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Master Degree course in Renewable energy systems

Master Degree Thesis

Energy Management System for Hybrid Photovoltaic Installations with Electrochemical Batteries and Genset

Supervisors
Prof. Filippo Spertino

Candidate
Giovanni andriolo

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Abstract

This report delves into various aspects of Energy Management System technology, offering a comprehensive exploration of its context, utilization, and development. In the backdrop of renewable energy's continuous growth, EMS systems emerge as essential tools for the seamless integration of these resources. Renewable energy, characterized by its low emissions and equitable global resource distribution, holds promise for broader accessibility compared to fossil fuels. However, its unpredictability and limited programmability pose challenges, especially within existing, dated electrical grid infrastructures.

To fully harness the potential of renewable energy, it is imperative to modernize both production methods and energy transmission and distribution systems. Energy Management Systems are positioned as the future enablers of renewable energy, addressing the complexities and demands of this evolving landscape. Nevertheless, this report highlights the several technical challenges surrounding integration, communication, and the incorporation of medium to high-voltage facilities within energy markets.

The report showcases a practical example, focusing on a microgrid connected to South Africa's grid, where photovoltaic energy offers significant growth opportunities. Yet, the local grid's limitations hinder such installations, except those operating at high voltage levels. This scenario mirrors challenges faced by numerous states and countries worldwide, emphasizing the report's broader applicability.

The study adopts a dual approach to modeling energy systems, employing both Excel and HOMER Grid software. While Excel proves effective for simple models, HOMER Grid's advanced capabilities reveal the unexploited potential of the installation. By incorporating peak shaving strategies and more in general dispatching algorithms, HOMER Grid yields highly favorable economic outcomes. The choice between these tools depends on the specific project needs and resource considerations, with HOMER Grid's sophistication balanced with the associated costs.

In conclusion, this report underscores the pivotal role of EMS technology in advancing renewable energy integration, accentuating both its potential and challenges. The South African microgrid case serves as a global model, illustrating the need for modernization in a changing energy landscape. The utilization of Excel and HOMER Grid demonstrates the importance of choosing the right modeling tool to unlock the full potential of renewable energy projects.

Contents

0.1 Glossary

BESS	Battery Energy Storage System
BMS	Battery Management System
BP	Blueprint
CEO	Chief Executive Officer
COO	Chief Operating Officer
CS	Customer Support
CTO	Chief Technical Officer
DEIE	Dispositif dâEchange dâInformations dâExploitation
eConf	Elumâs Control Platform
EMS	Energy Management System
ePM	Elumâs Monitoring Platform
EPC	Engineering Procurement and Construction
FAT	Facility Acceptance Teste
GE	Genset
HMI	Human Machine Interface
KPI	Key Parameters Indicators
I/O	Input / Output
IPP	Indipendent Power Producers
MC	Microgrid
O&M	Operation & Maintenance
PPC	Power Plant Controller
PCS	Power Conversion System
PDL	Poste De Livraison
PTR	Poste De Transformation
PV	Photovoltaic
SAT	Site Acceptance Test
SCADA	Supervisory Control and Data Acquisition
SLD	Single Line Diagram
SOC	State Of Charge
UPS	Uninterruptible Power Supply

Chapter 1

Energy Management Systems

1.1 Introduction

The need to urgently reduce reliance on fossil fuels, increase renewable energy production, and consequently decrease energy dependency has become imperative in the face of pressing environmental challenges and the quest for long-term energy security.
The current energy landscape demands a profound shift towards sustainable solutions that can mitigate the adverse impacts of fossil fuel consumption while ensuring a reliable and sustainable energy future.
Furthermore, reducing energy dependence holds significant geopolitical significance, as it reduces vulnerability to international energy dynamics and strengthens national autonomy.

To achieve these vital objectives, a fundamental reassessment of the current functioning of the electrical system is essential. The existing system, designed primarily for centralized power generation and distribution, is not adequately prepared or equipped to effectively manage a large-scale integration of renewable energy sources.
This centralized and hierarchical structure poses considerable challenges in integrating and effectively managing the intermittent nature of renewable energy sources such as solar and wind power.

These challenges are further amplified in regions across Africa, South America, and Asia, where the power grid is susceptible to frequent blackouts and voltage and frequency fluctuations.
In these regions, the instability of the national grid exacerbates the difficulties associated with integrating renewable energy sources and highlights the urgent need for alternative solutions.

In this context, distributed generation systems represent a prominent solution. These systems, better known as microgrids, offer a decentralized energy generation and distribution approach, enabling greater flexibility and resilience.
By embracing localized energy networks, such as photovoltaic systems, battery storage, and wind turbines, countries can overcome the limitations of the traditional grid infrastructure but also promote a more efficient energy utilization coupled with increased penetration of renewables [1] [3].

However, it is crucial to acknowledge the multitude of challenges associated with this approach, both technical and economic. From a technical point of view, system control and management cannot be overlooked, nor can the necessity of grid synchronization.
Additionally, establishing economic viability and regulatory frameworks will become imperative to incentivize this approach's widespread adoption and deployment.

1.2 Company overview

To ensure a cohesive narrative and facilitate report readability, I will begin by introducing the company, its structure, the products developed within the context of microgrids and PV power plants as well as a brief description of my position within the company.

Elum Energy is a French enterprise, founded in 2015. The company operates within the rapidly expanding renewable energy sector and conceives, develops, and commercializes control and monitoring solutions for photovoltaic installations and microgrids.

Since its inception, the company has aimed to simplify and expedite the development and integration of renewable energy sources through distributed generation systems. Over time, it has successfully gained recognition among industry leaders, with more than one thousand installations worldwide utilizing the Elum solution.
Currently employing around seventy individuals, the company is headquartered in the vibrant tenth arrondissement of Paris, while also maintaining offices in Sao Paulo, Casablanca, and Cape Town.

1.2.1 Company structure

The company is structured according to the different branches: Administrative, Commercial, Product, and Operations.

Administrative

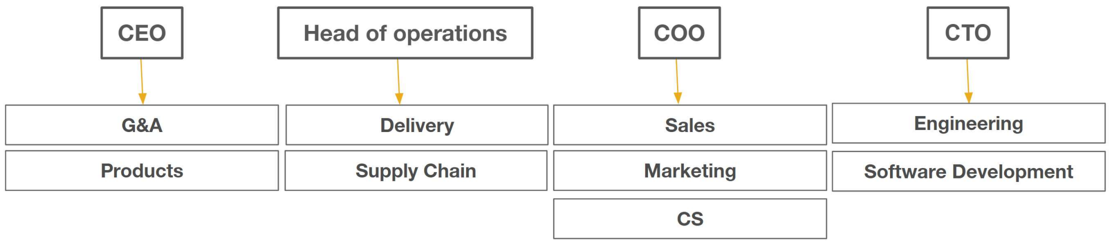
Headed by the CEO, covers administrative management and product development. Is responsible for overseeing and managing various administrative tasks and functions within the organization. This includes areas such as human resources, finance, operations, legal compliance, and general office management.

Commercial

Headed by General Manager and COO, includes sales, marketing, and technical support positions.
The Sales team is structured into distinct geographical zones and sub-teams, primarily due to the unique characteristics and dynamics of each market and region. This division enables team members to develop an in-depth understanding of their respective markets. On the other hand, the customer service team is responsible for assisting and resolving customer inquiries and issues on existing sites or those being developed.

Product

Led until April by the former CTO (position vacant at the moment), includes developers and research and development engineers. Is responsible for developing Elum's softwares, the microgrid monitoring and control platform, and the management and maintenance of IT services.



Operations

Headed by the operations manager, it is further divided into two groups: the delivery team and the supply team. The delivery is composed of six project managers and six technical managers. The project manager role is crucial within the company and involves a wide variety of skills and responsibilities.
In general, he is responsible for the complete management of the project, from planning to execution to organizing and controlling the work done. Strong technical knowledge of the product combined with excellent communication and organizational skills is imperative to ensure effective interaction with the various teams involved (sales, marketing, supply chain, and software developers) as well as with the client.

During the internship, the objective will be to acquire the necessary skills to face the many challenges and difficulties that characterize the function. Here are some of the main competences a PM has to master :

- Planning: it is necessary to plan the project from start to finish, establishing the scope, objectives, and deadlines. This implies the ability to analyze the context in which the project will take place, to define the objectives (particularly important in new or complex projects), the activities to be carried out and the resources to be involved.
- Resource management: it involves the ability to manage available resources, such as personnel, time, and tools needed to complete the project. It is important to assign tasks fairly and efficiently, manage communication and teamwork, and monitor the progress of the project.
- Risk management: identify potential project risks and plan effective strategies to manage them. In addition, it is important to anticipate obstacles or bottlenecks that could prevent the achievement of the project's objectives and to establish appropriate contingency plans to ensure its continuity and fluidity.
- Communication: communicate effectively with the team, clients, and all stakeholders involved in the project. It is essential to know how to listen and transmit information clearly and coherently. This aspect becomes particularly important in an international and heterogeneous context in terms of the expertise in which the company is placed, which can generate communication challenges between the different parties involved.

The supervision of all these phases, as well as internal and external coordination, leads to the successful integration of the Elum product within both the microgrid and power plant systems.

1.3 Controller integration

1.3.1 Context

In several regions of the world, the national power system is plagued by considerable instability, evidenced by frequent blackouts and fluctuations in both voltage and frequency (see Figure 1.1). These problems are usually attributed to an outdated infrastructure that is unable to adjust to power inflows and outflows [2].

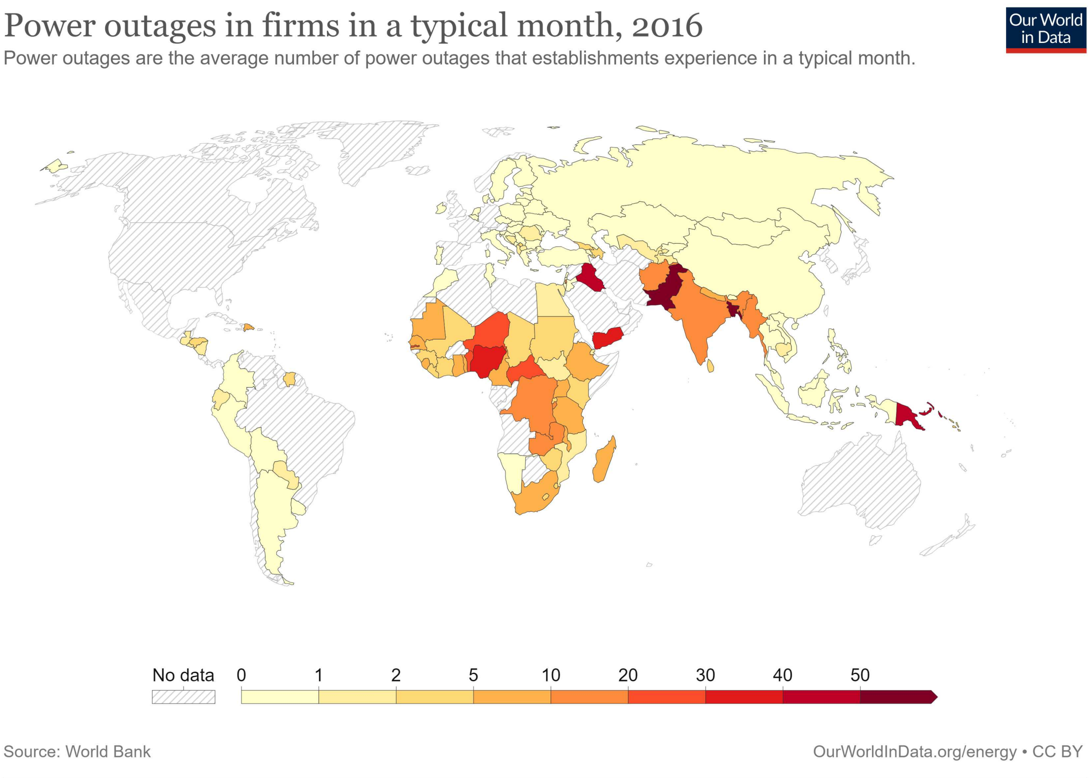


Figure 1.1. Percentage of average power outages in the world, experienced by firms [14].

Also lack of investment in modernizing and upgrading the electrical infrastructure, along with increasing energy demand, contribute to system instability.
Such power outages cause significant inconvenience to the population and negatively impact commercial, industrial, and critical infrastructure activities.

In such a context, using a photovoltaic installation to reduce one's energy dependence is a promising solution to generate sustainable and independent power.
However, the unpredictable nature of this energy source, coupled with an extremely unstable grid unable to regulate itself makes it necessary to implement these installations with microgrid-type systems capable of monitoring and controlling power flows to avoid

overloading an already strained power grid or trivially avoid incurring heavy fines imposed by governments.
In fact, by microgrid, we mean a local power generation and distribution system, typically consisting of several units dedicated to power generation and storage, such as photovoltaic panels and diesel generators, wind turbines, or batteries, that is usually able to operate on or off grid (islandend mode).

Within this context are the products and services provided by Elum, i.e., a controller equipped with a specific control logic that can monitor and command the devices and units within a microgrid to maximize photovoltaic penetration and ensure a certain continuity, stability, and security of energy supply.

1.3.2 Hardware & Software specifications

Elum Energy primarily offers two main services :

- Control of installations, including both microgrids and pure photovoltaic systems, such as those found in photovoltaic power plants
- Monitoring and data collection of these installations

These services rely on an advanced technology known as the **controller**.

Think of the controller as the conductor of an orchestra. Just as the conductor guides and coordinates the musicians, setting the tempo and ensuring harmony, Elum's controller serves as a central guide for managing and coordinating the various units on-site. However, instead of harmonizing a string quartet, it orchestrates a cluster of photovoltaic inverters coupled with a lithium-ion battery.

Although this analogy may seem simple, it provides an understanding of the controller's role within a microgrid.
The controller is essentially an industrial computer, much like the one used to write this report. However, there are some differences.
Unlike a regular computer, the controller doesn't have a keyboard and screen. Instead, it is equipped with various inputs and outputs that enable it to evaluate and monitor the status of different units on-site.
However, the fundamental principle of operation remains unchanged.

At this moment, by typing on a keyboard one provides 'inputs' to the computer. The computer processes this information and, based on its internal control and programming logic, generates 'outputs' by displaying the letters and words on our screen.
Similarly, the Elum controller communicates and exchanges information with the different devices within an installation, such as power meters, inverters, batteries, and generator controllers. Using its control logic, it interprets this information and performs subsequent actions accordingly.

Figure 1.2. Elum's controllers [?]

Figure 1.2, shows an example of two controllers: MOXA UC8100 on the left, and MOXA MC1100 on the right.
These models can vary in terms of computing power and the number of inputs and outputs they offer. The selection between the two models depends on several factors. These factors include the scale of the installation, the volume of data to be processed, any installation-specific constraints, and the preferences of the customer.

The controller is typically integrated into a case (see Figure 1.3) in which the rest of the necessary equipment is located: battery UPS, junction box, I/O module when needed, internet router, and various switches.
It is also possible to have a human-machine interface (HMI), to have direct access to the equipment. In some cases, if the customer requests, SCADA software can be integrated. However, this technology is required in special applications such as PPCs or plants of significant size and complexity that need to be controlled through this technology.

In this case, the integration of the system occurs through the combination of the casing with the controller within the installation.
The controller is equipped with a control logic that enables it to assess the various states it encounters and then calculate the control strategy based on the required configuration. However, several crucial steps are necessary to achieve this. When breaking it down step by step, the control logic within these machines can vary, and in this case, it is state-based control.

Without delving too much into technical details, EMS operates roughly as follows: it collects information from the units present on the site and evaluates their current state to generate the appropriate control law and commands (see Figure 1.4).
To better understand this concept, let's consider a simple example.

Figure 1.3. Different types of cases

Imagine a scenario where the controller is operating in a microgrid consisting of PV inverters, a genset, and two power meters, one measuring the load and the other measuring the grid.

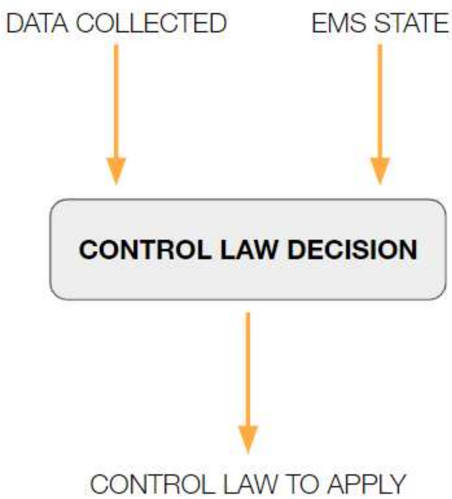


Figure 1.4. Control logic of the Elum's controller

Now, suppose one of the constraints at this site is not to exceed the maximum power limit of *100 kW* from the grid, as there would be significant penalties for doing so. In such a case, the following sequence of events occurs: At time *t0*, the EMS receives the information from the grid power meter indicating that the Active Power is *100 kW*.
It checks its current state and recognizes the need to comply with the constraint of not

exceeding the maximum active power requirement.
At time *t1*, after processing this information, the EMS initiates the appropriate control logic, which, in this case, involves activating the genset for peak shaving.

Due to privacy reasons a more detailed explanations of the controller archictecture and logic has not been provided.

However, to operate and implement this control logic, it is essential to establish communication with all the units within the site. This, in fact, is one of the most challenging aspects when dealing with these systems.

The Elum controller communicates using the Modbus protocol. The Modbus communication protocol is one of the most common and widely used communication protocols worldwide. It was developed by Modicon (now Schneider Electric) in 1979 and has since become an industry standard.
Communication protocol is a set of rules and guidelines that define how data is transmitted, received, and interpreted between different devices or systems. In practice, it establishes a common "language" and structure for communication [15].
For us humans, communication rules are often implicit and unwritten. We learn to communicate by observing and listening to others around us. The words we use, the gestures we make, and our facial expressions help us convey our messages.

But for devices like computers and machines, it's different. They require very specific and detailed rules, which are written and programmed, to know how to communicate with each other.
These rules are defined within a communication protocol, which dictates how devices must exchange information.

The challenge lies in being able to control and communicate with devices that do not communicate using the Modbus protocol and integrating them into the control logic. In fact, similar devices may communicate differently depending on the company that produces them.

Communication and integration are two of the primary challenges typically faced when installing these types of technologies in both microgrids and power plants.

The communication issues is typically adressed by converting the signals using a devices able to convert the different protocol of communication in modbus protocol, in case of different communcation protocol and by configurating the different parameters that may be required to establish the communication.

The integration of devices is addressed through the integration of the Modbus address table of the unit using a configuration file called the 'blueprint.' To avoid overloading the discussion, further details are available in Annex .1 and .3.

1.4 Literature Review

An extensive literature review was conducted to analyze existing papers on the utilization of this technology.
This review delves into current research on Energy Management Systems and their integration within solar power facilities.
The aim is to provide valuable insights into the issues faced when operating and enhancing solar power plants, along with proposing solutions to enhance their efficiency.
As will be shown in this review, there are many obstacles that need to be addressed from various perspectives. This technology is suitable not only for micro or nano grids, as will be demonstrated shortly, but also for large power plant applications.
Therefore, it is necessary to consider challenges not only from a technical standpoint but also from safety, economic and integration perspectives within a vast and complex energy market.
It checks out various important studies that help us understand how to smoothly fit Energy Management Systems (EMS) into solar power plants.

The research paper titled 'Design of Energy Management and Control System for Hybrid Power Plants' [7] delves deeply into the development of a specialized EMS for Hybrid Power Plants.
These HPPs are unique because they combine various renewable energy sources such as wind and solar, along with energy storage. This study proposes a novel approach to designing the HPP EMS and High-Performance Power Controller to enhance the synergy between these two systems.
The HPP EMS, or Hydropower Plant Energy Management System, plays a crucial role in optimizing energy sales in the market to maximize profitability. This involves assessing factors like energy demand, renewable energy source capabilities, and market conditions. However, it's important to note that the High-Performance Power Controller is responsible for executing these plans promptly.
Its primary goal is to ensure the seamless integration of the HPP system with the existing power grid, thus ensuring the efficient utilization of renewable energy.
Furthermore, the researchers extensively discuss strategies for system robustness, particularly in cases of communication disruptions. They propose innovative methods to ensure the Hybrid Power Plant continues to operate effectively and maintains its connection to the grid, even in challenging conditions.

The study titled "Stochastic Generation and Interstate Power Grid Expansion" [8] investigates the impact of wind and solar power plants coupled together, known for their variable energy output, on power systems.
The authors employ optimization models to thoroughly analyze how the integration of renewable energy sources into existing power grids could alter the dynamics. Their focus is on understanding how expanding power grids across states influences the successful integration of renewable energy sources.
The study's findings indicate that the inherent fluctuations in wind and solar power outputs do not significantly disrupt overall power systems.

While these fluctuations may lead to variations in power supply, the researchers emphasize that effective smart grid management and balancing techniques can adeptly address this issue.
Additionally, they highlight how the introduction of renewable energy sources can impact factors such as the fuel requirements of non-renewable power plants.
As renewable energy sources become increasingly integrated into the power generation mix, it becomes crucial to reevaluate the size and operational patterns of conventional power plants.
This adjustment is necessary to ensure the overall reliability and stability of the power system. Consequently, this study underscores the importance of considering broader implications when integrating renewable energy sources into power grids.

The article titled "A review of islanding detection techniques for renewable distributed generation systems" [9] provides a comprehensive examination of methods for detecting islanding in renewable distributed generation systems.
Islanding occurs when a generator continues to supply power to a location even when it's not connected to the main power grid. This can pose risks to utility workers and complicate the process of reconnecting systems when grid power is restored.
This study explores various techniques designed to promptly identify islanding incidents. These techniques utilize different approaches, such as monitoring the frequency of events, tracking rapid changes, and assessing voltage variations.
The research evaluates the effectiveness of each technique by considering factors such as the speed of detection, accuracy, and the rate of false alarms.
The overarching message of this research is the importance of employing effective islanding detection techniques. Doing so enhances the safety of utility workers and simplifies the process of reconnection, ultimately contributing to the overall reliability and stability of the power grid.

Implementing demand side management (DSM) strategies is of crucial importance in maintaining a balanced electricity supply and demand, thereby enhancing the overall reliability of the power system.
In the article titled "Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads" [10], the authors delve deeply into these strategies.
They extensively discuss demand response, a method wherein electricity consumption is actively managed in response to factors like fluctuating prices or grid conditions.
The article also explores the integration of smart energy systems and intelligent loads. This involves the use of advanced control techniques, data analysis, and automation to optimize energy utilization and adapt to changing requirements.
The study provides a comprehensive examination of various components and technologies associated with demand side management, including smart meters, energy management systems for buildings, and residential energy systems.
The research underscores the significant benefits of demand response in shaping power consumption, reducing peak demand periods, and bolstering the stability of the power

grid. It plays a pivotal role in enhancing energy efficiency and cost management, ultimately contributing to a more resilient and sustainable power grid.

The paper "A review of key power management strategies for microgrids" [11]. dives deep into how the integration of this technology within microgrid is performed.
Microgrids are small electric systems that can work on their own, serving specific areas or communities. They're tough and flexible, helping during power grid issues and making the whole thing more reliable.
The authors look at different ways microgrids manage power, like making it, storing it, and using it.
They focus on methods like controlling power step by step, managing when power is used, and responding to power needs. These strategies help control how power moves, use renewable energy better, and improve how the whole system works.
The study really shows how important these power strategies are for microgrids and how crucial will be to deploy this technology in the future as well.
They help the system stay stable, handle changes in how much power is needed, and get the most out of the energy sources around.

The study titled "Optimal Energy Management of Distributed Energy Resources and Demand Response in the Electricity Market" [12] explores the best ways to handle energy from distributed energy resources (DERs) and demand response in today's electricity market. Huge importance must be put on this challenge. More and more PV power plont are being integrate around the world and the trend is increasing.
DERs are a mix of energy creation and storage methods scattered across a network, including things like solar panels, windmills, and batteries.
The authors present a model that wants to make the most out of DERs and demand response for the good of both those who use energy and those who produce it.
They consider many factors in this model, such as electricity costs, how much power is used, available green energy, and the limits set by the power grid.
By looking at both the market's demands and how things operate, the model gives a full plan for using DERs, changing power usage, and supporting the grid.
This research stresses that managing energy the right way is key to make the most out of DERs, save energy, and move towards a green and more local power system.

The paper titled "Integrated Size and Energy Management Design of Battery Storage to Enhance Grid Integration of Large-Scale PV Power Plants" [13] discusses the role of battery storage in large solar power plants.
Batteries are crucial in handling the inconsistent nature of solar energy and ensuring it's smoothly integrated into the main power grid.
Yang and the team introduce a fresh take on designing battery storage. They focus on getting the size right and managing energy effectively. The goal is to find the best size and operation methods, and when to charge or release energy. With the right battery capacity and smart controls, the system can save extra solar energy when it's abundant and release it during high demand times.

Similar studies will be provided in this report aiming to find difference configuration and ways to model this systems.

The addition of solar energy to the main electrical grid offers numerous advantages. It provides a steady source of electricity, which is crucial in areas where power supply may be unstable.
Moreover, thanks to advanced electronic controls, it ensures a more consistent energy flow, reducing issues such as sudden voltage drops.
Additionally, harnessing solar energy to its full potential enhances the efficiency and overall purpose of large solar power plants.
By maximizing solar energy utilization, these facilities can generate a substantial amount of electricity, reducing harmful emissions and moving us toward a greener future.
Furthermore, the scalability of these systems ensures integration into various-sized systems, from kilowatts to megawatts, and even the most recent and incoming installations of gigawatts.
However, through the review and analysis of these papers, we have also noted that there are several challenges that must be addressed.
These challenges encompass aspects ranging from security and the integration of different types of renewable sources to participation in the energy spot market and the proper sizing of various units to find the best configuration.
All of these challenges must be tackled, aided by continuous research efforts, to effectively harness the vast abundance of renewable energies that will come in the years ahead.

Chapter 2

Techno-economic assessment via Excel / HOMER Grid models

2.1 Introduction

In the following chapter, I will delve into a comprehensive case study involving a real microgrid installation situated in South Africa, integrating one of Elum's controllers.

The idea in the previous chapters was to provide an overview of the various technologies that currently exist, how they function, and the typical challenges faced when integrating such systems. We then proceeded with the literature review to explore the different aspects that need to be addressed both now and in the future, aiming to gain valuable insights for the analysis that will be conducted.

Now, we will conduct an analysis of an installation, focusing on two particular models that will be created using Excel and HOMER Grid. This analysis aims to highlight the differences between the two software tools and understand which parameters are crucial in these installations, as well as the enormous advantages that come when using such devices.

2.2 Contexte

This installation comprises several crucial components, including gensets, photovoltaic systems, and energy storage batteries.
Within this chapter, I will detail the distinct phases, underlying assumptions, employed analytical tools, and the resultant findings.
Of particular significance will be the economic parameters, shedding light not only on the installation's economic viability but also on its technical aspects.

South Africa's dated electricity infrastructure, paired with sudden power outages has hampered electric power generation capacity for years and to this day continues to hinder the country's future economic expansion.
All of this, is set against a backdrop of load-shedding that, has increased dramatically since 2018 (as shown in Figure 2.1).

Until major investments in the electricity sector are made, the problem will continue to weigh on the shoulders of South African consumers, citizens, and businesses.
To remedy or alleviate the situation, based also on the latest annual trends that have resulted in a decisive lowering of prices, many corporations are switching to alternative PV grid-tied solutions.
The development of hybrid solutions is indeed playing a crucial role in the country's energy transition, driven and incentivized of course by the goals of decarbonization and reduction of greenhouse gas emissions.
From 2011 onward, following the implementation of the Integrated Resource Plan (IRP), by the Department of Energy (DoE) there has been a gradual and important increase in the deployment of PV installations, and future estimates from the IRP predict a future installation of an additional 7958 MW of PV power by 2030.

The occurrence of load shedding in South Africa corresponds with a decline in the Energy Availability Factor (EAF), which measures the performance of electricity-generating

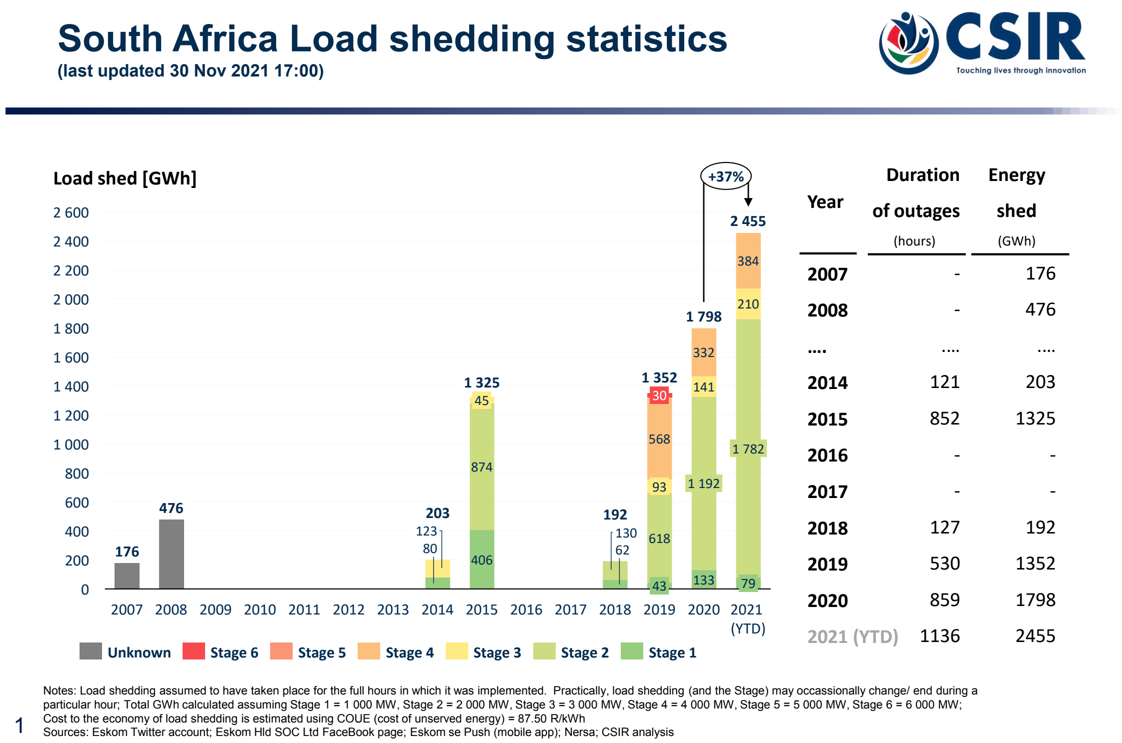


Figure 2.1. The number of days of load shedding in South Africa.

stations in supplying electrical energy to the national grid.
A steep decline commenced in 2018 when the EAF dropped to around 71.9%, just below the power utility's target of 74%. In recent years, specifically in 2021, 2020, and 2019, the EAF was approximately 61.8%, 65%, and 66.9%, respectively, see Figure 2.2.

It is evident how the electricity generated by coal power plants is yet the main electrical power source, also due to the massive reserves of coal present in South Africa, followed by renewable energies that at the moment account for only a small 6.7%.
Hence, the future expansion and deployment of green power sources on the one hand will reduce dependence on coal and thus greenhouse gas emissions, and on the other, it can reduce the impact of load shedding and lower the costs associated with it.
However, as mentioned in the preceding sections, the technical aspects of dealing with intermittent and non-modulating energy sources, such as solar power, pose unique challenges.
These challenges can manifest in various ways, ranging from daily fluctuations caused by factors like cloudy weather, short interruptions due to shading on photovoltaic panels, to longer-term issues like the accumulation of dirt over the years.
Additionally, it's important to highlight that in many countries, including South Africa, the national power grid may not readily accommodate electricity generated by small and medium-sized installations.

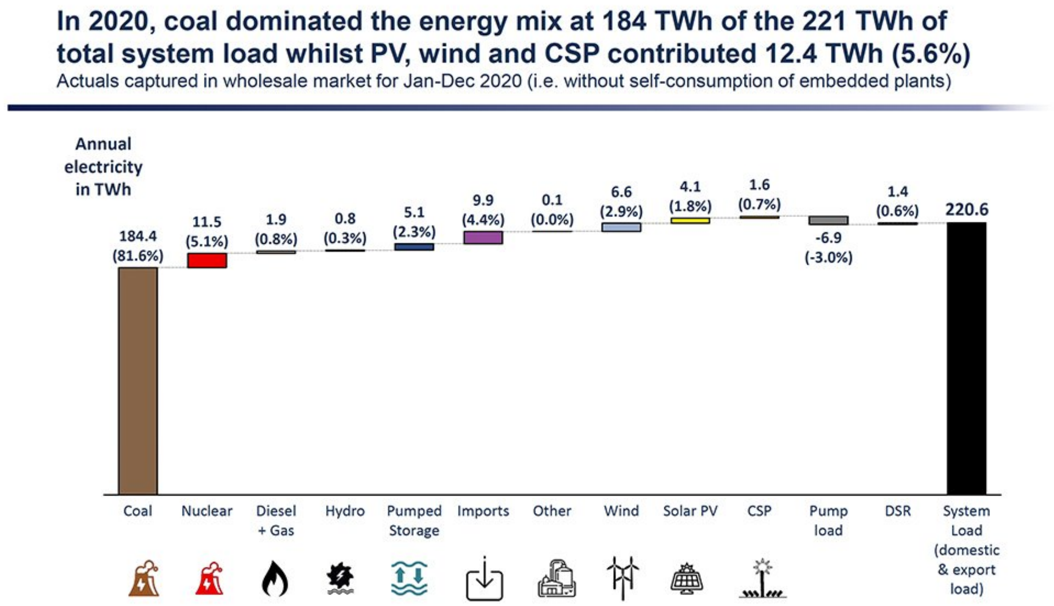


Figure 2.2. Installed generation capacity in South Africa.

Therefore, addressing these challenges often requires the implementation of an Energy Management System (EMS) along with energy storage solutions.

Moreover, the deployment of smart system-based hybrid installations is of particular interest in South Africa due to its intricate and complex tariff method.
The complexity of the South African tariff method is in fact a result of various intertwined factors that take into account the country's diverse range of municipalities and regions, each with its own district and economic conditions, historical factors, but also cross-subsidization with wealthier urban consumers subsidizing electricity access for rural households.
Hence, tariff structure varies on consumer types, consumption levels, time-of-use but also salty fees in some cases.
This intricate web of factors makes particularly appealing EMS-controlled hybrid microgrids due to the flexibility that they promote, their capability to optimize energy use and generation, and subsequently lower the costs and enhance the resilience of the system.

In Figure 2.3 [18] the simplest example of peak shaving is shown. The idea behind this is to 'shave' the peak of energy production from PV that can be experienced during mid-day and distribute it in the following (previous) hours, via energy storage method, in which, production therefore follows a decrease.
This is the basic peak shaving but, as it has been said before, the complex tariff method makes it possible to configure the system in different methods, whether one wants to maximize the PV production, lower the overall bill cost, or increase system stability and robustness.

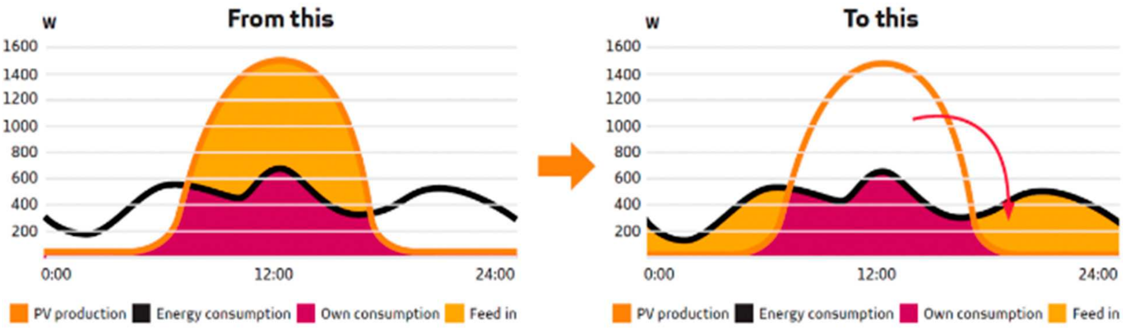


Figure 2.3. Solar PV self-consumption in South Africa.

2.2.1 Microgrid description

As previously noted, this case study centers around an established facility situated approximately 50 kilometers from Cape Town, specifically within the Stellenbosch municipality. This facility, originally planned as a small to medium-sized office building, was initially designed to draw power from the grid and, in the event of load shedding, to be backed up by a set of generators. Subsequently, in 2021, a photovoltaic (PV) installation was added to the roof of the building, complemented by a Battery Energy Storage System (BESS) and Elum's EMS. Here, are the technical parameters of the installation :

- **PV** : 700 kW - 7x Huawei 100KTL
- **BESS** : 500 kWh/320 kW
- **GENSET** : 2 MVA
- **ATS** : Automated Transfer Switch : an electrical device commonly used in backup power systems to automatically switch between two power sources, and ensure a continuous supply of electricity.

Moreover, a simplified Single Line Diagram, of the installation is provided below in Figure 2.4 [**?**]. A more precise SLD is provided in Annexe.

In accordance with Figure 2.4, the PV arrays all connect to an intermediate AC bus via the PV inverters.

The BESS, in turn, is connected to the DC load and dump load through a converter and the distribution network.

2.3 Method

The aim of this report is to perform a techno-feasibility analysis of the installation to evaluate its efficacy and economic viability.

There is no general rule for performing these analyses. In fact, it is up to the researcher to investigate the most interesting parameters based on the results they want to achieve, whether they are economic or energy-related parameters.

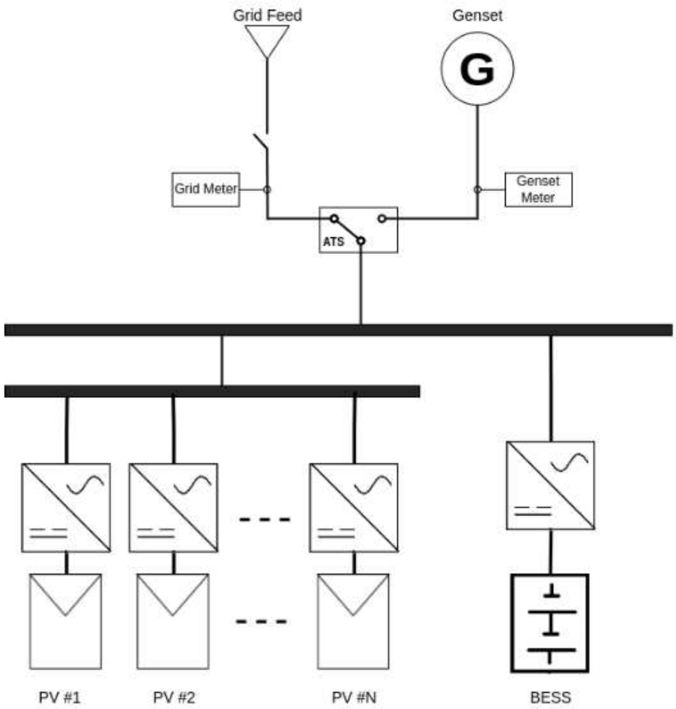


Figure 2.4. Simplified Single Line Diagram of the system.

However, there are several very common indicators in these analyses that allow us to assess performance and predict future behavior, all with the necessary approximations.
To do this, I used two software programs, both commonly used for conducting these types of analyses, each with its own limits, advantages, and drawbacks.
Firstly Excel has been used, and subsequently HOMER Grids.

Excel is a software widely known by the majority of people, often used for data analysis. Its advantages lie in its versatility, ease of use, and cost-effectiveness.
However, it may not be the ideal solution when dealing with highly complex models, large amounts of data, and the need for complex analysis.
Nevertheless, it remains a valuable tool for conducting these types of analyses.
HOMER (Hybrid Optimization Model for Electric Renewables) is a specialized software designed for the optimization and analysis of energy systems, particularly those incorporating renewable energy sources.
It is capable of modeling complex energy systems and assessing the economic and environmental impact of various scenarios.
HOMER is widely used for conducting these types of analyses. It can handle very complex systems and perform sensitivity analysis on a wide range of parameters.
However, it is complex software that requires a high level of familiarity to fully utilize its thousands of features. It can be costly and may not smoothly integrate parameters that

come from outside the energy domain.

Several parameters were considered, both related to energy and economics. Among these, certainly, the photovoltaic generation capacity, the penetration of renewable energy in the system, cash flows, and the Pay Back Time were included. The Pay Back Time represents the duration, starting from the initial total investment, required to break even.
Of course, it's essential to keep in mind that the ability to modify the system as desired, thanks to an Energy Management System, allows the user to excel in specific areas of interest.
For example, one might prefer an extremely efficient and low-emission system over one focused on return on investment or vice versa. Alternatively, they may prioritize system security and continuity of operation. To do this, necessary assumptions were naturally made to carry out the analysis.
Furthermore, sensitivity analyses were conducted to appreciate how variations in input variables or parameters affect the output or results of a model.
They indeed allow us to have a clearer view, especially in situations where there is uncertainty in the input data or where small changes in parameters could lead to significantly different outcomes.

2.4 PV Modelization

To proceed with the techno-economic model, the initial step involved the modeling of the photovoltaic installation.
This modeling serves as the primary driver of the analysis and acts as the source for subsequent result analysis.
Without the photovoltaic installation, neither the battery nor the Energy Management System (EMS) would have any utility.
Consequently, significant attention was dedicated to the modeling of these components.
The PV installation model was created using Helioscope, a software tool employed within the solar energy industry for the design and optimization of solar projects. Helioscope provides a variety of features and functionalities aimed at simplifying the process of solar project development.

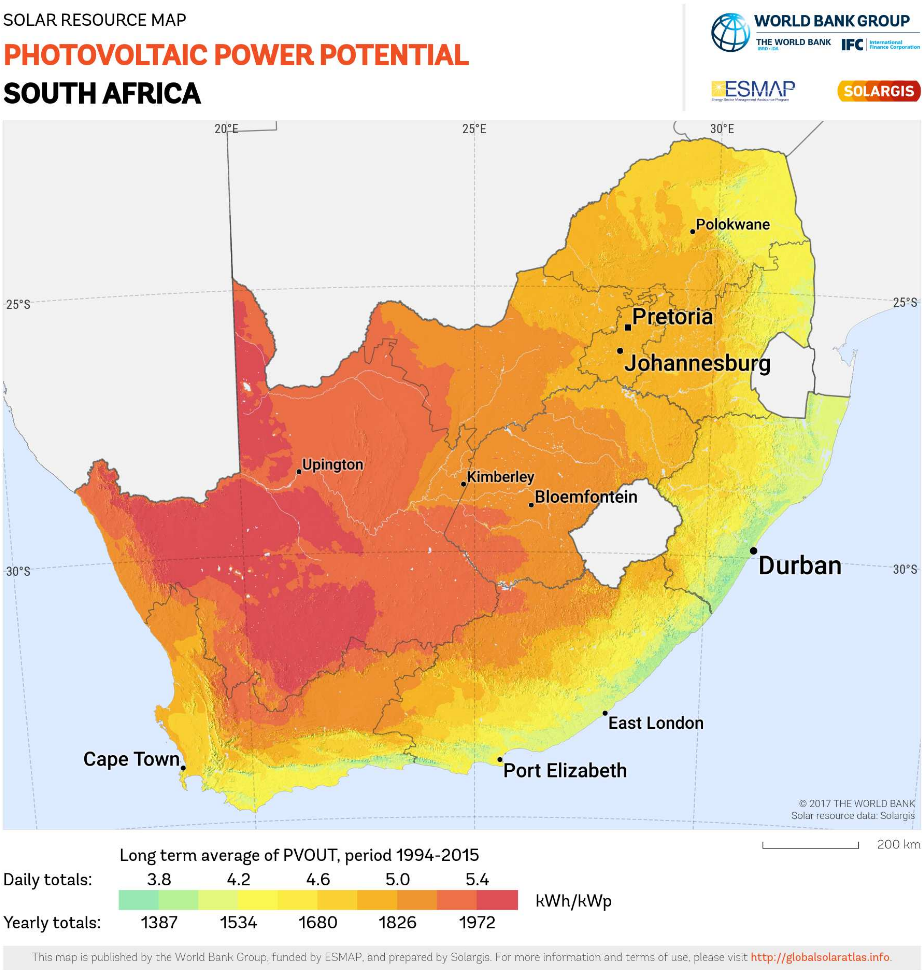


Figure 2.5. Solar Irradiation in South Africa.

As shown in Figure 2.5 [19], South Africa has a vast abundance of solar resources, especially in the northeast. However, even in the southern regions, such as Cape Town where the installation in question is situated, there are noteworthy solar resource availabilities.

Figure 2.6. Picture of the installation taken from Google Maps.

The site, shown in Figure 2.6, was composed of two main buildings with PV panels installed on the top of them. To obtain the annual yield of the PV installation using Helioscope, it is essential to provide a series of key parameters.
These include the geographical location of the site with geographical coordinates and local climate data, the configuration of the PV system, the orientation, tilt angle, details on electrical components, historical and meteorological data, and any specific project parameters.
By providing these detailed inputs, it is possible to obtain an accurate analysis of the annual yield of the photovoltaic system as well as the energy hourly date set.
Furthermore, it is also necessary to input specific parameters related to the solar modules used, the size of the cables and the specifications of the PV inverters.
Several details can be provided, such as : the panel type, efficiency rating, nominal capacity, temperature coefficient, manufacturer, model, wire type and size (copper or alluminum), cable lentgh, inverter type, inverter capacity and efficiency.
However, given the vast number of input parameters that can be entered, some data has been omitted due to a lack of information. Nevertheless, it has still been possible to appreciate the quality of the results obtained, as some inputs are relatively negligible compared to others.

In Figure 2.7 is shown the Monthly Total Irradiance, extracted by the dataset, for that particular geographic position.

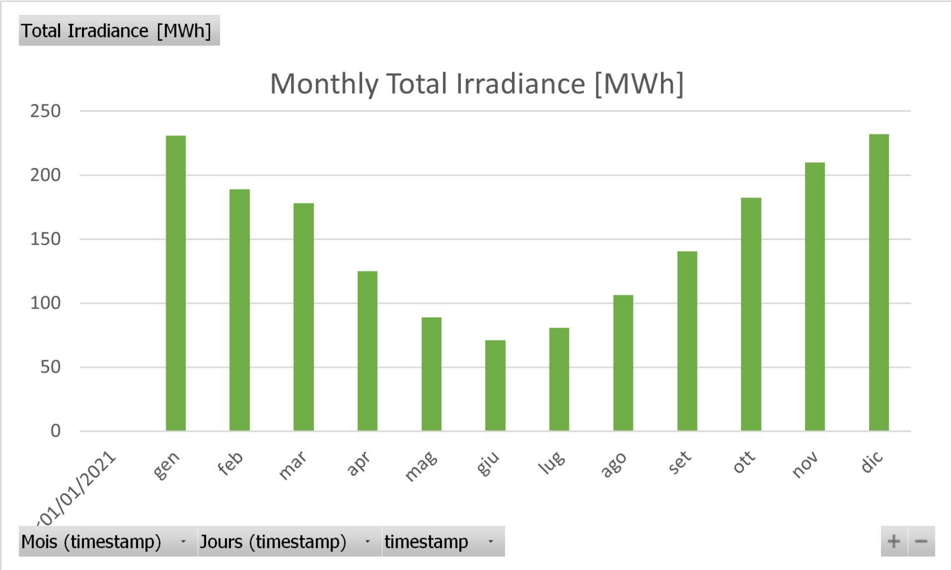


Figure 2.7. Monthly Total Irradiance.

Unlike what one might expect at European latitudes, the peak irradiation occurs in the months of December and January, as we are located in the Southern Hemisphere. Therefore, even the tilt of the panels, which is typically oriented towards the south in countries north of the equator, will be oriented towards the north.
From this input, the hourly production of the photovoltaic installation was then calculated using Helioscope.
To simplify the calculation, the panels were positioned with a north-facing azimuth orientation (360/0 degrees) and an average tilt angle of 12.5 degrees.
Given that the panels have varying inclinations from 10 to 15 degrees, an average string panel tilt angle was chosen for use. More information on the configuration can be found in Figure

From this configuration, the sources of losses were then extrapolated (Figure 2.9) and the electricity generated by the PV installations was finally calculated.

The energy generated by the PV installation ready for use is shown in Figure 2.10. Naturally, it follows the irradiance profile and is therefore subject to an inverted 'bell-shaped' pattern with production peaks in December and January. Furthermore, the electrical losses shown in Figure 2.9 allow us to appreciate the magnitude and scale of each of them. Among the most significant within the installation are:

- *Mismatch*: Occurs when PV panels within an array have different characteristics (e.g., shading, dirt, or aging), causing them to operate at varying efficiencies. This leads to energy losses as the overall system operates at the efficiency of the least productive panel.

- *Temperature*: High temperatures reduce the efficiency of the semiconductor materials in the panels, leading to temperature losses.

Components

Component	Name	Count
Inverters	SUN2000-100KTL-M1 (380/400) (Huawei)	7 (700.0 kW)
AC Panels	1 input AC Panel	1
AC Panels	3 input AC Panel	2
AC Home Runs	70 mm2 (Copper)	7 (497.6 m)
AC Home Runs	240 mm2 (Copper)	3 (966.4 m)
Strings	6 mm2 (Copper)	77 (29,894.0 m)
Module	Longi Solar, LR5-72HPH-540M (2021) (540W)	1,325 (715.5 kW)

Figure 2.8. Components.

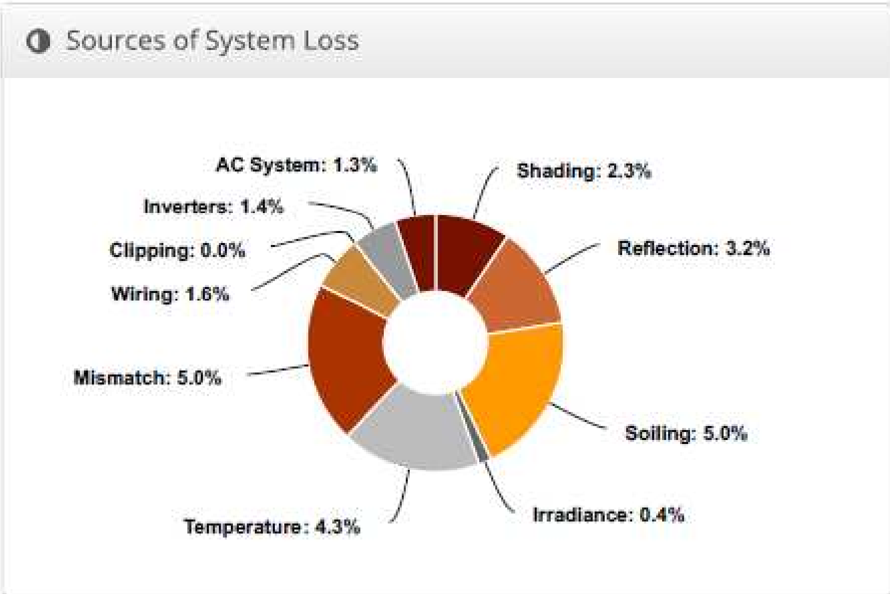


Figure 2.9. Sources of electrical losses within the PV installation.

- *Reflection*: Happens when sunlight is reflected away from PV panels instead of being absorbed and converted into electricity.
- *Soiling*: Due to the accumulation of dirt, dust, bird droppings, or other debris on the surface of PV panels. Dirty panels are less efficient at absorbing sunlight and converting it to electricity

These four account in fact for almost 80% of the total losses.

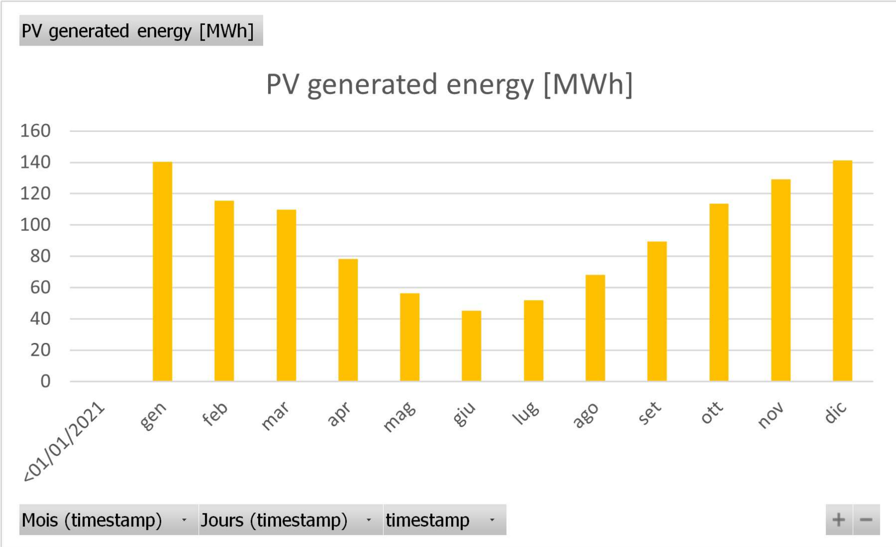


Figure 2.10. Monthly yield of PV generated energy.

2.5 Excel Model

After extracting the production parameters of the solar installation, with the necessary approximations, it was possible to proceed with the technical and economic analysis.
To do this, it is, of course, necessary first to present the overall building load profile and the system's operation.
In this case, the possibility of load shedding will not be considered; for ease of calculations, this means that no interruption of service will be simulated.
However, it will be introduced later through HOMER, which will allow for a more straightforward integration into the analysis.
The load profile is shown in Figure 2.11 and was obtained from the dataset made available by the installation.

As can be seen on the load profile, it is not regularly distributed as in the case of the PV generation, peak of consumption are present in January, March, May, and July as well.
However, even though at first glance, the electrical load may appear much larger and oversized compared to the PV installation, there are two factors to consider: the distribution of solar energy and electrical load throughout the day.
It is essential to remember that electrical production starts from zero during the night, peaks at midday, and then returns to zero at night.
As shown in Figure 2.13, it follows the classic bell-shaped curve.
On the other hand, the electrical load has a more consistent pattern, with appropriate simplifications, even during the night, as shown in Figure 2.12.
However, as also demonstrated in Figure 2.13, there are cases where there is an overproduction of power generated by the photovoltaic system.

Figure 2.11. Monthly profile of the Electrical load.

2.6 Tariff Structure

The tariff method plays a very important role in this context. As mentioned earlier, South Africa has an extremely complex tariff system that varies depending on the type of installation, the municipality it is located in, the season, the time-of-use, and includes substantial fines.
All of this is designed to have very precise control over an electric system that is not easily modulated.
Additionally, there are, of course, specific periods of load shedding that further complicate matters.

For this case it has been chosen the ***Two/three-part time-of-use (TOU) tariff***, namely a basic tariff structure.
Note that all rates are obviously in Rand, which is the South African currency, the results though, for ease of understanding will be shown in dollars.
This is a tariff that has different time periods and Seasons, shown in Figure 2.14 [20] in order to more accurately reflect the shape of the licensees long-run marginal cost of supply at different times [21].

A two-part TOU tariff normally has two tariff components, namely: a basic/fixed monthly charge (R/month), and an energy charge that is time and/or Seasonally-differentiated (c/kWh).
A three-part TOU tariff would comprise the two components mentioned above, plus a Network Demand Charge (R/kVA).
The TOU tariff is applicable to any customer category that is equipped with a time-of-use metered system, i.e. domestic/residential, businesses and industrial customers.

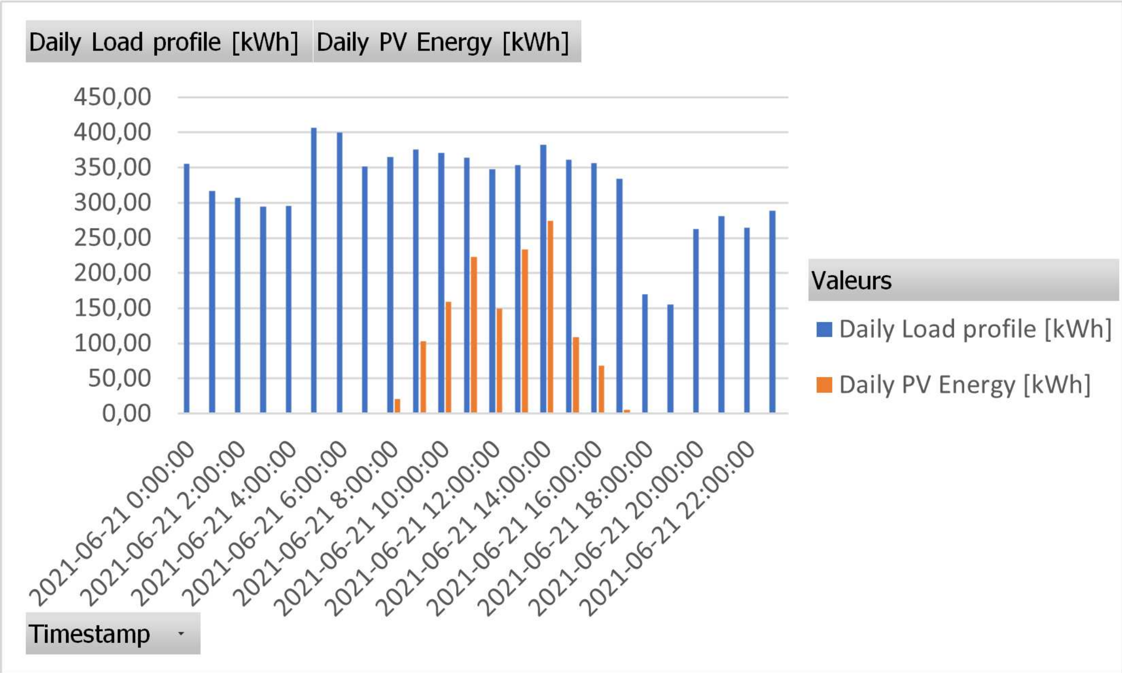


Figure 2.12. Daily Load and PV profile on 21st of June

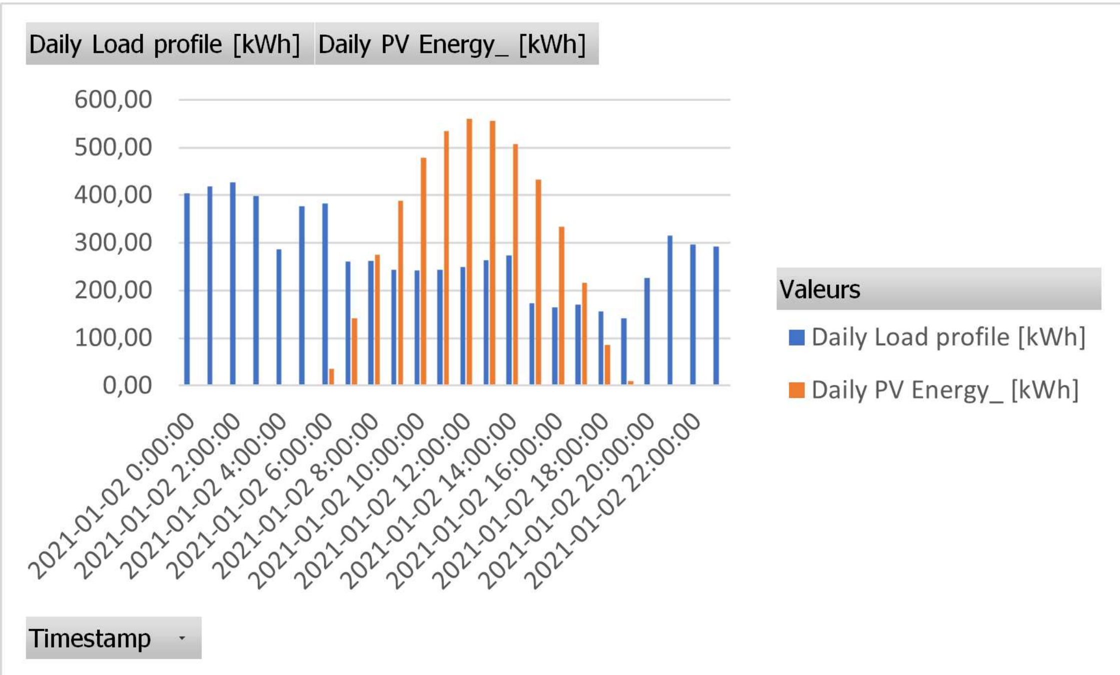


Figure 2.13. Daily Load and PV profile on 2nd of January

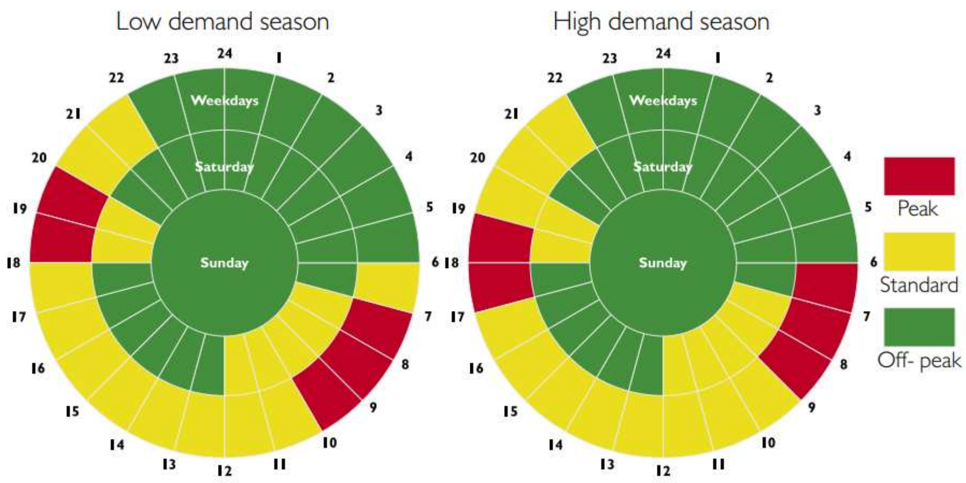


Figure 2.14. Low and High demand Seasons with TOU period for the Western Cape Province.

Furthermore, the ***Industrial/Manufacturing*** category was chosen.
This category refers to big industries and can be classified into industrial low and industrial high customers 2.15.
Consequently, considering the type of installation, its size, and its purpose, it was decided to choose the category **LARGE MV (MEDIUM VOLTAGE 11-22 KV) TIME OF USE** as shown in Figure 2.15 [21].

From the above images, it can be understood that electricity prices vary depending on the season (high or low season), and within the same season, they vary based on the day of the week.
More precisely, there will be peaks during the weekdays, decreasing during the weekend. The idea behind this type of tariff structure is to more accurately reflect the shape of the long-term marginal cost of energy at different times.
Furthermore, three additional costs are present, which will be very important for our economic analysis.

- **Basic Charge**: also known as the fixed charge or service charge, is a flat fee that customers pay regardless of their actual electricity usage.
  It covers the cost of maintaining the electrical infrastructure, metering, administrative expenses, and other fixed costs incurred by the utility.
  This charge is typically a fixed amount per billing period (e.g., per month).

- **Notified Demande Charge (NDC)**: is based on the notified maximum demand, is a component of the electricity bill that is calculated based on the customer's peak electricity demand (measured in kVA) during specific time periods, as agreed upon in the TOU tariff.
  This charge encourages customers to manage their electricity usage during peak demand periods.

TIME OF USE TARIFFS	
LARGE MV (MEDIUM VOLTAGE 11-22 KV) TIME OF USE	
Basic Charge (R/month)	5 188.16
Notified Demand Charge (R/kVA)	111.36
Notified Maximum Demand (R/kVA)	148.51
Reactive Energy Charge (c/kVarh)	4.40
Low Season:	
Energy Charge	
Peak (c/kWh)	163.07
Standard (c/kWh)	119.56
Off-Peak (c/kWh)	84.41
High Season:	
Energy Charge	
Peak (c/kWh)	451.45
Standard (c/kWh)	153.11
Off-Peak (c/kWh)	103.73

Figure 2.15. Tariff Structure with TOU for the Western Cape Province.

The Notified Demand Charge can vary depending on the time of day or season when the peak demand occurs.

- **Notified Maximum Demand (NMD)**: This refers to the maximum amount of electrical power (measured kVA) that a customer has agreed upon with the electricity utility or provider.
  It represents the highest level of electricity demand that a customer is expected to reach during a billing period.
  The customer notifies the utility of this value, and it is used as the basis for determining the pricing structure.
  If a customer's NMD exceeds, they may incur additional charges, which will be calculated every month based also on the number of events when the NMD has been exceeded [21].

The Reactive Energy Charge, won't be covered, due to its negligible costs. This parameter is often used to bill structures with a poor power factor.

2.7 Energy Scenarios

2.7.1 Scenario with only PV - Excel

After introducing the production profiles of the PV installation, the electrical load profiles of the system, and the chosen tariff structure in this case, we can now delve into detail on how solar energy production integrates with the load, the economic results, and the subsequent integration of an energy storage system.

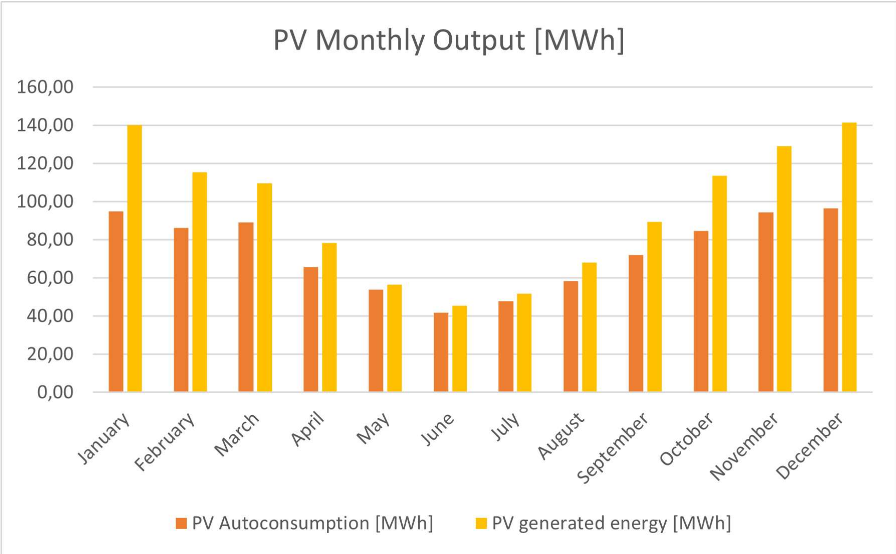


Figure 2.16. Comparison between PV Autoconsumption and PV generated Energy.

Upon analyzing the techno-economic parameters of the structure with only the PV installation, it becomes apparent that there is an underutilization of surplus photovoltaic generation, as depicted in Figure 2.16.
This phenomenon is particularly noticeable during the summer months when photovoltaic production is at its peak.
The primary limitation arises from the inability to export surplus photovoltaic energy to the grid, necessitating the restriction of PV inverter output to avoid substantial penalties. Consequently, the annual self-consumption rate stands at 78%.

Additionally, it is worth noting that the graphical representation does not account for the potential impact of load shedding, which could further reduce the self-consumption percentage.
In the event of load shedding, the diesel generator would function as a network-forming unit. However, unlike the electrical grid, diesel generators have limited capacity for power absorption, as they are essentially designed for unidirectional power supply.
In situations involving load shedding, a significant decrease in load consumption could result in the dissipation of excess power in the network-forming unit, potentially leading to serious and costly consequences.

This would then result in a more conservative use of PV installation in favor of greater grid stability but less PV penetration.

In Figure 2.17, monthly savings resulting from the use of photovoltaics are depicted. These savings are calculated taking into account the costs shown in Figure 2.15 and consist of monthly fixed costs, associated with the infrastructure for connecting to the grid, costs related to energy consumption ($/kWh), and costs due to peak electricity demand ($/kVA).

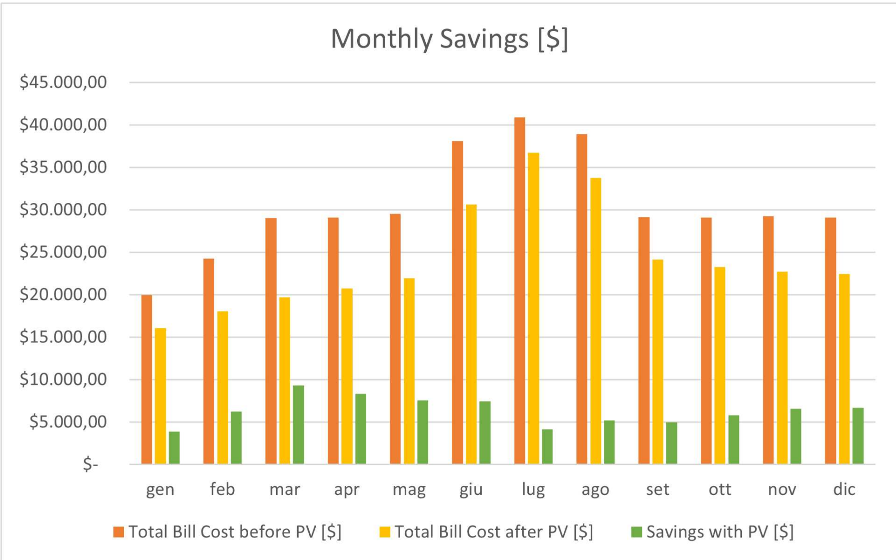


Figure 2.17. Monthly Savings with and without the PV installation.

The latter is, in fact, a moving average, which is why the total cost of the bill remains constant in the final months.
Specifically, the Notified Demand Charge (NDC), introduced earlier, is calculated based on the maximum monthly power in kVA drawn from the electrical grid and multiplied by the NDC rate. This is done every month.
However, once the following month surpasses this threshold and a higher power demand is requested from the grid, the new maximum power will be higher. This pattern continues throughout the year, as can be seen in Figure 2.18, resulting, in the final months, in a more expensive bill in terms of kVA.
To provide a simple example, if in January there is a very high peak power demand of 150 kVA, and for the rest of the year, it remains at 100 kVA, the bill for all months of the year will be calculated based on 150 kVA.
This is where the concept of Peak Shaving comes into play; using a storage system to flatten these peaks, resulting in a much lower bill afterward.

As shown in Figure 2.19, with the addition of photovoltaics (PV), the savings on the final cost are significant, leading to an annual reduction in the bill of 21%. This translates to a savings of *$76,000* per year.

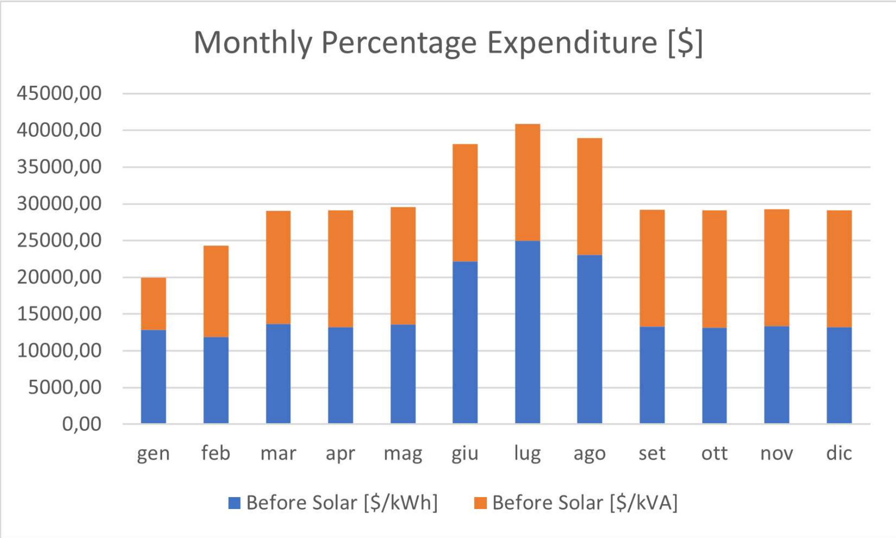


Figure 2.18. Percentage of kWh and kVA on the Monthly Bill .

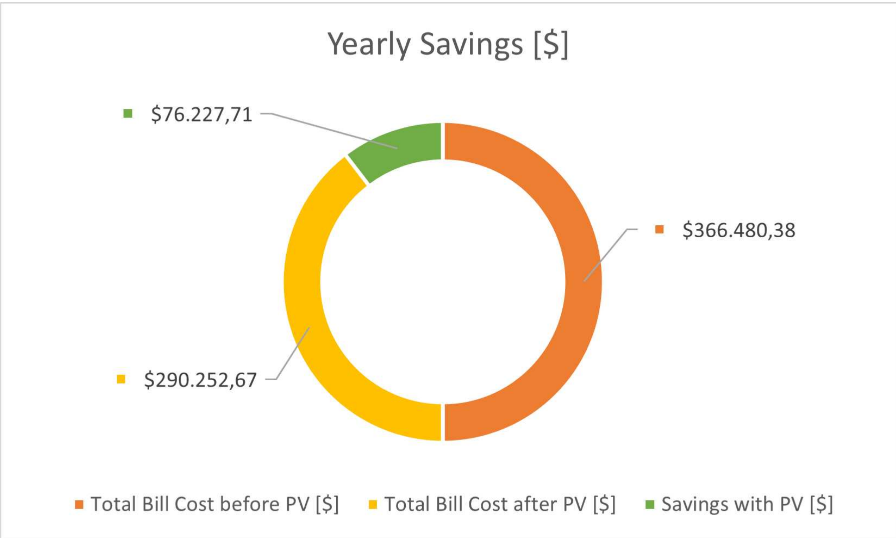


Figure 2.19. Yearly Savings with and without the PV installation.

2.7.2 Scenario with PV and Battery - Excel

As previously explained, the battery within the site can perform various functions. It acts as a grid-forming unit in case of load shedding and during operation with gensets. This allows for the possibility of increasing the penetration of photovoltaic energy. Furthermore, with proper sizing, it can cover daily excesses of photovoltaic energy and further increase the percentage of renewable energy used.

Additionally, it could be used to cover power peaks, as mentioned earlier, or be programmed to absorb energy from the grid during off-peak times (as shown in Figure 2.14) and reuse it when electricity is more expensive.
There are, therefore, various options for using the battery, and as mentioned before, the versatility of these systems lies in the Energy Management Systems (EMS), especially in the Elum solution, where the high level of configurability allows for changing the system configuration according to the desired outcomes.
In this case, given the complexity of the system, it was chosen to implement a configuration through Excel aimed solely at storing excess PV energy.
Therefore, a simpler algorithm was opted (Figure 2.21 compared to other possible configurations.

In order to model this battery, several considerations and approximations had to be made. The algorithm chosen for use is represented in the figure below. As clearly seen, it is a simplified algorithm where excess energy from the photovoltaic system is utilized and reused during "Standard" and "Peak" periods Figure 2.14.
To achieve this, a linear discharge curve with respect to the total capacity was considered. This approximation is reasonably (Figure 2.20 valid within the state of charge range considered (from 90% to 10%), which corresponds to a total capacity of 400 kWh.

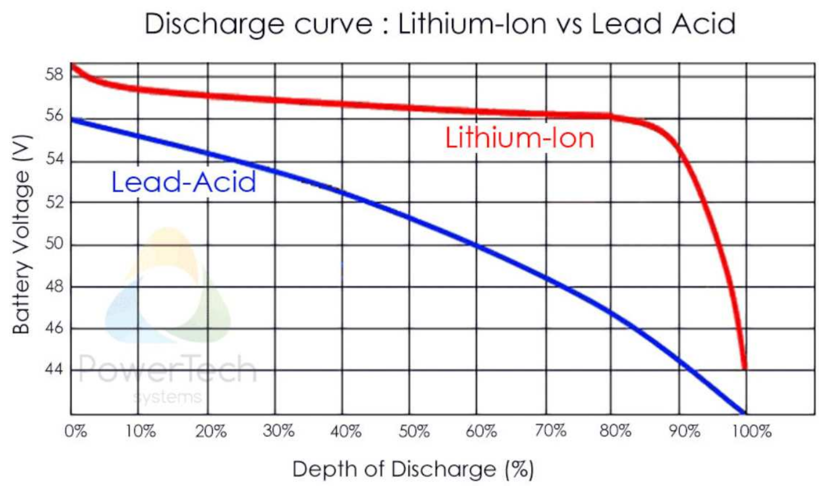


Figure 2.20. Discharge Curve based on State Of Charge - Lithium Ion battery v Lead Acid Battery.

At first glance, the battery within the installation may appear undersized, especially when considering Figure 2.13, where in just the two central hours, the PV production surplus compared to the load is 500 kWh.
However, as explained earlier, there are various configurations that can be employed, and thus, even a smaller battery can serve its purpose.

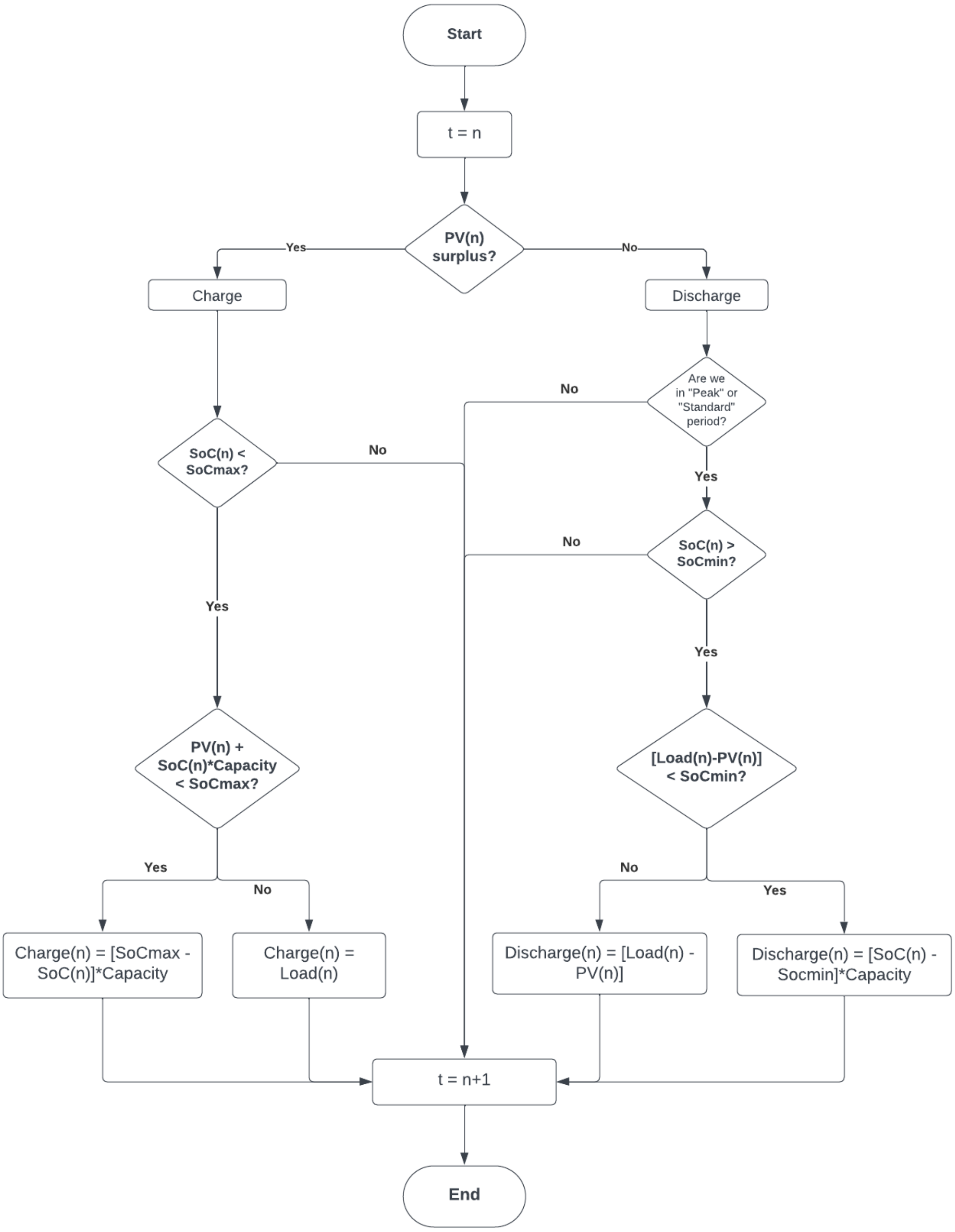


Figure 2.21. Logic implemented to model the BESS behavior.

Figure 2.22 below shows PV penetration versus total battery capacity. The current configuration (C1) allows for a 7% increase in PV penetration, which is not an extremely

high figure but still significant.
It's important to note that as the battery capacity increases, self-consumption increases linearly, reaching up to 20% when the battery capacity is multiplied by 8.
However, self-consumption is, of course, also dependent on excess PV production.

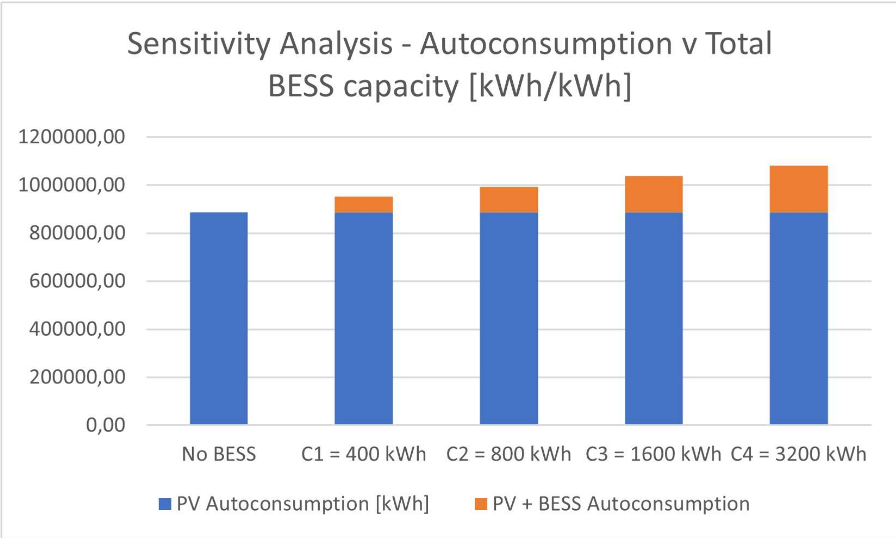


Figure 2.22. Sensitivity Analysis based on the Total BESS Capacity.

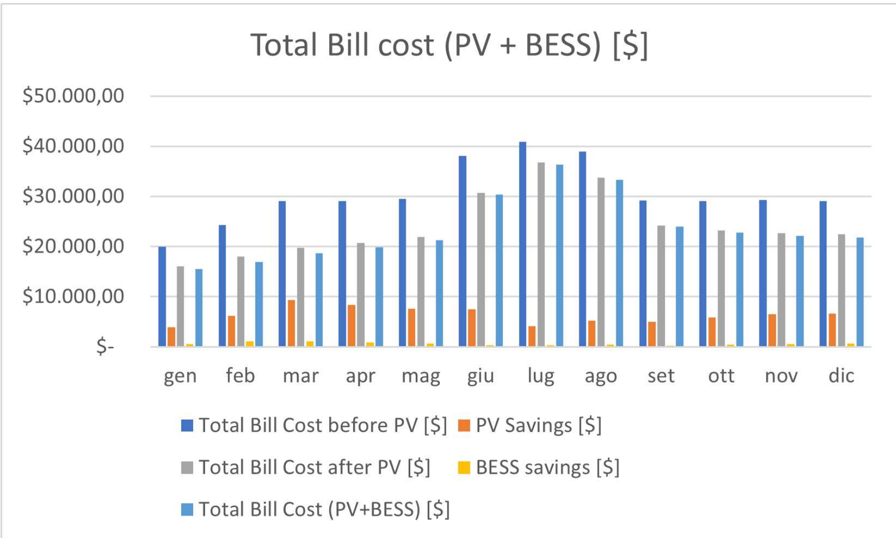


Figure 2.23. Monthly Comparison of the Bill cost.

For the battery to be useful in this type of configuration, it's necessary that the discrepancy between PV production and Load Consumption favors the former. This

does not seem to be the case in the current scenario.
As a result, the calculation of the new final bill was carried out with the PV and BESS configuration.
The final results obtained are displayed in the Figure 2.23.
Considering the system size in this case, the benefits of the battery, even with the current configuration (C1), still result in a significant annual savings of $8,000, as shown in Figure 2.24. It's important to note that as the battery capacity increases, there is a linear increase in the savings brought about by integrating the battery into the system, as depicted in Figure 2.25.
As mentioned earlier, the sizing of the battery relative to the photovoltaic system must be balanced.
In this case, the battery's capacity is much smaller than the photovoltaic system, which means that even with a larger battery, the savings remain limited.

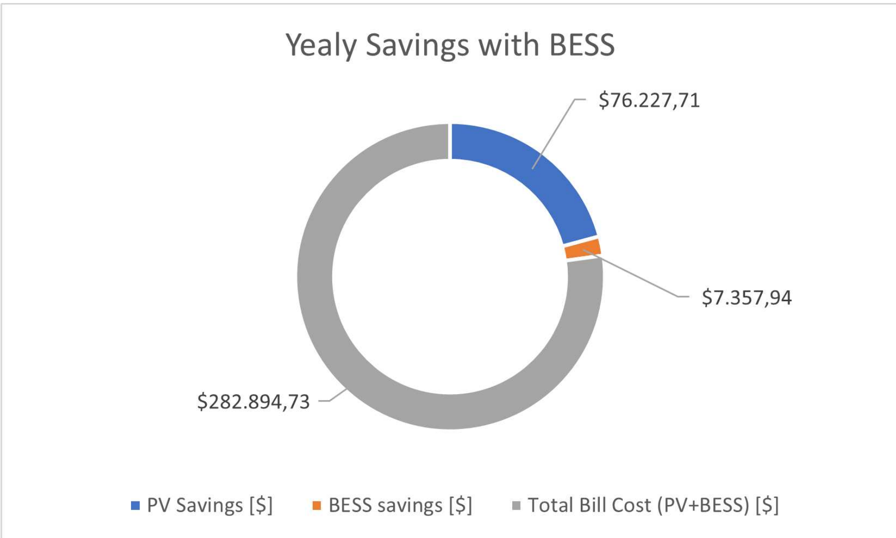


Figure 2.24. Total Bill cost with BESS

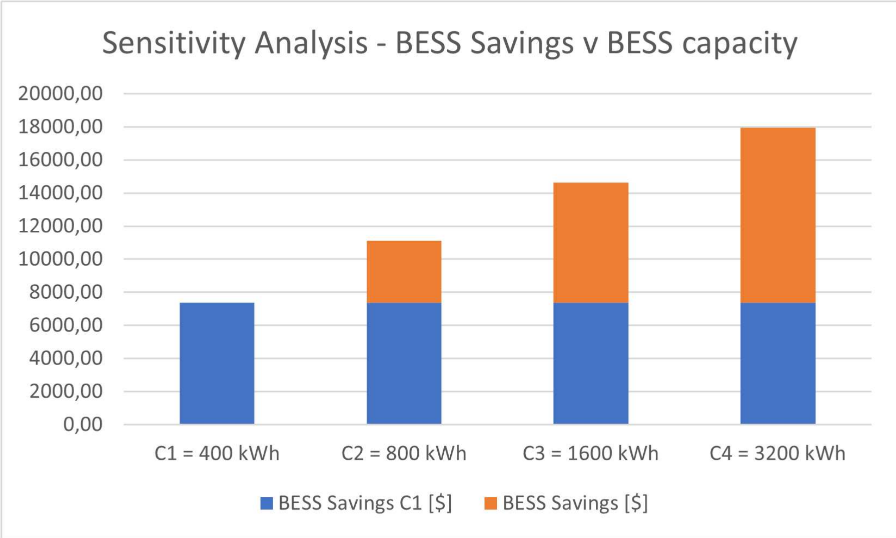


Figure 2.25. Sensitivity Analysis based on the total BESS capacity.

2.8 Price Assumptions

Before proceeding with the analysis of the payback time of a photovoltaic system, it is essential to conduct a series of initial assessments and considerations to gain a clear and comprehensive understanding of the investment.
Let's begin with the initial cost of the system, which includes not only the purchase of solar panels and associated components but also installation expenses, any structural modifications, and other incidental costs.
Maintenance costs are taken into consideration, as well as operational expenses.
Furthermore, the consideration of the discount rate, which reflects the time value of money and the risk associated with the investment, is crucial for evaluating overall profitability over time.
In light of these preliminary considerations, it is possible to proceed with a detailed analysis to calculate the payback time and assess the feasibility of the microgrid system. A detailed summary is provided in the Table 2.26 below.

The costs are taken from the actual installation and therefore reflect reality. This allows for an extremely detailed economic analysis.

	Specification	Qty	Total Sale Price (R)
PV Modules			
Solar Panels	JA Solar 540W	695	R1.761.502,00
Solar PV Mounting System			
Roof Mount	Roof Mount (Flat)	114480	R74.412,00
Roof Mount	Roof Mount (Ballast)	260820	R318.200,00
Roof Mount	Railless	340200	R340.200,00
Solar Inverter Components			
Solar Inverters	Huawei SUN2000 100 KTL	7	R766.960,86
Current Transformers (CTs)	2000/5A Split Core Current Transformer	3	R7.179,00
Smart Logger	ATESS Shinemaster	1	R7.886,00
Battery Components			
Battery	Freedom Won Lite Commercial 400/320	1	R1.358.978,00
Solar charge controller	ATESS PBD320	2	R875.000,00
Power Conversion System (PCS)	ATESS PCS320	1	R780.000,00
PCS warrenty extend	ATESS PCS320 warrenty extend	1	R195.000,00
Bypass cabinet	ATESS Bypass320	1	R3.000.000,00
Bypass cabinet Extension	ATESS Bypass320 warrenty extension	1	R75.000,00
TX	Atess 320kW Tx	1	R310.000,00
Generator Components			
Generator	Volvol Peta 2000kVA		
Generator Controller / Microcontroller	Deepsea	1	R100.000,00
Commissioning Support Services			
DC Hardware			
DC Cables (Red & Black)	Supply 6mm² x solar cable (Per M)	13,136	R166.689,00
DC Cable Accessories			
DC Combiner Boxes	24 Combiner Box	4	R42.836,00
DC cable management		375300	R131.355,00
Medium Duty HDG trays and covers	(76mm, 114mm, 152mm, 228mm, 304mm)		
Galvanised wire mesh trays and covers	(50mm, 100mm, 150mm, 200mm, 300mm)		
Energy Management	Elum ES/MC controller	1	R614.079,93
Comms & Metering			
Communications box enclosure			
Wall mount socket			
Data cable			
Data cable management			
Internet router			
Sim card & data			
Site Work			
DC Installation	Labour	375300	R168.885,00

AC Installation	Labour	375300	R319.005,00
Generator Installation	Including CoC		
Consumables	Consumables	375300	R18.765,00
Rigging			
Health & Safety	Health and safety file	1	R5.000,00
CCTV	Security Cameras		
Crane	EasyLife Lift Rental	5.0	R40.000,00
Storage	Container hire and transport	1	R18.000,00
Travel & Accommodation		1	R1.000,00
Shipping & Delivery	Western Cape	1	R32.000,00
PV Modules			
Other			
International Shipping			
Total Cost			R11.527.932,79

Figure 2.26. Sensitivity Analysis based on the total BESS capacity.

2.8.1 Economical Parameters

In light of these costs, the future cash flows and the time of investment payback were analyzed.
To do this, we took into account Operation & Maintenance costs totaling *$10,000* per year and a performance degradation coefficient of *0.73%* to account for annual plant degradation.

Year	Annual kWh Savings [R]	Annual kVA Savings [R]	BESS Savings	Accumulative Savings	O&M [$]	Finance Layout	Finance Layout [$]
						-R11,527,932.79	$ -599,452.51
1	R 1,118,537.84	R 347,379.62	R 141,498.80	R 1,607,416.25	R 10,000.00	-R9,930,516.54	$ -516,386.86
2	R 1,110,372.51	R 344,843.75	R 140,465.86	R 3,203,098.37	R 10,000.00	-R8,344,834.42	$ -433,931.39
3	R 1,102,266.79	R 342,326.39	R 139,440.45	R 4,787,132.00	R 10,000.00	-R6,770,800.79	$ -352,081.64
4	R 1,094,220.25	R 339,827.41	R 138,422.54	R 6,359,602.19	R 10,000.00	-R5,208,330.60	$ -270,833.19
5	R 1,086,232.44	R 337,346.67	R 137,412.05	R 7,920,593.35	R 10,000.00	-R3,657,339.44	$ -190,181.65
6	R 1,078,302.94	R 334,884.03	R 136,408.95	R 9,470,189.27	R 10,000.00	-R2,117,743.52	$ -110,122.66
7	R 1,070,431.33	R 332,439.38	R 135,413.16	R 11,008,473.14	R 10,000.00	-R589,459.65	$ -30,651.90
8	R 1,062,617.18	R 330,012.57	R 134,424.65	R 12,535,527.54	R 10,000.00	R927,594.75	$ 48,234.93
9	R 1,054,860.08	R 327,603.48	R 133,443.35	R 14,051,434.44	R 10,000.00	R2,433,501.65	$ 126,542.09
10	R 1,047,159.60	R 325,211.98	R 132,469.21	R 15,556,275.23	R 10,000.00	R3,928,342.44	$ 204,273.81
11	R 1,039,515.33	R 322,837.93	R 131,502.18	R 17,050,130.67	R 10,000.00	R5,412,197.88	$ 281,434.29
12	R 1,031,926.87	R 320,481.21	R 130,542.22	R 18,533,080.97	R 10,000.00	R6,885,148.18	$ 358,027.71
13	R 1,024,393.80	R 318,141.70	R 129,589.26	R 20,005,205.73	R 10,000.00	R8,347,272.94	$ 434,058.19
14	R 1,016,915.73	R 315,819.26	R 128,643.26	R 21,466,583.98	R 10,000.00	R9,798,651.19	$ 509,529.86
15	R 1,009,492.24	R 313,513.78	R 127,704.16	R 22,917,294.17	R 10,000.00	R11,239,361.38	$ 584,446.79
16	R 1,002,122.95	R 311,225.13	R 126,771.92	R 24,357,414.18	R 10,000.00	R12,669,481.39	$ 658,813.03
17	R 994,807.45	R 308,953.19	R 125,846.49	R 25,787,021.31	R 10,000.00	R14,089,088.52	$ 732,632.60
18	R 987,545.36	R 306,697.83	R 124,927.81	R 27,206,192.31	R 10,000.00	R15,498,259.52	$ 805,909.49
19	R 980,336.28	R 304,458.94	R 124,015.83	R 28,615,003.35	R 10,000.00	R16,897,070.56	$ 878,647.67
20	R 973,179.82	R 302,236.39	R 123,110.52	R 30,013,530.08	R 10,000.00	R18,285,597.29	$ 950,851.06

Figure 2.27. Summed-up table of Return of Investment.

The cashflow evaluation was done following a constant value of money during time, thus an interest rate equal to 0%.
The interest rate is a key element in the investment analysis, directly influencing the assessment of its profitability.
It represents the time value of money, the risk associated with the investment, and the cost of the capital employed.
A higher discount rate implies a higher investment cost and may require higher returns to be considered advantageous.

There are various configurations and choices available to evaluate this parameter.
Sometimes, you can assume an interest rate, also based on other analyses or existing projects. For example, [24] uses a discount rate of 5%, but without explaining the reasons behind.

On the other hand there are other methodologies that includes the use of Weighted Average Cost of Capital (WACC).
The Weighted Average Cost of Capital (WACC) is a crucial financial tool used for decision-making and updating cash flows. WACC is computed as the weighted average of a company's different sources of financing [25], as demonstrated in the following equation 2.1.

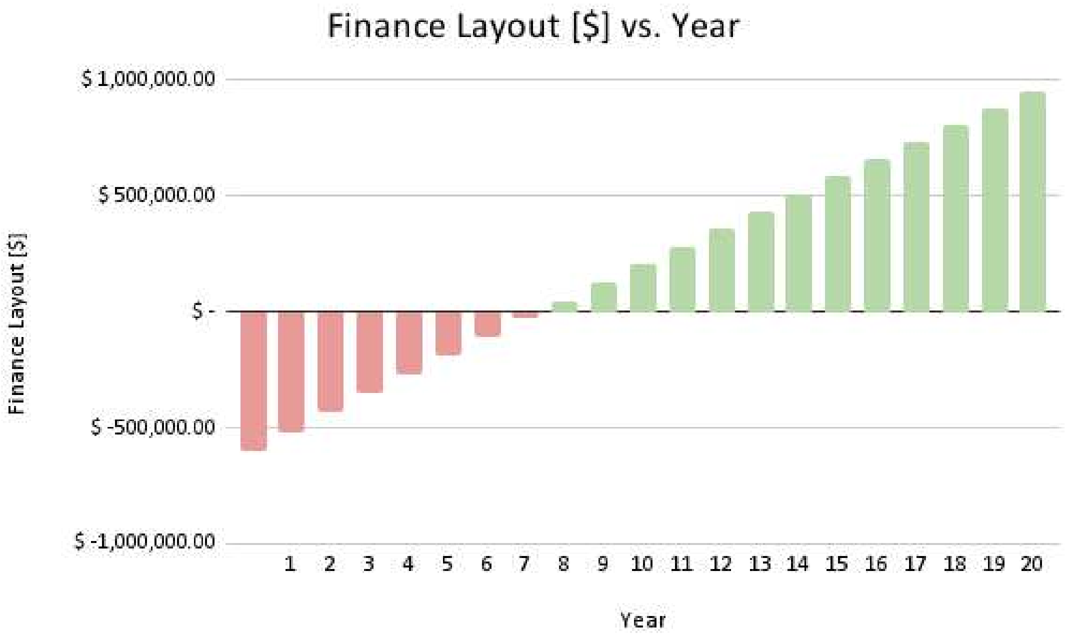


Figure 2.28. Return of Investment over 20 years.

$$WACC = ke \cdot E + kd \cdot D \cdot (1 - t) + D \tag{2.1}$$

Equation 2.1 shows that to figure out the discount rate in this case (WACC), one would need to know about the company's equity (E), debt (D), their respective financing costs (ke for equity and kd for debt), and the tax rate (t), which considers tax savings from deductible expenses.

The company's strategy for its capital structure, especially regarding how much debt to use, is closely tied to decisions about real and financial investments.
The company's desired debt level is influenced by its goals for market value growth.
Additionally, the type of industry the company operates in plays a significant role in these decisions, as different industries have varying levels of physical capital, which affects how the company allocates its resources [26].

All of these parameters were not known during the design of this model, so a constant value of money analysis was chosen.
Therefore, inflation, risk, and interest rate were not taken into account. This results in a final value of economic parameters that is not precisely accurate but tends to be overestimated. However, this overestimation is not so excessive as to compromise the validity of the results.

A summary of all the cashflows is provided in the Table 2.27.
It can be observed that the Payback Time (PBT) of the investment is *7 years*, and at the end of the plant's lifespan, the Net Present Value (NPV) amounts to *$950,851*. An

Internal Rate of Return (IRR), which is a parameter that provides insights into how profitable the investment is in the year, has been found to be *13.61%*.
The trend is depicted in Figure 2.28 [**?**].

Although a seven-year return on investment period was deemed significant, it still appears quite favorable. The majority of the cash flow, however, is generated by the PV system, with the battery accounting for only a minimal 7% in a year, due to its basic configuration and smaller size compared to the total power of the PV system. In the next model, conducted via Homer GRID, we will see how the battery will play a rather significant role and enable significant savings through peak shaving configuration performed by the microgrid controller.

2.9 Homer GRID model

As previously mentioned, Homer GRID is widely used software for conducting techno-economic models of this kind, which include microgrid installations with connections to the electrical grid.
The software is highly configurable, allowing for a multitude of models, sensitivity analyses on various parameters, and the extraction of various economic parameters.
Furthermore, it is possible to find the optimal configuration from various perspectives, whether it be the best in terms of energy efficiency, lower emissions, or the highest economic return.
Homer GRID is an extremely powerful software that allows for the analysis of systems from various perspectives.
Revisiting the same analysis as the previous case, we can immediately see how Homer GRID can provide us with much more information with great ease.
Initially, the general parameters of the plant were checked to ensure the consistency of the previously obtained results. After confirming the correctness of these parameters, the analysis of several variables was conducted.
The annual profiles generated through Helioscope for PV and the annual profile obtained from the actual meter readings of the installation were then uploaded.
Immediately one can see the strength of this software and its ability to analyze each variable from all points of view.

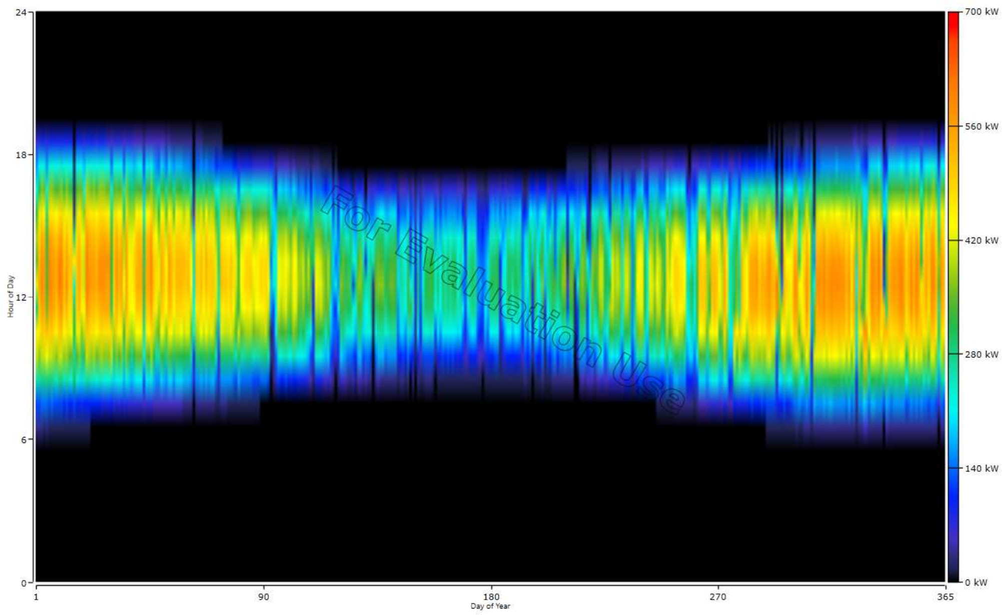


Figure 2.29. Yearly PV production

The figures 2.29 2.30 2.32 2.32 display the different ways in which data can be visualized, both on an annual basis and in various monthly distributions.

A data visualization like this provides us with a much clearer understanding of the

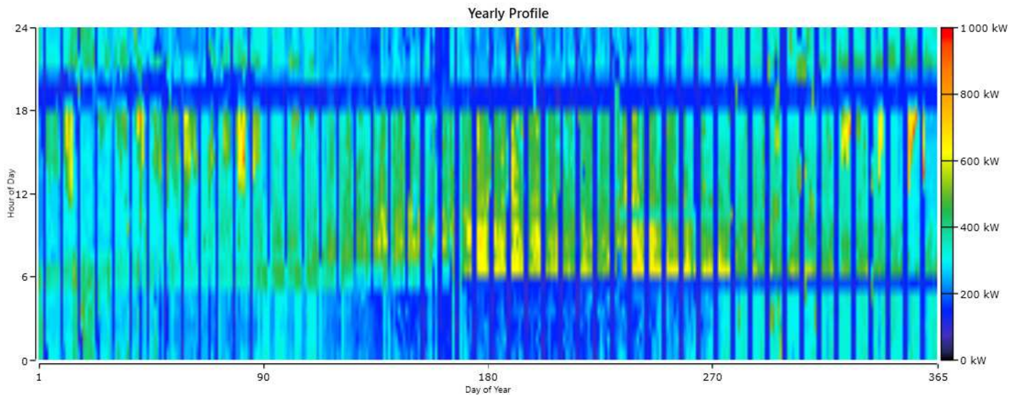


Figure 2.30. Yearly AC primary load

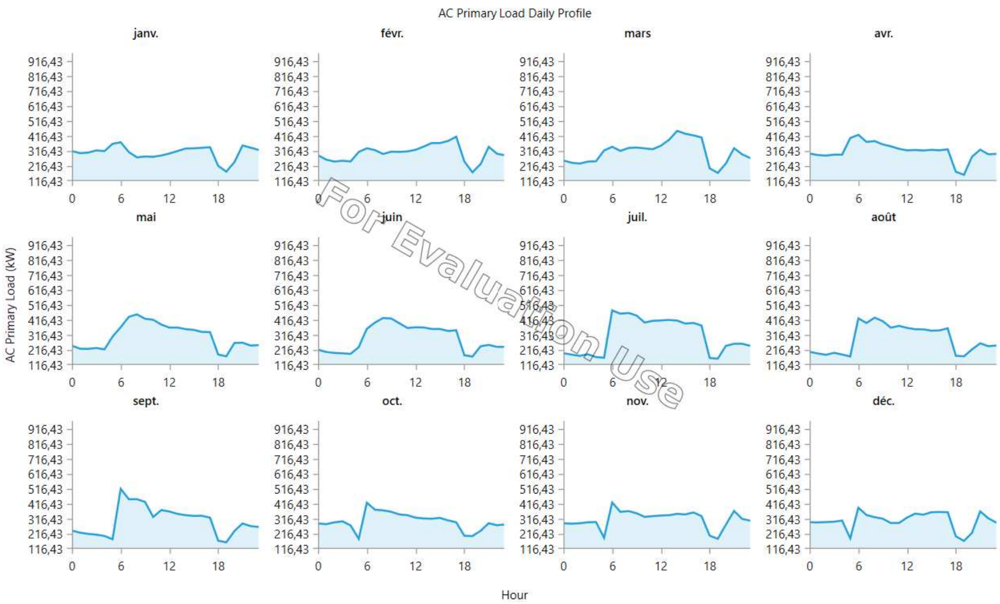


Figure 2.31. Monthly AC primary load

entire installation and translates into greater precision in the choices and various analyses that will be conducted in the future.
The analysis of the installation's performance was then conducted, thanks to the integration of the grid, the battery and the converter.
The Figure 2.33 below shows the configuration entered into the software.

After setting the parameters for the PV and load, the network, converter, and batteries were configured.
For the converter, the total power of 320 kW was entered, with a total lifespan of 20 years and an efficiency of 95%.

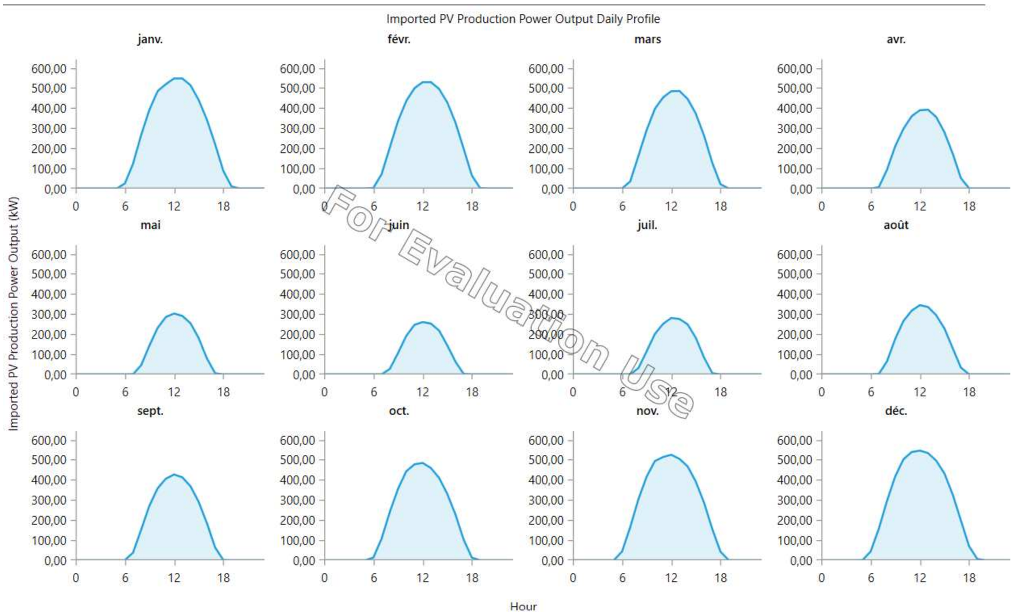


Figure 2.32. Monthly PV produciton

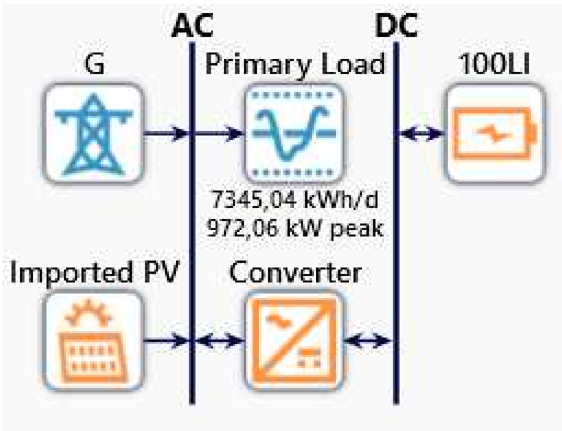


Figure 2.33. Homer GRID configuration

The batteries were modeled as five 100 kWh battery units each to simulate the total capacity of 500 kWh of the on-site battery.
The idealized storage model replicates a simple storage model, assuming a flat discharge curve since the supply voltage remains mostly constant during the discharge cycle.
Of course, not all of this total capacity is usable.
As in the Excel model, it is limited by the minimum and maximum state of charge of the lithium batteries. To simulate reality as closely as possible, the actual nominal capacity is therefore 400 kWh.

To model the connection to the grid, you had to set the tariff method according to the guidelines proposed in Figure 2.15.
Therefore, you proceeded to enter, as in the previous case, the Time of Use tariff method for kWh, the cost per kVA, and the fixed costs associated with the grid connection sizing.

Figure 2.34. Time Of Use tariff method modelled on homer

2.9.1 Dispatching strategy

The dispatch strategy in HOMER Grid specify how the HOMER engine operates storage and power sources to serve the load. It turns generators and batteries off and on, and it chooses how much power they produce or consume in each timestep to serve the load [23]. It can prioritize renewable energy use, enhance resilience during outages, optimize grid interactions, and prioritize critical loads. The choice of strategy depends on project goals and constraints.
This is the most important parameter that makes the HOMER model completely different from the Excel one.

The dispatching strategy in HOMER Grid is selected through the choice of the controller. Using a controller for the microgrid allows for simulating the exact behavior of the network, as the type of control configured within the network is exactly the same as what will be applied to the actual controller.
There are different types of controllers available in HOMER Grid: load following, cycle charging, peak shaving, or controllers importable via MATLAB.
The dispatch algorithm's task is to decide, at each time step, how to serve the electrical load with the available generation sources.
Among the various decisions it makes, it determines whether the battery should be charged from the grid, whether it makes sense to purchase from the grid, and/or whether to run the generator.
The dispatching in HOMER Grid has a 'look-ahead of 48 hours,' which means it knows:

- The electricity demand for each time step in the future

- The utility company's tariff plan
- The photovoltaic production for each time step in the future.

The following algorithm is used:

For a given system configuration and size, the Optimizer seeks to find the most economical grid energy demand limit for each month. Often, this is the lowest peak demand, which, when combined with the photovoltaic system and storage, can still meet the electrical load of the facility.

If the system is feasible, meaning the electrical demand is met at every time step without exceeding the peak demand limit, the economic costs of the system are calculated.

The dispatching looks ahead two days (48 hours) into the future at each time step when making a dispatch decision.
It looks into the future to see if there might be a capacity shortage in the next 48 hours and adjusts its dispatch decision to avoid it if possible.
This may involve purchasing more energy from the grid to further charge the battery during the current time step. Additionally, it tries to identify excess photovoltaic energy (moments when the photovoltaic output power exceeds the load) and aims to leave space in the battery to capture these excesses if possible.

Finally, when arbitrage is feasible, the dispatcher generally prefers offsetting purchases from the grid with direct battery energy sales.
For example, the dispatcher would prefer to serve all the load from the battery during periods of high grid prices rather than selling the entire battery immediately.
In a tariff context like the one described, where the peak and off-peak electricity hours are known, there is indeed the potential for significant benefits by leveraging the ability to charge and discharge the battery from the grid to offset peak hours with electricity purchased during standard or off-peak hours.
Furthermore, the ability to apply peak shaving and thus reduce the peaks of electricity (kVA) imported from the grid can lead to a substantial reduction in costs associated with grid demand charges.

2.10 Scenario with PV and Battery - HOMER

The new scenario, therefore, relies on the possibility of exploiting not the battery's capacity itself to harness the surplus PV power generated by the installation, but rather the complex tariff method, which allows us to recover energy when it costs less or during moments of PV surplus and release it into the grid to cover both demand peaks and required power peaks.

The complex tariff method in the context causes the monthly bill to be very high and increases throughout the year, as explained in 2.15.

In the Figure 2.35 above, we can observe how the use of the controller configured for peak shaving has significantly lowered the peak demand required by the facility.

In the previous case, the NDC (Notified Demand Charge) meant that even for a small peak demand, one would end up paying for the new power taken from the grid in the subsequent months. This made even a short peak, perhaps even at the beginning of the

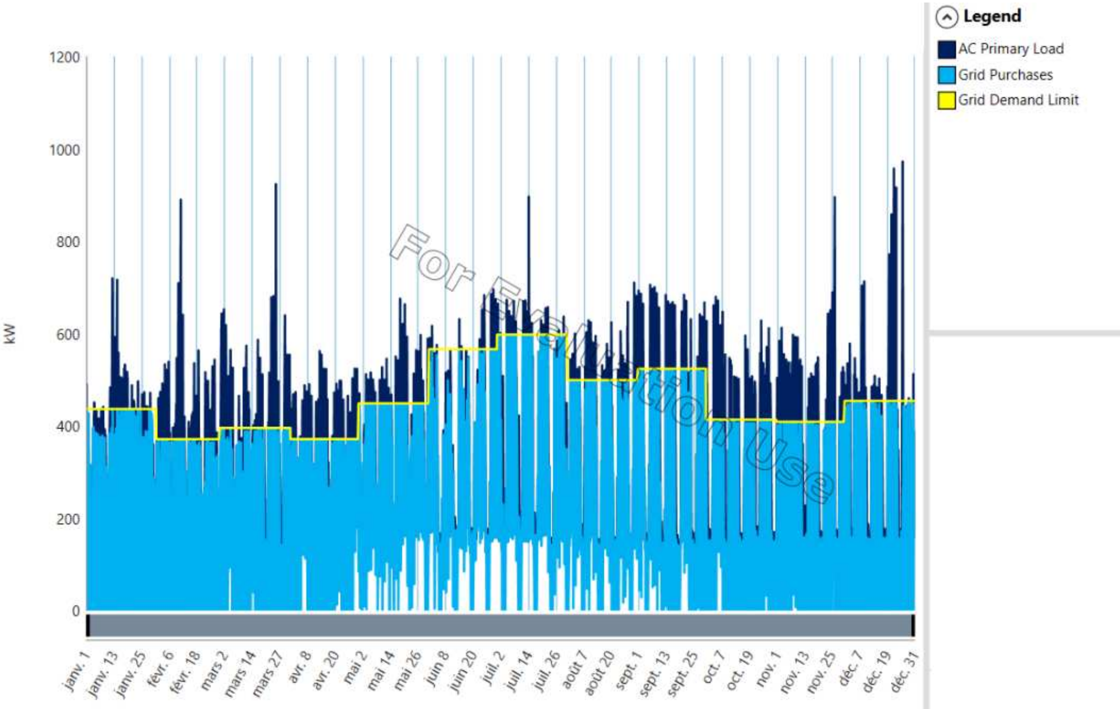


Figure 2.35. Demand of electricity from grid "Peak Shaved"

year, accountable for the total annual bill.
The ability to configure peak shaving significantly reduces costs, thus increasing the overall profitability of the installation.

Furthermore, thanks to HOMER Grid, it is possible to visualize interesting parameters related to each component within the network: usage time, power in and out matrix, usage hours, electrical losses, average power, maximum power, and more.

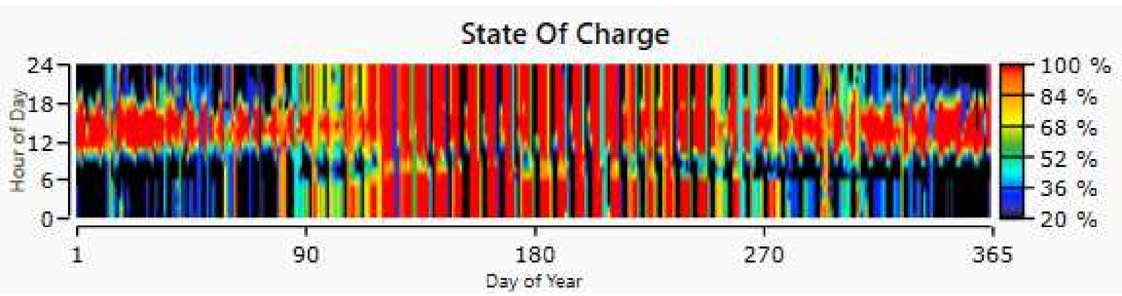


Figure 2.36. State of Charge Annual matrix for the batteries.

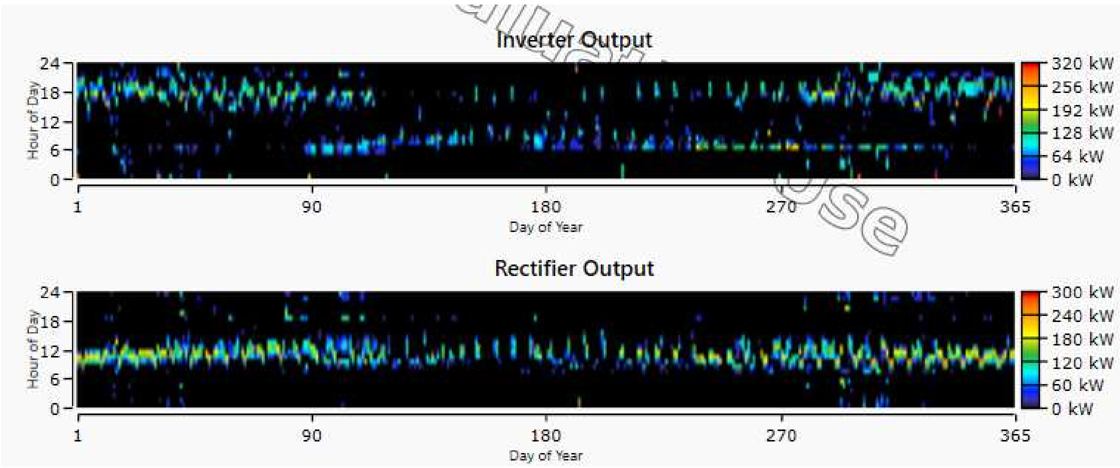


Figure 2.37. Inverter and rectifier output matrix on the PCS'side.

2.11 Financial Layout - HOMER

The economic results brought by this new configuration are substantial. The Operation & Maintenance parameters and the degradation coefficient are kept the same as in the previous case, as well as the interest rate.

Year	Annual Savings [R]	Interest Rate	O&M [$]	Finance Layout [$]
				-$600,492.51
1	2770000	0.00%	10000	-$466,452.51
2	2770000	0.00%	10000	-$332,412.51
3	2770000	0.00%	10000	-$198,372.51
4	2770000	0.00%	10000	-$64,332.51
5	2770000	0.00%	10000	$69,707.49
6	2770000	0.00%	10000	$203,747.49
7	2770000	0.00%	10000	$337,787.49
8	2770000	0.00%	10000	$471,827.49
9	2770000	0.00%	10000	$605,867.49
10	2770000	0.00%	10000	$739,907.49
11	2770000	0.00%	10000	$873,947.49
12	2770000	0.00%	10000	$1,007,987.49
13	2770000	0.00%	10000	$1,142,027.49
14	2770000	0.00%	10000	$1,276,067.49
15	2770000	0.00%	10000	$1,410,107.49
16	2770000	0.00%	10000	$1,544,147.49
17	2770000	0.00%	10000	$1,678,187.49
18	2770000	0.00%	10000	$1,812,227.49
19	2770000	0.00%	10000	$1,946,267.49
20	2770000	0.00%	10000	$2,080,307.49

Figure 2.38. Summed-up table of Return of Investment.

The positive effect of the new configuration is evident, and shown in Figure 2.39, despite no changes being made to the maintenance parameters, degradation rate, or interest rate, which have remained unchanged compared to the previous case.

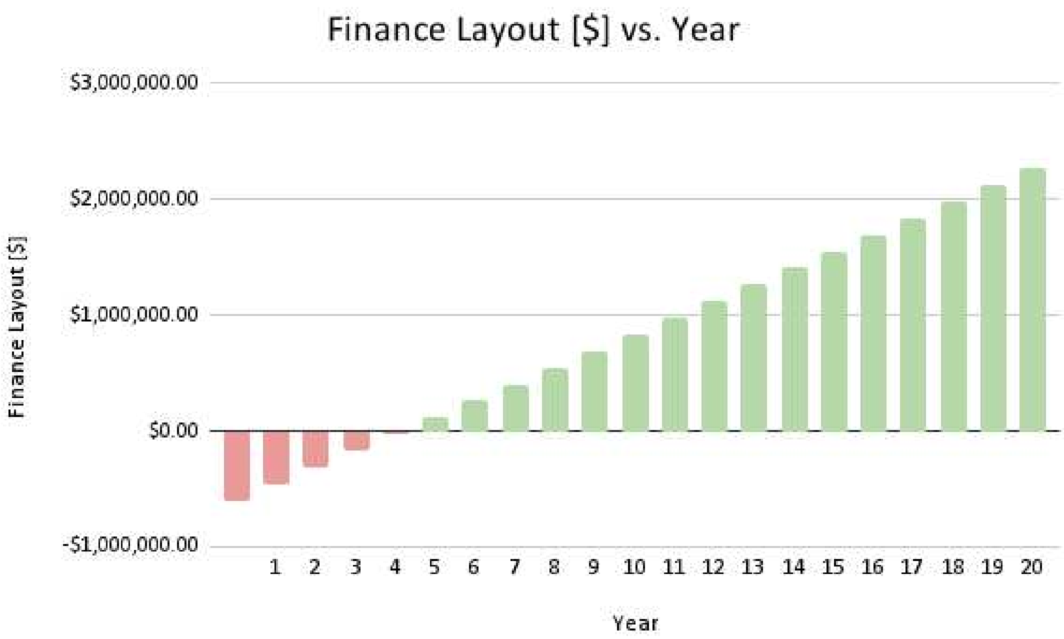


Figure 2.39. Return of Investment over 20 years with HOMER configuration:

The significant benefits of introducing a controller for peak shaving and optimizing on-site energy exchange translate to a Payback Time of 4.3 years and an Internal Rate of Return (IRR) of 23.9%.
These are highly promising economic and investment parameters.
Using HOMER, it was also possible to simulate a Payback Time with an assumed interest rate of 5%, as hypothesized in [25].
This resulted in a Payback Time of 4.6 years, which is not significantly different from the initial assumption. This validates the theory that even when assuming an interest rate value of 0%.

2.12 Results Comparison

Finally, it was possible to make a comparison of the KPIs (Key Performance Indicators) among the various case studies considered in order to assess the models and the different results obtained. A summary is provided in the Table 2.40 below.

	Base Case (only grid)	Excel Model	Homer Model
PV savings [$]	/	$76,227.71	$75,846.57
PV + BESS Savings [$]	/	$83,585.65	$144,040.00
Renewable energy Penetration [%]	/	35.5	39
Total Bill Cost [$]	$366,480.38	$282,894.73	$222,440.38
Pay Back Time (PBT) [year]	/	7	4.3
Internal Rate of Return (IRR) [%]	/	13.9	24.0

Figure 2.40. KPI comparison of the three case studies.

We can observe that in terms of savings from the pure PV installation, the two models are quite similar.
This is because in the PV model, there isn't a distinct control or dispatching logic; instead, a straightforward difference between load and production is performed, thus generating energy and offsetting reduced electricity consumption from the grid.
The Homer model differs due to the presence of some electrical losses (in the converter) that were not taken into account, resulting in slightly lower savings generated by the PV.
The real difference can be appreciated in the model where the entire network is simulated, including the PV installation and battery.

In the case of Excel, a very basic algorithm 2.21 was used to store surplus energy from the PV installation during times when production exceeds demand.
The actual utility, however, comes from being able to harness the surplus PV energy and store it in batteries to potentially cover periods of high grid energy costs or times when PV production may not be sufficient.
However, this principle is effective when the entire network is designed and sized for it. Since the PV installation is sized similarly to the load, and the batteries have a small capacity, this strategy is less effective, as demonstrated by the minimal economic benefits generated.

On the other hand, the Homer model highlights the potential for a completely different use of the battery when coupled with a specific control logic.
The integrated peak shaving controller in Homer demonstrates how even a small battery can prove to be extremely advantageous in economic terms, especially in contexts like this one.
Costs are reduced both in terms of the total energy drawn from the grid and, more importantly, in terms of the power demanded from the grid, significantly contributing to lowering the total annual bill cost.
The double advantage of this configuration is that it yields significant economic benefits,

reducing the annual bill by *39%* compared to the Excel model where total savings are *22%*. All of this is achieved with an energy storage system that is noticeably undersized (total capacity of *400 kWh*) relative to the total load.

Furthermore, to reaffirm the distinct logic within the two models, the penetration of renewable energy between them is quite similar, *35.5* and *39*, which further confirms that the real economic advantages, in a context like this, do not lie in increased use of renewable energy but rather in the intelligent utilization of batteries as energy buffers.
All of this is reflected in the economic parameters of the two installations. Although in the Excel case, the investment payback time is 7 years, which is still advantageous, it doesn't fully reflect the potential of the microgrid.
In the second case, a payback time of 4.3 years is extremely favorable from an economic perspective.
This makes the combination of controller and battery highly attractive economically and positions it at the forefront among potential future technologies.

Chapter 3

Conclusion

Within this report, various aspects of Energy Management System technology have been presented. Initially, the intention was to provide a general overview of the context surrounding this technology, delving into the reasons for its utilization and development.

In a continually growing context such as that of renewable energies, EMS systems are indeed necessary in order to seamlessly integrate these resources. Renewable energies possess numerous advantages, including low emissions, a more equitable distribution of resources worldwide, and the ability to ensure broader access compared to fossil fuels. The latter, on the other hand, tend to be more vertically and centrally structured in social, economic, and geopolitical contexts.

However, renewable energy sources also have their drawbacks, including their unpredictability and the fact that they are not programmable or easily modulated. Current electrical grids, as they are designed, represent rather dated infrastructure, even in developed countries like Italy and France.
They were originally conceived to receive and dispatch a very different type of energy. Their design was shaped by a centralized and stable form of energy, initially with coal and increasingly with nuclear and gas.
Current gas power plants, for example, can provide a constant and continuous flow of energy, and they are highly adjustable. We can choose to activate or deactivate a plant and adjust its power output.
However, this is not possible with renewable sources, particularly wind and solar.

This means that the integration of these energy sources must go hand in hand with the updating of both production methods and energy transmission and distribution methods. In this context, Energy Management Systems represent the future of renewable energy. Without them, we will not be able to fully reap the benefits of renewable energy sources. As demonstrated in this report, however, there are challenges and hurdles that must be overcome.
One of the major challenges is technical in nature, where integration and communication remain significant obstacles to overcome, as does the integration of medium to high-voltage facilities within energy markets.

In this report, I have chosen to provide an example of a microgrid connected to the grid in South Africa, a country where photovoltaic (PV) energy holds strong growth prospects but where the electrical grid is severely limited in its ability to accommodate this type of installation, except when dealing with high-voltage systems.

Furthermore, it's important to highlight that the situation in South Africa is representative of many states and countries around the world.
Once we step outside of the European continent, we find dozens of similar cases.
Therefore, the South African scenario can serve as a model for thousands of other installations worldwide.
To summarize the various steps, we first simulated the behavior of the real PV installation using highly precise data obtained in collaboration with the Engineering, Procurement & Construction company.
PV production data were simulated using the Helioscope software, while load data were provided by the same company. This allowed us to work with real and current data to provide a result and analysis that closely aligns with reality.

Subsequently, we simulated the performance parameters of the installation using a simplified Excel model.
Excel, despite being easy and straightforward to use, still provides accurate results, especially when dealing with simple and linear models.
In this case, a single-use scenario of the PV installation could easily be modeled using Excel, as there is no need for complex algorithms. The ease of use and cost-effectiveness make it a preferred choice over HOMER Grid.

On the other hand, we then simulated and calculated the same parameters using HOMER Grid, software specifically designed for techno-economic simulation of both short-term and long-term hybrid installations (such as PV, batteries, etc.) connected to the grid.
Right from the start, it became evident that this program offers significant capabilities, equipped with numerous functions that allow you to analyze the installation from various perspectives: economic, energy efficiency, safety, or emissions-related aspects.

The model created through HOMER has indeed unveiled the true potential of the installation and the genuine capabilities that might have been obscured by the Excel model.
HOMER introduced a dispatch method, specifically the peak shaving technique utilized within the installation via the Elum controller.
Thanks to this approach, the economic parameters have proven to be extremely favorable compared to those calculated via Excel, although the Excel model still maintained a certain level of credibility.
This is primarily because HOMER takes into account a multitude of parameters and can employ highly sophisticated dispatch algorithms, a task that would be quite challenging to achieve through software like Excel.

Depending on specific needs and objectives, one may choose to use either software. However, it's essential to factor in the costs associated with using software like HOMER Grid, which can provide more advanced insights but may come with licensing expenses.

Chapter 4

Appendix

.1 Modbus parameters

Modbus parameters :

- **Baudrate** : expressed in bits per second (bps), indicates the data transmission speed on the serial line. It represents the number of bits that can be transmitted or received in one second.
- **Parity** : is a technique used to detect transmission errors during serial communication. It can be set as None, Even, or Odd parity.
- **Byte size** : indicates the number of bits used to represent a data byte.
- **Stop bits** : indicate the number of additional bits transmitted after the data byte to signal the end of transmission [6].

.2 Stakeholders of the renewables energy market

EPC : The EPC is the stake older responsible for the entire process of designing, procuring materials, and constructing the PV system.
This company handles everything from initial planning to physically building the system, ensuring that all components are properly integrated and the entire system is constructed in accordance with technical specifications and regulations.

Aggregator: The aggregator is an intermediary that manages the collection and aggregation of energy produced from various sources, including PV systems.
The aggregator gathers energy from different installations and sells it on the energy market or supplies it to local power grids. This can help optimize the use of the generated energy and maximize economic benefits.

IPP : An IPP is an independent entity that owns and operates the PV system to produce electrical energy. IPPs can be companies or investors who have invested in installing and operating the system to generate revenue through the sale of electricity.
They may collaborate with aggregators to optimize energy usage and maximize profits.

Examples of IPP in France: Engie, EDF Renewables or Tenergie. Examples of IPP in Italy : Enel green or Sorgenia.

.3 Blueprint

The beginning of the BP contains general information about the device, vendor, reference, and device type.
After that, the protocol type (TCP or RSU), byte order and word order are given. The latter two are in fact used by the EMS to understand the order in which to read the information received. Byte order refers to the organization and sequence in which the bytes of a multibyte data item are stored in memory or transmitted over a network.
Numeric data is indeed represented by bytes, as is well known. However, data larger than one byte, such as 16-bit words, 32-bit integers or 64-bit floating-point numbers, require the storage of multiple bytes to represent the full value.
it is important to know the convention used by the device in question in order to ensure that the data is interpreted correctly.
After that, there are all the registers, that is, the variables that can be retrieved from the device in question. Some are more important, some others may be useless, depending on your use and needs.
The variables that we can retrieve are in fact of different types. Without going into too much detail and the particularities of them, there are generalities common to all of them :

- *definition uuid*: This line assigns a unique identifier (UUID) to the variable.
- *std var*: Name of the variable. In the case of the Figure 1 *AphA* represents the current on the phase A.
- *address*: This field specifies the Modbus address or register number associated with the data.
- *format*: This field indicates the data format or type. In the case of the Figure 1 the variable is a signed 16-bit integer.
- *register type*: This field specifies the type of register in which the variable is located.
- *channel access* This field defines the access level or permissions for accessing the data channel.Some variables are designated as 'read only', allowing us to only retrieve the current value. Alternatively, some variables can be classified as 'write only' or 'write/read', granting us the ability to both modify the value and send commands. Example of this is the 'Active Power Setpoint variable' of inverters that must be accessible for both read and writing for the EMS to regulate the power.
- *scale*: This field represents the scaling factor applied to the raw data

We can thus think of the blueprint as a file in which all the information needed to access, collect and interpret the variables of a given device is contained.

```yaml
---
blueprint_format: 1.0

device_type: solar_inverter
device_ref: 110CX v1.0
device_human_name: Sungrow string inverter
device_vendor: Sungrow

protocol: modbus_tcp
byte_order: little
word_order: little

static_device_metadata:
    nominal_power: 110000

registers:

    - definition_uuid: 23debd0b-6dc4-45f5-84c9-dee0291b3d1f
      std_var: AphA
      address: 5021
      format:  int16
      register_type: input
      channel_access: ro
      scale: 0.1

    - definition_uuid: 37eb1221-c5df-4fad-a637-ae87051f8148
      short_name: VARSet
      long_name: Reactive adjustment
      description: Reactive adjustment
      address: 5039
      format: int16
      register_type: holding
      channel_access: rw
      channel_type: timeseries
      aggregation_method: avg
      scale: 100

    - definition_uuid: 2851b438-6f61-4106-86fb-671628770f72
      short_name: VARCtl
      long_name: Reactive power Mode
      description: Reactive power Mode
      address: 5035
      format: uint16
      register_type: holding
```


Figure 1. Blueprint of a SunGrow inverter 110CX

Frequently, a device offers a multitude of variables that can be gathered, surpassing the actual requirements for controlling that specific device. Consequently, not all variables will be present, only the ones deemed useful for implementing Elum control logic.

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