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ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
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DESIGN AND ANALYSIS OF A STAND-ALONE SOLAR PHOTOVOLTAIC (PV) SYSTEM FOR ELECTRIFICATION OF RURAL HEALTH CENTERS IN ETHIOPIA: THE CASE STUDY OF LEMBA HEALTH CENTER

BY

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A thesis submitted to the Center for Renewable Energy Technology School of Graduate Studies of Addis Ababa Institute of Technology in Partial Fulfillment of the Requirements of the Degree of Master of Science in Renewable Energy

ADVISOR: TILAHUN NIGUSSIE (PHD)

DECEMBER 2024

ADDIS ABABA, ETHIOPIA

DECLARATION

I, the undersigned, declare that the thesis comprises my work. In compliance with internationally accepted practices, I have acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, and misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient grounds for disciplinary action by the University and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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DESIGN AND ANALYSIS OF A STAND-ALONE SOLAR PHOTOVOLTAIC (PV) SYSTEM FOR ELECTRIFICATION OF A RURAL HEALTH CENTERS IN ETHIOPIA: THE CASE STUDY OF LEMBA HEALTH CENTER

By Hermela Estifanos

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Director of Post Graduate Program	Signature	Date

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ABSTRACT

In many rural and remote regions of Ethiopia where healthcare facilities are situated far from the power grid, there is a pressing need for a sustainable and environmentally friendly energy source to meet crucial electricity demands for lighting, communication, refrigeration, and essential medical equipment. Leveraging solar photovoltaic (PV) systems that harness abundant year-round sunlight as their sole input, offers a silent, safe, clean, and renewable energy solution. This thesis delves into a meticulous examination, design, and optimization of an independent photovoltaic system tailored to cater to the energy requirements of the Lemba Health Center on a daily basis. A comprehensive methodology is outlined, detailing the specification of each system component in alignment with the typical energy consumption patterns at the designated site. Utilizing sophisticated tools such as HOMER PRO and RETScreen Expert software, the study conducts a thorough performance and economic evaluation to determine the power output of the proposed solar photovoltaic system and assess the associated costs.

The findings of the analysis underscore that the sizing of the standalone photovoltaic system hinges on factors such as load profile data, solar radiation levels, and the costs of system components. The HOMER analysis underscores the significant benefits and cost-effectiveness associated with deploying a photovoltaic system to power the health center, highlighting its superiority over traditional off-grid power systems and underscoring its positive impact on environmental conservation. Notably, the evaluation reveals that even during months with the lowest solar radiation, such as July, the system can meet the average energy demand, with a projected net present cost (NPC) of $68,155.56. Notably, this involves the installation of 15.3 kW peak power solar panels rated at 300W each.

Keywords: Standalone solar photovoltaic (PV) system, health center, HOMER PRO software

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CHAPTER ONE

INTRODUCTION

This chapter provides comprehensive background information and the rationale underpinning this thesis research. It begins by examining the scientific significance and importance of solar photovoltaic (PV) conversion, particularly within the context of rural health centers. Subsequently, the research problem is explicitly defined, followed by an outline of the primary objectives. Finally, the chapter concludes by clearly defining the anticipated significance and potential impact of this research.

1.1Background

Ethiopia is ideally situated for the use of solar energy because of its geographic location, which provides plenty of sunshine throughout the year with an average annual solar radiation of 5.5kWh/m^2/day. One of the ways of harnessing this solar energy is by directly converting it into electrical energy by using a solar cell consisting of a specific semiconductor diode, silicon in most cases (Ndagijimana et al., 2019). Light is absorbed by the semiconductor during the photovoltaic conversion process, resulting in free charge carriers (electrons and holes) that are subsequently separated by an electric field between the p- and n-type regions. This charge separation creates a difference in electric potential between the two zones, allowing an electric current to be drawn through an external load. PV systems are an appealing choice for connecting to the grid in remote places that are disconnected from the distribution network. The most common application for a solar PV system is the electrification of rural health facilities.

Health care is a fundamental human right, and people should have access to any health services they require. Aside from the UN Sustainable Development Goal, rural Ethiopia's healthcare systems remain inadequate, and while each health facility has unique challenges, one overarching concern is restricted access to power. The majority of Ethiopia's rural health facilities are off-grid, making it unable to perform even the most basic medical procedures. Lack of electricity restricts working hours and impedes the deployment of medical technology; even the absence of basic lighting and communications can complicate treatments, particularly emergency procedures, resulting in serious problems such as medicine spoilage and the inability to use essential medical and diagnostic devices (Franco et al. 2017).

Due to the underdeveloped generation and distribution capacity of national networks, many hospitals and clinics are forced to rely on diesel-powered generators, which are not only environmentally unfriendly but also frequently unreliable and costly to operate. International development organizations and government agencies working in this field around the world have recently begun to consider the deployment of PV systems for health services. This is primarily because the cost of installing these systems has decreased by 80% in the last ten years, and they provide health centers with independent, dependable, and efficient sources of electricity that have the potential to greatly increase and improve the delivery of health services (Tim Umoette, 2016).

The performance of the PV system is dependent on various parameters, including meteorological circumstances such as solar radiation, ambient temperature, and wind speed.(El-Houari et al., 2019). Photovoltaics stands out from other power-generating technologies in that it converts solar energy directly into electric power via an electronic solid-state process. In general, there are no moving components and no specific thermal stress involved, so they work silently and can offer improved reliability and reduced maintenance requirements with a long lifespan (Dubey, 2009). Though the installation cost of a solar photovoltaic power system is more than that of a gas, diesel, or propane-powered generator-based power generation system requires far less maintenance and operational cost. A comparison of installation costs (including labor), fuel costs and maintenance costs of conventional fuel-based power systems suggests that the solar PV power system can be a suitable alternate option with a short payback period(Assefa Endaylalu, 2018).

1.2 Problem Statement

Access to electricity in Ethiopia's rural areas is very low and remains mainly inadequate, inefficient, and severely unreliable, negatively impacting socioeconomic growth as well as the lives and livelihoods of rural inhabitants. According to the IEA’s estimate, approximately 60 million people had no access to electricity in 2019, which is more than about 55% of the total population of the country. Electric energy access is a far-away dream for many families in rural areas in developing countries like Ethiopia where about 80% of the population are living in rural and remote areas in which only 30% of the population have access to electricity (Barnes et al., 2016). Furthermore, irregular power supply, commonly agreed to be about 48-70 hours of power outages per week in Ethiopia, causes load shedding. Electrical energy access influences living standards, which affects agricultural productivity, education, and the health status of society(Abdisa, 2018). Rural healthcare providers are unable to use technologies such as water filtering systems, refrigerators for vaccine storage, and television to boost health knowledge. Furthermore, nighttime births become more challenging, resulting in greater maternity and child death rates in the village, as well as difficulty retaining medical staff due to a lack of electricity, even for illumination. The lack of consistent energy supply to health centers makes health treatment more difficult and deployment in remote regions less appealing. It is also discouraging for health staff to work there for a long time without lighting and power for using electrical appliances.

Due to the steady increase in the price of fuel, most conventional power generation systems have become expensive leading to an increase in the price of health services. Those systems are also not advisable due to their impact on environmental health. Besides, they require high maintenance since they have many moving parts. Most recently, as amply blessed with sunshine, Ethiopia is directing an increasing interest in powering rural facilities with solar energy. However, the implementation of this strategy is not yet equipped with design and installation knowledge and capabilities. Specific to this case study, Lemba health center, in Gondar zuria woreda is completely off-grid, and conventional power coverage is not there yet. The workers of the center try to complement the inaccessibility of power with randomly purchased solar panels mounted on the roof sparsely. The most frequent challenge they come across with such an arrangement is that the power they get is not sufficient enough to power all the equipment that needs power. Also, off-shine and nighttime lighting are impossible because of the improper design of the battery. These mishaps would have been avoided if the power system of properly designed PV system components had been installed.

1.3 Objectives

1.3.1. General objective

The main objective of this thesis work is to design and analyze the performance of a stand-alone (off-grid) solar photovoltaic (PV) power system forLemba health center in Gondar-zuriya woreda by using simulation software (RET Screen Expert and HOMER).

1.3.2. Specific objectives

- To estimate the daily energy consumption of the selected health facilities
- To design the solar PV system that will provide the calculated power demand from the solar insolation using HOMER software
- To evaluate the performance of the designed solar system using performance indicators like power output, economic viability, etc. with RETScreen Expert software
- To analyze the cost of the overall systems

1.4 Scope of the study

This thesis work primarily focuses on the design and analysis of a stand-alone solar PV system for powering Lemba Health Center. The investigation is accomplished by using analytical and simulation software both at the design and performance analysis level which finally be subjected to validation with related works of literature. The economic viability of the solar system to supply the required power for the full functioning of the health center is evaluated using the design results extended to the payback period. Each component of the solar power system is designed to provide continuous power for the health center even when the sunshine is not there for a significantly longer time. All the information required for the design and analysis is collected primarily by direct reading and secondarily by reviewing previously done works and locally published documents.

1.5 Significance of the study

The project ensures access to affordable, reliable, sustainable and modern energy for healthcare services. The project has also an undeniable impact on conservation and enhances other social and environmental benefits. It will provide a power supply for the health center to use technologies such as water treatment systems, refrigerators to store vaccination and television to improve health knowledge. Solar electrification enhances the delivery of medical services through the provision of quality light during the treatment of nighttime emergencies, emergency deliveries and security purposes at the main building and staff quarters. It also facilitates the service of instant immunization of children at Health Centers that previously did not have a vaccine refrigeration system.

The project boosts the motivation and morale of health workers, whose living conditions are improved by having access to cheaper and higher-quality light to complete work at night and the ability to charge mobile phones, particularly in isolated rural locations without access to grid electricity. It can also improve private and professional contact among health workers in remote areas by providing electricity for phone charging, hence increasing medical care delivery efficiency.

1.6 Organization of the thesis

This thesis comprises seven main chapters with appendices at the end.

Chapter 1 Introduction: One of these chapters is the present introductory chapter, which summarizes the background, aims or objectives, the research question to be addressed, the scope and limitations, significance of the thesis work.

Chapter 2 Literature review: This chapter explores the literature on solar photovoltaic conversion, PV power systems, their components and their application to rural health centers. Previous studies on performance analysis and feasibility studies employing different optimization Software for various applications were critically discussed with strong arguments for the success of the results from the point of view of our objective.

Chapter 3 Materials and methods: This chapter presents the nature of the techniques used to collect and study the incident solar radiation and estimated load demand profile for the selected site. The procedure for designing the list of components and their cost analysis are briefly discussed.

Chapter 4 Solar PV System Design: Analyzing the energy demand and the incident solar radiation data collected, the proper sizing of every component of the solar PV power system is carried out in this chapter. The arrangement of the system, the array of modules and the batteries decided based on operational and product specifications is also clarified.

Chapter 5 Techno-Economic Analysis: under this section of the document, a detailed description of each step of the homer analysis is explained. The input variables, the selection of system components from the HOMER library with their detailed specifications and their arrangement and connection to form the whole power system are the subject of this chapter.

Chapter 6 Result and discussion: Both the design and optimization results of the respective setups with clear discussions are subsequently presented. A comparison of those results with each other and the existing literature is also the subject of this chapter.

Chapter 7 Conclusions and recommendations: This chapter details the conclusion drawn from the main findings of this research and the recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

This chapter presents a comprehensive review of solar photovoltaic (PV) power systems with their main components and types. This review will focus on the concepts behind the photovoltaic effect and its dependence on environmental factors of the site and design parameters of the system, along with appropriate tools to perform a techno-economic analysis of a standalone PV system for a health center. Approaches to the performance analysis of a given PV system are also part of this chapter. The numerical and experimental investigations performed to assess the feasibility of solar PV power systems are the focus of this chapter; the findings of these investigations will also be given with scientific comments.

2.1 Overview of solar energy technology

Solar power, as the paramount source of readily available energy, has seen technological breakthroughs in recent years, allowing for the effective harnessing of solar radiation. While the utilization of sunlight dates back to ancient times, modern advancements have enabled its conversion into two valuable energy forms: solar photovoltaic and solar thermal energy, with the former representing a pinnacle of technological sophistication. Access to energy stands as a cornerstone to kickstart social and economic development in all societies. Countries like Ethiopia, endowed with extensive solar potential ranging from 5.2 kWh/m^2/day to 6.9 kWh/m^2/day, boasting an average of 10 solar hours and over 300 clear sunny days annually, still grapple with a shortfall in energy and power generation relative to demand (Assefa, 1989). While the upfront expenses may be substantial, solar photovoltaic systems are progressively emerging as a compelling choice for powering electrical needs, especially in isolated areas, owing to their exceptional dependability, minimal upkeep needs, extended durability, and adaptability with customizable system sizing tailored to even the most modest load requisites (Mukherjee, 1997).

2.1.1. Solar Energy

Solar power sets the stage as the quintessential resource, universally available, renewable, uncontaminated, and bountifully bestowed upon the Earth in the radiant forms of light and heat. These forms of solar energy can be effectively captured through a diverse array of evolving technologies, such as solar photovoltaic systems and solar thermal conversions. The sun's energy reserves are copious, teeming with the potential to satisfy the global hunger for power consumption. By adeptly transforming solar radiation into practical energy forms, the world's energy demands could feasibly be met. Various technologies, including photovoltaic systems, solar heating, thermal energy harnessing, and artificial photosynthesis, leverage the sun's brilliance and warmth. Solar energy reigns supreme among non-traditional energy sources, classified as active or passive based on their conversion mechanisms. Active solar techniques encompass the utilization of concentrated solar power, photovoltaic systems, and solar water heating, while passive techniques involve architectural design approaches, such as orienting buildings to maximize solar exposure, all in service of harnessing the sun's boundless energy potential (Endaylalu, 2018).

2.1.2. Solar energy incident on a tilted surface

The most important parameters for designing a solar system are the sun's position, tilt, and orientation of the PV surface. The output power of photovoltaics is affected by the amount of radiation that reaches the surface of the collector. However, the incident radiation is flat or horizontal. Therefore, the solar radiation incident on the inclined surface is an inclined radiation component and must be calculated from the global horizontal radiation. PV modules are typically angled rather than horizontally mounted to maximize radiation collection and minimize cosine losses and reflections. Data on solar radiation on such titled surfaces is therefore necessary for system designers. However, the most common surfaces for measured or calculated radiation data are either horizontal or normal incidence. Consequently, sloping radiation must be created from this data. The orientation and slope of a terrestrial surface determine how much insolation occurs there for a specific period (Khamisani et al. 2015).

2.1.3. Solar Photovoltaic (PV) Systems

Photovoltaic systems are the fastest growing photovoltaic technology with improved efficiency of solar to electricity conversion and consist primarily of a large number of PV modules, inverters, charging controllers, and battery storage banks, each plays a very important role in the overall performance of any installed solar-PV system. Solar PV systems largely rely on solid-state semiconductor technology, which converts a portion of the incident solar radiation (photons) into DC (direct current) energy (Khamisani et al. 2015).

The initial cost of a solar system is still higher than the initial cost of a motor generator. There are many applications where the low operating and maintenance costs of a PV system outweigh the low initial cost of the generator, making the PV system the most cost-effective long-term option. PV power systems can become a major alternative energy source in the future based on their several positive attributes like low maintenance, free and inexhaustible energy sources and robust and long lifetime system components (Ani, 2016).

2.1.4. Types of solar PV systems

Depending on component configurations, functional and operational needs, and the way the equipment is connected to other power sources and electrical loads (devices), PV systems can be divided into the following categories:

a) Standalone

The term "stand-alone system" refers to a solar system that is not linked to a utility grid and frequently features a battery for storage that is intended to function separately from the electric utility grid. A standalone solar photovoltaic system is, in fact, one of the most promising renewable energy systems due to its adaptability to almost any size of installation (Assefa, 1989).

b) Grid-connected

Grid-connected or utility-interties systems are those that are interconnected with the utility grid where electricity generated can be used locally and the surplus electricity is exported to the utility's grid. This system can use the utility grid as a backup supply in place of storage batteries. The essential part of those systems, which are made to run in parallel with the main grid, is the inverter, also known as the power conditioning unit (PCU), which transforms the DC power generated by the PV array into AC power that satisfies the utility grid's requirements for voltage and power quality. In order to enable the power generated by the PV system to either supply to on-site electrical loads or to backfeed the grid when the PV system output exceeds the on-site load demand, a bi-directional interface is created between the PV system's AC output circuits and the electric utility network, usually at an on-site distribution panel or service entrance.

c) Hybrid

Hybrid systems can be based on either off-grid or grid-tide inverters. Hybrid systems are powered by a combination of two or more power sources. For example, solar power and other energy sources such as diesel generators and other renewable energy systems are often considered hybrid systems. However, a hybrid system can also consist of renewable energy and a power grid system that cannot supply power from renewable energy sources to the grid. This application runs on a grid network that does not have a net metering policy applied. Hybrid renewable energy systems are typically designed to operate in remote areas or islands where grid expansion costs are high. However, hybrid energy systems coupled with conventional energy sources have also been proven to reduce cost and simultaneously improve the reliability of the electrical power supply in many off-grid and weak grid-connected locations (Kiros et al., 2020)

2.1.5. Solar PV system components

Solar systems typically consist of four essential elements, which can be combined as needed. These components include the solar photovoltaic panel, batteries for storing and making power available at night, the 'balance of system' elements (such as the charge controller to prevent under or overcharging of the battery), and an inverter if AC appliances are used. (Tavares et al, 1997).

i. The solar panel

A solar panel is made up of interconnected solar cells, which are semiconductors that convert solar energy into direct current. Solar cells are primarily built of crystalline silicon, while thin-film silicon is now being utilized more frequently. Based on the material PV cells are made from and/or the process of production, they can be classified as (Ani, 2016).

a) Single crystalline or monocrystalline cells: - are made from wafers and trimmed into rectangular shapes to increase cell count in solar panels. They are known as the most readily available and efficient cells since they provide the most power per square foot of module.
b) Multi- or poly-crystalline cells: - are created by melting and pouring comparable silicon material into a mold, rather than growing it into a single crystal. This results in a square block that can be sliced into square wafers with less wasted space or material than circular single-crystal wafers.

c) Thin-film cells: - These are created by directly depositing gallium arsenide, cadmium telluride, and copper indium dieseline on glass, stainless steel, or other suitable substrate materials. In low light, some of them outperform crystalline modules by a little margin.
d) Amorphous silicon cells: -Created by covering rolls of stainless steel with a few micrometer-thick amorphous films made of vaporized amorphous silicon. 1% of the material is used in this process as opposed to crystalline silicon. (Khamisani, et al.,2015).

There are many different sizes and output levels of solar panels, ranging from one watt to several hundred watts. A solar panel's output is determined by its size, the quantity of direct sunlight it receives, its direction, and how clean it is. Although the exact output will depend on the solar insolation levels, the output is often determined by multiplying the panel's capacity (e.g., 50Wp) by the number of hours of sunlight per day (four to five hours) (Mukherjee, 1997). A solar system can be developed modularly by connecting multiple solar panels to multiple batteries to boost capacity. Considering the danger of theft or vandalism is necessary because it is the most expensive part of the system. Without significantly decreasing its production, a solar panel should last for roughly 20 years (Kumar, et al.,2018). A sufficient number of cells must be used to get an acceptable output voltage. PV modules are made up of series-connected PV cells that, in an average irradiation situation, have a voltage that is comfortably between the battery and system voltage.

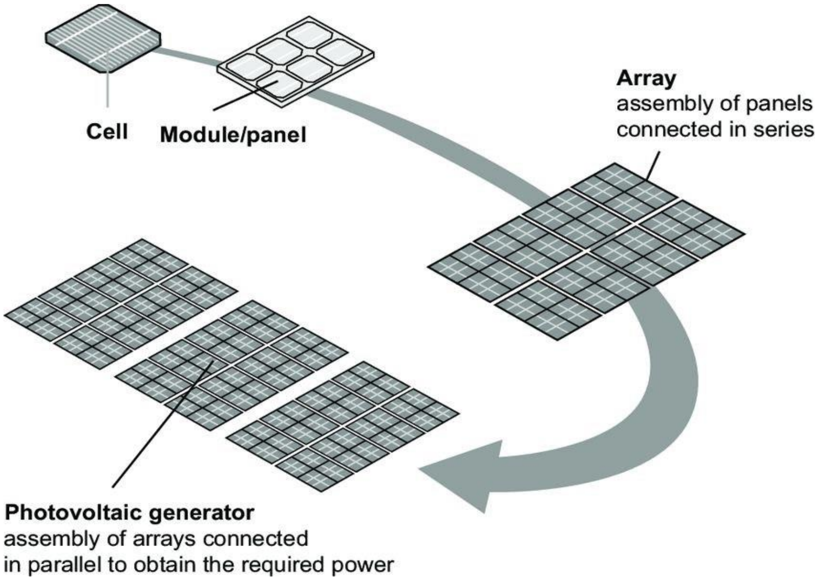


Figure 2.1 PV Array structural details (Endaylalu, 2018)

Figure 1.2 Solar photovoltaic (PV) cell and solar battery storage (Ndagijimana, et al., 2019)

ii. Battery

PV systems frequently include an energy storage mechanism since PV arrays only generate electricity when they are lighted. This allows the electrical energy to be stored for use at a later period throughout the day when it isn't as sunny. Lightbulbs, refrigerators, heaters, and other electrical appliances are connected to the battery, which stores the electricity produced by the solar panel. Larger PV systems are more likely to produce 24 V DC output, while 12 V is typically produced by the batteries. This implies that an inverter is necessary for AC equipment (see below). Although there are many different kinds of batteries, deep-cycle lead-acid batteries are the most often utilized and come standard in bigger systems. Car batteries are utilized in less expensive systems, but they are not made for severe discharge, and as a result, their performance—particularly their durability—is frequently subpar (GVEPInternational, 2013).

The number of charge-discharge cycles, proper maintenance, a reliable charge controller, and other variables like ambient temperature all affect how long a deep-cycle lead-acid battery lasts. It must, however, typically be able to endure for three to five years. A solar system's battery is frequently its weak point since improper use or neglect can significantly impair its performance. Due to poor installation quality and battery failure, several solar PV installations designed for Rwandan health centers and hospitals are no longer in use. Systems have been abandoned due to a lack of knowledge and upkeep. The environmental effect of batteries is also important to take into account because, if disposed of incorrectly, they can damage groundwater supplies. When the batteries reach the end of their useful lives, they must be recycled or disposed of safely. (Harsdorff, et al., 2009).

iii. Charge controller and Inverter

Battery life is negatively impacted by overcharging and over discharge, which the charge controller guards against. The charging controller is a crucial part of practically all battery storage systems because it turns off the PV array when the battery is fully charged and the load when the battery reaches a specific discharge level. To guarantee the best battery system performance under different charging, discharging, and temperature conditions, a controller for a system of batteries connected in series and parallel should be able to be adjusted. Direct current (DC) is changed to alternating current (AC) using an inverter. Only DC-operated appliances can be directly powered by the battery because of its DC output. (Khamisani et al. 2015).

However, most residential or medical gadgets require alternating current electricity. As a result, unless the system is extremely simple and merely comprises illumination in addition to charging the radio, phone, and battery, an inverter is required. However, this conversion comes at a cost because the inverter also draws power from the battery (Nafeh, 2009). Depending on its efficiency, an inverter might take anywhere from 15% to 50% of electricity. High-power appliances, such as an X-ray, will also require a large inverter capable of drawing the requisite peak power. The balance of the system must be precisely tuned to cope with the fast withdrawal of power (Mukherjee, 1997). Inverter selection will also depend on whether the inverter will be a part of a grid-connected system or a stand-alone system but is most commonly based on the waveform requirements of the load and the efficiency of the inverter (Ani, 2016).

Figure 2.3 Solar inverter and charge controller (Kumar et al., 2018)

2.1.6. Working principle of solar cells

The photovoltaic effect describes how solar cells directly convert sunlight into electricity. Solar energy, which travels as electromagnetic radiation, includes various forms such as light and radio waves. While the sun emits a broad spectrum of radiation, solar cells primarily utilize visible light. These cells employ semiconductor materials, primarily silicon, to generate electricity. A typical solar cell consists of two layers of silicon with distinct electrical properties: an n-type layer and a p-type layer. When sunlight strikes the cell, it excites electrons within the semiconductor material. These energized electrons then flow between the n-type and p-type layers, creating an electric current. This current, which can be either direct current (DC) flowing in one direction or alternating current (AC) where the current periodically reverses, is then collected through metal contacts.(Ani, 2016).

2.1.7. Equivalent electrical circuit of PV cell

Figure 2.4 shows the electrical circuit of a typical photovoltaic cell. The I-V characteristics curve illustrates how the internal resistance built up in the circuit during system operation connects the solar-generated current, diode current, shunt resistance, and shunt-leakage current in parallel and series.

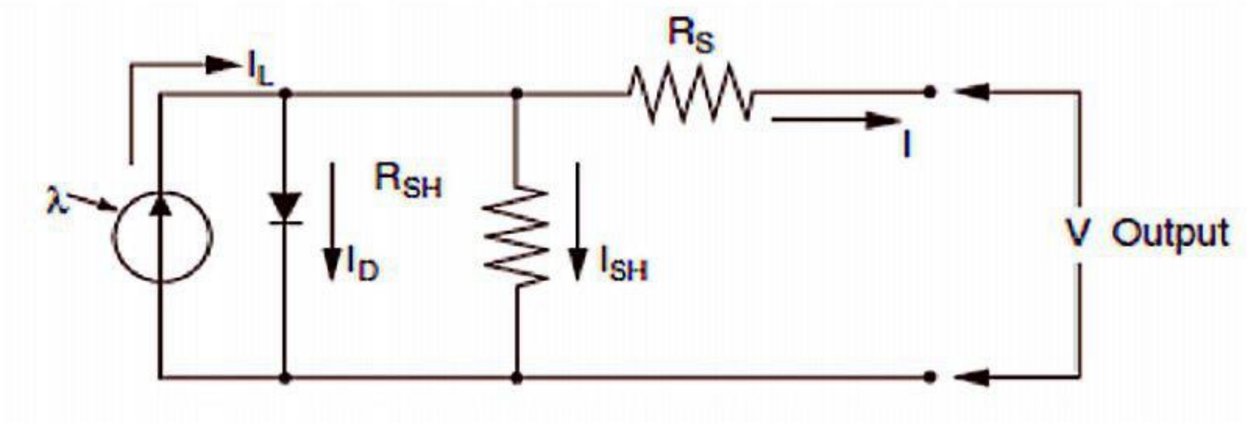


Figure 2.4 Equivalent electrical circuit of the PV module (Mu &Ya, 2019)

2.2 Software selection

Optimal sizing of a photovoltaic system, selecting an optimum number of PV modules, inverter, battery storage capacity, and tilt angle, is very critical to provide non-intermittent power for the intended application. That requires finding ultimate combinations for design parameters and testing the performance of the designed PV system using design and simulation software. Energy generated in PV systems depends mainly on solar energy available at the site which in turn depends on geographical location, ambient temperature, clearness index, tilt and orientation of the PV panel. The designer of the system should consider all those factors while sizing the solar PV system which is almost manually impossible. Doing so needs computing aid so that the final size of the system selected would satisfy the power demand of the client.

HOMER, a sophisticated tool created by the National Renewable Energy Laboratory (NREL), has been under development since 1993. This computer model was developed to aid in the design of micropower hybrid systems, allowing for the comparison of various types of power production technologies across a wide range of applications. HOMER, which models a power system's physical behavior as well as its life-cycle cost, enables the comparison of numerous design solutions based on technical and economic merit. One of HOMER's most significant advantages is its capacity to help comprehend and quantify the consequences of uncertainty or changes in inputs. HOMER can be used to build on-grid and off-grid micropower systems that include any combination of photovoltaic (PV) modules, small hydro, wind turbines, biomass power, microturbines, reciprocating engine generators, fuel cells, batteries and hydrogen storage. HOMER's primary duties are simulation, optimization, and sensitivity analysis to achieve the best possible results.

2.3 Related works

Most countries' present issues in assuring access to oxygen therapy in remote health facilities are tied to their healthcare systems. In addition to dependable power sources, hospitals and health districts require local technicians with maintenance expertise and ready access to spare parts, health workers who are familiar with the technology, clinical quality improvement programs, and stable financing, procurement, and replacement mechanisms for equipment. The World Health Organization recently issued updated guidelines for children's oxygen therapy as well as oxygen concentrator requirements. These guidelines are intended for health professionals, engineers, technicians, managers, and policymakers in low- and middle-income nations (Duke et al.,2016). Most of the health centers in Ethiopia that are found in rural and remote areas require an environmentally clean power supply. At the same time, the electrical load of the health centers is critical and requires continuity of the power supply.

(Hassan et al., 2010) Conducted a study of a completely stand-alone solar power system design for an emergency clinic using HOMER analysis software assuming typical daily energy consumption profiles for the four seasons. According to their result, the load data, the solar resource data and the investment cost-dependent sized solar power system will provide very beneficial and economical power for health centers (Hassan et al.,2010). Given the continuously decreasing cost of the PV system components with increased efficiency and reliability, the PV power system is potentially the preferable energy alternative for rural health facilities. An added importance of the solar power system especially for health centers is maintaining a clean and noiseless environment which makes the center ideal for patients. (Babatunde et al., 2019) Carried out a technical and economic evaluation to opt for off-grid hybrid energy system combinations based on photovoltaic (PV) and wind using HOMER software. The result shows that the solar PV system by itself or combined with any other energy source adequately meets the electrical energy demand of the health center subjected to the investigations (Babatunde et al, 2019).

(Tim et al, 2016) present the sizing of an offshore PV power system for a health facility. Their design shows that the daily load demand of an average health center for at least three days of autonomy can be satisfied by using reasonable PV modules (Tim Umoette, 2016). In addition to design optimization, the site selected for installation also affects the performance of the solar power system. Lower temperatures and speedy wind ambiance have been proven to be ideal spots to mount solar panels. (Duke et al, 2016) researched to determine the feasibility of using solar-powered medical equipment and powering health facilities on a large scale. As lack of reliable power is a significant obstacle to the use of basic medical instruments in rural and remote areas where access to conventional sources of power is logistically difficult and costly, the result of their study shows that solar photovoltaic power is needed to prevent deaths from emergency sickness and other serious illnesses in newborns, children and adults. The feasibility study shows that solar energy is an increasingly attractive option for meeting the power needs for lighting and other basic types of equipment of remote health centers to provide safe and effective 24 hours a day service.

(Babatunde et al., 2019) Presented an economic study of Nigeria's off-grid photovoltaic system based on the necessary load energy and geographic data. The energy requirements of various healthcare facilities in relation to patient capacity and services rendered, as well as the dependability of all power sources that offer rural health facilities the best possible power supply. Classifying health centers based on their energy need, they claimed that access to reliable, affordable and appropriate energy solutions for basic vital needs in rural health centers differs from one healthcare facility to another(Franco et al., 2017). Based on their classification, most of the rural Ethiopian health centers, like Lemba health center, fall under a category that can easily be supplied by solar energy. From this assessment, the solar PV power system is a very promising alternative to other conventional sources due to the abundance and complexity of the production technology. (El Shenawy et al, 2017) Carried out an economic analysis of a stand-alone solar PV power system to power rural health centers and schools. Considering the 20-year lifetime of mono-crystalline PV arrays, the initial cost of installation of a PV system is worth costing. This also gets more encouraging to take a fair interest when high irradiation levels and large sunshine hours are guaranteed in Ethiopia.

The design procedure of a solar PV system should be carefully done for each case of a health center because the main parameters of the design, the incident solar radiation and the power demand are specific to each specific health center. Software power evaluation of the design system will let the analytical design correct itself before installation. Among all the software, RETScreen Expert and HOMER have proven to be the most accurate and all-around for rural facilities (Manoj Kumar, 2017).

The selection of the software for each specified job can be subjected to several factors namely user-friendliness or simplicity of the graphical interface, the range of activities it encompasses (working capacities), external privileges it allows (like connectivity with other software), data requirements, commercial and educational availability and cost, working platform, scope and output, updatability, etc. (Sharma et al. 2014). The desirable simulation software for PV systems depends on the purpose of their use, specific area of application, or specialization (particular job). No design and simulation tool addresses all issues related to implementing solar energy, but instead, the ‘ideal’ tool is highly dependent on the specific objectives that must be fulfilled. Based on their intended use, the packages can be divided into simulation tools, economic evaluation tools, tools connected to the photovoltaic sector, tools for analysis and planning, tools for monitoring and control, solar radiation maps, and other web software (Sharma et al., 2014).

CHAPTER THREE

METHODOLOGY

In this chapter, the whole list of procedures and equipment used to solve the main and aforementioned problems are outlined. The data collection mechanisms, the design and performance analysis techniques and economic analysis strategies are discussed under a separate subsection. Other auxiliary activities like calculating the available incident solar radiation, analyzing the estimated electrical load of the site, specifying the characteristics of components, etc. are also explained clearly.

3.1 Approach and Method

3.1.1 Data Collection and Analysis

The required data for the design analysis was collected in two ways. Primarily, the power rating and the length of time each piece of equipment is being used were recorded on-site data collection. The daily solar radiation incident in a specific area on the campus of the health center was recorded directly. Secondarily, the metrological data for as long as possible was collected from the local metrological authorities which are used in line with the instantaneous weather data from NASA. The baseline and scaled hourly solar data are graphed using time series and duration curves in Appendix B and C respectively.

The raw data collected was organized and analyzed in such a way that it was informative to represent the total energy demanded that has been used in the system selection. In that respect, the data was tabulated so that it can display a clear image of the center's energy demand with main medical instruments in the top rows and the supplementary appliances at the bottom of the table with a possible number of each item functioning at the time the data collection and the predicted need as the center officials proposed to access. In addition to the analytical design, the data were also analyzed in the HOMER software in the load profile tab while inputting the required load for the optimization.

i. Estimation of power demand

Health institutions have varying energy requirements based on the services they provide and the necessary loads. Some basic services include vaccine refrigeration, lighting, medical equipment, and surgical care. Communication, water pumping and heating, space heating, and cooling are among the many services offered. To create reliable energy systems, it is necessary to carefully examine all areas of health facility energy needs, considering actual energy needs, future load increases, and electric and thermal energy needs.

When determining the sort of electricity required to sustain everyday operations, a facility must first assess its basic requirements. The needs assessment includes an inventory of the facility's equipment types and the power requirements for each item. Understanding the typical "daily load," or the amount of electricity necessary to operate equipment under regular working conditions, influences the power supply selection process. Once the daily energy requirement has been determined, a variety of electrification alternatives are evaluated.

From the power rating of medical equipment and other supplementary appliances and their average duty hours, the total energy consumption of each facility was calculated using equation (3.1)

$$Daily\ energy\ consumption\ \left(\frac{kWh}{day}\right) = \frac{power\ rating\ (W)}{1000\,\frac{W}{kW}} \times \frac{hoursused}{day} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ (3.1)$$

The total daily energy consumption for the whole health center was calculated by the summation of the daily energy consumption of each piece of equipment in the center that demands significant power.

ii. Sun-earth angle

The amount of solar radiation that falls on the earth's surface at any particular moment and location is determined by its orientation and tilt. System designers want data on solar radiation on the surface of flat plate collectors mounted at a specific fixed angle. However, the majority of the measurement data pertains to either vertical or horizontal incidence. As a result, it is frequently required to transform this data into sloping radiation. This information can be utilized to produce reliable estimates of slope radiation.

Liu and Jordan established an empirical approach for estimating the monthly average daily total radiation incident on a tilted surface in 1977. The ratio of daily radiation on a tilted surface (H_t) to the daily global radiation on a horizontal surface (H_g) can be calculated using equation (3.2)

$$\frac{H_t}{H_g} = \left(1 - \frac{H_d}{H_g}\right) R_b + \frac{H_d}{H_g} R_d + R_r \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where R_b= tilt factor for beam radiation

$$R_b = \frac{\omega_{st} sin\delta \sin(\emptyset - \beta) + cos\delta \; sin\omega_{st} \cos(\emptyset - \beta)}{\omega_s \sin\emptyset \; sin\delta + cos\emptyset \; cos\delta \; sin \, \omega_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.3)$$

Where $\emptyset$ = latitude of the location

β = tilt angle

δ = declination angle=23.45 sin ($\frac{360(284+n)}{365}$)where n = representative day of the year

ω_s = sunset or sunrise for horizontal surface = $cos^{-1}(-tan\emptyset \; tan\delta)$

ω_{st} = sunset or sunrise for tilted surface = $cos^{-1}(-\tan\,(\emptyset - \beta)\; tan\delta)$

R_d = tilt factor for diffused radiation $= \frac{1+cos\beta}{2}$

R_r = tilt factor for ground-reflected radiation

= $\rho(\frac{1-cos\beta}{2})$ where ρ is ground reflectance usually taken to be 0.2 if there is no snow

$\frac{\mathrm{H_d}}{\mathrm{H_g}} =$ Daily diffuse to global radiation ratio

$$\frac{\mathrm{H_d}}{\mathrm{H_g}} = 1.390 - 4.027\left(\frac{H_g}{H_o}\right) + 5.531\left(\frac{H_g}{H_o}\right)^2 - 3.108\left(\frac{H_g}{H_o}\right)^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots (3.4)$$

Where $H_o = \frac{24}{\pi} I_{sc}(1 + 0.033 \; cos \frac{360n}{365})(\omega_s sin\emptyset \; sin\delta + cos\emptyset \; cos\delta \sin \omega_s)$

Where I_{sc} = solar constant

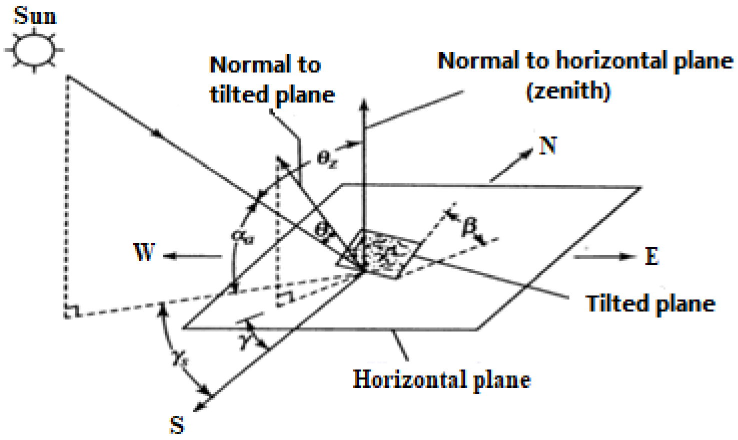


Figure 3.1 Sun-earth angles (Kalogirou, 2014)

3.1.2. Design of all the components of the solar power system

With the design objective of achieving the estimated power demand of the health facility with the given estimated incident solar radiation and other site considerations, each component of the solar PV power system was designed and selected with a sufficient area of the PV panels and a proper electric system schematic being guaranteed. The design has also considered the availability of the components and their compatibility with the common configuration of a stand-alone PV system and the specific installation requirements of the site selected. All the efficiency and wiring losses were also carefully considered in addition to the power ratings of each equipment in the facility to avoid under-sizing.

3.1.3. Market Survey

Detail information was obtained about all the instruments and components regarding price, rating, availability, functions, performance, etc. from an onsite market survey of local markets and an online market visit on Alibaba's official website based on the designed capacity and quantity so that the system will be affordable for all the health centers in the region. The surveyed price with detailed specification and availability data was presented in Appendix A.

3.1.4. HOMER analysis procedure

The National Renewable Energy Laboratory (NREL) developed a software application called HOMER Pro (version 3.11.2) to perform the optimal design and techno-economic feasibility study of the PV system.HOMER is a computationally simplified model for building both on-grid and off-grid distributed generation (DG). HOMER's optimization and sensitivity analysis algorithms enable the user interface to evaluate the economic and technical viability of a wide range of technical choices, taking into account swings in technology costs and energy resource availability. Ideal for developing micropower systems. It comprises an extremely powerful computational engine, logical units, and the real interface between the system and the user. It provides three functional models of conventional and renewable energy technologies: power source (solar photovoltaic, wind turbine, run-of-river hydropower, electric utility grid micro turbine, fuel cell) and generator (diesel, gasoline, biogas, alternative and custom fuels, co-fired). Battery banks, hydrogen, flow batteries, and flywheels are all storage options. Loads include daily profiles with seasonal variations, deferrable (water pumping, refrigeration), thermal (space heating, crop drying), and efficiency metrics. HOMER Pro offers the advantage of allowing you to run thousands of simulations in seconds using simplified non-differential optimization. To perform the techno-economic analysis using this software, a variety of input parameters are required, including hybrid system components with their economic and technical characteristics, local electric or heating load demand, solar energy data, system economics, and constraints and variability factors, as demonstrated in the following sections.

HOMER proposes an energy system that can meet electrical energy demand at the lowest overall net present cost (NPC), subject to other technological constraints. It can also run sensitivity studies on input variables. HOMER simulates a system's operational characteristics by maintaining energy balance controls at each time step throughout the year. The electric and thermal loads in each time step are compared to the energy the system can provide. When batteries and fuel-powered generators are added to the system, HOMER prioritizes the generator operation for each time step, determining whether to charge or discharge the batteries using load following (LF) or cycle charging (CC). Once the need is met by combining the components, the system's lifespan cost (discounted sum of initial investment, replacement, operation and maintenance, fuel and interest charges) is calculated. Furthermore, sensitivity analysis can be used for the stochastic input. HOMER software is used in this investigation (see Figure 3.2).

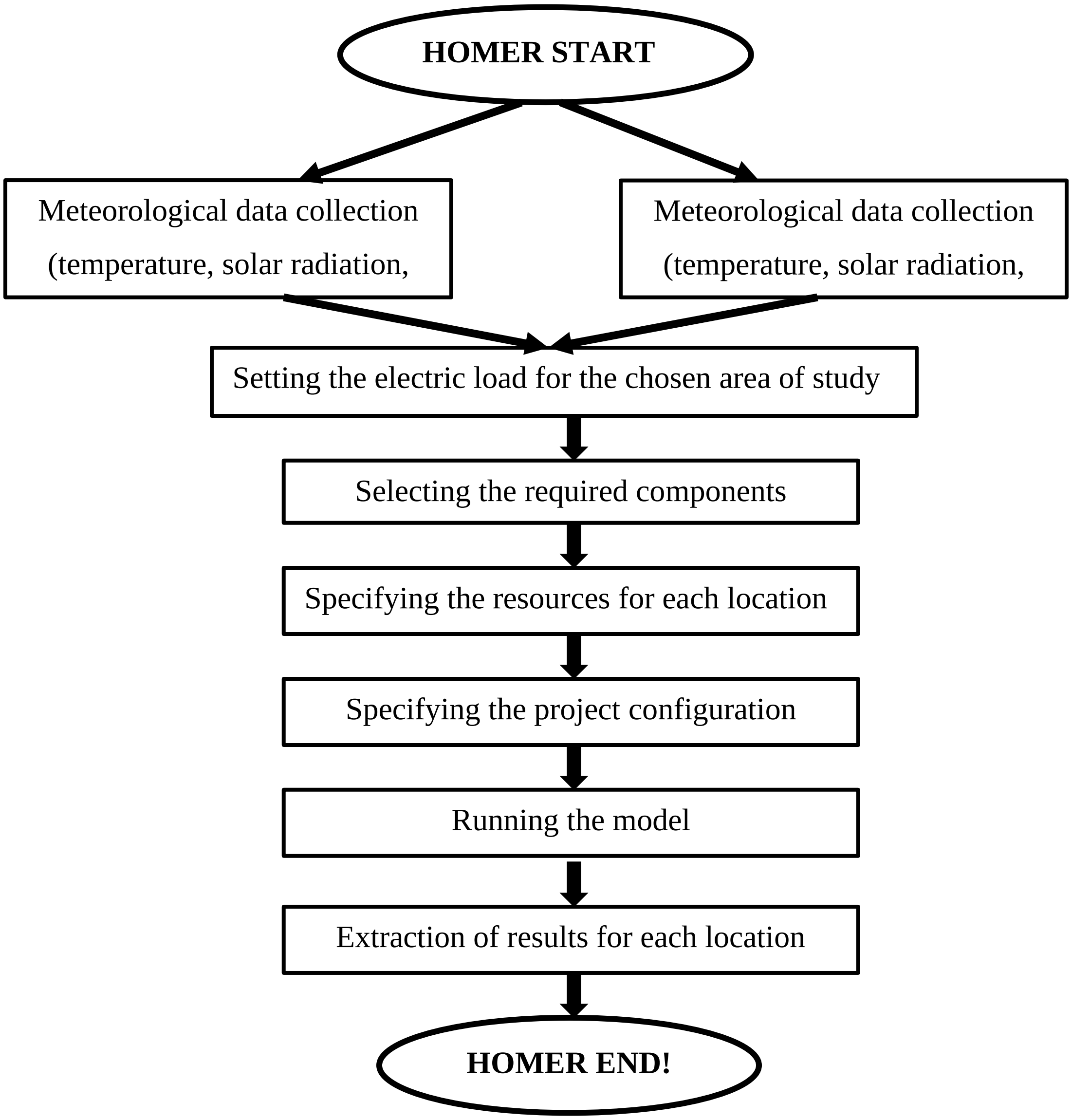


Figure 3.2 HOMER analysis workflow chart

The procedure and the method of implementing project objectives were summarized in the schematic diagram in Figure 3.3.

The suggested system consists of a diesel generator, PV, wind turbine, battery, and converter. The generator considered in the research follows the general parameters supplied by the HOMER program.

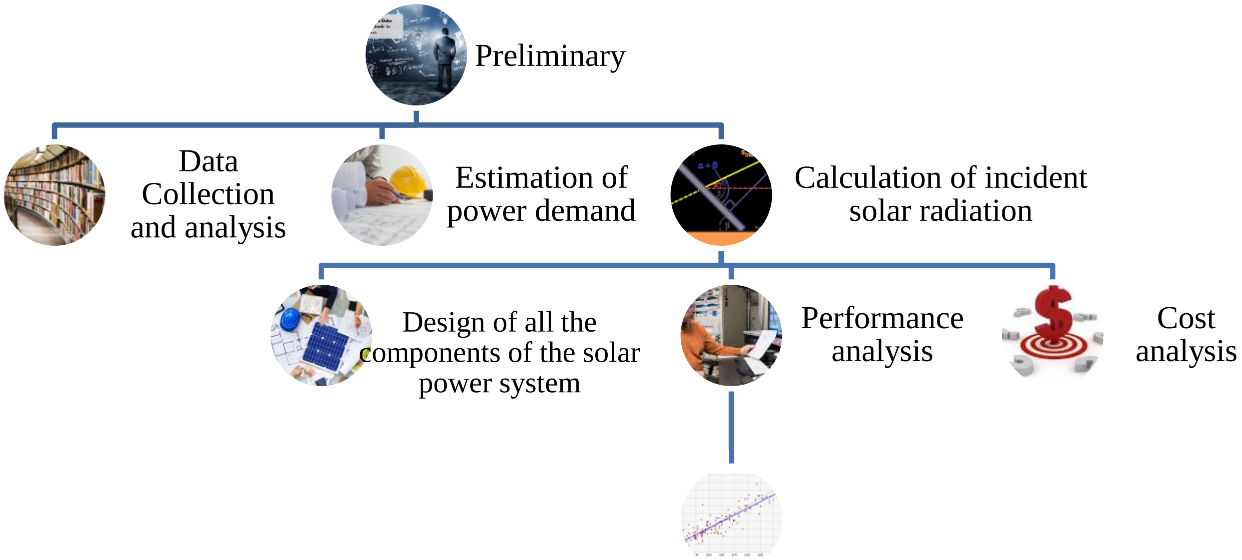


Figure 3.3 Schematic workflow diagrams

The schematic illustrates the application of a structured research methodology, characterized by a set of principles and procedures for conducting scientific investigations. This methodology guides research by providing a framework for selecting and coordinating research activities.

In this investigation, the methodology commenced with the collection of meteorological data and energy demand through site surveys. Subsequently, the collected data was analyzed, followed by the design of all necessary components of the solar PV system. The performance of each component was then evaluated using HOMER PRO and RETScreen expert software, as depicted in Figure 3.3.

CHAPTER FOUR

SOLAR PV SYSTEM DESIGN

This chapter focuses on data gathering, analysis, and the step-by-step design of solar power system components. The data collection process includes estimating energy consumption and available resources through site surveys, geographical and metrological research. Following that, each component of the system was selected and sized so that it corresponded to the power requirement generated by the available solar radiation.

Solar photovoltaic (PV) power plant design encompasses several crucial aspects, including the determination of appropriate sizes for PV modules, inverters, and batteries, as well as the strategic configuration of module circuits. These are determined by the estimated demand profile and incident solar radiation data that has been gathered. Geographical information and site meteorological data are necessary for solar PV plant design. The energy flow pattern from producer to consumer or consumer to producer should guide the sizing and selection of all necessary equipment with adequate capacity. Figure 4.1 shows the path of energy flow from the center of production to the center of consumption.

Figure 4.1 Energy flow pattern of solar PV power system

4.1 Site information

To accurately assess the size of the PV system, meteorological or environmental data for the site location in question had to be collected. Solar energy incidence in the considered site is extremely high, particularly during March and April. Table 4.1 displays the monthly average values of global solar radiation above the Lemba health center, as calculated from the NASA RETScreen website using the site's latitude and longitude. The site inspection and observation focused on existing practices based on energy consumption and electricity demand for each industry segment. Furthermore, all areas have been visited to determine the effectiveness of the current energy requirement. During the site visit, photos and some critical data were obtained to demonstrate the current state of Lemba Health Center.

Table 4.1 Incident solar radiation for Lemba Health Center (NASA CERES EBAF dataset accessed via NASA Power Data Access Viewer (PDAV) on August 15, 2022)

Month	**Daily Radiation in KWh/m^2 /day**
January	6.23
February	6.61
March	6.74
April	6.86
May	6.43
June	5.91
July	5.27
August	5.28
September	5.82
October	5.99
November	6.24
December	6.02

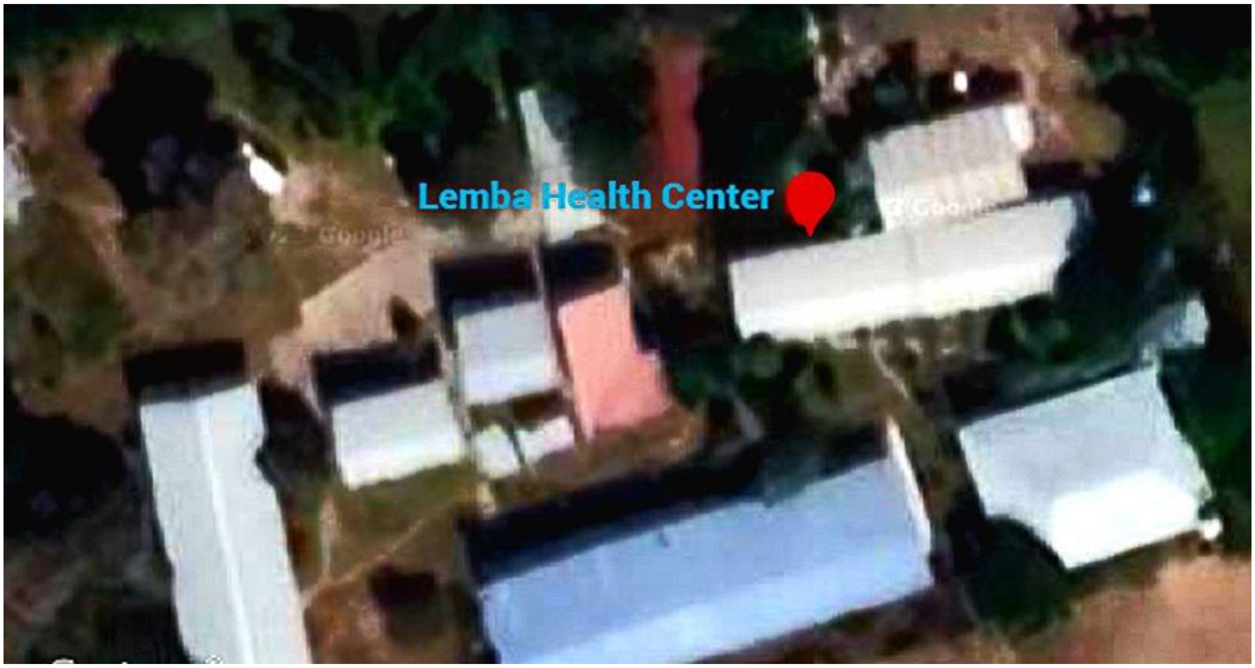


Figure 4.2 Areal view of Lemba Health Center (source: Google Earth, 2024, Location: 12°22' N 37°29' E)

4.2 Estimation of power demand

In order to provide care and diagnosis, charge mobile phones for communication, protect vaccines and other pharmaceuticals in portable cooler units, and power necessary equipment like lights, water pumps, lab equipment, and numerous other critical medical devices, the health center needs power. Since determining the system load to match the available energy source is the first step for any photovoltaic system designer when planning a stand-alone system, electric load estimation and forecasting for the health center's basic needs have been completed from onsite data collection. Given the variation in solar insolation during the summer rainy seasons, this was a difficult undertaking. Furthermore, the daily demand for such a facility may not necessarily remain consistent throughout the year (Al-Akori, 2014). The target facility is a health center the energy consumption profile is unpredictable except for some ordinary lighting systems for example external lighting which has to be turned on only at night times.

Table 4.2 Summary of estimated total power and energy consumption of Lemba Health Center (source: -site survey compiled data)

S/No	**Appliances**	**Unit Power Rating(W)**	**Possible number of units**	**Daily hours (hr/day)**	**Total Power (Watts)**	**Daily energy consumption (kWh/day)**
1	Infant Radiant Warmer	800	2	3	1600	4.8
2	Microscope	30	2	4	60	0.24
3	Vertical pressure steam sterilizer	4500	1	2	4500	9.0
4	Centrifuge	280	1	1	280	0.28
5	Refrigerator	220	2	24	440	10.56
6	Autoclave sterilizer	600	1	2	600	1.2
7	Oxygen concentrator	600	1	8	600	4.8
8	Mechanical ventilator	125	1	8	125	1.0
9	Hematocrit	100	1	3	100	0.3
10	Weight scale	10	2	1	20	0.02
11	Water boiler	1200	2	1	2400	2.4
12	Gynecological examination lamp	100	2	2	200	0.4
13	Indoor lighting lamps 4-inch tubes	40	21	12	840	10.08
14	External lighting lamps	100	3	12	300	3.6
15	Desktop computer	150	2	12	300	3.6
16	Laptop computer	65	3	3	195	0.585
17	Printer	120	1	1	120	0.12
18	Internet router	20	1	24	20	0.48
19	Mobile charging	5	14	3	70	0.21
20	Fan	20	3	4	60	0.24
21	Television	100	2	18	200	3.6

S/No	**Appliances**	**Unit Power Rating (W)**	**Possible number of units**	**Daily hours (hr/day)**	**Total Power (Watts)**	**Daily energy consumption (kWh/day)**
22	Cooking stove	3000	1	1	3000	3.0
23	Electric kettle	1500	1	1	1500	1.5
24	Total				**17530**	**62.015**

4.2.1 Panel Generation Factor

PV system size is dictated by the worst month condition; the month with the largest load and the lowest average solar radiation. The Panel Generation Factor plays a critical role in the successful design and sizing of solar photovoltaic (PV) systems. For each site location, it indicates the peak watt (Wp) capacity in Wh/day we can get from a panel.

$$PanelGenerationFacto = \frac{\mathrm{M}inimumd\mathrm{ailySolarRadiatio}n}{\mathrm{StandardTestConditionIrradianceforPVpanel}} \dots\dots\dots\dots\dots\dots\dots (4.1)$$

$$= \frac{5.27 \times 10^3}{1000} = 5.27$$

4.3 Energy required from PV modules

PV modules put at a specific site should supply the daily energy demand of the facility plus compensation for system losses, which are commonly assumed to be 30%, therefore the total energy required (Tim, 2016).

$$\text{Energy require} = \text{Energy Demand} \times \text{System Losses Compensation Factor} \dots\dots\dots\dots\dots. (4.2)$$

$$= 62.015 \times 1.3 = 80.6195 \text{ kWh/day}$$

4.3.1 Watt Peak rating for PV modules

The total peak Watt rating for PV modules determines system sizing, which depends on the energy consumed by modules and the panel generation factor.

$$\text{peak } watt\mathrm{ratingforPVmodule}s = \frac{\mathrm{EnergyrequiredfromPVmodule}s}{\mathrm{Panelgenerationfacto}r} \dots\dots\dots\dots\dots\dots\dots\dots.. (4.3)$$

$$= \frac{80.6195}{5.27} = 15.3 \; kWp$$

4.3.2. Number of PV modules

After determining the total power demand for the PV system, the next step is to calculate the required size of the solar panels to generate the necessary electricity. Using a 300W PV panel, the required number of modules required to provide the calculated output power will be (Ndagijimana et al., 2019)

$$\text{Number of modules required} = \frac{\text{Totalpeak wattrating}}{\text{PVmodulePeakRatedOutput}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(4.4)$$

$$= \frac{15.3 \times 1000}{300} = 50.99 = 51\ pv\ modules$$

≈ 60 for an even number of arrays.

4.4 Module circuit

The module circuit within a solar array refers to the series connection of solar panels, significantly influencing the array's size, the voltage supplied to the inverter, and the overall number of arrays required for the system.

4.4.1 PV Panels in Series

The number of modules in series (Ns) is determined by dividing the designed system voltage $\mathrm{V_{system}}$ (usually determined by the battery bank or the inverter) or maximum open circuit voltage of inverter and the nominal module voltage $\mathrm{V_{module}}$ at standard test conditions (STC)

$$\text{number of modules in onearray} = \frac{\text{maximum open circuit voltage of Inverter}}{\text{Open circuit voltage}} \dots\dots\dots\dots(4.5)$$

$$= \frac{600}{39.9} = 15.04\ modules$$

Then the total number of arrays in the solar field will be

$$\text{number of arrays} = \frac{\text{t}otalnumber\ \text{of modules}}{number\ of\ modules\ in\ onearray} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..\dots\dots(4.6)$$

$$= \frac{60}{15} = 4\ arrays$$

Table 4.3 Electrical specifications of the PV module

Electrical Characteristics	Test uncertainty for P_{max} =±3									
Model number	LR6-60PE-300M		LR6-60PE-305M		LR6-60PE-310M		LR6-60PE-315M		LR6-60PE-320M	
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power(Pmax/W)	300	222.2	305	225.9	310	229.6	315	233.4	320	237.1
Open circuit voltage (Voc/V)	39.9	37.2	40.2	37.5	40.5	37.8	40.8	38.1	41.0	38.3
Short Circuit Current (Isc/A)	9.96	8.03	9.99	8.05	10.02	8.08	10.05	8.10	10.14.	8.17
Voltage at max power (Vmp/V)	32.3	29.8	32.7	30.2	33.1	30.6	33.5	30.9	33.7	31.1
Current at max power (Imp/A)	9.28	7.44	9.33	7.48	9.36	7.51	9.41	7.55	9.50	7.62
Model efficiency (%)	18.3		18.7		19.0		19.3		19.6	
STC (Standard Testing Condition): Irradiance 1000W/m^2, Cell Temperature 25 °C, Spectra at AM 1.5										
NOCT (Nominal Operating Cell Temperature): Irradiance 800 W/m^2, Ambient Temperature 25 °C, Spectra at AM 1.5, wind speed at 1 m/s										

4.5 Inverter selection

Inverters in photovoltaic (PV) systems must have a power capacity exceeding the combined power rating of all connected AC appliances. This ensures they can handle the maximum anticipated power demand. A common practice is to oversize the inverter by 20% to accommodate potential fluctuations.

The appropriate inverter size is determined by the peak power demand, ensuring it can handle the total wattage requirement. A typical guideline is to select an inverter that is 25% to 30% larger than the total estimated power consumption.

$$The\ inverter\ size = 1.3 \times 15.3\ kWp = 18.89KWp$$

One Leonics MTP-413F of 25kW capacity at 120Vdc is selected to convert the generated DC power to AC power.

Table 4.4 Technical specifications of inverter

Parameters	Inputs values
Number of MPP Trackers	2
Max.input current ($I_{dc\ max}$)	33.0/27.0 A
Max. short circuit current, model array	48.5/40.5 A
DC input voltage range (U_{dcmn}- $U_{dc\ max}$)	200-1000V
Feed–in start voltage ($U_{dc\ start}$)	200V
Nominal input Voltage ($U_{dc,r}$)	600V
MPP voltage Range ($U_{mpp\ min\text{-}Umpp\ max}$)	420-800V
Usable MPP voltage range	200-800V
Number of DC connections	3+3
Max PV generator Power ($P_{dc\ max}$)	30KW_{peak}

4.6 Sizing of Battery system

In a stand-alone photovoltaic (PV) system, the battery storage system is a crucial component due to the intermittent nature of solar energy generation. Designing an off-grid power plant necessitates a robust storage medium capable of storing sufficient energy to sustain the operation of medical appliances during periods of low or no solar radiation, such as nighttime and cloudy days.

Table 4.5 Specifications of the battery

Manufacturer	EnerSys
Battery Model	PowerSafe SBS 400
Nominal Voltage	48V

Depth of Discharge	50%
Battery Capacity	100
Battery Efficiency	90%
Life of a Battery	4 years

$$\text{Battery capacity} = \frac{\text{TotalWh required} \times \text{DaysofAutonomy}}{\text{Nominal BatteryVoltage} \times (1 - \text{DOD}) \times \text{Batteryefficiency}} \ldots\ldots\ldots (4.7)$$

$$= \frac{62015 \times 2}{48 \times (1 - 0.5) \times 0.9} = 5742.13Ah$$

The total number of batteries required depends on the capacity of each battery with SmatLi-672V-200AH-F/S

$$\text{Number of Batteries} = \frac{\text{BatteryCapacityRequired}}{\text{SingleBatteryCapacity}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.8)$$

$$= \frac{5742.13}{100} = 57.42 = 57 \; batteries$$

The generated electricity can be consumed immediately or stored (for example, in batteries) for later consumption at night.

4.7 Sizing of the charge controller

The primary role of a charge controller in a photovoltaic (PV) system is to prevent overcharging of the battery bank. During the charging process, the voltage across the lead-acid battery gradually increases. This voltage rise occurs due to the internal resistance of the battery, which opposes the charging current (Iq). To ensure optimal battery lifespan and safe charging, the charge controller must be capable of handling the maximum current output of the PV array, which is typically its short-circuit current.

$$\text{Solar charge controller rating} = \text{n}umber\ of\ modules \times I_{sc} \times 1.3 \ldots\ldots\ldots\ldots\ldots\ldots (4.9)$$

$$= 57 \times 9.96 \times 1.3 = 738\ A$$

4.8 Economic analysis of the PV plant

The initial cost of microgrids is frequently a barrier to their implementation. The financial costs of dispersed energy resources are thought to be higher than those of centralized power-producing systems. When compared to the cost of establishing high-voltage transmission lines, solar PV systems are more likely to be cost-effective.

To determine whether the PV plant is price competitive when compared to other renewable powerplant options such as wind and biogas power plants, a financial assessment should be performed using realistic values or current market prices for the components associated with the overall implementation. The plant cost includes

- ✓ Cost of Modules
- ✓ Cost of Batteries
- ✓ Cost of Inverters
- ✓ Miscellaneous {Operation and Maintenance cost, Installation Cost, Electrical Items (Cables, etc.), Packing and Freight}.

Table 4.6 Cost estimation (Source: online price cataloged)

Item	Specifications	QTY	Unit price (USD)	Total price (USD)
PV module	300W monocrystalline	60	60	3,600
Battery	48V 100Ah	57	165	9,900
Inverter	20kW	1	1,128	1,128
Controller	60A 48V	13	175	2,100
Total				16,728

CHAPTER FIVE

TECHNO-ECONOMIC ANALYSIS

The Hybrid Optimization Model for Electric Renewables (HOMER) software was utilized as the design and optimization tool for this project. HOMER incorporates models of various energy components and evaluates the feasibility of different technological solutions based on available budget and resources. To effectively use HOMER, it requires data on solar resources, energy consumption patterns, economic constraints, control strategies, and detailed information about the types, quantities, costs, efficiency, and lifespan of system components.

5.1 Solar energy resources

In this section, the solar resource raw data of monthly average daily solar irradiance (kWh/m^2 /day) and clearness index downloaded from National Renewable Energy Lab and NASA surface meteorology using latitude, longitude and time zone of this area and solar energy database are used as an input to HOMER. Lemba health center is located in the south of Maksegnit town as shown in Fig 5.1. specifically, at 12°22′ N and 37°29′ E.

Using the spotted specific location as an input on HOMER, the monthly average global horizontal solar insolation which will be used as a resource input for the analysis was downloaded as shown in Figure 5.2. The bar chart shows the monthly average daily solar irradiance (kWh/m^2 /day), and the line graph indicates the clearness index for the selected site. It is observed that the highest solar potential occurs in April whose peak value is 6.89 kWh/m^2 /day. On the other hand, the lowest solar potential is found during July with a pick value of 5.27 kWh/m^2 /day.

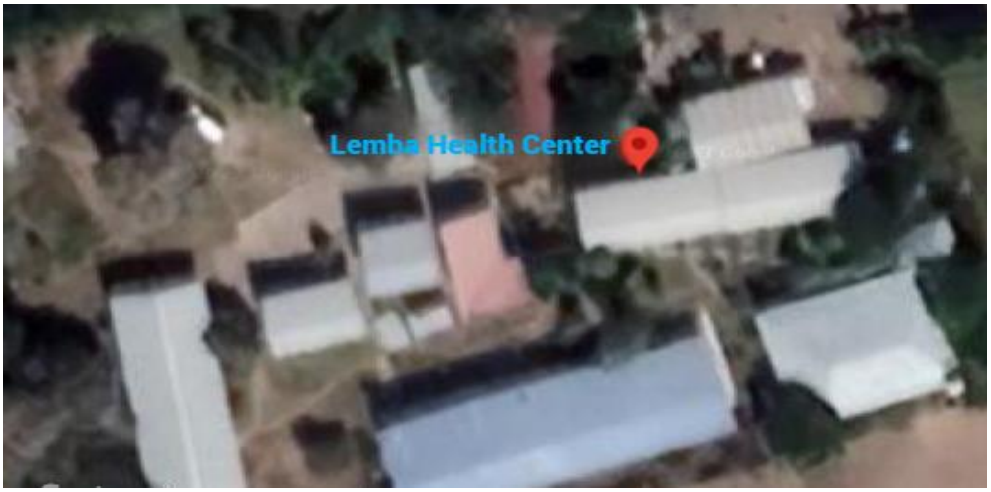


Figure 5.1 Location of the site (Google Earth, 2024, Location: 12°20'03.3"N 37°31'34.8"E)

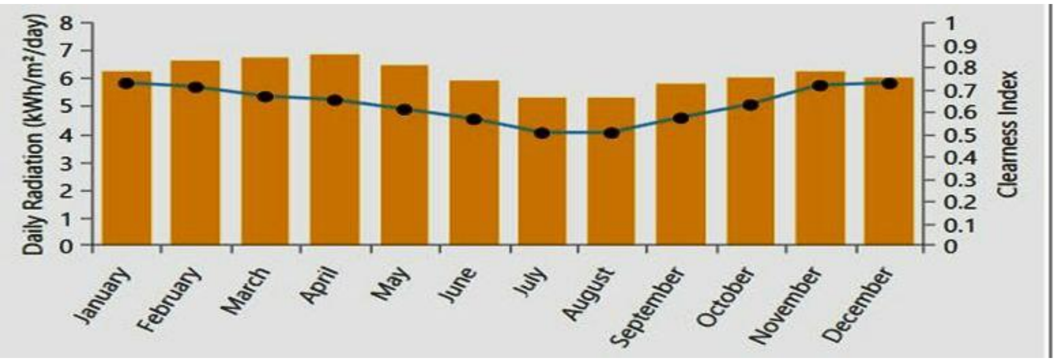
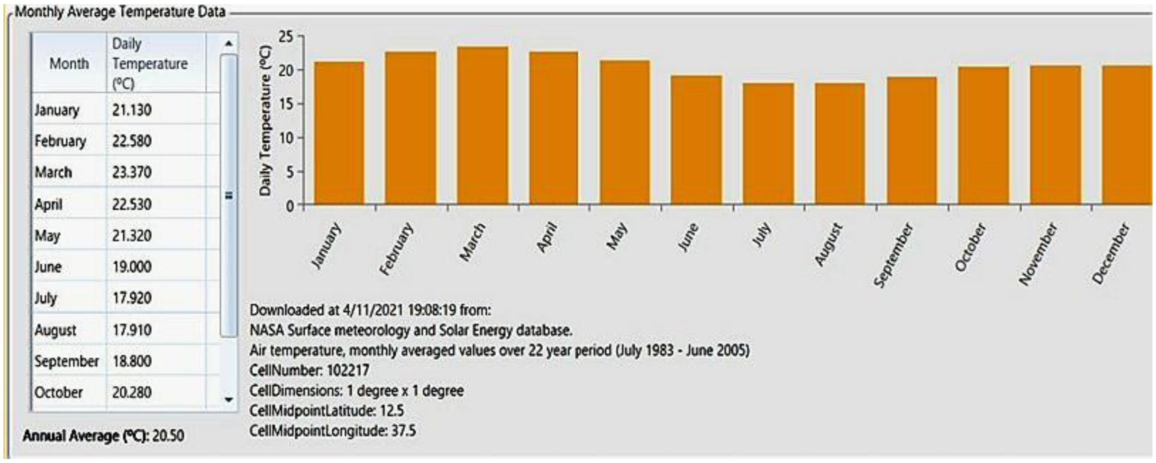


Figure 5.2 Monthly average solar irradiation and clearness index

Similarly, the monthly average ambient temperature and wind speed are shown in Figure 5.3 and 5.4 respectively.



Month	Daily Temperature (°C)
January	21.130
February	22.580
March	23.370
April	22.530
May	21.320
June	19.000
July	17.920
August	17.910
September	18.800
October	20.280

Annual Average (°C): 20.50

Downloaded at 4/11/2021 19:08:19 from:
NASA Surface meteorology and Solar Energy database.
Air temperature, monthly averaged values over 22 year period (July 1983 - June 2005)
CellNumber: 102217
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: 12.5
CellMidpointLongitude: 37.5

Figure 5.3 Monthly average temperatures

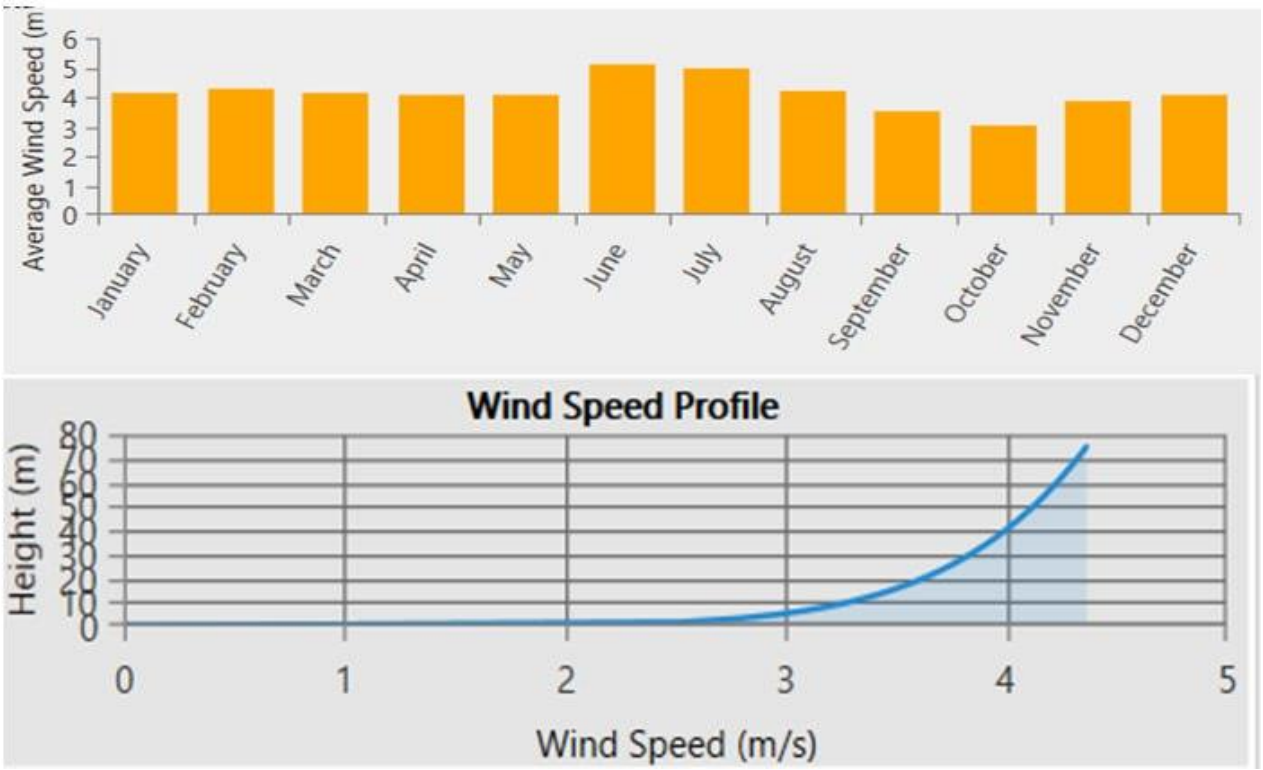


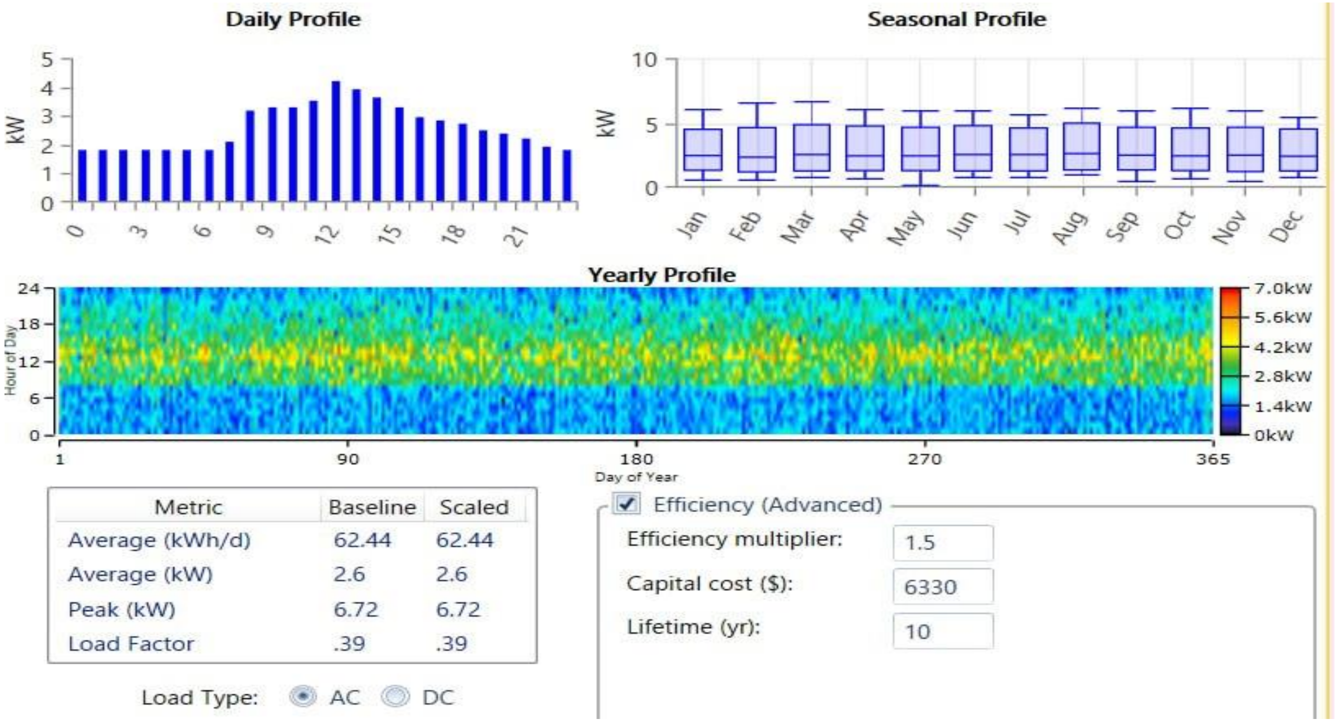
Figure 5.4 Wind speed data for the selected location

Accurate load profiling is essential for designing an optimal system that meets energy demands while minimizing over-design costs. To this end, a comprehensive annual electric load profile for the target region was developed by analyzing collected load data.

In the case of a health center, the daily electricity demand remains relatively consistent throughout the year. As depicted in Figure 5.5, the load profile exhibits a minimum at midnight and a peak around midday. The peak load was determined to be 6.34 kW, and the average daily energy consumption was 62.24 kWh/day, aligning with the collected data. This information was subsequently input into the HOMER software's electric load toolbar.

The primary load represents the immediate energy requirements of the system, encompassing lighting, machinery operation, and other devices such as televisions, radios, computers, and printers. The power load within the health facility is assumed to remain constant throughout the year. Figure 5.6 illustrates the diurnal fluctuation of the primary load profile for the selected health center, as calculated by HOMER after incorporating monthly load data.

Given that most appliances in the health center and service areas operate on alternating current (AC), the system was designed to accommodate AC loads. The load profiles exhibit consistent daily patterns, with similar peak demands, average demands, and base demands.



Metric	Baseline	Scaled
Average (kWh/d)	62.44	62.44
Average (kW)	2.6	2.6
Peak (kW)	6.72	6.72
Load Factor	.39	.39

Load Type: ● AC ○ DC

☑ Efficiency (Advanced)

Efficiency multiplier: 1.5

Capital cost ($): 6330

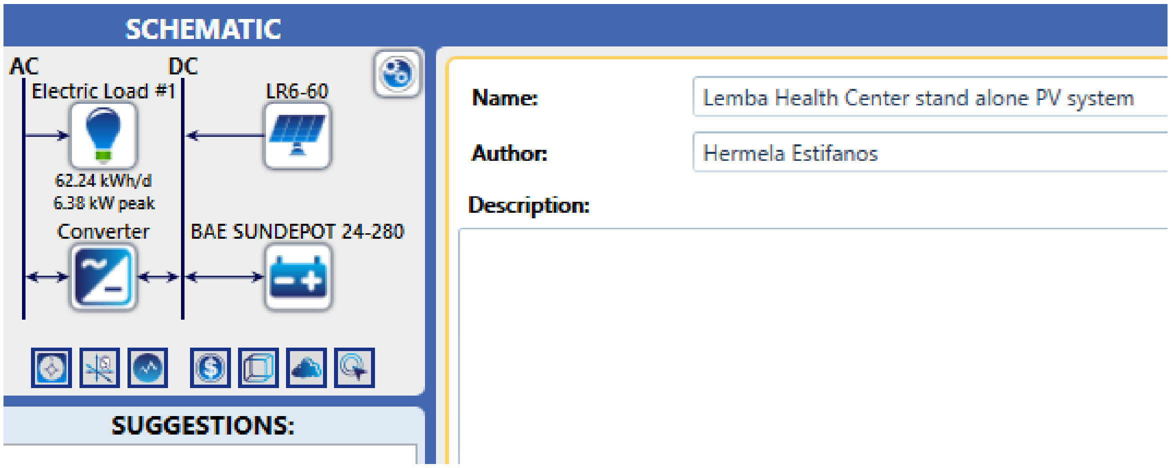
Lifetime (yr): 10

Figure 5.5 Estimated load profile

5.2 Model design of solar PV grid connected using HOMER

Stand-alone PV systems utilize solar energy as their primary source, complemented by batteries for energy storage and a power inverter to facilitate the transfer of energy between AC and DC circuits.

The HOMER simulation tool was used to design the system, incorporating components selected from the HOMER Library with their specific specifications and a defined connection scheme as illustrated in Figure 5.6. The system converter interconnects the AC and DC sides. The DC side houses the batteries and PV panels, while the load is connected to the AC side.



Name: Lemba Health Center stand alone PV system

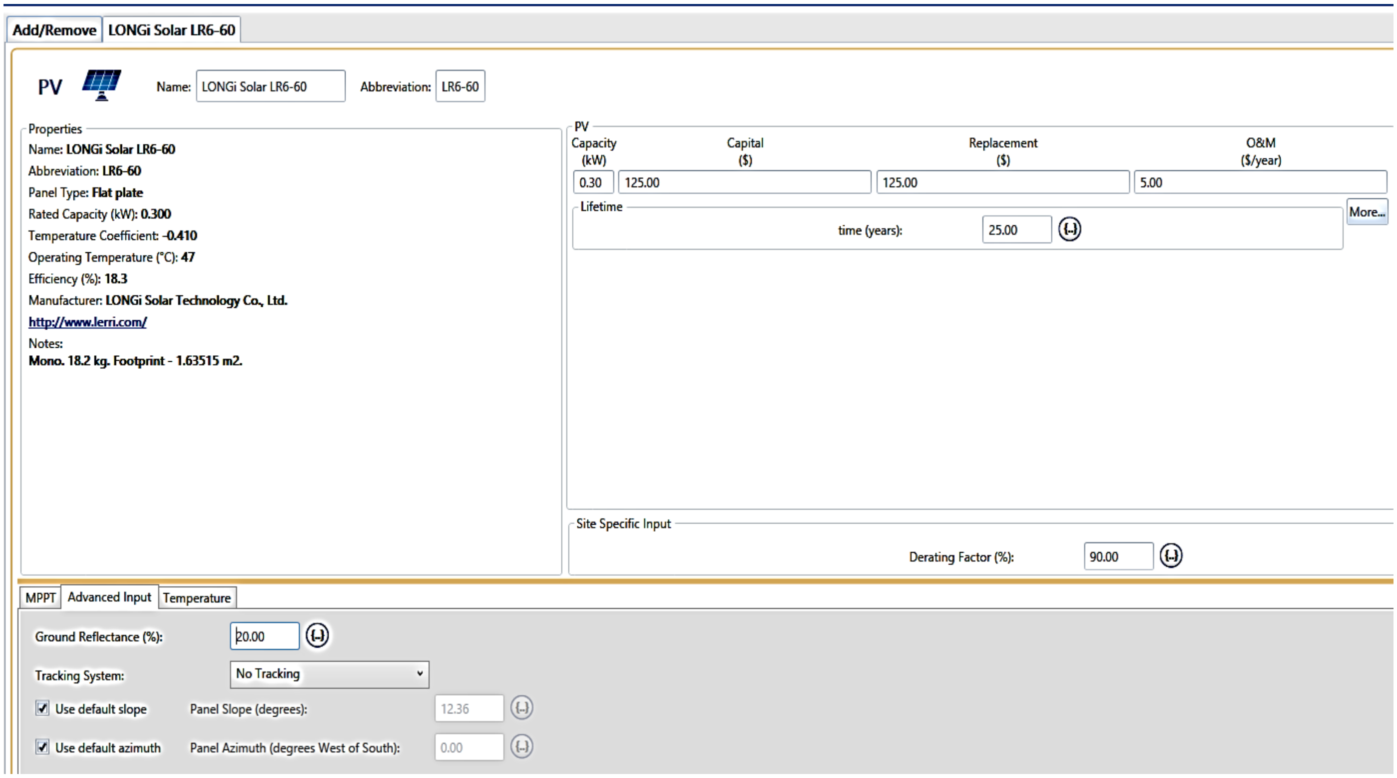
Author: Hermela Estifanos

Description:

Figure 5.6 System architecture or design configuration of the stand-alone PV system

300W LONGi Solar LR6-60 panel was used in the analysis. The initial, replacement, and operational costs were adjusted to encompass the balance of system and other expenses, as outlined in Table 5.1.

Table 5.1 Parametric specifications of the selected PV module



Name: LONGi Solar LR6-60
Abbreviation: LR6-60

Properties
Name: **LONGi Solar LR6-60**
Abbreviation: **LR6-60**
Panel Type: **Flat plate**
Rated Capacity (kW): **0.300**
Temperature Coefficient: **-0.410**
Operating Temperature (°C): **47**
Efficiency (%): **18.3**
Manufacturer: **LONGi Solar Technology Co., Ltd.**
http://www.lerri.com/
Notes:
Mono. 18.2 kg. Footprint - 1.63515 m2.

PV

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/year)
0.30	125.00	125.00	5.00

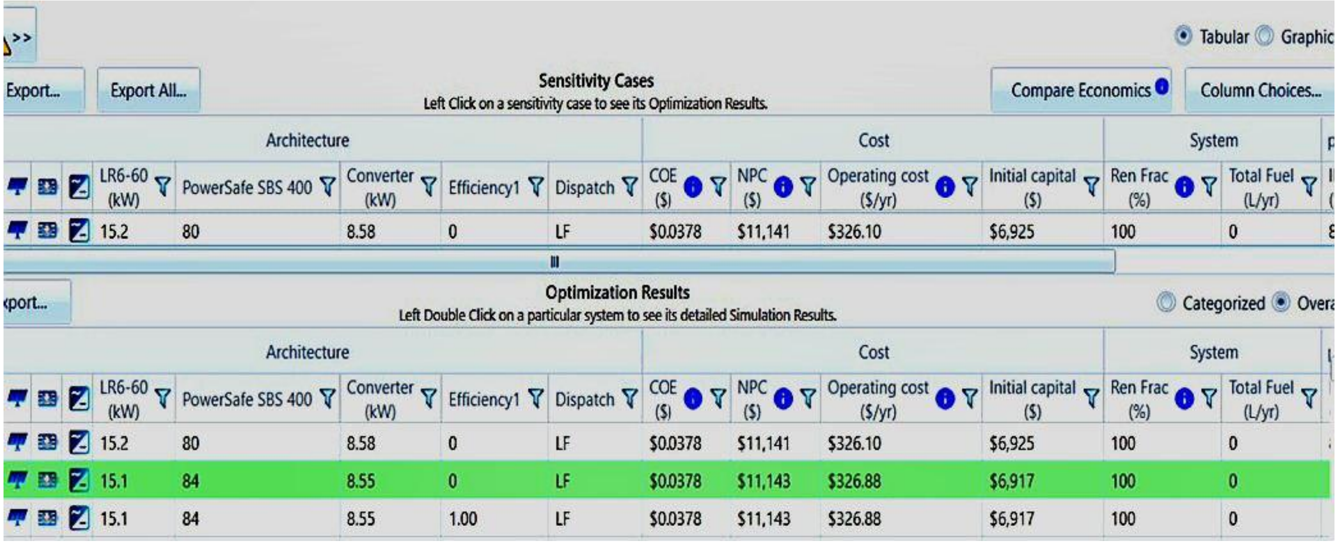
Lifetime
time (years): 25.00

Site Specific Input
Derating Factor (%): 90.00

Ground Reflectance (%): 20.00
Tracking System: No Tracking
☑ Use default slope   Panel Slope (degrees): 12.36
☑ Use default azimuth   Panel Azimuth (degrees West of South): 0.00

After a thoroughly specified input of all the required components, site information, load profile, etc. the simulation was run on HOMER Pro.

Table 5.2 Optimization Result



Sensitivity Cases
Left Click on a sensitivity case to see its Optimization Results.

Architecture					Cost				System	
LR6-60 (kW)	PowerSafe SBS 400	Converter (kW)	Efficiency1	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
15.2	80	8.58	0	LF	$0.0378	$11,141	$326.10	$6,925	100	0

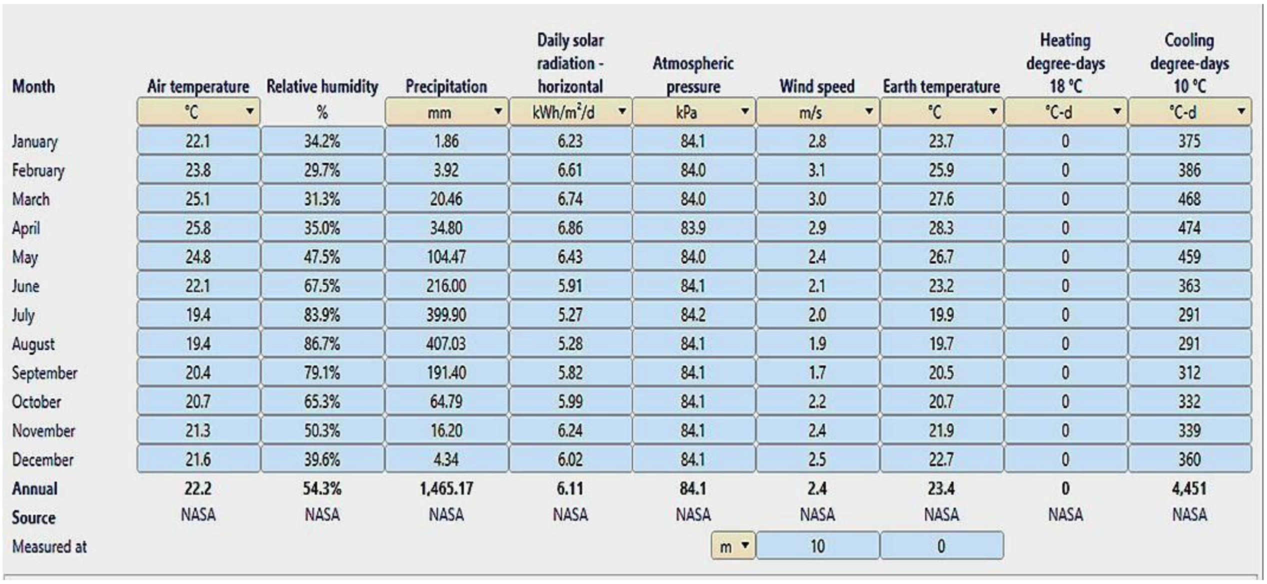
Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture					Cost				System	
LR6-60 (kW)	PowerSafe SBS 400	Converter (kW)	Efficiency1	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
15.2	80	8.58	0	LF	$0.0378	$11,141	$326.10	$6,925	100	0
15.1	84	8.55	0	LF	$0.0378	$11,143	$326.88	$6,917	100	0
15.1	84	8.55	1.00	LF	$0.0378	$11,143	$326.88	$6,917	100	0

5.3 Performance Analysis using RETScreen Expert

RETScreen expert is used to study the thermo-economic and environmental performances of a 15.3KW stand-alone ground-mounted solar PV power system. It is a useful tool for analyzing and evaluating the feasibility of both grid-connected and stand-alone PV systems. Using the input data like the monthly average solar radiation on the site, RETScreen expert can predict the annual and monthly energy generations, capacity factors and other important economic measures. Furthermore, the legal and technological viability and economic justification of the power system can be assessed by the feasibility study using this software. As shown in Table 5.3 the monthly average incident radiation, wind speed, etc. of data generated by the RETScreen expert using the geographical coordinates of the health center site agrees with the one generated by the Homer software. This ensures that the proper geographical location on the map is spotted as the first step for analysis.

Table 5.3 Monthly average metrological data from RETScreen expert



Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	22.1	34.2%	1.86	6.23	84.1	2.8	23.7	0	375
February	23.8	29.7%	3.92	6.61	84.0	3.1	25.9	0	386
March	25.1	31.3%	20.46	6.74	84.0	3.0	27.6	0	468
April	25.8	35.0%	34.80	6.86	83.9	2.9	28.3	0	474
May	24.8	47.5%	104.47	6.43	84.0	2.4	26.7	0	459
June	22.1	67.5%	216.00	5.91	84.1	2.1	23.2	0	363
July	19.4	83.9%	399.90	5.27	84.2	2.0	19.9	0	291
August	19.4	86.7%	407.03	5.28	84.1	1.9	19.7	0	291
September	20.4	79.1%	191.40	5.82	84.1	1.7	20.5	0	312
October	20.7	65.3%	64.79	5.99	84.1	2.2	20.7	0	332
November	21.3	50.3%	16.20	6.24	84.1	2.4	21.9	0	339
December	21.6	39.6%	4.34	6.02	84.1	2.5	22.7	0	360
Annual	**22.2**	**54.3%**	**1,465.17**	**6.11**	**84.1**	**2.4**	**23.4**	**0**	**4,451**
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

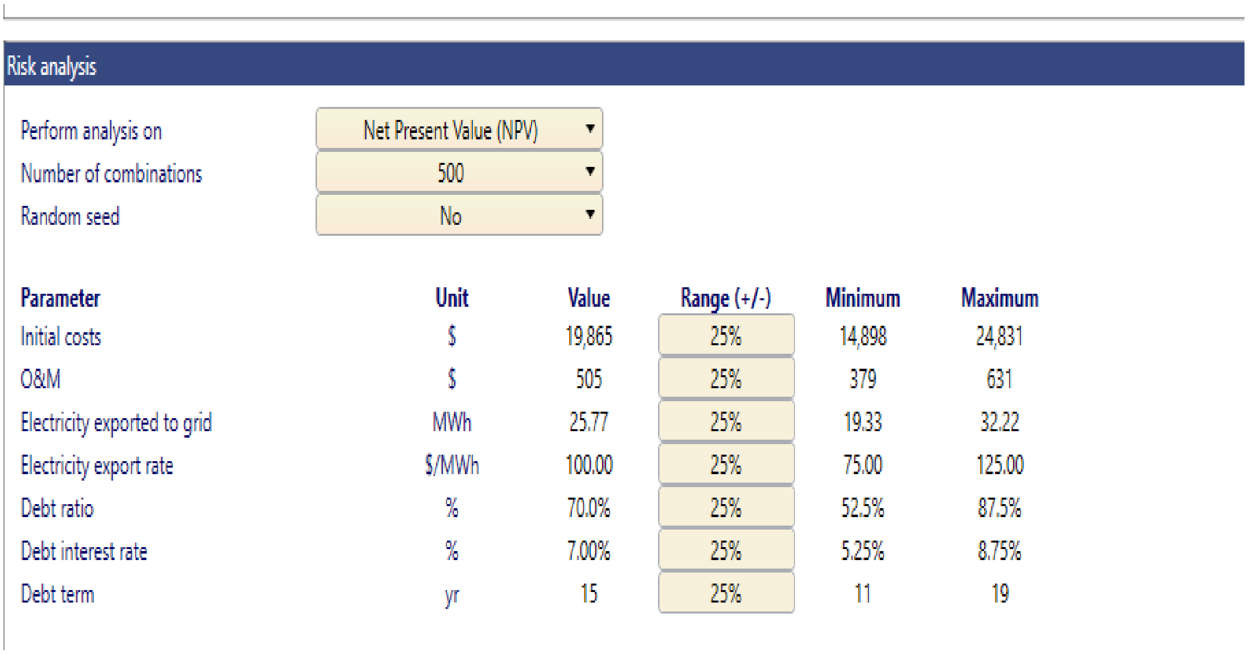
Figure 5.7 demonstrates that the performance of 15.3 kW of a stand-alone PV system is about to be analyzed.

Facility type	Power plant
Type	Photovoltaic
Description	15.3
Prepared for	Lemba Health Center
Prepared by	Hermela Estifanos
Facility name	Stand- alone PV power system
Address	Lemba Kebele
City/Municipality	Gonder Zuriya
Province/State	Amhara
Country	Ethiopia

Figure 5.7 General description of the layout of the plant

The annual CO_2 gas emission reduction as compared to the diesel-fueled generator is shown in Figure 5.8. The proposed case removes nearly 100% of CO_2 gas emissions which shows the environmental characteristics of a stand-alone PV system.

Table 5.4 Risk analysis of the proposed system



Risk analysis

Perform analysis on: Net Present Value (NPV)
Number of combinations: 500
Random seed: No

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	19,865	25%	14,898	24,831
O&M	$	505	25%	379	631
Electricity exported to grid	MWh	25.77	25%	19.33	32.22
Electricity export rate	$/MWh	100.00	25%	75.00	125.00
Debt ratio	%	70.0%	25%	52.5%	87.5%
Debt interest rate	%	7.00%	25%	5.25%	8.75%
Debt term	yr	15	25%	11	19

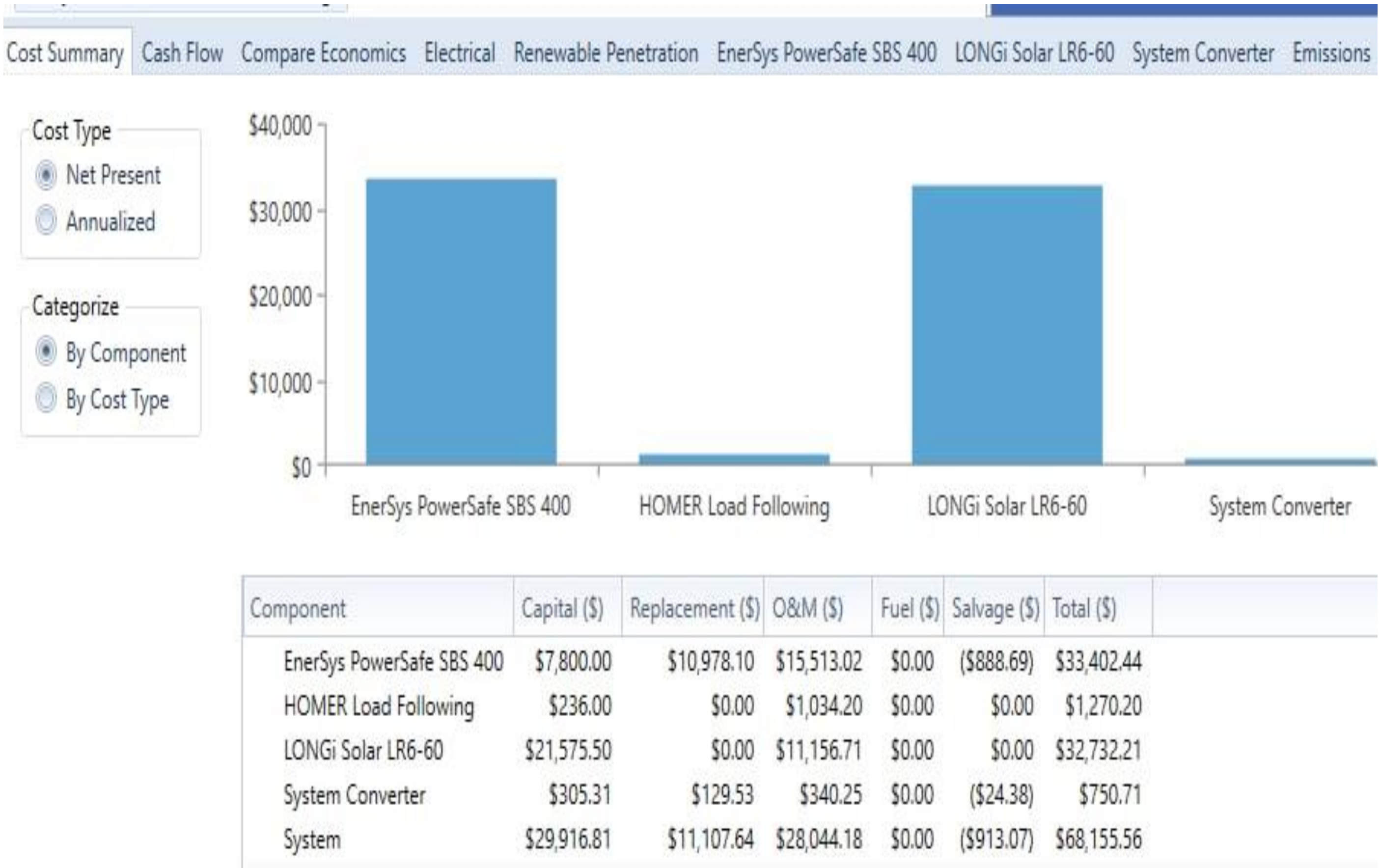
CHAPTER SIX

RESULT AND DISCUSSION

This chapter presents the findings from both analytical and HOMER studies. The impact of various factors on the dependent variables is analyzed. The HOMER results are compared to relevant literature, and a brief evaluation of the reliability of each method is conducted.

The proposed power system integrates PV panels, batteries, and a converter to supply the electrical demand outlined in the load profile. Figure 6.1 illustrates that the net present cost (NPC) of the designed system is $68,155.56.

As depicted in Figure 6.2, the energy bank emerges as a significant cost driver due to the recurring replacement costs throughout the microgrid's lifespan. The optimal battery configuration, determined through HOMER simulations, comprises 80 batteries with a voltage of 48V arranged in 20 strings



Cost Type
● Net Present
○ Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
EnerSys PowerSafe SBS 400	$7,800.00	$10,978.10	$15,513.02	$0.00	($888.69)	$33,402.44
HOMER Load Following	$236.00	$0.00	$1,034.20	$0.00	$0.00	$1,270.20
LONGi Solar LR6-60	$21,575.50	$0.00	$11,156.71	$0.00	$0.00	$32,732.21
System Converter	$305.31	$129.53	$340.25	$0.00	($24.38)	$750.71
System	$29,916.81	$11,107.64	$28,044.18	$0.00	($913.07)	$68,155.56

Figure 6.1 Cost summary for the PV power system

System Architecture:
LONGi Solar LR6-60 (15.2 kW)
EnerSys PowerSafe SBS 400 (20.0 strings)

System Converter (8.58 kW)
HOMER Load Following

Total NPC: $11,141.03
Levelized COE: $0.03784
Operating Cost: $326.10

Quantity	Value	Units
Batteries	80.0	qty.
String Size	4.00	batteries
Strings in Parallel	20.0	strings
Bus Voltage	48.0	V

Quantity	Value	Units
Autonomy	99.3	hr
Storage Wear Cost	0.000589	$/kWh
Nominal Capacity	431	kWh
Usable Nominal Capacity	258	kWh
Lifetime Throughput	161,195	kWh
Expected Life	15.0	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	10,894	kWh/yr
Energy Out	10,584	kWh/yr
Storage Depletion	16.8	kWh/yr
Losses	327	kWh/yr
Annual Throughput	10,746	kWh/yr

Figure 6.2 Battery Capacity Analysis

Based on the HOMER PRO results, the variation in monthly average electric production is related to the variation of monthly average solar radiation. For months with higher incident solar radiation like January and December, the average electricity production is also higher. But it is lesser for months like June, those of which are with low intensity of radiation. Comparatively, the electric production is still slightly higher than the worst scenario of high demand month.

Production	kWh/yr	%
LONGi Solar LR6-60	100,421	100
Total	100,421	100

Consumption	kWh/yr	%
AC Primary Load	22,780	100
DC Primary Load	0	0
Total	22,780	100

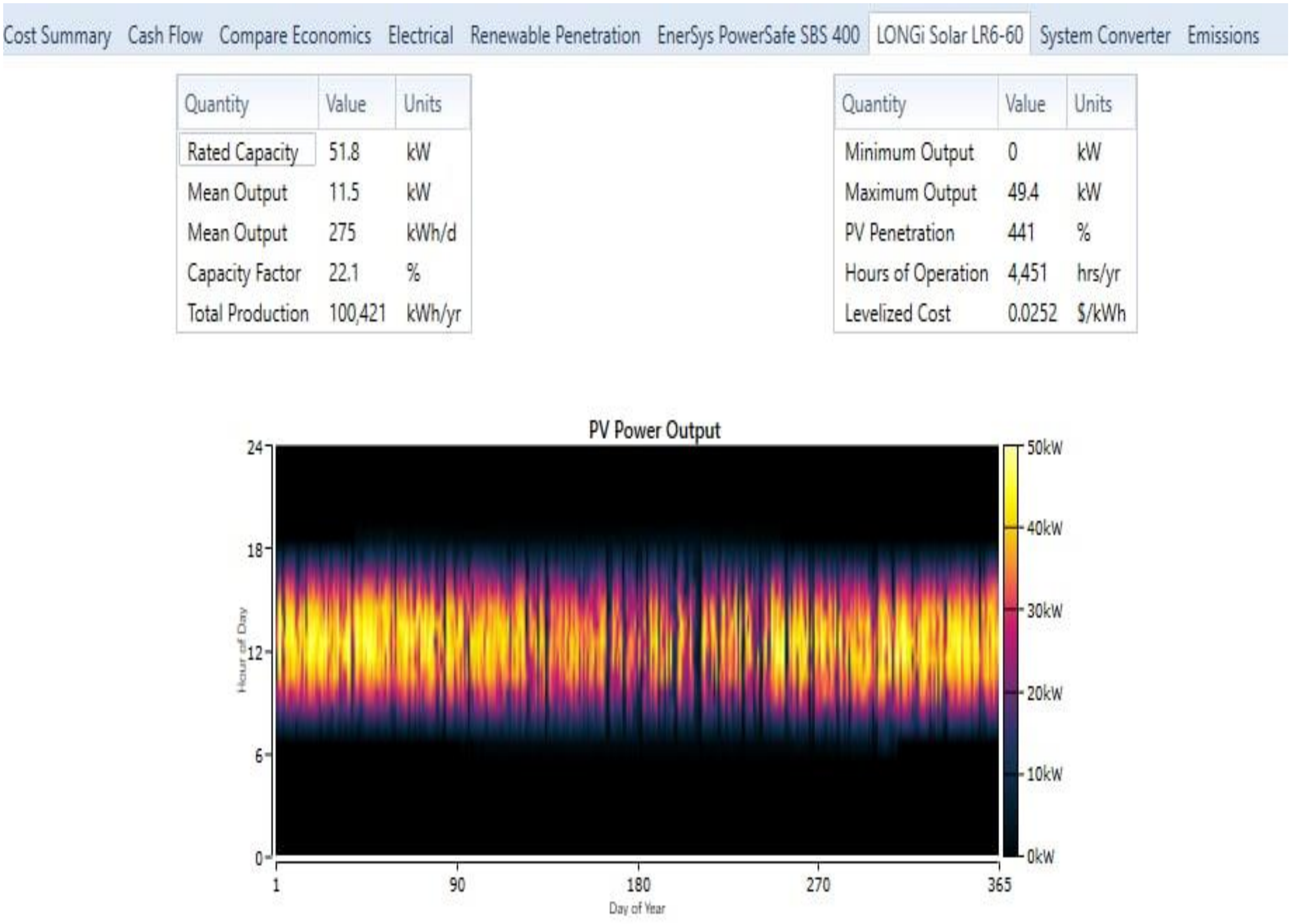
Quantity	kWh/yr	%
Excess Electricity	76,161	75.8
Unmet Electric Load	10.1	0.0444
Capacity Shortage	22.7	0.0996

Quantity	Value
Renewable Fraction	100
Max. Renew. Penetration	3,547

Figure 6.3 Monthly Average Electric Production

6.1 Power output PV panel

Figure 6.4. shows a typical daily power output in kW of the PV modules in relation to hours of a day throughout 12 months. It is indicated that power output during the day steadily increases and reaches its maximum in the middle of the day and then decreases back during the evening. Solar power output also varies seasonally in such a way it decreases during June, July, August, September and early October.

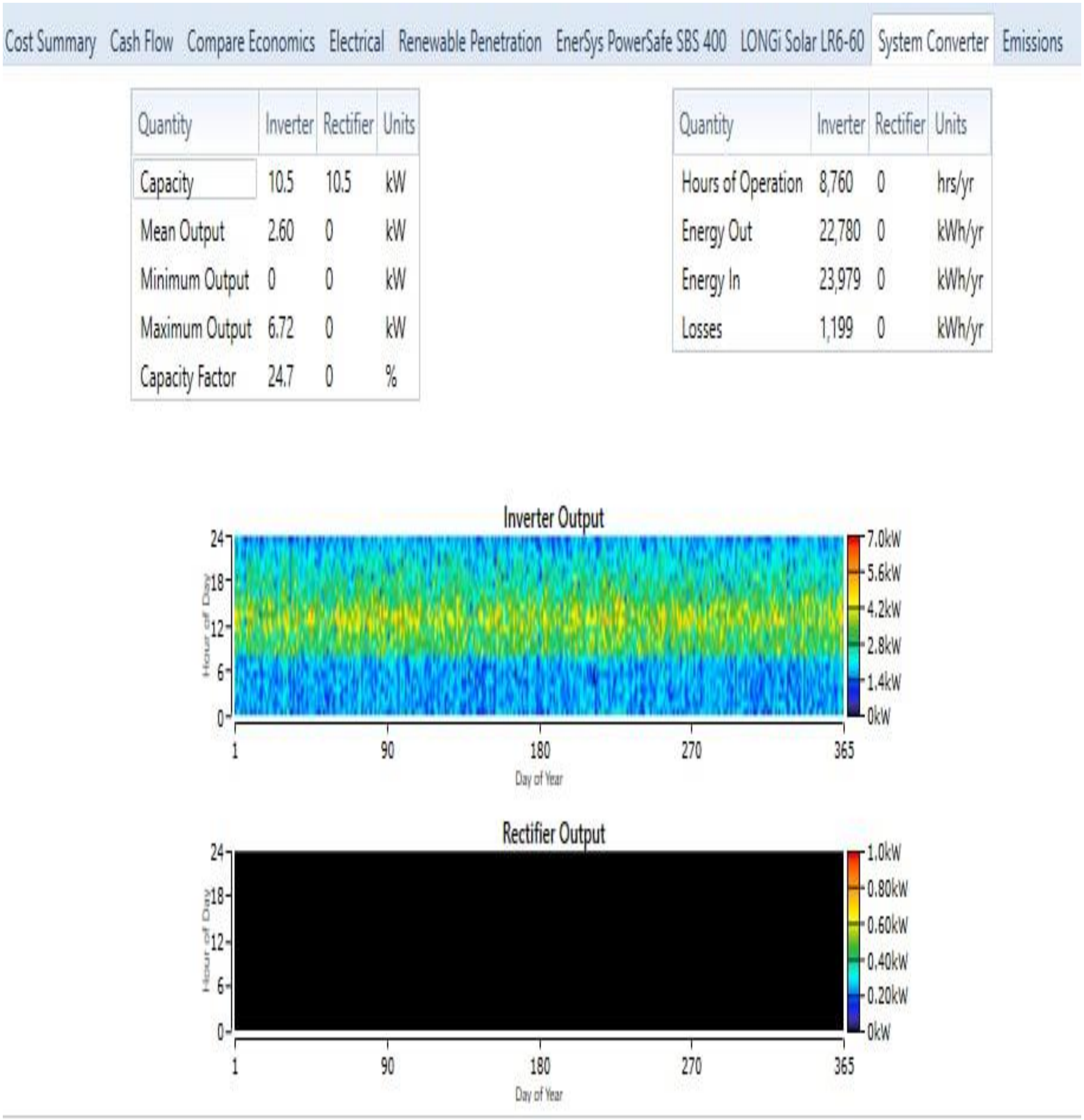


Quantity	Value	Units
Rated Capacity	51.8	kW
Mean Output	11.5	kW
Mean Output	275	kWh/d
Capacity Factor	22.1	%
Total Production	100,421	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	49.4	kW
PV Penetration	441	%
Hours of Operation	4,451	hrs/yr
Levelized Cost	0.0252	$/kWh

Figure 6.4 PV power output throughout the year and daytime

Two inverters of capacity 10.5 kW as shown in Figure 6.5 proposed by the simulation which is still coincident with the capacities calculated in the analytical design.



Quantity	Inverter	Rectifier	Units
Capacity	10.5	10.5	kW
Mean Output	2.60	0	kW
Minimum Output	0	0	kW
Maximum Output	6.72	0	kW
Capacity Factor	24.7	0	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	8,760	0	hrs/yr
Energy Out	22,780	0	kWh/yr
Energy In	23,979	0	kWh/yr
Losses	1,199	0	kWh/yr

Figure 6.5 Inverter Capacity Analyses

Figure 6.6 shows the correlation between the global solar irradiance and the AC primary load.The AC primary load is the total amount of energy that goes towards serving the AC primary load(s) during the year.

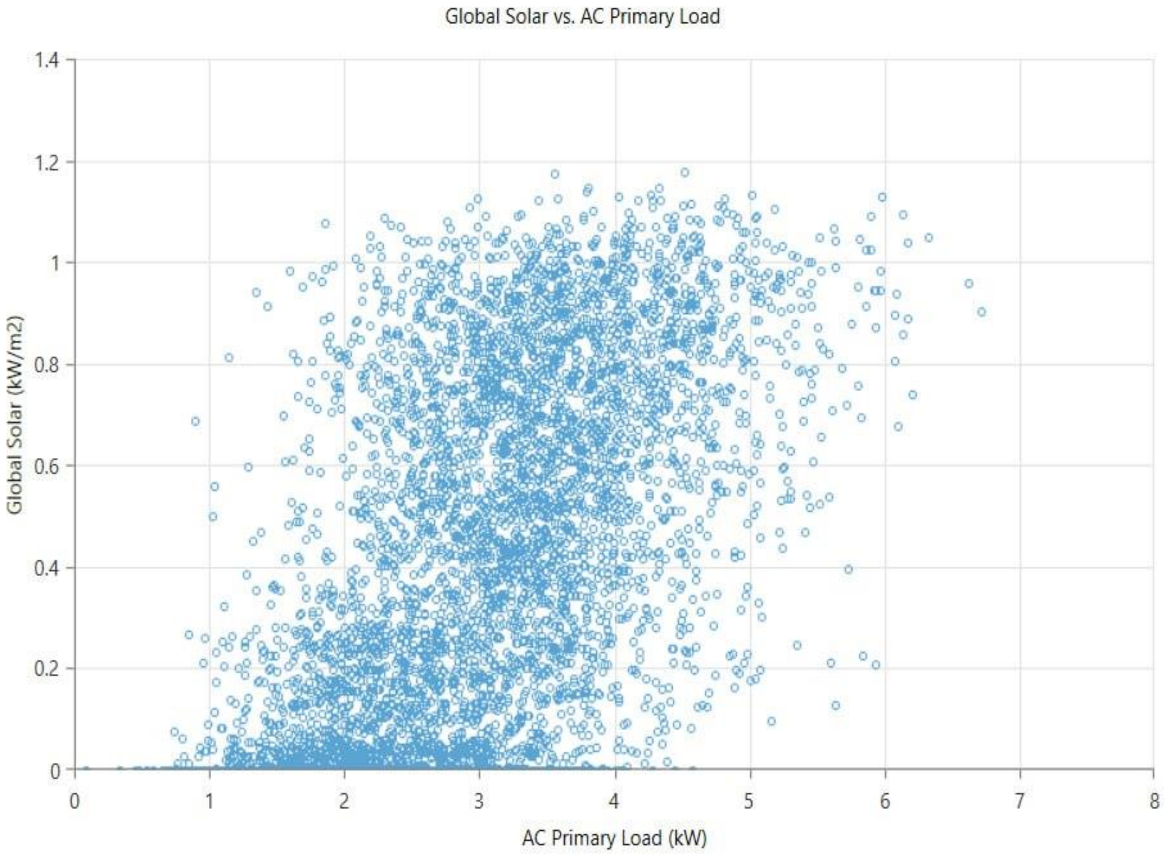


Figure 6.6 Correlation between the global solar irradiance and the AC primary load

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The primary goal of this thesis was to use HOMER software to design an off-grid solar PV power system for the Lemba Health Center in Gondar Zuria Woreda, Ethiopia. The Meteorological Department of Ethiopia provided the specified system's horizontal global radiation. HOMER was used to examine the average monthly profiles and hourly data from both sources. The results demonstrate that solar energy potential is certainly exploitable for electricity generation. The suggested system has a fixed PV panel; therefore, the initial system's nominal cost will be determined by the size and number of PV panels, the size and number of used batteries, and the transfer capacity. PV system performance is determined by the range of daily radiation (kW/m^2/day) index and clarity for each month of the year.

According to the findings of this study, using photovoltaic technology for electricity production and supply has proven to be a long-term option for health clinics in rural towns remote from the national electric grid. Photovoltaic systems cannot provide a continuous electric power supply unless they are coupled to another storage system. This has become a significant difficulty during rainy days to deliver the required electrical power. As a result, batteries are often connected with solar panel systems. Furthermore, after selecting and describing the appropriate components for the entire system, the system was modeled in HOMER software, and system simulations were performed to determine the best system that can be more economical and reliable for supplying power to Lemba Health Center, as well as to predict load demand and consumption. According to the simulation results, electrifying rural health centers with a 15 kW off-grid solution is more cost-effective. Solar PV is a suitable choice for electricity generation because it is less expensive and contributes to energy independence, as well as being one of Ethiopia's most abundant renewable energy resources.

The comprehensive thermal modeling, sizing, and optimization of a standalone PV system with thorough cost calculations have been presented in this thesis for a typical health center in a remote part of Ethiopia. The planned system costs \$7243 and generates electricity for \$0.0378/kWh. It comprises 60 12 V and 100 Ah batteries, a 2.6 kW inverter, and 15 kW PV. This study outlines a thorough design process for a PV system for off-grid areas where grid power is not practical or cost-effective. By using this approach, it is possible to size a system, simulate it, and calculate its predicted performance. As a result, this research may be useful in designing a standalone PV system.

Finally, this thesis offers a foundation and framework for the evaluation of the remedy in other regions of the nation where the sun shines quite intensely.

7.2 Recommendation

This study's findings suggest that advanced models outperform conventional models in terms of improving the performance and reliability of solar photovoltaic power systems. The efficacy and dependability of standalone solar photovoltaic power systems for rural health center electrification, such as at Lemba Health Center. Thus, some of the proposals presented are as follows:

- A nationwide off-grid solar energy policy serves as a road map for integrating solar technologies into health facilities and other public assets. The strategy should include information about off-grid places, public infrastructure, the number of recipients, income, and other factors.
- The latitude of the location determines the panel's orientation and tilt angle.
- The solar cell with a tracking device has higher efficiency than the stationary one.
- Design the PV system to meet the health facility's actual or predicted demand. Consider essential, important, and non-critical loads to enable a 'graceful degradation strategy' in the event of limited energy supply. Modules connected in parallel can generate more power than modules connected in series, and the mismatch also impacts the system's performance.
- Professionally install PV systems, taking into account sun azimuth, inclination angle, shadow, and other factors.
- Stakeholders should be encouraged to apply these techniques in solar photovoltaic power systems.

7.3 Future Work

Battery storage systems require significant upfront costs, which can hinder their long-term financial viability. To address this, future research could explore hybrid energy storage systems that combine batteries with other technologies like compressed air, hydrogen, flywheels, or pumped hydro. This approach could help capture and store clean, renewable energy more cost-effectively.

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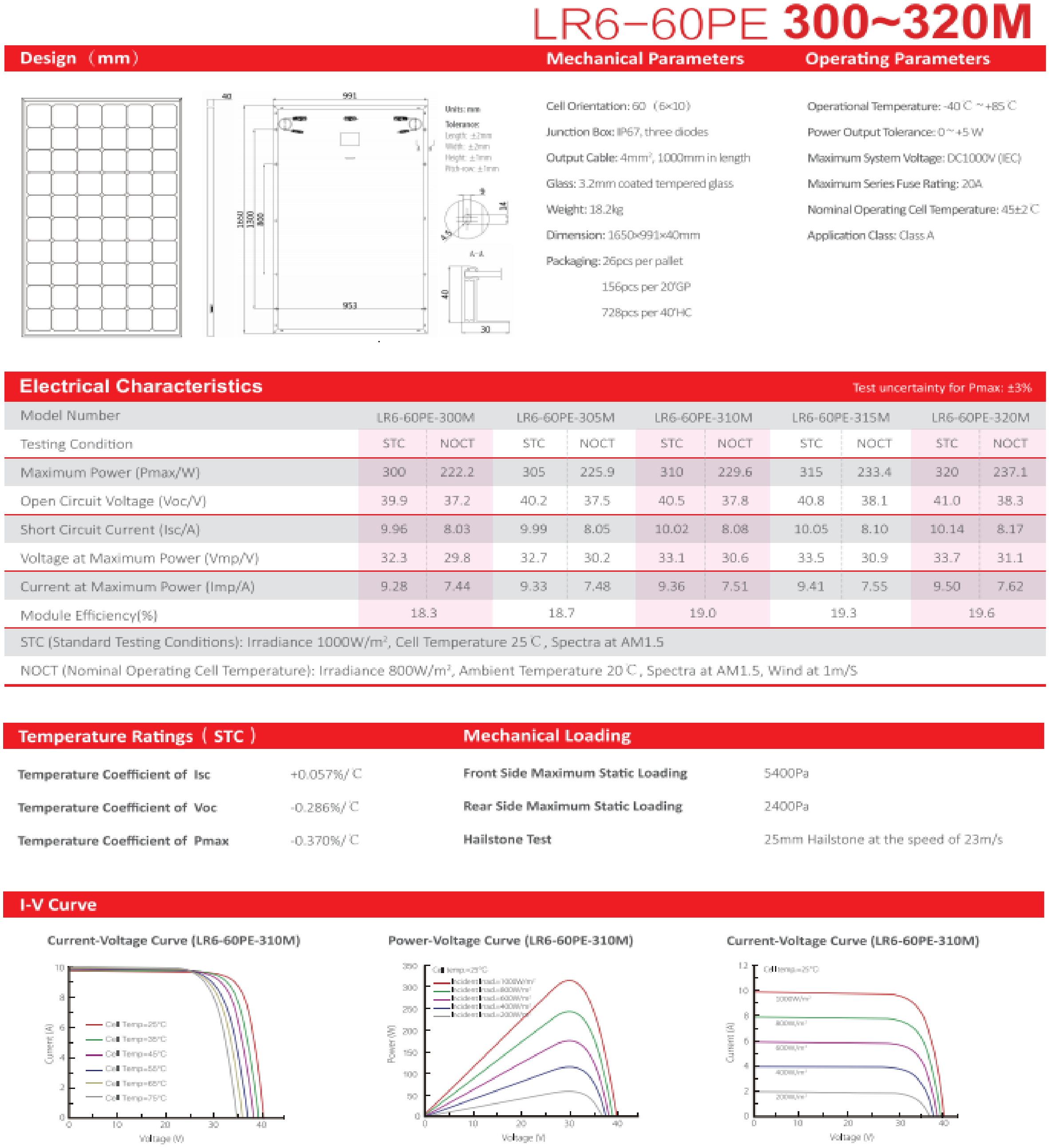
APPENDIX

Appendix A: Material specifications and their market availability



LR6-60PE **300~320M**

Design (mm)

Mechanical Parameters

Cell Orientation: 60 （6×10）

Junction Box: IP67, three diodes

Output Cable: 4mm², 1000mm in length

Glass: 3.2mm coated tempered glass

Weight: 18.2kg

Dimension: 1650×991×40mm

Packaging: 26pcs per pallet
156pcs per 20'GP
728pcs per 40'HC

Operating Parameters

Operational Temperature: -40℃ ~ +85℃

Power Output Tolerance: 0 ~ +5 W

Maximum System Voltage: DC1000V (IEC)

Maximum Series Fuse Rating: 20A

Nominal Operating Cell Temperature: 45±2℃

Application Class: Class A

Electrical Characteristics

Test uncertainty for Pmax: ±3%

Model Number	LR6-60PE-300M		LR6-60PE-305M		LR6-60PE-310M		LR6-60PE-315M		LR6-60PE-320M	
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax/W)	300	222.2	305	225.9	310	229.6	315	233.4	320	237.1
Open Circuit Voltage (Voc/V)	39.9	37.2	40.2	37.5	40.5	37.8	40.8	38.1	41.0	38.3
Short Circuit Current (Isc/A)	9.96	8.03	9.99	8.05	10.02	8.08	10.05	8.10	10.14	8.17
Voltage at Maximum Power (Vmp/V)	32.3	29.8	32.7	30.2	33.1	30.6	33.5	30.9	33.7	31.1
Current at Maximum Power (Imp/A)	9.28	7.44	9.33	7.48	9.36	7.51	9.41	7.55	9.50	7.62
Module Efficiency(%)	18.3		18.7		19.0		19.3		19.6	

STC (Standard Testing Conditions): Irradiance 1000W/m², Cell Temperature 25℃, Spectra at AM1.5

NOCT (Nominal Operating Cell Temperature): Irradiance 800W/m², Ambient Temperature 20℃, Spectra at AM1.5, Wind at 1m/S

Temperature Ratings（STC）

Temperature Coefficient of Isc	+0.057%/℃
Temperature Coefficient of Voc	-0.286%/℃
Temperature Coefficient of Pmax	-0.370%/℃

Mechanical Loading

Front Side Maximum Static Loading	5400Pa
Rear Side Maximum Static Loading	2400Pa
Hailstone Test	25mm Hailstone at the speed of 23m/s

I-V Curve

Current-Voltage Curve (LR6-60PE-310M)

Power-Voltage Curve (LR6-60PE-310M)

Current-Voltage Curve (LR6-60PE-310M)

LEONICS®

APOLLO MTP-410 series Three Phase Bidirectional Dual Mode Hybrid Inverter for Mini-Grid System

MODEL		MTP-411E	MTP-412E	MTP-413E	MTP-411F	MTP-412F	MTP-413F	MTP-414F	MTP-415F	MTP-416F	MTP-417F	MTP-418F	MTP-419F	MTP-4110F	MTP-4111H	MTP-4113H	MTP-4115H	MTP-4117H
RATED POWER		10 kW	15 kW	25 kW	10 kW	15 kW	25 kW	30 kW	45 kW	60 kW	75 kW	90 kW	100 kW	120 kW	150 kW	200 kW	250 kW	300 kW
BATTERY	Nominal Voltage	120 Vdc			240 Vdc										480 Vdc			
	Max.charging current	56 A	84 A	130 A	28 A	42 A	72 A	84 A	125 A	168 A	200 A	250 A	280 A	335 A	200 A	280 A	350 A	418 A
	Max. battery current	114 A	170 A	284 A	57 A	85 A	142 A	170 A	255 A	340 A	425 A	510 A	570 A	680 A	425 A	570 A	710 A	850 A
EXTERNAL DC CHARGER*	Nominal voltage	120 Vdc			240 Vdc										480 Vdc			
	Maximum current	100 A	100 A	200 A	57 A	60 A	100 A	100 A	200 A	300 A	300 A	400 A	400 A	400 A	300 A	400 A	400 A	500 A
AC INPUT FROM GENERATOR	Recommended generator power	> 20 kW	> 30 kW	> 50 kW	> 20 kW	> 30 kW	> 50 kW	> 60 kW	> 90 kW	> 120 kW	> 150 kW	> 180 kW	> 200 kW	> 240 kW	> 300 kW	> 400 kW	> 500 kW	> 600 kW
	Voltage	380 / 400 / 415 Vac (L-L), 220 / 230 / 240 Vac (L-N) ± 10%																
	Phase	Three phase																
	Frequency	50 / 60 Hz ± 3 Hz																
	Max. AC current	32 A	48 A	80 A	32 A	48 A	80 A	96 A	144 A	191 A	240 A	287 A	319 A	382 A	478 A	637 A	796 A	955 A
	Automatic start / stop	Relay dry contact 10 A (2 sets of ACC contact for 2 generators)																
AC OUTPUT	Voltage	380 / 400 / 415 Vac (L-L), 220 / 230 / 240 Vac (L-N)																
	Voltage regulation	± 3% (steady load), < 7% at 100% step load within 0.1 sec.																
	Phase	Three phase																
	Frequency	50 / 60 Hz ± 0.1% (auto sensing)																
	Wave form	Pure sine wave																
	THD	total < 3%																
	Max. surge current	200%																
	Max. AC current	15.2 A	22.7 A	37.8 A	15.2 A	22.7 A	37.8 A	45.4 A	68.2 A	90.9 A	113.6 A	136.3 A	151.5 A	181.8 A	227.3 A	303 A	378.8 A	454.5 A
ISOLATION	Galvanic isolation	yes																
EFFICIENCY	Inverter peak efficiency	> 94%					> 95%											
PROTECTION		Over current, Over load, Short circuit, Over temperature, Over voltage, Under voltage																
INDICATOR	LED	External Charging, Bypass, Generator Running, Generator Failure,Stand by/Run, Inverter, Charging, Load on Inverter, Overload, Low Battery, High temperature, Fault																
	LCD display	Inverter (voltage, current, frequency, power, reactive power), Generator (voltage, current, frequency, power, reactive power), Battery (voltage, current, state of charge(%), charging current), Heat sink temperature, Battery temperature (option), Equalization date, Today DC Inverter Energy (Input, output) Today AC Inverter Energy (input, output), Accumulated DC energy (input, output), Accumulated AC Energy (input, output), System status, Time, Date, Data Log																
AUDIABLE ALARM		Low battery, Inverter fault, High temperature																
COOLING		Automatic cooling fan																
ENVIRONMENT	Temperature	0 - 45˚C																
	Relative humidity	0 - 95 % (Non - condensing)																
DESIGN REGULATION	Standard	AS/NZ 3100:2002, IEC 61683 (for efficiency test)																
	Enclosure	IP31 (IP65 option)		IP54 (IP65 option)	IP31 (IP65 option)		IP54 (IP65 option)	IP31										
DIMENSION W x H x D (cm)	Control Unit	60 x 188 x 105					60 x 188 x 105 / 80 x 80 x 65			90 x 212 x 100		150 x 212 x 82					110 x 205 x 105	
	Transformer Unit	-					- / 80 x 103 x 65			-		-					110 x 205 x 105	
WEIGHT (approx. in kg)	Control Unit	430	440	450	430	440	450 / 141	460 / 141	63 / 141	815	860	1,015	1,045	1,215	1,375	1,495	775	775
	Transformer Unit	-	-	-	-	-	- / 303	- / 310	- / 370	-	-	-	-	-	-	-	1,300	1,500

Continuous product development is our commitment. In that manner, the above specifications may be changed without prior notice. Note: * As specified in the order.

Authorized Distributor

LEO ELECTRONICS CO.,LTD.

27, 29 Soi Bangna-Trad Rd 34, Bangna, Bangna, Bangkok 10260 THAILAND Tel. 0-2746-9500, 0-27468708 Fax. 0-2746-8712 e-mail : RNE@leonics.com

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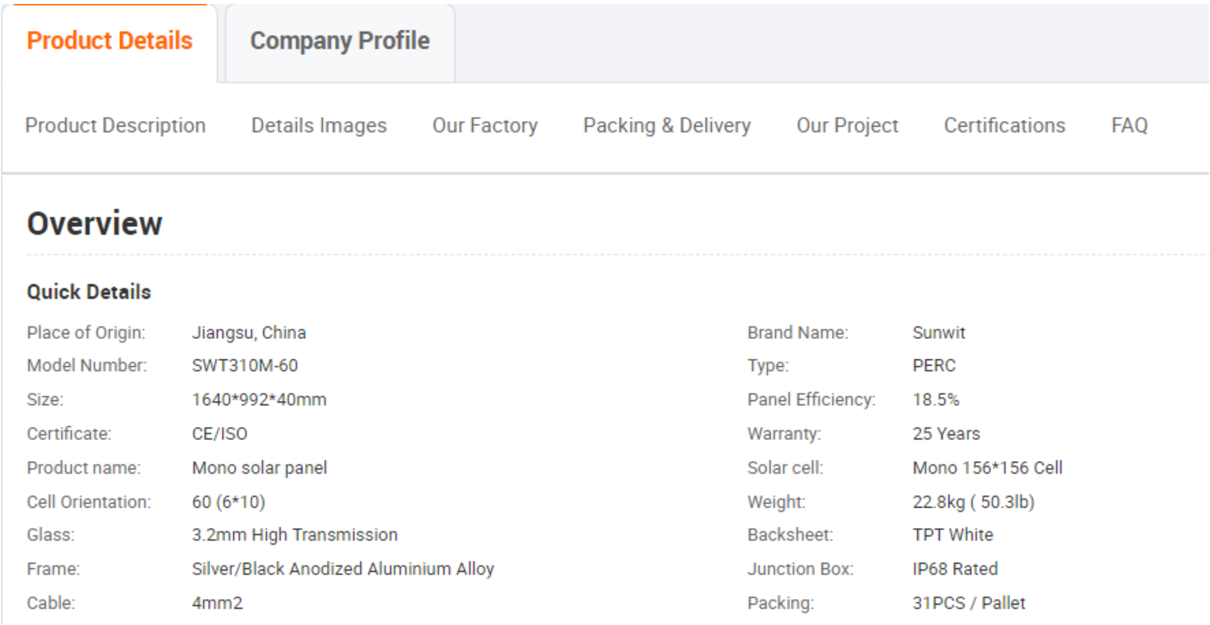
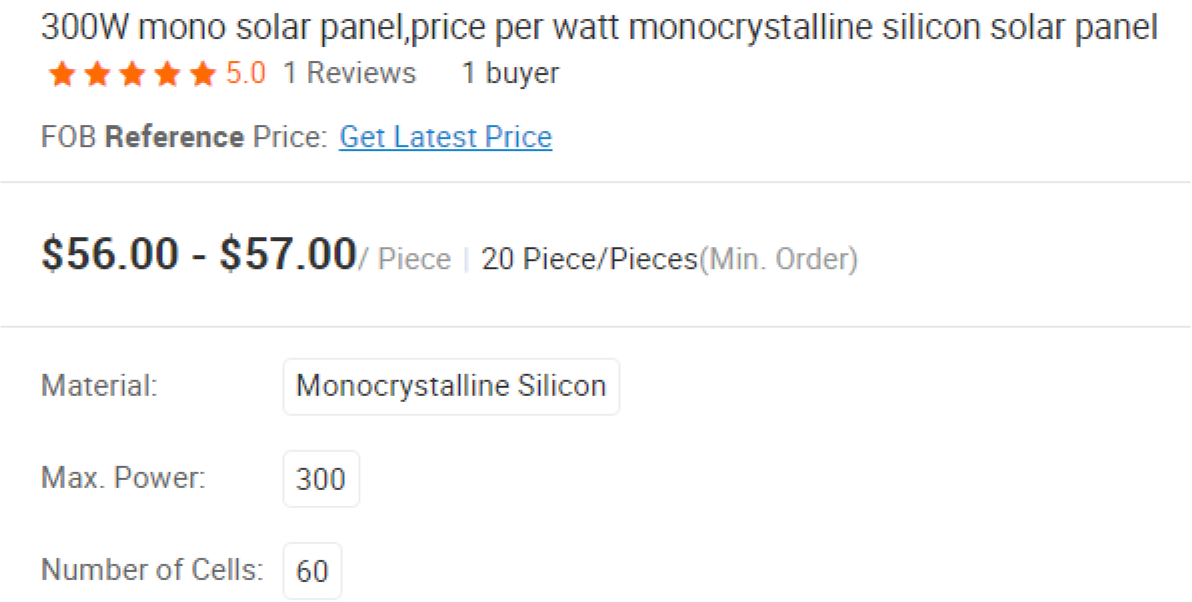
Authorized Dealer



Overview

Quick Details

Place of Origin:	Jiangsu, China	Brand Name:	Sunwit
Model Number:	SWT310M-60	Type:	PERC
Size:	1640*992*40mm	Panel Efficiency:	18.5%
Certificate:	CE/ISO	Warranty:	25 Years
Product name:	Mono solar panel	Solar cell:	Mono 156*156 Cell
Cell Orientation:	60 (6*10)	Weight:	22.8kg (50.3lb)
Glass:	3.2mm High Transmission	Backsheet:	TPT White
Frame:	Silver/Black Anodized Aluminium Alloy	Junction Box:	IP68 Rated
Cable:	4mm2	Packing:	31PCS / Pallet



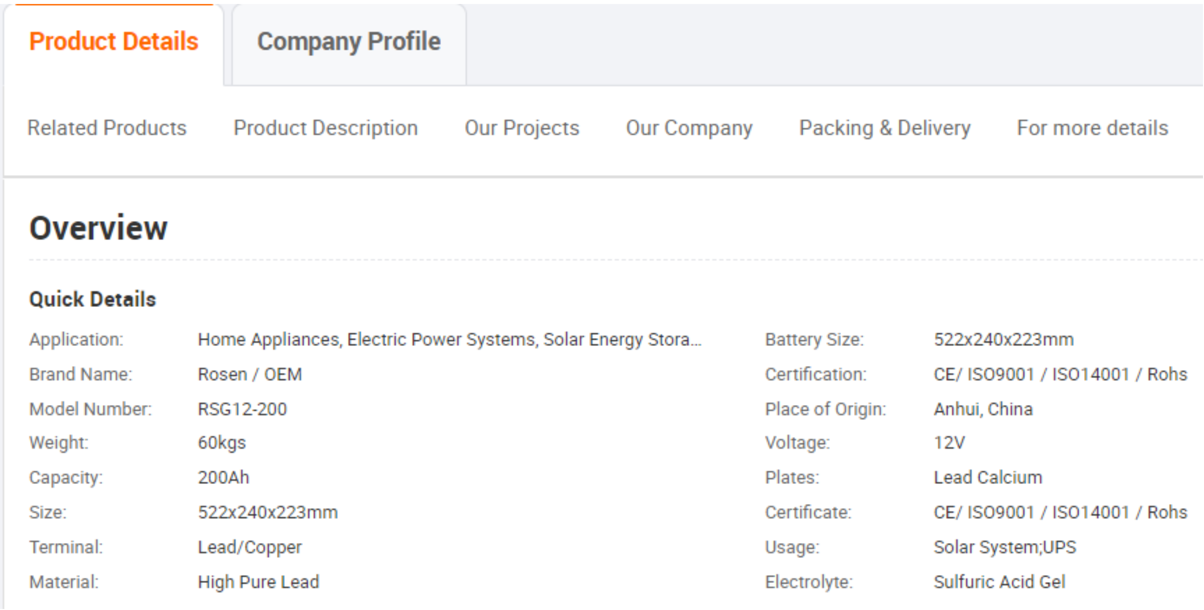
300W mono solar panel,price per watt monocrystalline silicon solar panel

★★★★★ 5.0 1 Reviews 1 buyer

FOB **Reference** Price: Get Latest Price

$56.00 - $57.00/ Piece | 20 Piece/Pieces(Min. Order)

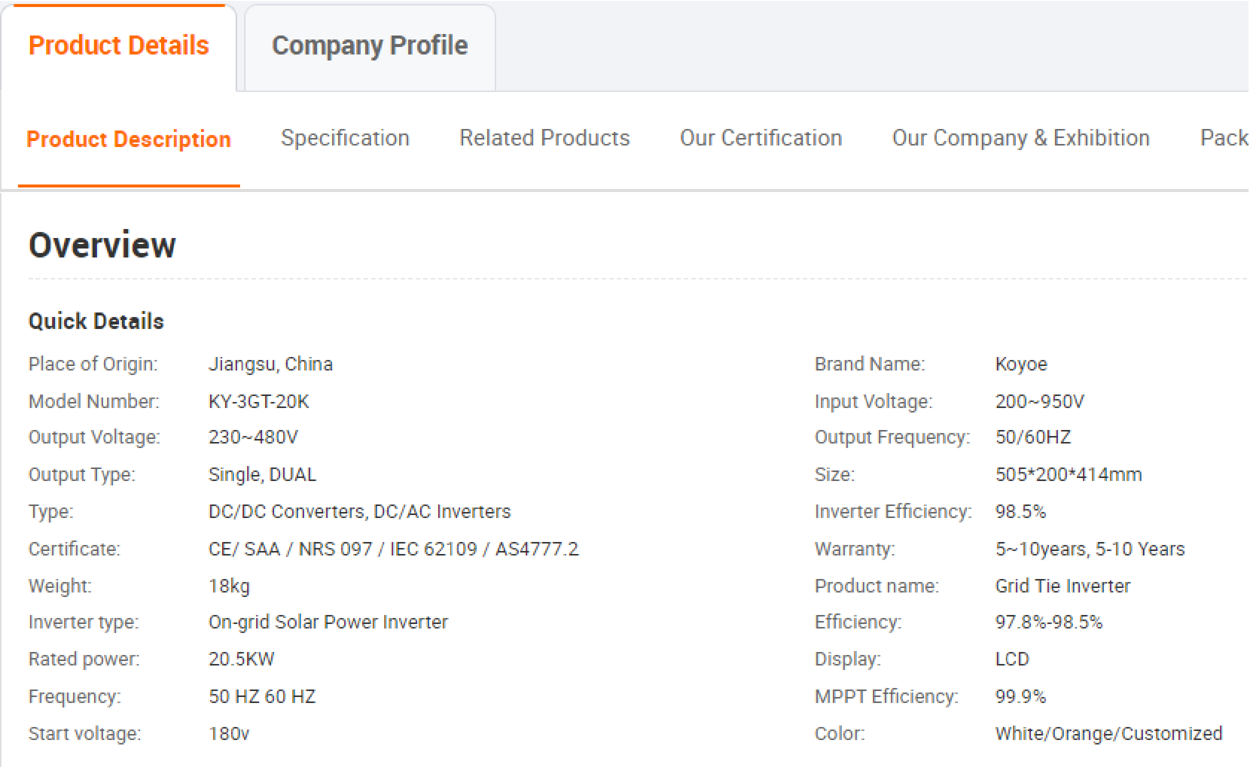
Material:	Monocrystalline Silicon
Max. Power:	300
Number of Cells:	60



Overview

Quick Details

Application:	Home Appliances, Electric Power Systems, Solar Energy Stora...	Battery Size:	522x240x223mm
Brand Name:	Rosen / OEM	Certification:	CE/ ISO9001 / ISO14001 / Rohs
Model Number:	RSG12-200	Place of Origin:	Anhui, China
Weight:	60kgs	Voltage:	12V
Capacity:	200Ah	Plates:	Lead Calcium
Size:	522x240x223mm	Certificate:	CE/ ISO9001 / ISO14001 / Rohs
Terminal:	Lead/Copper	Usage:	Solar System;UPS
Material:	High Pure Lead	Electrolyte:	Sulfuric Acid Gel

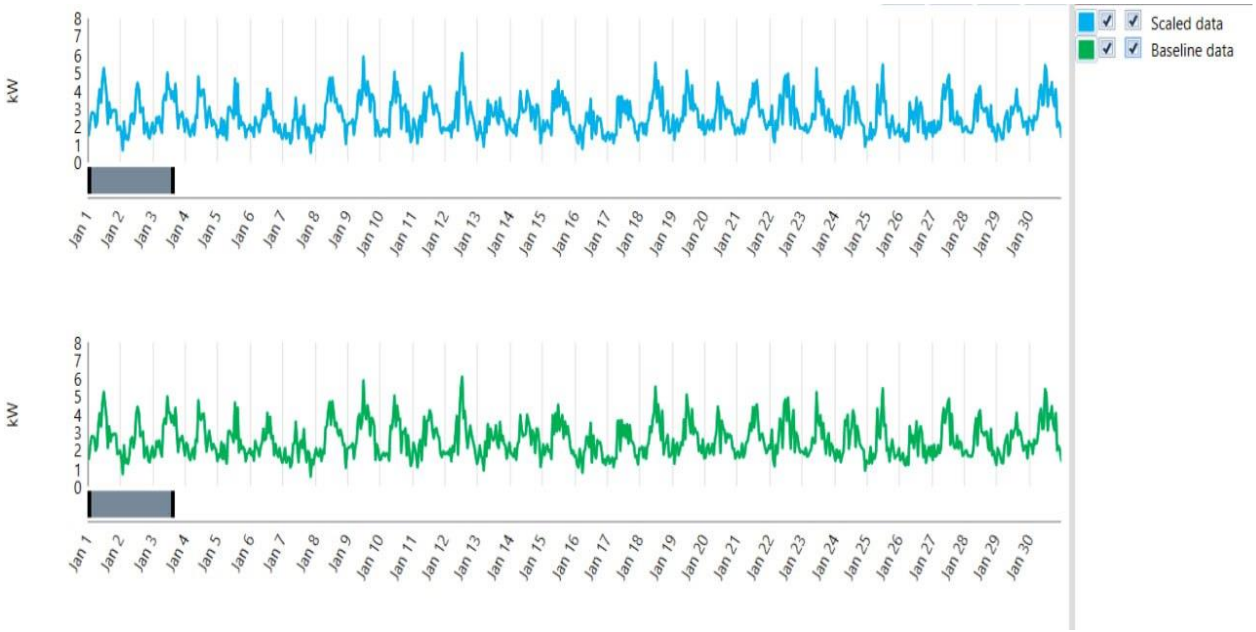


Overview

Quick Details

Place of Origin:	Jiangsu, China	Brand Name:	Koyoe
Model Number:	KY-3GT-20K	Input Voltage:	200~950V
Output Voltage:	230~480V	Output Frequency:	50/60HZ
Output Type:	Single, DUAL	Size:	505*200*414mm
Type:	DC/DC Converters, DC/AC Inverters	Inverter Efficiency:	98.5%
Certificate:	CE/ SAA / NRS 097 / IEC 62109 / AS4777.2	Warranty:	5~10years, 5-10 Years
Weight:	18kg	Product name:	Grid Tie Inverter
Inverter type:	On-grid Solar Power Inverter	Efficiency:	97.8%-98.5%
Rated power:	20.5KW	Display:	LCD
Frequency:	50 HZ 60 HZ	MPPT Efficiency:	99.9%
Start voltage:	180v	Color:	White/Orange/Customized

Appendix B: Baseline and Scaled Hourly Solar Data



Appendix C: Duration Curve