Optimal Determination and Sizing of Standalone Solar Power AC Home System for Rural Area [A Case Study at Doni Kombe Rural Area]

Geremew TufaNegese

A Thesis Submitted to the Department of Electrical Power and Control Engineering

School of Electrical and Computer Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Power System Engineering

Office of Graduate Studies

Adama Science and Technology University

September, 2022

Adama, Ethiopia

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Declaration

I hereby declare that this Master's Thesis entitled "Optimal Determination and Sizing of Standalone Solar Power AC Home System for Rural Area [A Case Study at Doni Kombe Rural Area] is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Geremew Tufa	________________	September 17, 2022
Name of Student	Signature	Date

Recommendation

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis "Optimal Determination and Sizing of Standalone Solar Power AC Home System for Rural Area [A Case Study at Doni Kombe Rural Area] prepared under my guidance by Geremew Tufa Negese submitted in partial fulfillment of the requirements for the degree of Masters' of Science in Electrical Power and Control Engineering. Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedures.

Dr, Tefera T.Y		September 17, 2022
Advisor	Signature	Date

Approval Sheet

I, the advisor of this thesis entitled "Optimal Determination and Sizing of Standalone Solar Power AC Home System for Rural Area [A Case Study at Doni Kombe Rural and developed by Geremew Tufa Negese, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Tefera T, Y		September 17, 2022
Advisor	Signature	Date

We, the undersigned members of the Board of Examiners of the thesis by Geremew Tufa Negese have read and evaluated the thesis entitled "Optimal Determination and Sizing of Standalone Solar Power AC Home System for Rural Area [A Case Study at Doni Kombe Rural Area] and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electrical Power and Control Engineering.

Chair Person	Signature	Date
Internal Examiner	Signature	Date
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Final approval and acceptance of the thesis are contingent upon the submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
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LIST OF ACRONYMS

AC	Alternating Current
AGM	Absorbed Glass Mat
Ah	Ampere-hour
ALCC	Annual life cycle cost
Bc	Battery cost
Ca	Calcium
Cc	Charge controller cost
DC	Direct Current
DOD	Depth of discharge
HOMER	Hybrid optimization Model for Electric Renewable
Isc	Short Circuit Current
LCC	Life cycle cost
LCOE	Levelized cost of energy
MPP	Maximum PowerPoint
NiCd	Nickel Cadmium
Np	Number of parallel module
NPV	Net Present Value
Ns	Number of series module
O &Mc	Operation and Maintenance Cost
PSH	Peak Sun Hour
PV	Photo Voltaic
PWM	Pulse Width Modulation

SOC	State of Charge
UV	Ultra Violate
Voc	Open circuit voltage
VR	Voltage Regulation
VRL	A Valve Regulated Lead-Acid
WP	Peak Watt

Abstract

The energy obtained from solar is a clean and renewable source of energy. The main objective of this thesis was to determine optimal size of standalone solar power AC home in order to provide an electric power supply for Doni Kombe rural area with the best techno-economic system. Therefore, a standalone power system based on renewable energy sources is an option to overcome the power supply problem for rural electrification. In this thesis, standalone PV, Battery bank, and the inverter has been simulated and optimized for the rural area of Doni Kombe village among Boset Woreda of East Shewa Zone in the Oromia region of Ethiopia. Based on the design of the standalone system. During optimization of the power system, HOMER Software has been used to design an optimal standalone power system. Solar PV was considered the primary source to supply electricity to the load that has been suggested for residential. While designing this system, the simulation and optimization were performed based on the load demand, climatic data, the economics of integrated system components, and other parameters in which the total NPC and COE have to be minimized to select an economically and technically feasible standalone power system. So that, a standalone PV/battery bank system has been investigated by the thesis as an optimal system with the primary load demand, the peak load of the village, scaled annual average, PV/battery bank system components concerning its initial cost, O&M cost, NPC and COE for a household with a total number of 1643, 864kwh/day, 171kW, 6.05 $Kwh/m2/day$*, 836 number of batteries, 1078 number of modules, 214kW inverter, $1,219,716,$156,313/year,$ 2,888,32 and $0.858 respectively as well as a large number of* CO_2 *was avoided. Therefore, this study has concluded that a standalone power system can be examined and optimized during the peak load hours of the Doni Kombe rural area as well.*

Keywords: *Battery bank, HOMER, Primary Load, PV System, Rural Electrification.*

CHAPTER ONE

INTRODUCTION

1.1 Background

Electrical energy becomes important now a day in life activity. As the population of the country gradually increase, it becomes difficult for the government to supply peoples with basic electricity. The government's ambition is to overcome the scarcity and expand the rural electrification for all villages through renewable energy resources like solar energy and wind energy. In our solar system, the sun gives the energy to sustain life.(Kachdorian , 1997&Ritchie,1999) suggested that a PV system is direct conversion of sunlight to electric energy using semiconductor materials and does not require bright sunlight to operate as well as it can also produce electricity on cloudy and rainy days from reflected sunlight. It becomes a source of electric energy due to pollution-free, silent, increased capacity with rising load, and simplicity to operate and installed anywhere. Solar energy is the most fully sufficient available to us and its initial cost is low compared to that of wind energy. (Khan, S.April, 2009) investigate that the PV systems can be designed as standalone or grid-connected systems but Grid-connected PV system becomes complex in installation as the parameter of the grid and the PV system does not match perfectly. The main drawback of a grid-connected PV system is its controllability of the system. The off-grid PV system is simple to setup and it performs efficiently with the help of a battery backup system. PV panels have a fixed position to collect solar energy.(Al-Shamani AN et al.,2015) investigated that The optimum relationship between PV array and battery storage to meet load demand is obtained through the successful operation of the standalone PV system. Sunlight shining on the solar cells induces or generates dc electric power. This dc power is supplied to an inverter that converts Dc into Ac without affecting the quality of the power supply. PV cells and modules do not utilize heat but only sunlight.

1.2. Statement of the Problem

Since electric energy become very important in daily life activity, it is so difficult for the government to overcome the power supply problem as the population gradually increases. So that a large number of rural areas population live without electricity power supply due to insufficient energy generation to cover power demand nowadays. Therefore, renewable energy become an option to supply energy due to its being environmentally friendly, silent, and installed anywhere. To overcome the increased power demand of the population, renewable energy power systems should be expanded. Standalone PV/ battery bank system is the best way to generate electricity for the rural population. This thesis focuses on standalone solar PV/battery bank for rural electrification due to solar radiation availability for Doni Kombe village which could not join the main grid still now.

1.3 Objective of the Study

1.3.1 General Objective

The main objective of this thesis is to determine and sizing the optimal standalone solar power AC home for Doni Kombe rural communities in order supply electric energy that is directly converted from solar energy through PV modules.

1.3.2 Specific Objectives

- To Estimate load demand.
- To Optimally size each component used in the standalone system based on watt-hour demand.
- To Estimate solar potential of Doni Kombe rural area.
- To design and mathematically model the standalone PV system.
- To analyze the cost of standalone PV system.
- To perform the simulation using Homer software and observe the characteristic of the standalone PV system.
- To discuss the standalone PV system of Doni Kombe.

1.4. Scope of the Study

This study focused on mathematical determination, design, and modeling of standalone PV/battery bank as well as simulating the result by HOMER software to find the best optimized system.

1.5 Limitations of the Study

This study is limited to the model and design of a standalone system for 1643 households'. The system uses HOMER Software as a tool to show the optimal appropriate power.

1.6 Significance of the Study

The necessity of this study is to model and design a standalone PV/battery bank system that is suitable for the power demand of Doni Kombe rural electrification. Therefore, in a standalone system, a battery bank is used to save energy when there is high energy generation as well as provide electric energy during low generation. So, this thesis provides the guidelines for those who want to implement the standalone system and expand rural electrification to other areas in Ethiopia. Generally, since the pollution of air and wastage of energy become the main problem, it is very important to expand renewable energy due to its new technology and existence forever.

1.7 Thesis Outline

The thesis consists of five chapters namely:

Chapter one discussed the introduction that deals with the background, statement of the problem, objectives, scope, limitation of the study, and significance of the study.

Chapter two expressed the theoretical overview of standalone PV components.

Chapter three discussed materials and methodology which studied the potential assessment of solar energy in the Doni Kombe rural area. The assessment is based on primary (local source, load data) and secondary data (from NASA). Estimation of load, design of the standalone system, and overview of HOMER software were presented.

Chapter four discussed the simulation result and discussion part of the thesis.

Chapter five expressed the conclusions, recommendation as well as suggestion for further work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Background

The solar system is a silent, environmentally friendly, pollution-free, and renewable source of electrical energy.(Strong & Scheller,1993) Suggested that a PV system is the direct conversion of solar energy into electricity and uses the DC output of the solar panel to power the load. The battery bank is used to store energy for use when there is demand. The dc output of the batteries is converted by the inverter to Ac voltage to run Ac loads. Off-grid solar energies provide an option to use renewable energy where there is a utility power supply.(Patel, 1999) explained that Solar energy is a very efficient and pollution-free energy resource. One of the greatest benefits of solar energy is that it is an unlimited source of energy; it will protect the environment from pollution and decrease the impact of climate change.(Bizuayehu T.(2011)&R. Chedid and Y. Saliba(1996) concluded that Photovoltaic technologies operate by catching the photons of light and controlling them to generate free electrons which produce an electric current. Therefore, PV cells are semiconductor cells that can convert solar rays into electrical power

2.2 Basic Theory of Renewable Energy

(Patel, M.R., (2006) &Gipe, P. 2004) Suggested Electrical energy has an important role in economic development. Therefore the energy generated from solar, and wind energy sources are increasing rapidly, especially in developed countries. PV cells are electronic semiconductor device technology and can produce an electric current directly from sunlight.

2.2.1 Basic Theory of Solar Energy

(Anca D. Hansen, et al., 2008) investigated that Solar energy is an important source of renewable energy and is broadly classified as either passive solar or active solar depending on how they capture and convert into solar power. Active solar techniques involve the use of PV systems

2.2.2 PV Module

(Messenger and Jerry Ventre, 2000) suggested that The basic unit of a photovoltaic system is the photovoltaic cell. A PV cell is made of at least two layers of semiconducting materials, usually, silicon doped with special additives. One layer has a positive charge, the other negative. Light observed by cells induces an electric field across the layers, causing electricity to flow. The intensity of the light determines the amount of electrical power each cell generates. A PV cell is a convertor that changes light energy into electricity

2.2.3 Components of PV Module

To size the PV, the following components are required.

2.2.3.1 Solar cell

It is the basic unit of the PV system. A typical silicon solar cell produces only about 0.5v. Therefore multiple cells are connected in series to form larger units called PV modules which are used to connect cells and provide weather protection. (AldoV, 2005) implied The modules are normally enclosed between a transparent cover usually glass and a weatherproof backing sheet which is typically made from polymer or glass as well as can be formed for extra mechanical strength and durability. Usually, 36 solar cells are connected to give a voltage of about 18V which is reduced to 17V as these cells get hot in the sun. So that it is enough to charge a 12V battery. Similarly, 72 cells module generates about 34V which can be used to charge a 24V battery. The most common cells are (12.7×12.7) cm or 5×5 inches,(15×15)cm or 6×6 inches and generate 3 to 4.5W which is very small power. The typical module size is 1.4 to $1.7m^2$.

2.2.3.2 PV Strings

(Wagner, H. and Mathur, J., 2009) suggested that individual modules can be connected in series, parallel, or both to increase either output voltage or current which leads to increased output power. PV strings are several modules connected in series. In a series connection, the negative terminal of one module is connected to the positive terminal of the next module. In a series connection, voltages add up and the current remains constant. In a parallel connection, the current (I) adds up, and the voltage is constant.

2.2.3.3 PV Array

(Tzanak, 2006) explained that PV array is formed from parallel-connected multiple PV strings which are used to maximize the current. Parallel connection increases the current, while voltage remains the same. So that, modules are connected to form an array. The ac power supply could be obtained by inverter through conversion of dc power produced by the module. The module in a PV array is usually first connected in series to obtain the desired voltage. The individual strings are then connected in parallel to allow the system to produce more current.

2.2.4 PV Types

(Anca D. Hansen, etal. 2008) investigated Crystalline PV cells are made from silicon which is first melted and then crystallized or cast of pure silicon. A thin slice of silicon is cut from a single crystal of silicon to make individual cells. The conversion efficiency of this type of PV cell is 10% -20%. Crystalline PV cells represent about 90% of the market today. Crystalline cells are classified as mono crystalline and polycrystalline cells.

2.2.4.1Mono Crystalline Silicon Cell

It is a single crystal of high purity of castings of pure silicon with a typical dimension of 12.5 or 15cm. Ingots have a cylindrical shape, which is cut into thin slices and made round, semi-round, or squire shape. These cells are the most electrically efficient and require less surface area to generate an equivalent amount of power. They have a wide range of transparency options. The drawback of this type of cell is its higher cost. It is required for limited installation area as well as maximum electricity generation. Its commercial efficiency is 14%-19%

2.2.4.2 Poly Crystalline PV

The ingot which casts to form polycrystalline cells is cut into thin sheets of semiconductor material that are used to create cells. Even though the lower cost makes them a popular choice for relatively large installation, these cells are less efficient than Mon crystalline. Commercial module efficiencies range is around 12%-15%.

2.2.4.3 Thin-Film PV

This kind of photovoltaic is formed by spraying a thin semiconductor layer of PV material onto glass and metal. Even though they have higher light absorption than equivalent crystalline material, they suffer from poor cell conversion efficiency due to their non-single crystal structure requiring larger-sized cells. The semiconductor material used for the thin-film types of the photovoltaic cells includes cadmium telluride, copper indium Di serenade, amorphous silicon, and thin-film silicon. Among these amorphous silicon has the highest light absorption over 40 times higher than crystalline silicon but low efficiency which is 5%-7%.

2.2.5 Factors Affecting PV Module Performance

(Tomas Petru , 2001) suggested a PV module's performance is directly proportional to the amount of sunlight it receives. If a PV module is shaded, even partially, its performance will be affected. The factors that affect the solar power outputs are:

2.2.5.1 Environmental Factors

- **Location:-**When designing a PV system, location is the necessary point. The amount of solar availability received by the photovoltaic modules is very important to the financial feasibility of any PV system. Latitude is a primary factor.
- **Solar Irradiance:-**It is a measure of how much power in watts per square meter will be achieved at the location.
- **Solar Insolation:-**It is a measure of solar irradiance that reaches a PV surface area at any provided time. Solar power access in a given location is expressed as $Kwh/m^2/day$ meaning that it is peak sun hour (PSH). For example, if solar radiation for a location is $5Kwh/m^2/day$ then PSH for that location will be 5 hours. Now, if a 1kW solar panel is installed on the location, it will generate $1Kw \times 5h = 5Kwh$ energy per day excluding any losses.
- **Air Mass:-**It expresses the thickness and clarity of the air through which the sunlight passes to reach the modules (sun angle affects this value). The standard is 1.5
- **Sun Angle and PV Orientation:-**The direction that a solar panel faces is referred to as its orientation. The orientation of the solar array is so important as it affects the amount of sunlight striking the array and hence the amount of power the array will generate. The amount of sunlight striking the array also varies with the time of day because of the sun's movement across the sky. Solar modules should be installed so that as much available radiation is collected. The highest efficiency of a PV module or peak power will be obtained when its surface is perpendicular to the sun's rays.
- **Shading:-**Shading is one of the most important parameters for the power loss in a PV array. Even the partial shading of one cell of a 36-cell module can decrease the power output significantly. Potential shading sources can be trees and bushes, neighboring buildings, and self-shading by the multiple rows of modules themselves. Calculations need to be done to find the minimum distance between PV Array rows to avoid winter mid-day shading. The general rule of thumb is to locate the array at a distance

a from the object that is at least twice the height of the object. Thin-film PV modules are more tolerant to partial shading than crystalline silicon PV modules

2.2.6 Electrical Characteristics

(Ritchie, 1999) suggested the type of solar power generated by a photovoltaic solar cell is DC power which same as a battery. Most photovoltaic solar cells generate a "no-load" open-circuit voltage of about 0.5 to 0.6 volts when there is no external circuit connected. This output voltage depends on the load current (I) demands of the PV cell. For example, on a very cloudy day the current demand would be low and so the cell could supply the full output voltage. But as the current demand of the load increases a brighter light (solar radiation) is needed at the junction to maintain a full output voltage.(Bizuayehu T., 2011) explained However, there is a physical limit to the maximum current that a single photovoltaic solar cell can generate no matter how intense or bright the sun's radiation is. This is called the maximum deliverable current and is symbolized as Imax. The I_{max} value of a single photovoltaic solar cell depends upon the size or surface area of the cell, the amount of direct sunlight hitting the cell, its efficiency of converting this solar power into a current, and of course the type of semiconductor material that the cell is manufactured from silicon, gallium arsenide, cadmium supplied cadmium telluride etc. Most commercially available photovoltaic solar cells have solar power ratings which indicate the maximum deliverable solar power, $P\max$ that the cell can provide in watts and is equal to the product of the cell voltage V multiplied by the maximum cell current I.

2.2.7 Photovoltaic Electrical Characteristics

(R. Bharanikumar, 2010) implied It provides the current and voltage at which the photovoltaic cell supplies the maximum output power and is based on the cell being under standard conditions of sunlight and temperature with no shading. The available power (W) from the PV is the product of current and voltage at that point

2.2.7.1 Short Circuit Current (ISC)

A photovoltaic module will generate its maximum current when there is no resistance in the circuit. This would be a short circuit between its positive and negative terminals. This maximum current is called the short circuit current (Isc). This value is greater than I_{max} which relates to the normal operating circuit current. Under this condition, the resistance is zero and the voltage in the circuit is zero.

2.2.7.2 Open Circuit Voltage (V_{OC})

Open circuit voltage (Voc) means that the PV cell is not connected to any external load and is therefore not generating any current flow (an open circuit condition). This value depends upon the number of PV panels connected in series. Under this condition, the resistance is infinitely high and there is no current.

2.2.7.3 Maximum Power (P_{max} or MPP)

It expresses the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where $P_{max}=V_{max} \times I_{max}$. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp).

2.2.8 PV Panel Energy Output

(Wagner, H. and Mathur, J., 2009) Suggested the power output of a photovoltaic solar cell is given in watts and is equal to the product of voltage times the current (V x I). The optimum operating voltage of a PV cell under load is about 0.46 volts at the normal operating temperatures, generating a current in the full sunlight of about 3 amperes. Then the power output of a typical photovoltaic solar cell can be calculated as: P = V x I = 0.46 x 3 = 1.38 watts. This 1.38 watts is not enough power to do any usable work. However, when the PV cells are connected in series, the voltage is added and when connected in parallel (side-by-side) the current is added. A suitable combination of PV modules in series and parallel provides the desired voltage, current, and power output .For a specific load, PV module output depends on two major factors.

2.2.8.1 Solar Intensity

The amount of sunlight falling onto the surface of the PV cell affects its output. The more sunlight enters the cell, the more current it generates. The voltage will remain constant.

2.2.8.2 Temperature

PV cell performance decrease at higher cell temperatures. The operating voltage drops with increasing cell temperature. So, in full sun the output voltage decreases by about 5% for every 25°C increase in cell temperature. Then photovoltaic panels with more solar cells are recommended for very hot climates than would be used in colder ones to offset power output losses due to high temperatures.

2.2.9 System Configurations

2.2.9.1Grid-Connected PV Systems

In a grid-connected PV system, the PV array is directly connected to the grid-connected inverter without a storage battery. (Patel, M.R., (2006) explained If there is enough electricity flowing in from the PV system, no electricity flows in from the utility supply. If the system is producing more power, the excess will be transported into the energy utility grid, turning the meter backward. During the times when the electricity didn't generate bythe PV system, such as at night, the power grid will supply all the demand. The energy utility supply will generate energy credit to providers based on solar generation. This is called "Net Metering". In this process, the energy goes in and out through a single meter. Grid-Connected System is the simplest and most cost-effective way to connect PV modules to the regular utility power supply. If utility power is reliable and well maintained in an area, and energy storage is not a priority, a battery will not be needed. But if the utility power goes down, even if there is solar, the PV system will be off for the safety of the utility workers. The main application of grid-connected PV systems is in cities, where the national power grid is available. A grid-connected system can be an effective way to lower the dependence on utility power and increase renewable energy generations as well as improve the environment. System doesn't always require covering all electrical needs and is less expensive. The main drawback of a grid-connected system is that it doesn't prevent grid power failure.

2.2.9.2 Standalone PV Systems

Off-grid PV systems have no connection to an electricity grid. (Saleh IM. 2006)Suggested A simple standalone PV system is an automatic solar system that generates electrical power to charge banks of batteries during the day for use at night when the sun's energy is unavailable. Deep cycle lead-acid batteries are generally used to store the solar power generated by the PV panels, and then discharge the power when energy is required. Deep cycle batteries are not only rechargeable, but they are designed to be repeatedly discharged almost down to a very low charge. A charge controller is connected between the solar panels and the batteries. The charge controller operates automatically and ensures that maximum output of the solar panels is directed to charge the batteries without overcharging or damaging them. An inverter is needed to convert the DC power generated into AC power for use in appliances. It is more cost-effective to install a standalone PV system than pay the costs of having the local electricity supply extend their power lines and cables directly to the home. The system meets all electrical needs for households, with no connection to the conventional power grid, works in remote locations, and protects against power failures. But it requires a much more powerful system, produces more power than average consumption is significantly more expensive and could run out of power.

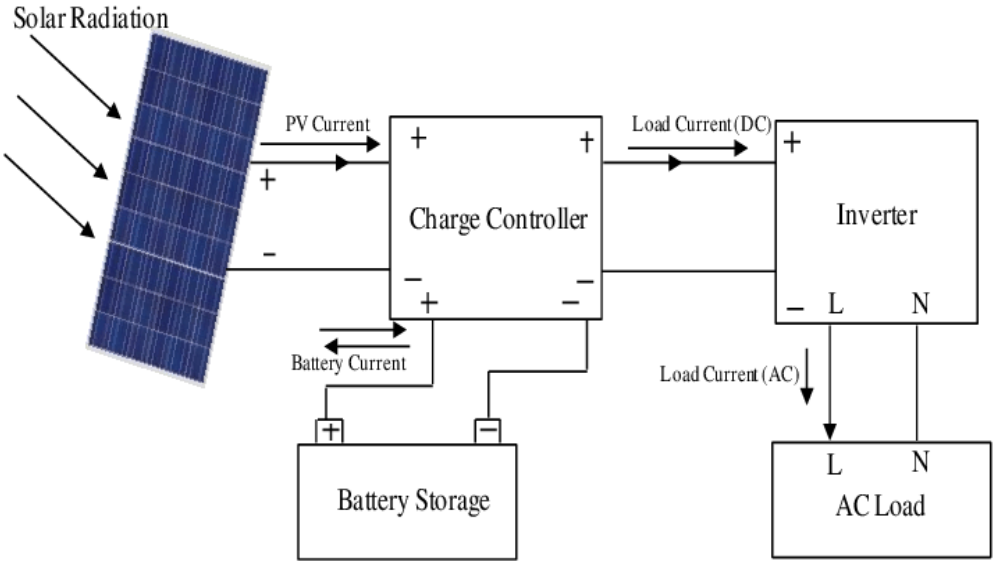

Fig.2.1: Block Diagram of Standalone PV system (R. Bharani Kumar, 2010).

Fig.2.2: PV Array (Tzanakis, 2006).

2.3 Battery

(Anca D. Hansen, etal., 2008) suggested that Since a photovoltaic system‘s power output varies throughout It stores electric energy for supply during nighttime or during an extended period of cloudy or when the PV array by itself cannot supply enough power. In a standalone PV system, the number of days the battery storage operates electrical loads directly from the battery without any energy input from the PV array is called days of “autonomy any given day, the battery storage system can supply a relatively constant power source, even when the photovoltaic system is disconnected for repair and maintenance ofgenerating minimum power in periods of decreased sunlight. In general, electrical storage batteries can be divided into two major categories, primary and secondary batteries.

- ✓ **Primary Batteries:-**Primary batteries can store and deliver electrical energy but cannot be recharged. Typical carbon-zinc and lithium batteries commonly used in consumer electronic devices are primary batteries. Primary batteries are not used in PV systems because they cannot be recharged.
- ✓ **Secondary Batteries:-**A secondary battery can accumulate and supply electrical energy and can also be recharged by allowing a current through it in an opposite direction to the discharge current. Rechargeable batteries are the most effective storage mechanism available. Battery storage capacity is rated in ampere-hours, which is the current supplied by the battery over a set number of hours, at a normal voltage, and at a temperature of 25ºC. Most PV systems use lead-acid batteries or conventional flooded batteries. Nickel-cadmium batteries are usually the best option when very high reliability is needed.

2.3.1 Batteries Types and Classification

2.3.1.1 Lead Acid Batteries

Lead-acid batteries are most common in PV systems, as they are cheap, reliable, and have relatively good energy storage density. Lead battery cells consist of two lead plates immersed in dilute sulphury acid which creates a voltage of about 2V between the plates. Cells are then connected in series to have 12V batteries. These are available as flooded and sealed configurations.

2.3.1.2 Flooded lead-acid Batteries

These are the most common lead-acid batteries. They contain vents that allow the resulting hydrogen gas from electrolysis to escape. As a result, the electrolyte level will fall over a sometime, and must be monitored and topped up with water, preferably distilled water. The hydrogen gas produced is highly flammable. Care must be taken to ensure that there is adequate ventilation above and around flooded batteries.

2.3.1.3 Sealed Batteries

These are spill proof and do not require periodic maintenance. They are also known as valve -regulated lead-acid (VRLA) batteries these contain electrolyte, which is immobilized in some manner. Under excessive overcharge, the normally sealed vents open under gas pressure through a pressure regulating mechanism. Electrolytes cannot be replenished in these battery designs; therefore, they are intolerant of excessive overcharge. VRLA batteries are available in two different technologies: Absorbed Glass Mat (AGM) and Gelled Electrolyte. AGM lead-acid batteries have become the industry standard, as they are maintenance-free and particularly suited for grid-tied systems where batteries are typically kept at a full state of charge. Gel-cell batteries, designed for freeze resistance, are generally a poor choice because any overcharging will permanently damage the battery. The following describes the types of Lead-acid batteries commonly used in PV systems;

2.3.1.4 Lead-Antimony Batteries

(Moien A. Omer, 2018) suggested that Lead-antimony batteries are a type of lead-acid battery which uses antimony (Sb) as the primary alloying element with lead in the plate grids. The use of lead-antimony alloys in the grids has both advantages and disadvantages. Advantages include supplying more mechanical strength than pure lead grids excellent deep discharge, and high discharge rate performance. Lead-antimony grids also limit the shedding of active material and have a better life than lead-calcium batteries when operated at higher temperatures. Disadvantages of lead-antimony batteries are a high self-discharge rate, and as the result of necessary overcharge, require frequent water additions depending on the temperature and amount of overcharge. Most lead-antimony batteries are flooded, open vent types which avoid caps to allow water additions. They are well suitable for application in PV systems due to their deep cycle capability and ability to take abuse; however, they do require periodic water additions. (Makvart ,2000) investigated The frequency of water additions can be reduced by the use of catalytic recombination caps or battery designs with excess electrolyte reservoirs. The health of flooded, open vent lead-antimony batteries can be easily checked by measuring the specific gravity of the electrolyte with a hydrometer. Lead-antimony batteries with thick plates and robust design are generally classified as motive power or traction type batteries, are widely available, and are typically used in electrically operated vehicles where deep cycle long-life performance is required.

2.3.1.5 Lead-Calcium Batteries

Lead-calcium batteries are a type of lead-acid battery that uses calcium (Ca) as the primary alloying element with lead in the plate grids. Like lead-antimony, the use of lead-calcium alloys in the grids has both advantages and disadvantages. Advantages include providing greater mechanical strength than pure lead grids, a low self-discharge rate, and reduced gassing resulting in lower water loss and lower maintenance requirements than for lead-antimony batteries. Disadvantages of lead-calcium batteries include poor charge acceptance after deep discharges and shortened battery life at higher operating temperatures and if discharged to greater than 25% depth of discharge repeatedly.

2.3.1.6 Lead-Antimony/Lead-Calcium Hybrid

These are typically flooded batteries, with capacity ratings of over 200 ampere-hours. A common design for this battery type uses lead-calcium tubular positive electrodes and pasted lead-antimony negative plates. This design combines the advantages of both lead-calcium and lead-antimony design, including good deep cycle performance, low water loss, and long life.

2.3.2 Alkaline Batteries

Because of their relatively high cost, alkaline batteries are only recommended where extremely cold temperatures (-50°F or less) are anticipated or for certain commercial or industrial applications requiring their advantages over lead-acid batteries. These advantages include tolerance to high temperatures, low maintenance requirements, and the ability to be fully discharged or over-charged in a safe condition. The most common type of alkaline battery used for a PV system is the Nickel Cadmium battery.

2.3.2.1 Nickel Cadmium Batteries

Nickel-cadmium (Ni-Cd) batteries are secondary or rechargeable batteries and have several advantages over lead-acid batteries that make them attractive for use in stand-alone PV systems. These advantages include long life, low maintenance, and survivability from excessive discharges, excellent low-temperature capacity retention, and non-critical voltage regulation requirements. The main disadvantages of nickel-cadmium batteries are their high cost and limited availability compared to lead-acid designs.

2.3.3 Battery Parameters

Deep cycle batteries are generally used in solar PV systems and are especially designed for the type of charging and discharging cycles they require to carry on. These batteries can be characterized (in addition to their ability to be recharged) by high power density, high discharge rate, flat discharge curves, and good low-temperature performance. The most common type of batteries used in solar PV applications are maintenance-free “lead-acid batteries” as this type of battery is the most cost-effective for energy storage. Parameters associated with deep-cycle lead-acid batteries are.

2.3.3.1 Battery Voltage

Voltage is electrical pressure. A standard car battery is 12 volts. This voltage is the addition of the six (6) smaller lead-acid cells connected in series which make up a larger 12V battery. Each lead-acid cell has a voltage of about 2 volts. Battery banks used for alternative energy systems are usually connected in series to produce DC voltages of 12, 24, 36, or 48 volts.

2.3.3.2 Battery Current

Current is the flow of electrons. The rate of this flow per unit time is called an ampere. Batteries store power as direct current (DC) which is used for lighting or to power the inverter which changes it into alternating current (AC). The maximum supplied current from deep cycle batteries is the highest current a battery can drive through a load without its terminal voltage dropping significantly due to the battery’s internal resistance, and without causing the battery to overheat. Deep cycle batteries are connected in parallel to increase the available output current.

2.3.3.3 Rated Battery Capacity

Battery capacity is the amount of energy a battery contains and is usually rated in Ampere hours (Ah) at a given voltage. So, a battery with a rating of 1,000 ampere-hours can supply 100 amperes for 10 hours, or 10 amperes for 100 hours, or 1 ampere for 1000 hours, and so on. To determine the total amount of power a deep cycle battery can supply, multiply the ampere-hours (Ah) by the terminal voltage. The storage capacity of an average car battery is about 40 to 85 ampere-hours. Rated capacity will not be obtained repeatedly when the batteries are used in PV systems. However, rated capacity determines battery performance. When comparing the rated capacity of different batteries, the same discharge rate is being used.

- **Depth of Discharge (DOD):** Depth of Discharge (DOD) is the percentage of the rated battery capacity that is withdrawn from the battery. The ability of a battery to withstand discharge depends on its construction.
- **Deep Cycle Battery Wiring:** Any number of batteries can be connected in series to produce an output voltage that is a multiple of the battery voltage. Batteries connected in parallel increase the current by the number of branches. However, it is better to limit the number of connected branches to a maximum of three (3) as parallel battery banks tend to circulate unwanted currents from branch to branch.
- **Temperature Correction:** Batteries are sensitive to temperature extremes and a cold battery will not supply as much power as a warm one. The battery should be kept near room temperature close to 25°C. Batteries should be located in an insulated or other temperature-regulated enclosure to minimize battery temperature variations. This enclosure should be separated from controls or other PV system components for safety reasons. Adequate ventilation of these enclosures is required, for the removal of toxic and explosive mixtures of gasses (hydrogen) that may be produced by the batteries.

2.3.3.4 State-of-Charge (SOC)

This is the amount of capacity remaining in a battery at any point in time. It is equal to 1 minus the depth of discharge given as a percentage.

- **Battery Life (cycles):** The lifetime of any battery is difficult to forecast because it depends on various factors such as charge and discharge rates, depth of discharges, number of cycles, and operating temperatures. It would be unusual for a lead-acid type battery to last longer than 15 years in a PV system but many last for 5-10 years. Nickel-cadmium batteries will generally last longer when operated under similar conditions and may operate satisfactorily for more than 15 years under optimum conditions.

- **Charging Cycle:** In stand-alone systems, the cycle of the battery is within 24 hours, charging during the daytime and discharging at night. Typical daily discharge may range from 2 -20% of the battery capacity.
- **Days of Autonomy:** Autonomy refers to several days a battery system will supply a given load without being recharged by the photovoltaic array. Exactly selecting a number of days will depend on the system, its location, its total load, and the nature of the system's load. Weather conditions determine the number of no sun days which may be the most significant variable in determining autonomy.

2.3.3.5 Battery Rating and Sizing

The nominal capacity of the battery is given from the following expression

$$Q_n = I_n \times T_n \quad (2.1)$$

Where, I_n: constant discharge current, amp , Tn: discharge time.

2.3.3.6 Battery Installation

Batteries should be installed in an enclosed space, separated from controls or other PV system components which may have cooling/heating mechanisms to protect them from excessive temperatures. When temperature swings are reduced, the battery will have a better performance, longer life, and lower maintenance.

2.3.3.7 Battery Maintenance

Batteries require periodic maintenance. For flooded batteries, the electrolyte level should be maintained well above the plates and the voltage and specific gravity of the cells should be checked for consistent values. The specific gravity of the cells should be checked with a hydrometer, particularly before the onset of winter. In cold environments, the electrolyte in lead-acid batteries may freeze. (Gipe, P. (2004) suggested the freezing temperature is a function of a battery's state of charge. When a battery is completely discharged, the electrolyte becomes water and the battery may freeze. Even the sealed battery should be checked to make sure connections are tight and there is no indication of overcharging.

2.3.3.8 Battery Safety

Batteries which are used in photovoltaic systems are potentially dangerous if improperly handled, installed, or maintained. Dangerous chemicals, heavy-weight, and high voltages and currents are potential hazards and can result in electric shock, burns explosion, or corrosive damage to a person or property. Also, hydrogen gasses and fumes emitted during charging of these lead-acid deep cycle batteries are irritant and potentially explosive, so always ventilate the battery area well. Clean any spillages of electrolyte on or around the batteries and check the battery terminals and cables for tightness lubricating with petroleum jelly if needed. With proper care and maintenance, deep cycle lead-acid batteries will have a long service life in any solar-powered PV system. Gloves, eye protection such as goggles, and masks must be worn when handling lead-acid batteries and electrolytes as “battery acid” both burns and irritates skin and eyes.

Fig.2.3 Battery (Tomas Petru, 2001).

2.3.4 Charge Controller

Batteries are connected to the PV array through a charge controller. The charge controller prevents the battery from overcharging or discharging and provides information about the state of the system or enables metering as well as payment for the electricity used. There are two main charging regulation methods:

- **Interrupting (on/off) regulation**: The controller allows all available PV current to the battery during charging. On reaching the maximum allowable voltage, the controller switches off the charging current. When the voltage falls to VR – VRH, the current is reconnected.
- **Constant voltage regulation**: The controller can modify the VR set-point by sensing the battery condition or using a low VR to avoid excessive gassing, coupled with provision for an occasional gassing ‘equalization’ charge.

2.4 Types of Charge Controllers

- **Shunt Controller:** The shunt (parallel) regulator has a switch that is open when the battery is charging and closes when the battery is fully charged. These controllers require a large heat sink to dissipate the excess current.
- **Series Controller:-**Series controllers disconnect the array when the battery voltage reaches the high voltage level. These are small and inexpensive and have a greater load-handling capacity than shunt-type controllers. These can be single PMW, single stage, or multistage types.

2.4.1 PWM Controllers

Some controllers regulate the flow of energy to the battery by switching the current fully on or fully off. This is called "on/off control." Others reduce the current gradually. This is called "pulse width modulation" (PWM). Both methods work well when set properly for the needed type of battery. A PWM controller holds the voltage more constant. If it has two-stage regulation, it will first hold the voltage to a safe maximum for the battery to reach full charge. Then, it will drop the voltage lower, to sustain a "finish" or "trickle" charge. Two-stage regulating is important for a system that may experience many days or weeks of excess energy (or little use of energy). It maintains a full charge but minimizes water loss and stress.

2.4.2 Multistage Controllers

Multistage controllers allow different charging currents as the battery nears the full state-of- charge. This technique also enhanced a more efficient method of charging the battery. As the battery nears its full state of charge (SOC) its internal resistance increases. Most charge controllers are three-stage controllers. These chargers prevent the destruction of battery life. The voltages at which the controller changes the charge rate are called set points. Some controllers have adjustable set points, while others do not.

2.5 Selection of Charge Controllers

Charge controllers are selected based on:

- ✓ **PV array voltage:** The controller’s direct current voltage input must match the nominal voltage of the solar array.

- ✓ **PV array current:** The controller must be sized to handle the maximum current produced by the PV array. The total current from the PV array is determined by the number of modules or strings in parallel, multiplied by the module current.
- ✓ **Interaction with Inverter:-**Since most charge controllers are used in off-grid systems, their default settings may not be suitable for a grid-connected system. The charge controller must be set up such that it does not interfere with the proper operation of the inverter.
- ✓ **Interaction with Batteries:-**The charge controller must be selected to supply the charging current suitable for the type of batteries used in the system. Most PV systems use deep-cycle lead-acid batteries of either the flooded type or the sealed type. Sealed batteries need to be regulated to a delicately lower voltage than flooded batteries or they will dry out and be ruined.
- ✓ **Temperature compensation:** - The ideal set points for charge control vary with a battery's temperature. When the controller senses a low battery temperature, it will raise the set. If the batteries are introduced to temperature swings greater than about 17°C, compensation is necessary.

Fig.2.4: Charge controller (Gipe, P., 2004).

2.6 Inverter

The photovoltaic array and battery produce DC voltage. Inverters are used to convert the Dc electricity to Ac electricity used by electrical appliances. It provides a wide range of power classes ranging from a few hundred watts to several kilowatts. It is a power conditioning unit. It is classified into three. These are:

2.6.1 Standalone Inverters

It is used as an off-grid system. The inverter draws its DC energy from batteries charged by photovoltaic arrays and supplies AC energy to the facility’s use. Many stand-alone inverters also incorporate integral battery chargers to supply fully the battery from an AC source, when available. Stand-alone inverters typically operate at 12, 24, and 48volts DC input and create 220volts AC at 50 Hertz. The selection of the inverter input voltage and understanding its terminology is an important decision.

2.6.2 Grid Tie Inverters

It does not provide backup power during utility outages. They are designed to shut down automatically when there is a loss of grid supply, for safety reasons. They need to match the phase with a utility-supplied sine wave.

2.6.3 Battery Backup Inverters

These are special inverters that are designed to draw energy from a battery, manage the battery charge via an onboard charger, and transportation of excess energy to the utility grid. These inverters are capable of supplying AC energy to required loads during a utility outage and are planned to have continuous power even though the electric utility is no longer present. When specifying an inverter, it is necessary to consider the requirements of both the DC input and the AC output.

- For a grid-connected PV system, the DC input power rating of the inverter should be selected to match the PV panel or array.
- For standalone systems, the power inverters are chosen based on the input battery voltage, maximum load, the maximum surge required variations in voltage, and any optional features needed.

Fig.2.5 Inverter (AldoV,2005).

2.7 Power Conversion Efficiency

(Kachdorian, 1997) suggested that this value gives the ratio of output power to the input power of the inverter. Some power is lost in the conversion process. Therefore, while selecting the inverter, conversion efficiency should be high.

2.7.1 Duty Rating

This rating provides the amount of time the inverter can supply its rated power. Some inverters can operate at their rated power for only a short time without overheating. Beyond this time the hardware will fail.

2.7.2 Input Voltage

This is based on the total power supplied to the AC loads and the voltage of any DC loads. Generally, the larger the load, the higher the inverter input voltage. This keeps the current at levels where switches and other components are readily available.

2.7.3 Surge Capacity

Most inverters can exceed their rated power for limited periods(seconds). The necessary Surge of specific loads should be determined. Some transformers and AC motors need starting currents several times their operating level for several seconds.

2.7.4 Standby Current

This is the amount of current (power) used by the inverter when no load is active (power loss). This is a necessary parameter if the inverter will be left on for long periods to supply small loads. The inverter efficiency is lowest when load demand is low.

2.7.5 Voltage Regulation

This shows the variability in the output voltage. Better units will generate a nearly constant root-mean-square (RMS) output voltage for a wide range of loads.

2.7.6 Voltage Protection

The inverter could be failed if the DC input voltage is beyond its level. If the battery is overcharged, It becomes beyond the nominal which causes failure of the inverter. Inverters have sensing circuits that will disconnect the unit from the battery if it is beyond the specified voltage limit.

2.7.7 Frequency

Most loads require 50 Hz. High-quality devices need precise frequency control variations that can cause poor performance of clocks and electronic timers.

2.7.8 Modularity

In some systems, it is preferable to use multiple inverters. These can be connected in parallel to service various loads. Manual load switching is sometimes provided to allow one inverter to meet specific loads in case of failure which leads to an increase inthe system’s reliability.

2.7.9 Power Factor

The cosine of the angle between the current and voltage waveforms generated by the inverter is the power factor. For resistive loads, the power factor will be 1.0 but for inductive loads, the power factor will drop. The power factor is based on the load, not the inverter.

2.8 Disconnect

(Akella. A.K et al., 2007) Suggested that Automatic and manual safety disconnects prevent the wiring and components from power surges and other-equipment failure. They also provide a guarantee to the system so that it safely shut down and system components can be removed for maintenance and repair. A disconnect is needed for each source of power or energy storage device in the system. Ignorance of properly located disconnect will lead leave the power on during maintenance, resulting in a safety hazard.

2.8.1Array DC Disconnect

The array DC disconnect, also called the PV disconnect, is used to safely interrupt the flow of electricity from the PV array for maintenance or troubleshooting. The array DC disconnects may also have integrated circuit breakers or fuses to prevent power surges.

2.8.2 Inverter DC Disconnect

Along with the inverter AC disconnects, the inverter DC disconnects is used to safely disconnect the inverter from the rest of the system. In many cases, the inverter DC disconnects will also serve as the array DC disconnects.

2.8.3 Inverter AC Disconnect

The inverter AC disconnects the PV system from both the household electrical wiring and the grid. Frequently, the AC disconnect is installed inside the household's main electrical panel. However, if the inverter is not located near the electrical panel, an additional AC disconnect should be installed near the inverter.

2.8.4 Exterior AC Disconnect

Utilities commonly require exterior AC disconnects that are lockable and have visible blades which were mounted next to the utility meter so that it is accessible to utility personnel. An AC disconnects located inside the electrical panel or integral to the inverter would not satisfy these requirements. One alternative that is as acceptable to some utilities as an accessible AC disconnect is the removal of the meter itself, but this is not the norm. Before purchasing equipment, consult the electric utility to determine their requirements for interconnection.

2.8.5 Battery DC Disconnect

In a battery-based system, the battery DC disconnects is used to safely disconnect the battery bank from the rest of the system.

2.8.6 Installation

An inverter should be installed in a controlled environment because high temperatures and excessive dust will reduce lifetime and may cause failure. The inverter should not be installed in the same enclosure as the batteries because the corrosive gassing of the batteries can damage the electronics and the switching in the inverter might cause an explosion. However, the inverter should be installed near the batteries to keep resistive losses in the wires to a minimum. After conversion to AC power, the wire size can be reduced because the AC voltage is usually higher than the DC voltage. This means the AC current is lower than the DC current for an equivalent power load.

2.8.7 Balance of System

2.8.7.1 Auxiliaries Items

(Kadir Bakirci, 2012) explained that these components give the interconnections and standard safety features required for any electrical power system. These include an array combiner box, properly sized cabling, fuses, switches, circuit breakers, and meters.

2.8.7.2 Distribution Board – AC Breaker & Inverter AC Disconnect Panel

A component of the electricity supply system, where all the electrical wiring of the house meets with the supply of the electricity, whether that's the grid or off-grid system. It distributes the electrical power supply into subsidiary circuits for different rooms in the house, whiles a protective fuse or circuit breaker for the individual circuits, protects the house wiring against electrical fires and safeguards the circuit's electrical wiring. These breakers also allow electricity to be disconnected for servicing.

2.8.7 Battery Over current Protection

The output conductors of the battery bank should be protected against overcurrent, by high rupturing capacity (HRC) fuses or DC-rated circuit breakers, as follows:

- Where the battery bank is electrically floating (i.e. neither side of the battery is earthed), protection should be provided in both positive and negative battery where one side of the battery bank is earthed, and protection shall be provided in the unearthed battery lead.

2.8.8 Disconnection Devices

Safety disconnects or switches are placed into power systems to allow equipment to be safely installed and maintained. Typically, there are four locations where disconnect devices are required in photovoltaic systems. They are:

- Between the array and the charge regulator
- Between the regulator and the battery
- Between the battery and any dc loads or load centered.
- Between the battery and the inverter.

In many cases, the disconnection means can be combined with the over-current protection in the form of a DC circuit breaker. If this is so, necessary care should be taken while selecting circuit breakers that will fit the purpose. The location of fault current protection related to battery systems is generally between the battery and charge controller. The protection should be mounted as close as practicable to the battery terminals. During charging, the spark ignition of any hydrogen emitted from the batteries should not be there.

2.8.9 Meters and Instrumentation

2.8.9.1 Utility Kilowatt-Hour Meter

(Renewable, 2018) A meter that measures electricity transported to the grid, (when the energy supply is exceeding the limit) or imported from the grid, (when the energy supply does not meet the energy demands). Switch from import to export and vice versa will be automatically controlled without any human intervention.

2.8.9.2 System Meter

System meters measure and show the charge of the battery bank, production of electricity from solar panels, and amount of electricity in use. It is impossible to operate a system without a system meter, therefore meters are strongly recommended.

2.9 Combiner Box

Wires from individual PV modules or strings are run to the combiner box. These wires may be single-conductor pigtails with connectors that are pre-wired onto the PV modules. The output of the combiner box is one larger two-wire conductor in a conduit. A combiner box typically includes a safety fuse or breaker for individual strings and may include a surge protector.

2.9.1 Surge Protection

It protects the system from power surges that may occur nearby power lines struck by lightning. A power surge is an increase in voltage significantly above the designed voltage limit.

2.9.2 Earthing& Grounding

Earthling is the procedure where one or more parts of an electrical system are physically connected to the ground, which is assumed to have zero-volt potential. This method has zero potential which protects the human being from electrocution and is primarily used to avoid shock. It is located under the earth between the equipment bodies underground. Whereas in “Grounding” the circuit is not physically connected to the ground, but its potential is zero concerning other points and is primarily used for unbalancing when overloads happen in the electric system as well as preventing the entire power system from malfunctioning. It is located between the neutral of the equipment being used and the ground. All components of the PV system and any exposed to metal, including equipment boxes, receptacles, appliance frames, and PV mounting equipment should connect to a grounding electrode (the metallic device used to make actual contact with the earth). An equipment-grounding conductor is a conductor that does not normally carry current and is connected to the earth. Earthing is an important safety requirement to prevent electrical shocks caused by a ground fault. A ground fault occurs when a current-carrying conductor comes into contact with the frame of an appliance or electrical box.

2.9.3 Cables & Wiring

Important considerations should be taken while selecting cables and wires. Therefore Array cables should be appropriate for DC application, water-resistant, and UV-resistant. Reinforced or double-insulated cables should be used when laid in a metallic tray or conduit. Total voltage drop in all AC and DC cables shall be less than 4%. Cables are to be laid/ installed in such a way that all connections and wiring should be protected from any contact and mechanical damage. (Sharma.P. et al., 2016) suggested that the cable shall have the ability to carry current safely without overheating in specified conditions that the cable will be laid/ installed. String fuses can be used to prevent cables from overloading and are usually used for systems with more than four strings.

2.9.4 Related Works

The thesis investigated and focused on the design and of a standalone system to meet the supply load demand. (Sevket Burak, 2016).

The thesis has examined and implemented on maximum power point tracking controller for the adjustment in the climate condition for photovoltaic system design. (Sumair Mashraf, 2020).

The thesis suggested the design of a rooftop solar photovoltaic system to provide the required energy by the air conditioning unit of the train to maintain a continuous electric power supply. The study states that the standalone PV system is the alternative power supply for the rail route to continuously condition the air during the absence of a utility power supply. (Rukia Hassen, 2020). The thesis has recommended and suggested that effective solution for the electric power supply problem in the residential centers through the system. (Moien A. Omer, 2018).

This thesis has been performed by HOMER software to model and optimizes the standalone solar power system. However, it is different from related studies in terms of application, load demand, climatic data, and location. Consequently, this case study implements the working capability of solar energy supplying to the targeted area under the investigation of optimized techniques upon the analysis of the required data using HOMER software and accordingly fills the gap by implementing different scenarios of sensitivity and as well optimization tools.

CHAPTER THREE
MATERIALS AND METHODS

3.1Flow Chart for Research Methodology

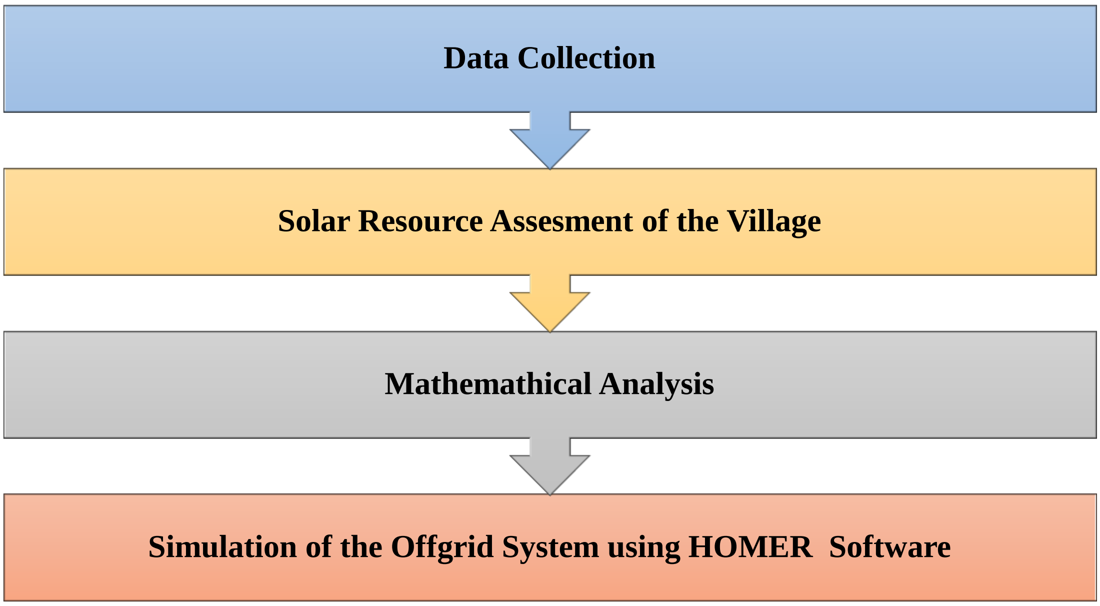

Fig 3.1 Flow chart diagram for the research methodology.

3.2 Data collection and Assessment

3.2.1. Primary Data

It expresses the data collected by myself by conducting a field survey. During this survey, the primary data required for this thesis were the number of appliances and of the household which is about 1643.

3.2.2 Secondary Data

It expresses the data have been collected from NASA surface metrology. For this thesis, solar radiation data and several household appliances are taken from Doni Kombe village during the survey.

3.2.2.1 Solar Resource Assessment of the Village

The solar resource of the village varies from 6.08Kwh/m^2/day in January to 5.36Kwh/m^2/day in August, which is the winter in Ethiopia, and the clearness index daily radiation of the village is obtained from NASA surface metrology at the center latitude

8.558N and longitude 39.28E, for a PV system to supply sustainable power, the daily radiation should be greater than 4Kwh/m^2/day.

Table. 3.1: Global solar radiation (Iarc.nasa.gov/cgibin/sse/sse.cgi?senrohit22@gmail.com).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu	Sept	Oct	Nov	Dec
Kwh / m2/day	6.08	6.57	6.520	6.31	6.36	5.77	5.23	5.36	5.84	6.31	6.27	6.08
Clerness Index	0.7	0.68	0.63	0.6	0.62	0.57	0.5	0.6	0.57	0.64	0.8	0.7

3.2.3 Determination and Sizing of Standalone PV System

Appropriate system determination and component sizing is a fundamental requirement for reliable operation, better performance, safety, and longevity of solar PV systems. Standalone or off-grid PV systems are different from grid-connected inverters. Stand-alone PV systems can be considered a type of banking system. The battery is the bank account. The PV array generates energy and charges the battery, and the electrical loads consume energy. The sizing objective for a stand-alone PV system is a critical balance between energy supply and demand through the determination of the average daily load requirements, conducting a critical design analysis, Sizing battery bank for system voltage and required energy storage capacity, inverter, charge controller, PV array to meet average daily load requirements.

3.2.4 PV System Sizing and Procedures

A photovoltaic system for a stand-alone photovoltaic power system involves a five-step process that will allow the photovoltaic system to be accurately size based. Estimating the electric load sizing and specifying an inverter, sizing and specifying batteries, sizing and specifying an array as well as specifying a controller.

3.2.4.1 Factors Affecting System Sizing

- The average power demand per day can be achieved by itemizing all appliance and their hours used each day which is called load profile.
- Using energy-efficient equipment such as a compact fluorescent lamp (CLF) for illumination to reduce energy requirements.

- Geographical location that indicates panel orientation and the solar insulation, usually $Kw/m^2/day$.

3.2.4.2 Potential of solar resource data

The position of the sun in the sky, the slope and orientation of a collecting surface, and the reflecting properties of the neighboring structure are very important for any solar-based system design.

3.2.5 Mathematical Analysis (Modeling of Standalone System)

3.2.5.1 Estimating the Electric Load

The first task for any PV system design is to determine the system load. The load determination is straightforward. Make a list of the electrical loads to be powered by the PV system. Energy calculation describes the sum of wattage of equipment that is going to be powered using the photovoltaic system. Every piece of equipment has fixed power consumption that can be found on its nameplate the power required by an appliance can be measured or obtained from the nameplate. The power requirements are calculated by multiplying the numbers of hours per day that specific appliances will operate each day. To obtain the average energy demand in watt-hours per day, the electrical devices available, at the residence are itemized with their power ratings and time of operation during the day. This average energy consumption is used to compute the device sizes and ratings of the solar array and system wiring.

$$Eday = \sum PiNt \tag{3.1}$$

Where: E -total daily energy,

P - Power rating of electrical device,

N- Number of electrical devices and t is the daily number of hours for which each device operates.

Table. 3.2: Home appliance and Daily Energy Consumption.

Home Appliance	Quantity	Rating(W)	Adjusted Power(W)	Hrs./day	Kwh/day
Lightning (internal)	1643	10	16430	4	66
Lightning (External)	1437	10	14370	12	172
Stove	56	1000	56000	1.5	84
Refrigerators	203	60	12180	24	294
Television	321	50	16050	8	129
Coffee Maker	117	150	17550	0.45	8
Ceiling Fun	314	120	37680	3	113
Total	4091	1400W	171Kw	52.9	864Kwh/day

Table. 3.3: Hourly data.

Hr	1	2	3	4	5	6	7	8	9	10	11	12
Kw	26.6	26.6	26.6	26.6	26.6	26.6	47.6	29	12.2	12.2	29	45
Hr	13	14	15	16	17	18	19	20	21	22	23	24
Kw	65	30.8	12.2	12.2	12.2	28.2	78.4	59	96.7	96.7	26.6	26.6

Table. 3.4: PV Modules Efficiency.

PV Type	Description	Module Efficiency	Surface Area (m^2)
Mon crystalline	High Light Absorption	14%-19%	7
Polycrystalline	Bright	12%-15%	9
Thin-Film	Very Flexible	6%-8%	17

Solar photovoltaic array size is determined by the following parameter:

The PV array for stand-alone systems is sized to meet the average daily load.

- Solar insolation was receive data from the site.
- System losses, soiling, and higher operating temperatures are factored in estimating array output.
- Characteristics of the PV modules. The system voltage determines the number of series-connected modules required per source circuit.

- The system power and energy requirements determine the total number of parallel source circuits required. The array is sized to meet the average daily load.
- Using module power output and energy (watt-hours or amp-hours) delivered by a photovoltaic module for an average day can be determined. Then, knowing the requirements of the load and the output of a single module, the array can be sized.
- Once these factors are made available, the sizing process continues. To avoid under-sizing, losses must be considered. To correct inverter, wiring, and other losses, the total energy required per day should be multiplied by 1.2. It becomes then, total energy required is 864 kW x 1.2 =1037 kWh/day. Following this inverter dc input voltage should be chosen properly which means from $12V$, 24V, and $48V$. the suitable inverter dc input voltage is $48V$ since the energy required is above 5 kW.
- The total amp hours required can be calculated by dividing the energy required by suitable inverter input dc voltage which means 48v.This becomes$\frac{1037000}{48}$=21604 Amp-hour is the total amp-hour required by AC load per day.

3.2.2 Sizing and Selecting of Standalone PV System

A PV array is a linked collection of solar modules. The power generated by one module is not enough to meet the power required by residential. Therefore, the modules are linked to form an array. The modules in the PV array are usually first connected in series to obtain the desired voltage. The individual strings are then connected in parallel to allow the system to generate more current as required. To size, a PV array, daily energy from the load should be determined. The energy desired energy achieved is then divided by average sun hours per day to obtain the peak power. The peak power is then divided by the selected dc voltage to obtain the total DC. Finally, the number of series and parallel modules can be determined to provide the array size.

$$I_{total}= \frac{Peak\ power\ System}{Dc\ voltage} \quad (3.2)$$

A number of series modules (Ns)=$\frac{\text{System dc voltage}}{\text{Module rated voltage}}$

A number of parallel module (Np) =$\frac{Whole\ module\ current}{Rated\ current\ of\ one\ module}$

Total number of modules=Number of Series Modules × Number of Parallel Modules.

1. Total average Amp-hour per day is21, 604 Amp-hour.

2. To compensate for battery charge, the total amp-hour should be multiplied by 1.2. Therefore, the result became 21,604$\times$1.2=25925 Amp-hour.

3. Average sun hours per day in Doni Kombe rural area is6.

4. Total solar array amp required is $\frac{25,925}{6}$ = 4,321 A

5. The peak or optimum amps of the solar module used8.01amp (RT250M, 250W, 31.22V, 8.01A)

6. To determine the required total number of solar modules in parallel, the total solar array amp required per peak amps of the solar module which means $\frac{4321}{8.01}$ = 539

7. Number of modules in series could be calculated as dividing nominal system voltage by individual array voltage which means $\frac{48}{31.22}$= 1.54. Rounding gives the value of the number of modules i.e., No. of modules = 2.

8. A total number of modules required is line 6$\times$line 7 which means 539$\times$2 =1078.

3.2.6 Sizing and Selecting Battery Bank

The required battery bank should have safe energy storage value to particularly select its specifications as well as to determine the entire battery bank in amp hour. Then a number of series and parallel branches of the bank will be determined. Therefore, the following steps are used to compute. Battery capacity, number of series and parallel branches of the bank. To size, the battery bank, our daily amp-hour of21,604 amp-hour is required which is calculated above and the number of autonomy days that the system should support is 3.Therefore, the amount of Amp-hour the system will need to store is 21,604$\times$3=64,812 Amp-hour.

The depth of discharge which provides the safety factor for the battery that has been chosen for the system is 0.8.so that the battery is protected from overcharging and draining. Therefore $\frac{64812}{0.8}$=81015 Amp-hour. To ensure that the battery bank will have enough capacity to resist the cold weather condition effect, a multiplier factor should be selected.

Therefore ($81015 \times 1.03 = 83445$)is the total battery capacity that will be needed.(Li-ion 12V,400Ah is selected for the system).

Number of batteries in parallel= Battery capacity divided by selected battery capacity

$\frac{83445}{400}$=209 batteries will be needed.

The number of batteries in series = nominal system voltage divided by the battery voltage

(48V/12V=4 batteries will be needed).

Total Number of batteries =N_P x N_S=209×4= 836 batteries will be needed totally.

3.2.7 Sizing of Charge Controller

The size of the voltage controller is that it controls the flow of current. Sizing the appropriate charge controller starts by determining the desired total current that the controller should withstand.

$I_{Controller} = 1.25 \times N_P \times I_{SC}$ (3.3)

Where, Isc = Short ckt current of PV module.

N_P = Number of parallel modules

1.25 = number of factors recommended by energy international.

Therefore, total current of charge controller becomes

I_{SC} = 1.25 x 539 x 8.41= 5,666.23 A

Rating of charge controller in ampere and voltage is (4321 Amp,48V)

The selected controller is ($MPPT\ 48V, 60A$) due to its efficiency.

Number of charge controller =Total current of charge controller per ampere of individual controller which is =$\frac{5,666.23}{60}$ = 94.383 ≈ 94

3.2.7 Sizing and Selecting of Inverter

While sizing and selecting the inverter, it is important to compute the continuous DC that will be supplied at the input of the inverter.

Therefore, the minimum inverter rating is expressed as

Maximum Ac load $\times 1.25$=(171000$W \times 1.25 = 214Kw$,1phase,48V /230V)

3.2.8 Sizing of System Wiring

The Selection of the correct size & type of wire enhances the performance & reliability of the PVC system. The purpose of this step is to forecast the size and the type of wire in the following loops:

- $\rightarrow$ Cable between PV modules and charge controller.
- $\rightarrow$ Cable between the charge controller and load.
- $\rightarrow$ Cable between charge controller and battery.

The sections of the cable must cause less than 3% voltage drop between PV module and charge controller, and less than 2% between battery and charge controller, less than 5% between the charge controller and load.

If 3% voltages drop between the PV module and charge controller, The Maximum module to the controller is given by 1.25% of the short circuit current of the module. Length of cable= 10m, maximum current= $1.25 \times 8.41 amp$ =10.5A, voltage drop =5/100, conductivity of copper = 58×10^6s/m. Therefore, the cross-section area of the cable.

$$Amm^2 = \frac{2\ xLxI}{58\ x\ 0.03\ x\ 48} = 2.5\ mm^2 \qquad (3.4)$$

From cable standard, 4 mm^2 are used.

If a 5% voltage drop between controller and load,

The maximum controller to load current is dividing total load power by system voltage,

$$I= \frac{171,000}{48} = 3,562.5\ A$$

Length of cable is 10m. Cross section area of cable is

$$Amm^2 = \frac{2\ x\ 10\ x\ 3,562.5}{58\ x\ 0.05\ x\ 48} = 512\ mm^2 \qquad (3.5)$$

From standard, $630mm^2$ is used.

If a 2% voltage drop occurs between battery and controller, the length of the cable is5m. The cross-section area will be:

$$\text{Amm}^2 = \frac{3{,}562.5}{55.68} = 64.08 \text{ mm}^2 \quad (3.6)$$

The cross section area becomes 64.08 mm^2 which will be used for a 0.02 voltage decrease between the battery and the controller.

Table.3.5: Technical data and Electrical parameter of PV module.

Electrical Parameter	Rating
Power Rating	$2 \times 500W$
Max. Operating Current	9.38A
Output Voltage	53.33V
Short Circuit Current	9.68A
Open Circuit Voltage	65.18V
Weight	36.5Kg
Dimension	$1992 \times 1302 \times 36mm$
Series Fuse Rating	15A

3.2.9 Economic Analysis

The most evaluation method for the economic behavior of energy systems is life cycle cost(LCC) analysis. In a renewable energy system, overall system life stages will be covered. These are the capital cost and initialization stage, operation & maintenance stage, and replacement stage. The initial capital cost of any system is the cost required for purchasing all system components; this includes PV arrays, and storage system, charge controller, inverter, and installation (including wiring and other auxiliaries). Operation and maintenance costs include annual periodic expenses for system management, and regular maintenance. For continuous operation and to ensure efficient system performance. Some parts of the system must be replaced every 5-10 years according to the battery type and the operating conditions. The analysis must be carried out according to the longest life component of all system parts. The life cycle of the crystalline silicon modules used is around 20 years, whereas the life cycle of the storage batteries can run up to 10 years and will need to be replaced every 10years. For future estimations two important parameters must be considered; the inflation rate which represents the increase in costs of overall system life and the discount rate represents the decrease in the components cost with future mass production.

The array costs(PVc)=11,858,000birr.

Storage batteries cost (Bc) = 50,160,000birr.

Inverter cost ($Invc$) = 187,500birr.

Charge controller (Cc) =1,710,800birr.

For the PV array life cycle of 20 years and the10years battery life, the installation cost (Ic) is 10% of the PV cost while the annual cost ($O\&Mc$) is 2% of the PV initial cost. Given the inflation rate of 4% and a discount rate of 8%, the system life cycle cost and the unit electrical cost can be estimated.

3.3 Cost Estimation

All equipment required to be used to invest the project.

$$\text{Replacement cost} = \frac{A_1}{(1+i)^n} \tag{3.7}$$

A1 is the initial cost of the battery, charge controller, and inverter.

i is the discount rate of 8%.

n is a life-time of 10 years.

Cost of batteries/pcs= $60{,}000 - birr.$ charge controller = 18,200 birr

PV_C = 11,000 birr , Inverter = 187,500 birr

Replacement cost of battery= $\frac{50{,}160{,}000}{(1+0.08)10}$ = 23,233,735 birr

Replacement cost of charge controller= $\frac{1{,}710{,}800}{(1+0.08)10}$ = 792,431 birr

Replacement cost of inventor $=\frac{187,500}{(1+0.08)10}$= 86,849 birr

Investment cost=PVc+Bc+Invc+C=63,916,300 birr

Other cost= 15% x 63,916,300 birr = 9,587,445 birr

Amount of money required for total cost is

Total cost = Replacement cost + O&M cost+ Investment cost +other cost

= 23,233,785 + 792,431 + 86,846 + 301,668 + 63,916,300 + 9,587,445 = 97,943,475 birr

The annual $O\&Mc$ cost can be calculated depending on the system capital cost taking into consideration, the inflation and discount rate expressed as follow.

$$O\&Mc = 2\%PVc \times (1+i/1+d)\left[1-(1+i/1+d)20/1-(1+i/1+d)\right]$$

$O\&Mc = 2\% \times 11{,}858{,}000 \times 0.096(0.53/0.04) = 301{,}668 - birr.$ Since the battery, controller, and inverter life is considered 10 years, they must be replaced once in the system's lifetime.

$$Bc_1 = Bc \div (1+0.08)10 = 50{,}160{,}000 \div 2.16 = 23{,}233{,}785 - birr.$$

$$Cc_1 = Cc \div (1+0.08)10 = 1{,}710{,}800 \div 2.16 = 792431 - birr.$$

$$Inv_1 = Inv \div (1+0.08)10 = 187{,}500 \div 2.16 = 86849 - birr.$$

Installation cost= 10% PV cost

The system lifetime cost can be calculated by adding the PV, battery, battery replacement, inverter, controller, installation, operation and maintenance costs.

$$LCC = PVc + Bc + Bc_1 + Invc + Invc_1 + Cc + Cc_1 + Ic + O\&Mc$$

$$LCC = 11{,}858{,}000 + 50{,}160{,}000 + 23{,}233{,}785 + 187{,}500 + 68{,}849 + 1{,}710{,}800 + 792{,}431 + 1{,}185{,}800 + 301{,}668 = 89{,}516{,}833 - birr$$

The annual life cycle cost $(ALCC)$ can be estimated as follow.

$$ALCC = LCC \times \left[1-(1+i/1+d) \div 1-(1+i/1+d)20\right]$$

$$ALCC = 89{,}516{,}833 \times (0.037 \div 0.53) = 6{,}249{,}288 - birr.$$

The unit electrical cost in birr/ Kwh can be estimated from the annual lifecycle cost and the annual energy generated by the PV system.

Unit electrical cost= $ALCC \div (365 \times EL) = 6249288 \div (365 \times 864) = 19.82 - birr / Kwh$.

the unit cost of the installed system over 20 years of operation is $19.82 Kwh$.

NPV is the profitability of the project. The investment is profitable if NPV is positive and un profitable otherwise. It is given by the following equation:

$$NPV = -Itotal + \sum_{k=1}^{N} Gk(1+t) - k \tag{3.8}$$

Where, I_{total} is the initial investment cost, Gk is the cash flow of the year k, N is the estimated year of the project and t is the depreciation rate of the investment and is considered as 10%. Assuming constant revenue and expense, the cash flow will not be varied throughout the estimated life of the project then,

$$NPV = -97943475 + \sum_{k=1}^{20} 19.82(1+0.01) - k = 14,849,084 - birr.$$

Since NPV is positive, the project is profitable.

Payback period= $\frac{\text{Invst}}{\text{E}_\text{d} \text{ x } 19.82/kWh\ x\ 365}$

Payback period= $\frac{63,916,300}{864 \text{ x } 19.82\ x\ 365} = 10$ years

3.4Environmental Analysis

The following equation describes the green nature of renewable energy installation amount of Co_2 is avoided.

$$QCo_2 = EpNQo \tag{3.9}$$

Where:

Ep -Energy produced per year N - Lifetime

Q_0=Greenhouse emission factor of the PV generator is 0.094kg/ Kwh China manufactured. Therefore, $Qco_2 = 864Kwh \times 365 \times 20 \times 0.094 kg / Kwh = 5,928,876.8 kg$ overall Co_2 emissions will be reduced.

3.5 Over View of Homer Software

HOMER (Hybrid Optimization Model for Electric Renewable) Software is a power optimization model which simplifies the performance evaluating designs for both standalone and grid-connected power systems for different applications. in power system design, components to be included in the system are the size, quantity of the component, and cost of each component should be taken under consideration. Power systems that do not properly design, can lead to a shorter life of the batteries, increase the cost of energy production, and an insufficient supply of electricity demand. HOMER is a computer model investigated originally by the national renewable energy laboratory (NREL). It has different energy-generating components that represent the considered architecture that can be selected in its library by the user and provide a simplified alternative to different power system comparisons based on the economic and technical aspects.

3.6 Modeling of Standalone System with Homer

HOMER is used to model a power system as well as its life cycle cost, which means the total cost of installing and operating the system over its life time. It also helps the modeler to compare many different design alternatives based on their technical and economic advantages The life cycle cost of the power system can be modeled by HOMER software and it provides various design option based on their technical and economic advantages. The design of a standalone PV system for the Doni Kombe rural area of 1643 households was carried out based on the theoretical background that has been discussed before. Homer software is used to perform the thesis. Therefore the main objective of the thesis was to design and model PV with a battery-based standalone system to meet the load required by the community.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Results

The optimal PV system is the one that can provide the required electricity at the lowest price. In this chapter, the result of the feasibility of the PV system is presented, and discussed the results obtained from the Homer software simulations and based on the simulation result. The optimal system selection has been performed. The main objective of this thesis is to model and design an optimized standalone system to find an alternative power supply system for a rural area that is far from the main grid system. From simulated results, minimum COE is considered as a selected energy system.

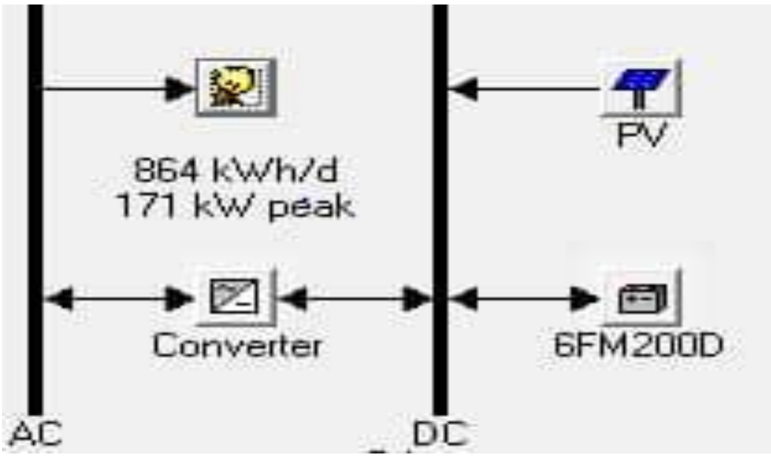

Fig.4.1: HOMER diagram for standalone PV/battery converter set- up.

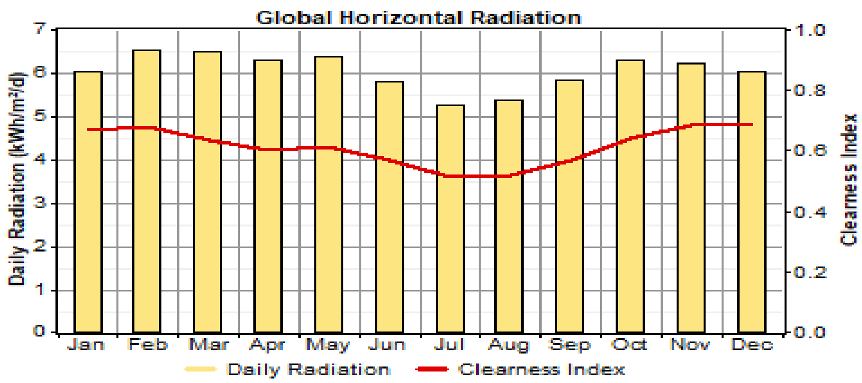

Fig.4.2: Clearness index and average daily solar radiation.

The diagram below shows the daily load profile of the household appliances operated at different times. Therefore, the load has become maximum from 21hr up to 22hr.

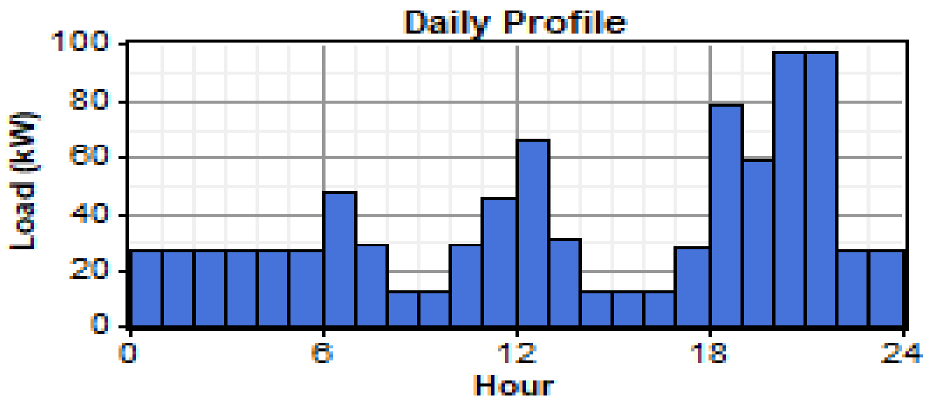

Fig. 4.3**:** Daily load profile.

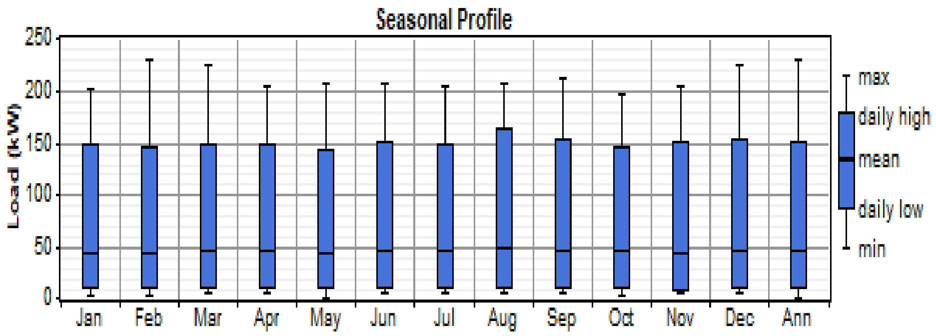

Fig. 4.4: Seasonal load profile.

4.2 Optimization using Homer Software

Homer software performs the following three activities.

- **Simulation** :- it compares the energy provided from the system and the load demand in 1 hour of 8760 hours to decide either to use load following or dispatch strategy to operate battery and solar PV. For the system that has a battery and solar PV, it requires having a dispatch strategy which includes load following and cycle charging.
- **Sensitivity Analysis:-**it evaluates the effect of external parameters and optimization for each sensitivity variable that is input into the software.
- **Optimization**: - it simulates various system configurations to determine the optimal system based on the decision of variables.

4.2.1 Sensitivity Analysis Results

The HOMER/Simulink software shows the result in ascending order of initial capital cost, operating& maintenance cost, net present cost, and cost of energy per kWh on the first rows which indicate the feasibility of the system.

(kWh/d)	Solar (kWh/m²/d)				PV (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
864.000	6.045				864	836	214	$ 1,219,716	156,313	$ 2,888,324	0.858	1.00	0.00
96.700	6.541				864	836	214	$ 1,219,716	61,434	$ 1,875,515	4.978	1.00	0.00
78.400	6.036				864	836	214	$ 1,219,716	61,434	$ 1,875,515	6.140	1.00	0.00
59.000	5.840				864	836	214	$ 1,219,716	61,434	$ 1,875,515	8.159	1.00	0.00
12.200	5.246				864	836	214	$ 1,219,716	61,434	$ 1,875,515	39.456	1.00	0.00

Fig. 4.5: Simulation result of least cost effective scenarios.

The graph below shows that the net present cost which remains constant up to 5.840 then starts to increase up to 6.045. Then decrease up to 6.541.

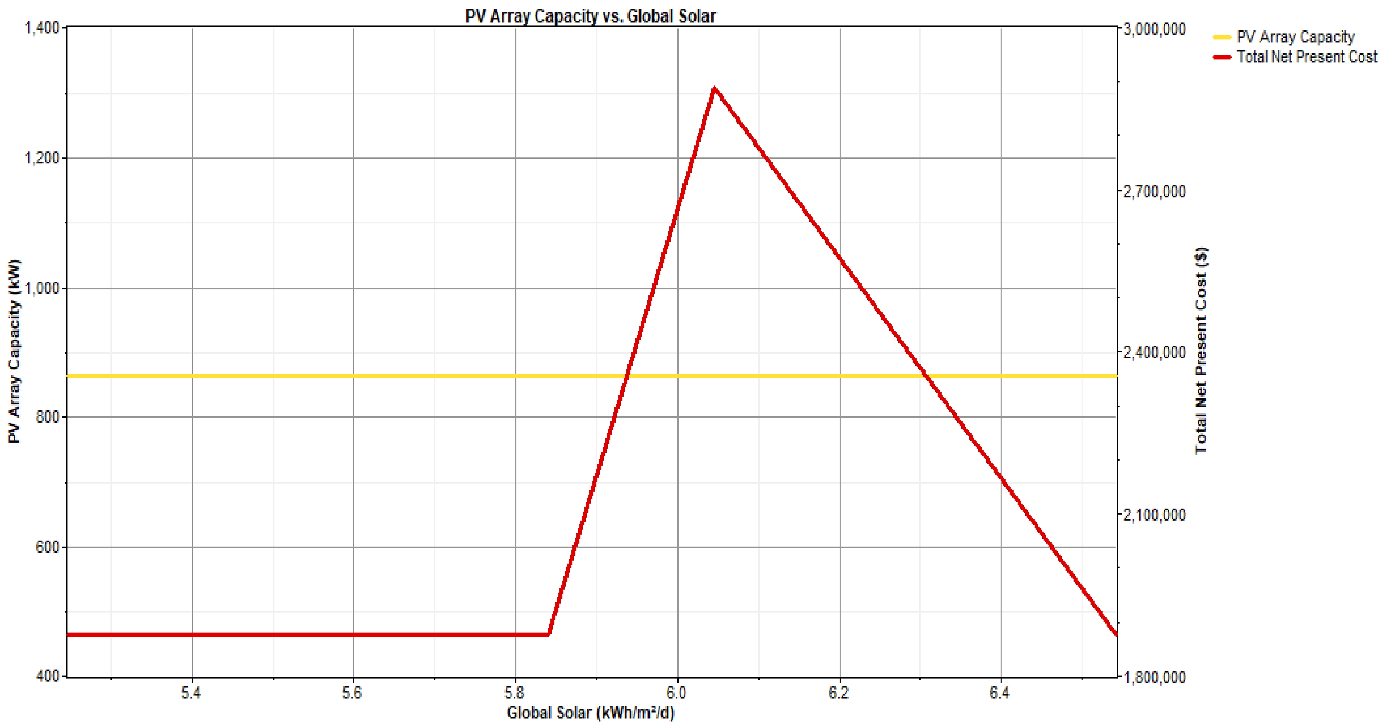

Fig. 4.6: PV array capacity w.r.t NPC.

The following graph shows that the system considers 6.05 Kw/m^2 of average solar radiation. The optimized system capital cost, operating cost, NPC, and COE that will be cost effective due to decrease in COE from$39.456 Kwh to $ 0.858/ Kwh, $1,219,716, $156.313/year, $2,888,324, $0.858/Kwh respectively.

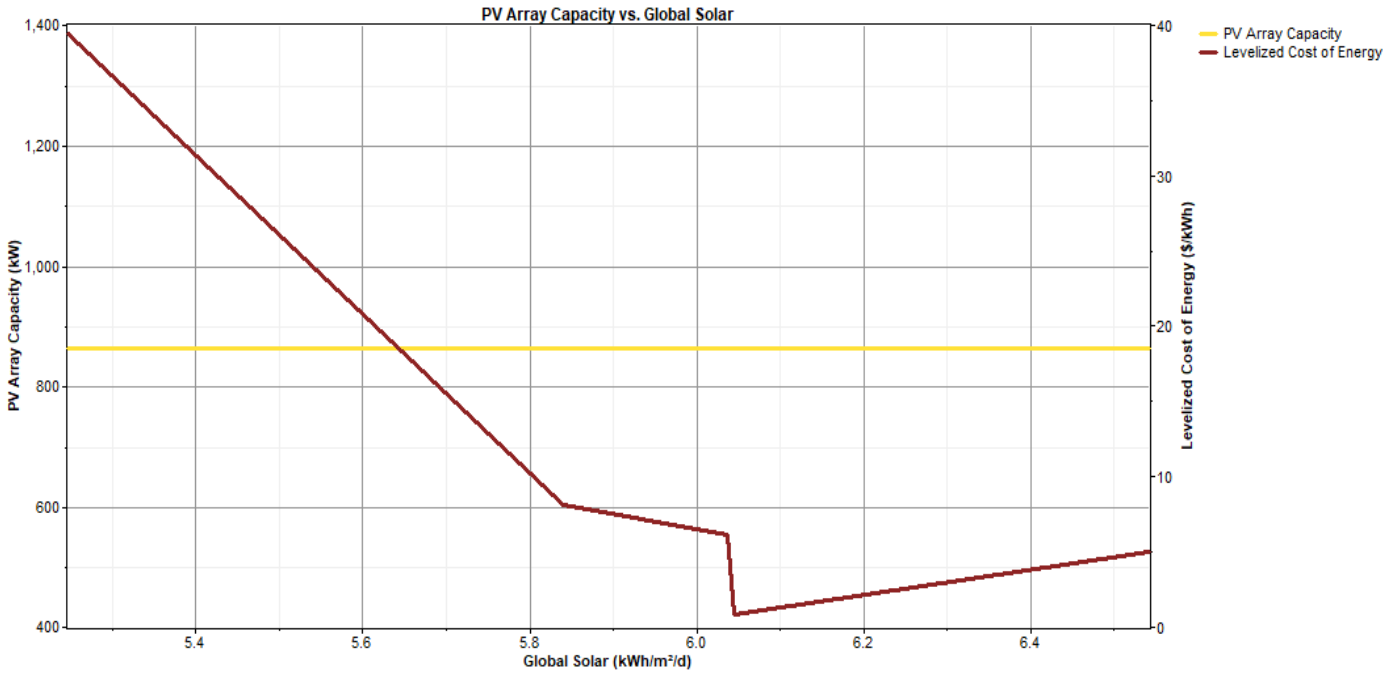

Fig. 4.7: PV array capacity w.r.t LCOE.

The graph below shows that there is no shortfall that occurs between the required operating capacity and the actual amount of operating capacity the system can provide.

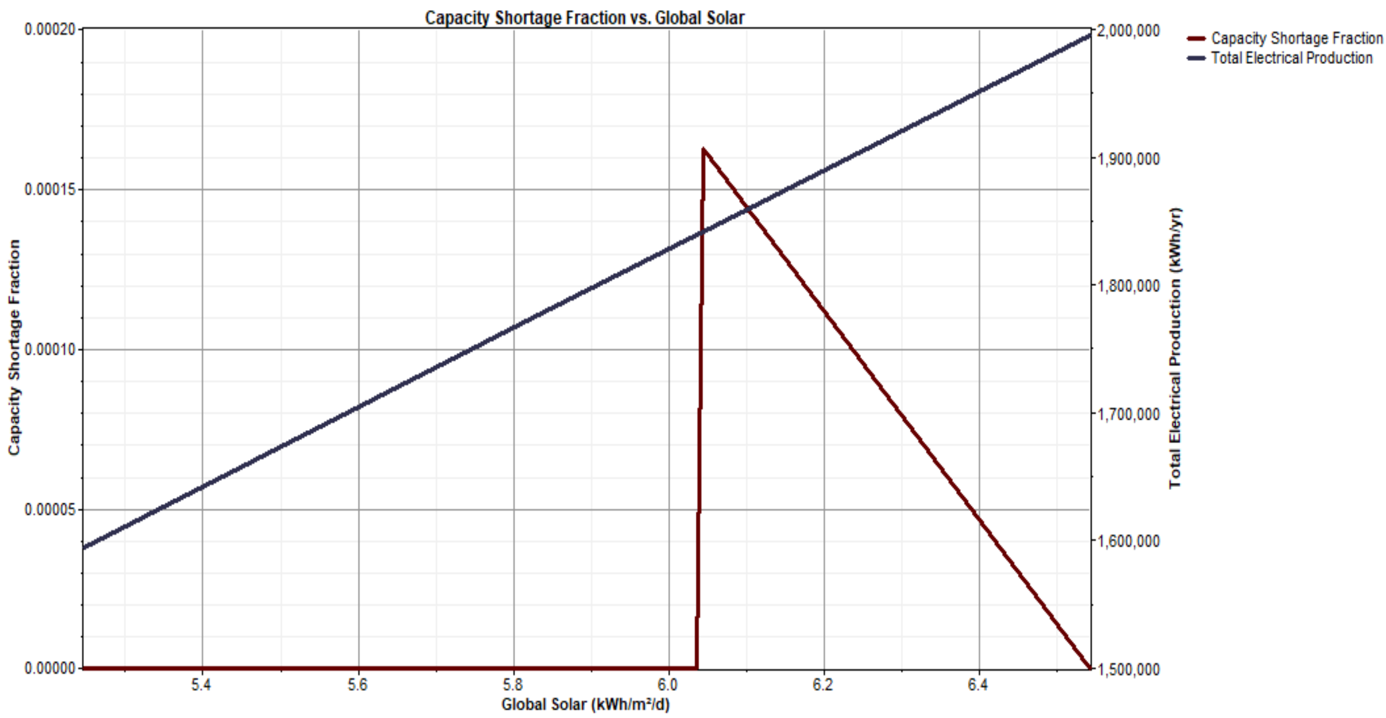

Fig. 4.8: Capacity Shortage Fractions with respect to total electrical production.

4.2.2 Optimization Results

During optimization, system simulation results are listed according to their NPC and COE. The maximum load demand will occur between 21hr to 22hr which is around 96.7 kW. Therefore the solar PV operates most efficiently when work near its full load. Based on homer modeling, the optimal system for Doni Kombe rural area is 864 kW of PV panels, 400Ah and converter of 214 kW. This optimal system produces renewable energy with the levelized cost of energy (LCOE) 0.858 $/Kwh.

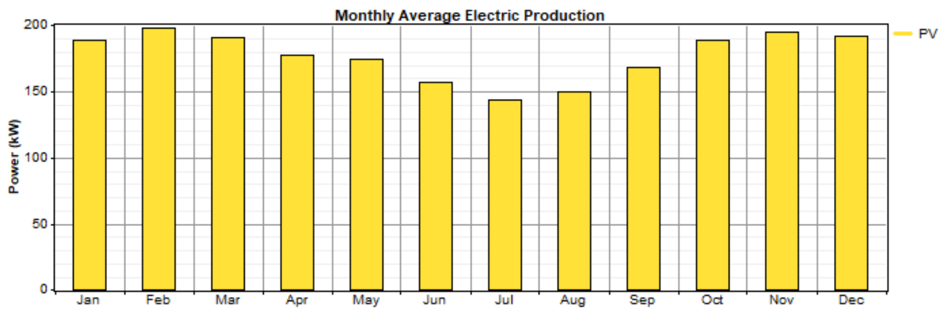

Fig. 4.9: Electricity generation.

In this system the total power generation is 100%, excess electricity is 79.2%, capacity shortage is 0.0 % and unmet electric load is 0.0%.The power architecture shows that excess electricity can be provide for the demand growth of the community in the future.

4.2.3 Cost Summary

It shows graphical representation of each component as well as other required material in terms of their capital cost, O &M cost and total cost as well as in terms of component, cost and entire life span of the system type.

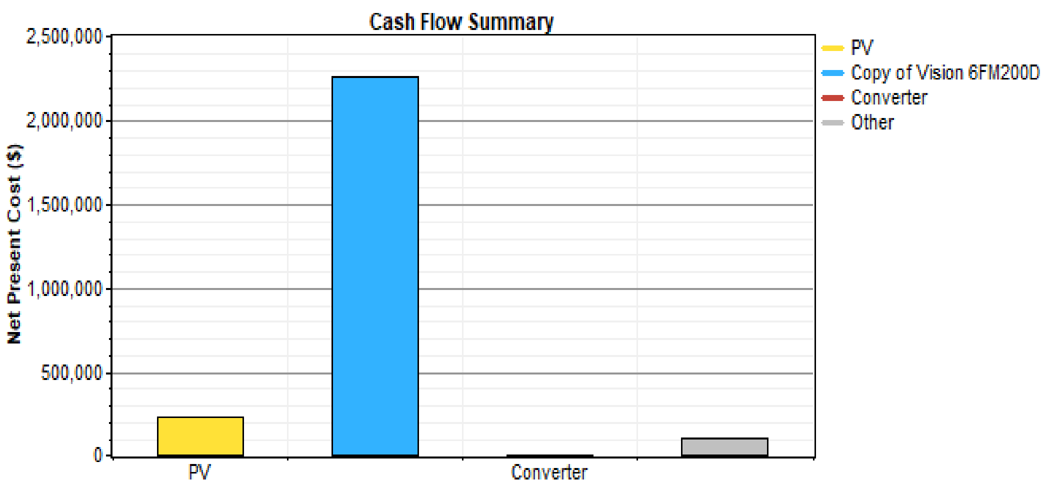

Fig. 4.10: Cash flow summary over lifespan in terms of component type.

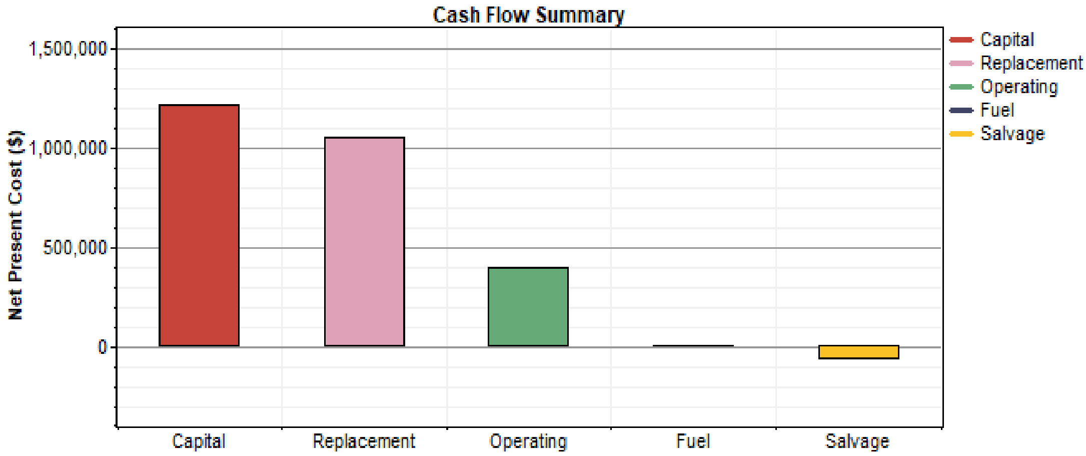

Fig. 4.11: Cash flow summary of system over life span in terms of cost type.

The following figure shows the cash flow diagram indicates that the typical expenditure of various components of the system. For this system, it will initially spend high amount of money and spend smaller amount of money periodically. In every 10 years, system battery, charge controller and inverter will be replenished because of its limited lifespan. At the end of the lifespan of the system, salvage value will return or the system will replaced completely.

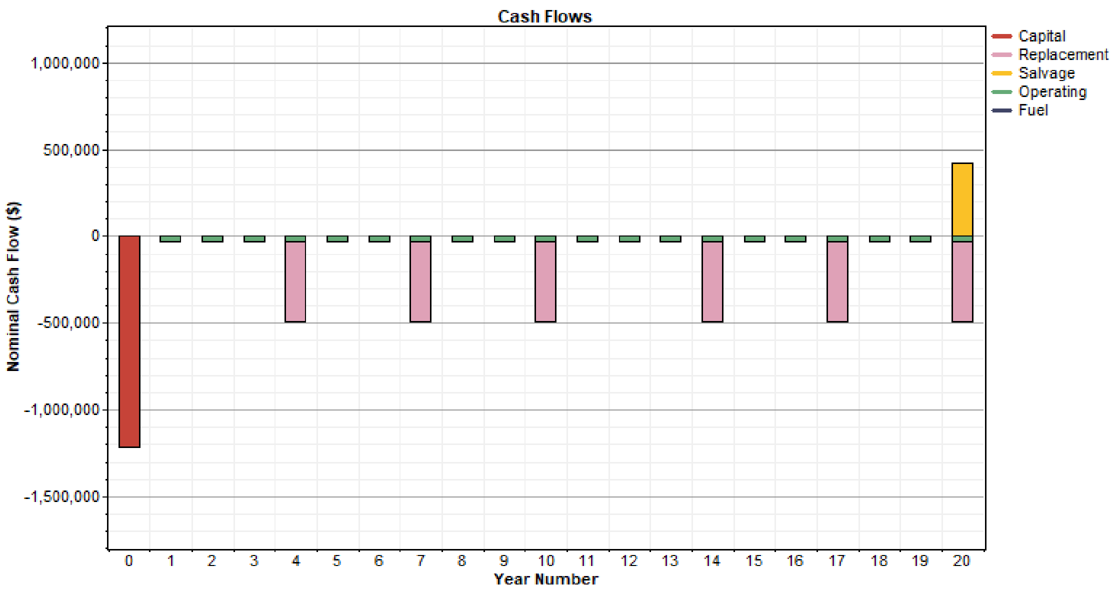

Fig. 4.12: Cash flow of entire life span of the system.

4.3 Discussions

The main objective of this thesis is to model and design an optimized standalone system in order to provide electric power to the rural communities with cost effective. Based on daily load demand, the daily load profile different from 0 to 6 (only external lights & refrigerator working), 6 to 12 (stoves, coffee maker, TV & refrigerator is working), 12 to 18(stoves, coffee maker, fun &refrigerator is working), 18 to 24(stoves, coffee maker, internal & external lights, ceiling fun &refrigerator is working). So that the standalone system is designed, modeled& optimized as 836 batteries, 1078 PV modules, 214Kw invertor, 94 charge controllers & COE of $ 0.858/Kwh & large number of CO_2 is removed. The maximum load demand will occur between 21hr to 22hr which is 96.7Kw. The power generation of Doni Kombe rural area which has 1643 households that require 864Kwh/day, 171Kw peak load is 100% & there is no capacity shortage. As well as excess electricity which can be provided for the demand that will growth in the future is generated. The standalone PV system for Doni Kombe rural area community needs initially high investment cost & require small amount of money periodically as well as in every 10 years, system batteries, invertor, & charge controller need to be replaced due to its limited life span. Therefore, after 20 years, the system totally replaced. Generally, the standalone solar system is cost effective when it operates near to its full load.

Table. 4.6: Standalone system component specifications.

Description	PV	Battery	Controller	Inverter
Type	Mon crystalline	Li- ion	MPPT	Standalone
Rating	250w	400Ah	48V,60A	214kW
Number	1078	836	94	1
Capital Cost	11,858,000 birr	50,160,0000 br	1,710,800 br	187,500 br
Replacement cost	0	23,233,785 br	792,431 br	86,849 br
O&M	0	1,504,800 br	51324 br	5625 br
Efficiency	19	90	85	90
Life Time	20	10	10	10

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of this thesis was to provide electric power supply for Doni Kombe rural area with the best techno economic of standalone PV power system. In the design of PV system, the scaled annual average of 6.05 $Kwh/m2/day$ was investigated by the thesis for household with total number of 1643 and the total energy demand was around 864 Kwh/day with peak power of 171 Kw. The standalone PV system has been modeled by the Homer software after the selection of the components and their characteristics. The simulation has been made in order to determine the system which is the best lowest cost economically while providing continuous load demand. A standalone PV system has been investigated as optimal system with 1078 PV, 836 batteries, 214kW inverter, 94 charge controllers and \$0.858 / Kwh respectively. From environmental analysis, 5,928,876.8kg Co_2 emission was avoided.

5.2 Recommendation

For further investigation, the following recommendations are given in order to modify this thesis as such that the initial investment cost is high; the government should support to upgrade the interests of populations to use electricity. This thesis has been performed to solve the electric power supply problem for Doni Kombe rural area found in East Shewa Zone/Oromia/Ethiopia.

5.3 Suggestions for Future Work

- The implementation of this standalone PV/ battery bank system in residential, commercial areas, governmental as well as no governmental organization become independent from unexpected blackout and interrupted power supply on the national power grid. Since the environmental issue is taken under consideration, such a renewable energy should be expanded in order to overcome power supply problem of rural areas.
- To test the effectiveness of the research, further study can be applied by modeling the standalone off-grid solar energy optimization techniques using PV Syst or ETAP software, and make comparison with the results of this case study can be performed.

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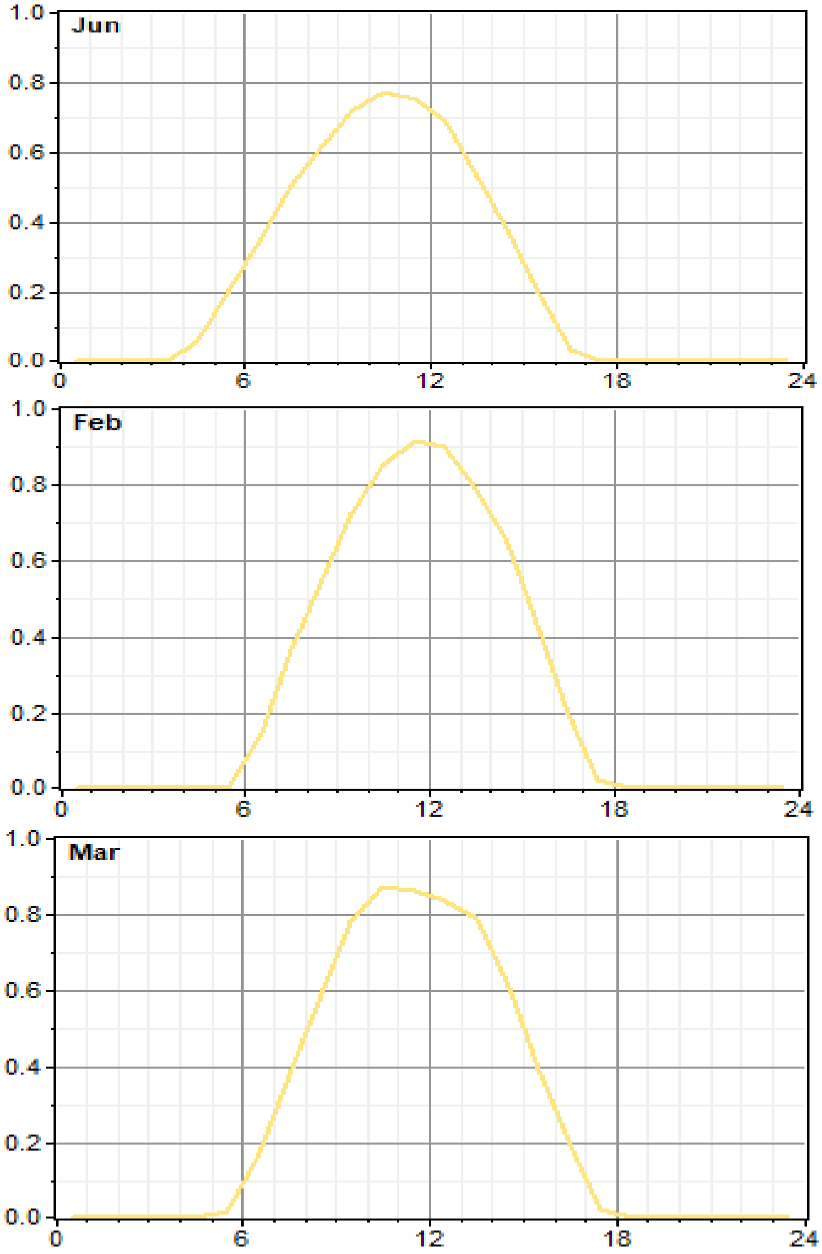
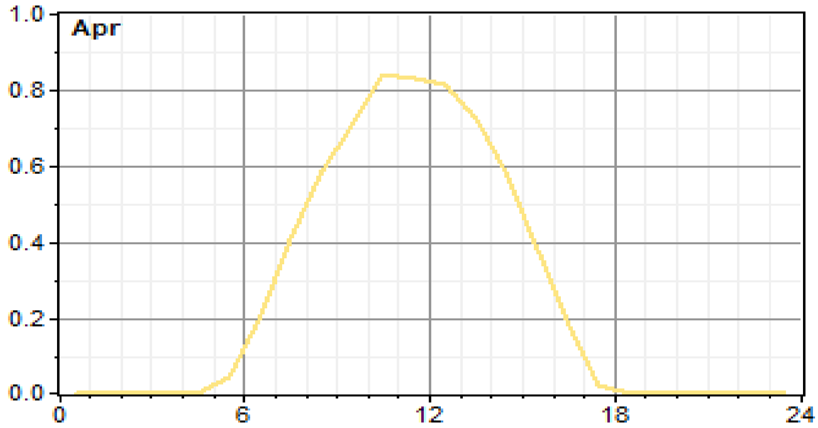
APPENDIX

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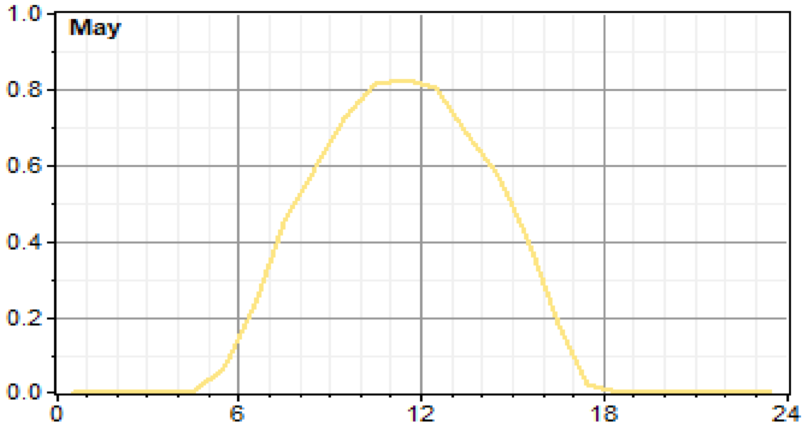
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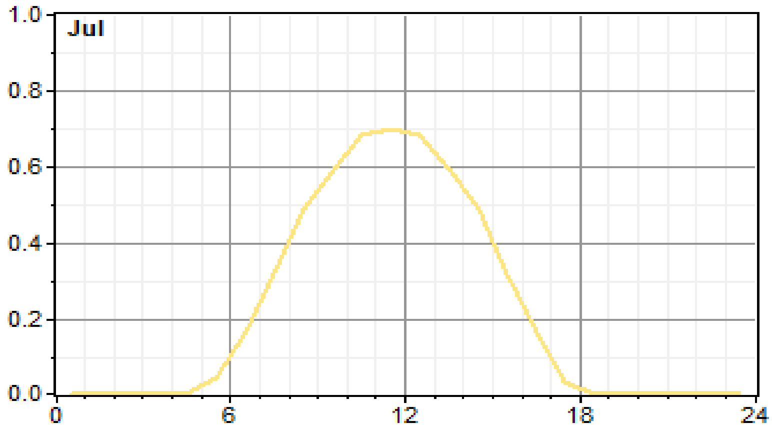
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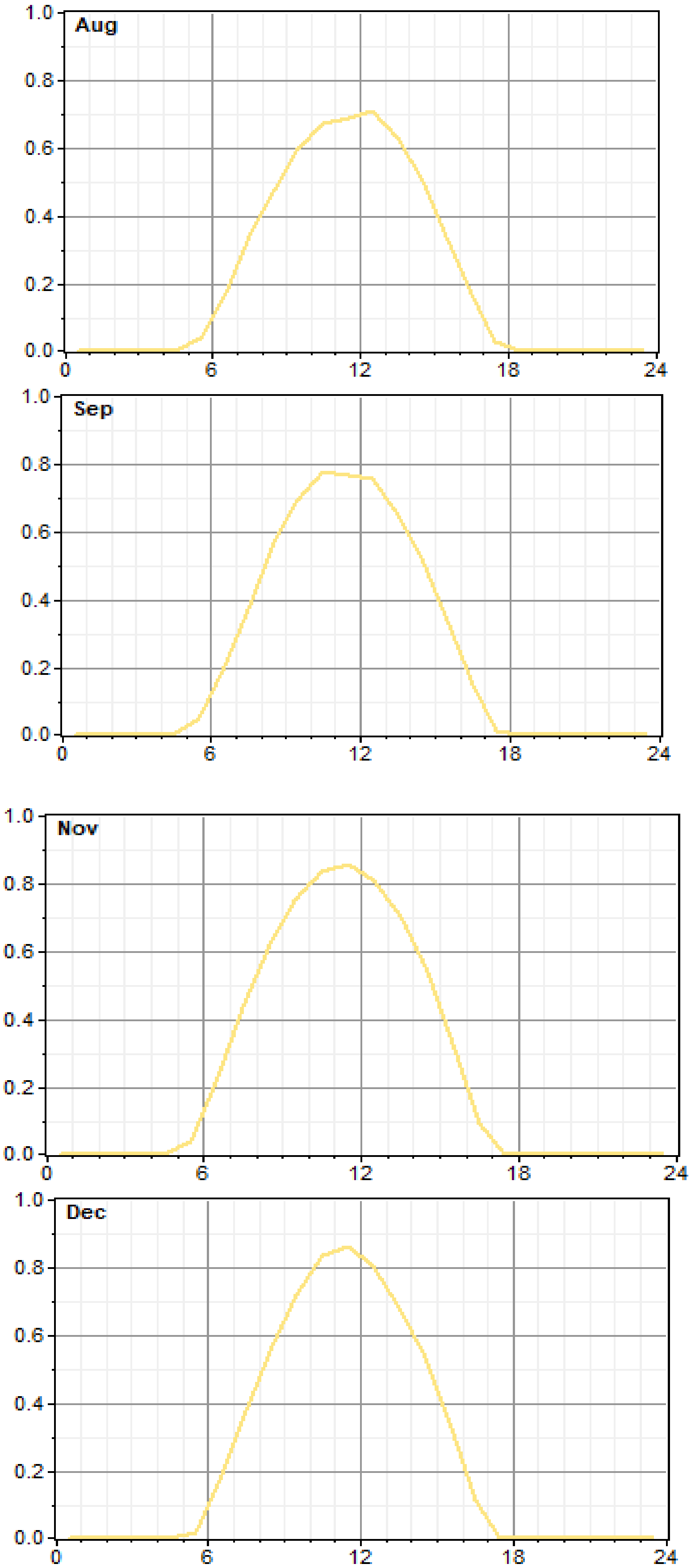
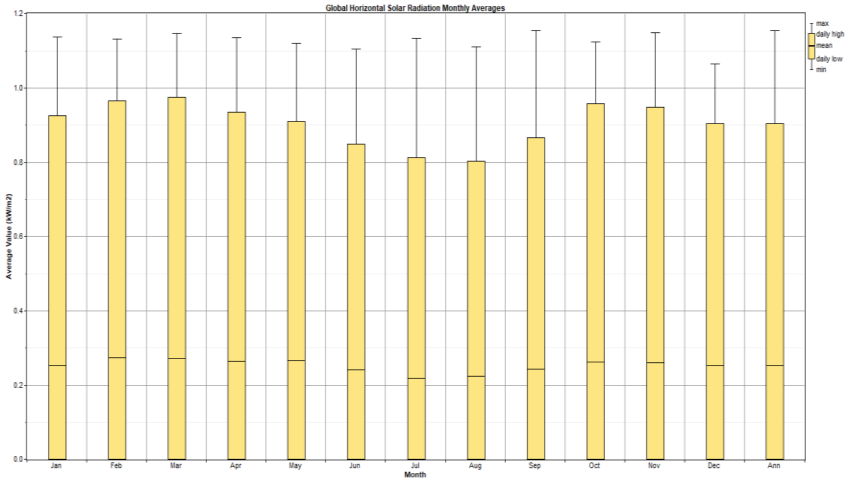
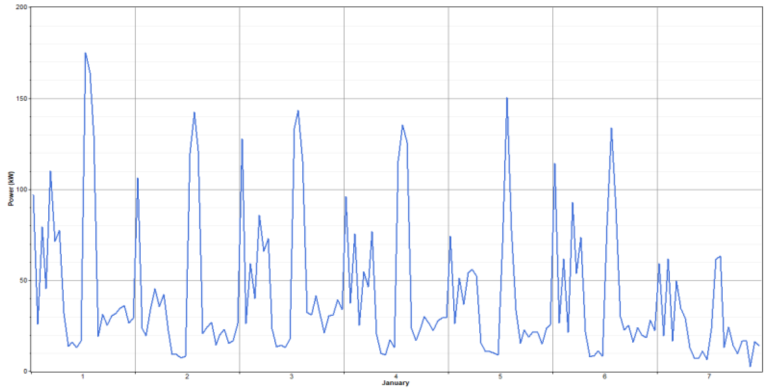


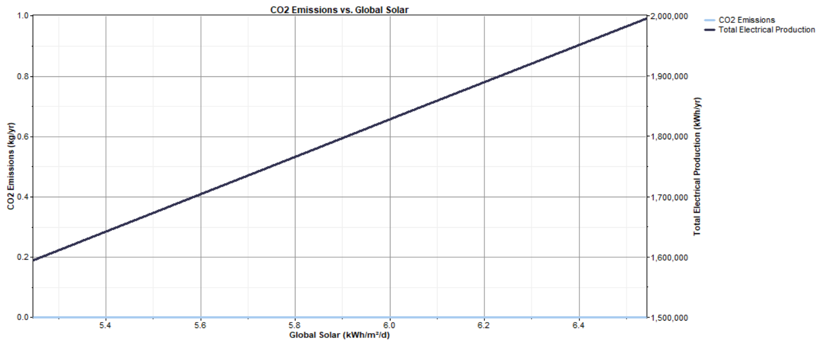
Appendix1Global Solar Radiation Daily Profile.



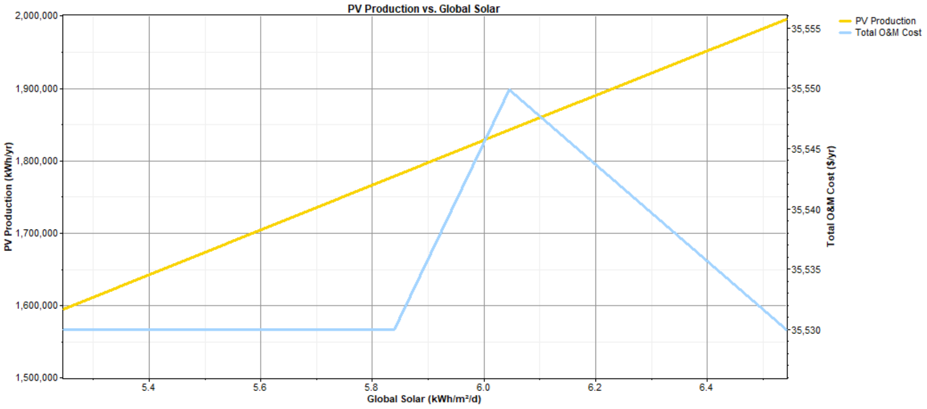
Appendix 2 Global Solar radiation Monthly Average.



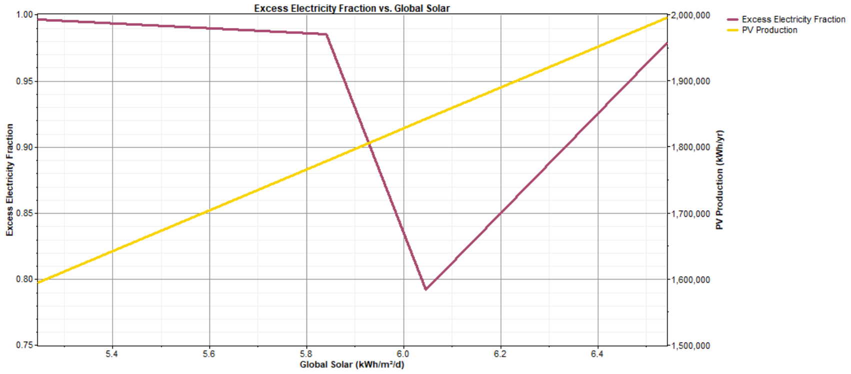
Appendix 3Hourly Data.



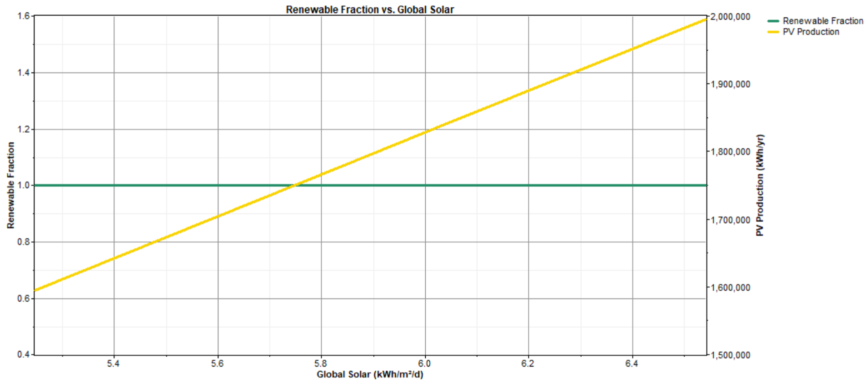
Appendix 4 Co_2 Emission w.r.t Total Electric production.



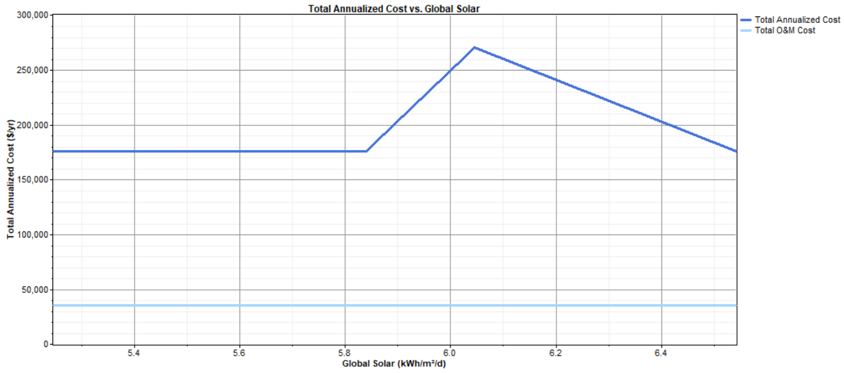
Appendix 5PV Production w.r.t Total O&M Cost.



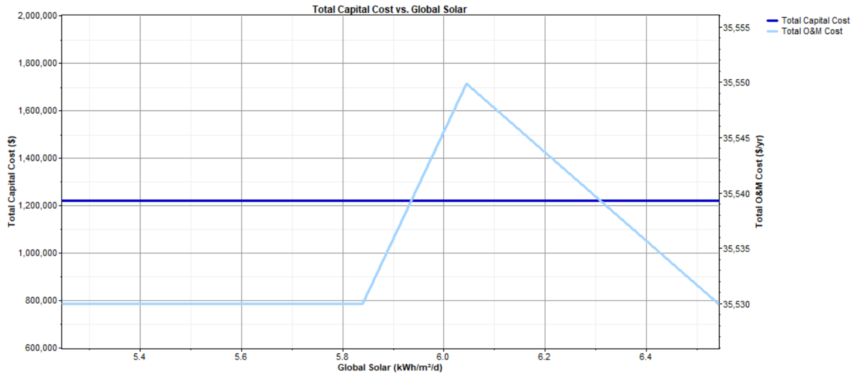
Appendix 6 Excess Electricity Fraction w.r.t PV production.



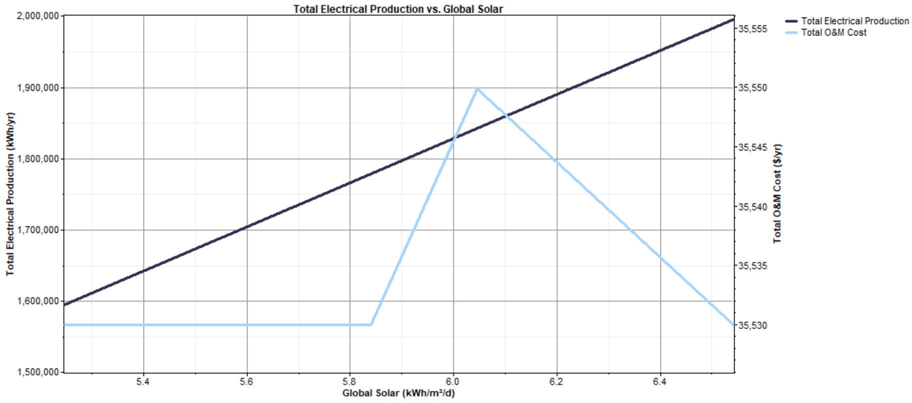
Appendix 7 Renewable Fraction w.r.t PV production.



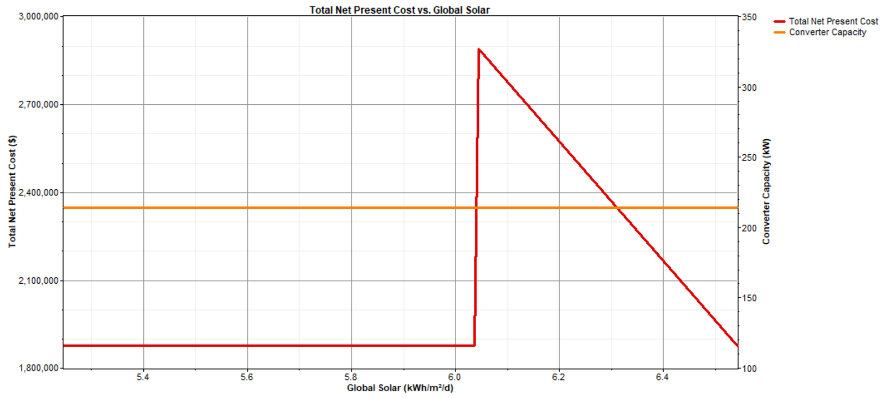
Appendix 8 Total Annualized Cost w.r.t Total O&M Cost.



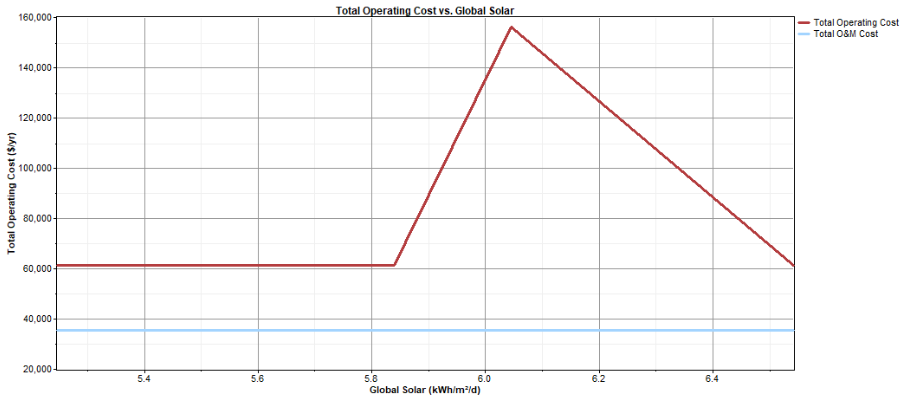
Appendix 9 Total Capital Cosw.r.t Total O&M Cost.



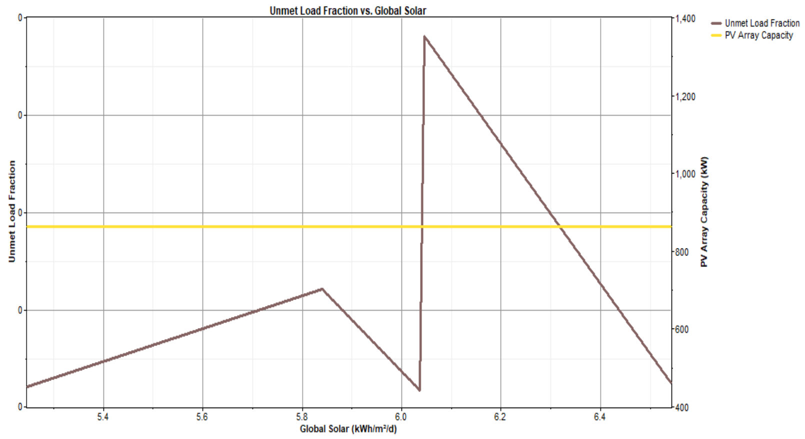
Appendix 10Total Electrical Production w.r.t Total O&M Cost.



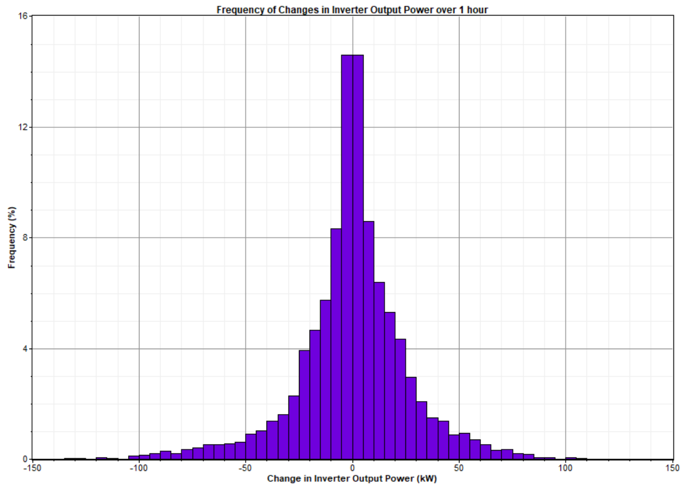
Appendix 11 Total NPC w.r.t Convertor Capacity



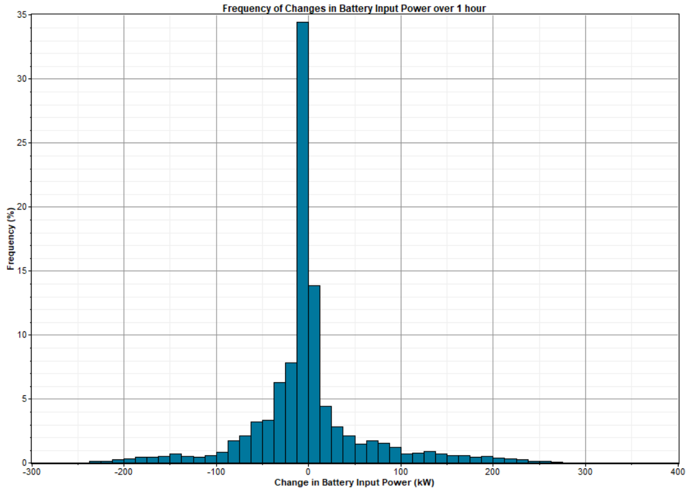
Appendix 12 Total Operating Cost vs. Global Solar Radiation.



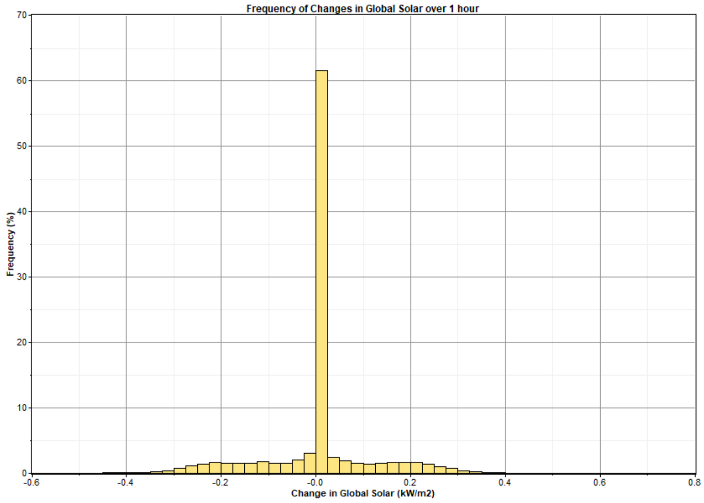
Appendix 13 Unmet Load Fractions w.r.t PV Array Capacity.



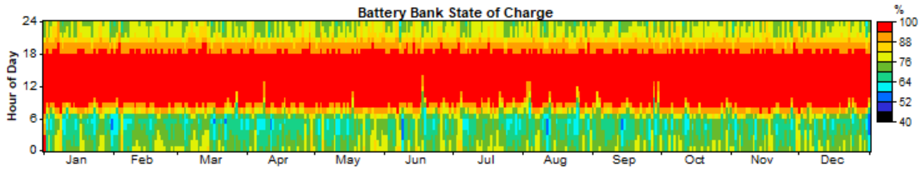
Appendix 14. Chang in invertor output power



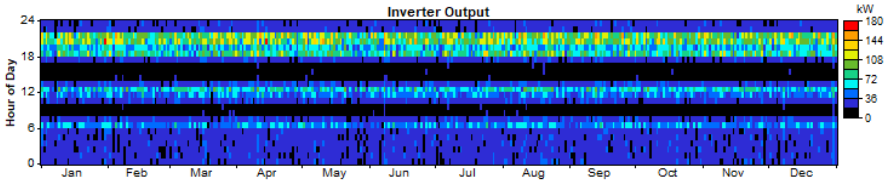
Appendix 15. Change in battery input power.



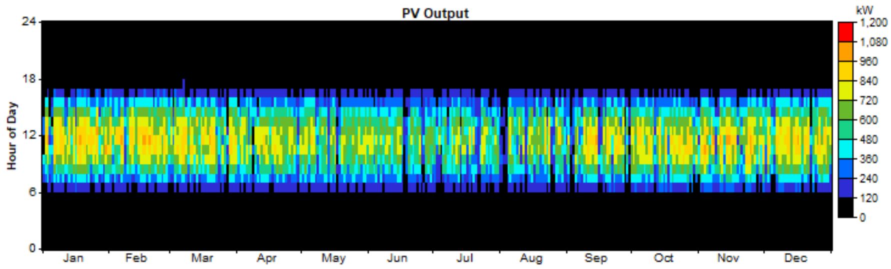
Appendix 16. Change in Global Solar.



Appendix 17. Battery Bank State of Charge.



Appendix 18 invertor output.



Appendix 19. PV Output.