



METTU UNIVERSITY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

# Load Assessments and Design of Solar Power System for Rural Electrification (Case Study of Hula ARBA Village)

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## Abstract

The energy from the sun can be used to win the energy shortage generated by the scarcity of other resources of energy. Solar energy is green, free and found everywhere over the world. In addition to overcome the crisis happen due to shortage of generated power, solar power reduces the green house impact on the environment because it is clean energy. Not only this its operation period is also long and operation and maintenance cost is minimum once it is installed.

This paper presents the load demand assessment of the rural area and designing of the solar power capacity that can generate the amount of power assessed from the house hold of the village. The methodology of the paper has been done by knowing the number house hold in the village then and asking their plan what they want to use if they electrified. Then depending on their plan the rating of the electric device rating is identified and the load is determined. Thus, Load demand assessment shows that the amount power required by the village is 25274KWh per day including five years forecast.

The most important elements of solar power system that designed in this paper are Solar panel, charge controller, Battery bank and Converter. According to this design the number of the solar panel, charge controller, battery bank and converter needed to produce or generate the required power are 20155, 20162, 87752 and 3761 respectively. Lastly the designed solar system simulated on homer software to see that whether the amount power generated and demand of the customer meet each other. In this paper the implementation and cost analysis of the project is assumed to be the next phase as it is expressed under specific objectives.

**Keywords:** - *Solar system, Solar panel, Charge controller, Battery, Converter, Homer.*

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**List of Abbreviations**

PV	Photo Voltaic
DC	Direct Current
AC	Alternating Current
SA	Stand Alone
UI	Utility Interactive
KM	Kilo Meter
N	North
E	East
W	Watt
MW	Mega Watt
KW	Kilo Watt
Wh	Watt hour
KWh	Kilo Watt hour
MWh	Mega Watt hour
$P_t$	Total Power
$P_{es}$	Power Rating of Electric Stove
AM	Anti-Meridian
PM	Past –Meridian
PWM	Pulse Width Modulation
MPPT	Maximum Power Point Tracker
A	Ampere
V	Volt
DOD	Depth of discharge
DOA	Day of Autonomy
Ah	Ampere hour
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background

Solar energy is one of the primary sources of clean, present in a great quantity and inexhaustible energy that not only provides alternative energy resources, but also improves environmental pollution. Nowadays, the trend of using the solar energy is exponentially increasing and the focus for this type of clean energy and to transfer to electrical power has been interesting since it avoids the state of being polluted which may happen with other source of energy. [3]

The two main category of solar energy include active solar energy and passive solar energy. Active solar energy involves equipment or an action to convert solar energy into a useful form. One example of active solar energy is the use of solar cells to convert energy from the sun into electrical energy that can be used in the home. Passive solar energy does not require any specific action or equipment. An example of passive solar energy is with regard to strategy placing windows in a home to permit sunlight to enter and provide heat.

The energy from the sun can be used to overcome the energy crisis generated by the scarcity of Fossil fuel resources. Solar energy is free and everywhere. Due to the decreasing of solar photovoltaic energy cost, it's superior in the renewable energy sources and widely utilized in many countries.

There are two ways of solar tracking, namely Single axis and Dual axis solar tracking systems. When tracking the sun, it is noted that the direction of the sun, as seen by the solar panel, will differ in two directions.

The azimuth angle is the horizontal oriented angle from the observer to sun, while the zenith or altitude angle represents the vertical oriented angle from the observer to the sun.

The horizontal direction is used for single axis solar tracker while the combination of the horizontal and vertical directions is referred to as two axis or dual axis solar trackers [1].

The purpose of a solar tracker is to accurately determine the state of the sun. This enables solar panels interfaced to the tracker to obtain the maximum solar radiation. With this particular solar tracker a closed-loop system was made consisting of an electrical system and a mechanical system with the assistance of electronics.

Solar energy is the solar radiation that reaches the earth which is then being converted to electrical Power through distinct strategies. Solar buildings generally utilize solar PV panels to produce electricity. Solar PV panels produce direct current (DC) electric power when exposed to sun light, and a DC-AC converter normally converts DC to AC power, which is the conventional form of the electric power in a typical building. Using DC electric power directly from solar PV panels is a somewhat challenging as most of the electric appliances are functioning using an AC power [20].

## 1.2 Statement of the problem

With the rapid increase in population and economic development, the problems of the energy insufficiency with demand of the customer and global warming effects are today a cause for increasing concern. The utilization of replaceable energy resources is the key solution to solve these problems.

In present day the emerging technology of the renewable energy source is more preferable than non-renewable source and it reduces the problem of greenhouse effect which is the great problem of our planet. So developing of such green energy source in different part of the world may overcome such problems.

Ethiopia is one of the countries developing in high rate. This development has direct relationship with energy. Thus designing of green energy source such as solar, wind, geothermal and the like used to reduce the shortage of the electric supply.

As this country developing the energy demand of the community increases day to day and the supply capacity of the Ethiopian Electric power did not much demand. To reduce the supply demand imbalance designing of such renewable energy is useful for isolated and integrated areas.

In this paper the assessment of the load demands of the proposed village and designing of Solar System which applicable for off grid will be discussed.



### **1.3 Objectives**

#### **1.3.1 General Objective**

The general objectives of this paper are to Load Assessment and Design of solar system for rural electrification.

#### **1.3.2 Specific objectives**

- Assessing energy demand of proposed village
- Designing of proposed Solar system (Each part of solar system)
- Simulation of designed system
- Cost Analysis and Implementation (this second phase of this project)

### **1.4 Scope**

The scope of the project is up to simulation using homer software for the first phase and followed by implementation for the second phase.

## CHAPTER TWO

### LITERATURE REVIEW

The sun gives the energy to manage continuity of life in our solar system. In 60 minutes, the earth gets enough energy from the sun to meet its energy requirement for about a year. Gathering solar energy to control electrical machines begins by altering the energy from the sun to power. Solar PV is the direct transformation of solar energy into power. PV systems can be utilized to utilize the solar energy in all applications and with fossil fuel assets and the truth that they are going to be depleted this century. Today, more than 1.4 billion individuals everywhere throughout the world need access to power. To enhance access to power to the next level in the rural areas on the planet, a decentralized off-grid installations are considered in type of solar PV [10].

The photovoltaic systems are classified according to how the system components are connected to other power sources such as standalone (SA) and utility-interactive (UI) systems. In a stand-alone system depicted in Figure2.1, the system is designed to operate independent of the electric utility grid, and is generally designed and sized to supply certain DC- and/or AC electrical loads [21].

System sizing is the process of evaluating the adequate voltage and current ratings for each component of the photovoltaic system to meet the electric demand at the facility and at the same time calculating the total price of the entire system from the design phase to the fully functional system including, shipment, and labor [21].

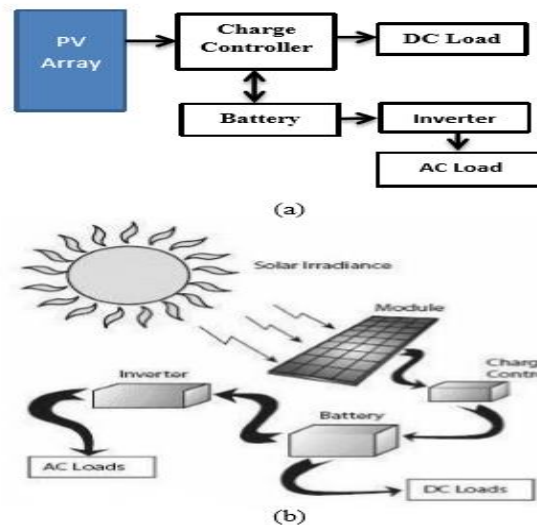


Figure 0-1 Stand-alone photovoltaic System (a) Block diagram (b) Schematic Diagram

The solar solution will need to be customized depending on the village, available materials, need, and income of the potential customer. However, in its most basic form it consists of a small solar photovoltaic panel, a charge controller to regulate the current and voltage, a storage battery (usually a lead-acid battery in distributed applications), and the load, which consists of everything in the house demanding electricity [4].

This includes lights, television, a cell phone charger, etc. It is not rocket science; rather it is a simple, basic technology that is being applied in a new small-scale way to address a need. When distributing these systems it is important to keep the needs of the customer in mind. Not all energy needs are the same, even in a community without electricity, so being open to customizing the product is a good idea. Some families will not be able to afford as large a system as others, some may have larger homes with greater lighting needs, or some may prefer to trade off less lighting for more appliances, like a television. The point is that a one-size-fits-all approach is not ideal. Before attempting to sell any systems, it is a good [4].

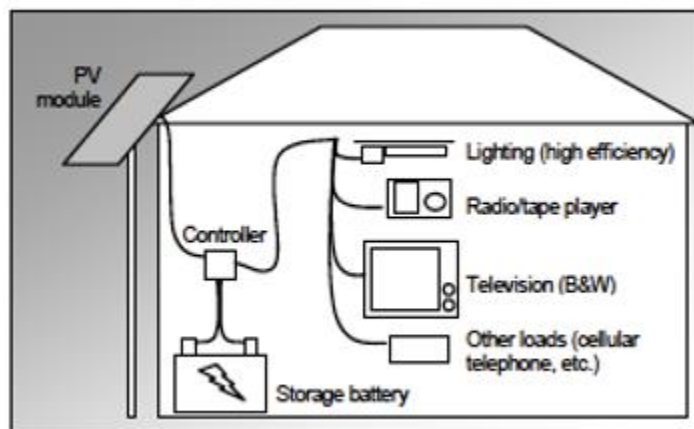


Figure 0-2 Components of a solar home system

This paper differs from the literature used in this paper, first the electric load demand of the rural village assessed and numerically determined then designing of the solar power system that can capable of the demand of the village with considering of the load increases for five years without system over loading.

## CHAPTER THREE

### METHODOLOGY

#### 3.1 Work Flowchart

The methodologies followed to accomplish this project is shown in figure 3.1

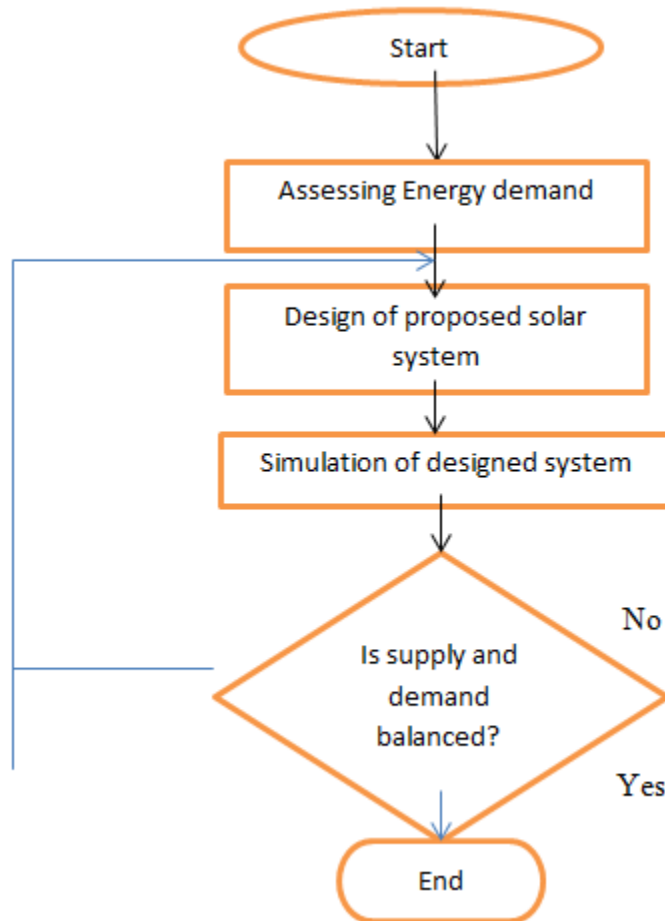


Figure 0-1 work Flow chart

#### 3.2 Energy demand Assessment

As expressed under the work flow chart section the first stage of this work is energy demand assessment. This paper presents the designing of solar system for the village that no electrified before by utility of the country. The village that going to be electrified by this design found in Ethiopia. This village (Hula Arba) is found around 200KM far from Addis Ababa and north of Assela town which is capital of Arsi zone and situated on map (8.065577544498861N, 39.06740455078125E) location.



**Figure 0-2 Location of the village to be electrified**

The number of household living in proposed village is one thousand households. As the village is going to be electrified for the first time the load type considered is domestic load like lighting, Television, Radio, refrigerator, Electric stove and oven, washing machine and Charger. In addition to this one health care center and one public school are there. Thus the total demand for which the system is designed is the sum of individual power consumption. The power rating of each electric device and that of school and health care center is shown in table 3.1.

S. No	Energy consumption devices	Rating power Watt (W)
1	Lighting bulb	18
2	Television	120
3	Radio charger	15
4	Refrigerator	300
5	Electric stove	2100
6	Electric oven	2150
7	Phone Charger	7
8	One Public school	330
9	One mosque	144
Total		

Table 3.5 Electric devices that planned to use by households

As shown in the table 3.1 the total energy demand of on site is the sum of energy consumed by each device. As the data assessed from individual household four hundred household can use all electric devices listed in table 3.1, two hundred customers uses only Lighting bulb, Television, Radio and charge, Two hundred fifty households uses all except washing machine and refrigerator and one hundred fifty uses only for lightning, radio and charger.

### 3.2.1 Load Calculation

The load calculation was done in two iterations. The first iteration was a rough load estimation to determine the minimum PV amperage needed to complete the project, so that donations of PV panels being searched for [6].

Based on-site experience and site measurements, we assumed lighting by fluorescent bulbs and a minimum of eight bulbs necessary for sufficient lighting of the school and health center [6]. Thus using these references and others load assessment of the village also calculated in this paper.

#### 3.2.1.1 Load calculation for lightening bulb

Incandescent bulbs were chosen as the dominant form of lighting for their availability in the region and low-cost. Fluorescent bulbs were chosen for their higher efficiency and longer durability [6].

The number of households living in proposed village is one thousand so the load required by lightning bulb is calculated based on this number. The rating of one florescent bulb as indicated under table 3.1 is 18W. The operating hours of this bulb per day is 12 hours because it is operate evening. Thus the total load per day is calculated as follows.

$$\text{Load per day} = \text{Rating} * \text{Number of operation hours per day}$$

$$p_l = 18w * \frac{12h}{day} = \frac{216Wh}{day}$$

The total power required by households can be found by multiplying load per day (P<sub>l</sub>) with total number of households as shown below.

$$P_{\text{total load of bulb}} = 1000 * \frac{216Wh}{day} = 216KWh/day$$

As it can be shown from calculation the load demand for lightening bulb is 216KWh per day.

### **3.2.1.2 Load calculation of Television**

The load calculation of television in this paper is based on rating of single television. According to reference [7] the rating of television is 120W. Based on this rating the total power demand of the village will be calculated as follows assuming that the operation hours 12hours of the day time plus 4hours of night time. Note this operation hours assumption may or may not be exact but it near exact because most people watch their television up to midnight.

$$P_t = 120W * 16 \frac{h}{day} = 1.92KW/day$$

The total power required by households can be found by multiplying load per day ( $P_t$ ) with total number of households as shown below.

$$P_{total\ load\ of\ television} = 1000 * 1.92KW/day = 1.92MW/day$$

Thus calculation shows that the total load required for television consumption is 1.92MW.

### **3.2.1.3 Load calculation of Radio charger**

According to the reference [9] the r rating of or electric consumption of radio charger is 15W. The operation hours per day of radio and television is similar thus the total operation hours per day of radio is assumed to be 12 hours day time plus 4 hours of night which is the time until the sleep time and gives total operation time of sixteen (16) hours per day. From the assessed load demand all customers of the village will use radio. Therefore the calculation of the load considers all customers. The electric consumption hours of the device per day is calculated as follows.

$$P_{radio} = 15W * \frac{16h}{day} = \frac{240Wh}{day}$$

According to data assessed all customers can use radio, so the total load required by the village is rating of radio multiplied by number of customers as follows.

$$P_{total\ of\ Radio} = 1000 * \frac{240Wh}{day} = \frac{0.24MWh}{day}$$

AS it can be seen from the calculation the total load required by the radio charger is 0.24MWh per day.

#### 3.2.1.4 Load calculation of Refrigerator

In similar way refrigerator load calculation will be calculated as follows. According to the reference [7] the refrigerator rating is 300W. By its operation the operation of typical refrigerator is twenty four hours per day (24hours/day).

$$P_r = 300W * \frac{24h}{day} = \frac{7.2KWh}{day}$$

According to data assessed four hundred customers can use refrigerator, so the rating of refrigerator is multiplied by number of customers as follows.

$$P_{total\ load\ of\ refrigerator} = 400 * \frac{7.2KWh}{day} = \frac{2.88MWh}{day}$$

Thus the total load required for refrigerator is 2.88MW/day.

#### 3.2.1.5 Load calculation of Electric stove

Similarly the load calculation of electric stove will be calculated as follows. According to the reference [7] the rating of typical electric stove is 2100W. The electric stove is operate for specified time of the day, let estimate morning for breakfast, midday for lunch, evening for dinner and rarely around nine o'clock to ten o'clock local time for mekses (which local word) which is the name given for the food eaten at that time. According to the tradition of that area breakfast is in between 12am and 3am local time. Thus during breakfast the possible operation time is 3hours. In similar way the lunch is in between 5am and 8pm local time. So during the lunch time operation time is 3hours. For dinner the time is from 12pm to 3pm (night). In between this time there is 3hours. For mekses there is 1hour.



Therefore the total operation of the electric stove per day is the sum of breakfast time, lunch time, dinner time and mekses which gives total of 10hour. Thus the rating of electric stove per day is calculated as follows.

$$P_{es} = 2100W * \frac{10h}{day} = \frac{21KW}{day}$$

The total power required by households can be found by multiplying rating per day ( $P_{es}$ ) with total number of households uses the electric stove. The total number of household's uses the electric stove is 650.

$$P_{total\ load\ of\ electric\ stove} = 650 * \frac{21KW}{day} = \frac{13.65MW}{day}$$

The total power required for electric stove is 13.65MW per day.

### 3.2.1.6 Load calculation of Electric oven

The electric stove is device used to make enjera which cultural food of Ethiopian. One house hold makes an enjera within an interval of two to three day. For making an enjera once it takes two to three hours based on the quantity. Therefore the electric consumption of electric oven is differing from household to household. If one household makes an enjera within an interval of two days making for three (3) hours the time of operation of the electric oven is nine (9) hours per week. By changing this operation time per day we will get 1.286 hours per day. According to the reference [9] the rating of the electric oven is 2150. Thus the rating of electric oven per day will be.

$$P_{eo} = 2150W * \frac{1.286h}{day} = \frac{2.765KWh}{day}$$

From the assessed data two hundred and fifty households will use the electric oven, so total required by the customers for this device will be calculated as follows.

$$P_{total\ of\ electric\ stove} = 250 * \frac{2.765KWh}{day} = \frac{0.691MWh}{day}$$

Thus the total power required will be 0.691MWh/day.

### **3.2.1.7 Load calculation of phone charger**

Similarly the load calculation of phone charger will be calculated as follows. According to the reference [7] the rating of typical phone charge is 7W. In one household there may be a number of families there, this causes there is a number of mobile is there. This makes difficult to estimate the operation time of phone charger. By assuming that the average hour of the day which twelve hours and the calculation will be as follows.

$$P_{charger} = 12W * \frac{7h}{day} = \frac{84Wh}{day}$$

Now the total load required for phone charger is found by multiplying rating of the charger per day the total customer.

$$P_{total\ of\ phone\ charger} = 1000 * \frac{84Wh}{day} = \frac{0.084MWh}{day}$$

Thus the total load required for the phone charger is 0.084MWh/day.

### **3.2.1.8 Load calculation for public school**

From the load demand assessed from the village going to be electrified there one public school which have twelve class rooms and three office for staffs. Each class requires four florescent lamps because of the size of the class. The individual office requires two florescent lamps. Thus the total florescent lamp required by the school is fifty four (56) lamps. The operation hours of light bulb is mostly based on night classes and consumption of plasma television which used to deliver the class session. During the day time the schedule of the school is starts morning 8AM to 5PM which gives nine hour of operation time. For the light bulb we will consider the night students those take lessons during night time starts from 6PM to 4PM which gives four hour of operating time. According to the reference [11] the power rating of the 50 inch plasma Tv is 150 Watts. Therefore the load is calculated as follows.

$$P_{light\ of\ school} = 18W * \frac{4h}{day} = \frac{72Wh}{day}$$

$$P_{school\ plasma} = 150W * \frac{9h}{day} = \frac{1.35KWh}{day}$$

The total load demand of the school is the sum of load of light and consumption of plasma television.

$$P_{school} = \frac{72Wh}{day} + \frac{1.35KWh}{day} = \frac{1.422KWh}{day}$$

### 3.2.1.9 Load calculation for Mosque

There is one mosque or prayer place in the village which requires eight lighting lamps and the lamps operates for twelve hours, thus the load calculates as follows.

$$P_{ligh\ tof\ mosque} = 18W * \frac{12h}{day} = \frac{216Wh}{day}$$

### 3.3 The summary of load demand assessed from the proposed village

The solar system designed for the demand required, so the individual house hold appliances and two sectors energy demand will be sum up to give the total power demand of the village for which the designed is going to be done. The summary of the load is given in table 3.2.

**Table3. 6 summary of the load required by the village [4, 8, 9, 11]**

S. No	Energy consumption devices	Rating per day (KWh/day)
1	Lighting bulb for homes	216
2	Television	2040
3	Radio charger	240
4	Refrigerator	2880
5	Electric stove	13650
6	Electric oven	691
7	Phone Charger	84
8	One Public school	1.422
9	One mosque	0.216
Total		19802.638

As it can be seen from the table 3.2 the total load demand of the village is 19802.638KWh per day. The solar system is designed by considering this load and forecasting policy of the country.

To satisfy the demand for electricity caused by the country’s economic growth, the Government’s future plan for the power market sector has been divided into short, medium and long term plans of 5,10 and 25 year periods respectively [12].

**Table 3.7 data used for forecasting, design and planning of distribution system and components [12].**

Current peak load (MWh/day)	Annual load growth in % (EEP) data		Design and planning of future load demand in period (year)			Annual load growth in % (world bank) data
	Growing area	Saturated area	Short term	Medium term	Long term	
19.802638	5	2	5	10	25	6

Based on data of table 3.3 annual load growth of growing area is 5% of present load and by assuming that after a number of years alternative energy source can reach around the area the short term forecast is considered in this paper. Thus the load demand of the village including forecast is calculated as follows. Thus, Five percent (5%) present load demand is:

$$P_{5\% \text{ of present load}} = 0.05 * \frac{19.802638MWh}{day} = \frac{0.9901319MWh}{day}$$

The load forecast calculation is Present load plus five percent of the present load

**Table3. 8 Load forecasted of the village for five years**

Base year load (MWh/day)	Year 1 load (MWh/day)	Year2 load (MWh/day)	Year3 load (MWh/day)	Year 4 load (MWh/day)	Year5 load (MWh/day)
19.80238	20.79277	21.83241	22.92403	24.07023	25.27374

Therefore each design and equipment selection of the solar system design should be designed to tolerate the load increment for five years that is up to 25.27374MWh/day. Thus this load is the load for which the solar system is designed.

### 3.4 Material required

The materials required for this project are listed as follows:

- Solar cell
- Charge Controller
- Battery
- Inverter

### 3.5 Material description

#### 3.5.1 Solar Cell

Any device that directly converts the energy of light into electrical energy through the photovoltaic effect is called photovoltaic cell. The overwhelming majority of solar cells are fabricated from silicon with increasing efficiency and lowering cost as the materials range from amorphous (non-crystalline) to polycrystalline to crystalline (single crystal) silicon forms. Unlike batteries or fuel cells, solar cells do not utilize chemical reactions or require fuel to produce electric power, and, unlike electric generators, they do not have any moving parts [13].

The solar cells are the basis of any solar power system. A composed of individual solar cells comprise a solar panel. Each cell generates electrical energy when exposed to light. Depending on the nature of the connections between solar cells, solar panel system can achieve a number of different combinations of volt and ampere ratings. Consequently, solar panels can have a number of different power output ratings. If there are number of different solar panels, it may need to combine their outputs with a combiner box. The typical solar cell is shown in figure 3.3.



**Figure 0-3 Typical solar cells**

### **3.5.2 Solar panels**

The solar panel's role is to amplify, protect and direct electricity. Solar cells can produce only a limited amount of energy. When building a solar energy system, multiple solar cells are connected in series or parallel circuits to create a solar module. This produces higher currents and more energy. The modules also seal all of the solar cells and wiring in a protective case to guard it from the weather. These modules are then wired together as a solar panel. It is important to note that a solar panel may consist of just one module or multiple, meaning modules and panels are sometimes used interchangeably [15].

By connecting all of these parts into solar panels, the resulting electricity has a more precise path to follow. When the electrical current leaves the solar cells to travel through the electrical load, it is captured by the load and sent through the solar panels. The method by which the solar cells are wired together determines how the electrical current will flow through the solar panels. Whichever way it flows, it will direct the electricity from all the solar cells together. All the electricity will then be directed out of the solar panels and toward the inverter, where the rest of the photovoltaic process is completed [13].

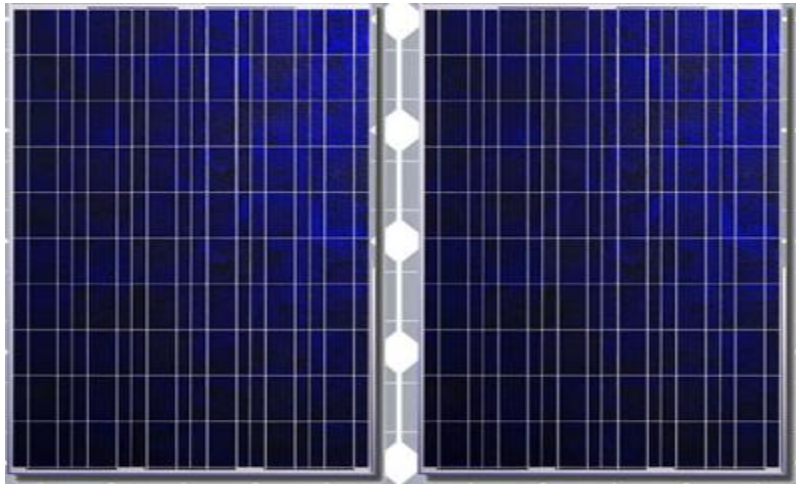


Figure 0-4 Typical solar panel

### 3.5.3 Charge Controller

The power output of a solar panel system fluctuates depending on the amount of sunlight it receives. Because the sun moves across the sky over the course of a day, panels output a different amount of power throughout the day. When cells receive no sunlight, the output power is zero. If the device power directly from a solar panel, the device may not receive enough power to sustain operation. Therefore, the power must be stored in a battery. However, before it goes to a battery, it should travel through a charge controller. The charge controller is a device that regulates the power coming from the solar panels with the right voltage and current to the battery. This is important for safe and efficient battery charging [15]

The PWM controller is in essence a switch that connects a solar array to a battery. The result is that the voltage of the array will be pulled down to near that of the battery.

The MPPT controller is more sophisticated (and more expensive): it will adjust its input voltage to harvest the maximum power from the solar array and then transform this power to supply the varying voltage requirement, of the battery plus load [16].

There are different types of the charge controller depending on the safety features, reputation of quality and price point. The Outback Flexmax FM80 is one of the best solar controllers on the market as it supports a wide variety of system designs and battery types. With a huge max input voltage capacity, the Outback controller is

perfect for off-grid systems that people installed on roofs or rural areas. This controller operates with 48V DC battery and 80A maximum output current [17].



**Figure 0-5 Charge controller**

### 3.5.4 Battery

The Power from a charge controller travels to a battery for storage. A battery stores the power from the solar power system based on its ampere hour rating. Amp hours denote the amount of amps of current that a battery could output in one hour before needing a charge. Typically, a solar power battery is not discharged quickly over the course of an hour, but slowly over the course of a number of hours. Many ampere hour ratings assume a 20-hour discharge time [2].

The most important ones to select and evaluation are the battery's capacity & power ratings, depth of discharge (DoD), round trip efficiency, assurance, and manufacturer. Batteries used in home energy storage typically are made with one of three chemical compositions: lead acid, lithium ion, and saltwater. In most cases, lithium ion batteries are the best option for a solar panel system, though other battery types can be more affordable [16].





**Figure 0-6 Lithium Ion Batter**

### 3.5.5 Inverter

Batteries and solar cells provide direct current power or DC. This means that the current flows in one direction. However, many home appliances electrical devices and systems require alternating current (AC) power. For this reason, a various solar panel system will have a power converter that converts DC power from the battery or solar panels to AC power suitable for the electrical makeup of house devices [2].

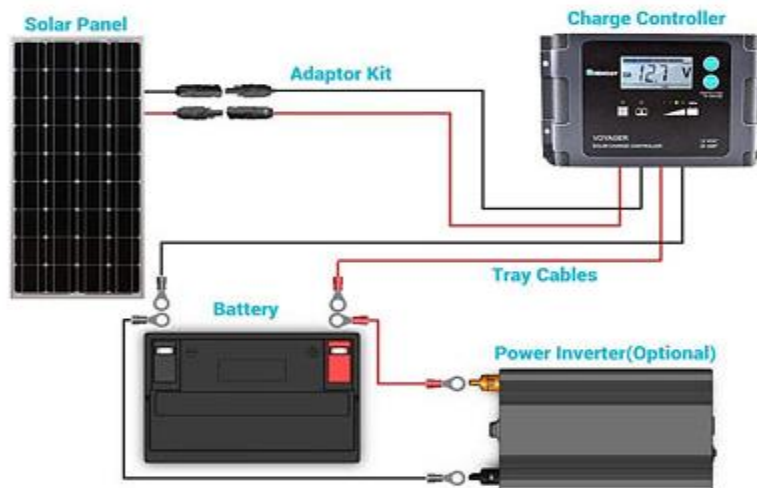
Solar panels convert sunlight directly into DC electricity which is then stored in deep cycle batteries. In an off-grid solar system it is the job of an inverter to convert the DC electricity to AC electricity. Off Grid Inverters ranging from 3000 Watts to 7000 Watts are usually designed to operate with 24V and 48V battery banks. Most of our larger inverters have a higher quality pure sine wave output that is safer and less likely to produce interference with electronics. Some inverter models can be stacked to increase the total power can provide to off-grid home or application [17]. Typical solar power inverters rating with 7000W shown in figure 3.7.



**Figure 0-7 Inverter or converter**

### 3.6 General connection of system components

The Components of the solar power system going to be designed is connected as shown in the figure 3.8.



**Figure 0-8 components connection**

### 3.7 Software materials

Software material used to simulate the designed solar power system is homer software. The HOMER Pro® micro grid software by HOMER Energy is the global standard for optimizing micro grid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. Homer Pro, or HOMER (Hybrid Optimization of Multiple Electric Renewables), simplifies the task of evaluating designs for both off-grid and grid-connected power systems. When you design a power system, you must make many decisions about the configuration of the system. HOMER simulates energy systems, shows system configurations optimized by cost, and provides sensitivity analyses.

## **CHAPTER FOUR**

### **SYSTEM DESIGN AND SIMULATION**

#### **4.1 System Design**

##### **4.1.1 Solar panel design**

Design of solar panel is based on total power demand of the village. Because the solar panel is going to purchase from the market , so under this topic determining of the number of solar panels that can generate the amount of power required by the customers from the energy of the sun. According to the data assessed from the village the total amount of the power required by the village including five years forecast is 25.274MW. Note that five years forecast does not implies that solar system is stop operation after five year rather it implies it may not have the capacity of supply the additional load after five years. In this paper because of its high efficiency and good heat tolerance Monocrystalline Silicon Modules will be used. The efficiency of the monocrystalline module or panel is 15% to 20% and Rated Power of the panel 300W is used [19].

Determining of the solar panel is based on the how sunny it is in prosed area for the design of the solar system. This is determined by using PVWatts software which is used to calculate solar radiation of the given area by accepting the resource data or location of the site and system information online and gives the solar radiation of the site in (KWh/m<sup>2</sup>/day), AC energy (KWh) and energy value (\$) monthly and hourly. In this paper monthly solar radiation used because the paper focused on design of solar power system. The identification of proposed location and solar radiation of the site is shown in the table 4.1 and 4.2 respectively.

**Location and Station Identification**

Requested Location	ogolcho
Weather Data Source	(INTL) ADDIS ABABA/BOLE, ETHIOPIA 65 mi
Latitude	8.98° N
Longitude	38.8° E

**PV System Specifications** (*Residential*)

DC System Size	25274 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

**Table 4.1 site identification**

Month	Solar Radiation ( kWh / m <sup>2</sup> / day )	AC Energy ( kWh )	Value ( \$ )
January	6.59	3,980,717	N/A
February	6.52	3,588,711	N/A
March	6.02	3,675,492	N/A
April	5.39	3,211,004	N/A
May	5.17	3,184,839	N/A
June	4.71	2,824,503	N/A
July	4.18	2,625,000	N/A
August	4.45	2,784,414	N/A
September	5.36	3,199,905	N/A
October	6.40	3,952,774	N/A
November	7.06	4,179,919	N/A
December	6.86	4,183,616	N/A

**Table 4.2 solar radiation of site**

The solar power system is designed for the worst months which produce minimum solar radiation. From the solar radiation column the minimum solar radiation is 4.18KWh/m<sup>2</sup>/day. The selected solar panel can produce 300w. Then the number of module required is calculated as follows:

$$\frac{4.18KWh}{day} * \frac{0.3KW}{one\ solar\ power} = \frac{1.254KWh}{day\ one\ solar\ panel}$$

$$\frac{25274KWh}{day} * \frac{one\ solar\ panel}{\frac{1.254KWh}{day}} = 20155\ solar\ panel$$

Therefore, to generate the amount of power required by village is twenty thousand one hundred fifty five (20155) panels are required.



**Figure 0-1 Typical solar power system farms**

### 4.1.2 Inverter Design

An inverter chosen that can handle the maximum electric wattage that must be drawn by all of the electric appliances when they are all turned on at the same time; however, some safety factor is needed here to design such a proper off-grid PV system. Thus, the safety factor is 1.2 [19]. According to the [19] the efficiency of the converter is 96%. Thus:

$$\text{efficiency of the inverter} = \frac{\text{output power}}{\text{input power}}$$

The output power is the power required by customers which means the amount of power for which the system to be designed and the inverter efficiency is known from manufacturer. Thus unknown input power to the inverter can be calculated as follows.

$$\text{Input power} = \frac{\text{output power}}{\text{inverter efficiency}} = \frac{25274KW}{0.96} = 26327.1KW$$

Off grid converters are ranging from 3KW to 7KW are usually designed to operate with 24V and 48V battery banks. By taking the maximum rating of the inverter the total number of inverter needed for this design calculated as:

$$\begin{aligned} \text{Number of inverters} &= \frac{\text{Input power to the inverter}(KW)}{\text{Rating of the inverter}(KW)} \\ &= \frac{26327.1KW}{7KW} = 3761 \end{aligned}$$

Therefore, as it can be seen from calculation the number of inverter required for this solar power system will be three thousand seven hundred sixty one (3761) inverters which rated with 7KW each.

### 4.1.3 Battery bank design

It stores electric energy for providing to electrical devices when there is a need. Normally a battery bank consists of number of batteries which are wired in series or parallel according to needed battery bank by the solar PV system [2].



Battery bank to provide the off-grid PV system would be normally, expressed as ‘days of autonomy’; because it is based on the number of days that one expects the system to provide electric power without receiving any input charge from the off-grid solar PV array. Moreover to the days of autonomy, load usage pattern should be also considered [19]. According to the reference [19] the days of autonomy and depth of discharge used in this paper are 2 and 50% respectively. Then battery capacity is calculated as follows:

$$\begin{aligned} \text{Battery capacity (Ah) required} &= \frac{\text{Total power required}}{\text{inverter } \eta * \text{nominal battery voltage} * \text{DOD}} * \text{DOA} \\ &= \frac{25274\text{KWh}}{96\% * 48\text{V} * 50\%} * 2 = 2193.92\text{KAh} \end{aligned}$$

Where: DOA Day of Autonomy

DOD is Depth of Discharge

$\eta$  is the sufficiency of the inverter

The number of battery calculated based on battery capacity, the battery selected is lithium ion battery of 48V and 25Ah.

$$\begin{aligned} \text{Number of batteries} &= \frac{\text{Total Battery capacity (Ah) required}}{\text{individual Battery capacity}} \\ &= \frac{2193.92\text{KAh}}{25\text{Ah}} = 87757 \text{ batteries} \end{aligned}$$

Therefore, the number batteries required to handle the solar system will be eighty seven thousand seven hundred fifty seven (87757).

#### 4.1.4 Charge Controller

A charge controller decides how much current ought to be injected into the batteries for its most ideal electric performance. As it decides the efficiency of the whole solar PV system, it affects the operating life of the batteries and it is considered to be a vital segment in the solar PV system [19].

Charge controller is going to be selected in order to regulate the voltage and current coming from the PV panels going to the battery bank and prevents battery overcharging and also prolongs the battery life.

Charge controllers are selected based several criterion but one of the most common method is to find the maximum AC wattage of the solar system appliances as the inverter should handle this power plus some safety factor that one must take into consideration due to the face that sometimes, some appliance like refrigerators or washing machine requires a surge current and power that is normally higher than their rated current and watts simultaneously [19].

The controller must be designed to handle the maximum current produced by the PV array. The controller used in this design is operates with 48V DC battery and 25Ah maximum output current as it described under components description. Thus it can be designed as:

$$\begin{aligned} \text{Charge controller amprage (I)} &= \frac{\text{Total array wattage(KW)}}{\text{Battery bank nominal voltage (V)}} \\ &= \frac{P}{V} = \frac{25274KW}{48V} = \mathbf{526541.666amps} \end{aligned}$$

Therefore, the number of charge controller needed to handle this maximum current calculated as follows:

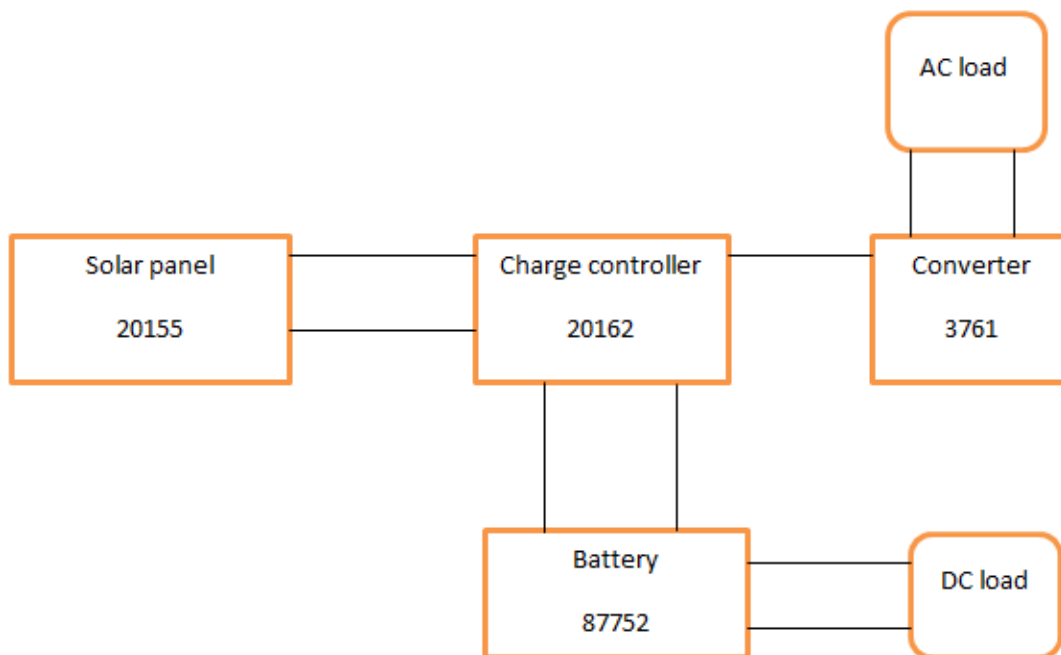
$$\begin{aligned} \text{Number of charge controller} &= \frac{\text{Charge controller amprage}}{\text{Operating capacity of the charge controller}} \\ &= \frac{526541.666amps}{25amps} = \mathbf{21062} \end{aligned}$$

Thus, the calculation shows that number of charge controller required to electrify the proposed rural village is twenty one thousand sixty two (21062) charge controllers.

## 4.2. Overall block diagram of solar system

The overall block diagram of the proposed solar system that designed to electrify the proposed rural village is shown in figure 4.2. This black diagram indicates the designed components with respective required number of components.





**Figure 0-2 General block diagram of the designed solar system**

### 4.3 simulation result discussion

#### 4.3.1 Developing of design on the soft ware

Designed solar power system is simulated using homer software, which one of the software's used for optimization of energy sources. All components required for this solar power system that designed under system design were developed on homer software. The value in number or in rating each component that means solar panel, charge controller, battery and converter or inverter used as input for the software. In addition to these the assessed load demand of the village also connected as electric load which connected as AC load and deferrable load which connected as DC load. The difference AC and DC is for AC load the converter is required while for DC load converter is not required it connected directly to the battery. The developed of the system on the homer software is shown in the figure 4.2 which taken by snapshot from homer work page.

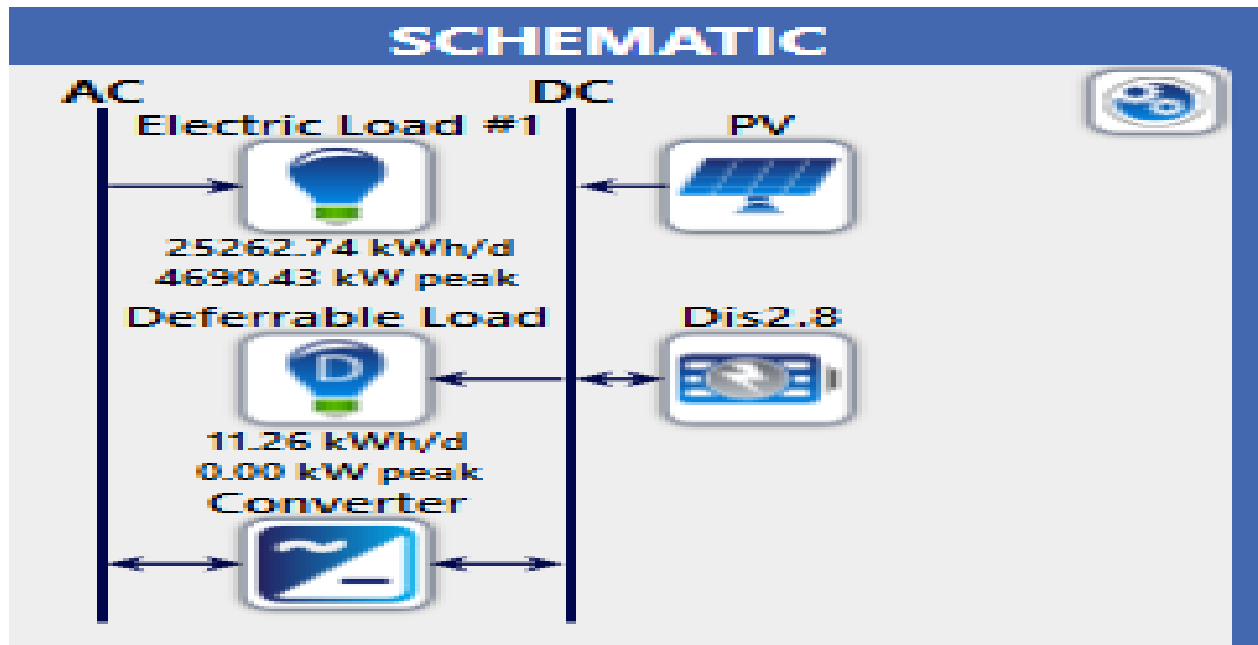


Figure 0-3 Schematic of the system developed on software

#### 4.3.2 Result discussion

The simulation result of the developed design on the software gives the profile of the system on daily, seasonally and yearly base. The amount power generated by the designed solar power system is shown on figure 4.4.

Monthly average electric production shows that capacity of the designed solar power system and the load assessed from village to be electrified so the design meet the requirements. The individual simulation result of battery bank, solar PV and system converter also shown figure 4.5, 4.6 and 4.7 respectively.

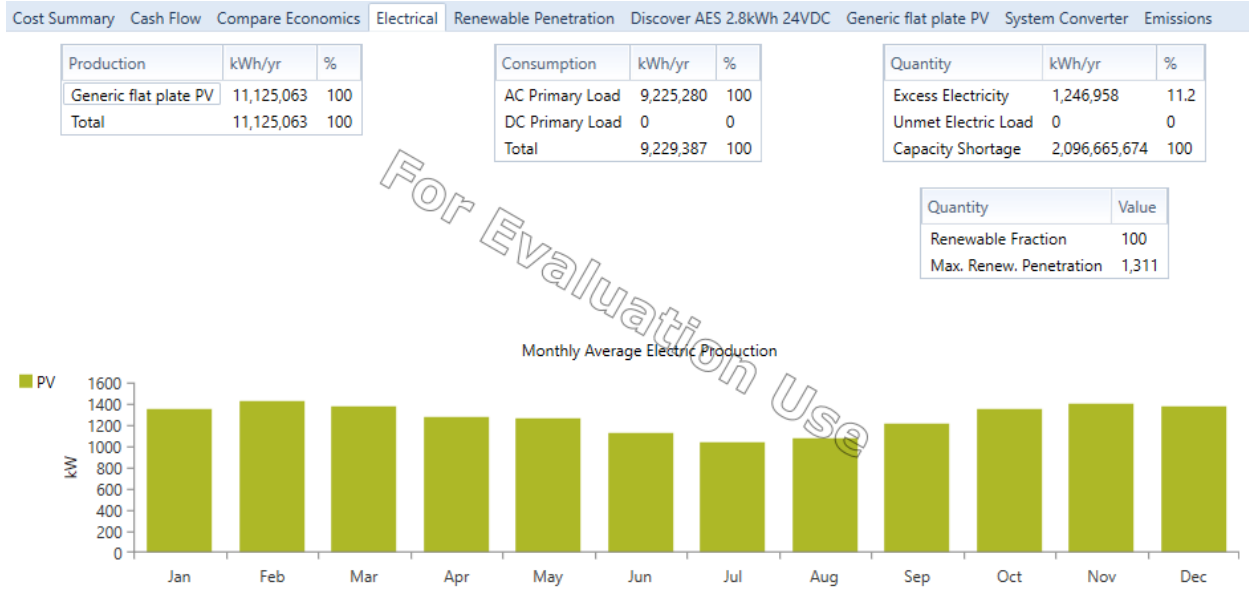


Figure 0-4 Monthly Average of Electric production

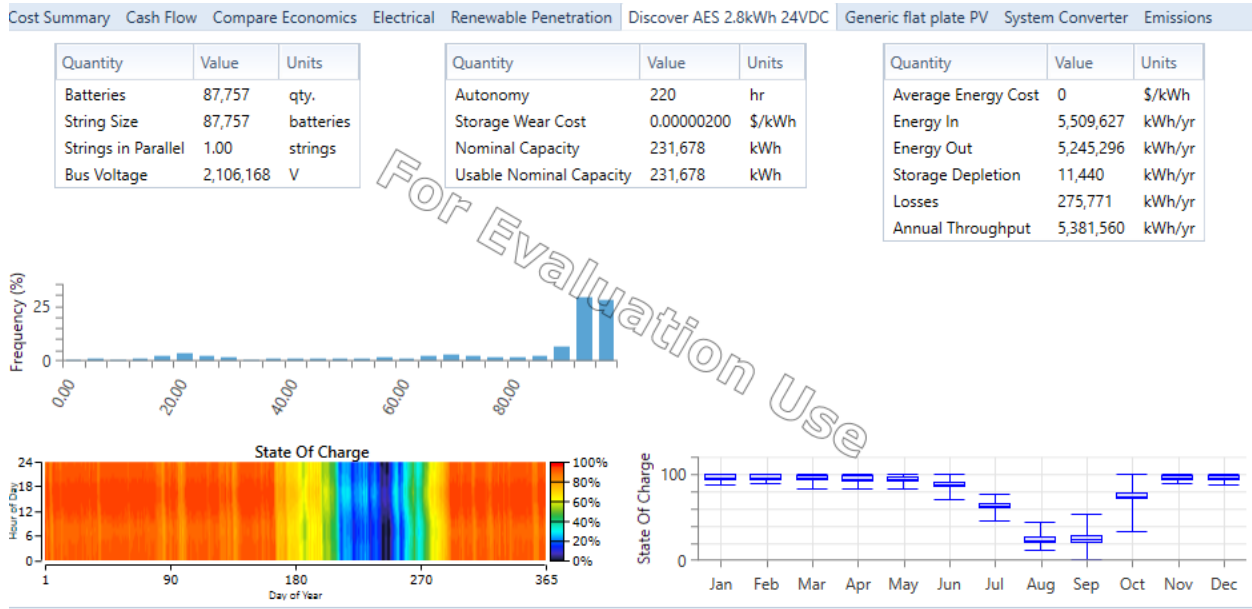


Figure 0-5 state of charge of battery bank

Cost Summary Cash Flow Compare Economics Electrical Renewable Penetration Discover AES 2.8kWh 24VDC Generic flat plate PV System Converter Emissions

Quantity	Value	Units
Rated Capacity	6,208	kW
Mean Output	1,270	kW
Mean Output	30,480	kWh/d
Capacity Factor	20.5	%
Total Production	11,125,063	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	5,967	kW
PV Penetration	121	%
Hours of Operation	4,439	hrs/yr
Levelized Cost	0.478	\$/kWh

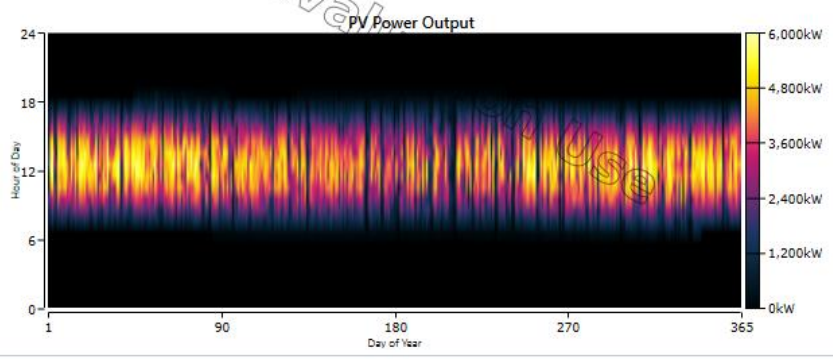


Figure 0-6 Solar PV power output

Cost Summary Cash Flow Compare Economics Electrical Renewable Penetration Discover AES 2.8kWh 24VDC Generic flat plate PV System Converter Emissions

Quantity	Inverter	Rectifier	Units
Capacity	26,327	26,327	kW
Mean Output	1,053	0	kW
Minimum Output	46.5	0	kW
Maximum Output	4,693	0	kW
Capacity Factor	4.00	0	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	8,760	0	hrs/yr
Energy Out	9,225,280	0	kWh/yr
Energy In	9,609,667	0	kWh/yr
Losses	384,387	0	kWh/yr

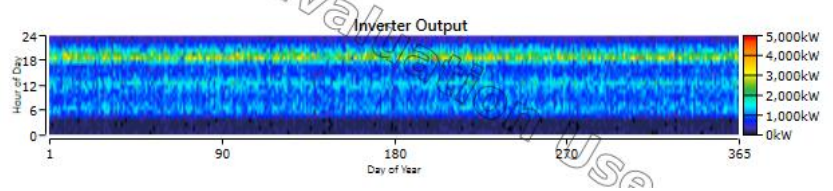


Figure 0-7 inverter output

## **CHAPTER FIVE**

### **CONCLUSION AND RECOMMENDATION**

#### **5.1 conclusion**

Solar energy is one of the primary sources of clean, present in a great quantity and inexhaustible energy that not only provides alternative energy resources, but also make a better environmental pollution. So this paper is presents electrification of rural village to electrify the rural village that does not electrify before.

The purpose of this project is to assess load demand of the village and design a 25.274MWh/day solar power system for a rural village that is used for residential purposes. The designed PV system is intended to cover 100 % of the energy demand required by the village for electric home appliances. As the system captures the sun's energy using the solar PV array, it stores the surplus of its need in the batter bank and uses it at the night times and autonomy day when the solar PV system is incapable of energy production. It is quite unambiguous that this project perfectly serves the energy demand of village. The system is designed and simulated using homer software. The cost analysis of the project is planned during implementation.

#### **5.2. Recommendation**

- The Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU) should invest for implementation because it electrifies the rural village and also profitable.
- None-governmental organization should also invest the budget for implementation
- The government and individual house hold should invest in collaboration because it helps both parts.

## REFERENCES

- [1]. Design and Implementation of an Off-Grid Solar Tracker Control System using Proteus Version 8.1
- [2]. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3658738/>
- [3]. Design and Simulation of Dual Axis Solar Tracker for Optimum Solar Energy Absorption, Hussain A. Attia , Beza N. Getu, and Yousif I. Al-Mashhadany American University of Ras Al Khaimah, UAE
- [4]. An Industry Analysis and Social Venture Plan Steve Dahlke, ENTR 311 Social Entrepreneurship, Terri Barreiro College of St. Benedict and St. John’s University
- [5]. Design and Simulation of a Sun Tracking Solar Power System
- [6]. Dr. Liping Guo, Northern Illinois University
- [7]. Design of a Solar Tracker System for PV Power Plants Tiberiu Tudorache <sup>1</sup>, Liviu Kreindler <sup>1,2</sup>
- [8]. Design and Implementation of a Solar Power System in Rural Haiti by Shaheer M. Hussam
- [9]. <https://generatorist.com/power-consumption-of-household-appliances>
- [10]. <https://www.daftlogic.com/information-appliance-power-consumption.htm>
- [11]. Design of an Off-Grid Solar PV System for a Rural Shelter, Presented by Noor Hussain Al Dulaimi – 2008203032 ,Supervised by Dr. Ammar Alkhalidi, First Semester 2016/2017, Amman, Jordan
- [12]. <https://www.wholesalesolar.com/solar-information/how-to-save-energy/power-table>
- [13]. <http://www.plasmatvbuyingguide.com/hdtv/plasmatv-green.html>
- [14]. Study and evaluation of the reliability and design of power distribution system: case study Addis Ababa power distribution by kiros tesfay
- [15]. <https://www.britannica.com/technology/solar-cell>
- [16]. <https://rgsenergy.com/how-solar-panels-work/the-difference-between-solar-cells-and-solar-panels/>
- [17]. Solar Photovoltaics, N. D. Kaushika Anuradha Mishra Anil K. Rai, Technology, System Design, Reliability and Viability
- [18]. <https://www.victronenergy.com/blog/2014/07/21/which-solar-charge-controller-pwm-or-mppt/>
- [19]. <https://www.energysage.com/solar/solar-energy-storage/what-are-the-best-batteries-for-solar-panels/>
- [20]. [https://search.yahoo.com/yhs/search?hspart=blp&hsimp=yhs-default&type=hmp\\_155\\_785\\_0&p=Flexmax+FM80+charge+controller+capacity&rnd=2113573345&param1](https://search.yahoo.com/yhs/search?hspart=blp&hsimp=yhs-default&type=hmp_155_785_0&p=Flexmax+FM80+charge+controller+capacity&rnd=2113573345&param1)
- [21]. Design of an Off-Grid Solar PV System for a Rural Shelter ,Presented by Noor Hussain Al Dulaimi – 2008203032, Supervised by Dr. Ammar Alkhalidi First Semester 2016/2017 , Amman, Jordan

- [22]. Design & Sizing of Stand-alone Solar Power Systems A house Iraq, Ali Najah Al-Shamani<sup>1,2</sup>, Mohd Yusof Hj Othman<sup>1</sup>, Sohif Mat<sup>1</sup>, M.H. Ruslan<sup>1</sup>, Azher M. Abed<sup>1</sup>, K. Sopian<sup>1</sup>. <sup>1</sup>Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia. <sup>2</sup>Al-Musaib Technical College, Al-Furat Al-Awsat Technical University, 51009 Babylon, Iraq.