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Presented by

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TECHNICAL AND ECONOMIC FEASIBILITY ASSESSMENT FOR A SOLAR PV MINI-GRID (CASE STUDY OF MATEKENYA AREA, DOWA DISTRICT, MALAWI)

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Declaration

I declare that this thesis is my work. I have followed the recommended ethics and it has never been presented elsewhere. The information from other literatures has been acknowledged and listed in the references.

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Dedication

I dedicate this work to my parents Mr and Mrs. Maliro. Thank you for your support. I also dedicate to all my mentors who have been supporting me throughout my education and beyond.

Acknowledgement

I would like to acknowledge my supervisors Dr Bakary Diarra and Prof Ravi Samikannu for your guidance and support throughout this work. I appreciate your contribution towards this work.

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Abstract

Countries are trying to accomplish Sustainable Development Goal (SDG) number 7 which aims to achieve universal access to energy by 2030. However, electricity access in Africa is at 44% [1] which is very low as compared to other regions. Malawi is one of the countries in sub-Saharan Africa which have very low electrification rate. Currently, the rate is at 18% [2] which is even less than the average electrification rate for Africa. Development of mini-grid systems is one of the potential solutions that can help to improve electricity access rate since most of the population lives in rural areas. The main objective of this work was to conduct technical and economic feasibility assessments for Matekenya village, one of the rural community areas in Malawi which is far from the national grid. The load assessment was conducted by administering a questionnaire developed using Kobo toolbox and data collection was done using an android app called Kobo collect. The data collected was used to establish the area's load profile which was fed into HOMER on the electric load section. The solar resource used in this work was taken from NASA using the area's GPS coordinates, and the average horizontal solar irradiation was 5.22 kWh/m^2/day. The quotations of various system components such as solar panels, batteries and converters were requested and used as HOMER inputs. The discount rate used for this paper is 12% and expected inflation rate was 9.1%. Simulations were made in two categories, one without sensitivity cases and another with sensitivity cases. The on with sensitivity cases had the following results. The net present cost of the system (NPC) was found to be $21170640. The Levelized Cost of Energy (LCOE) was found to be $0.1334. The operating cost was $380215.40. The initial capital cost was $14290444.84. The major contributor to the system cost was the storage system followed by solar panels and the lowest cost is for converter system. Optimization results with sensitivity analysis showed that The NPC was $11744020, Levelized COE was $0.074, and the operating cost was $213036. The system requires initial capital cost was $7890000.

Based on the Malawi feed-in tariff policy, the feed-in tariff for solar PV energy into the grid is $0.10/ kWh which means that the LCOE for optimization results without sensitivity cases is higher than the feed-in tariff. Despite having the LCOE higher than the feed-in tariff, the average electricity rate for Malawi is $0.13/kWh. the LCOE for optimization results with sensitivity cases was lower than the fee-in tariff. this makes the system cost-competitive for implementation if other system parameters remain constant. Based on results it showed that the system is technically and economically feasible to use solar PV to supply electricity to Matekenya village. In addition, the village has high potential for production use of electricity and the willingness to be connected is also high.

Résumé

Les pays tentent d'atteindre l'objectif de développement durable (ODD) numéro 7 qui vise à atteindre l'accès universel à l'énergie d'ici 2030. Cependant, l'accès à l'électricité en Afrique est de 44% [1], ce qui est très faible par rapport à d'autres régions. Le Malawi est l'un des pays d'Afrique subsaharienne à avoir un taux d'électrification très faible. Actuellement, le taux est de 18% [2] ce qui est même inférieur au taux d'électrification moyen en Afrique. Le développement de systèmes de mini-réseaux est l'une des solutions potentielles pouvant contribuer à améliorer le taux d'accès à l'électricité puisque la majorité de la population vit en zone rurale. L'objectif principal de ce travail était de mener des études de faisabilité technique et économique pour le village de Matekenya, l'une des zones communautaires rurales du Malawi qui est loin du réseau national. L'évaluation de la charge a été réalisée en administrant un questionnaire développé à l'aide de l'outil Kobo et la collecte de données a été effectuée à l'aide d'une application Android appelée Kobo collect. Les données collectées ont été utilisées pour établir le profil de charge de la zone qui a été ensuite introduit dans la section de charge électrique du logiciel HOMER. La ressource solaire utilisée dans ce travail a été extraite des données de la NASA en utilisant les coordonnées GPS de la zone dont l'irradiation solaire horizontale moyenne était de 5,22 kWh/m^2/jour. Les devis des divers composants du système tels que les panneaux solaires, les batteries et les convertisseurs ont été demandés et utilisés comme entrées de HOMER. Le taux d'actualisation utilisé pour ce document est de 12 % et le taux d'inflation attendu était de 9,1 %. Les simulations ont été faites dans deux conditions, une sans tenir compte de la sensibilité et une autre avec la sensibilité. Les cas avec sensibilité ont donné les résultats suivants : le coût actuel net du système (CNP) s'élevait à 21 170 640 $, le coût actualisé de l'énergie (LCOE) s'élevait à 0,1334 $; le coût d'exploitation était de 380215,40 $. Le coût en capital initial était de 1429044,84 $. Le principal contributeur au coût du système était le système de stockage suivi des panneaux solaires et le coût le plus bas est celui du système de conversion. Les résultats d'optimisation avec analyse de sensibilité ont montré que le coût actuel net (CNP) était de 11744020 $, le COE nivelé était de 0,074 $ et le coût d'exploitation était de 213036 $. Le système nécessite un coût en capital initial de 7890000 $.

Sur la base de la politique des tarifs de rachat du Malawi, le tarif de rachat de l'énergie solaire photovoltaïque par le réseau est de 0,10 US$/kWh, ce qui signifie que le LCOE pour les résultats d'optimisation sans la sensibilité est supérieur au tarif de rachat. Bien que le LCOE soit supérieur au tarif de rachat, le tarif moyen de l'électricité pour le Malawi est de 0,13 $/kWh. Le LCOE des résultats d'optimisation avec sensibilité était inférieur au tarif d'entrée. Cela rend le système rentable pour la mise en œuvre si les autres paramètres du système restent constants. Sur la base des résultats, il a montré que le système est techniquement et économiquement faisable pour fournir de l'énergie solaire photovoltaïque pour l’électrification du village de Matekenya. De plus, le village a un fort potentiel de production d'électricité et la volonté d'être connecté est également élevée.

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Acronyms and Abbreviations

SDG	**: Sustainable Development Goals**
NASA	**: National Aeronautics and Space Administration**
NPC	**: Net Present Cost**
LCOE	**: Levelized Cost of Energy**
PV	**: Photovoltaics**
OECD	**: Organization for Economic Co-operation and Development**
IPP	**: Independent Power Producer**
NGO	**: Non-Governmental Organization**
NiCd	**: Nickel Cadmium**
NiMH	**: Nickel Metal hydride**
DOD	**: Depth of Discharge**
DC	**: Direct Current**
AC	**: Alternating Current**
ESIA	**: Environmental and Social Impact Assessment**
PPA	**: Power Purchase Agreement**
OM	**: Operation and Management**
HSE	**: Health Safety and Environment**
LF	**: Load Following**
CC	**: Cycle Charging**
HVD	**: High Voltage Disconnect**
LVD	**: Low Voltage Disconnect**

PWM	**: Pulse Width Modulation**
MPPT	**: Maximum Power Point Tracking**
Pb	**: Lead**
PbO_2	**: Lead Oxide**
H_2SO_4	**: Sulfuric Acid**
VRLA	**: Valve Regulated Lead Acid**
TA	**: Traditional Authority**
GHI	**: Global Horizontal Irradiation**

CHAPTER 1: INTRODUCTION

Countries are trying to accomplish Sustainable Development Goal (SDG) number 7 which is universal access to energy but energy demand is constantly increasing. According to world balances, energy production by region based on 2017 statistics is as follows: 30% OECD, 28% Non-OECD Asia, 14% middle East, 14% Non-OECD Europe14%, 8% Africa and non-OECD Americans 6% [3]. These variations show inequalities when it comes to access to energy due to economic reasons and geographical position at global level. The total amount of energy supplied at global level is achieved using various energy sources such as natural gas, oil, coal, nuclear and renewable energy technologies. The share of each source is as follows: oil 32%, coal 27%, natural gas 22%, nuclear 5% and renewables 14% (International Energy Agency, 2019). As seen from the percentage share of each type of fuel, there is dominance of fossil-based fuels which contribute above 80% of global energy supply.

Energy produced by Africa in 2017 was 8% of world's energy production (International Energy Agency, 2019). This is very small as compared to the size and the population of the continent with other regions. This indicates the low level of development in Africa. The world energy resources are not evenly distributed allowing some countries to meet their energy needs easily while those that don't have enough resource find it hard to meet theirs. The shares of primary energy supply by fuel source are as follows: 24% oil, 45% biofuels and waste, 15% natural gas, 14% coal, 1% hydro and 1% other renewables (International Energy Agency, 2019). Regarding power generation mix in Africa, natural gas contributes 40%, coal 31% and the remaining percentage is for hydro and other renewable sources. The total electrification rate for Africa is 44%[1] which means more than half of the population does not have electricity access. It should be noticed that even though the electrification rate for Africa is at 44%, some countries are far below this rate.

Malawi is one of the countries with low electrification rate. In 2018, Malawi registered a population of 17,563,749 [4]. Out of this population, only 16% lives in urban areas while the remaining 84% lives in rural areas [4]. Electricity access rate for Malawi is 18% [2] which is less than half of the electrification rate of the continent. Electricity access for urban areas is 55.16% against 10.45% for rural areas [5]. Despite having low electrification rate, Malawi has good average of solar radiation which is above 6 kWh/m^2. This solar radiation level is suitable for solar electricity generation.

1.1 PROBLEM STATEMENT

Africa have plentiful energy resources such as wind, solar, geothermal and hydro despite having low electricity access rate. Malawi is one of those countries that are very far from meeting Sustainable Development Goal number 7 (SDG7) by 2030 since its electrification rate is only 18%. In addition to that, most people live in rural areas which have only 10% electrification rate. One way of achieving universal access to energy is to develop mini-grids because many people in rural areas are live too far from the grid. It may take time for them to have access to the national grid. Mini-grids will help to increase the country's overall electrification rate in general and to uplift the social-economic well-being of the populations living in rural areas in particular.

1.2 Objectives

1.2.1 Main objective

The study's main was to find out if it is technically and economically feasible to meet electricity needs for Matekenya community using solar PV mini-grid system.

1.2.2 Specific objectives

The specific objectives of this study are:

1. To determine the electricity needs for Matekenya village
2. To assess the availability of the solar resource in the Matekenya village
3. To determine the size of the system that can be suitable for Matekenya
4. To determine if it is technically and economically viable to install a mini-grid in Matekenya.

1.3 Relevance of Study

In every energy related project, technical and economic feasibility assessments are required. This study is important because it will help in providing important data on the viability of developing a solar mini-grid in Matekenya. This can help the Matekenya area to reduce the time it should take for the community to have access to energy because it can easily be spotted by potential Independent Power Producers (IPP) or Non-Governmental Organisation (NGOs).

1.4 Research Questions and the Working Hypothesis

1.4.1 Questions

- ✓ What is the population and number of households in Matekenya?
- ✓ What are government or public service institutions available in Matekenya?
- ✓ What are commercial activities and businesses happening in Matekenya?
- ✓ What source of energy are they using now?
- ✓ What is the energy demand for Matekenya area?
- ✓ What is solar resource available in the area?
- ✓ What is the size of the system required to meet the demand of the area?
- ✓ Is it economically viable to install that size of the system in that area?

1.4.2 Working Hypothesis

Is it technically and economically feasible to install a solar PV mini-grid in the Matekenya area?

1.4.3 Thesis outline

This thesis is outlined as follows: Chapter 2 contains the literature review related to solar PV which includes background of the PV technology, types of solar panels, structure and operation principle of a solar cell, components of solar PV system, types of solar PV systems, mini-grid systems, types of mini-grids, mini-grid development, and mini-grids in Malawi. Chapter 3 contains the methodology used for the research: questionnaire development, how load assessment was done, how load profile was developed, solar resource assessment, system components inputs, system economic input, and sensitivity variables. Chapter 4 presents results and discussion. The results include results of optimization without including sensitivity variables and results of optimization with sensitivity variables. Results with optimization with sensitivity variables were divided into two groups. Chapter 5 is about conclusion and recommendation.

CHAPTER 2: LITERATURE REVIEW

2.1 Background of PV technology

The PV technology started by the discovery of the photovoltaic effect. Alexandre Edmond discovered Photovoltaic effect was in 1839 while he was experimenting with electrolytic cells when he exposed electrodes to the light [6][7][8]. Another discovery was made by William Grylls Adams and Richard Evans Day in 1876 [6][7][8]. They discovered that selenium produces electricity when exposed to light [6]. In 1883 Charles Fritts developed a solar cell using selenium [6][7][8]. In 1904 Wilhelm Hallwachs made a semiconductor junction solar cell from copper and copper oxide [6]. In 1905 albert Einstein published a paper on photoelectric effect on quantum basis [6][8]. In 1918 a Polish scientist Jan Czochralski developed a method of growing single crystals in metals used in silicon production [6] . In 1950 bell labs produced solar cells for space activities. In 1954 the first modern silicon photovoltaic cell was announced at bell labs, these cells had more than 4% efficiency. In 1955 Western Electric began commercial production of solar cells. improvements have been made on solar cells since then. These improvements range from manufacturing process, raw materials used and efficiency of solar cells which has made solar PV technology cost competitive with other energy technologies.

2.1.2 Types of solar panels

There are generally three types of solar panels on the market and these include: monocrystalline, polycrystalline and amorphous (thin-film) solar panels. Figure 1 shows the types of panels

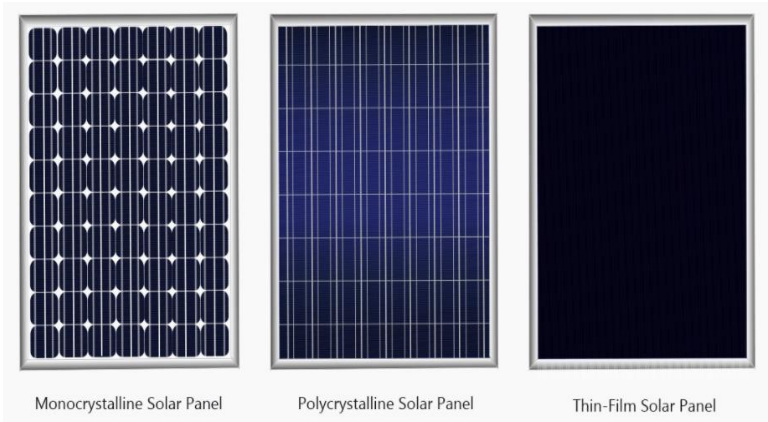


***Figure 1: Types of solar panels**.*[9]

2.1.3 Monocrystalline solar panels

Monocrystalline solar panels as the name suggest are made from multiple independent cells, each cell made from single wafer of silicon crystals. The efficiency of these solar panels ranges from 15% to 24%. They are the most efficient panels currently on the market. Due to their high efficiency, they have high power densities compared to other types of solar panels. One of the drawbacks of monocrystalline solar panels is that they are expensive compared to other types of solar panels.

2.1.4 Polycrystalline solar panels

Polycrystalline solar panels are made from multiple solar cells, each cell is made of silicon wafers. Polycrystalline panels are more efficient than amorphous panels, but their efficiency is relatively lower than monocrystalline panels. It ranges from 13% to 18%. Since their efficiencies are lower than monocrystalline and higher than amorphous panels, they occupy more space per unit energy as compared to monocrystalline but less space per unit energy than monocrystalline but less space per unit energy than amorphous panels. Prices of polycrystalline panels are lower compared to monocrystalline panels and are higher compared to monocrystalline panels.

2.1.5 Amorphous solar panels

Also known as thin-film solar panels, these panels do not contain single independent cells as discussed in other types of solar panels. They are formed through deposition process. The silicon material is directly deposited on glass or plastic to form panel. Their method of production is very simple and cheap making them the cheapest type of panels on the market. These panels are can operate on extremely cloudy day and can maintain good output even if a part of the panel is shaded compared to other types of panels where shading a small part can have a significant effect on the overall output. The properties mentioned above make amorphous panels suitable for solar roofs, solar powered radios and other electronic devices. The main drawback of amorphous panel is their low efficiency compared to other two types of panels. This means that they occupy large space per unit energy which in turn makes them very expensive in large scale applications because the developer needs to purchase a large size of land and mounting materials for the same amount of energy that other panels can produce.

2.1.6 Structure and operation principle of a solar cell

Solar PV cells are made using semiconductors and they have a special property called built-in electric field which provides the force or voltage to drive the current through an external load[10]. Built-in electric field is created within a PV cell by putting two layers of different semiconductor materials into contact [10]. One layer of semiconductor material is made of n-type semiconductor and another layer is made of p-type semiconductor. N-type layer has more electrons which have negative charge while P-type have more holes which are positive charge. Since these materials have excess electrons and holes respectively. when they are put in contact, they create P-N junction hence creating an electric field. This field make electrons flow easily to current at the same time holes will be created in opposite direction readiness to receive electrons. Figure 2 shows a p-n junction of a solar cell.

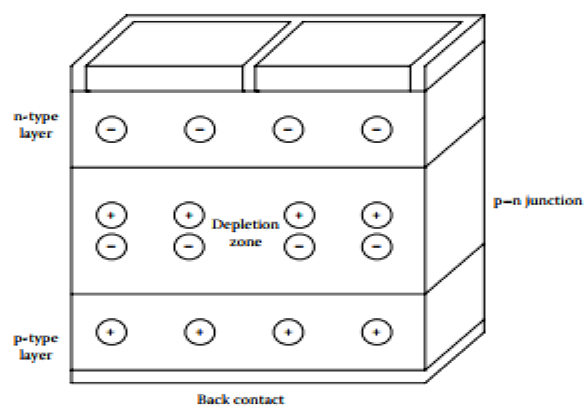


Figure 2: p-n junction of a solar cell [10]

Solar cells operate based on the principle known as photovoltaic effect. Photovoltaic effect is the generation of a potential difference at the junction of two different materials in response to electromagnetic radiation [11]. When light strikes the solar cell, the energy that has been absorbed by the cell. The absorbed energy will generate free charge carriers which will start moving causing electricity to start flowing.

2.2 Components of solar PV system

2.2.1 Solar panels

The solar panel is composed of a group of interconnected solar cells. The solar cells are connected in series and parallel strings depending on the amount of voltage required to be achieved. For example, if a 12V panel is required using 0.5V cells, 24 cells will be connected in series. The number of cells in parallel will be determined based on power rating required under standard conditions. These cells will be mounted on one aluminum frame. Solar panels can also be interconnected to form an array. These are connected in parallel base on power and voltage that the system has to deliver. For example, if a 24-volt system has to deliver 200W, two panels of 12 volts and 8.5W will be used connected in series. If the same power is required at 12V, the same size and number panels will be connected in parallel. Figure 3 shows a solar cell, module, and array.

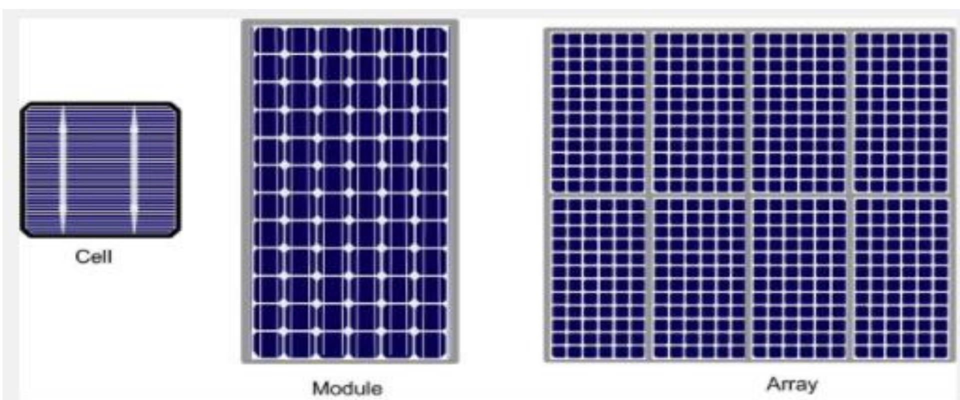


Figure 3: Solar cell, module and array[12]

2.2.2 Batteries

Batteries store energy by converting electrical energy to chemical energy and convert it back to electrical energy when it is time for use. They fall under electro-chemical type of energy storage. They can be classified as primary batteries or secondary batteries. Primary batteries are non-rechargeable while secondary batteries are rechargeable. In solar PV systems, batteries are used to store energy generated during sunshine and supply it at night or at the time of low irradiation. They are also used to smoothen the power system operation by reducing voltage fluctuations.

Types of secondary batteries are; lead acid batteries, nickel cadmium (NiCd) batteries, nickel metal hydride batteries (NiMH), lithium ion, zinc air and lithium polymer[13]. These batteries have common parameters that may vary based on the type. Some of the parameters include; battery capacity, battery voltage, depth of discharge (DOD), battery life, charge and discharge rate (C-Rate), self-discharge and specific energy[14]. Battery capacity is a measure of energy stored in the battery. It is expressed in Amp hours (Ah). Battery voltage is the potential difference that the battery has between its terminals. Total voltage of the battery is based on the arrangement of cells inside the battery and the voltage of each connected cell. DOD is the measure of energy withdrawn from the battery as a percentage. For example, for a 100Ah capacity battery you have withdrawn 80Ah that means the DOD is at 80%. The state of charge is the difference between full charge and the DOD of the battery in percentage of the full capacity. Using the same example as above the state of charge is (100-80) which is equal to 20%. Battery life cycle is the number of charge and discharge cycles a battery can withstand before the nominal capacity decreases to less than 80% of its initial rated capacity. Charge and discharge rate also known as C-Rating is the value that is obtained from the ratio of the of the battery's capacity to the number of hours of full charge or discharge. This means that C-Rating of the battery is calculated by dividing battery capacity by total hours of charge and discharge. For example, a 100 Ah battery with a C-Rating of C/10 or 0.1C meaning they charge or discharge in 10 hours charge or discharge current will be 100/10, equal to 10A. Self-discharge is the capacity lost when a battery is not in use. This can be reduced by storing them under recommended temperatures. Specific energy of the battery is the amount of energy that is stored per unit mass of the battery. It is also known as energy density. Table 1 shows some of the performance parameters of batteries mentioned above.

Table 1: Performance parameters of batteries [15]

Parameter	Lead acid	NiCd	NiMH	Li FeO4
Specific energy (Wh/kg)	30-50	45-80	60-125	90-120
Internal Resistance (mΩ)	<100 for 12V pack	100-200, 6V pack	200-300, 6V pack	25-50 per cell
Life cycle (80% discharge)	200-300	1000	300-500	100-2000
Charge time	8-16h	1h typical	2-4 h	1 h or less
Overcharge tolerance	High	Moderate	Low	Low
Self-discharge/ month at room temperature	5%	20%	30%	<10%
Cell Voltage	2V	1.2V	1.2V	3.3V
Charge cut of voltage(V/cell)	2.4V, float 2.25	Full charge detection by Voltage	Full charge detection by Voltage	3.6
Discharge cut-off Voltage (V/cell)	1.75	1	1	2.8
Charge and discharge rate (Peak load current)	5C	20C	5C	>30C
Charge and discharge rate (Peak load current for best results)	0.2C	1C	0.5C	<10C
Charge temperature(°C)	-20 to 50	0 to 45	0 to 45	0 to 45
Discharge temperature(°C)	-20 to 50	-20 to 65	-20 to 65	-20 to 60
Maintenance	3-6 months (topping charge)	30-60 days (discharge)	60-90 days (discharge)	Not required
Safety	Thermally stable	Thermally stable, fuse protection common	Thermally stable, fuse protection common	Protection circuit Required

Lead acid batteries are the most used ones in applications including PV systems because of their low cost. They consist of a lead (Pb) anode, lead oxide (PbO_2) and sulfuric acid (H_2SO_4) as the electrolyte [13]. These batteries can be flooded or sealed / gel type.

Flooded cell type batteries are most common. They are subdivided into flat and tubular plates. The electrodes of flooded type batteries are completely submerged in the electrolyte. When fully charging these types of batteries, hydrogen and water are produced from water during the chemical reaction at the positive and negative plates. These gases escape through the vents of the battery, that is why it is necessary to add water to the battery after a certain period.

Sealed or Gel type batteries, also known as valve regulated lead acid (VRLA) batteries, are maintenance free batteries. They are categorized into two types gelled electrolyte type and absorbed glass mat type. During the charging process of these batteries, the reaction produces oxygen and water in positive and negative plates. The gases recombine to form water after discharging which eliminates the need for adding water. Sealed batteries are mostly used for solar PV applications because they are easy to transport and suitable for remote applications because of their maintenance-free properties. Batteries are made in wide range of voltages therefore they are connected in series and/or parallel based on the required voltage to be achieved and the power to be stored. For example, if the system voltage is 48V and available batteries are 12V each, four batteries will be connected in series.

2.2.3 Charge controllers

Charge controllers also known as charge regulators are devices used to control overcharging and over discharging of the batteries. The charge controller disconnects the battery from the power source when its voltage level reaches the design limit to protect from overcharging. An example for this scenario is when a 12V battery is charged fully at 14.4V and for anything in excess to this level, the charge controller applies its High Voltage Disconnect (HVD) to stop the battery from charging. To protect from over discharging the charge controller disconnects the load from batteries when their voltage is lower than a minimum set by manufacturers. An example of this scenario is when the 12V battery is at 11.5V, the charge controller applies its Low Voltage Disconnect (LVD) to disconnect the battery from the load. Types of charge controllers include: shunt type charge controller, series charge controller, Pulse Width Modulation charge controllers

(PWM) and Maximum Power Point Tracker charge controllers (MPPT). From all these charge controllers, two are available on the market and these are: PWM and MPPT controllers.

PWM controllers use transistors and they operate by switching these transistors at high frequency with various modulated widths while maintaining constant voltage [16]. Since batteries cannot charge when the PV voltage is lower than battery voltage, there is a need to have equal voltage PV panels and batteries charge controllers. Figure 4 shows a PWM Charge controller.

Figure 4: PWM Solar Charge controller[17]

MPPT charge controller uses DC-DC converters to convert panel or array voltage to the voltage that suits the battery voltage. These can accept a wide range of voltages and convert them to those voltages that are suitable to charge the battery. MPPT controllers are more efficient than PWM controllers which make them more economic at large scale. Figure 5 shows MPPT Charge controllers.

Figure 5: MPPT Charge controller[18]

2.2.4 Inverters

Inverters are devices that convert direct current (DC) into alternating current (AC). They are also called DC-AC converters. Inverter classification is based on input, output, power rating and application.

Input based classification of inverters includes; voltage fed inverters, current fed inverters and variable DC-link inverters. Voltage fed inverters are inverters with constant input voltage. In this type of inverters, the current varies according to load demand but voltage remains constant. The capacitor is provided between the source and the inverter in this type of inverter. The current fed inverters have constant input current and their voltage vary according to the load. The inductor is provided between the source and the inverter in this type of inverters. Variable DC-link inverters have both dc current link and DC voltage link in between the source and inverter. The input voltage is controllable by changing the values of the inductor and capacitor in the DC link.

Output based classification of inverters includes; square wave inverters, quasi square wave inverter, and sine wave inverter. Square wave inverters are inverters that convert the dc input to a square wave output. They are easy to produce but the square wave is not suitable in some electric applications such as AC motors and transformers. Quasi square wave inverters are similar to square wave the only difference is that the output goes to zero before it switches to positive or negative direction. This is the modification of the square wave and it can work well with most electronic devices. Sine wave inverters are inverters that produces almost a perfect sine wave in their output. This are compatible with all electronic devices are suitable for utility grid supply systems. Figure *6* shows classification of inverter based on output.

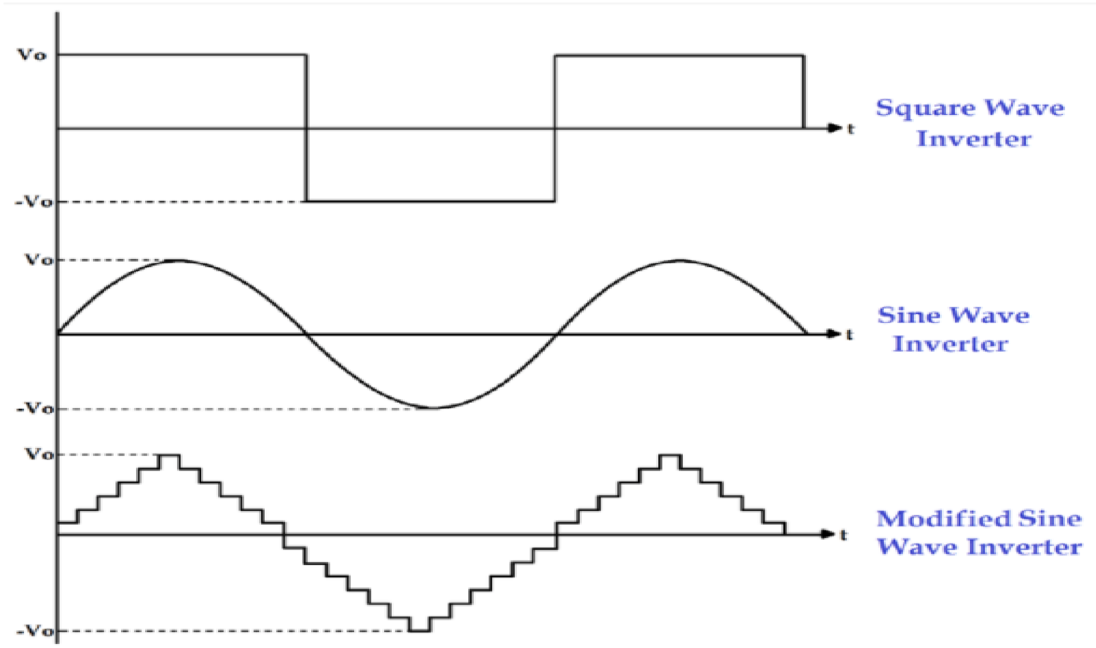


Figure 6: Classification of inverter based on output [19].

Classification of inverters based on type of load include single phase inverters and three phase inverters. Single phase inverters are used in single phase circuits and are used in low and medium power demand applications. Three phase inverters are used in three phase circuits and are used in high power and three phase applications.

Classification based of inverters on application include; grid tie inverters, standalone inverters, hybrid inverters and solar micro inverter. Grid tie inverters are inverters that are synchronized with the grid. These inverters cannot operate in absence of the grid. Standalone inverters are inverters that convert DC power to AC power in absence of the grid. They are primarily used in standalone renewable energy systems. Micro inverters are inverters that are used to covert DC to AC power for a single panel. Hybrid inverters are inverters that combine properties of charge controller gid tie inverters and standalone inverters. They are now common because of their flexibility in use.

2.2.5 Protection devices

These are devices that are used protect accidents associated with the PV system or any damage to other important components. Protection devices include fuses, disconnects, and circuit breakers.

Disconnects are features that are used to isolate the components or remove the connections for safe maintenance of the system. In a PV system the disconnects will be located in both AC side and DC side. For example, between panels and charge controller, charge controller and batteries, and charge controller and inverter. Positioning disconnects in such positions will help to isolate each component during replacement or repair without the risk of being electrocuted.

Fuse is the overcurrent protection device that protect the circuit by popping and break the circuit. A fuse is made up of filament that will remain in good condition if the circuit current is at designed level. When the current exceeds the maximum allowed level, the circuit will get hot and the filament in the fuse will pope, breaking the circuit. The fuse will not be repaired but replaced.

Circuit breakers are overcurrent protection devices that protects the circuit by opening the circuit through tripping. When current exceed the maximum designed for the circuit breaker, it trips to open the circuit, preventing the current from continuing to flow. Unlike fuses the circuit breakers can be reset so they don’t need frequent replacements. Figure 7 shows a fuse and a circuit breaker.

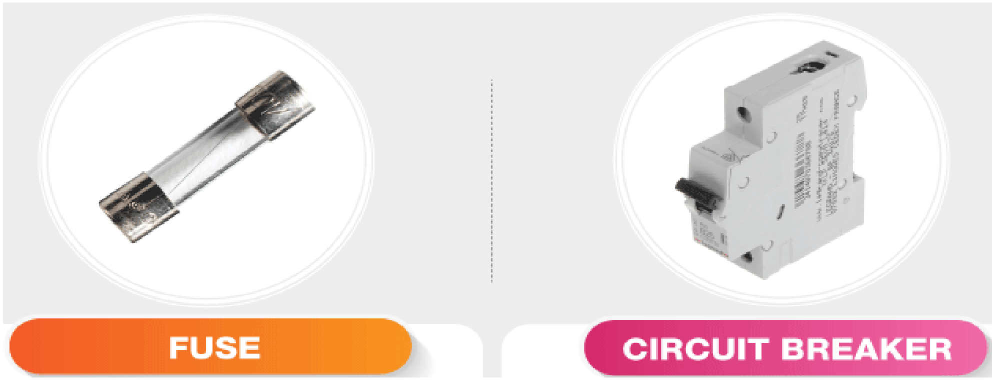


Figure 7: Fuse and Circuit breaker [20]

2.2.6 Mounting system

In a PV system mounting system depends on purpose, size and availability of space. Solar PV system can use roof mount, ground mount or pole mount system. Ground mount systems are suitable for large scale solar PV systems. These mounting systems can be self-fabricated or bought. It is recommended to use corrosion resistant materials when constructing a mounting structure.

2.3 Types of solar PV systems

Solar PV systems can be classified as grid tie systems, standalone systems and Hybrid systems.

Grid tie system is a Solar PV system that is connected to the utility grid. It uses grid tie inverters when changing DC power from panels to AC power. Grid tie systems do not have storage and they do not operate when the grid go off. This type of system is cheaper compared to other systems and in countries where net metering is allowed, owners can have good financial gains when they are generating more power compared to what they are consuming. The only drawback is that they are not suitable in places with long period of blackouts because due to lack of storage, owners will not have power supply even if they have a PV system. Figure 8 shows grid tie system.

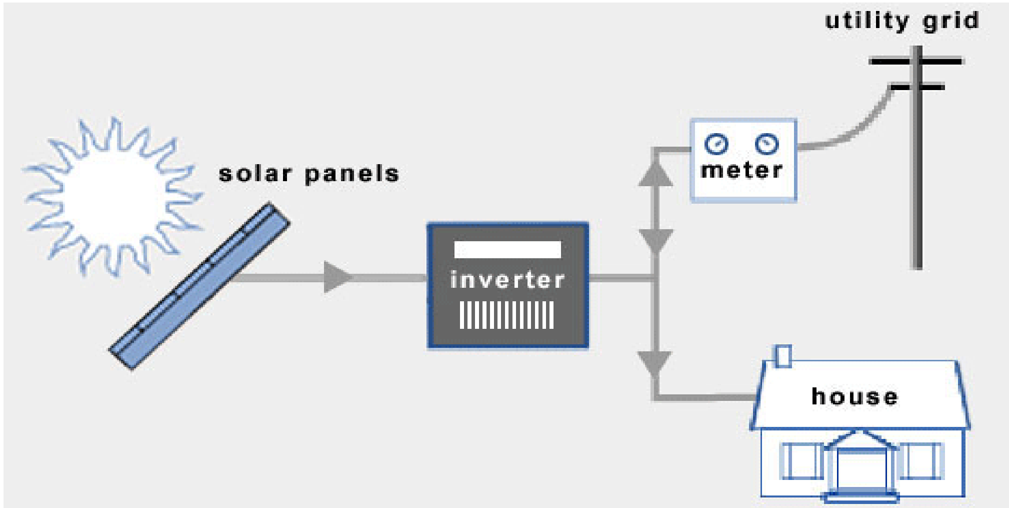


***Figure 8**: Grid tie system is a Solar PV system* **[21]**

Standalone system is also known as off grid system. As the name suggest these are systems that operate without relying or being connected to the grid. As opposed to grid tie systems these systems mostly use storage. They are more suitable in places where there is no electricity and far from the grid. This is being taken as solution to rural electrification in most countries. Standalone systems have high cost compared to grid tie systems. Figure 9 shows a standalone photovoltaic system.

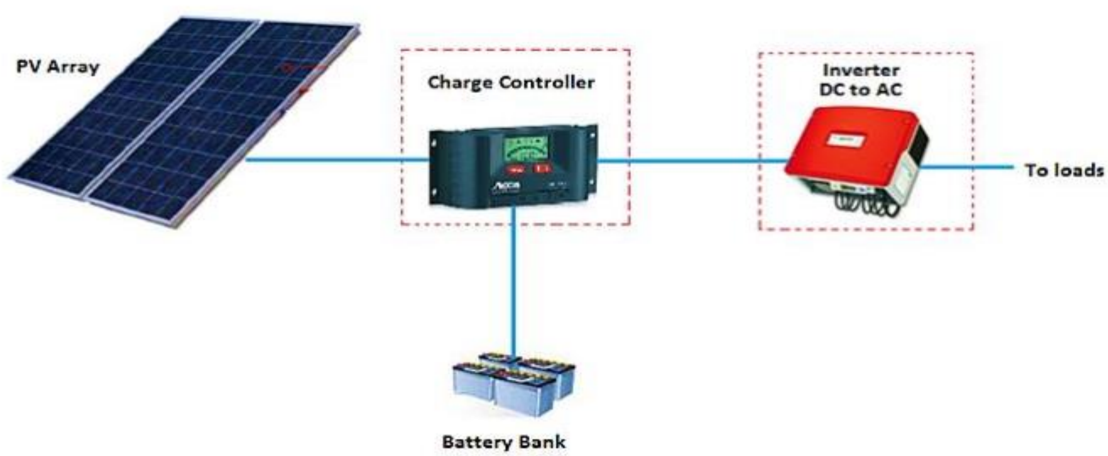


Figure 9**: Standalone photovoltaic system[22]**

Hybrid system is a combination of two or more sources of power to supply electricity. Hybrid systems use hybrid inverters. They are many types of hybrid systems including PV-grid, PV-wind, and PV-diesel genset. Depending on the combination, the system may need storage or not.

Hybrid systems are more reliable than other systems which depend on one source. Figure 10 shows a PV-Wind hybrid system.

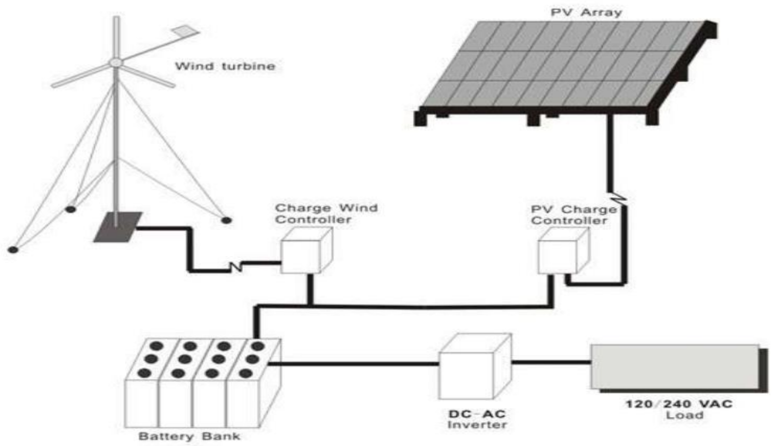


Figure 10: PV-Wind Hybrid system [23]

2.4 Mini-grid systems

Mini-grid is the small and isolated electricity generation and distribution system that can be used to power communities or institutions that are not connected to the main utility grid. They are composed of generation, distribution and end-users. Mini-grid can use one or more sources of energy to generate electricity. Examples of sources of electricity for mini-grid include solar, wind, hydro, biomass and diesel. Some of the sources may need backup while others don't. Sources that need backup have a high level of unpredictability, which may result in fluctuations in electricity supply. The generation capacity for mini-grid can range from kilowatts to 100 megawatts [24].

2.5 Types of mini-grids

Mini-grid can be classified as autonomous or interconnected [25]. Autonomous mini-grids are independent of other grid and can be subdivided into lower tier level of service and higher tier of service. Lower tier of service grid is in Tier 3-4 with power supplied less than 24 hours and is used to support basic loads [25]. Higher tier service is in tier 5 and it supplies power for 24 hours and it they are more reliable hence can be used for productive use [25]. Interconnected mini-grids are those that has the capability of connecting to neighboring grids. This category can be further subdivided into interconnected community application and interconnected large industrial application. Interconnected community application can be used as a back to the main grid or designed to sustain the main critical loads or used as main source of power with the main grid as a backup [25]. It is tier 5+ and more reliable. Interconnected large industrial application are designed for high reliability and they belong to tier 5++ [25].

2.6 Mini-grid development

Mini-grid development consist of three phases which are project development, implementation and operation [26].

Project development phase consist of early stage and late stage. Early stage of project development phase involves site selection, feasibility study, resource assessment, demand assessment, technical design, preparing business and financial model and late stage of project development phase consist of securing land rights, environmental and social impact assessment(ESIA), securing licenses approval of tariffs, community engagement framework establishment and procurement of equipment [26]. To complete the first stage the field survey is required. The field survey structure of the can be dived into four sections: general information, wealth, income and general expenses, current energy sources and usage and electricity demand [26]. General information section data to be collected include: name, age, phone number, GPS location, employment status, and sector of occupation [26]. this section aims to is for identify the interviewee, identify economic activities in the community, and get an overview of the community distribution, which can be useful in siting and implementation. Wealth income and general expenses section collets information on construction materials of the house, modes of transport used, monthly expenses, airtime expenditures, and bank account or mobile money usage [26]. The of this section aims to measure the ability to pay and interviewee economic capabilities which helps when setting tariffs and setting other operation and maintenance parameters. Current energy sources and usage section collects information on energy sources that the interviewee is using and expenses on energy [26]. This of the section aims to measure the interviewees willingness to pay and potential energy sources that compete with the prospective mini-grid. Willingness to pay can also be assessed by asking a direct question the interviewee whether he or she is willing to pay for the coming service. Electricity demand section collects information on appliances owned by the interviewee, plans to buy appliances if connected to the mini-grid, and need for electricity [26]. This aims at establishing the load profile and general perception towards mini-grid.

Implementation phase involves installation and commissioning, securing power purchase agreement(PPA), setting up service contracts and payment system and drafting of operation and maintenance (OM) and manuals health safety and Environment (HSE) manuals[26].

Operation phase incudes operation and maintenance, stimulation of productive use, performance monitoring, revenue generation and planning for scaling up [26].

2.7 Mini-grids in Malawi

Mini-grids were introduced in Malawi around 2006. Most of them were used for pilot studies and their failures have helped the country to get useful experience in terms of management and model of operation [27]. Some of mini-grid initiatives in Malawi are summarised in the Table 2.

Table 2: Summary of mini-grid initiatives in Malawi

Mini-grid name and location	Key stakeholders and funders	Description of system	Business Model and End-user	Status
MEGA, Mulanje	MMCT, Practical Action, SG, Sgrr	Hydro 220 kW	Domestic	Active since 2014
SE4RC: Nyanvuwu and Chimombo in Nsanje district (30kW and 25kW respectively) and Mwalija and Oleole in Chikwawa district (55kW and 30kW)	PAC, CARD, FISD	55kW, 30kW, 30kW and 15kW	Domestic and Irrigation	Active since 2018
Sitolo, Mchinji	CEM, CES	Solar 80kW	Domestic	Active since 2019

Solar Village Mini-grids; Nkhatabay, Nkhotakota, Chiladzulu, Mzimba, Thyolo and Ntcheu	GoM	Solar Wind Hybrid (35kW in all sites)	Domestic	None is working currently since 2012
Likoma and chizumulu Island	GoM	1MW and 300kW (Solar PV and Diesel)	Domestic and institutional	active
Usingini	PAC	Hydro (300kW)	Domestic and Commercial	Ongoing project (still at implementation stage)
St Gabriel	Roman Catholic	Solar-Diesel Min-grid (35kW)	Domestic and Commercial	Active since 2017
Nkhata bay Hospital	GoM	Solar Mini-grid and Solar Geysers	Institutional	Active since 2015
Dedza Micro-grid	United Purpose, University of Strathclyde	Solar Micro-grid (5kW)	Domestic and Productive Users	Feasibility study complete
Kavuzi Mini-hydro Power Project	Kavuzi community in the name of Kavuzi Electricity Generation and Supply Association (KEGSA)	Micro-hydro 50 kW	Domestic and Commercial	Feasibility study and designs completed
Chipopoma Hydropower Project	Chipopoma community	Micro-hydro 50 kW	Domestic and Commercial	Materials procured

Source: adopted from Mini-grids in Malawi: Status, Opportunities and Barriers [28] updated by author.

Currently mini-grid concept is being supported in policies, strategies and standard. Examples of policies and strategies concept include; National Energy Policy 2018, Malawi Renewable Energy Strategy, Regulatory framework for mini-grids and feed in tariff policy. The main objective for national energy policy for Malawi is to increase access to affordable, reliable, sustainable, efficient and modern energy for people in the country [27]. In one of the policy statements the government shows commitment to support small-scale renewable energy initiatives by communities or entrepreneurs. This is done by developing appropriate regulations and reviewing feed in tariffs to accommodate mini grids [27]. Malawi Renewable Energy Strategy sets the target of having a minimum of 50 operational mini-grid sites by 2025. These mini-grids will include those for self-consumption and those selling to excess power communities and to the national grid[29]. Feed in Tarif Policy aims to facilitate resource mobilisation by providing security to investments and market stability to investors in the energy sector[30]. Regulatory framework for mini-grids was developed to provide guidelines for mini-grid development and operation in Malawi. It helps in mini-grid development solicitation process and provide requirements for approval of mini-grid project [31]. As an example of providing guidelines regulatory framework for mini-grid state that for feasibility report of mini-grid of less than 150 kW to be considered adequate it should contain the following: a section discussing resource assessment; a section of electricity demand analysis; a section discussing the power plant technology choice and adequacy of system; justification of the technology choice relative to other available options based on any relevant economic viability assessment; implementation drawing for the system and land requirement for the project implementation. This study will follow the requirements outlined in this strategy.

CHAPTER 3: METHODOLOGY

This document used both qualitative and quantitative methods. A questionnaire was used to collect data. Data collected was used to establish the load profile which was used as HOMER input on load. The details of load assessment and Other HOMER input will be discussed in the next sections. Figure 11 shows the map of the area under study.

***Figure 11**: Map of Matekenya Area from Google map as on 25/07/2021*

3.1 Questionnaire development

An electronic questionnaire was developed using kobo toolbox. This tool was chosen to make sure that the quality of data is maintained and to avoid errors that may occur during data entry from paper questionnaire to electronic platforms for processing. Kobo toolbox also helped to take the GPS of each respondent that helps in establishing the map of the area.

The questionnaire developed had three sections; the first section was for respondent details, the second section labelled part 1 was specifically for village headman to respond and the last section was for household.

The first part mainly focused on respondent identification and contained identification information such as respondent serial number, name, gender, GPS coordinate, employment and occupation sector.

The second section was for village headman to give information about the village and focused on knowing population of the area, number of households, public institution available in the area and most economic activities in the area. The questions for this section were as follows; what is the population of Matekenya? what is the number of households? How many public institutions do you in Matekenya? And what are economic activities that most people are involved in?

The third section of the questionnaire was designed for households. This part contained three categories. These categories include questions that assess energy needs, questions that assess ability to pay and questions that assess the willingness to pay. Questions that assess energy needs include:

- ✓ What are the appliances do you have or would like to have that uses or will be using electricity?
- ✓ With the follows up questions such as how long do you use or will you be using that appliance during daytime?
- ✓ How long do you use or will you be using that appliance during Night time?

Questions that assess ability to pay in the questionnaire are as follows:

- ✓ What economic activities do you do to earn a living?
- ✓ How much do you spend on monthly basis for charging your cell phones? How much do you spend for airtime in a month?

Questions that assess willingness to pay include:

- ✓ If there is a project to supply electricity to you, are you willing to be connected?
- ✓ How much are you willing to pay for electricity once you get connected?

Some questions can help to assess both abilities to pay and willingness to pay these questions include:

- ✓ What are the current sources of energy you are using?
- ✓ How long do you use each energy source per day for each function mentioned above?
- ✓ How much money do you spend for each type energy?

These questions also help to identify potential energy source that would compete with the mini-grid.

3.2 Load assessment

Load assessment was conducted by administering the questionnaires. This questionnaire was administered using android application called Kobo collect. The questionnaire was administered to households that are potential candidates for using the mini-grid based on the geographical location, proximity to economically active area and public institutions that are available in the area. The respondents were selected based on structures that were along the trading centre in the area. Before administering the questionnaire, community leaders such as chiefs were approached to be aware and to have their consent to do research in their area. The first person approached was the Traditional Authority (TA), the overall leader for community, then the Village headman. The village headman was approached and he assisted in providing the total number of households in his location, the population of the area, institutions available in the area and major economic activities that happen in the area by answering the second section of the questionnaire. The questionnaire assessed 95 structures along the trading centre and only structure that are in use were assessed. These structures include houses, shops, school blocks, clinic and church. Figure 12 shows a map showing the positions structures assessed.

Figure 12: Map showing position of structures assessed

The point that is isolated from other points is where the village head responded to his dedicated section questions. Therefore, no structure was assessed in that location since it was outside the main area of interest.

3.3 Load profile

The data collected was downloaded into excel format so that it can be used to establish the load profile. This profile was established based on responses given by respondents. If the respondents mention the appliance they use, they were asked to give the range of time or number of hours that they will be using the appliance in daytime as well as in nighttime. These responses were plotted into excel sheet to give the total power consumption for each and every hour that was used as HOMER input. Figure 13 shows how data was organized to produce the load profile that will be fed into HOMER.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1	What are	power ra	quantiy	total pow	How long	night duration	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	12PM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12AM	
310	Air compr	1000	1	1000	6am-6pm	0						1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000								
311	Popcorn n	250	1	250	6am-10ar	0						250	250	250	250																
312	10 bulbs	20	10	200	0	6pm-6am	200	200	200	200	200													200	200	200	200	200	200	200	
313	TV	150	1	150	6am-6pm	6pm-8pm						150	150	150	150	150	150	150	150	150	150	150	150	150	150						
314	Sound sys	100	1	100	6am-12pr	4pm-8pm						100	100	100	100	100	100	100	100	100	100	100	100	100	100						
315	Fridge	200	1	200	6am-6pm	6pm-6am	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	
316	Maize mil	15000	1	15000	6am-6pm	0						15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000								
317	Welding n	2400	1	2400	6am-4pm	0						2400	2400	2400	2400	2400	2400	2400	2400	2400	2400										
318	8 Bulbs	20	8	160	0	6pm-6am	160	160	160	160	160													160	160	160	160	160	160	160	
319	TV	150	1	150	7am-6pm	6pm-9pm							150	150	150	150	150	150	150	150	150	150	150	150	150	150					
320	Sound sys	100	1	100	6am-6pm	6pm-6am	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
321	Sewing m	100	1	100	6am-6pm	6pm-10pm						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100				
322	Weaving r	100	1	100	8am-6pm		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
323	Hotplate	1000	1	1000	6am-8am	6pm-8pm						1000	1000											1000	1000						
324	Fridge	200	1	200	6am-6pm	6pm-6am	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	
325	4 bulbs	20	4	80	0	6pm-9pm																		80	80	80					
326	20 phone	5	20	100	6am-6pm	6pm-9pm						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100					
327	Barbersh	60	1	60	6am-6pm	6pm-9pm						60	60	60	60	60	60	60	60	60	60	60	60	60	60	60					
328	Hotplate	1000	1	1000	6am-8am	6am-8pm						1000	1000											1000	1000						
329	6 bulbs	20	6	120	0	6pm-11pm																		120	120	120	120	120			
330	TV	150	1	150	7am-6pm	6pm-7pm							150	150	150	150	150	150	150	150	150	150	150	150							
331	Fridge	200	1	200	6am-6pm	6pm-6am	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	
332	Radio	100	1	100	6am-6pm	6pm-9pm						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100					
333	Barbersh	60	1	60	7am-7pm								60	60	60	60	60	60	60	60	60	60	60	60							
334	6 bulbs	20	6	120	0	6pm-10pm																		120	120	120	120				
335	Radio	100	1	100	12pm-6pr	6pm-10pm												100	100	100	100	100	100	100	100	100	100				
336	TV	150	1	150	6am-12pr	6pm-10pm						150	150	150	150	150	150							150	150	150	150				
337	4 bulbs	20	4	80	0	6pm-10pm																		80	80	80	80				
338	5 phones	5	5	25	6am-12pm							25	25	25	25	25	25														
339	Radio	100	1	100	6am-6pm	6pm-10pm						100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100				
340						Total	20416	20266	20266	20206	19426	110076	135241	120581	118056	118271	135561	120576	117646	115996	114186	1E+05	83331	72901	54516	38286	27796	21926	21506	20546	
341																															

Figure 13: Data organisation in excel sheet to come up with load profile.

The total hourly consumption was entered into HOMER software. Figure 14 shows the daily load profile in homer software.

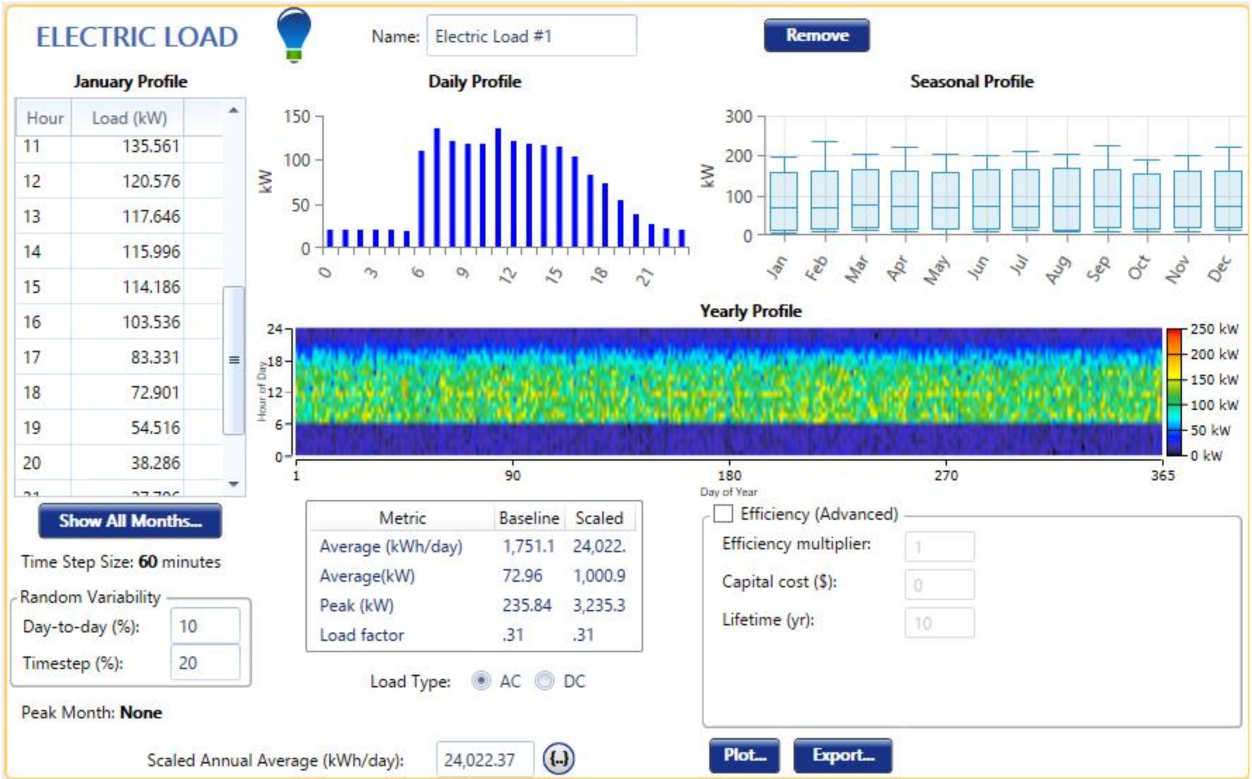


Figure 14: Load Profile in HOMER

As seen in the figure the daily load profile is similar to industrial load where the peak in the day time. This is due to the businesses that the respondents are planning to have when they have access to electricity such as maize mills, welding machines and others productive uses. **Table 3** shows the total quantity of each appliance mentioned by respondents and power rating used when establishing the power rating.

Table 3: The appliances intended to be used by respondents, power rating and total quantity

appliance	power rating (W)	quantity(number)
bulbs	20	692
TV	150	44
Fridge	200	28
Radio	100	35
Barbershop	60	20
Hotplate	1000	31
Iron	1000	15
Welding machine	2400	12
maize mill	15000	4
phones	5	266
Sterilization machine	2000	1
Microscope	100	1
Saloon	600	1
Fan	50	1
Sewing machine	100	4
printers	100	3
laptops	60	7
Photocopier	100	1
Kettle	1000	1
Wood Router Machine	1600	1
Drilling machine	1000	1
Electric Planer	2400	1
Projector	200	4
Bakery(oven)	2000	2
Desktops	150	4
Charging batteries	100	1
Air compressor	1000	1
Popcorn popper	250	1
Video Show	200	1
Weaving machine	100	1

NB: 15000kW for maize mills accounts for both Milling and hulling. It is assumed that it will use 7500 kW each of them.

3.4 Solar Resource assessment

The area under consideration has no nearby weather station therefore solar radiation data was taken from NASA. The data obtained is the average global horizontal radiation for a period of 22-year period from July 1983 to June 2005. Based on GPS coordinate -13.5690086 34.0491666 (13°33.9′S, 34°2.9′E). The site's global horizontal irradiance (GHI) ranges from 4.470 kWh/m^2/day to 6.540 kWh/m^2/day and the average is 5.22 kWh/m^2/day. The lowest GHI is in January and the highest in October. The clearness index ranges from 0.403 to 0.636. Figure 15 shows Solar GHI resource for the area.

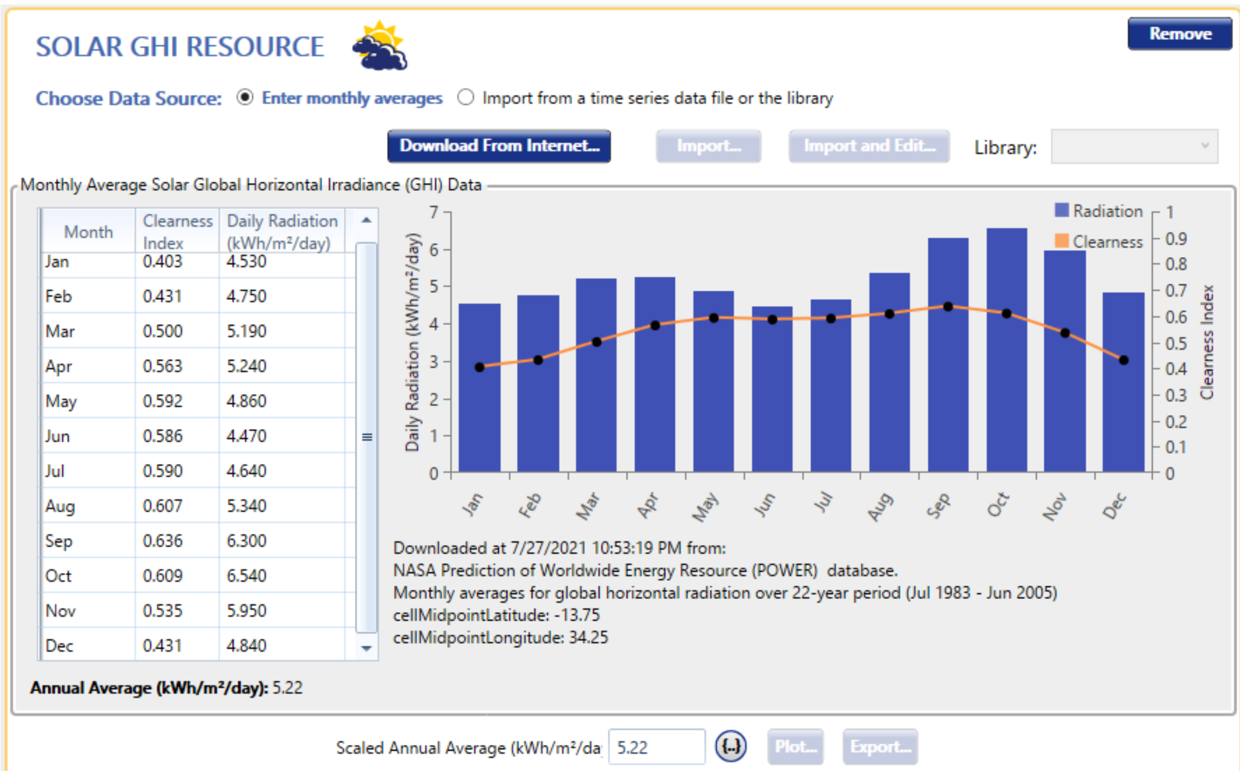


Figure 15: Solar GHI resource for the study area.

3.5 System components

The study focused on standalone solar PV mini-grid. Therefore, the system components that were used in addition to load are converter, modules and batteries. The configuration of the system is shown in Figure 16.

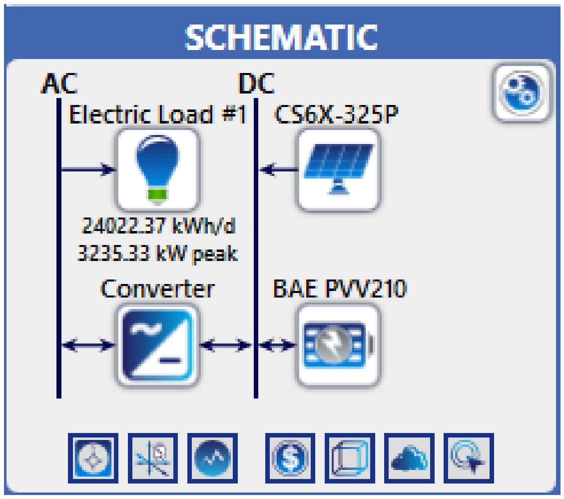


Figure 16:Configuration of the system

Quotations for each component were sourced from various suppliers and details for each component input are given in the follow up sections.

3.5.1 Solar PV input

Solar PV input was done by selecting modules in HOMER library. The module selected was CS6X-325P manufactured by Canadian solar. The power rating of the selected module is 325W and has an efficiency of 16.94%. Based on the quotations received from various suppliers the total cost was equivalent to \$99.4. The power rating was entered into HOMER in kW as 0.325kW and the unit cost for a module as \$99.4. Figure 17 shows the details of Solar PV input.

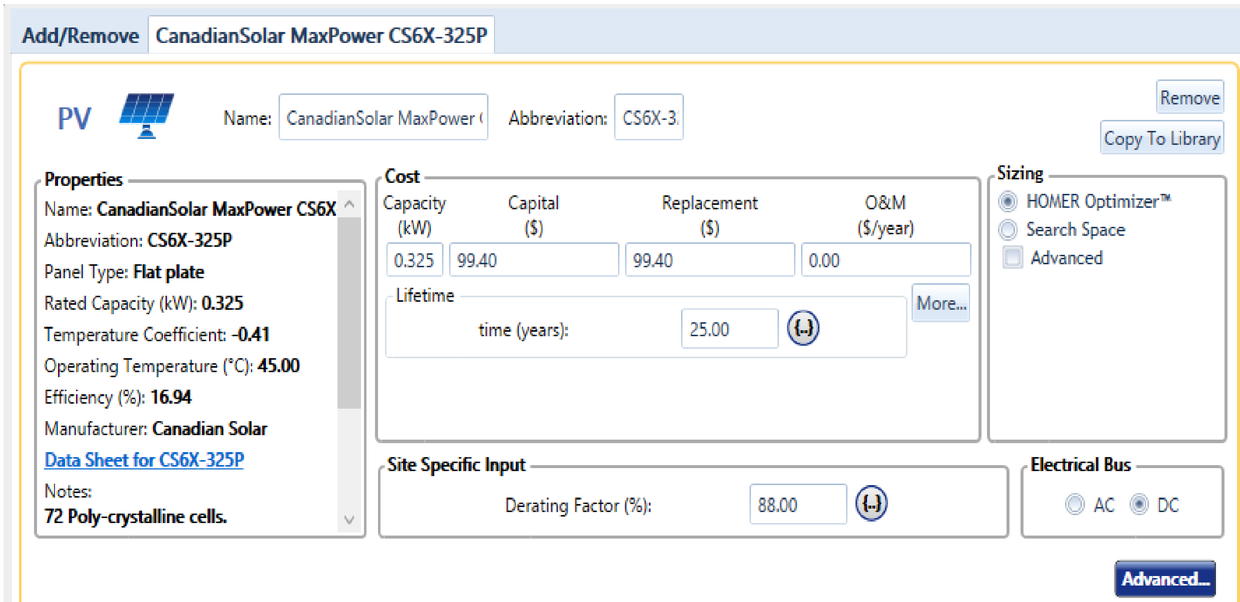


Figure 17: Solar PV input

3.5.2 Storage input

The system under study was standalone solar PV mini-grid therefore storage to be of paramount importance. The storage helps to reduce fluctuations in electricity supply and supplies electricity to the load in night hours. The storage input used was the lead acid battery. The battery used was BAE PVV 12V 210. This is a maintenance free battery with good qualities suitable for this application. Based on quotations from the suppliers the cost per unit for the battery is equivalent to $523.23 and this was used as capital cost and replacement cost. The string size used is 16 so that it should fit the inverter input voltage of 192V. Figure 18 shows details of battery input.

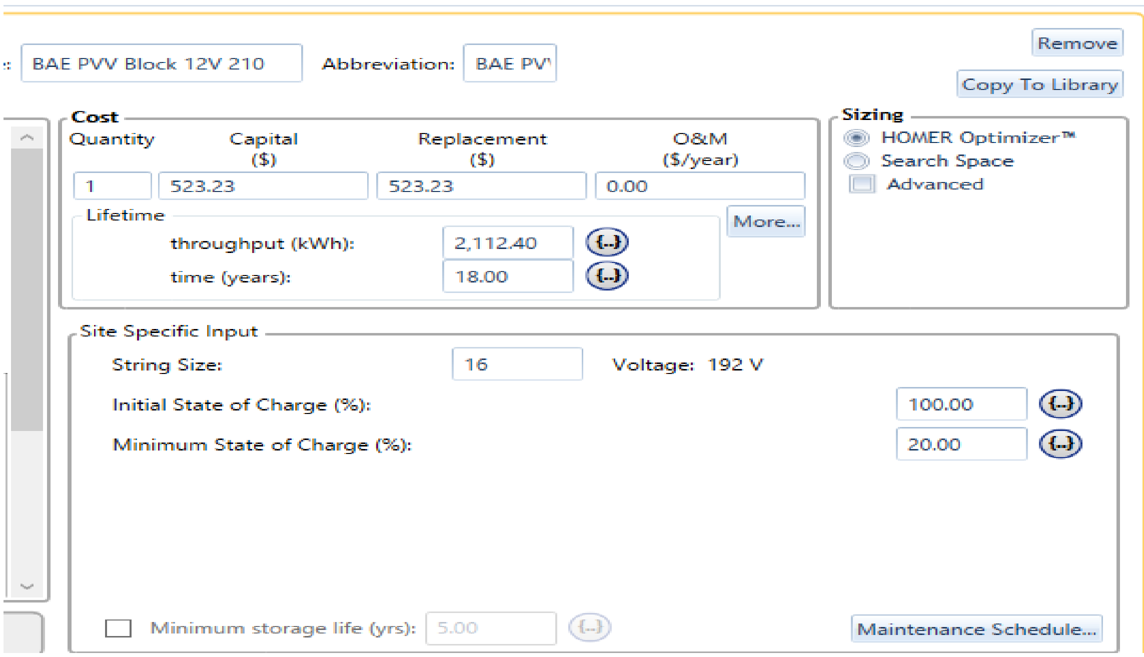


Figure 18: Battery input

3.5.3 Converter inputs

In this system, converter was considered to be used to charge the batteries (DC-DC conversion) and converting power from DC to AC (DC- AC conversion) which is the energy form that the loads will be using. The inverter proposed in this system is a 100kW inverter with 95% efficiency. Based on quotations from the supplier the total cost of the inverter including shipping cost was $15643.22. Figure 19 shows the converter input details of the system.

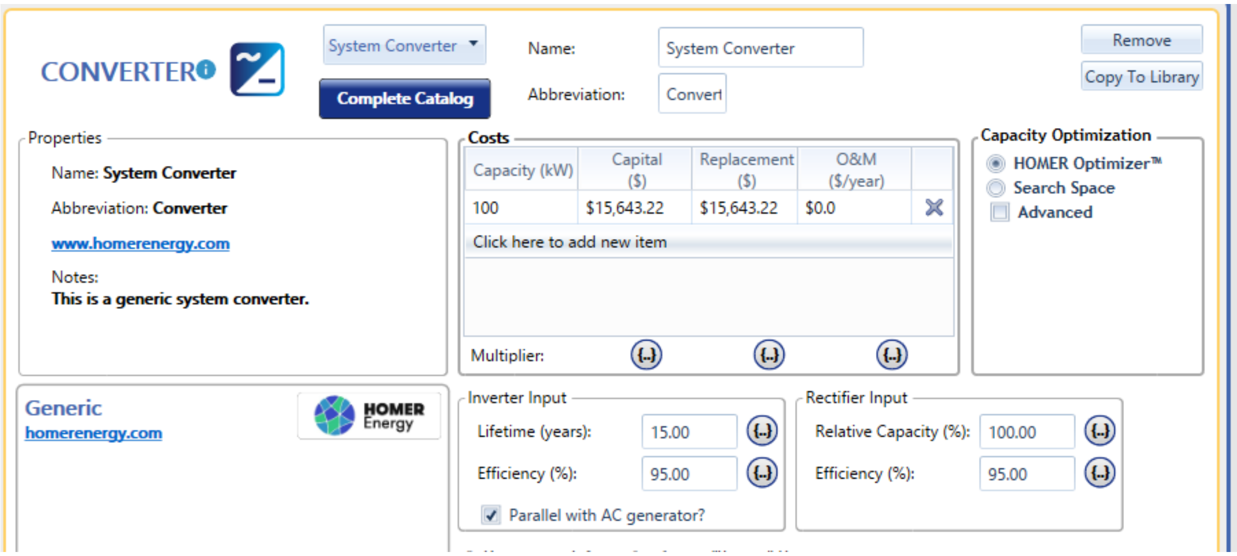


Figure 19: Converter input

3.6 System economic input

In order to perform economic analysis of the system there are economic parameters required to be entered into HOMER. These parameters include nominal discount rate, expected inflation rate, project life time, fixed capital cost and fixed operation and management cost. The nominal discount rate and expected inflation rate were based on rates on Reserve Bank of Malawi in the month of June 2021 which were 12% and 9.1% respectively. The project life is set to 25years. System fixed costs were estimated by distribution cost, cost of prepaid meters and cost of mounting racks. According to the world bank[32] the distribution cost system per km is $14980/km. The total distance for the distribution system was estimated by measuring the distance on the google map and was found to be 2.12km. The total distribution cost was obtained by multiplying the total distance measured by the distribution cost per km which was equal to $317557.6. Figure 20 shows how the distance was measured.

Figure 20: Total distance measured

Prepaid meter cost was found by searching cost of meter cost on www.alibaba.com and the average cost was $50. This cost was multiplied by the number of respondents which is 95 and the total cost was $4750. The cost of mounting structures was found by searching the cost of ground mounting system per kW on Alibaba and the one selected was $75/kW. This cost was multiplied by the rated capacity of the system which was 15070kW. The total cost for the mounting system was $1243500. After adding all the fixed costs, the total was $1280007.6. The fixed system operation and management cost was estimated to be $36000. Figure 21 shows the economic Inputs used.

Figure 21: Economic inputs

3.7 Sensitivity Variables

Sensitivity analysis is done to see the effect of changing one variable on dependent variables in the system. This document focused on 10 sensitivity parameters: capacity shortage, battery replacement multiplier, battery capital cost multiplier, PV replacement multiplier, PV capital cost multiplier, scaled annual average, nominal discount rate, inflation rate, project lifetime and system fixed capital cost. These simulation parameters were used in groups to reduce the time taken to get the results. The first group consists of capacity shortage, battery replacement multiplier, battery capital cost multiplier, PV replacement multiplier, PV capital cost multiplier, and scaled annual average. **Table 4** shows the first group of sensitivity parameters and the values used for simulations.

Table 4: First group of sensitivity parameters

Capacity Shortage (%)	BAE PVV210 Replacement cost multiplier (*)	BAE PVV210 Capital cost multiplier (*)	CS6X-325 Replacement cost multiplier (*)	CS6X-325 Capital cost multiplier (*)	Scaled annual average (kWh/day)
0	0.5	0.5	0.5	0.5	2424.25
10	1	1	1	1	24022.368
20	1.5	1.5	1.5	1.5	38950.56

The values used for capacity shortage were 0%, 10% and 20%. 0% means there is no capacity shortage and 10% means there will be only 10% allowable capacity shortage and the same applies to 20%. For batteries and PV multipliers, the factor values 0.5,1, and 1.5 were used. A factor of 1 means that no changes are made on that parameter. A factor of 0.5 means that it has been reduced by half whereas a factor of 1.5 means it has been increased by half. Values used for the scaled annual average were 2024.25, 24022.368 and 38950.56 kWh/day.

The second group of sensitivity parameters include: nominal discount rate, inflation rate, project lifetime and system fixed capital cost. **Table 5** shows the second group of sensitivity parameters and values used.

Table 5: Second group of sensitivity parameters

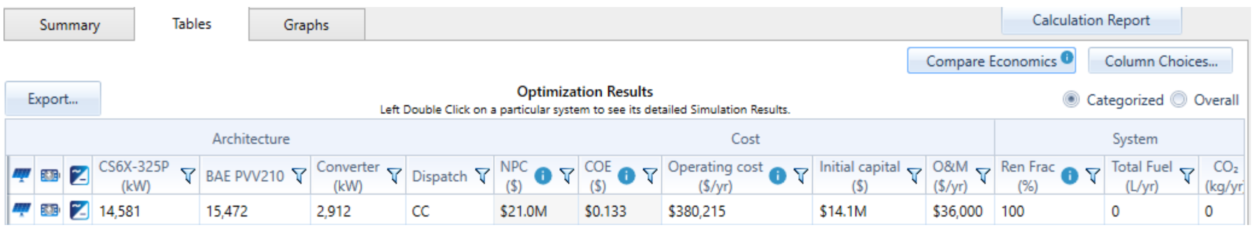
Inflation rate (%)	**Discount rate (%)**	**Project lifetime (years)**	**System fixed cost ($)**
0	0	15	58482.6
1	1	20	1130082
2	2	25	1845657.6
3	3	30	
4	4		
5	5		
6	6		
7	7		
8	8		
9	9		
10	10		
11	11		
12	12		
13	13		
14	14		

On inflation rate and nominal discount rate, values used ranges from 0% to 14%. For project life time the values used include 15years, 20years, 25years and 30years. Values used for the fixed system cost were \$58482.6, \$1130082, and \$1845657.6. These costs were calculated by using array size whose scaled down average was used as input in the first group of parameters when calculating fixed system cost.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Simulation results without sensitivity variable

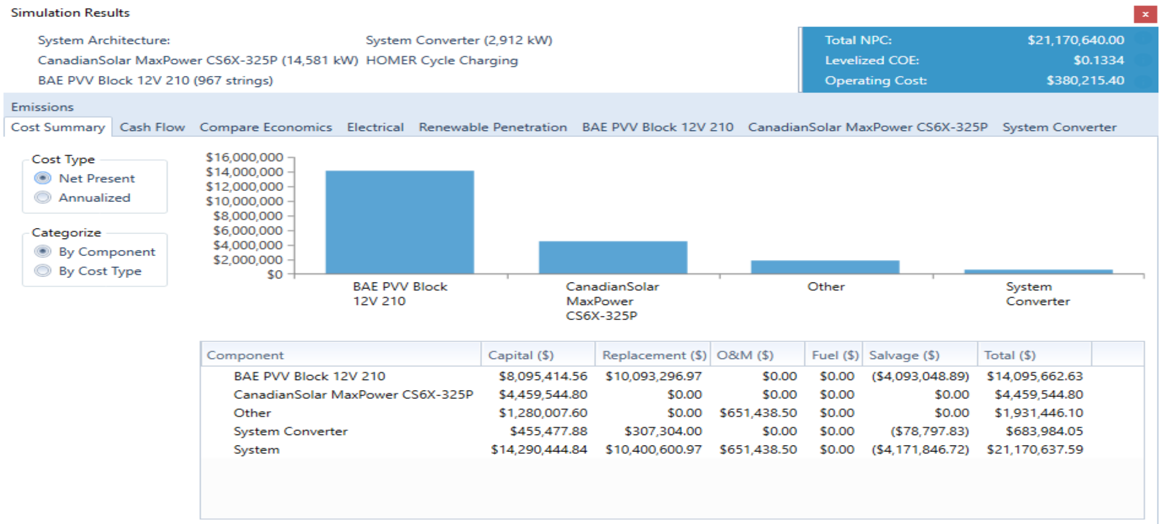
The categorized optimization results from HOMER were displayed on the result panel. There is only one system on categorized results. The architecture of the system consists of 14581kW of panels, 15472 batteries and 2912kW inverter. On the cost, the net present cost of the system (NPC) was found to be $21170640. Levelized cost of energy (LCOE) was found to be $0.13. The operating cost was $380215.40. The initial capital cost and operation and management cost were $14290444.84 and $36000 respectively.



Architecture				Cost					System		
CS6X-325P (kW)	BAE PVV210	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	O&M ($/yr)	Ren Frac (%)	Total Fuel (L/yr)	CO_2 (kg/yr)
14,581	15,472	2,912	CC	$21.0M	$0.133	$380,215	$14.1M	$36,000	100	0	0

Figure 22: Categorized optimization results for HOMER with no sensitivity parameters

The PV array had the capital cost of $4459545 and production of 23203326 kWh/year. The batteries had an autonomy of 29.9 hours and the total cost amounting to $8095414.56 and the converter has a capital cost amounting to $455477.88. Figure 23 shows cost summary of the system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
BAE PVV Block 12V 210	$8,095,414.56	$10,093,296.97	$0.00	$0.00	($4,093,048.89)	$14,095,662.63
CanadianSolar MaxPower CS6X-325P	$4,459,544.80	$0.00	$0.00	$0.00	$0.00	$4,459,544.80
Other	$1,280,007.60	$0.00	$651,438.50	$0.00	$0.00	$1,931,446.10
System Converter	$455,477.88	$307,304.00	$0.00	$0.00	($78,797.83)	$683,984.05
System	$14,290,444.84	$10,400,600.97	$651,438.50	$0.00	($4,171,846.72)	$21,170,637.59

Figure 23: Cost summary of the system

The cost the cost summary, it can be seen that the major contributor of the system cost was the storage system followed by solar panels and the lowest cost is for converter system The cashflow of the system by cost type nominal for 25years is presented in the Figure 24.

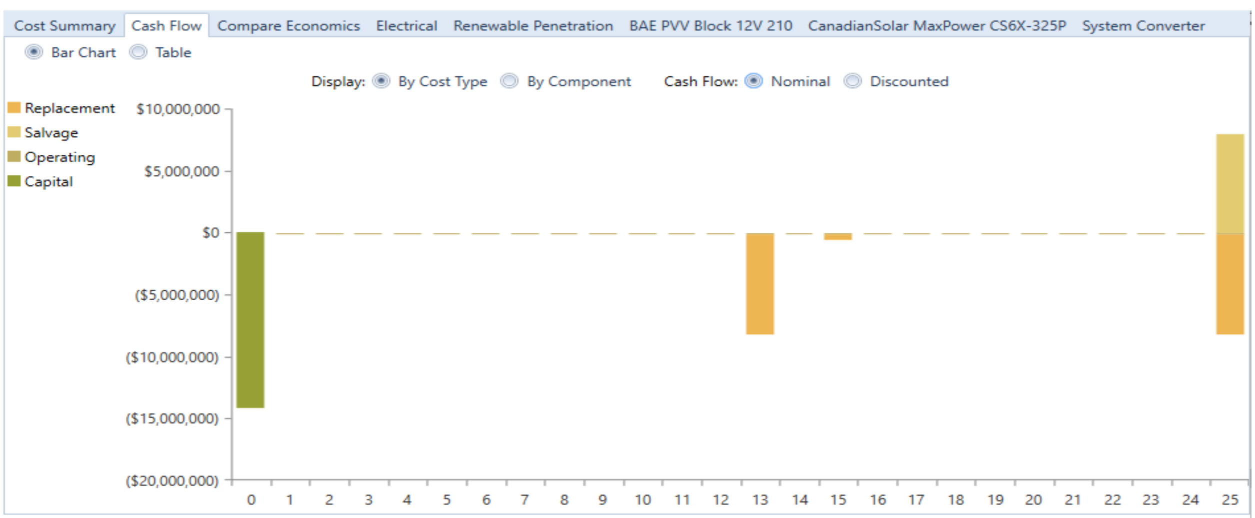


Figure 25: Cashflow summary of the system

The figure above shows that it is observed that the system has high investment cost in the initial year followed by replacement cost in year 13, 15 and 25. Replacement cost in the year 13 and 25 reflects battery replacement in the system and in the year 15 reflects inverter replacement.

4.1.1 Electrical Simulation results

The system has only ac primary load with a total of 8766878kWh/year. The excess of electricity amounts to 13703001 kWh/year which accounts for 59.1%. This shows that the battery system is highly oversized. The unmet load of the system amounts to 1286 kWh/year which accounts for 0.015% and a capacity shortage of 8678 kWh/year which accounts for 0.099%. The renewable energy fraction of the system was 100% and maximum renewable penetration was 1814%. *Figure* shows a summary of electrical simulation results.

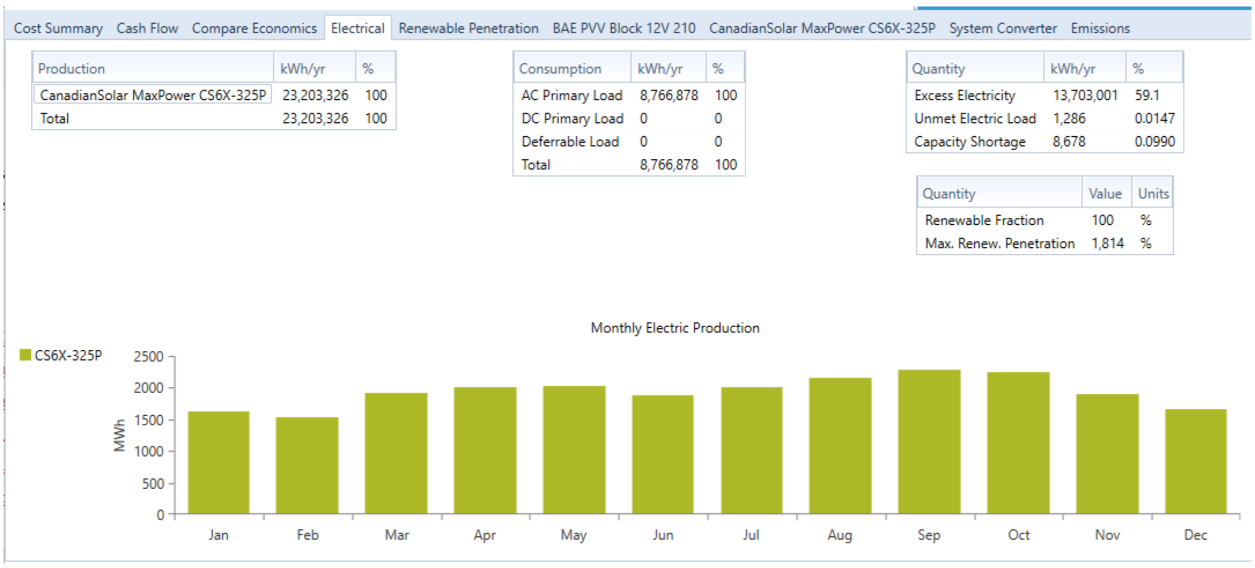


Figure 25: Summary of electrical simulation results

4.1.2 Battery system simulation results

The number of batteries required for the system was 15472 with string size of 16 batteries and 967 parallel strings. The bus voltage was 192V. The autonomy of the system was found to be 29.9 hours and the storage wear cost was at 0.261$/kWh. The nominal battery capacity of the system was at 37397 kWh and the usable nominal capacity was at 29918kWh. The lifetime throughput of the battery system was 32683053 kWh and the expected life 12.3 years. The energy input and output of the battery system were 2784523kWh/year and 2512491 kWh/year respectively. The storage depletion was at 6767kWh/year, losses at 278800kWh/year and annual throughput of 2648398 kWh/year. Figure shows simulation results for battery system.

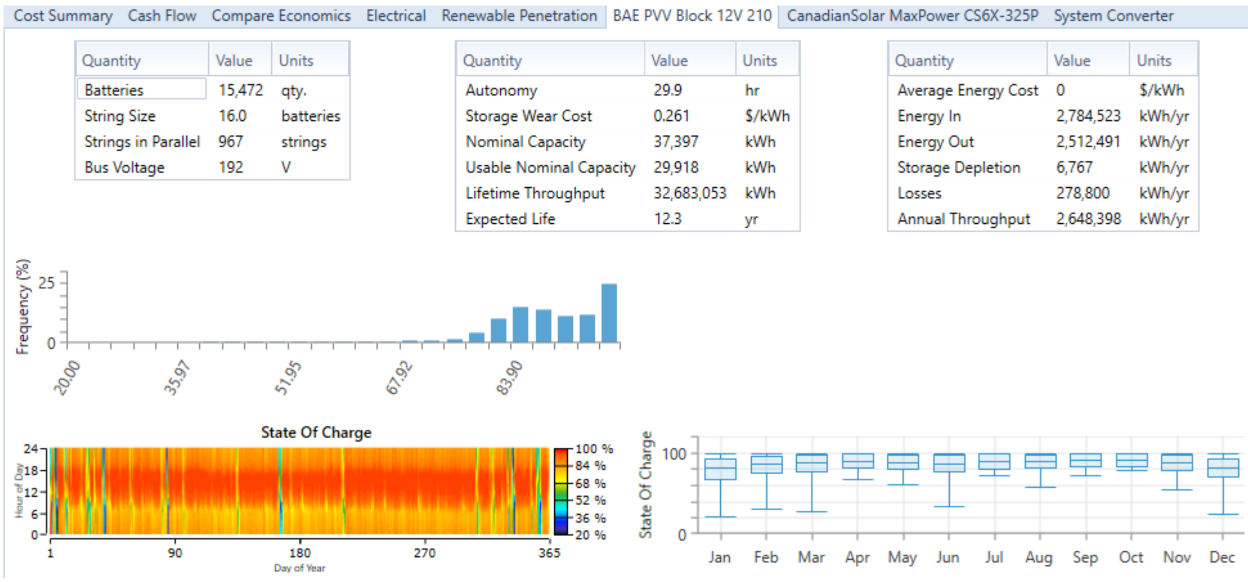
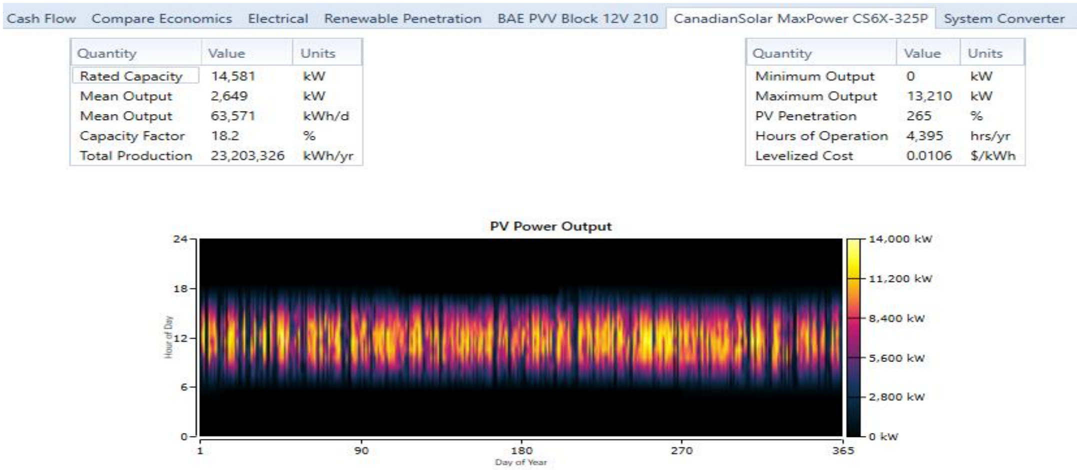


Figure 26: Simulation results for battery system

4.1.3 Solar PV simulation results

The rated capacity of the system was 14581 kW. The mean output of the system was 2649kW which translates to 63571kWh/day. The system total production was 23203326 kWh/year with a capacity factor of the system of 18.2%. The maximum output of the system was 13210 kW with PV penetration of 265%. The total hours of operation per year was 4395 hrs/year and levelized cost was 0.012$/kWh. Figure 26 shows summary of Solar PV simulation results.



Quantity	Value	Units
Rated Capacity	14,581	kW
Mean Output	2,649	kW
Mean Output	63,571	kWh/d
Capacity Factor	18.2	%
Total Production	23,203,326	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	13,210	kW
PV Penetration	265	%
Hours of Operation	4,395	hrs/yr
Levelized Cost	0.0106	$/kWh

Figure 26: Summary of Solar PV simulation results

4.1.4 Simulation results for converter

The total capacity of the converter system based on simulation was 2912kW for both inverter and rectifier. The maximum output was also 2912kW and the capacity factor was 34.4%. The total hour of operation of this inverter system was 8759 hrs/year. The total energy input for the inverter was 9228292 kWh and the energy output 8766878 kWh with losses amounting to 461415kWh/year. Figure 28 shows summary of simulations results for converter system.

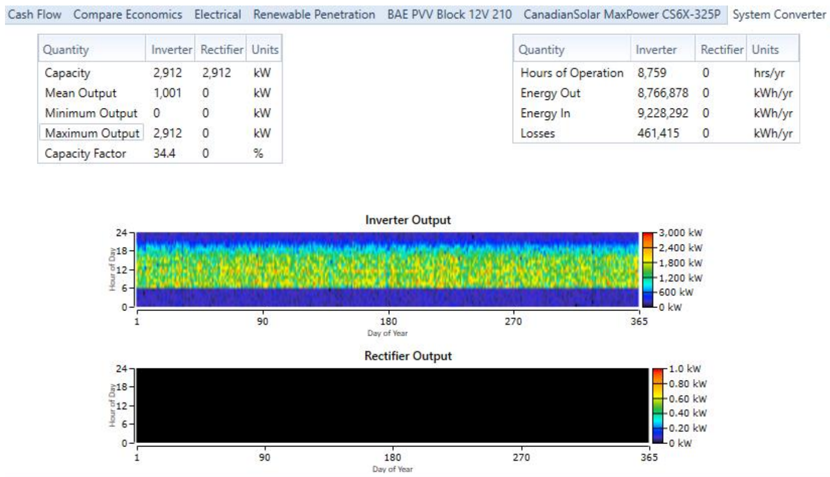


Figure 28: Simulation results for converter system

4.2 Sensitivity analysis

4.2.1 Sensitivity results for first group of variables

The first group of variables consisted of capacity shortage per year, battery capital cost, battery replacement cost, PV capital cost, PV replacement cost and load scaled down average. Details of these parameters are in Table 4 in previous section. HOMER formulate sensitivity cases and displays optimization results for each case. Figure 29 shows the first 5 sensitivity cases and overall optimization results where first 8 optimization results are displayed. The first sensitivity case is when the capacity shortage is 0%, battery capital cost multiplier is 0.5, battery replacement cost 0.5, PV capital cost multiplier is 0.5, PV replacement cost multiplier is 0.5 and load scaled down average is 24022kWh/day. First and second of the overall optimization results were similar except that the first result was load following (LF) while second result was cycle Charging.

Summary | Tables | Graphs | Calculation Report

Export... | Export All... | **Sensitivity Cases** Left Click on a sensitivity case to see its Optimization Results. | Compare Economics | Column Choices...

Capacity Shortage (%)	BAE PVV210 Replacement Cost Multiplier (*)	BAE PVV210 Capital Cost Multiplier (*)	CS6X-325P Replacement Cost Multiplier (*)	CS6X-325P Capital Cost Multiplier (*)	Electric Load #1 Scaled Average (kWh/d)	CS6X-325P (kW)
0	0.500	0.500	0.500	0.500	24,022	14,486
0	1.50	0.500	0.500	0.500	24,022	17,018
0	1.00	0.500	0.500	0.500	24,022	16,080
0	0.500	1.50	0.500	0.500	24,022	28,858
0	1.50	1.50	0.500	0.500	24,022	28,526

Export... | **Optimization Results** Left Double Click on a particular system to see its detailed Simulation Results. | Categorized | Overall

Architecture				Cost					System		
CS6X-325P (kW)	BAE PVV210	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	O&M ($/yr)	Ren Frac (%)	Total Fuel (L/yr)	C (kg
14,486	15,632	2,903	LF	$11.7M	$0.0740	$213,037	$7.89M	$36,000	100	0	0
14,486	15,632	2,903	CC	$11.7M	$0.0740	$213,037	$7.89M	$36,000	100	0	0
14,090	15,712	2,953	LF	$11.7M	$0.0741	$215,098	$7.86M	$36,000	100	0	0
14,090	15,712	2,953	CC	$11.7M	$0.0741	$215,098	$7.86M	$36,000	100	0	0
14,489	15,472	2,952	LF	$11.8M	$0.0741	$215,232	$7.86M	$36,000	100	0	0
14,489	15,472	2,952	CC	$11.8M	$0.0741	$215,232	$7.86M	$36,000	100	0	0
14,843	15,376	2,938	LF	$11.8M	$0.0741	$213,969	$7.88M	$36,000	100	0	0
14,843	15,376	2,938	CC	$11.8M	$0.0741	$213,969	$7.88M	$36,000	100	0	0

Figure 29: Sensitivity cases and overall optimization results

When results are categorized with the same sensitivity cases, only one sensitivity case was displayed. The displayed result is the cycle charging with 14486 kW PV panels, 15632 Batteries and 2902kW converter. The Net present Cost of this System (NPC) was $11744020, the Levelized COE was $0.074, and the operating cost was $213036. The system requires an initial capital cost of $7890000 and the operation and Management cost was $36000. Figure 30 shows categorized optimization results.

Export... | **Optimization Results** Left Double Click on a particular system to see its detailed Simulation Results. | Categorized | Overall

Architecture				Cost					System		
CS6X-325P (kW)	BAE PVV210	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	O&M ($/yr)	Ren Frac (%)	Total Fuel (L/yr)	CO_2 (kg/yr
14,486	15,632	2,903	CC	$11.7M	$0.0740	$213,037	$7.89M	$36,000	100	0	0

Figure 30: Categorized optimization results.

4.2.2 Effects of sensitivity parameters on Net Present Cost

Spider plots were used to display the effects of sensitivity parameters on the total net present cost of the system. The results of this simulation are shown in the figure 31.

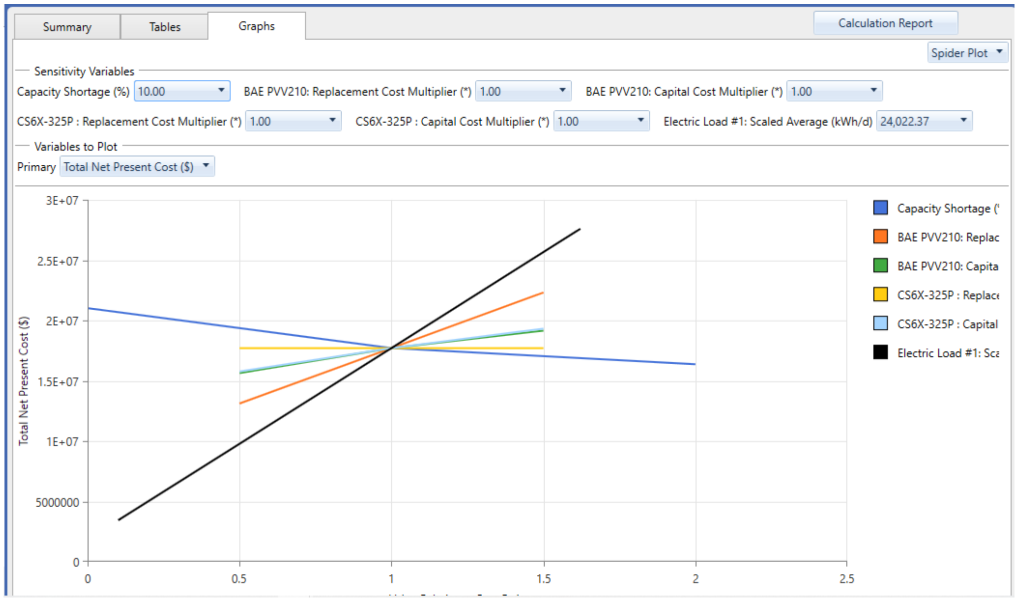


Figure 31: Spider plot for effects of sensitivity parameters on total net present cost

From the spider plot, it can be seen that the net present cost is highly affected by the load scaled down average and less affected by PV replacement cost. Increase in the load scaled down average increases the total net present cost. At a load scaled down average of 24022.37 kW/d the total net present cost was $17701660. Increasing the load scaled average to 38950.56 kWh/d increases the net present cost to $27592950 and reducing it to 2424.25kWh/d reduces the net present cost to $3435209. Further increase (or decrease) increases (or decreases) the net present cost by a significant amount. Another parameter that affects the total net present cost of the system is the battery replacement cost. Increasing the battery replacement cost by a factor of 0.5 (from 1 to 1.5) increases the cost from around $17701660 to $22311550.00 and a decrease by 0.5 decreases the total net present cost to around $13108780. Battery capital cost and PV capital cost has almost similar effect. An increase in battery capital cost with a scale factor of 0.5 will increase the net present cost from almost $17701660 to $19152850 and a decrease by a factor of 0.5 from a factor of 1 decreases the cost to around $15634860. An increase of PV capital cost by a factor of 0.5 will increase the net present cost from almost $17701660 to $19316140 and a decrease by a factor of 0.5 from a factor of 1 decreases the cost to around $15768170. The capacity shortage decreases the net present cost. An increase in capacity shortage from 10% to 20% reduces the total NPC from $17701660 to $16366790 and a decrease in the capacity shortage to 0% increase the cost from $17701660 to $21015316.62. The PV replacement cost had no effect on the system.

4.2.3 Effects of sensitivity parameters on capital cost

The spider plot it shows that total capital cost is mostly affected by load scaled average battery capital cost and PV capital cost. Battery replacement cost and PV replacement cost have no impact on total capital cost. Figure 32 shows the spider plot for effects of sensitivity parameters on capital cost.

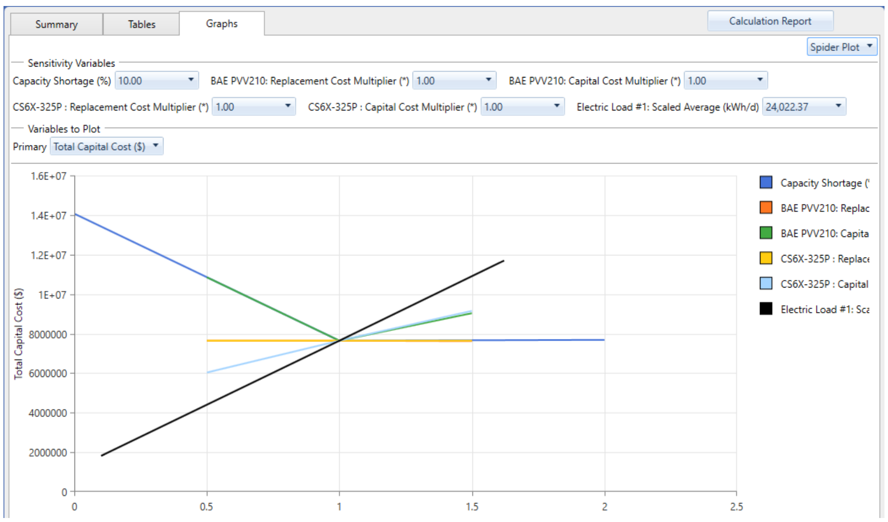


***Figure 32**: Effects of sensitivity parameters on capital cost.*

Increasing the load scaled average to 38950.56 kWh/day increases total capital cost from $7640429.04 to $11692055.06 and decreasing load scaled down average to 2424.25Kwh/d reduces the total capital cost from $7640429.04 to $1811703.40. Increasing battery capital cost by a factor of 0.5 to make it 1.5 increases the total capital cost from $7640429.04 to $9032297.10 and reducing it by a factor of 0.5 increases it to around $108463026.47. For PV capital cost, increasing capital cost by 0.5 increases the total capital cost from $7640429.04 to $9147786.86 and reducing it by a factor of 0.5 reduces the total capital cost to $6028859.79. Increasing capacity shortage from 10% to 20% changes total capital cost from $7640429.04 to $7684224.72. reducing it from 10% to 0% changes it to $14064199.04.

4.2.4 Effects of sensitivity parameters on total operating cost

Based on the spider plot parameters that has high impact on total operating cost are load, capital cost and battery replacement cost. Figure 33 shows the effects of sensitivity parameters on total operating cost.

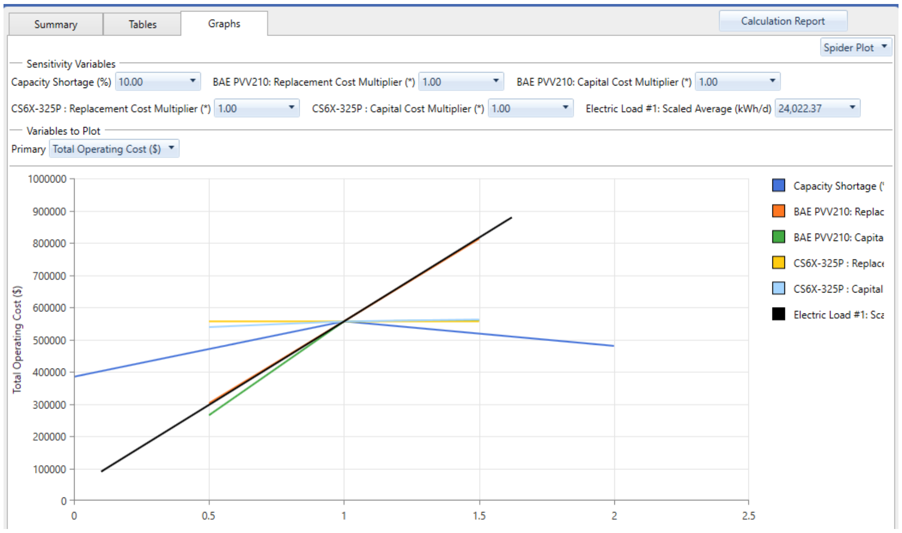


***Figure 33**: Effects of sensitivity parameters on operating cost*

Increasing battery capital cost by 0.5 that is from 1 to 1.5 increases operation cost from $556007.10 to $810000 and decreases to $264626.60. Increasing load scaled average increases operating cost. Increasing the load scale average from 24022.37kWh/d increases operating cost from $556007.10 to $878720.50 decreasing it to $89718.67 Increasing battery replacement cost by the factor of 0.5 from 1 to make it 1.5 increases the total operating cost from $556007.10 to $ 559285.10 and reducing their cost by a factor of 0.5 from 1 it will reduce the total operating cost to $301989.10. On capacity shortage, increasing the capacity shortage from 10% to 20% changes the operating cost from $556007.10 to $479818.80 and reducing it to 0% it changes to $384134.80. PV capital increase by a factor of 0.5 increases the operating cost from $556007 to $561926.70 and reducing it by a factor of 0.5 reduces it to $538216.80. PV replacement cost have no significant effect in total operating cost.

4.2.5 Effects of sensitivity parameters on LCOE

The parameters that have more impact on cost of energy are load and battery replacement cost and the minimum impact is observed on PV replacement cost. Figure 34 shows spider plot for effects of sensitivity parameters on LCOE.

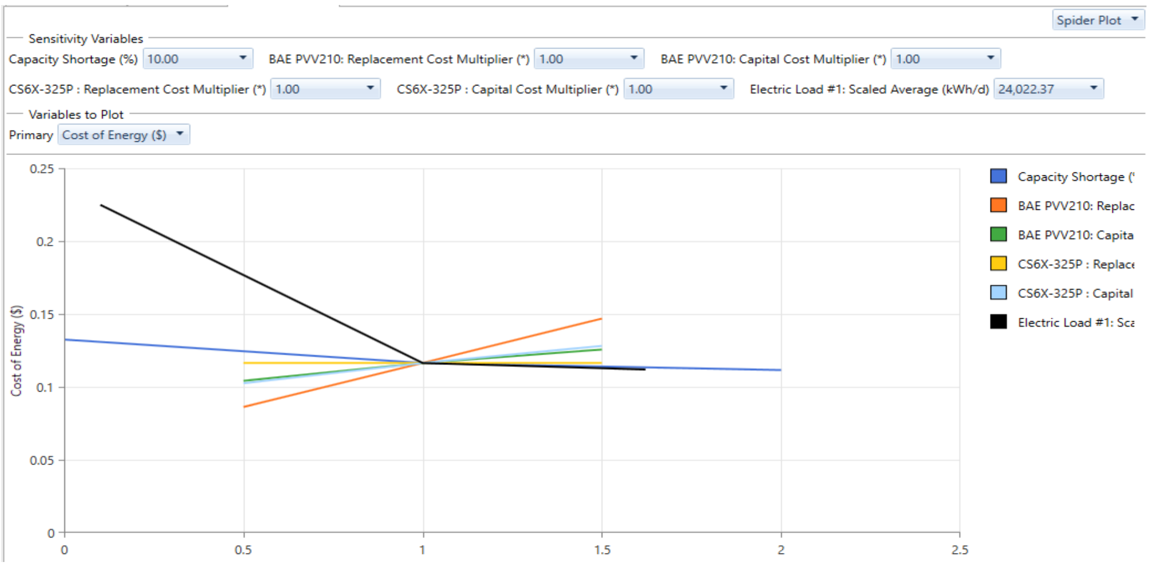
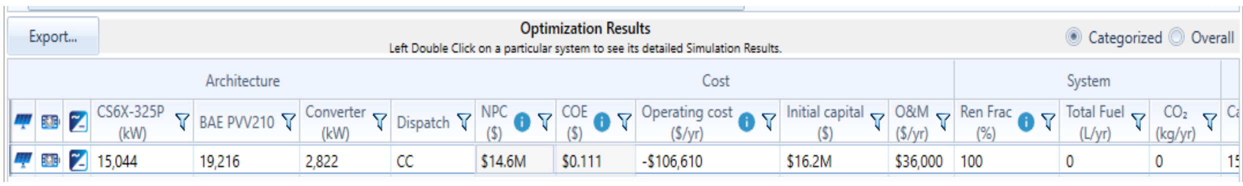


***Figure 34**: Effects of sensitivity parameters on LCOE.*

Increasing the load scaled average decreases the cost of energy. This is demonstrated by an increase in the cost of Energy as the load scaled average is reduced from a scale factor 1. There was also a slight decrease in energy cost when increasing the load after a scale factor of 1. Increasing load scaled average from 2424.25 to 24022.37 reduces cost of energy from 0.2249/ kWh to $0.1164/kWh. further increase of the load to 38950.56 kWh/d reduces it further to $0.1119/kWh. Increase in battery cost also affects the cost of energy. Increasing the replacement cost of battery by a factor of 0.5 from 1 to make it 1.5 increases the cost of energy from around $0.1164 to $0.1469. Reducing the battery replacement cost by factor of 0.5 will reduce the cost of energy from $0.1164 to $0.08620. battery capital cost and PV capital cost has almost similar effect. Increase in their cost increases the cost of energy. Increasing their cost by a factor of from 1 by 0.5 to reach 1.5 increases the cost from around $0.1164 to $0.1256 and $0.1281/kWh respectively while reducing it by a factor of 0.5 reduces it from $0.1164/kWh to $0.1042 and $0.1025/kWh respectively. capacity shortage also affects the cost of energy. Increasing the capacity shortage from 0% to 10% reduces the cost of energy from \$0.1325/kWh to \$0.1164/kWh and increasing the capacity shortage to 20% reduces the cost of energy further to \$1116/kWh. PV replacement cost do not have any effect on cost of energy.

4.3 Sensitivity results for second group of parameters

Second group of sensitivity parameters used in this paper consist of nominal discount rate, expected inflation rate, project lifetime and system capital cost. The categorized results for these parameters are PV system 15044kWh, number of batteries 19216, converter 2822. The net present cost \$14627740, cost of energy \$0.1112, operating cost -\$106610 and initial capital cost of \$16226898.18. Figure 35 shows categorized results for optimization with second group of parameters.



Export... | Optimization Results | Left Double Click on a particular system to see its detailed Simulation Results. | Categorized | Overall

Architecture				Cost					System		
CS6X-325P (kW)	BAE PVV210	Converter (kW)	Dispatch	NPC (\$)	COE (\$)	Operating cost (\$/yr)	Initial capital (\$)	O&M (\$/yr)	Ren Frac (%)	Total Fuel (L/yr)	CO_2 (kg/yr)
15,044	19,216	2,822	CC	\$14.6M	\$0.111	-\$106,610	\$16.2M	\$36,000	100	0	0

Figure 35: Categorized Results for optimization

Details of the effects of these parameters are net present cost, total capital cost, operating cost and cost of energy are explained below.

4.3.1 Effects on the net present cost

The parameter which has high impact on net present cost was project lifetime. Increase in project life time increases the project net present cost. Nominal discount rate also affects net present value. Increasing nominal discount rate from 0% will increase net present cost and it will reach a maximum. Further increase of the discount rate from the maximum point will result in decrease in net present cost. Expected inflation rate had almost similar effects on net present cost. Increasing expected inflation rate from 0% will increase net present cost and it will reach a maximum and then any increase will result in decreasing of the netpresent cost .another factor is fixed capital cost of the system increase capital cost of the system increases the net present cost of thesystem but magnitude is lower than other factors. Figure 36 shows effects of sensinsitivity parameters on total net presnt cost.

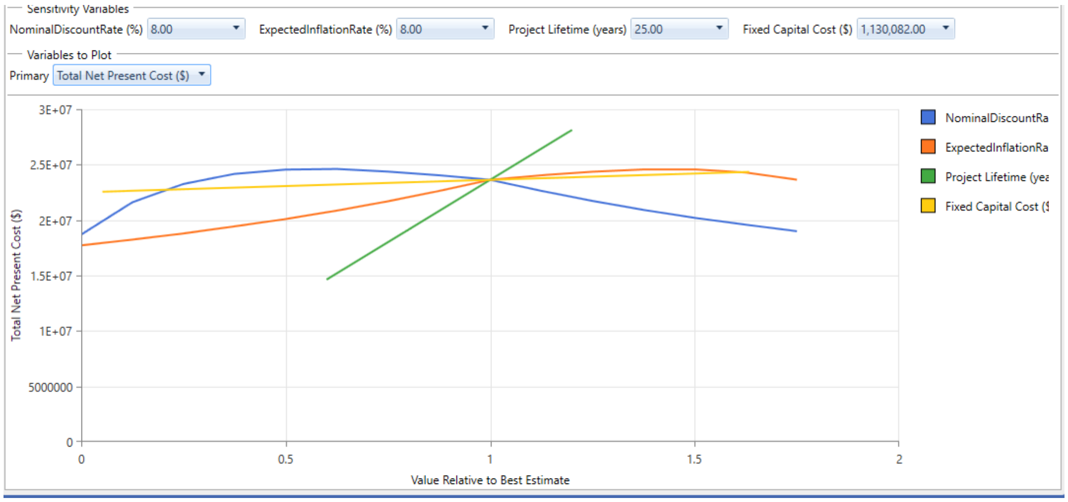


Figure 36: Effects of sensinsitivity parameters on total net presnt cost.

4.3.2 Effect on Total capital cost

The overall effect of expected inflation on capital cost is that it increases as the inflation is increasing from 0% going up. But there somepoints points where the change was minimal or constant. On nominal discount rate, the overall effect of increasing nominal discount rate from 0% going up is the decrease in the total capital cost. However the rateof decrease changes from point to point. For fixed capital cost, Increasing fixed capital cost increases the total capital cost of the system. The increase in project lifetime has no significant impact on total capital cost. Figure 37 shows a spider plot for effects sensitivity parameters on capital cost.

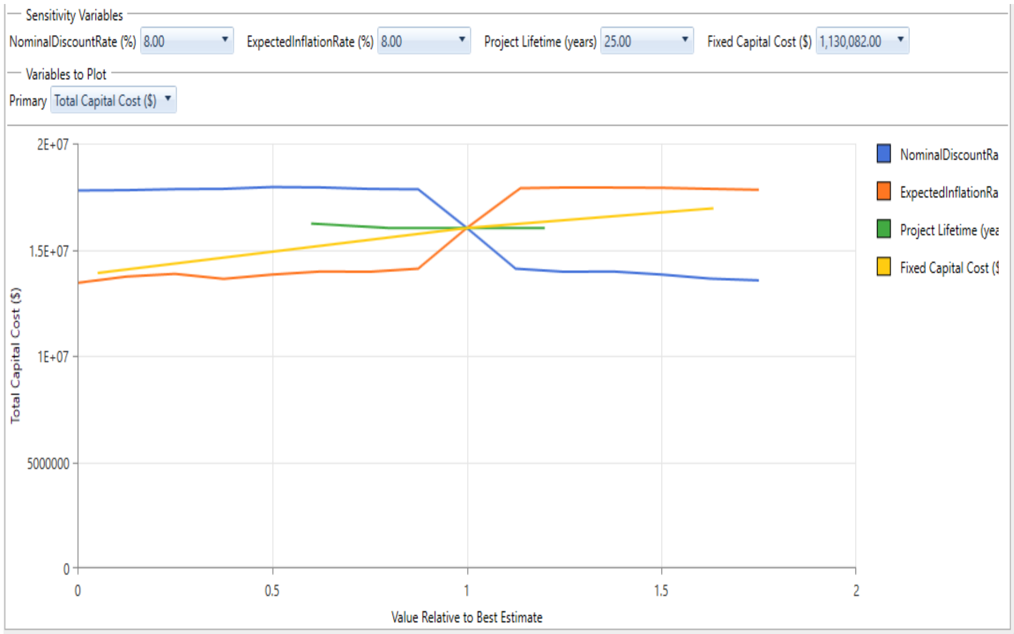


Figure 37: Effects sensitivity parameters on capital cost.

4.3.3 Effects of sensitivity parameters on total operating cost

Project lifetime is the parameter that has more effect on total operating cost than to other parameters and fixed capital cost has less effect on thetotal operating cost. Figure 38 shows the effect of sensitivity parameters on total operating cost.

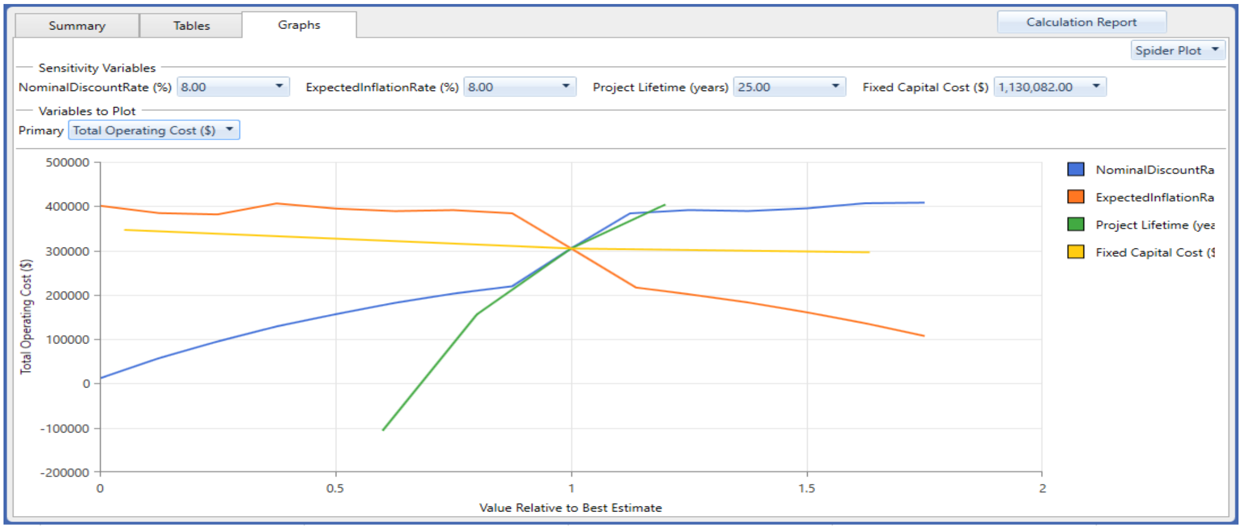


Figure 38: Effects of sensitivity parameters on total operating cost.

Increase in project life time increases the total operating cost. On expexted inflation rate, the overal effect of increasing the inflation rate is the decrease in thetotal operating cost. Increasing the nominal discount rate has the overall effect of increasing the total Operating cost. Increasing fixed capital cost reduces the total operational cost but the effectis less compared to other parameters.

4.3.4 Effects of sensitivity parameters on cost of energy

Nominal discount rate and expected inflation rate have more impact on the cost of energy while project life time and fixed capital cost have very little impact on the cost of energy. Figure 39 shows effects of sensitivity parameters on cost of energy.

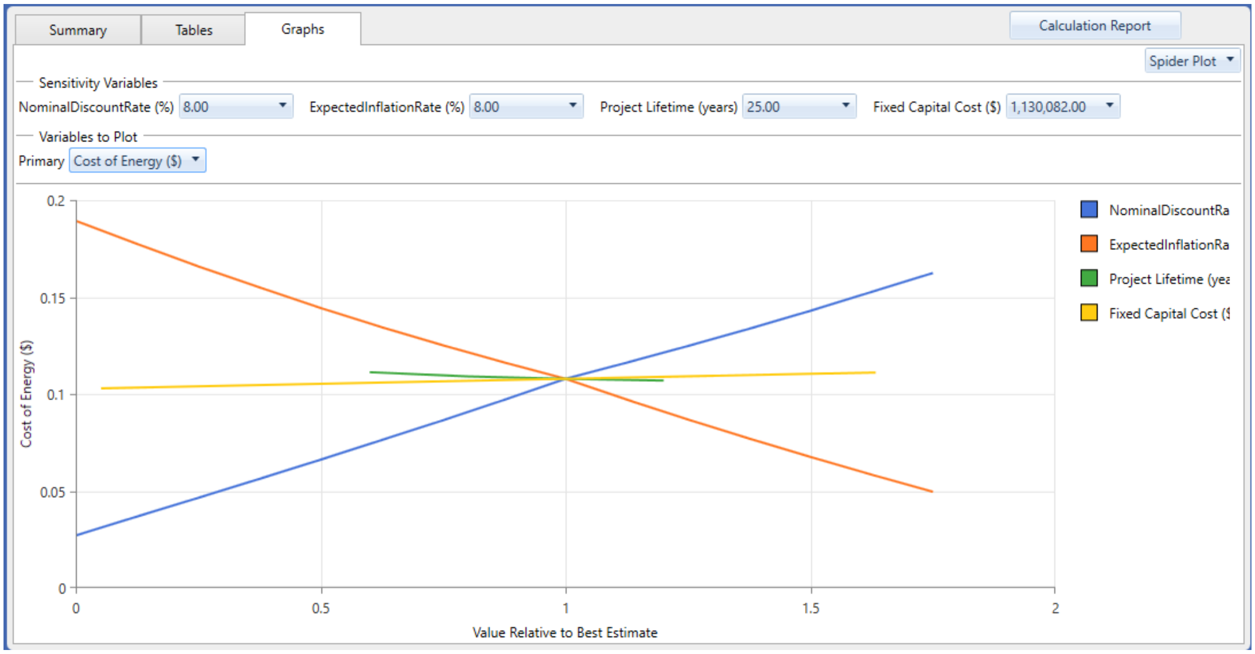


Figure 39: Effects of sensitivity parameters on cost of energy.

Increasing the nominal discount rate increases the cost of energy. On the other hand, increasing expected infltion rate decreases the cost of enrgy. Increasing the fixed capital cost increases the energy cost but the increase is less significant the above parameters. The impact of project life time on cost of energy is not significant aswell.

4.4 Energy use and Social Economic Indicators of Matekenya Village

This section contains the results that indicate the economic potetiontial for the village, their current energy use and their willingness to pay. The village had around 200 households, a secondary school, a primary school, a health post and a market which has shops and some productive use of electricity. 96 questionaires where adiministered. Out of 96 questionnaires 95 were adiministered per structure or household. The structures assessed were located where most economic activitiess take place in the village. Most of the structures assessed were being used as houses which respresent 54.2% of the structures followed by structures that were beinng used as houses and shop with with 15.6%, and 8.3% shops respectively. ***Table 6*** shows more details onstructures that were assessed.

***Table 6*: Structures assessed**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	1.0	1.0	1.0
	Bar and house	3	3.1	3.1	4.2
	Barbershop	1	1.0	1.0	5.2
	CCAP Church	1	1.0	1.0	6.3
	Girls hostel	1	1.0	1.0	7.3
	Health Post	1	1.0	1.0	8.3
	House	52	54.2	54.2	62.5
	House and shop	1	1.0	1.0	63.5
	Maize mill	1	1.0	1.0	64.6
	Pastors house	1	1.0	1.0	65.6
	Primary School block 1	1	1.0	1.0	66.7
	Primary School block 2	1	1.0	1.0	67.7
	Primary School block 3	1	1.0	1.0	68.8
	Primary School block 4	1	1.0	1.0	69.8
	Primary School office	1	1.0	1.0	70.8
	Secondary School Administration block	1	1.0	1.0	71.9
	Secondary School block 1	1	1.0	1.0	72.9
	Secondary School block 2	1	1.0	1.0	74.0
	Secondary School laboratory	1	1.0	1.0	75.0
	Shop	8	8.3	8.3	83.3
	Shop and house	15	15.6	15.6	99.0
	Water tank	1	1.0	1.0	100.0
	Total	96	100.0	100.0	

4.4.1 Current sources of energy

The sources of energy that were being used were assessed to find out potential competitor of the mini-grid. The results showed that most people use solar PV for lighting and wood for cooking. In this case the term solar PV may range from Pico lights to home systems. **Table 7** shows energy sources that are already in use in the area.

Table 7: Current sources of energy

The current source of energy in use					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Batteries	25	15.4	15.4	15.4
	Candles	3	1.9	1.9	17.3
	Candles and batteries	1	.6	.6	17.9
	Charcoal	18	11.1	11.1	29.0
	Charcoal and wood	9	5.6	5.6	34.6
	Diesel	1	.6	.6	35.2
	Solar PV	59	36.4	36.4	71.6
	Solar PV and candle	1	.6	.6	72.2
	Wood	45	27.8	27.8	100.0
	Total	162	100.0	100.0	

The Average expenditure on current sources of energy was MWK9190.19 (11.24 USD). with a standard deviation of 7105.28 knowing expenditure will also help to assess ability to pay of the respondents.

4.4.2 Ability to pay

Ability to pay was also be assessed by knowing disposable income. Amount of airtime used is one of ways of determining disposable income. The results of this study showed that the average monthly expenditure on airtime is MWK5056 (6.18 USD). Table 8 shows results for monthly expenditure on airtime

Table 8: Results for monthly expenditure on airtime

Report		
Monthly expenditure on airtime		
Mean	N	Std. Deviation
5050.56	89	5730.23

4.4.3 Willingness to be connected and willingness to pay

Almost all respondents showed interest to be connected if there can have a chance to be supplied with electricity. **Table 9** shows the results of willingness to be connected.

Table 9: Results of willingness to be connected

willingness to be connected					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	1.0	1.0	1.0
	Yes	95	99.0	99.0	100.0
	Total	96	100.0	100.0	

Respondents were asked to mention the amount they are willing to monthly once the connected. The results for willingness to pay showed that people are willing to pay MWK 9200/Month (11.25 US$/month) on average. **Table 10** shows the results of willingness to pay.

Table 10: Results of willingness to pay

Report		
willingness to pay		
Mean	N	Std. Deviation
9200.00	85	12654.33

CHAPTER 5: CONCLUSION AND RECOMMENDATION

The aim of this document was to find out if it was technically and economically feasible to use solar PV mini-grid to supply electricity to Matekenya Village. In order to achieve this; electricity needs for Matekenya were determined, the solar resource for the area was assessed, the sizes of the system component required and their cost were determined, and the system optimization done with and without sensitivity variables. The results of optimization without sensitivity variable and with sensitivity variables were both taken into consideration.

Optimization results with no sensitivity variable were as follows: the net present cost of the system (NPC) was found to be $21170640. Levelized cost of energy (LCOE) was found to be $0.13. The operating cost was at $380215.40. The initial capital cost and operation and management cost were $14290444.84 and $36000 respectively. Based on the Malawi feed-in tariff policy [29] the feed-in tariff for solar PV energy into the grid is $0.10/kWh which means that the LCOE is higher than the feed-in tariff. Despite having the LOCE higher than the feed-in tariff, the average electricity rate for Malawi is $0.13/kWh. This makes the system cost-competitive for implementation if other system parameters remain constant. However, the Investment and NPV cost for this system are too high.

Optimization results with sensitivity analysis showed that The Net present Cost (NPC) was $11744020, Levelized COE was $0.074, and the operating cost was $213036. The system required initial capital cost was $7890000 and the operation and Management cost was $36000. This system is more economical than the one without sensitivity variable.

From the results it can be seen that it is technically and economically feasible to use solar PV to supply electricity to Matekenya village. The village also has a high potential for productive use of electricity and as well as a willingness to be connected.

RECOMMENDATION

- The analysis used in this study did not consider energy efficiency measures that can help to reduce the load and make the system more economical. Therefore, for implementation purpose it will be recommended to consider that.

- To address the system's high investment cost, it is recommended to start with smaller system when implementing the PV system.

Future Scope

- Since the study area has shown interest in the project through their willingness to be connected, a study on best financing mechanism for Min-grid in the area should be conducted.
- The detailed design for the site should be produced for further implementation of the project

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APENDICES

Appendix 1: Time Frame

Activity	**Dates**	Month													
		June			**July**				**August**				**September**		
		Wk1	Wk2	Wk3	Wk4	Wk1	Wk2	Wk3	Wk4	Wk1	Wk2	Wk3	Wk4	Wk1	W
Finalising questionnaire and testing survey tool	1-20														
Data collection	21-30														
Data analysis	1-21														
Writing report	22-31														
Publication of paper	16-31														
presentation	1-31														

Appendix 2: Questionnaire

Questionnaire for Matekenya Solar PV mini-grid feasibility assessment

Respondent details

Respondent serial number

Part 1: For Village headman

What is the population of this area?

Name

Gender

- ◯ Male
- ◯ Female

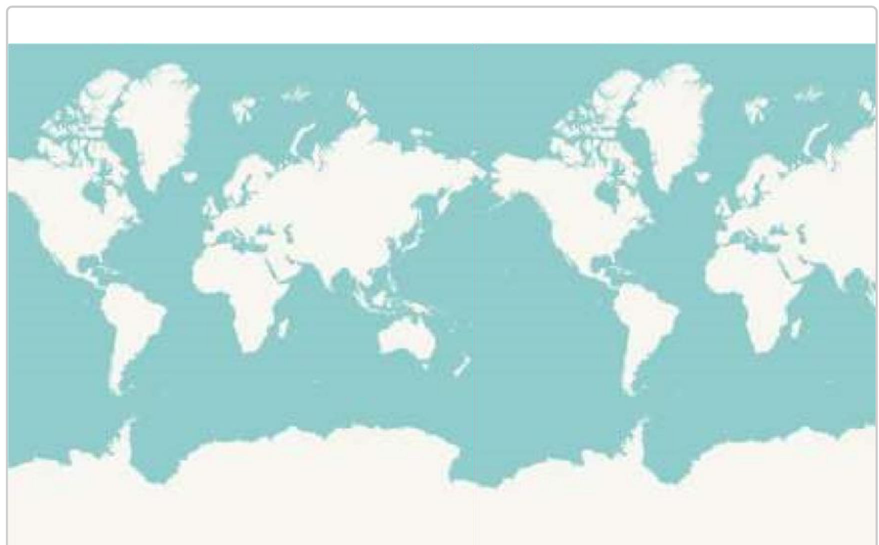
GPS Coordinate

latitude (x.y °)

longitude (x.y °)

altitude (m)

accuracy (m)



Employment

Occupation sector

1

What is your role in this area?

- ◉ Village headman
- ◯ Community Member

What is the number of Households in this area?

64

How many public institutions do you have in this area? e.g., Schools, health centers etc.

What are economic activities that most people in this area are mostly involved in?

Part 2: For households

What is the use of structure being assessed? E.g. shop

What are materials used for construction?

- Ceramic bricks - Iron sheets
- Ceramic bricks-Grass thatched
- Mud bricks-Iron sheets
- Mudbricks-Grass thatched
- Others

The following section will be on current source of energy each source will be addressed separately 1

» Current source of Energy

What is the current source of energy you are using?

How long do you use this energy source per day?

How much money do you spend on this source of energy per month?

How much do you spend on monthly basis for charging your cell phones? (if he or she is not sure it will be broken down as follows; how many times do you charge your phone per week? How much do you pay per charging cycle?)

How much do you spend for airtime per month? 2

If there is a project to supply electricity to you, are you willing to be connected?

- ○ Yes
- ○ No

How much are you willing to pay for electricity once you get connected?

The following section will be on load assessment each appliance will be completed before going to next

» Load Assessment

What are the appliances that you have or would like to have that uses or will be using electricity?

What is the power rating of the appliance mentioned?

How long do you use or will you be using that appliance during day time?

how long do you use or will you be using that appliance during Night time?

What are the appliances that you have or would like to have that uses or will be using electricity?

What is the power rating of the appliance mentioned?

How long do you use or will you be using that appliance during day time?

how long do you use or will you be using that appliance during Night time?