safety standards and regulations when designing, installing and operating a photovoltaic system. Working with qualified solar professionals and complying with current codes and requirements will ensure that your photovoltaic system is adequately protected.

III.3.5.1 Branch fuse

For fuses we need to know the right fuse for our system therefore we are going to calculate the voltage and current that the fuse can handle.

- **Voltage**

$$V_F = 1{,}15 * V_{oc} * N_{sps} \qquad \textbf{(III.4)}$$

- **Current**

$$1{,}5 * I_{sc} \leq I_F \leq 2 * I_{sc} \quad \textbf{(III.5)}$$

III.3.5.2 Fuse for circuit breaker

A circuit breaker is needed for the security of the PV system, to select most favorable the one, we need to calculate the voltage and current that the fuse can handle.

- **Voltage :**

$$V_{CBF} \geq 1{,}15 * V_{oc} * N_{sps} \quad \textbf{(III.6)}$$

- **Current:**

$$I_{CBF} \geq 1{,}5 * I_{sc} * N_{spp} \quad \textbf{(III.7)}$$

III.3.6 Irradiation effect

The power output of solar panels is influenced by solar irradiation levels. Increasing in solar irradiation leads to a higher power output, and decreasing in solar irradiation results a lower power output. Thus, the capacity of a solar panel varies proportionally with the amount of solar irradiation it receives, and we can refer to it by the relation:

1000W/m² ⟶ ***Solar panel capacity W***

The wanted irradiation W/m² ⟶ ***…. W*** **(III.8)**

III.3.7 Temperature effect

The temperature effect on the solar panels, using the coefficient of power attenuation:

- For every 1°C more than the STC temperature the panel loses a percentage (defined on the data sheet) of its capacity, and in the opposite way the solar panel gains the same percentage of its capacity.

III.3.8 The performance ratio

The performance ratio is the difference between the real power generated by a photovoltaic system and the power that is expected from the system.

$$PR = \frac{the\ real\ power}{the\ expected\ power} \quad \textbf{(III.9)}$$

III.3.9 Number of modules in series

The wiring type in PV systems is so important, so we are going to calculate the number of solar panels from the equation III.10, and thus we get to know the number of parallel too.

$$N_{sps} = \frac{V_{dc\,Max}}{V_{oc}} \qquad \textbf{(III.10)}$$

III.3.10 The inverter:

The inverter is one of the main components in a PV system, by using the equation III.11, we will define the ideal inverter for the generated PV capacity.

$$P_{inverter} = \frac{System\ output * Correction\ coefficient}{\eta\ inverter} \qquad \textbf{(III.11)}$$

The correction coefficient here is taken: 1.296

- If P ≤ 500 W, the output voltage of the inverter will be 12 V.
- If 500 ≤ P ≤ 2000 W, the output voltage of the inverter will be 24 V.
- If P > 2000 W, the output voltage of the inverter will be 48 V.

Conclusion

Homer and PVsyst are two software tools commonly used for dimensioning photovoltaic systems. Although they have similar functionalities, they differ slightly in their approaches and specific fields of application. Homer is more oriented towards the overall design and optimization of hybrid systems, while PVsyst focuses specifically on the analysis and modeling of photovoltaic systems. These tools are complementary and can be used together for a more comprehensive and accurate assessment of a photovoltaic project, taking into account both technical and economic aspects. Our work focuses on the simulation and optimization of a PV system using two software tools, HOMER Pro and PVsyst. Additionally, we utilized specific equations and to calculate and estimate the necessary components for the PV system. By considering these factors, we aim to ensure a successful implementation of the PV system, maximizing its efficiency and effectiveness.

CHAPTER IV

Introduction

For the optimal performance and efficiency of a wanted PV installation, its needed to carefully select the appropriate components, so accurate calculations need to be made. In this chapter and by performing accurate calculations and considering key factors on a PV installation such as power capacity, and energy consumption, we can determine the most suitable components that will contribute and lead us to an efficient and profitable installation. We used the software HOMER Pro and PVsyst and other tools to help us in calculations.

IV.1 Frigomedit

The company "MEDITERANNEENE DU FROID", by abbreviation FRIGOMEDIT, is a public economic enterprise. Established in September 2010, as a joint-stock company, with a capital of 100,000,000 Algerian Dinars, fully subscribed by the State. with the goal of achieving a storage capacity of 1 million m3. FRIGOMEDIT owns 50 cold storage complexes and 5 companies specialized in cold storage. Also, the actual main activities for the company are:

- The storage, packaging, and marketing of products intended for the local market and exportation.
- Contribution to the regulation of the market for priority products by establishing a safety stock of consumer goods and seeds. Importation and exportation of all agricultural and food products.
- Development of public refrigerated storage capacities.

The company is seeking the expertise of academics in photovoltaic energy to assist in the study of the feasibility and implementation of a new energy security.

One of the most energy consuming facility under the name Frigomedit, is Frigomedit El-Oued, exactly in Trifaoui.

Figure IV.1: Frigomedit

IV.2 Electric consumption in El-Oued

Frigomedit El-Oued is a large cold storage facility located in "Trifaoui", with a latitude of 33.40°. An upper view for the facility is showed on figure IV.1.

The facility electrical consumption is detailed in table IV.1.

Table IV.1: electricity consumption in Frigomedit

	Electricity consumption (kw)	Duration (h/day)	E (kw/J)
The refrigeration system	643.3	18	11579.4
Water treatment	49	8	392
Treatment lines	38	14	532
indoor lighting	20	14	280
outdoor lighting	10	15	150
air conditioning	35	14	490
electrical outlets	5	15	75
Various equipment	15	1	15
Total			13513,4

IV.3 Choosing the components

STC: cell temperature of 25°C and an irradiance of 1000 W/m² with an air mass 1.5 (AM1.5) spectrum.

IV.3.1 Solar panel

In our case we are going to choose a monocrystalline solar panel of a 450 W, we can see more about the panel on the data sheet shown in table IV.2.

Table IV.2: 450W Mono-panel data sheet

Type: Monocrystalline	Number of Cells: 144 cells
Trademark: Canada	Weight: 24.9 kg
Photovoltaic efficiency: 20.37%	Size: 2108 x 1048 x 40 mm
STANDARD TEST CONDITIONS DATA	
CS3W	450MS
Maximum Power (Pmax)	450 W
Maximum power voltage (Vmp)	40.5 V
Maximum power current (Imp)	11.12 A
Open-circuit voltage (Voc)	48.7 V
Short circuit current (Isc)	11.65 A
Module photovoltaic efficiency	20.37%
Operating temperature	-40oC~+85°C
Maximum voltage	1000 V (IEC/UL) or 1500 V (IEC/UL)
Module fire performance	Type 1 (UL 1703) or Class C (IEC 61730)
Max. series fuse rating	20 A
Application classification	Class A
Power tolerance	0 ~ +5 W

IV.3.1.1 Solar panel's efficiency

From the equation III.1 we get:

$$Efficiency\ (\%) = \frac{\frac{450}{2.108*1.048}}{1000} * 100\% \qquad \textbf{(IV.1)}$$

$$Efficiency\ (\%) = 20.37\%$$

IV.3.1.2 Number of the PV panels

To find the number of PV panels that could be installed on a roof, we need to know first the available area on the roof.

Figure IV.2: Upper view on Frigomedit El-oued

The facility's roof area = 6109,2m².

IV.3.1.3 The inclination angle (Tilt angle)

From the tool "Google earth", the latitude on Trifaoui is: 33.24°, and so on, a solar panel on our system will have a tilt angle of 33°.

IV.3.1.4 The minimal distance between solar panels

After keeping in mind space for the maintenance team (2.5m on each side) and after using the tool "Easysolar shade calculator" the shading between the panels is estimated to about 3.6m as it is shown in the figure IV.3.

Figure IV.3 : Tilt angle and the distancing between panels

Using the equation III.2, the number of solar panels in parallel is:

$$N_{SPp} = \frac{6109{,}2}{3{,}6*1{,}048} = 1620 \qquad \textbf{(IV.2)}$$

In case of STC and from III.3, the PV system generates:

$$System\ output = 1620 * 450 = 729\ kW \qquad \textbf{(IV.3)}$$

The system will be installed as the figure IV.4.

Figure IV.4: A design for the PV system on the roof of Frigomedit "Trifaoui"

IV.3.2 Temperature effect

Temperature effects the efficiency of the solar panel, as the table III.3.

Table IV.3: Temperature effect

TEMPERATURE CHARACTERISTICS	
Coefficient of power attenuation	-0.36 % / °C
Coefficient of voltage attenuation	-0.29 % / °C
Coefficient of current attenuation	0.05 % / °C
Operating temperature of cell	41 +/- 3 °C

According to “PVgis” tool we can get the real capacity of the PV panel as the following table:

Table IV.4: The effect of temperature and irradiance on the solar panel's capacity

Month	Average daily irradiation (Wh/m²)	The average hourly irradiance (W/m²)	Average temperature (°C)	Capacity with Irr. effect (W) No temp	Capacity with Irr. effect (W	The PV array (kW)
January	5727	776.17	10.7	349.28	372.446	603,362
February	6768	854.5	14	384.525	402.345	651,798
March	6864	864.3	16.6	388.935	402.543	652,119
April	7195	926.42	21.7	416.889	422.235	684,020
May	7079	918.67	27.4	413.4015	409.5135	663,411
June	7226	936.25	31.3	421.3125	411.1065	665,992
July	7321	946.33	32.5	425.8485	413.6985	670,191
August	7215	929	**33.2**	418.05	404.766	655,720
September	6847	840.16	28.2	378.072	372.888	604,078
October	6264	808.17	21.4	363.6765	369.5085	598,603
November	5732	773.33	16.8	347.9985	361.2825	585,277
December	4734	740.33	12.1	333.1485	**354.0465**	573,555

For every 1°C more than the STC temperature the panel loses 0.36% of its capacity and in the opposite way the solar panel gains 0.36% of its capacity.

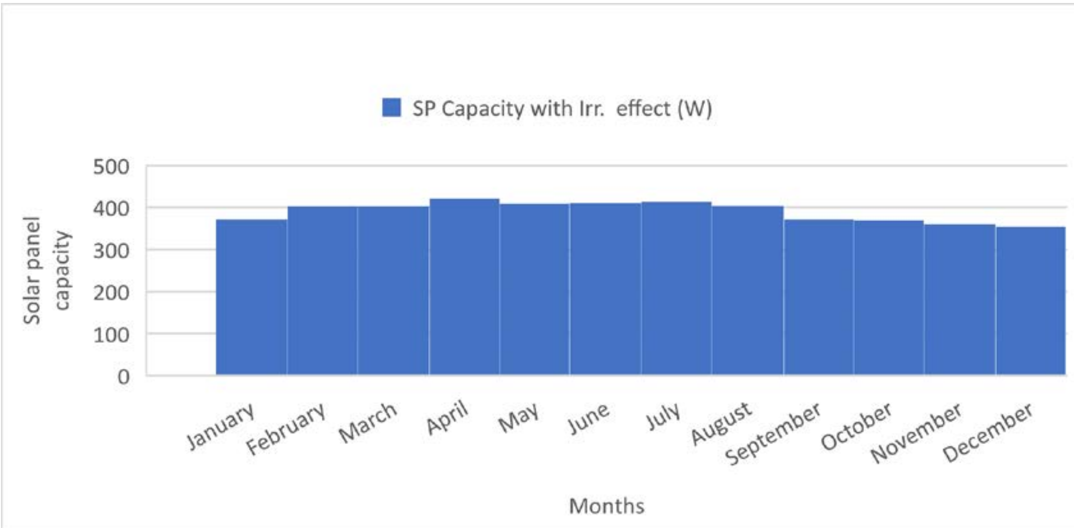


Figure IV.5 : Histogram of the variation of solar panel capacity according to months

Histogram of the variation of solar panel capacity according to months

IV.3.3 The performance ratio

From the equation III.9, to how energy efficient and reliable your PV plant is.

$$PR = \frac{573,555}{729,000} = 0.79 \qquad \textbf{(IV.9)}$$

IV.3.4 Number of modules in series

According to the data sheet in table IV.2, we can define the number of solar in series using III.10:

$$N_{sps} = \frac{1500}{48,7} = 30,8 \approx 30 \qquad \textbf{(IV.10)}$$

Therefore, the PV system can handle 30 panels in series, and 54 panels in parallel.

IV.3.5 Choosing the inverter

To choose the inverter we need first to calculate the power of the inverter using equation III.11.

We know that the system output is 729 kW**,** and the correction coefficient is set to be 1.296.

$$P_{inverter} = \frac{729*1.296}{0.9} = 1.049\ MW \qquad \textbf{(IV.11)}$$

- $P_{inverter}$ > 2000 W, the output voltage of the inverter will be 48 V.

For security measures we are going to choose an inverter of 1.1MW/48V. the model **COG1MTL** is our choice.

Table IV.5 : Inverter's specification

Model No.		COG1MTL	
Power		1100 kW	
Input Data (DC)		Output Data (AC)	
Max. DC Power	1200 kW	Max. AC Power	1100 kW
Max. DC Voltage	1100 V	Nominal AC Power	1000 kW
Nominal DC Voltage	650 V	Output AC Voltage Range	250~362 V
Rated DC Voltage	650 V	Nominal AC Voltage	310 V
Max. DC Current	2200 A	Rated AC Voltage	310 V
Rated DC Current	2200 A	Max. AC Current	3800 A
MPP(T) Voltage Range	450~950 V	Rated AC Current	3600 A
DC Inputs	8	Frequency	50, 60 Hz
Dimensions (H/W/D)	1500x2000x650 mm	No of feed-in phases	3
Weight	3000 kg	Max. Efficiency	98 %
Power Consumption at Night	< 50 W	Cooling	Fan
Protection Class	IP54	Max. Altitude	4000 m
Humidity	0-95 %	Display	LCD

After analyzing the inverter's data sheet, we noticed that the inverter can't handle 30 panels in series because of its $V_{dc\ Max}$, so we are going to calculate the correct number of solar panels in series:

$$N_{sps} = \frac{1100}{48,7} \approx 20 \quad \textbf{(IV.10.1)}$$

The PV system can handle 20 panels in series, and 81 panels in parallel.

IV.3.6 Protection:

IV.3.6.1 Branch fuse

to accurately choose a branch fuse we have to calculate the voltage and the current that can handle using II.4 and II.5 respectively:

- **Voltage**

$$V_F = 1,15 * 48,7 * 20 = 1120,1\,V \quad \textbf{(IV.4)}$$

- **Current**

$$1,5 * 11,65 \le I_F \le 2 * 11,65 \quad \textbf{(IV.5)}$$

$$17,475\,A \le I_F \le 23,3\,A$$

The branch that we are going to choose is needed to handle 1200V and 20A.

IV.3.6.2 Circuit breaker DC:

Calculating the voltage for the circuit breaker, equation III.6:

$$V_{CBF} \ge 1,15 * 48,7 * 20 \ge 1120,1\,V \quad \textbf{(IV.6)}$$

Also, calculating its current, equation III.7:

Here we are going to take N_{spp} as the number of solar in parallel in each combiner box.

$$I_{CBF} \ge 1,5 * 11,65 * 9 = 258,75\,A \quad \textbf{(IV.7)}$$

We will choose a Circuit breaker that can handle up to **1200V** and **260A**.

IV.3.6.3 DC surge protector

Table IV.6 : DC surge protector

Type	VP C40 Series class II
Applications	for PV installations
Other characteristics	compact, varistor, gas discharge tube, plug-in, DC
Voltage	Max.: 1,000 V
Primary current	Max.: 40,000 A Min.: 20,000 A

IV.3.6.4 AC surge protector

Table IV.7 : AC surge protector

Type	DAC15C Series type 2, type 3
Applications	anti-surge
Other characteristics	compact, varistor, 4-pole, common-differential mode, thermoplastic, DIN rail, draw-out, low-voltage, AC, three-phase
Voltage	Max.: 150 V Min.: 0 V 120 V, 208 V, 230 V, 400 V
Primary current	Max.: 15,000 A Min.: 0 A 5,000 A

IV.3.7 Combiner box

We have 81 panels in parallel, for security measures we are going to divide the PV system in 9 combiner boxes, each box contains 9 strings.

- The combiner box contains all of the protection components.

IV.3.7.1 Parallel box

We are going to use the parallel boxes to minimize the number of entries in the inverter.

IV.4 Techno-economic study

IV.4.1 The system's cost

The prices of the used equipment are obtained from the manufacturers, and we multiply that price with the VAT (1.19), and the customs tax (1.15) and (1.3) for the importer.

Table IV.8 : Equipment cost for El-Oued

Equipment	Price per unit in USD	Quantity	Final price USD	The final price in DA
Solar panels	185.4 inc VAT	1620	449,020.26	60,617,735
Inverter	16,600	1	29,532.23	3,986,851
PV modules Support	51.85 USD per panel	1620	94,000	12,690,000
Cables and accessories	700 USD per meter	20 m	15,000	2,025,000
Combiner box	400	9	3,600	486,000
Mounting cost	22.22USD per panel	1620	36,000	4,860,000
Maintenance			30,000	4,050,000
TOTAL			657,152.49	88,715,586

Usually, the facility works with the full capacity for the whole day (24h), which is about 815.3 kW.

According to the electric bill obtained from Frigomedit, the price changes from day to night. The price of 1kW is **1.8064 DA** at night, and **8.7202 DA** in day.

- We found these prices on the electric bill.

We suppose that the sunshine duration every month is 10h. So, we can estimate how much the PV system saves from the electric bill over the months, for example in case of January:

The PV system generates 603,362 kW, meanwhile the facility consumes only 52.48 kW. So, the PV array will save 10h of the day consumption for 31 days, we can calculate the monthly saving:

$$52{,}48 * 10 * 31 * 8.7202 = 141{,}867.19\ DA$$

Table IV.9 : The PV system consumption and cost saving

Month	Real capacity (W)	The PV array (kW)	PV array saves (DA)	Average Facility consumption per day kW
January	372,446	603,362	141,867.19	52,48
February	402,345	651,798	271,829.56	111,33
March	402,543	652,119	1,762,848.512	815,3
April	422,235	684,020	1,789,437.361	815,3
May	409,5135	663,411	283,301.85	104,8
June	411,1065	665,992	1,742,275.032	815,3
July	413,6985	670,191	1,811,701.863	815,3
August	404,766	655,720	1,772,582.959	815,3
September	372,888	604,078	291,219.8	111,32
October	369,5085	598,603	1,618,180.743	815,3
November	361,2825	585,277	314,188.8	120,1
December	**354,0465**	573,555	284,680.52	105,31
			12,084,114.19	

The PV system saves yearly about 12,084,114.19 DA, and the full system installation cost about 88,715,586 DA with a lifespan of more than 20 years.

For a conclusion to our techno-economic study, the payback period is estimated to be in:

$$\frac{88{,}715{,}586}{12{,}084{,}114.19} \approx 7.3\ years$$

After only 7.3 years, the facility will recoup the initial cost of the system, leaving it with an additional of about 13 years of savings, and that is estimated to be about 153,468,250.2 DA.

Furthermore, we will propose a contract with Sonelgaz, allowing us to integrate the entire system into the grid during months when the facility's electricity consumption is minimal (6 months).

IV.5 The simulation using PVsyst

After entering to the software, we used the grid-connected system option. Then, we selected the site we are planning to do the system in (Frigomedit, Trifaoui, El Oued).

On the orientation page, the panels orientation will be a 32° tilt and 0° azimuth to get the minimum loss to the system, according to the sun's path on EL-Oued, figure III.5.

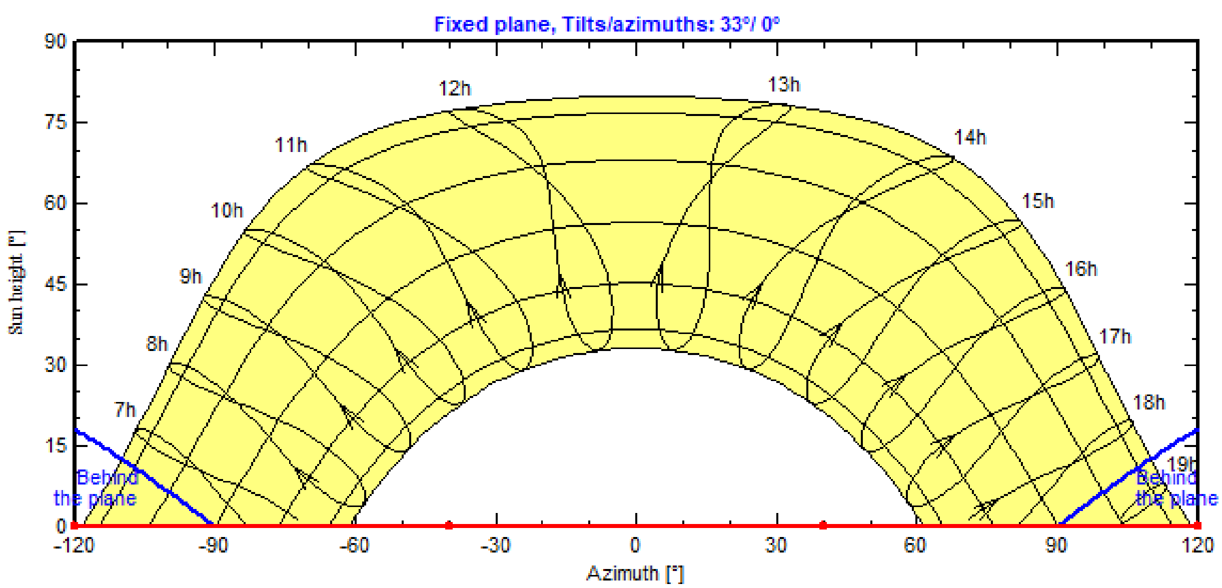


Figure IV.6 : The sun path

After choosing these components (45Wp/35v panel and 1100kW/650-1100v inverter), and defining the available area (3579 m²), PVsyst shows that the system will be composed of 20 modules in series and 81 modules in parallel.

After selecting the needed components to the system, we can present it in figure IV.7.

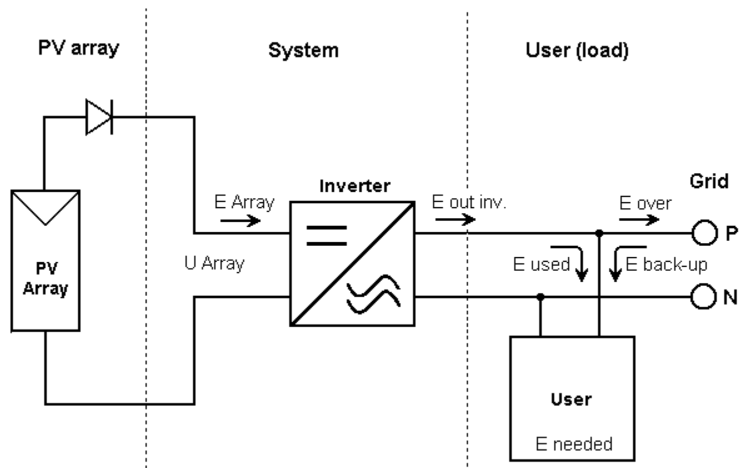


Figure IV.7 : Simplified sketch of our system

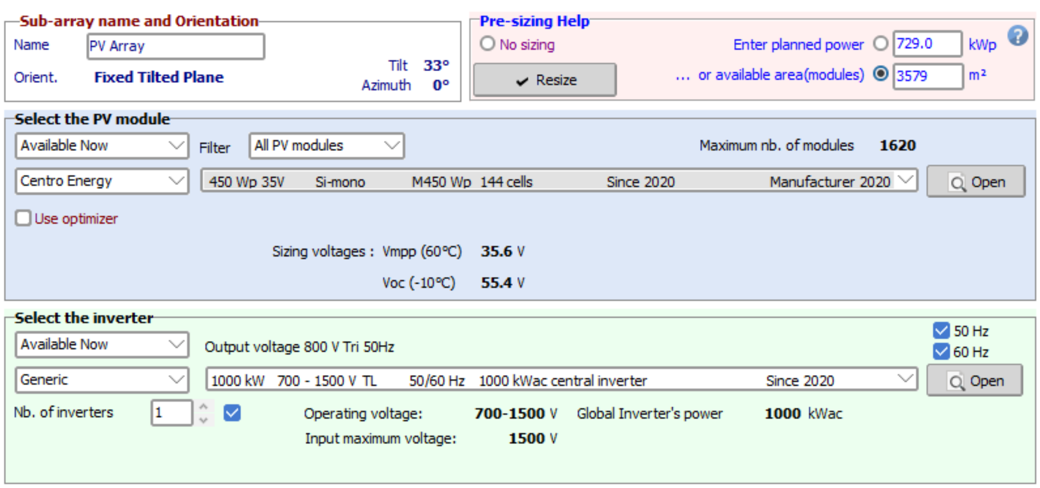


Figure IV.8 : The selected area and components on our project

IV.5.1 The main results

After launching the simulation, the results show that the system has a performance ratio of 0.839 average, which means that the system's output is 83.9% of the expected output, it is still relatively good performance ratio. We can see also the monthly PR on figure IV.9.

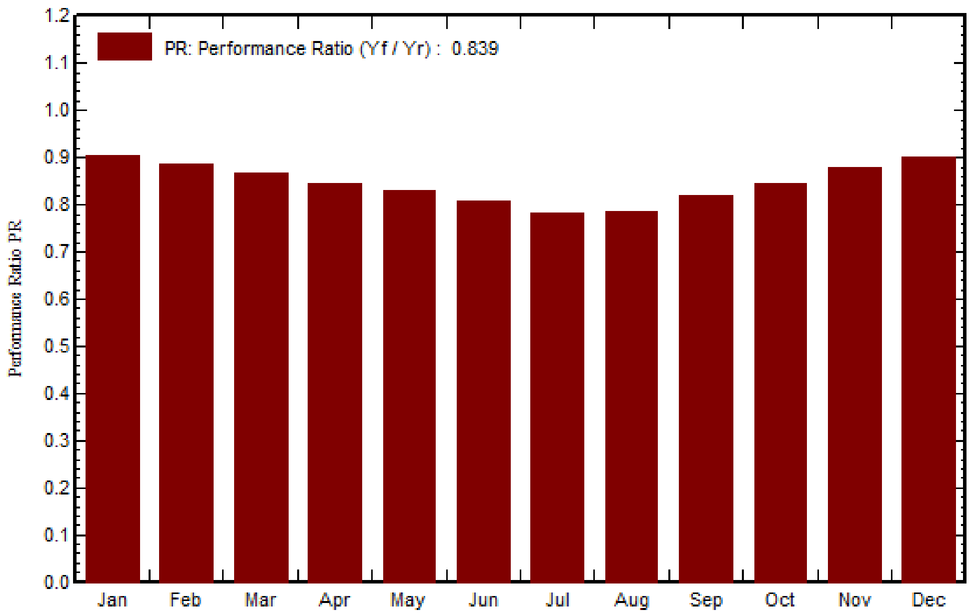


Figure IV.9 : The monthly performance ratio

And we can also mention the losses on our system on figure IV.10, on a nominal power of 729 kWp the system loses a collection of 14.4%, system components loss of 1.7%. So, the useful energy output is 83.9%.

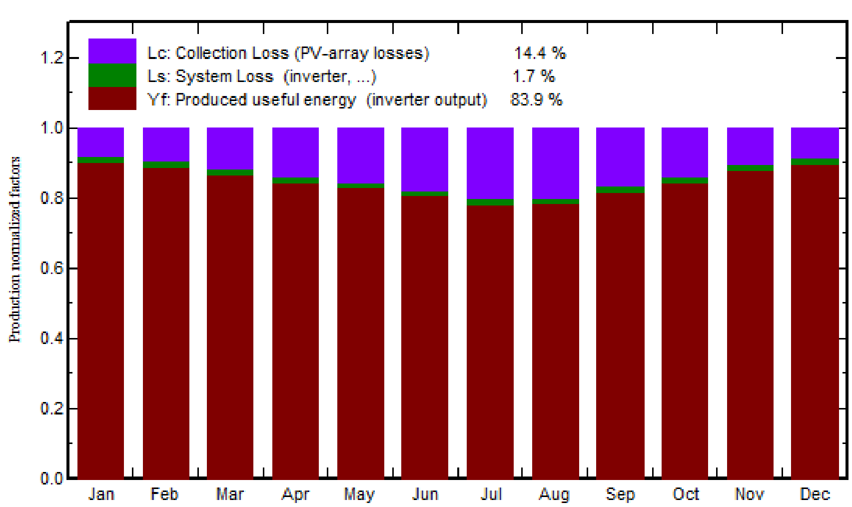


Figure IV.10 : Normalized production and loss factors

The balances and main results are summarized in table IV.10. It consists of parameters such as horizontal plane based global irradiation, horizontal plane based diffuse radiation, ambient temperature, global irradiation on the collector plane, energy supplied to the grid and overall energy yield of the array, and the performance ratio. The balances summarize that the average annual global irradiation on the horizontal plane is 1766.8 kWh/m2. The incident global irradiation on the collector plane is 1976.5 kWh/m2. The diffuse radiation on the horizontal plane is 843.6 kWh/m2. The effective energy output and the injected energy values were calculated as 1233.1 MWh and 1209 MWh. The current obtained from the PV array is in DC form. So, we need to transform it into AC current which will result in some loss of energy due to system losses. The input energy will have different value as compared to the output energy value. For the 450 kWp Si-mono PV system, the PV system injects annual energy of 1256.5 MWh. The month of August sees the maximum injection of energy with a value of 112.9 MWh. The lowest amount of energy that's supplied to the grid is during December with a value of 83.9 MWh.

Table IV.10 : Simulation results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	86.2	38.5	10.57	129.7	127.9	87.0	85.4	0.903
February	97.2	44.7	12.61	130.3	128.3	85.9	84.2	0.887
March	138.1	73.5	17.56	159.0	156.2	102.5	100.5	0.867
April	171.8	82.6	21.84	179.4	176.0	112.6	110.4	0.844
May	198.1	101.2	26.83	187.2	183.1	115.4	113.1	0.829
June	203.2	100.9	31.39	185.0	180.9	110.9	108.7	0.806
July	212.2	99.1	35.23	197.0	192.7	114.5	112.2	0.781
August	196.4	92.3	34.20	197.5	193.8	115.2	112.9	0.784
September	156.6	75.9	29.23	175.5	172.4	106.7	104.6	0.818
October	128.3	60.5	24.11	163.7	161.2	102.8	100.9	0.845
November	97.5	40.7	16.09	144.1	142.2	94.1	92.4	0.879
December	81.0	33.8	11.40	128.0	126.3	85.5	83.9	0.899
Year	1766.8	843.6	22.65	1976.5	1940.8	1233.1	1209.0	0.839

GlobHor: Global horizontal irradiation.

DiffHor: Horizontal diffuse irradiation.

T_Amb: Ambient Temperature.

GlobInc: Global incident irradiation.

GlobEff: Effective global irradiation.

EArray: Effective energy at the output of the array.

E_Grid: Energy injected into grid.

PR: Performance Ratio.

IV.5.2 Loss diagram

To conclude our PVsyst simulation, we can find on the PVsyst's report a diagram about all sorts of field losses that happens through the year, losses due to irradiance and temperature levels, wiring losses, and all the main losses that we need to consider in our project's simulation. We can notice that the largest loss come from the temperature effect with a 9.8%.

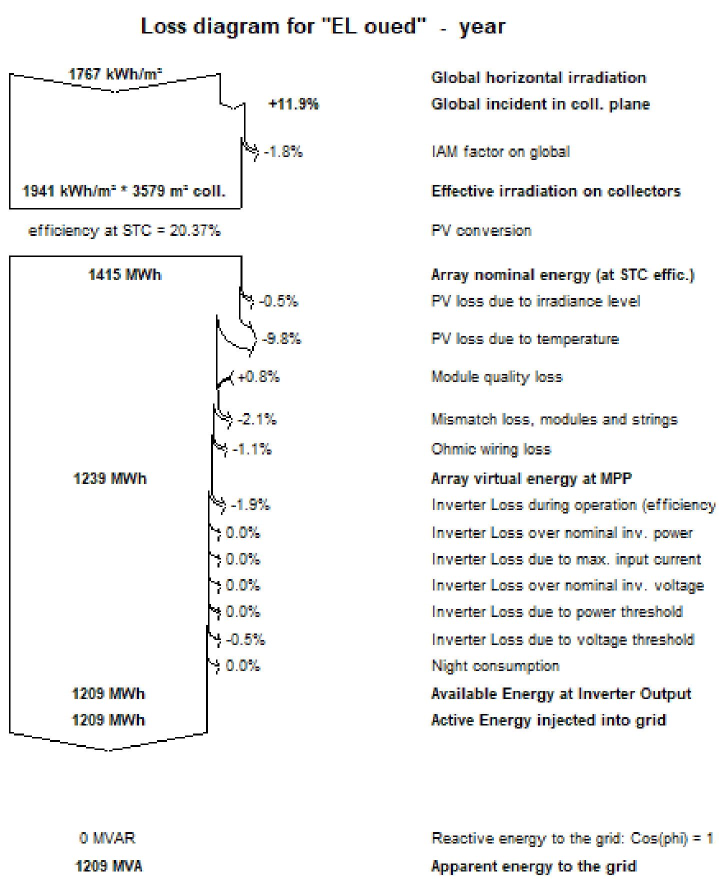


Figure IV.11 : Loss diagram

IV.6 The simulation using Homer Pro

From table IV.11, we can notice the difference between our cold storage powered by grid connected PV system (blue) and only by grid system (white), we can observe that:

The COE (Is the cost of energy or the price of 1 kWh) of the PV system is lower than the grade system.

The operating cost per year of the PV integrated system is lower than the grid connected system.

Table IV.11 : HOMER pro results

Architecture			**System**
PV array (kW)	Grid (kW)	INVERTER (kW)	Ren Frac (%)
2729	999999	1100	15.9
	999999		0
Cost			
NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
5.72M	0.0619	416,676	329,880
5.91M	0.064	457,085	0
PV array		**Grid**	
Capital Cost ($)	Production (kWh/yr)	Energy Purchased (kWh)	Energy Sold (kWh)
300,348	1,162,454	6,006,902	14935.27
/	/	7,141,955	/

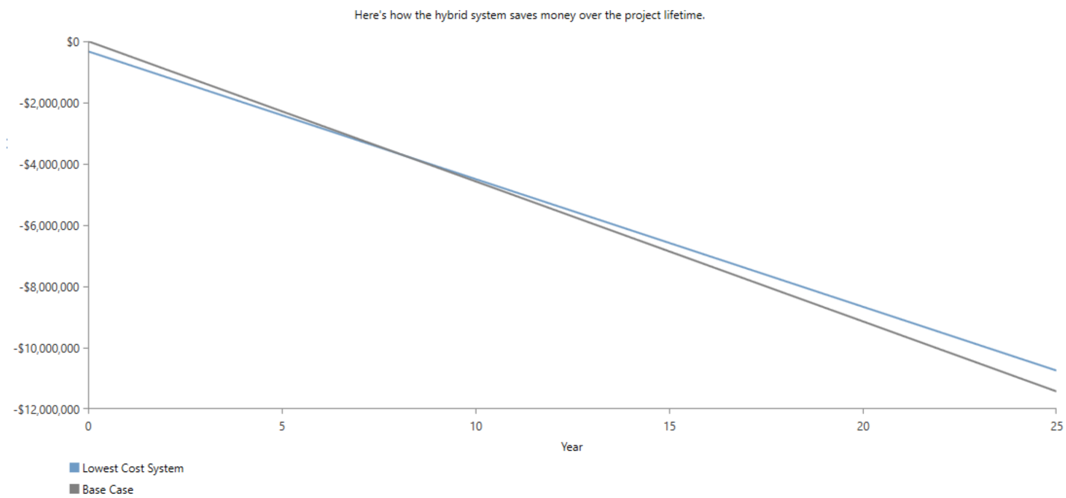


Figure IV.13 : Cost over project lifetime PV system (blue) grid system (black)

Economic Metrics

IRR	11%
ROI	8.2%
Simple Payback	8.2 yr

	Base Case	Lowest Cost System
NPC	$5.91M	$5.72M
Initial Capital	$0.00	$329,880
O&M	$457,085/yr	$416,676/yr
LCOE	$0.0640/kWh	$0.0619/kWh

Figure IV.12 : Financial data of the project

We observe from figure IV.13, that according to Homer Pro the payback period will be on 8.2 years, with keeping in mind the operation and maintenance cost.

IV.7 Boufarik-Blida Frigomedit unit

The highest energy consumption recorded in Frigomedit Blida is in the month august, with a monthly consumption of 66737,46 kW (48248,34 at day and 18379,12 at night), and they paid 340,399.27 DA on the electric bill. But the facility of Boufarik unit does not consume that much of energy at the most of the months (only in August, July and September). So, if we size a PV system for the three months only, we will have a lot of wasted solar energy. Based on our energy consumption analysis, we recommend installing an 80 kWp PV system. It is capable of meeting the daily energy needs for the majority of the months and also most of the consumption in the rest of months.

Figure IV.14 : Unit of Boufarik- Blida

If we use the same solar panel as the calculations of Frigomedit El-Oued, table IV.2 we can install 178 panels, with a total peak power of 80.1kWp. For this system and after using equation II.11, an inverter of 110kW/48V could cover our needs. We have three free roof areas we can install the system in, figure IV.15.

Figure IV.15 : Estimated design on the available areas

We recommend installing the system in the area in figure IV.16 to minimize the cabling price, because it is the closest to the cold rooms.

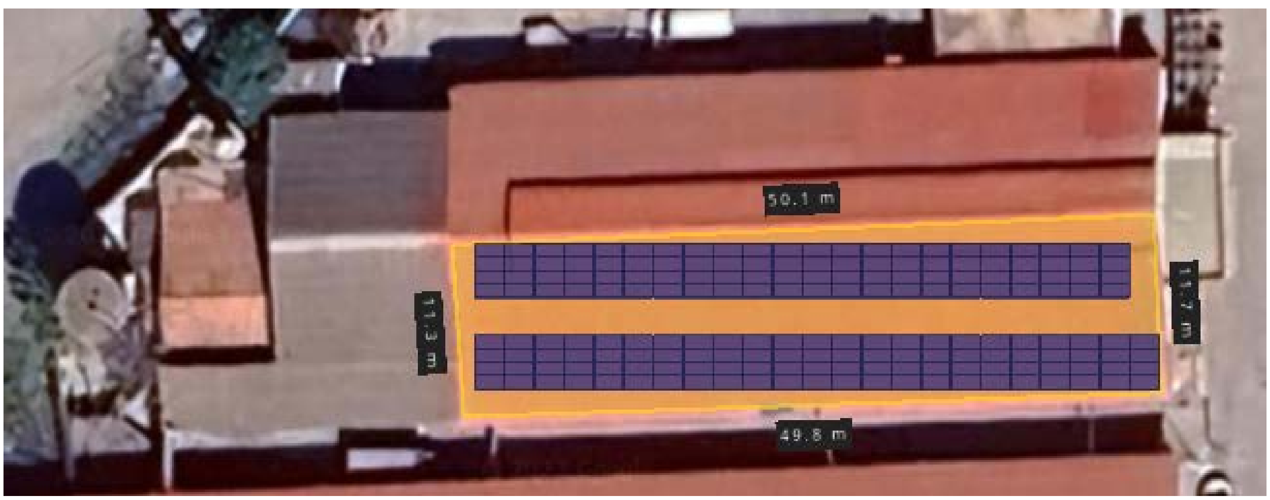


Figure IV.16 : The most favorable area

IV.8 Facility consumption and PV system savings

In case of STC the system provides 80.1kWp, and we can estimate how much the PV system can save for us in table IV.10, knowing that the price of 1 kWh is 4.2830 at day, and we suppose that the PV system function for 10h/Day.

Table IV.12 : The facility consumption and PV system savings

Month	Facility monthly consumption kW		Electric bill (DA)	PV array saves (DA)
	Day	Night		
January	16113.44	7683.05	132,022.36	72957.51
February	14369.64	7000.49	122,121.97	65062.03
March	17585.19	8178.37	147,434.92	79621.22
April	13867.23	6986.94	120,623.91	62787.25
May	25478.85	11852.67	198,897.70	115361.7
June	29000.89	13083.03	213,277.60	152341.1
July	36962.56	16380.58	279,923.20	157399.73
August	48248.34	18379.12	340,399.27	157399.73
September	38737.78	16103.67	279,316.84	152322.32
October	4286.66	51827.43	150,216.36	19408.89
November	8553.71	24014.58	125,902.85	38729
December	16113.44	7683.05	132,022.36	72957.51
Total				**1,146,347.9**

From the table IV.10 we can notice that the PV system can save yearly about 1,146,347.9 DA.

IV.9 The PV system cost

The prices of the used equipment are obtained from the manufacturers, we multiply that price with the VAT (1.19), and the customs tax (1.15).

Table IV.13 : Equipment cost for Boufarik unit

Equipment	Price per unit in USD	Quantity	Final price in USD	The final price in DA
Solar panels	185.4 inc VAT	178	49,336.794	6,660,467
Inverter	3,449	1	6,135.94	828,351.9
PV modules Support	51.85 USD per panel	178	9,229.3	1,245,956
Cables and accessories	700 USD per meters	10	7,000	945,000
Combiner box	400	2	800	108,000
Mounting cost	22.22USD per panel	178	3,955.16	533,946.6
Maintenance			7,300	985,500
TOTAL			**83,757.19**	**11,307,221**

The whole PV system will cost 11,307,221 DA with a lifespan expected to be at least 20 years, so after calculations the payback period will be in about 10 years.

IV.10 The comparison

The results obtained from the techno-economic study for the implementation of PV systems in El-Oued and Boufarik indicate that both systems are financially viable and worth installing (168,467,047.5 DA for El-Oued and 11,463,479 DA for Blida). However, there are noticeable differences between the two. It can be concluded that the installation in El-Oued is more advantageous from a financial perspective, thanks to its shorter payback period and higher income generation. However, the Blida installation remains a viable and beneficial option, although with a longer payback period and relatively lower income.

IV.11 El Karma-Oran Frigomedit unit

The company Frigomedit is set to launch a large cold storage facility in Oran El-Kerma. With an area of 11,334.9 m², the facility presents an excellent opportunity for implementing renewable energy solutions (PV system).

Figure IV.17 : Unit of Frigomedit at El karma Oran

By applying the same study and methodology as done in Frigomedit El-Oued and Blida, and considering factors such as panel spacing and shading, you determined that it would be possible to install about 3020 solar panels with a total peak power capacity of 1.359 MW.

Figure IV.18 would likely represent the arrangement of the solar panels in the installation, indicating how they are positioned. This figure can serve as a visual representation of the design and help to understand the proposed setup.

Figure IV.18: Design for a roof PV system on Frigomedit Oran

IV.12 **Suggested system for Frigomedit Oran**

Based on the state-of-the-art information provided in the first chapter, we recommend to cover the inside walls with Phase change materials in the cold rooms. PCM has a lot of benefits for a high consumption cold storage, it can help in cost saving. Decrease the compressor run time. By utilizing PCM technology, the thermal properties of the cold rooms can be significantly optimized. PCMs have the ability to absorb excess heat during peak load periods and release it when the demand decreases. This process helps maintain a more stable temperature within the cold rooms, preventing temperature fluctuations that can impact the quality and integrity of stored products. The Research conducted by P. Sarafoji et al indicated in their research that using PCM in cold storage can replace 16% of the total power consumption, and so on it can save us about 16% of the electric bill.

Furthermore, we can implement the system in figure V.6.we can explain the schematic diagram of the distributed solar PV direct-drive cold storage system as:

At first, the PV array generates DC electricity. It goes directly to the controller (MPPT) and inverter to convert the DC electricity into AC electricity. The controller also ensures that the PV array is operating efficiently and safely. After that, we find the frequency converter to adjust the frequency of the AC electricity produced by the inverter to match the requirements of the refrigeration unit (a hybrid inverter will do all of the previous work). The schematic also shows how the refrigeration unit functions and its components. It starts from the compressor, which compresses the refrigerant gas and increases its temperature and pressure. The high-pressure, high-temperature refrigerant gas is then sent to the condenser, where it releases its heat and condenses into a high-pressure liquid, and then flows to the throttle valve to regulate the flow of refrigerant into the air cooler by controlling the pressure drop across it. As the refrigerant passes through the throttle valve, its pressure and temperature decrease. After that, the refrigerant goes to the air cooler to be cooled by passing air or water over it. The cooled refrigerant then flows to the cool storage tank which stores the cooled refrigerant and the cold exchange fluid until they are needed to cool the space. The refrigerant goes back to the compressor. During this process, when the cold energy reduces the water temperature in the cold storage tank to the freezing point, the water freezes, and the excess cold energy is stored in the ice storage tank in the form of the sensible heat of water, latent heat of ice, and a small part of the sensible heat of super cooled ice. If the solar radiation is not enough and the PV array output cannot start the compressor, so it stops working. The solenoid valve opens to enable the cold exchange working fluid to circulate inside the cold exchange copper tube and the fan coil unit. Then, the fan coil unit blows out the cold energy that has been stored in the cold storage tank, to provide the cold energy required to maintain the lower temperature and continuous cooling. For the cooling tank, it is not available on the market yet, but with the accurate calculations and manufacturing we will be able to maintain the desired system.

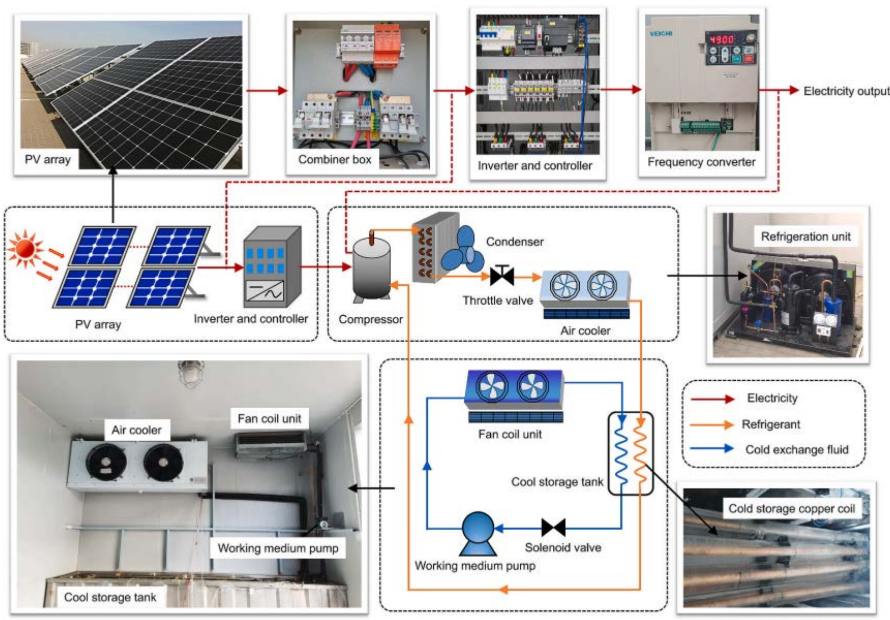


Figure IV.19 : Schematic diagram of the distributed solar PV direct-drive cold storage system

The price of the PV system may seem like a huge amount of money, but as we saw on El-Oued and Blida cases the higher the consumption and the PV system is, the better payback and the big income is. In addition, here we are going to enhance the system by using phase change materials and a cool storage tank. We ensure that this implementation is viable and worth considering it.

Table IV.14 : Equipment cost for Oran

Equipment	Price per unit in USD	Quantity	Final price USD	The final price in DA
Solar panels	185,4 inc VAT	3020	888,177.676	119,903,986.3
Inverter	1,8 MW	1	889,525.00	120,085,875
PV modules Support	51.85 USD per panel	3020	214,289.31	28,929,056.85
Cables and accessories	700	20m	15,000	2,025,000
Combiner box	400	10	4,000	540,000
Mounting cost	22.22USD per panel	3020	67,110.44	9,059,909.4
Cooling coil tank	Not available on the market		----	---
Maintenance			16,000	2,160,000
TOTAL			2,094,102.43	282,703,827.5

Conclusion

In conclusion, on this chapter we focused on designing an efficient and cost-effective PV system for a cold storage facility in El Oued. Also, we analyzed the electric consumption, selecting appropriate components (solar panels, inverters, and protection devices), and conducting a techno-economic study. Simulation using PVsyst and economic analysis using Homer Pro were thoroughly analyzed as well.

Also we are going to explore the implementation of PV systems in two additional locations within the same company, Frigomedit. By examining the facilities in Blida-Boufarik and Oran- El Kerma, we aimed to compare and evaluate the PV installations in El-Oued and Blida and project these findings onto the Frigomedit facility in Oran. The insights gained from comparing the PV installations in El-Oued and Blida will provide valuable guidance for the Frigomedit facility in Oran. By understanding the specific challenges and opportunities associated with each location, Frigomedit can make informed decisions regarding the integration of PV systems in their operations.

GENERAL CONCLUSION

GENERALE CONCLUSION

In conclusion, this thesis has focused on exploring the renewable energy potential, specifically in terms of photovoltaic systems, for integration into the Frigomedit cold storage complexes located in El-Oued, Blida, and Oran.

Throughout our work on this thesis, various components required for a viable PV system have been analyzed, including solar panels, inverters, and potential energy storage solutions. Advanced software tools such as HOMER Pro and PVsyst have been employed to simulate and optimize the performance of PV systems. The application of relevant equations, models, and software tools has enabled the assessment of different PV system configurations in terms of their performance and economic feasibility. By comparing and analyzing the obtained results, this study has provided valuable insights into the optimal design and configuration of PV systems for the Frigomedit cold storage complexes. The findings of this research contribute to the understanding of integrating sustainable and efficient energy solutions into cold storage facilities, thereby enhancing their sustainability, energy efficiency, and overall environmental impact.

Overall, this thesis emphasizes the importance of considering renewable energy options, particularly PV systems, for powering cold storage facilities. The integration of PV systems into the Frigomedit cold storage complexes in El-Oued, Blida, and Oran has the potential to not only reduce energy costs and carbon emissions but also enhance the overall sustainability and operational efficiency of these facilities.

REFERENCE

[1] installed capacity, 2019 (actual) vs. 2028 (projected) (CREG, BNEF).

[2] Salman Zafar, ECOMENA magazine, without page, available on:

Renewable Energy in Algeria | EcoMENA

[3] MINISTRY OF ENERGY AND MINES: Energies Nouvelles, Renouvelables et Maitrise de l'Energie

[4] Nagaraju, J., Vikash, K. and Krishna Murthy, M.V., 2001. Photovoltaic-powered cold store and its performance. International journal of energy research, 25(5), pp.389-396.

[5] CREG. (2015). Programme de Développement des Energies Renouvelables 2015–2030.http://www.creg.gov.dz/images/stories/PDF/creg15mars.pdf

[6] Eddine, B.T. and Salah, M.M., 2012. Solid waste as renewable source of energy: current and future possibility in Algeria. International Journal of Energy and Environmental Engineering, 3, pp.1-12.

[7] https://eresources.nlb.gov.sg/

[8] (http://www.fsec.ucf.edu/en/consumer/solar_Electricity/basics/cells_modules_arrays.htm)

[9] https://www.victronenergy.com/inverters/phoenix-inverter-vedirect-250va-800va#pd-nav-image

[10] Benhadid-Dib, S. and Benzaoui, A., 2012. Refrigerants and their environmental impact Substitution of hydro chlorofluorocarbon HCFC and HFC hydro fluorocarbon. Search for an adequate refrigerant. Energy Procedia, 18, pp.807-816.

[11] renewable energies target In Algeria, Algerian Ministry of Energy

[12] Created internally by a member of the Energy Education team. Adapted from: Ecogreen Electrical. (August 14, 2015). Solar PV Systems [Online]. Available: http://www.ecogreenelectrical.com/solar.htm

[13] https://images.squarespace-cdn.com/content/v1/5dd0ac39fcb3826c703bba89/1574039732686-1YTFKG9GDVHEF7VF0U9J/mpptpwm.png?format=750w

[14] Copyright Frigomundo Coldstore B.V. | Created by QUÈM Identiteit Makers

[15] https://www.electricaltechnology.org/2020/09/series-parallel-and-series-parallel-connection-of-solar-panels.html

[16] https://globalsolaratlas.info

[17] https://www.coldmax.com/info/classification-of-cold-storage-room-51273671.html#:~:text=Cold%20storage%20is%20usually%20divided,products%20require%20different%20room%20temperatures.

[18] https://www.enclosureclimatecontrol.com/lb12531309mb34rdyr-din-rail-lockable-disconnect-switch-125a-600v-3-p-ip65-ul-csa/

[19] G F HUNDY, A R TROTT, T C WELCH, REFRIGERATION, AIR CONDITIONING AND HEAT PUMPS Fifth Edition P20, 2016.

[20] https://www.istockphoto.com/photo/solar-pv-rooftop-grounding-system-gm638341884-114395785

[21] https://www.which.co.uk/news/article/smart-meters-and-solar-panels-whats-the-sticking-point-aDWlE6C8Nyjk

[22] Smets, A., Jäger, K., Isabella, O., Van Swaaij, R. and Zeman, M., 2016. Solar Energy: The physics and engineering of photovoltaic conversion, technologies and systems. Bloomsbury Publishing.

[23] https://www.kei-ind.com/blog/everything-you-need-to-know-about-solar-wires-and-cables/#:~:text=A%20solar%20cable%20is%20one,conditions%2C%20temperature%2C%20and%20UV.

[24] https://sinetechstore.co.za/shop/inverters/grid-tie-inverters/omnipower-20kw-48v-optimised-3-phase-grid-tie-inverter-for-pv-solar/

[25] Muhammad H. R, Power Electronics Handbook (Third Edition) 2011, Pages 1289-1330

[26] Kumar, N.M., Kumar, M.R., Rejoice, P.R. and Mathew, M., 2017. Performance analysis of 100 kWp grid connected Si-poly photovoltaic system using PVsyst simulation tool. Energy Procedia, 117, pp.180-189. [27] https://sinetech.co.za/advice-on-lightning-and-surge-protection.html

[28] Basu, D.N. and Ganguly, A., 2016. Solar thermal–photovoltaic powered potato cold storage–conceptual design and performance analyses. Applied energy, 165, pp.308-317.

[29] Sider, I., Al-Maghalseh, M. and Alnather, Z., 2019. Energy consumption evaluation of air-cooled chiller with cold storage system powered by photovoltaic modules. Advances in Science, Technology and Engineering Systems Journal, 4(3), pp.235-43.

[30] Du, W., Li, M., Wang, Y., Ma, X., Hu, C., Zhang, Y. and Zhang, Z., 2021. Dynamic energy efficiency characteristics analysis of a distributed solar photovoltaic direct-drive solar cold storage. Building and Environment, 206, p.108324.

[31] Sarafoji, P., Mariappan, V., Anish, R., Karthikeyan, K. and Reddy, J., 2021. Performance study of solar photovoltaic cold storage system using phase change materials. Materials Today: Proceedings, 46, pp.9623-9629.

[32] Ikram, H., Javed, A., Mehmood, M., Shah, M., Ali, M. and Waqas, A., 2021. Techno-economic evaluation of a solar PV integrated refrigeration system for a cold storage facility. Sustainable Energy Technologies and Assessments, 44, p.101063.

[33] https://easysolar.app/en/