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A THESIS FOR PARTIAL FULFILLMENT OF THE AWARD OF MASTER OF SCIENCE DEGREE

Title:

DESIGN AND IMPLEMENTATION OF SOLAR PV POWER SYSTEM FOR ADAMA SCIENCE &TECHNOLOGY UNIVERSITY ICT BUILDING

By:

Fekadu Fulli…………………………GSR/0003/07

Jemal Ahmed ………………………..GSR/0004/07

Mekuriaw Alemu …………………GSR/0005/07

Name of Advisor: Mr. TafeseAsrat

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DECLARATION

We hereby declare that this thesis project entitled "Design and Implementation of solar PV power system for ASTU ICT Building Server Room" in partial fulfillment of the requirements for the award of the degree of Master of Science in Industrial Automation and Control Technology Management is the result of our own research except as cited in references. The work carried out from March to May 2016 under the supervision of TafeseAsrat, Department of Electrical and Computer Engineering, Adama Science and Technology University. The matter embodied in thesis project has not been accepted for any degree and is not submitted in candidature of any other degree or diploma.

Name	Signature	Date
Fekadu Fulli	________________	______________________
Jemal Ahmed	________________	______________________
Mekuriaw Alemu	________________	______________________

I, the advisor, hereby declare I have read this project and in my opinion this thesis project is sufficient in terms of scope and quality. This thesis project has been submitted for examination with my approval.

Tafese Asrat ________________ ________________

(Advisor) Signature Date

APPROVED BY BOARD OF EXAMINERS

______________________	______________________
Chairman, Department of ECE	**Signature**
______________________	______________________
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______________________	______________________
External Examiner	**Signature**

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Then after, we thank the authorized persons of ASTU ICT building server room for providing us necessary information and allowing us to observe and take data from the loads during our case study. Lastly but not least, we thank National Meteorological Agency, Adama branch administrative and technical bodies for their cooperation in providing us instrumentally processed data of altitude, latitude and peak sun hours of the past five consecutive years in Adama.

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ACRONYMS AND ABBREVIATIONS

EEP	Ethiopian electric power
PV	photovoltaic
ICT	Information &communication technology
a-si	Amorphous silicon
CdTe	Cadmium telluride
CIS	Copper indium selenium
UPS	un-interruptible power supply
AC	Alternative current
DC	Direct current
KWh	Kilo watt hours
GHP	Geothermal heat pump
BTL	Biomass to liquids
RAPS	Remote area power supply
MW	Mega watt
CSP	Concentrated solar power
CPV	Concentrated photovoltaic
STE	Solar thermal energy
CST	Concentrated solar thermal
I_{SC}	Short circuit current
V_{OC}	open circuit voltage
STS	standard test condition
P_{MM}	maximum power point
I_{MP}	maximum power current
V_{MP}	maximum power voltage
FF	Fill factor
Ah	Ampere hour
G	Global
EVA	Ethyl vinyl acetate
CIGS	Copper indium gallium selenium
PWM	Pulse width modulation

MPPT	Maximum power point tracking
LED	Light emitting diode
AGM	Absorbed glass mat
VDC	Direct current voltage
LCD	Liquid crystal display
Pbo_2	Lead dioxide
H_2SO_4	Hydro-sulfuric acid
SIL	Starting, lighting & ignition
Sb	Antimony
Ca	Calcium
VRLA	Value regulated lead acid
Ni-Co	Nickel cadmium
NiO2H	Nickel hydroxide
KOH	Potassium hydroxide
(CD(OH)2	Cadmium hydroxide
DOD	Depth of discharge
SMPS	Switch mode power supply
NOCT	Normal operating cell temperature
CC	Charge controller
O&M	Operating & maintenance
NPC	Net present cost
SOC	State of charge

ABSTRACT

In this thesis, we have developed the design for implementation of solar PV power system for Adama Science and Technology University ICT Building Data Center. Currently the building uses utility power from grid (EEP) at normal conditions; and it uses diesel generator as a backup during power interruption. The target of this work is to solve real problems of the site by a solar PV power system to supply especially the critical loads of this particular building, so that the system will be independent of grid which interrupts frequently. The thesis/project have been accomplished by undergoing case study at the site; designing the capacities of photovoltaic panel, battery, charge controller, inverter and connecting cables. This helps to deal with current status, major achievements and future aspects of solar energy in ASTU and evaluation of current energy strategies for overcoming the obstructions and implementing solar PV power for the future. Solar radiation is an integral part of different renewable energy resources. It consists of a study of photovoltaic technology, where solar energy plays an important role for the power supply either as a standalone system or in case of emergency by replacing diesel generator which causes environmental pollution. The design functionality of the system has been shown by a model project.

Keywords: Solar panel, photovoltaic, batteries, charge controller, server, generator, excel, Homer software, model

CHAPTER ONE

1. INTRODUCTION

1.1 Motivation

In ASTU ICT Building data center we have observed that when the grid electric power interrupts, all the servers and their switching devices stop their service. The UPS there does not maintain the power for more than one second and the manually operated generator takes some time intervals to provide the backup service. This results in interruption of internet connection in ASTU campus, which in turn negatively influences the quality of education in the university. Hence we have been motivated to design and implement a stand-alone solar PV power system for the site. The target of this work is to replace the existing power sources by a solar PV power system to supply especially the critical loads of this particular building, so that the system will be independent of grid power from EEP which frequently interrupts.

1.2 Background

Solar energy is a permanent and natural energy source on the earth and it is available for use in its direct and indirect forms [1]. Solar Photovoltaic (PV) panel is another empowering technology that can convert part of the sunlight into useable electricity. Photovoltaic power generation has been receiving considerable attention as one of the most promising energy generation alternatives. It can hold the world electricity consumptions. Photovoltaic (PV) industry has been continuously growing at a rapid pace over the recent years. In addition, new standards and testing schemes are developed to be comparable with the new or improved technologies. Photovoltaic can be recognized as one of the most promising renewable energy sources. The costs of the generated electricity from photovoltaic is decreasing year by year and it is expected to be cheaper than conventional recourses, and this leads the customers to install their PV systems instead of using the expensive conventional electricity from the utility [2]. In future, real time power especially from domestic systems will be more important to take into consideration because higher penetration of PV systems will affect the grid performance. Furthermore, it is the base of controlling energy management systems for the smart homes. The uncertainty of the photovoltaic performance models is still too high; the early existing PV performance models mainly deal with the ideal PV module characteristics rather than the dynamic situation under the surrounding conditions [3]. Photovoltaic systems are mainly grouped in two categories; Stand-alone system (also called off-grid) and grid connected system (also called on-grid). Stand alone systems can be integrated with another energy source such as Wind energy or a diesel generator which is known as hybrid system. The storage is the main difference between these categories, where the produced electrical energy is stored in batteries in off-grid system and the public grid utility is the storage tank for the excessive produced energy from on-grid systems. On-grid systems are installed more often nowadays, some countries offer incentives to encourage people to invest in Photovoltaic and to reduce green house gas emissions. Photovoltaic systems can provide electricity for home appliances, villages, water pumping, desalination and many other applications [4].

Utilization of solar hybrid system is essential in every field of life. In [5], an experiment is conducted using the PV panel to supply electricity in the building like to serve tube lights, energy saver bulbs, computer, photo copiers, printers, fax machines and refrigerators etc. Since we know that energy especially electricity is the basic requirement for the social and economic development of a country, the use of electricity has to be increased day by day in every field or department of a country. For instance, industries require continuous and uninterrupted supply of electrical energy [6].

Due to increased demand of electricity in a country like Ethiopia, energy crises have been raised. In [7, 8], various energy sources like oil, coal, natural gas are presented, where the authors pointed out that these sources are limited in the country and if these are used at the current rate then these energy sources will be finished very quickly in the upcoming decades [9]. The shortfall of energy leads to bring in use the fossil fuel-based power plants which generate substantial greenhouse gases effecting global climate [10]. Photovoltaic system makes use of PV panels which convert solar energy directly into electrical energy. The solar hybrid system gives green, clean, climate friendly and inexhaustible energy to mankind. The solar power system requires less maintenance and low running cost, though it has high initial implementation cost [11].

The load shedding causes serious impact on business, industries, factories, everyday life of a citizen and more importantly on the education systems like in Adama Science & Technology

University. In order to provide modern education in the ASTU, continuous electrical energy should be supplied to this institute in the working hours. In this thesis, we have presented a 'Design and Implementation of Solar PV Power System for Adama Science & Technology University ICT Building Data Center Server Room'.

1.3 Statement of the problem

The ASTU ICT building data center server room uses a generator when the utility grid power interrupts. There are a number of problems which result in unsuccessful provision of internet service in ASTU campus. On one side, when the interruption occurs, system reconfiguration is needed for the reason that the UPS feeds power only for less than one minute; the data machines may be damaged. On the other hand, since the generator is manually operated it takes time until the operator operates it; and also it is clear that a generator has drawbacks like high operating cost (fuel price), high maintenance cost, high noise, environmental pollution and global warming. To avoid all these problems, we have been initiated to design a solar PV power system for the data center.

1.4 Research Questions for the specific objectives

Q1. Are the loads AC, DC or both?

Q2. Is a load used for a few days in a week or only on weekends?

Q3. How long does a load operate per day?

Q4. Is a meteorological data available nearby the site?

Q5. What is the value of peak sun hour nearby the site?

Q6. What is the specified system voltage for the design?

Q7. Is power losses considered or not?

Q8. Are manufacturer's data available on solar PV devices?

Q9. What are standards of solar PV inverters?

1.5. Objectives of the study

1.5.1. General objective of the study

The purpose of this study is to design and implement the solar PV power system for Adama Science & Technology University ICT building data center server room by avoiding unnecessary power interruptions.

1.5.2. Specific objectives of the study

The specific objectives of this study are to determine:

- The capacity of solar PV panel for the particular power requirement.
- The capacity of battery for the specified solar PV panel.
- The capacity of charge controller for the battery.
- And specify the inverter size.
- And develop a model for the functionality of the project.

1.6. Significance of the Study

The importance of this study is to ensure sustainable power supply from solar PV panel for the server room of Adama Science and Technology University ICT building. The main benefit of this solar PV power system is to solve the problems caused by power interruption in the ICT server room. When the sun shine is low or none, the system feeds power to the ICT server room loads from the rechargeable battery. This power system has vital features like; low running cost, low maintenance cost, it is noise free, it does not pollute the environment, and it contributes to reduce global warming.

1.7. Delimitation and Limitation of the study

1.7.1. Delimitation

The goal of this study was to implement the designed solar PV electric system for the full load of ASTU ICT building server room, but now it has been limited to model implementation only.

1.7.2. Limitation of the study

The challenges we faced in this system implementation is the high initial cost of solar PV devices. This shortage of finance is what limited the work to the model implementation for the functionality of the system.

1.8. The scope of the study

The studied solar PV system has been designed so as to produce 220V /50Hz sinusoidal AC source at the inverter output to give power to the electrical loads having a total rated power of 60 KW and a total power consumption demand of 1412 KWh/day. It consists of a charge controller to control over charging and the system is capable of feeding to loads via the charged battery (back up) in the absence of sun light. Before the research implements, system design in ASTU particularly for ICT Building Data server room, we develop model for the functionality of project.

1.9. Method Overview

The methodology in this system basically consists of data collection and analysis methods.

1.9.1 .Data Source

The source of data for designing & implementing this thesis is from ASTU ICT building data center and National meteorological Agency, Adama branch. These enable us to gather current and accurate data from the real site.

1.9.2. Collected Data

Before designing the system, we collected data from Adama Science and Technology University ICT building and National meteorology Agency, Adama branch. These data include:

- List of different types of appliances.
- Power rating of each item.
- Voltage rating of each device.
- Current rating of each device.
- Usage duration (hour) of each load.

- Peak sun hour value.
- Latitude and Altitude value.

The data were collected by:

Observing the ASTU ICT building server room electrical appliance loads' data from the name plate, interviewing the server room authorized persons and obtaining meteorological data from National Meteorological Agency, Adama branch.

- Interviewing the respective persons in the site.
- Recording all the load power rate of each device in the ICT building.
- Taking actual measurements of the loads using measuring instruments.
- Obtaining documented or recorded meteorological data from National Meteorological Agency in Adama branch.

1.9.3. Analysis Method

The thesis /project, solar PV power system design, is analyzed by using Excel software and HOMER software.

1.10. Organization of Thesis

The thesis has the following parts, and organized as follows:

Chapter 1 introduces the thesis as a whole. The early and basic explanations are mentioned in this chapter. This chapter consists of the thesis introduction, objectives, statement of problem, scope of the thesis, significance of the thesis, Delimitation and Limitation of the study and methods.

Chapter 2 Reviews different papers, books and journals related to the thesis.

Chapter 3 provides Methodology and its detailed description.

Chapter 4 this chapter addresses the simulation results from data analysis.

Chapter 5 Presents the Discussions (conclusions) and recommendation.

CHAPTER TWO

2. REVIEW OF THE LITERATURES

2.1. Renewable Energy sources

Renewable energy is generally defined as energy that is collected from resources which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat[12]. Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. Renewable energy resources and significant opportunities for energy efficiency exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency, and technological diversification of energy sources, would result in significant energy security and economic benefits [13].

Based on REN21's, 2014 report, renewable contributed 19 percent to humans' global energy consumption, 22 percent to their generation of electricity in 2012 and 2013, respectively. This energy consumption is divided as 9% coming from traditional biomass, 4.2% as heat energy (non-biomass), 3.8% hydro electricity and 2% is electricity from wind, solar, geothermal, and biomass. Worldwide investments in renewable technologies amounted to more than US$214 billion in 2013, with countries like China and the United States heavily investing in wind, hydro, solar and bio fuels[14].

It would also reduce environmental pollution such as air pollution caused by burning of fossil fuels and improve public health, reduce premature mortalities due to pollution and save associated health costs that amount to several 100 billion dollars annually only in the United States[15]. Renewable energy sources, that derive their energy from the sun, either directly or indirectly, such as hydro and wind, are expected to be capable of supplying humanity energy for almost another 1 billion years, at which point the predicted increase in heat from the sun is expected to make the surface of the earth too hot for liquid water to exist[16][17].

2.2. Solar Photovoltaic

Photovoltaic (**PV**) is the name of a method of converting solar energy into current electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon commonly studied in physics, photochemistry and electrochemistry.

Solar PV has turned into a multi-billion, fast-growing industry, continues to improve its cost-effectiveness, and has the most potential of any renewable technologies together with CSP[18][19]. Concentrated solar power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Commercial concentrated solar power plants were first developed in the 1980s. CSP-Stirling has by far the highest efficiency among all solar energy technologies.

Photovoltaic systems can provide electricity for home appliances, villages, water pumping, desalination and many other applications.

Figure 2.1 explains briefly the different photovoltaic system applications:

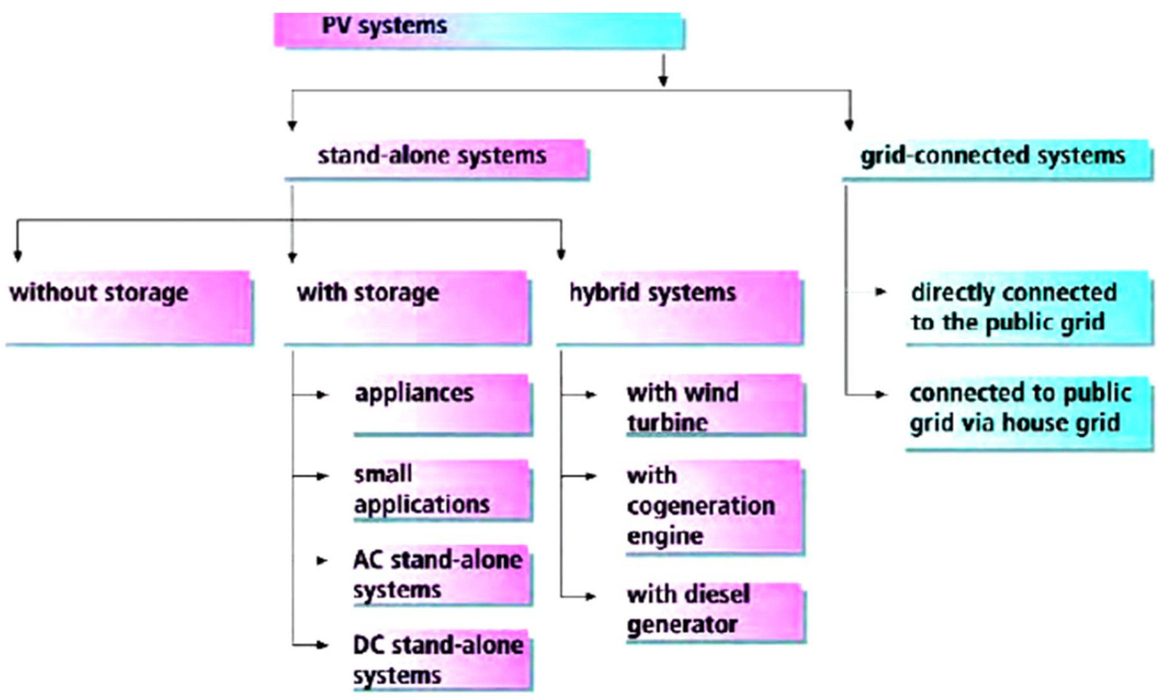

Figure 2.1: Photovoltaic systems applications.

A photovoltaic system employs solar panels composed of a number of solar cells to supply usable solar power. The process is both physical and chemical in nature, as the first step involves the photoelectric effect from which a second electrochemical process takes place involving crystallized atoms being ionized in a series, generating an electric current[20]. Power generation from solar PV has long been seen as a clean sustainable [21] energy technology which draws upon the planet's most plentiful and widely distributed renewable energy source – the sun. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. It is well proven, as photovoltaic systems have now been used for fifty years in specialized applications, and grid-connected PV systems have been in use for over twenty years Photovoltaic output power depends on many factors; such as sun position, weather conditions, module temperature, thermal characteristics, module material composition and mounting structure. Real time power generation should be investigated precisely for grid performance, because a high penetration of PV production could create instability in the grid [22]. Photovoltaic are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons. The photovoltaic effect refers to photons of light exciting electrons into a higher state of energy, allowing them to act as charge carriers for an electric current. The term photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Virtually all photovoltaic devices are some type of photodiode. Solar cells produce direct current electricity from sun light which can be used to power equipment or to recharge a battery. The first practical application of photovoltaic was to power orbiting satellites and other spacecraft, but today the majority of photovoltaic modules are used for grid connected power generation. In this case an inverter is required to convert the DC to AC.

PV cell: The basic photovoltaic device that is the building block for PV *modules* .All modules contain cells. Some cells are round or square, while thin film PV modules may have long narrow cells. Module is the basic building block of systems can connect modules together to get any power configuration. Cells are too small to do much work. They only produce about 1/2 volt, and we usually need to charge 12 volt batteries or run motors. A typical module has 36 cells connected in series, plus to minus, to increase the voltage. 36 times ½ volt yields 18 volts. However, the voltage is reduced as these cells get hot in the sun and 12-volt batteries typically need about 14 volts for a charge, so the 36 cell module has become the standard of the solar battery charger industry. With connected cells and a tough front glass, a protective back surface and a frame, the module is now a useful building block for real-world systems. The cells make up the module, and the modules make the power array. If you need more than 12 volts, you can connect modules in series too. If you need more than the current from one module, you can connect modules in parallel.

PV module: A group of PV *cells* connected in series and/or parallel and *encapsulated* in an environmentally protective *laminate*. The PV module is the smallest package that produces useful power. The process involved in manufacturing these modules requires high precision and quality control in order to produce a reliable product. It is very difficult, and therefore not practical, to make homemade modules.

PV panel: A group of *modules* that is the basic building block of a PV *array*. Panel is a term used for a group of modules that can be packaged and pre-wired off-site. The size of the panel (or large modules) is often related to how much weight and size two workers can effectively handle on a roof surface.

PV array: A group of *panels* that comprises the complete PV generating unit. If a PV system has more than one grouping of PV modules, we call each grouping a sub-array. The total of all the sub-arrays is then called the complete PV array.

2.2.1. Photovoltaic characteristics

Two PV modules with the same rated power –even with the same technology- will not provide the same output power and energy yield. Also, the different thermal characteristics play an important role in module efficiency as well as the output power; this is because the PV module is influenced by a variety of environmental factors and solar cell physics. Hence, testing and modeling the PV module/system in the outdoor environment with specifying the influences of all significant factors, are very important to check the system performance and to facilitate efficient troubleshooting for photovoltaic module/system through considering hourly, daily and monthly or annual basis [23]. This is performed through the European project (SOPHIA) which defines the relevant aspects and deficits of the module and system performances in order to benchmark a standardized test procedure data base. It is very important to measure the produced PV systems peak power to protect the grid and power needed at high consumption.

Irradiation effect: Photovoltaic output power is affected by incident irradiation. PV module short circuit current (I_{SC}) is linearly proportional to the irradiation, while open circuit voltage (V_{OC}) increases exponentially to the maximum value with increasing the incident irradiation, and it varies slightly with the light intensity [24].

The open-circuit voltage (V_{OC}) is the maximum voltage available from a solar cell, and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current.

The short-circuit current(I_{SC}) is the current through the solar cell when the voltage across the solar cell is zero (i.e., when the solar cell is short circuited), it is usually written as I_{SC}.

Figure 2.2 describes the relation between Photovoltaic voltage and current with the incident irradiation.

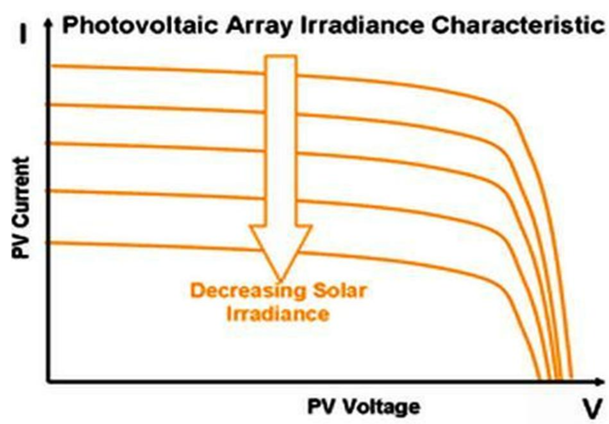

Figure 2.2: Effects of the incident irradiation on module voltage and current [25]

Temperature effect: Module temperature is highly affected by ambient temperature. Short circuit current increases slightly when the PV module temperature increases more than the Standard Test Condition (STC) temperature, which is 25^{o}C. However, open circuit voltage is enormously affected when the module temperature exceeds 25^{o}C. In other words the increasing current is proportionally lower than the decreasing voltage. Therefore, the output power of the PV module is reduced [25].

Figure 2.3 explains the relation between module temperature with voltage and current.

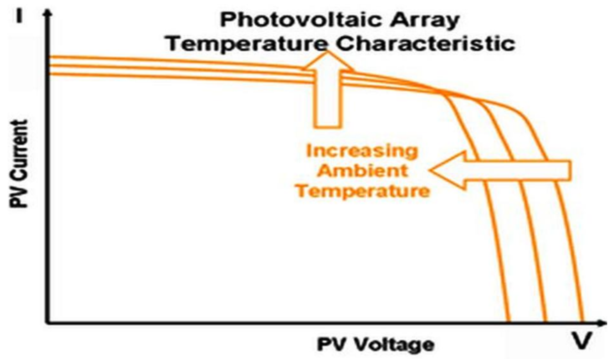

Figure 2.3: Effect of ambient temperature on module voltage and current [25]

Maximum power point (P_{MPP}): Maximum electrical power of the PV module is equal to the current at maximum power point (I_{MP}) multiplied by the voltage at maximum power point (V_{MP}), which is the maximum possible power at Standard Test Condition (STC)-.V curve Referring represents the maximum power point (P_{MPP}) of the PV module/system. At this point the maximum electrical power is generated at STC [26].

The usable electrical output power depends on the PV module efficiency which is related to the module technology and manufacture.

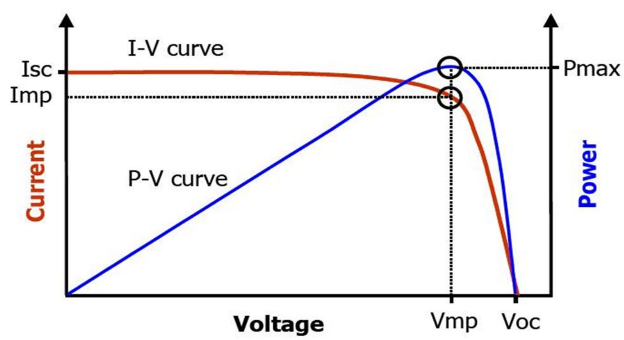

Figure 2.4: Maximum power point [26]

Fill factor (FF): The fill factor is an important parameter for PV cell/module; it represents the area of the largest rectangle, which fits in the I-V curve. The importance of FF is linked with the magnitude of the output power. The higher the FF, the higher is output power. The ideal FF value is 1 which means that the two rectangles are identical [26]. Figure 2.5 illustrates the fill factor which is the ratio between the two rectangular areas and is given by the following formula.

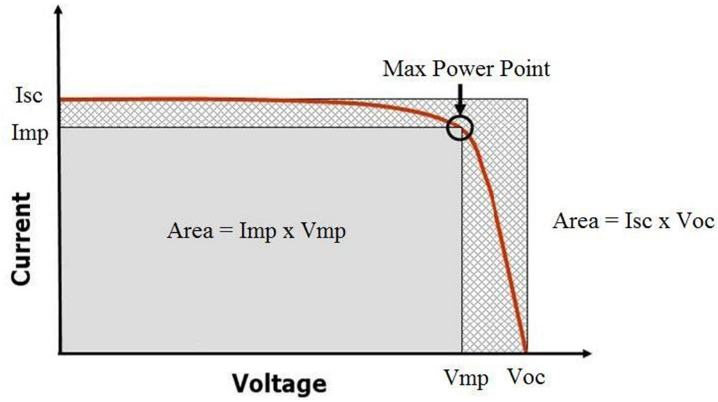

Figure 2.5: Fill Factor [26]

PV Module efficiency (η): The PV cell/module efficiency is the ability to convert sunlight to electricity. The efficiency is necessary for space constraints such as a roof mounted system. Mathematically, it determines the output power of the module per unit area. The maximum efficiency of the PV module is given by:

$$\eta_{PV_{max}} = \frac{V_{MP} * I_{MP}}{G * A} * 100\%$$

Where *G* is global radiation and considered to be 1000 W/m^2 at (STC) and *A* is the Area of the PV module [27].

2.2.2. Photovoltaic module technologies

The single junction technology is grouped into two main types; silicon crystalline and thin film technologies. Currently, multi-junction technology is under research and processing, to enhance the PV modules efficiency and to improve the response sensitivity of the sun light spectrum in order to cover the entire incident irradiation wavelength.

Figure 2.10 shows the main parts of the PV module structure, they are as follows:

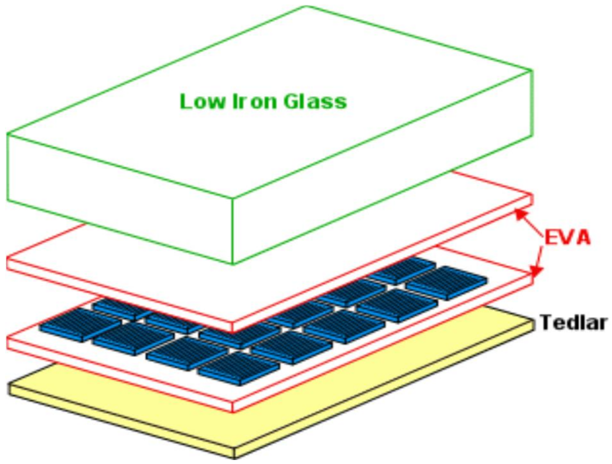

Fig 2.6: PV module layers [27]

Front surface: mainly is a glass cover, and it must have a high transmission and lower flections capability for the concerned sun light wavelength. Low iron glass is commonly used because low cost, strong, of stable, it’s highly transparent and impermeable to water and gases and has good self-cleaning properties.

Encapsulate: is used to provide a strong bond between the solar cells in the module, it should be stable at different operating temperatures and should be transparent with low thermal resistance. EVA (ethyl vinyl acetate) is commonly used with a very thin layer at the front and back surface of the assembled cells [27].

PV cells: is the part which is responsible for producing power.

Back surface: is the back sheet for the PV module, it can be made from Tedlar (thin polymer sheet) material or glass for building façade. It must have low thermal resistance [27].

The following are some of the available PV technologies in the market.

2.2.2.1. Crystalline technology

Crystalline technology is the most efficient PV modules available in the market. In general, silicon based PV cells are more efficient and longer lasting than non-silicon based cells. On the other hand, the efficiency decreases at higher operating temperature [28].

A. Mono crystalline Technology

Mono crystalline is the oldest, most efficient PV cells technology which is made from silicon wafers after complex fabrication process [28]. Mono crystalline PV cells are designed in many shapes: round shapes, semi-round or square bars, with a thickness between 0.2mm to 0.3mm [28]. Round cells are cheaper than semi-round or square cells since less material is wasted in the production. They are rarely used because they do not utilize the module space.

Figure 2.7 shows the mono crystalline PV module and cell layered structure.

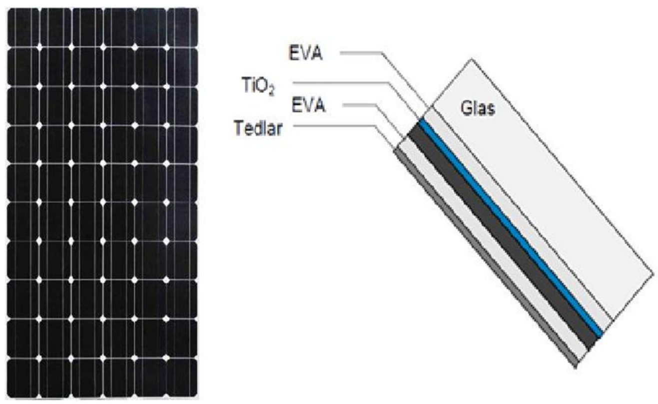

Fig.2.7: Mono crystalline PV module and cell layered structure [29]

The main properties of mono crystalline PV module are:

- Efficiency: 15% to 18%.
- Form: round, semi round or square shape.
- Thickness: 0.2mm to 0.3mm.
- Color: dark blue to black (with ARC), grey (Without ARC).

B. Polycrystalline

Polycrystalline PV modules are cheaper per unit area than mono crystalline; the module structure is similar to the mono crystalline [29]. To increase the overall module efficiency, larger square cells should be used. By using larger cells the module cost will be lower, because less number of cells is used.

Figure 2.8 shows a polycrystalline cell and module.

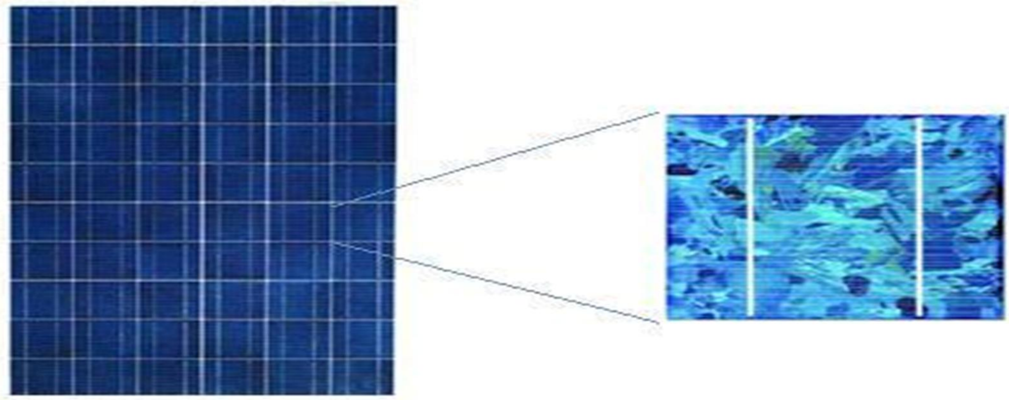

Figure 2.8: Polycrystalline cell and module [30]

The main properties of polycrystalline PV module are [30]:

- Efficiency: 13% to 16 %.
- Form: Square.
- Thickness: 0.24mm to 0.3mm.
- Color: blue (with ARC), silver, grey, brown, gold and green (without ARC).

2.2.2.2. Thin film Technology

Thin film technology represents the second PV generation; due to less production materials and less energy consumption, it's cheaper. Amorphous crystalline silicon, copper tech Indium Selenium (CIS) and Cadmium Telluride (CdTe) are used as semiconductor materials. Because of the high light absorption of these materials, layer thicknesses of less than 0.001mm are theoretically sufficient for converting incident irradiation [30]. It can be seen that thin film technology has the lower cell thickness, semiconductor consumption and primary energy consumption. Thin-film cells are not limited to standard wafer sizes, as in the case of crystalline cells. Theoretically, the substrate can be cut to any size and coated with semiconductor material. However, because only cells of the same size can be connected in series for internal wiring, for practical purposes only rectangular formats which are used for thin film technology. Despite the relatively low efficiency per unit area, thin film technology has many advantages when compared to crystalline technology [30]:

- Better utilization of diffuse and low light intensity.
- Less sensitive to higher operating temperature
- Less sensitive to shading because of long narrow strip design, while a shaded cell on crystalline module will affect the whole module.
- Energy yield at certain condition is higher than crystalline technology.

A. Amorphous Silicon technology (a-Si)

In this case, silicon is deposited in a very thin layer on to a backing substrate such as; metal, glass or even plastic. Figure 2.9 shows layered structure of an amorphous cell. This technology is not preferred to utilize for roof installation due to its low efficiency per unit area which leads to consume a larger area than utilizing crystalline silicon [30].
Another disadvantage of a-Si PV cells is light-induced degradation (known as the which reduces the module efficiency during the first 6-12 months of operation before leveling off at a stable value of the nominal output power [30].

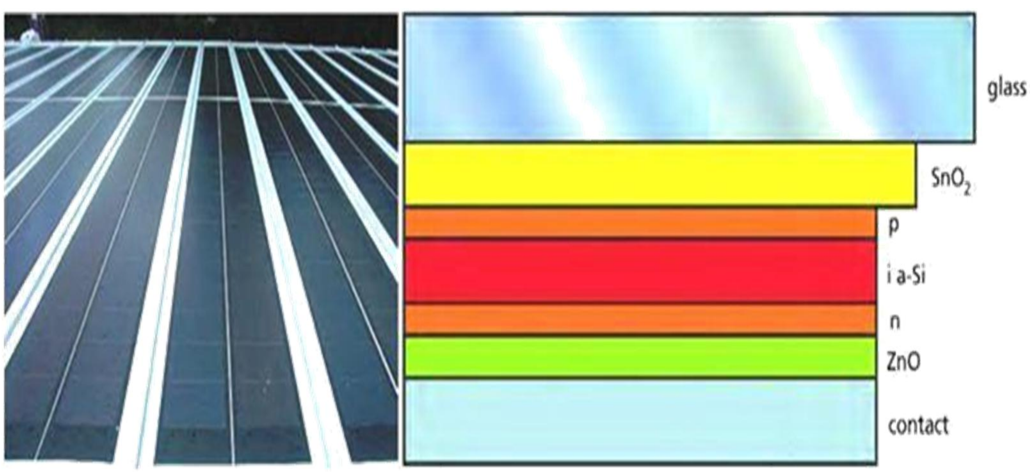

Figure 2.9: Flexible amorphous modules and layered structure of an amorphous cell [30]

The main properties for amorphous silicon PV module are [30]:

- Efficiency: 5% to 7% module efficiency (stabilized condition).
- Thickness: 1mm to 3mm substrate material, which approximately 0.3μm amorphous silicon
- Color: reddish brown to blue or blue-violet.

B. Copper indium Selenium technology (CIS) [59]

Currently, Copper Indium Selenium or diselenide technology is the most efficient thin film technology. CIS compound is often also alloyed with gallium (CIGS) and/or sulphur, and it is not susceptible to light-induced degradation like amorphous silicon.. The other advantages of CIS are:

- Low cost processing method and using less than 1/200 active material vs. crystalline silicon.
- Has a wide spectrum response for the sun light.
- Has the highest module efficiency among thin film technology

Figure 2.10 shows the layered structure for CIS module

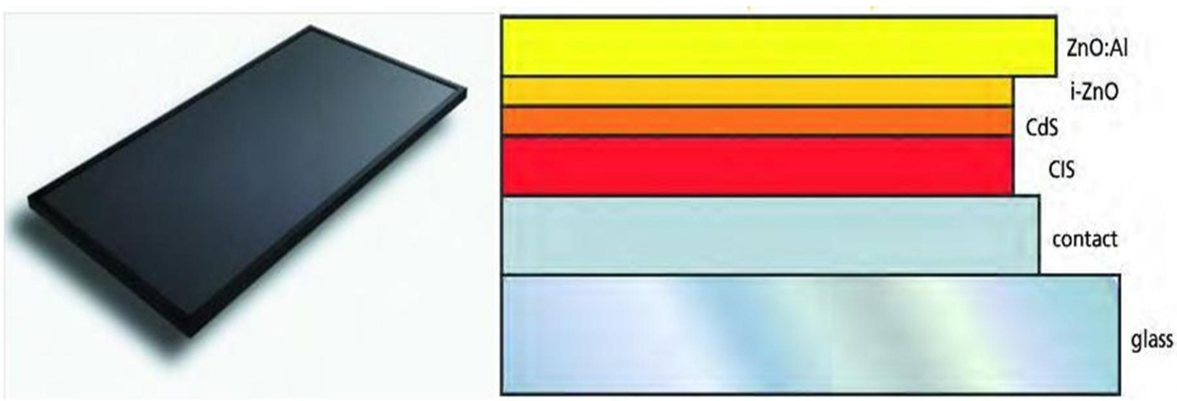

Fig.2.10: CIS modules based on copper indium disulphide and layered structure of a CIS cell [30].

The main properties for CIS PV module are [30]:

Efficiency: 9% to 11% module efficiency.

Thickness: 2mm to 4mm substrate material (non-hardened glass) with 3μm of which approximately 1μm to 2μm CIS.

Color: dark grey to black.

C. Cadmium Telluride technology CdTe

The main advantage of this technology is the lowest production cost among thin film technologies. The back contact is a weak point in CdTe cells since it is responsible for ageing. Modern high-grade CdTe modules do not suffer any initial degradation such as Amorphous technology.

Figure 2.11 shows the layered structure of CdTe PV module [30].

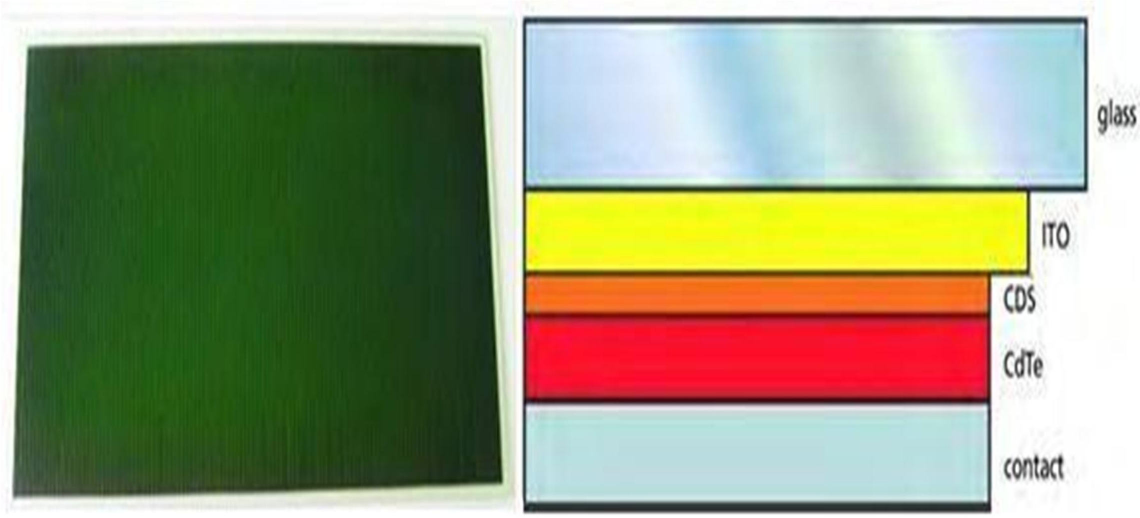

Figure 2.11: CdTe module and layered structure of a CdTe cell Source [30]

The main properties for CdTe PV modules are [30]:

- Efficiency: 7% to 8.5% module efficiency.
- Thickness: 3mm substrate material (non-hardened glass) with 0.005mm coating.
- Color: reflective dark green to black.

D. Micromorphous tandem Technology

Micromorphous silicon module technology combines microcrystalline and amorphous silicon in tandem structure to enhance the performance of the module; they are assembled in the top and bottom of photovoltaic cell. Microcrystalline cells have similar optical properties as the crystalline cells. Also, micromorphous cell has the ability to response to a broad band of the solar spectrum wave length, and the efficiency could reach to 9.1%. The light-induced degradation is very slight comparing with amorphous cells [30]. Figure 2.12 shows layered structure and spectrum response for a certain micromorphous PV module.

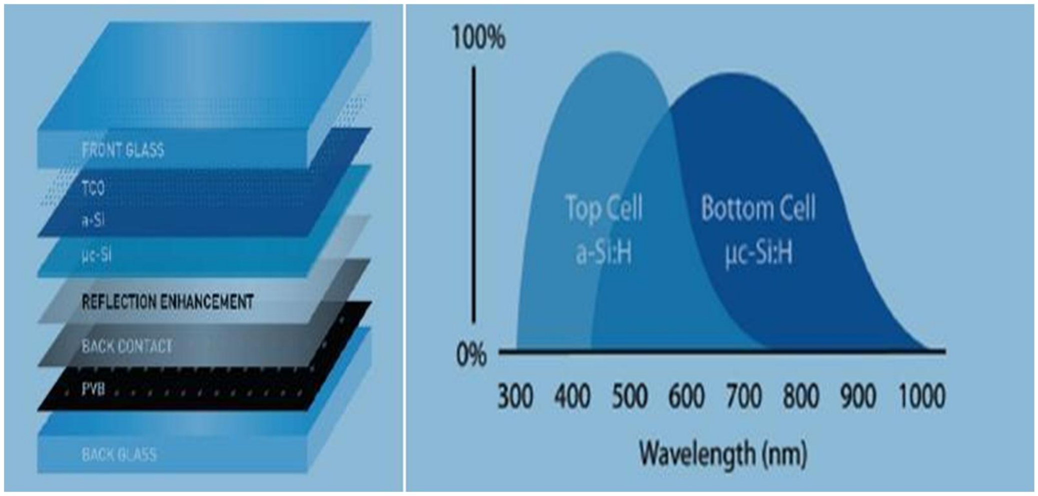

Figure 2.12: Micromorphous layered structured and its spectrum response [31].

2.3 Charge Controller

A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from electric batteries [32]. It prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. Regardless of the battery type chosen for a particular system, a *charge controller* remains an essential component. The primary function of a charge controller is to prevent the battery bank from being overcharged when there is abundant solar insolation available. Overcharging a battery can lead to electrolyte imbalances and depletion. In cases of severe overcharging, batteries can be completely destroyed along with any instrumentation in the vicinity. . It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life [33][34]. The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or to control circuitry integrated within a battery pack, battery-powered device, or battery charger [35].

There is a wide range of charge controllers available, and the design requirements of the system dictate which charge controller should be utilized. The maximum charge rate is the first parameter to consider along with the system voltage. The amp rating of the charge controller should be oversized by a minimum of 25% for enhanced reliability. Greater functionality will be required for more complex systems and those that are deployed year. The Types of charge controllers are the following [36].

Simple one stage or two stage controls: These types rely on relays or shunt transistors to control the voltage in one or two steps. These essentially just short or disconnect the solar panel when a certain voltage is reached. For all practical purposes these are dinosaurs, but you still see a few on old systems - and some of the super cheap ones for sale on the internet. Their only real claim to fame is their reliability - they have so few components, there is not much to break.

Three-stage and/or PWM: Quite a few charge controls have a "PWM" mode. PWM stands for Pulse Width Modulation. PWM is often used as one method of float charging. Instead of a steady output from the controller, it sends out a series of short charging pulses to the battery - a very rapid "on-off" switch. The controller constantly checks the state of the battery to determine how fast to send pulses, and how long (wide) the pulses will be. In a fully charged battery with no load, it may just "tick" every few seconds and send a short pulse to the battery. In a discharged battery, the pulses would be very long and almost continuous, or the controller may go into "full on" mode. The controller checks the state of charge on the battery between pulses and adjusts itself each time. The downside to PWM is that it can also create interference in radios and TV's due to the sharp pulses that it generates. Such types include Morningstar, Xantrex, Blue Sky, Steca, and many others. These are pretty much the industry standard now, but you will occasionally still see some of the older shunt/relay types around, such as in the very cheap systems offered by discounters and mass marketers.

Maximum power point tracking (MPPT): These are the ultimate in controllers, with prices to match - but with efficiencies in the 94% to 98% range, they can save considerable money on larger systems since they provide 10 to 30% more power to the battery. For more information, see our article on MPPT. Most controllers come with some kind of indicator, either a simple LED, a series of LED's, or digital meters. Many newer ones, such as the Outback Power, Midnite Classic, Morningstar MPPT, and others now have built in computer interfaces for monitoring and control. The simplest usually have only a couple of small LED lamps, which show that you have power and that you are getting some kind of charge. Most of those with meters will show both voltage and the current coming from the panels and the battery voltage. Some also show how much current is being pulled from the LOAD terminals. All of the charge controllers that we stock are 3 stage PWM types and the MPPT units (in reality, "4-stage" is somewhat advertising hype - it used to be called equalize, but someone decided that 4 stage was better than 3). And now we even see one that is advertised as "5-stage".

Equalization: Equalization does somewhat what the name implies - it attempts to equalize - or make all cells in the battery or battery bank of exactly equal charge. Essentially it is a period of overcharge, usually in the 15 to 15.5 volt range. If you have some cells in the string lower than others, it will bring them all up to full capacity. In flooded batteries, it also serves the important function of stirring up the liquid in the batteries by causing gas bubbles. Of course, in an RV or boat, this does not usually do much for you unless you have been parked for months, as normal movement will accomplish the same thing. Also, in systems with small panels or oversized battery systems you may not get enough current to really do much bubbling. In many off-grid systems, batteries can also be equalized with a generator+ charger.

2.3.1 Functions of Charge Controllers

Charge controller functions include the following:

- The simplest charge controllers really only perform the overcharge protection function. It is essentially an on/off switch for the PV panels. They are typically sealed units and cannot be re-set to account for variations in battery type. Nevertheless, the simplicity and sealed nature of these controllers makes them quite appropriate for low-power, summer-only applications.

- The next level of sophistication allows for changing the charge parameters. For instance, the voltage level can be set to accommodate the differences between flooded-cell, gel-cell, and AGM-type batteries.

- Temperature compensation is critical for polar applications. Essentially, at colder temperatures, voltages must be increased to achieve the same state of charge. At –40º C, a temperature-compensated charge controller will run about 2.74 volts per cell (16.4 volts in a 12-volt nominal system) to maintain a 100% state of charge. At 50º C, the same temperature-compensated charger would run 2.3 volts per cell (13.8 volts) to maintain a 12-volt battery at a 100% state of charge. Some charge controllers have this functionality built into the circuit board, whereas others use a remote sensor.

- Some charge controllers can also function as load controllers, or they can function to send excess energy to a diversion load. As a DC load controller, the function is typically to serve as a low-voltage disconnect. This allows the battery bank to be protected from over discharge as discussed previously. When used in the diversion control mode, excess energy that would otherwise be wasted when the battery is full is instead routed to a dump load, most typically a resistive air or water heater. This can be a very important function in polar environments where heat is usually a useful energy source. Note that most charge controllers with these capabilities can still only operate in one of the three modes—either as a charge controller, diversion controller, or DC load controller. Multiple controllers may be required.

- The next level of functionality involves multi-stage charge control, most typically bulk, absorb, and float levels This allows for a high current rate during the bulk stage, which then tapers off current as the voltage rises into the absorb level. The float stage reduces voltage to prevent excessive gassing and is really meant as a trickle charge to keep the batteries fully topped off. For battery longevity, it is critical that the float level is reached and maintained for fairly long periods of time.

- Pulse width modulated (PWM) chargers sense; small voltage drops and reacts by sending out short charging cycles. This can occur many times per minute. It allows for more accurate charging at the float level and tends to reduce sulfation of batteries kept at float for long periods of time.

- The latest generation of charge controllers incorporates a technology called maximum power point tracking, or MPPT. This function is designed to increase the efficiency of the PV array by converting the typically higher voltage (17-21 VDC in a 12 VDC nominal system) to the 14 VDC or so required to charge the battery. Stated simply, the un-useable high-end voltage is converted to useable extra amps. Remember the relationship between volts, amps, and watts: watts = amps x volts. An MPPT charge controller takes advantage of this relationship to deliver more useable power from the PV array to the batteries. The electronics utilized to make this work are quite sophisticated, however, and the price of the controller is consequently much higher. At the moment, there are only a few MPPT charge controllers available. However, because the benefits are quite obvious and quantifiable, there will no doubt be several more showing up on the market, and prices should start to come down.

- Finally, some high-quality charge controllers allow for a higher array voltage than the system voltage. For instance, a PV array can be wired for a 48 VDC nominal output to feed a 24 VDC nominal battery bank. The advantage of the higher array voltage is that significantly smaller conductors can be used without incurring unacceptable voltage drops. This can be an important consideration if the PV array needs to be set some distance away from the battery bank due to site or project requirements. For a look at relative conductor sizes and current carrying capacities, see the chart in the section on conductors below. Note that higher array voltages also pose a greater shock hazard. It is nearly impossible for a person to be shocked by a 12 VDC nominal system (although sparks will still fly if an un-insulated positive lead comes in contact with a grounded component) in contrast to a 48 VDC nominal or higher system. The open-circuit voltage on a 48-volt PV array is typically more like 80 to 90 volts and is quite capable of delivering a shock. If relatively untrained individuals will be setting up or servicing the system, it may be prudent to stick with 24 or lower voltages for the system.

In conclusion, select a charge controller that meets or exceeds the requirements of the system. It may not be necessary to spend hundreds of dollars on a charge controller if the needs of the system are quite basic. Also consider that the liquid crystal displays (LCD) usually found on high-end models will likely be inoperable and may even crack at extremely low temperatures

2.4. Solar Power Batteries

Batteries are often used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Other reasons because batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, battery charge controller is used in these systems to protect the battery from overcharge and over discharge. In stand-alone systems, the power generated by the solar panels is usually used to charge a lead-acid battery. Other types of battery such as nickel-cadmium batteries may be used, but the advantages of the lead-acid battery ensure that it is still the most popular choice. A battery is composed of individual cells; each cell in a lead-acid battery produces a voltage of about 2 Volts DC, so a 12 Volt battery needs 6 cells. The capacity of a battery is measured in Ampere-hours or Amp-hours (Ah). To properly select batteries for use in stand-alone PV systems, it is important that system designers have a good understanding of their design features, performance characteristics and operational requirements [37]. The information in the following sections is intended as a review of basic battery characteristics and terminology as is commonly used in the design and application of batteries in PV systems.

Battery Construction: Battery manufacturing is an intensive, heavy industrial process involving the use of hazardous and toxic materials. Batteries are generally mass produced, combining several sequential and parallel processes to construct a complete battery unit. After production, initial charge and discharge cycles are conducted on batteries before they are shipped to distributors and consumers. Manufacturers have variations in the details of their battery construction, but some common construction features can be described for most all batteries. Some important components of battery construction are described below.

Cell: The cell is the basic electrochemical uniting a battery, consisting of a set of positive and negative plates divided by separators, immersed in an electrolyte solution and enclosed in a case.

Active Material: The active materials in a battery are the raw composition materials that form the positive and negative plates, and are reactants in the electrochemical cell. The amount of active material in a battery is proportional to the capacity a battery can deliver. In lead-acid batteries, the active materials are lead dioxide (PbO_2) in the positive plates and metallic sponge lead (Pb) in the negative plates, which react with a sulfuric acid (H_2SO_4) solution during battery operation [38].

Electrolyte: The electrolyte is a conducting medium which allows the flow of current through ionic transfer, or the transfer of electrons between the plates in a battery. In a lead-acid battery, the electrolyte is a diluted sulfuric acid solution, either in liquid (flooded) form, gelled or absorbed in glass mats. In flooded nickel- cadmium cells, the electrolyte is an alkaline solution of potassium hydroxide and water. In most flooded battery types, periodic water additions are required to replenish the electrolyte lost through gassing. When adding water to batteries, it is very important to use distilled or de-mineralized water, as even the impurities in normal tap water can poison the battery and result in premature failure.

Grid: In a lead-acid battery, the grid is typically a lead alloy framework that supports the active material on a battery plate, and which also conducts current. Alloying elements such as antimony and calcium are often used to strengthen the lead grids, and have characteristic effects on battery performance such as cycle performance and gassing. Some grids are made by expanding a thin lead alloy sheet into a flat plate web, while others are made of long spines of lead with the active material plated around them forming tubes, or what are referred to as tubular plates.

Plate: A plate is a basic battery component, consisting of a grid and active material, sometimes called an electrode. There are generally a number of positive and negative plates in each battery cell, typically connected in parallel at a bus bar or inter-cell connector at the top of the plates. A pasted plate is manufactured by applying a mixture of lead oxide, sulfuric acid, fibers and water on to the grid. The thickness of the grid and plate affect the deep cycle performance of a battery. In automotive starting or SLI type batteries, many thin plates are used per cell. This results in maximum surface area for delivering high currents, but not much thickness and mechanical durability for deep and prolonged discharges. Thick plates are used for deep cycling applications such as for forklifts, golf carts and other electric vehicles. The thick plates permit deep discharges over long periods, while maintaining good adhesion of the active material to the grid, resulting in longer life.

Separator: A separator is a porous, insulating divider between the positive and negative plates in a battery, used to keep the plates from coming into electrical contact and short-circuiting, and which also allows the flow of electrolyte and ions between the positive and negative plates. Separators are made from micro-porous rubber, plastic or glass-wool mats. In some cases, the separators may be like an envelope, enclosing the entire plate and preventing shed materials from creating short circuits at the bottom of the plates.

Element: An element is defined as a stack of positive and negative plate groups and separators, assembled together with plate straps interconnecting the positive and negative plates.

Terminal Posts: Terminal posts are the external positive and negative electrical connections to a battery. A battery is connected in a PV system and to electrical loads at the terminal posts. In a lead-acid battery the posts are generally lead or a lead alloy, or possibly stainless steel or copper-plated steel for greater corrosion resistance. Battery terminals may require periodic cleaning, particularly for flooded designs. It is also recommended that the clamps or connections to battery terminals be secured occasionally as they may loosen over time.

Cell Vents: During battery charging, gasses are produced within a battery that maybe vented to the atmosphere. In flooded designs, the loss of electrolyte through gas escape from the cell vents it a normal occurrence, and requires the periodic addition of water to maintain proper electrolyte levels. In sealed or valve-regulated batteries, the vents are designed with a pressure relief mechanism, remaining closed under normal conditions, but opening during higher than normal battery pressures, often the result of overcharging or high temperature operation. Each cell of a complete battery unit has some type of cell vent.

Case: Commonly made from a hard rubber or plastic, the case contains the plates, separators and electrolyte in a battery. The case is typically enclosed, with the exception of inter-cell connectors which attach the plate assembly from one cell to the next, terminal posts, and vents or caps which allow gassing products to escape and to permit water additions if required. Clear battery cases or containers allow for easy monitoring of electrolyte levels and battery plate condition. For very large or tall batteries, plastic cases are often supported with an external metal or rigid plastic casing.

2.4.1. Battery Types and Classifications

Many types and classifications of batteries are manufactured today, each with specific design and performance characteristics suited for particular applications. Each battery type or design has its individual strengths and weaknesses. In PV systems, lead-acid batteries are most common as we said before, due to their wide availability in many sizes, low cost and well understood performance characteristics. In a few critical, low temperature applications nickel-cadmium cells are used, but their high initial cost limits their use in most PV systems. There is no “perfect battery” which battery type is most appropriate for each application. In general, electrical storage batteries can be divided into two major categories, primary and secondary batteries [39].

2.4.1.1. Primary Batteries

Primary batteries can store and deliver electrical energy, but cannot be recharged. Typical carbon-zinc and lithium batteries commonly used in consumer electronic devices are primary batteries. Primary batteries are not used in PV systems because they cannot be recharged [40] [41].

2.4.1.2 Secondary Batteries

A secondary battery can store and deliver electrical energy, and can be recharged by passing a current through it in an opposite direction to the discharge current. Common lead-acid batteries used in automobiles and PV systems are secondary batteries [42] [43].

Lead-Acid Battery Classifications

Many types of lead-acid batteries are used in PV systems, each having specific design and performance characteristics. While there are many variations in the design and performance of lead-acid cells, they are often classified in terms of one of the following three categories:

SLI Batteries: Starting, lighting and ignition (SLI) batteries are a type of lead-acid battery designed primarily for shallow cycle service.

Motive Power or Traction Batteries: Motive power or traction batteries are a type of lead acid battery designed for deep discharge cycle service, typically used in electrically operated vehicles and equipment such as golf carts, forklifts and floor sweepers. These batteries have a fewer number of plates per cell than SLI batteries; however the plates are much thicker and constructed more durably. High content lead-antimony grids are primarily used in motive power batteries to enhance deep cycle performance. Traction or motive power batteries are very popular for use in PV systems due to their deep cycle capability, long life and durability of design.

Stationary Batteries: Stationary batteries are commonly used in un-interruptible power supplies (UPS) to provide backup power to computers, telephone equipment and other critical loads or devices. Stationary batteries may have characteristics similar to both SLI and motive power batteries, but are generally designed for occasional deep discharge, limited cycle service

Table 2.1.Battery selection table for PV systems

Battery type (Standard application area)	SLI (Cars)	SLI (Trucks)	Lighting/Leisure (caravans boats cottages)	Solar (modified for PV use)	Semi Traction (golf carts, lawn mowers etc.)	Traction (fork lift trucks i.e.)	Stationary (telecom i.e.)
Positive plate design	Pasted	Pasted	Pasted	Pasted	Pasted/ Rod	Tubular	Tubular/ Rod
Advantages	High power	High power			Fairly high power	Accepts deep discharge	Rugged
	Rapid recharge possible	Rapid recharge possible			Acceptable cycle life	Accepts overcharge	Reliable
		Longer PV- life than car battery	Longer PV- life than car battery	Longer PV- life than car battery		Good for cycling application	
Disadvant-ages	Sensitive to deep discharge	Sensitive to deep discharge	Limited cycle life	Limited cycle life	Limited cycle life	Require high overcharge	Sensitive to high overcharge and deep discharge
Relative invest-ment cost (Ref. 2)	1.0-1.3	1.3-1.5	1.5-2	1.4-1.6	1.5-2.0	4-8	4-7
Comments	**Very short life in most PV systems. Not recommend ed for PV systems**	**Can achieve acceptable lifetime in low cost PV system with shallow cycling**	**Can achieve accept-able lifetime in low cost PV system with shallow cycling**	**Best lifetime in low cost PV systems**	May give favourable life cycle cost in professional PV system with shallow cycles	May give favourable life cycle cost in professional PV system with deep cycles	Plante type is not recommende d for PV systems.

There are several types of lead-acid batteries manufactured. The following sections describe the types of lead-acid batteries commonly used in PV systems.

A. Lead-Antimony Batteries

Lead-antimony batteries are a type of lead-acid battery which uses antimony (Sb) as the primary alloying element with lead in the plate grids. The use of lead-antimony alloys in the grids has some advantages. The advantages include providing greater mechanical strength than pure lead grids, and excellent deep discharge and high discharge rate performance. Lead-antimony grids also limit the shedding of active material and have better lifetime than lead-calcium batteries when operated at higher temperatures. Most lead-antimony batteries are flooded, open vent types with removable caps to permit water additions. They are well suited to application in PV systems due to their deep cycle capability and ability to take abuse, however they do require periodic water additions.

B. Lead-Calcium Batteries

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

C. Flooded Lead-Calcium, Open Vent

Often classified as stationary batteries, these batteries are typically supplied as individual 2 volt cells in capacity ranges up to and over 1000 ampere-hours. Flooded lead-calcium batteries have the advantages of low self-discharge and low water loss, and may last as long as 20 years in stand-by or float service. In PV applications, these batteries usually experience short lifetimes due to salvation and stratification of the electrolyte unless they are charged properly.

D. Flooded Lead-Calcium, Sealed Vent

Primarily developed as 'maintenance free' automotive starting batteries, the capacity for these batteries is typically in the range of 50 to 120 ampere-hours, in a nominal 12 volt unit. Like all lead-calcium designs, they are intolerant of overcharging, high operating temperature and deep discharge cycles. They are “maintenance free” in the seawater, but they are also limited by the fact that you cannot add water which generally limits their useful life. These batteries are often employed in small stand-alone PV systems such as in rural homes and lighting systems, but must be carefully charged to achieve maximum performance and life. While they are low cost, they are really designed for shallow cycling, and will generally have a short life in most PV applications

An example of this type of battery that is widely produced throughout the world is the Delco 2000. It is relatively low cost and suitable for unsophisticated users that might not properly maintain their battery water level. However, it is really a modified SLI battery, with many thin plates, and will only provide a couple years of useful service in most PV systems.

E. Lead-Antimony/Lead-Calcium Hybrid

These are typically flooded batteries, with capacity ratings of over 200 ampere-hours. A common design for this battery type uses lead-calcium tubular positive electrodes and pasted lead-antimony negative plates. This design combines the advantages of both lead-calcium and lead-antimony design, including good deep cycle performance, low water loss and long life. Stratification and salvation can also be a problem with these batteries, and must be treated accordingly. These batteries are sometimes used in PV systems with larger capacity and deep cycler equipments. A common hybrid battery using tubular plates is the Exide Solar battery line manufactured in the United States.

F. Captive Electrolyte Lead-Acid Batteries

Captive electrolyte batteries are another type of lead-acid battery, and as the name implies, the electrolyte is immobilized in some manner and the battery is sealed under normal operating conditions. Under excessive overcharge, the normally sealed vents open under gas pressure. Often captive electrolyte batteries are referred to as valve regulated lead acid (VRLA) batteries, noting the pressure regulating mechanisms on the cell vents. Electrolyte cannot be replenished in these battery designs; therefore they are intolerant of excessive overcharge. Captive electrolyte lead-acid batteries are popular for PV applications because they are spill proof and easily transported, and they require no water additions making them ideal for remote applications where maintenance is infrequent or unavailable. However, a common failure mode for these batteries in PV systems is excessive overcharge and loss of electrolyte, which is accelerated in warm climates. For this reason, it is essential that the battery charge controller regulation set points are adjusted properly to prevent overcharging. This battery technology is very sensitive to charging methods, regulation voltage and temperature extremes. An optimal charge regulation voltage for captive electrolyte batteries varies between designs, so it is necessary to follow manufacturer's recommendations when available. When no information is available, the charge regulation voltage should be limited to no more than 14.2 volts at 25 C for nominal 12 volt batteries. A benefit of captive or immobilized electrolyte designs is that they are less susceptible to freezing compared to flooded batteries. Typically, lead-calcium grids are used in captive electrolyte batteries to minimize gassing; however some designs use lead-antimony/calcium hybrid grids to gain some of the favorable advantages of lead-antimony batteries.

The two most common captive electrolyte batteries are the gelled electrolyte and absorbed glass mat designs.

I. Gelled Batteries

Initially designed for electronic instruments and consumer devices, gelled lead-acid batteries typically use lead-calcium grids. The electrolyte is 'gelled' by the addition of silicon dioxide to the electrolyte, which is then added to the battery in a warm liquid form and gels as it cools. Gelled batteries use an internal recombinant process to limit gas escape from the battery, reducing water loss. Cracks and voids develop within the gelled electrolyte during the first few cycles, providing paths for gas transport between the positive and negative plates, facilitating the recombinant process. Some gelled batteries have a small amount of phosphoric acid added to the electrolyte to improve the deep discharge cycle performance of the battery. The phosphoric acid is similar to the common commercial corrosion inhibitors and metal preservers, and minimizes grid oxidation at low states of charge.

II. Absorbed Glass Mat (AGM) Batteries

Another sealed, or valve regulated lead-acid battery, the electrolyte in an AGM battery is absorbed in glass mats which are sandwiched in layers between the plates. However, the electrolyte is not gelled. Similar in other respects to gelled batteries, AGM batteries are also intolerant to overcharge and high operating temperatures. Recommended charge regulation methods stated above for gelled batteries also apply to AGMs. A key feature of AGM batteries is the phenomenon of internal gas recombination. As a charging lead-acid battery nears full state of charge, hydrogen and oxygen gasses are produced by the reactions at the negative and positive plates, respectively. In a flooded battery, these gasses escape from the battery through the vents, thus requiring periodic water additions. In an AGM battery the excellent ion transport properties of the liquid electrolyte held suspended in the glass mats, the oxygen molecules can migrate from the positive plate and recombine with the slowly evolving hydrogen at the negative plate and form water again. Under conditions of controlled charging, the pressure relief vents in AGM batteries are designed to remain closed, preventing the release of any gasses and water loss.

G. Calcium-Calcium

The next stage has dominated on a wide front in recent years and is called Calcium-Calcium. This involves the antimony on both the negative and positive plates being replaced by calcium alloy. The benefits are obvious. The fluid loss of the battery is about 80 % lower than that of antimony batteries and the self-discharge is lower, i.e. they can remain unused for longer periods without losing a lot of their charge. The disadvantage is that they are more demanding when charging if they have been over-discharged. Efforts made in avoiding the gassing had a positive effect, namely that the bubbles moved about in the acid causing it to be thoroughly mixed when charging. Without these bubbles the acid can stratify at different densities, acid weights, and is quite a common phenomenon. An acid weight of 1.35or more at the bottom and maybe 1.17 at the top when you are looking for an even weight of 1.28 may cause the battery to be affected by sulphating and increased grid corrosion despite the battery being apparently fully charged.

H. Nickel-Cadmium Batteries

Nickel-cadmium (Ni-Cad) batteries are secondary or rechargeable batteries, and have several advantages over lead-acid batteries that make them attractive for use in stand-alone PV systems. These advantages include long life, low maintenance; survivability from excessive discharges, excellent low temperature capacity retention, and non-critical voltage regulation requirements. The main disadvantages of nickel- cadmium batteries are their high cost and limited availability compared to lead-acid designs. A typical nickel-cadmium cell consists of positive electrodes made from nickel-hydroxide (NiO (OH)) and negative electrodes made from cadmium (Cd) and immersed in an alkaline potassium hydroxide (KOH) electrolyte solution.

When a nickel-cadmium cell is discharged, the nickel hydroxide changes form (Ni(OH)2) and the cadmium becomes cadmium hydroxide (Cd (OH)2). The concentration of the electrolyte does not change during the reaction so the freezing point stays very low.

Ni-Cd Types:

a) Sintered Plate Ni-Cads

Sintered plate nickel cadmium batteries are commonly used in electrical test equipment and consumer electronic devices. The batteries are designed by heat processing the active materials and rolling them into metallic case. The electrolyte in sintered plate nickel-cadmium batteries is immobilized, preventing leakage, allowing any orientation for installation. The main disadvantage of sintered plate designs is the so called 'memory effect', in which a battery that is repeatedly discharged to only a percentage of its rated capacity will eventually 'memorize' this cycle pattern, and will limit further discharge resulting in loss of capacity. In some cases, the 'memory effect' can be erased by conducting special charge and discharge cycles, regaining some of its initial rated capacity.

b) Pocket Plate Ni-Cads

Large nickel cadmium batteries used in remote telecommunications systems and other commercial applications are typically of a flooded design, called flooded pocket plate. Similar to flooded lead-acid designs, these batteries require periodic water additions; however, the electrolyte is an alkaline solution of potassium hydroxide, instead of a sulfuric acid solution. Advantages: These batteries can withstand deep discharges and temperature extremes much better than lead-acid batteries, and they do not experience the 'memory effect' associated with sintered plate Ni-Cads. The main disadvantage of pocket plate nickel cadmium batteries is their high initial cost; however their long lifetimes can result in the lowest life cycle cost battery.

2.4.2 Considerable values of a chargeable battery

Charging and discharging: Battery charging and discharging rates are often discussed by referencing a "C" rate of current. The C rate is that which would theoretically fully charge or discharge the battery in one hour. For example, trickle charging might be performed at C/20 (or a "20 hour" rate), while typical charging and discharging may occur at C/2 (two hours for full capacity)[44].

Depth of discharge (DOD): is normally stated as a percentage of the nominal ampere-hour capacity; 0% DOD means no discharge. Seeing as the usable capacity of a battery system depends on the rate of discharge and the allowable voltage at the end of discharge, the depth of discharge must be qualified to show the way it is to be measured.

Lifespan and cycle stability: If batteries are used repeatedly even without mistreatment, they lose capacity as the number of charge cycles increases, until they are eventually considered to have reached the end of their useful life.

2.5. Power inverter

Inverter is an electronic device or circuitry that changes direct current (DC) to alternating current (AC) [45]. The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source. A power inverter can be entirely electronic or may be a combination of mechanical effects (such as a rotary apparatus) and electronic circuitry. Static inverters do not use moving parts in the conversion process.

2.5.1. Classification of Inverters

Solar inverters may be classified into three broad types [46]:

Stand-alone inverters are used in isolated systems where the inverter draws its DC energy from batteries charged by photovoltaic arrays. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source, when available. Normally these do not interface in any way with the utility grid, and as such, are not required to have anti-islanding protection.

Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages.

Battery backup inverters are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection.

2.5.2. Input and output of inverter

Input voltage: a typical power inverter device or circuit requires a relatively stable DC power source capable of supplying enough current for the intended power demands of the system. The input voltage depends on the design and purpose of the inverter. Examples include:

12 VDC; for smaller consumer and commercial inverters that typically run from a rechargeable 12 V lead acid battery [47].

24 and 48 VDC; which are common standards for home energy systems.

Output waveform: an inverter can produce a square wave, modified sine wave, pulsed sine wave, pulse width modulated wave (PWM) or sine wave depending on circuit design. The two dominant commercialized waveform types of inverters as of 2007 are modified sine wave and sine wave. There are two basic designs for producing household plug-in voltage from a lower-voltage DC source, the first of which uses a switching boost converter to produce a higher-voltage DC and then converts to AC. The second method converts DC to AC at battery level and uses a line-frequency transformer to create the output voltage [48].

Square wave: This is one of the simplest waveforms that an inverter design can produce and is best suited to low-sensitivity applications such as lighting and heating. Square wave output can produce "humming" when connected to audio equipment and is generally unsuitable for sensitive electronics.

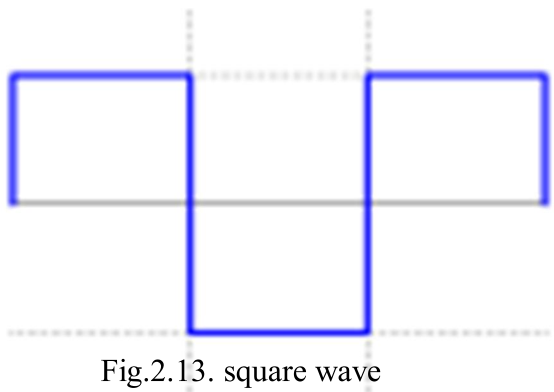

Fig.2.13. square wave

Sine wave: A power inverter device which produces a multiple step sinusoidal AC waveform is referred to as a sine wave inverter. To more clearly distinguish the inverters with outputs of much less distortion than the "modified sine wave" (three steps) inverter designs. Power inverter devices substitute for standard line power, a sine wave output is desirable because many electrical products are engineered to work best with a sine wave AC power source.

The standard electric utility power attempts to provide a power source that is a good approximation of a sine wave.

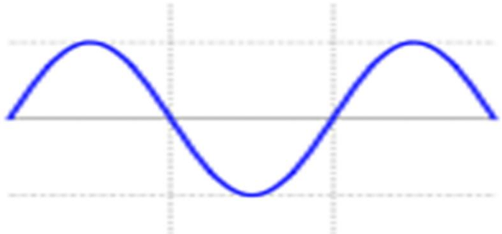

Fig.2.14. Sine wave

Sine wave inverters with more than three steps in the wave output are more complex and have significantly higher cost than a modified sine wave, with only three steps, or square wave (one step) types of the same power handling. Switch-mode power supply (SMPS) devices, such as personal computers or DVD players, function on quality modified sine wave power. AC motors directly operated on non-sinusoidal power may produce extra heat, may have different speed-torque characteristics, or may produce more audible noise than when running on sinusoidal power.

Modified sine wave: it has a non-square waveform that is a useful rough approximation of a sine wave for power translation purposes.

Most inexpensive consumer power inverters produce a modified sine wave rather than a pure sine wave. The waveform in commercially available modified-sine-wave inverters is a square wave with a pause before the polarity reversal, which only needs to cycle back and forth through a three-position switch that outputs forward, off, and reverse output at the pre-determined frequency[48].

Output frequency: The AC output frequency of a power inverter device is usually the same as standard power line frequency, 50 or 60 hertz

If the output of the device or circuit is to be further conditioned (for example stepped up) then the frequency may be much higher for good transformer efficiency.

Output voltage: The AC output voltage of a power inverter is often regulated to be the same as the grid line voltage, typically 120 or 240 VAC, even when there are changes in the load that the inverter is driving. This allows the inverter to power numerous devices designed for standard line power. Some inverters also allow selectable or continuously variable output voltages.

Output power: A power inverter will often have an overall power rating expressed in watts or kilowatts. This describes the power that will be available to the device the inverter is driving and, indirectly, the power that will be needed from the DC source. Smaller popular consumer and commercial devices designed to mimic line power typically range from 150 to 3000 watts.

Not all inverter applications are solely or primarily concerned with power delivery; in some cases the frequency and or waveform properties are used by the follow-on circuit or device.

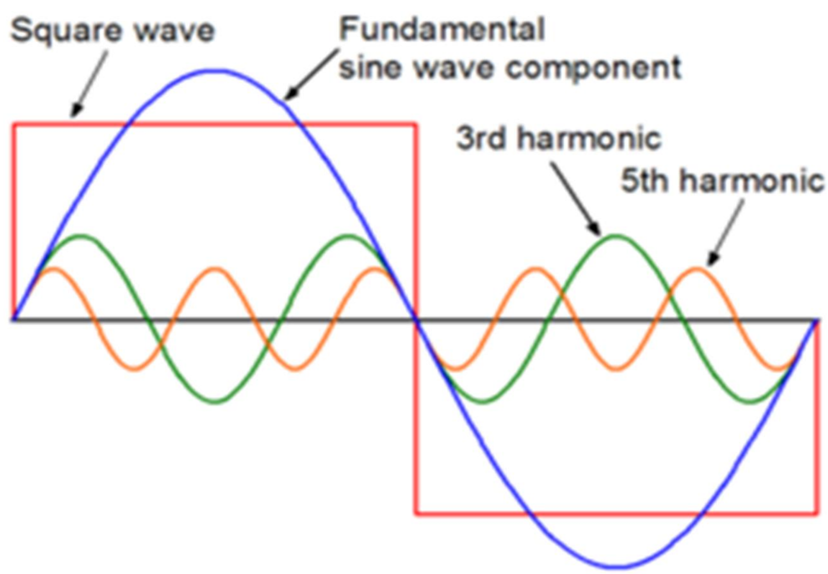

Fig.2.15 Square waveform with fundamental sine wave component, 3rdharmonics&5thharmonic

CHAPTER THREE

3. METHODOLOGY

3.1. Data Source

Before designing the project a researcher needs to gather necessary data from their respective sources. So we gathered load profile data from ASTU ICT Building server room and meteorological data from National meteorological Agency, Adama branch.

Load profile data were used to identify the primary loads of the ASTU ICT Building server room, to determine operating hours of each load, and to identify loads as AC, DC or both, whereas meteorological data is used to obtain the peak sun hour (PSH) or insolation/ irradiation value of each day which helps to design or calculate the charging current of the solar PV power system project.

3.2. Data Collecting Methods

To collect the necessary data for our study, we have used the following methods:

3.2.1. Interview

Interviewing is "a formal face-to-face meeting in which facts or statements are elicited from another. It is used to collect data from a small group of subjects on a broad range of topics. Either structured or unstructured interview can be used for the study. Structured interviews are comparable to a questionnaire, with the same questions in the same order for each subject and with multiple choice answers. For unstructured interviews questions can differ per subject and can depend on answers given on previous questions, there is no fixed set of possible answers [49][50].

Using unstructured interview research method, we have interviewed the ASTU ICT Building server room authorized personnel about what the primary loads are there, for how much time each load operates, what problems occur during grid power interruption, and the alternatives they used to reduce the problem. From the interview, we have identified the server room primary loads and we recorded the load of each device’s power rating; similarly we understood that almost all the loads operate for 24 hours. The other response obtained from the interview is data reconfiguration is needed when the grid electric power interrupts and they have been using diesel generator as a backup.

3.2.2. Observation

The other method used to develop load profile data is the observation method. Observation method is way of gathering data by watching behaviors, events, or noting physical characteristics in their natural settings. Observations can be overt (everyone knows they are being observed) or covert (no one knows they are being observed and the observer is concealed). The benefit of covert observation is that people are more likely to behave naturally if they do not know they are being observed [51]. In our case we used the overt type observation method and we have identified that all the stated server room loads are Alternative Current (AC) loads; also we have observed the voltage ratings and the power or current rating from the name plates' data of each load and finally we recorded the load profiles as shown in table 3.1.

Table 3.1Full load profile of ASTU ICT Building Server Room

D	E	F	G	H	I	J	K
Column D	Column E	Column F	Column G	Column H	Column I	column J	
server	27	220	0.92	24.84	24	596.16	
core switch	6	220	1.68	10.08	24	241.92	
Air conditioner	3	220	4.4	13.2	24	316.8	
switching	10	220	0.44	4.4	24	105.6	
lamp	18	220	0.036	0.648	12	7.776	
Keyboard Virtual Machine	8	220	0.176	1.408	24	33.792	
computer	23	220	0.2	4.6	24	110.4	
Box K :Total load power rating				59.176	KW		
Box L: Total daily energy d						1412.448	KWh

3.2.3. Documentation analysis

Documentation method is a way of collecting data by reviewing existing recorded documents. Documents may be hard copy or electronic and may include reports, program logs, performance ratings, funding proposals, meeting minutes, newsletters, and marketing materials[52].In our case we have obtained an electronic copy of recorded data for peak sun hour or insolation value of the past five years, latitude value and altitude value from National meteorological Agency, Adama branch. These data are listed below.

Table 3.2: Average peak sun hour of each month of the past five years in Adama.

Month	Peak sun hours
Jan	9.780259
Feb	9.441828
Mar	8.24979
Apr	8.620778
May	7.811135
Jun	6.644557
Jul	6.143151
Aug	7.079938
Sep	10.21606
Oct	8.620994
Nov	10.63201
Dec	10.17709

Longitude = 8^{o}33”23.8’N
Latitude=39^{o}17”02.5”E
Altitude=1648m above sea level

The peak sun hour value of each month is the average value of the thirty days peak sun hour values in that month for each of the five years (from 2011 to2015). From these PSH values the one which is used in the system design is the lowest value, 6.143151~6.14. The month corresponding to this value, in our case July is termed as the design month [53].

3.3. Block Diagram

The block diagram of a solar PV power system is illustrated in figure below.

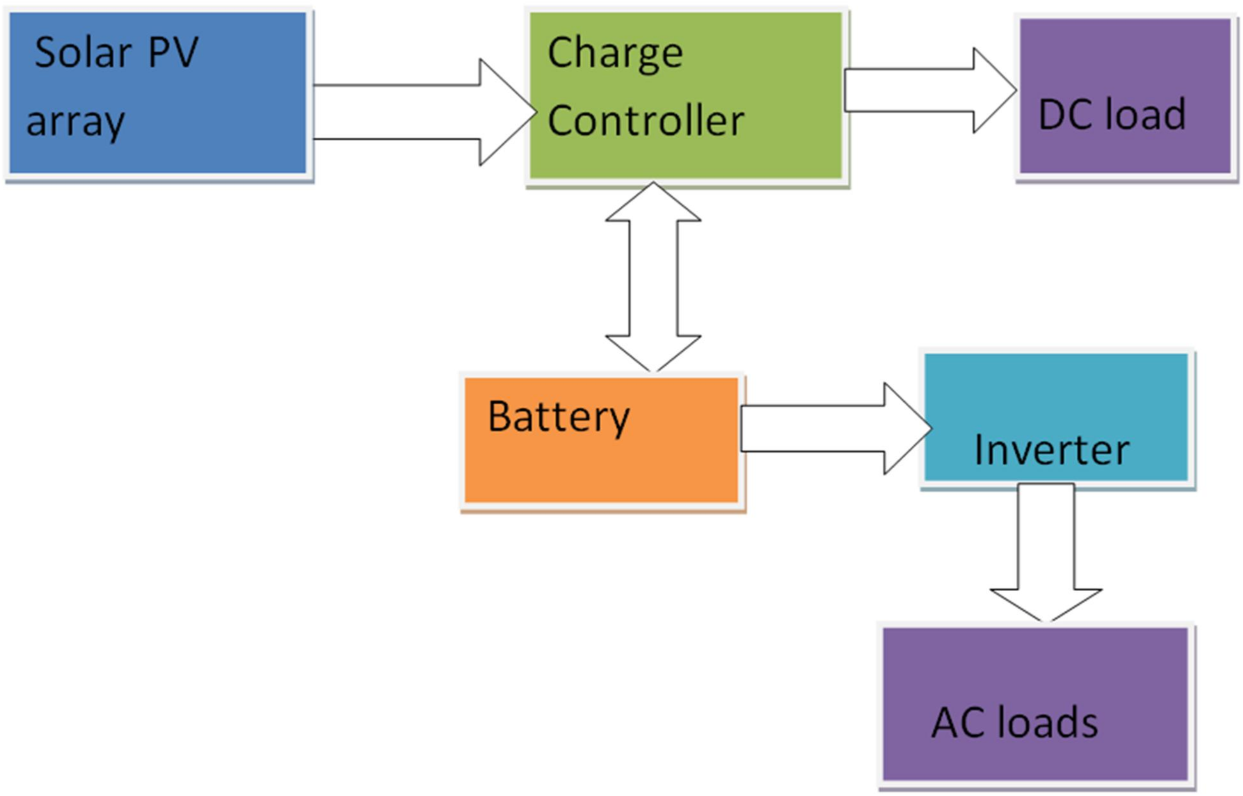

Fig.3.1. block diagram of solar PV system.

3.4. System Design

Without design a solar investment may turn out to be less functional and more expensive than intended. For our system design we used Excel software. It plays a great role in designing analysis of a solar PV power system. Excel performs the following activities.

- It determines the capacities quantities of each solar PV devices based on the total daily load energy demand and operating hours of each load.
- It evaluates the costs of individual devices as well as the costs of the whole system.

The general integrated design process of our project is as follows:

- Obtaining of the solar radiation value available around the site.
- Collection of the loads those are supported by the system.
- Construction of a load profile, calculation of design load and design energy.
- Selection of the system voltage.
- Calculation of the required battery capacity based on the design loads.
- Estimation of the output of a single PV module at the proposed site location.
- Calculation of size of the PV array.
- Determination of inverter sizing.
- Cost and financial analysis.

The individual loads have been well understood in terms of; their voltage ratings, current ratings, power ratings and hours of usage each day etc. This information's are used to size the array and battery to handle unexpected bad weather. This has been attained by collecting all the necessary data information from the selected site, Adama Science &Technology University ICT building Data center.

3.3.1. Design Considerations

- The design method is a tool that simulates how solar PV systems work.
- The types and prices of available equipments should be checked from a shop around.
- The loads should be estimated carefully and realistically. Over estimation of the load would increase the cost of the system significantly. Under estimating the size of the load might result in continual battery problem.

3.3.2. Design Procedure

There are two common methods by which system designer's size off-grid PV systems. These are ampere-hour method and watt-hour method. Both methods give the same answer if done properly. The ampere-hour sizing takes in to account the real world behavior of PV modules and batteries. In our case we have used the ampere-hour method. Our PV system design procedure is subdivided in to four worksheets of excel software [53]. All the worksheets communicate to each other so that the variation in a load, size, or operating hour automatically results in change of all the calculated values. These design procedures are as follows.

- Worksheet 1: Calculation of load energy and selection of system voltage.
- Worksheet 2: Survey of solar resource selection of PV modules.
- Worksheet 3: Sizing and selection of battery.
- Worksheet 4: Sizing and selection of inverter and charge controller.

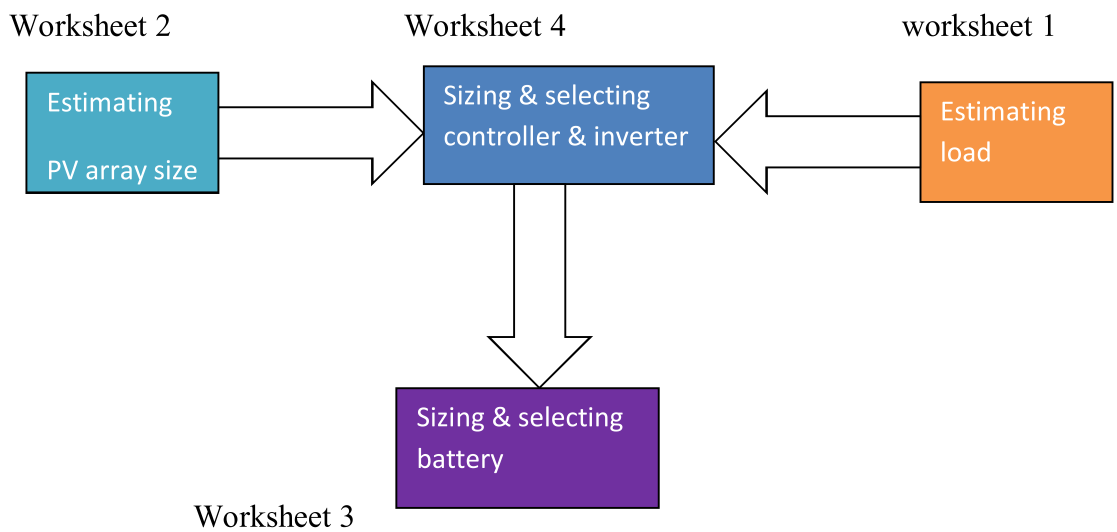

Fig.3.2.Block diagram representation of the design worksheets

The design process had been accomplished, before purchasing and installing the off-grid PV system. The specific steps of the individual worksheets are described below.

Worksheet 1: Total Daily System Energy Requirement and System Voltage

This is the amount of energy the PV array must generate to meet total daily load demand plus the extra energy required to cover system losses; before beginning a list of all the loads that the system will power. It consists of the following steps.

Step 1: Calculating the daily load energy demand in watt-hours.

The total daily system energy requirement is the amount of energy required each day to power the load. This is measured in watt- hours and ampere-hours.

Step 2: Estimating system energy losses.

Not all energy produced by the module is available for use in the system, as some is lost in the cables, batteries, charge controllers and inverters. With the ampere-hour designing system, which uses the actual current outputs of the modules, there are concerns about two types of efficiencies:

- General System Efficiency: the efficiency of cables, battery and charge controller. This can be taken to be 80 percent, meaning 20 percent of the energy is lost.
- Inverter Efficiency: a good inverter one for use in off-grid PV systems will be about 85 percent efficient under average loads. Because of the extra losses in the inverter, AC energy in a system will suffer higher losses than DC energy, 80 percent general efficiency multiplied by 85 percent inverter efficiency equals about 65 percent overall efficiency. This means that about 35 percent of the electricity fed by the PV array in to the battery that is converted in to AC electricity by the inverter will be lost.

  Therefore for DC energy losses, the total daily DC energy demand is multiplied by 20 percent and for AC energy losses, multiply the total daily AC energy demand by 35 percent.

Step 3: Calculating the total daily system energy requirement

The total daily system energy requirement is obtained by adding the total energy demand and the total energy loss.

Step 4: System voltage

System voltage is the nominal voltage at which the batteries, charge controller &solar array operate. Also system appliances often operate at the system voltage. A system voltage can be 12V DC, 24V DC or 48V DC according to the size of off-grid PV system. For PV system having peak power below 100wp 12V DC is the system voltage. The system voltage is used to calculate ampere-hour. Ampere-hour=Energy (WH)/ System voltage (V).

Step 5: Daily system charge requirement

The daily system charge requirement is obtained by dividing the daily total system energy requirement by the system voltage.

Worksheet 2: Sizing and choosing the Modules

The size of the module or array is calculated using the daily total energy requirement and solar resource data for the site. To accurately calculate this manufacturer's data is also needed.

Step 1: Calculating the solar insolation value for the site.

Before selecting modules, it is needed to estimate the solar energy available at the site; this is the daily insolation in peak sun hours per day or kilo watt hours per square meter (KWh/m^2) in the design month. Records from a nearby meteorological station should be used if they are available. If there is no local meteorological station, insolation can be estimated using national records which should be available for major cities, using the nearest city.

First from meteorological data, the least of monthly mean daily insolation figures in peak sun hours or in KWh/m^2 should be checked for a nearby site. Next, the month with the lowest daily in solation has to be identified, this is termed as 'design month' and it is used to size the array for a stand-alone system. Most off-grid PV systems are designed for the month of the year with the lowest insolation so that when the sun is least available, the system will work.

Step 2: Calculating the system design charging current.

The modules in a system must be chosen so that their energy output matches the total daily system energy requirement. For a solar electric system to succeed over the long term, the average daily output of the modules must equal the average daily energy requirements.

The charge requirement is divided by the design solar insolation value. This is the system charging current. Enough modules are needed to produce this charging current at the system voltage.

Step 3: Determining the size of module or number of modules required to produce the system design charging current.

Enough modules have to be selected to produce the system design charging current at the operating voltage and conditions at the site. This has been done by dividing the system design charging current by the normal operating current. The normal module operating current refers to the expected output current of a module at the operating temperature on a sunny day .Some module manufacturers provide data for expected module current output at normal operating cell temperature (NOCT). If the data is not provided by the manufacturers, the I-V curves of the modules are used to estimate its current output.

Worksheet 3: Battery sizing and selection

Choice of battery is limited by what is on the market and how much is be to spend. Steps are listed below for choosing and sizing a solar PV battery.

Step 1: Identifying the available batteries from a shop around

Selection of available battery has to be done in a table which includes information about important characteristics of the battery.

Step 2: Calculating the required capacity of battery in amp-hours

The capacity of the battery required depends on three primary factors:

- The daily system charge requirement in amp-hours that must be supplied to the loads each day. This has already been calculated in worksheet 1 .
- The maximum allowable depth of discharge factor. This is the deepest depth of discharge that is ordinarily allowable with the battery. Shallow cycle batteries should not be cycled below 20 percent depth of discharge, while deep discharge batteries can regularly handle 50 percent discharges.

The reserve storage factor or the number of days of storage needed. This varies with site and is higher for sites with cloudy weather. In sunny areas, depending on the applications, this number may be as low as one to two days only. A reserve of greater than four days must not be used because it will greatly increase the cost of the battery bank and increase the risk that, during cloudy weather or winter periods, batteries will not be fully charged and will be damaged by cycling in a low of state of charge. Over sizing the battery is not recommended, especially where there are long cloudy periods and where load requirement is not strict.

Step 3: Determining the configurations of battery set

Batteries should be configured at the system voltage; the battery configuration should be drawn.

Step 4: Determining battery's special charge controller setting if any.

Sealed AGM and gel cell batteries require a special setting on the charge controller. The charge regulation requirement of a battery has to be known.

Step 5: Knowing battery's maintenance requirements and cycle life

Virtually all wet cell batteries need to be cleaned and topped up with distilled water regularly.

Worksheet 4: Choosing the charge controller /Inverter sizing and selection.

Charge Controllers: all off-grid solar PV systems need some type of charge controller and there are various types that offer a range of functions. Controllers need to be sized to the system voltage.

Step 1: Selecting the charge controller size

The controller must be sized to handle both the maximum short circuit current from the array and the maximum demand of the load. To determine the array current size, the maximum short circuit current of the array has to be calculated and multiplied by 1.25.

Step 2: Selecting desired charge controller features

Depending on the size of the system, the appliances used and the solar insolation at the site, a controller will be required to perform different functions. Important features to consider include: over charge protection, high voltage disconnect, low voltage disconnect, solar charge and low voltage warning lamps, voltage and current meters etc.

Inverters: Some off-grid PV systems like the one we have designed require inverters. There are various types that offer a range of functions.

The following are steps to determine inverters.

Step 1: Is an inverter needed?

Many off-grid PV systems 100 percent on 12V DC and do not require inverters. In our case we need inverters, because the distribution voltage is 220V AC.

Step 2: Is an inverter charger needed?

The inverter should be decided whether it will function only as an inverter or if it also needs an integrated battery charger. Inverter chargers, usually for systems above 500Wp, accept power from generators or from the mains grid in the case of backup systems and can change the batteries when the solar resource is low.

Step 3: Inverter rating

The inverter must deliver the maximum AC load that is expected from AC devices of worksheet 1. The recommended inverter rating is then obtained by multiplying maximum AC load 1.25.

Step 4: Selecting desired inverter features

The desired feature of the required inverter has to be filled in the table provided there. The waveform of inverter has to match the needs of appliances.

3.4. Software Implementation

We employed HOMER software in our study for the simulation of the critical loads. HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed-generation applications**.**

HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in a year. For each hour, HOMER compares the electric and thermal demand in the hour to the energy that the system can supply in that hour, and calculates the flows of energy to and from each component of the system. For systems that include batteries, HOMER also decides for each hour how to operate to charge or discharge the batteries.

HOMER performs these energy balance calculations for each system configuration that we want to consider. It then determines whether a configuration is feasible, i.e., whether it can meet the electric demand under the conditions that we specify, and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance and interest.

In our case, for the sake of complexity, we have applied this software implementation only for the critical loads of the ASTU ICT building server room. We used the critical loads profile of the following table for the input of HOMER Software.

Table 3.3: Critical load profile For ASTU ICT building data center server room.

Column D AC appliances	Column E quantity	Column F voltage Volt	Column G power KW	Column H total power KW	Column I Daily use hour	column J Daily energy use KWh
server	10	220	0.92	9.2	12	110.4
core switch	7	220	1.68	11.76	12	141.12
Box K :Total load power rating				20.96 KW		
Box L: Total daily energy demand						251.52 KWh

Based on the above data the system feasibility analysis has been performed using the HOMER software by the following steps.

Step 1 Defining the Power System

The power system design is defined by clicking the Add/Remove button. Through the Add/Remove window we are able to select a number of different components including multiple loads, battery banks, PV arrays and other power system components.

Step 2 Defining the Site Load

HOMER enables to model one or more load profiles for a single site; these loads can be defined in different ways. Alternatively the primary loads could define the power profile for the AC and DC equipment. The hourly load profile of each load needs to be entered into primary load according to the setup defined in the schematic and model. HOMER determines the average daily consumption of the system based on the outlined power profiles. By introducing different values for the power scaled annual average it is possible to conduct a sensitivity analysis showing the effects of the overall performances influenced by the change in the average daily power consumption.

Step 3: Solar Resources

Solar resources must be imported from a nearby meteorology Agency. It is advisable that the average radiation should have a constant trend and the annual radiation must be above the lowest insolation value in order to have a reliable source of power coming from the photovoltaic panels.

Step 4 Equipment

Converter**:** in HOMER the converter in the power system represents both a rectifier, converting the alternating current (AC) provided by photovoltaic panels to direct current (DC) required powering the telecom equipment and an inverter if needed within the poser system. The key parameter to consider when defining the Converter is the Size, Cost, O&M Cost and Energy Conversion efficiencies.

Batteries**:** by clicking on the battery icon in HOMER you are able to define the battery bank used in the power system. HOMER has a built-in list of batteries each with its own unique specification that can be used. If the particular battery of interest is not included in the list it can be created and saved in HOMER by clicking the 'New' button next to the existing battery list. When choosing an existing battery or defining a new battery the key parameters to consider or include are: Capacity, Voltage, Round Trip Efficiency, Min State of Charge, Capacity Curve and Lifetime Curve.

Photovoltaic system: Solar panels are available in different shape and size. The size of the photovoltaic system depends on the power requirement of the site but it is important to take into account also the location and the available space on site.

3.5. Model Hardware Implementation

The functionality of this thesis/project is certified by using a model implementation of solar PV power system that feeds one personal computer and one fluorescent lamp which are pointed up in the following load profile table.

Table3.4 Load profile of the model project.

Column D AC appliances	Column E quantity	Column F voltage Volt	Column G power KW	Column H total power KW	Column I Daily use hour	column J Daily energy use KWh	
computer	1	220	0.2	0.2	2	0.4	
lamp	1	220	0.018	0.018	2	0.036	
Box K :Total load power rating				0.218	KW		
Box L: Total daily						0.436	KWh

These loads are determined to be operated for two hours. They have a total power rating of 218 watts and a total daily energy demand of 436 WH/day.

CHAPTER FOUR

4. FINDINGS AND ANALYSIS (MODEL & SIMULATION)

4.1. Analysis of the System Design

The analysis of solar PV devices we have obtained using Excel are as follows.

Analysis of Total Daily System Energy Requirement and System Voltage

This analysis deals with the following items.

The daily load energy demand: We have obtained it by adding together the energy that all the individual appliances and lamps use on an average day. The appliances of all of our loads are AC. We entered all the loads and we obtained calculations of their energy use.

The total daily load energy demand = ∑ all appliances' energy demand………..eq. 4.1.

Energy losses: since there are no DC loads in our case, the AC energy loss has been obtained by multiplying the total daily AC energy demand by 0.35.

Energy losses = total daily energy demand *0.35……………………………..…….eq. 4.2.

The total daily system energy requirement: we have obtained the result by adding the total energy demand and the total energy loss.

The total daily system energy requirement = total energy demand + total energy loss...eq. 4.3.

System voltage: since the PV system we have designed is rated 300Wp and additionally with a 24V system voltage, voltage drop is lower than using a 12V, we have used 24v Dc as the system voltage.

The daily system charge requirement: we have obtained this value by dividing the daily total system energy requirement by the system voltage.

The daily system charge requirement = total energy requirement/system voltage…………eq. 4.4.

The overall analysis of load profile is shown in table 4.1. below.

Table 4.1. load profile and total daily energy requirement for full loads of the ICT server room.

D	E	F	G	H	I	J	K
Column D	Column E	Column F	Column G	Column H	Column I	column J	
server	27	220	0.92	24.84	24	596.16	
core switch	6	220	1.68	10.08	24	241.92	
Air conditioner	3	220	4.4	13.2	24	316.8	
switching	10	220	0.44	4.4	24	105.6	
lamp	18	220	0.036	0.648	12	7.776	
Keyboard Virtual Machine	8	220	0.176	1.408	24	33.792	
computer	23	220	0.2	4.6	24	110.4	
Box K :Total load power rating				59.176	KW		
Box L: Total daily energy d						1412.448	KWh
2. Estimate System Enery Losses				Box M AC losses		494.3568	KWh
Energy is always lost due to inefficiencie in cables,				3.Add Ac energy demand and AC loss energy			
modules,batteries, charge controllers a		inverters.		Box N : Total Daily system			
The extra amount of energy lost must		estimated		energy requirement		1906.8048	KWh
and added to the daily energy demand.							
For DC power multiply Bo:	0.2						
For Ac power multiply Box	0.35			5.Calculate Daily System Charge requirement			
4. Select System Voltage				Divide box :N by the system voltage			
Box O: System Voltage	24	Volts		Box P:		79.4502	KAh

Analysis of Sizing and choosing the Module

Fortunately there is a nearby meteorological station for our system implementation site, and we entered this monthly data &determined lowest PSH.

Then we have obtained the system charging current by dividing the charge requirement by the design solar insolation value.

Charging current = charge requirement/ insolation value…………………………...eq. 4.5.

We have selected enough modules to produce the system design charging current at the operating voltage and conditions at the site. This has been done by dividing the system design charging current by the normal operating current.

Number of module = charging current/ operating current……………………..eq. 4.6.

The overall analysis of module is shown in table 4.2.

Table 4.2.Sizing and choosing the module

A	B	C	D	E	F	G	H	I	J
Worksheet -2: Sizing and Choosing the Modules									
Use this work sheet to produce the size of array in your system									
step-1: Obtain the sites insolation value									
Box 2A: Solar Records from NMA					Step-2: select design solar				
Adama branche (Avarge2011-2015)					insolation value (daily average)				
Mean insolation data should be filled									
in below (daily average).									
	Month	Peak sun hours		Select the		Box-2B			
	Jan	9.780259		monthly insolation		Design month peak sun hour			
	Feb	9.441828		figure		(daily average)			
	Mar	8.24979					6.14315		
	Apr	8.620778							
	May	7.811135							
	Jun	6.644557							
	Jul	6.143151							
	Aug	7.079938							
	Sep	10.21606							
	Oct	8.620994				Step-3: Calculate the design			
	Nov	10.63201				charging current			
	Dec	10.17709							
	Box -2C	6.143151		Box -2D			Box - 2E		
	79.4502	KAh		6.143	=		12.9331	KA	
	Daily system			Design solar			system design		
	charge requirement			insolation value			charging current		
				charging current		Details of selected module			
	From work sheet-1			peak sun hours		Type		Poly crystalline	
	Box-Q			Daily average		Model			P300
Step-4: select enough modules to produce the						peak (Wp)			300
design charging current.						rated voltage (V)			24
Use the manufacturer's data						rated current (A)			12.5
						oprating current (A)			12.49
Step-5: draw the configuration of the module array						short circuit current(A)			13.23
						number of module			1035

Analysis of Battery sizing and selection

The system daily total system charge requirement in amp-hours has been obtained from table 4.1. And the required system battery capacity has been resulted by multiplying daily charge requirement by the reserve days and dividing this result by the maximum DOD.

Battery capacity= daily charge requirement* reserve days/ maximum DOD…………..eq. 4.7.

The overall design analysis of battery analysis is shown in table 4.3.

Table 4.3. Battery sizing and selection

A	B	C	D	E	F	G	H	J	L
WorkSheet-3: Battery sizing & selection									
This worksheet is used to select battery & charge controller									
step 1: selecting the availeble battery									
Types of battery		Voltage	Capacity	Recommende		Recommended		Cycle Life @	
				Daily DoD(%		Max DoD(%)		25% DoD	
AGM		24V	0.85	0.5		0.6		0.15	
Step-2: Calculate the required capacity of									
battery in Amp-hours.									
Box 3A			Box 3B			Box 3C		Box 3D	
79.45	KAh		1		÷	0.6	=	132.417	KAh
Daily system charge			Reserve Days			maximum DoD		Required system	
requirement			Minimum 1			Express as decimal		Battery capacity	
			Maximum 4			(ex. 30% is 0.30			
From worksheet 1 Box Q									
						Make a drawing of battery configuration/voltage			
Step-3 Determine the battery						Indicate the voltage and parallel/series connections			
configuration									
						Details of selscted battery			
Step-4: does the battery require				Yes	No	Type		AGM	
and maintenance need.						Individual battery capacity		2000	Kah
Maintenance Need			**How often**			Individual battery voltage		24V	V
Cleaning corrossion			Yes	Monthly		Battery bank voltage		24V	V
Checking SoC			Yes	Weekly		Number in series		0	
Topping up			Yes	Monthly		Number in parallel		66.2085	
Equalizer			Yes	quarterly		Total number of batteries		66.2085	
Expected			Cycle			Total battery capacity(KAh)		132.417	
Life cycle		0.125	(Days)			Rated cycle life @ 25% DoD		0.15	

Analysis of choosing the charge controller /Inverter sizing and selection

We have determined the array current size by multiplying the maximum short circuit current of the array by 1.25.

Charge controller (array) current = max I_{SC} *1.25…………………………………......eq. 4.8.

The recommended inverter rating has also been obtained by multiplying maximum AC load by 1.25.

Inverter rating = total AC load power rating*1.25…………………….…………...eq.4.9.

The waveform of inverter has been selected to match the needs of appliances. The overall design analysis of charde controller & inverter is shown in table 4.4.

Table 4.4. Choosing and sizing of charge controller and inverter.

A	B	C	D	E	F	G	H	I	J	K
Worksheet-4: Charge controller/Inverter Sizing and Selection										
This worksheet is used to select charge controller and inverter.										
charge Controller Sizing and Selection										
Step-1: Select charge controller size										
Array Input Rating										
Box 4A			Box 4B							
13.6994	**x 1.25=**		17.1242	KA						
maximum array			Array Input Rating							
short circuit Current										
killo Amps										
Step-2: Select desiered CC Feature										
Controller specification			Rating			Protection			Yes	No
Rated voltage			24V	.		Short circuit protection (array)			√	
Maximum array Isc Input			17.13KA			Short circuit protection (load)			√	
Type		PWM				reverse polarity (array)			√	
						reverse polarity (load & battery)			√	
						lightinng protection			√	
						open circuit battery			√	
Inverter Sizing and Selection										
Step-1: Is an inverter needed?										
step-2: inverter and Charger Rating										
Box 4E			Box 4F							
59.176	**x 1.25**		73.97	KW	Type	Sine Wave				
Maximum AC Load			Inverter Rating							
Killo watts										
Rated Charge Current										
For Battery charging (KA)			17.1242							

The summery/ results of the capacities &costs of the full load and critical load are shown in Appendixes A-D.

4.2. Software Analysis

For this system we placed check marks besides Primary Load 1, PV, Converter, and Battery 1. At the bottom of the window we selected ‘Do Not Model Grid’. The overall analysis of step 1 is illustrated in figure 4.1.

As we have already mentioned before, the system consists of PV modules, batteries, charge controller and inverter. We have used the critical load capacity of solar PV devices as input for the HOMER Software.

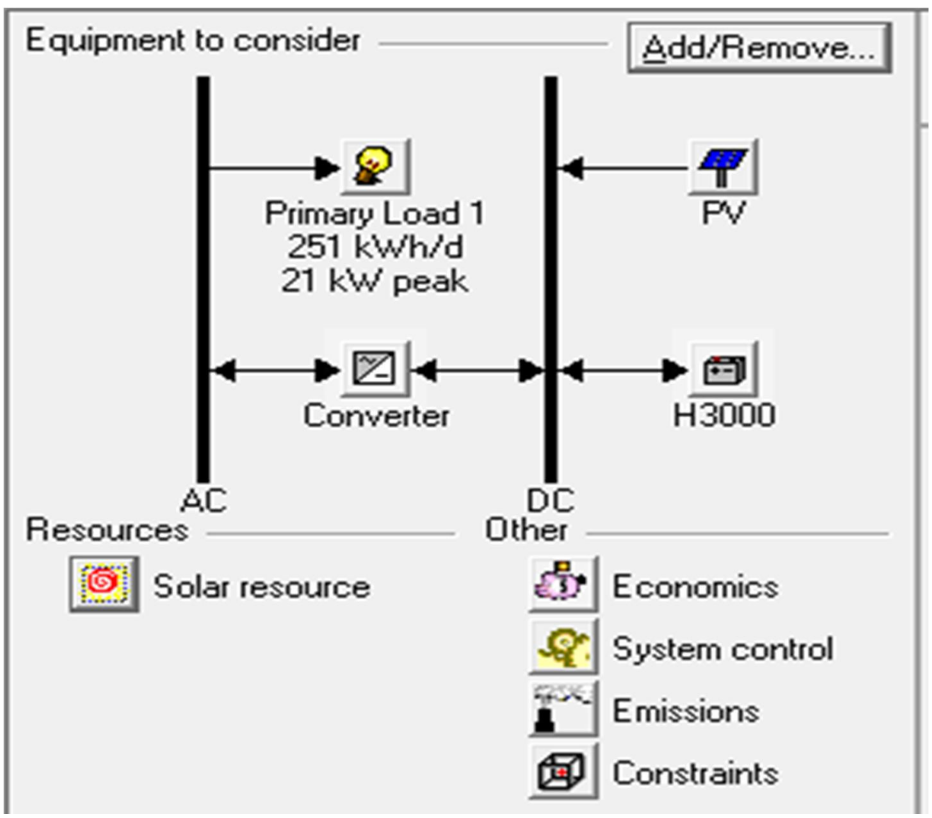

Fig.4.1. Screen show of solar power system

*Primary load input***:** primary load was inserted by clicking on the icon for Primary load 1, setting the load to AC and defining the hourly profile as indicated in the diagram below. The scaled annual averages of the combined primary loads have become 251 KWh/d. The overall analysis of step 2 is shown in figure4.2.

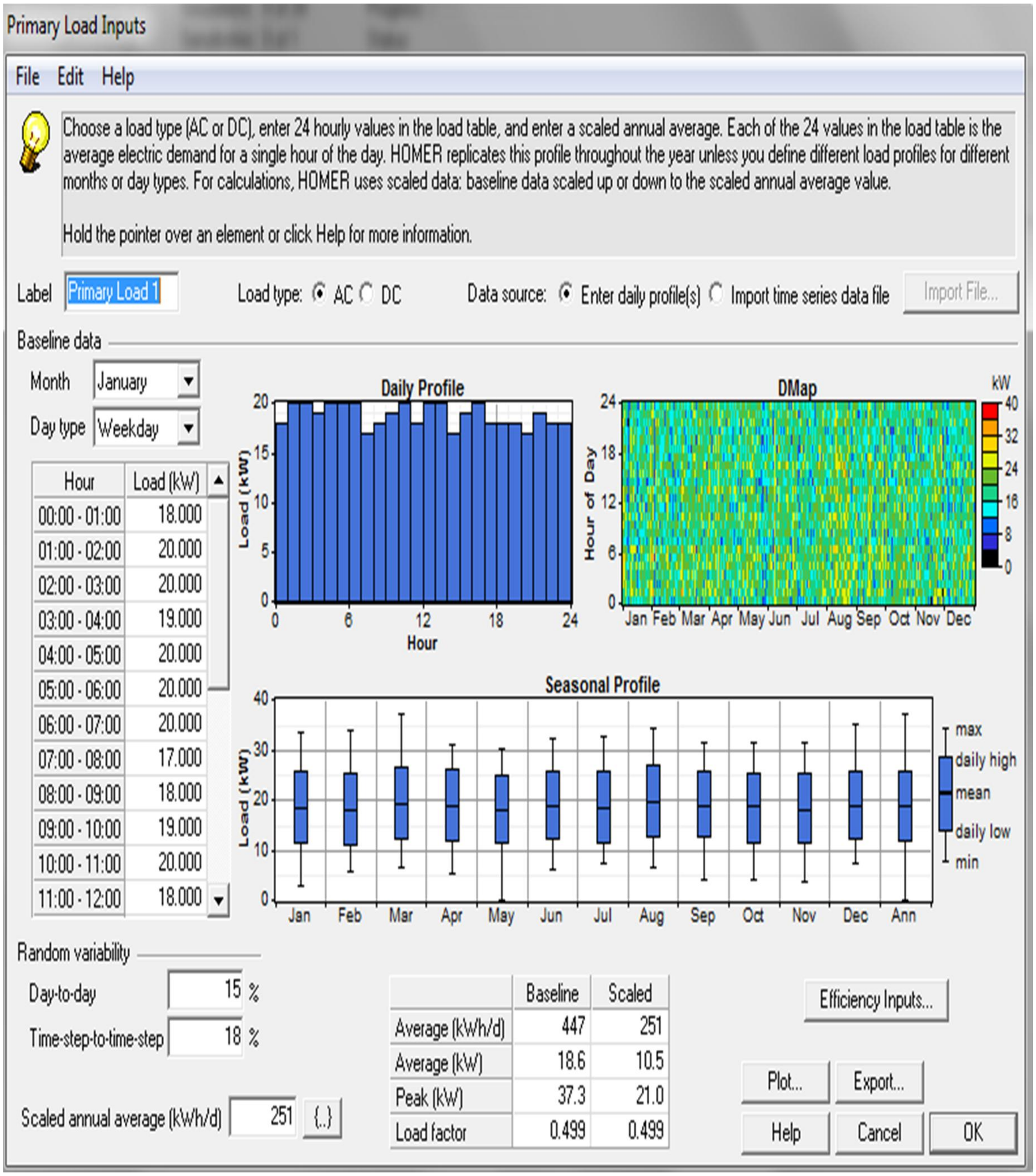

Fig.4.2.Primary load input

Solar resources: are imported directly from the National meteorology Agency of Adama Branch. Using the coordinates, the annual average solar radiation of this area is 7.84 KWh/m2/d. It is advisable that the average radiation should have a constant trend in order to have a reliable source of power coming from the photovoltaic panels.

The overall analysis of step 3 is illustrated in figure 4.3.

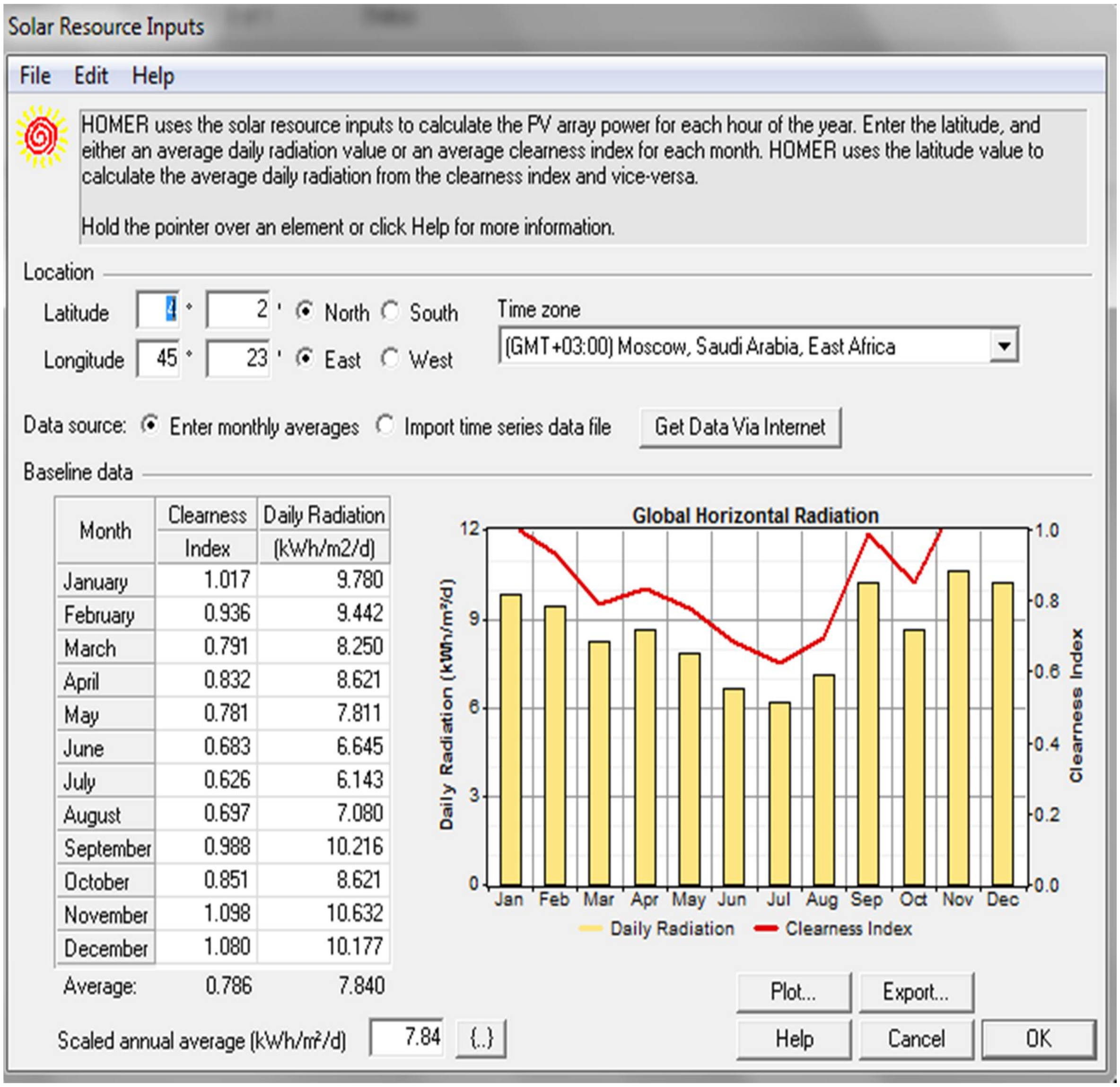

Fig.4.3. solar resource inputs

Converter system: For this critical loads standard efficiency parameters have been considered for a 24KW inverter, (Capacity relative to inverter 100%, Efficiency 85%). The overall analysis of the converter input is shown in figure 4.4.

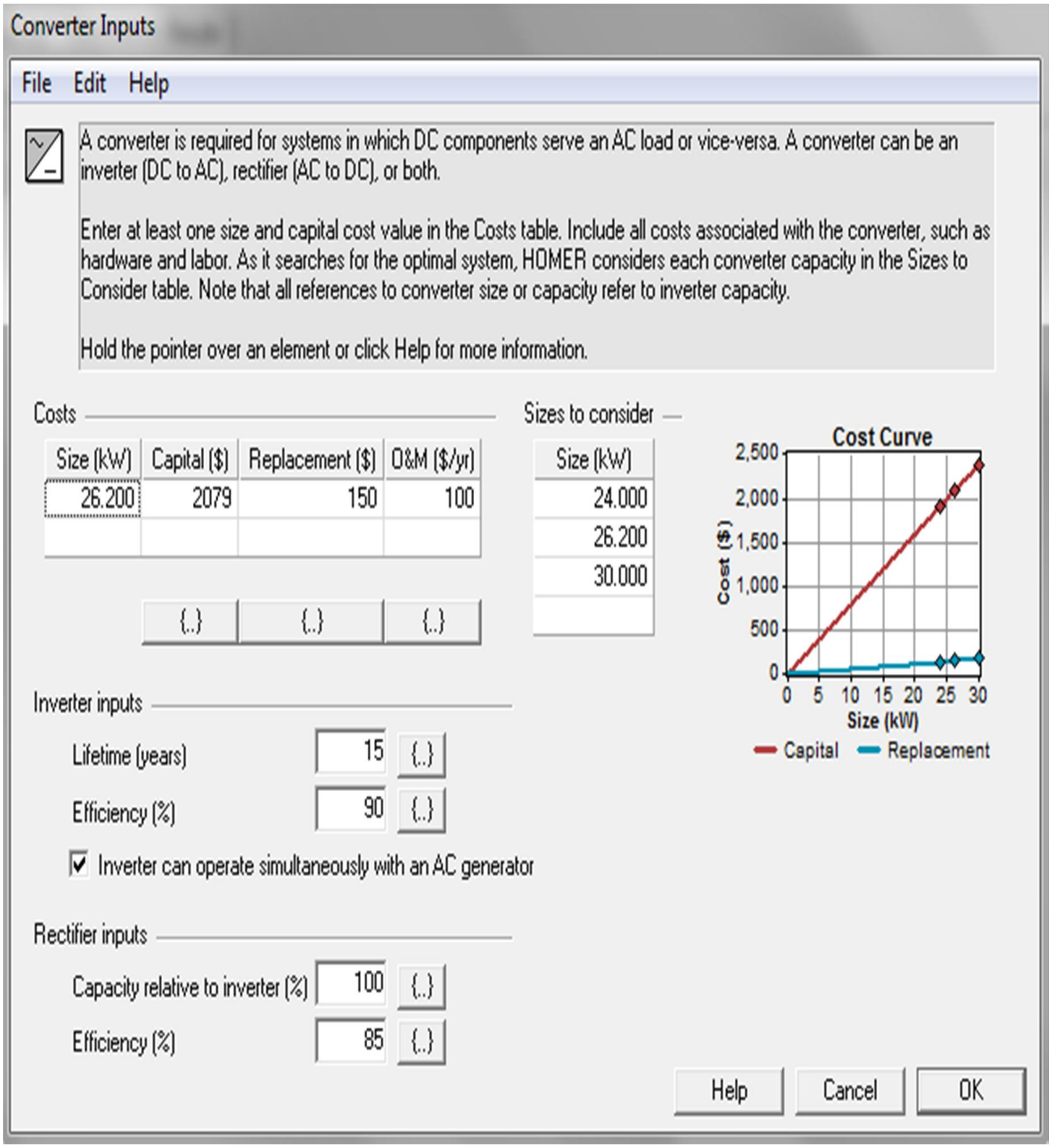

Fig.4.4. Converter input

Battery system: we have entered the cost of the battery, the number of batteries per string and the number of strings of batteries to be modeled. We have considered eight strings of H3000, 2V, 3000Ah sealed lead-acid batteries in which 12 batteries are consisted per string. These batteries require reduced maintenance and are suitable for renewable installations which require high demand levels. The details of these batteries, including life time and capacity curves, are already built-in in HOMER. The overall analysis of the battery input is shown in figure 4.5.

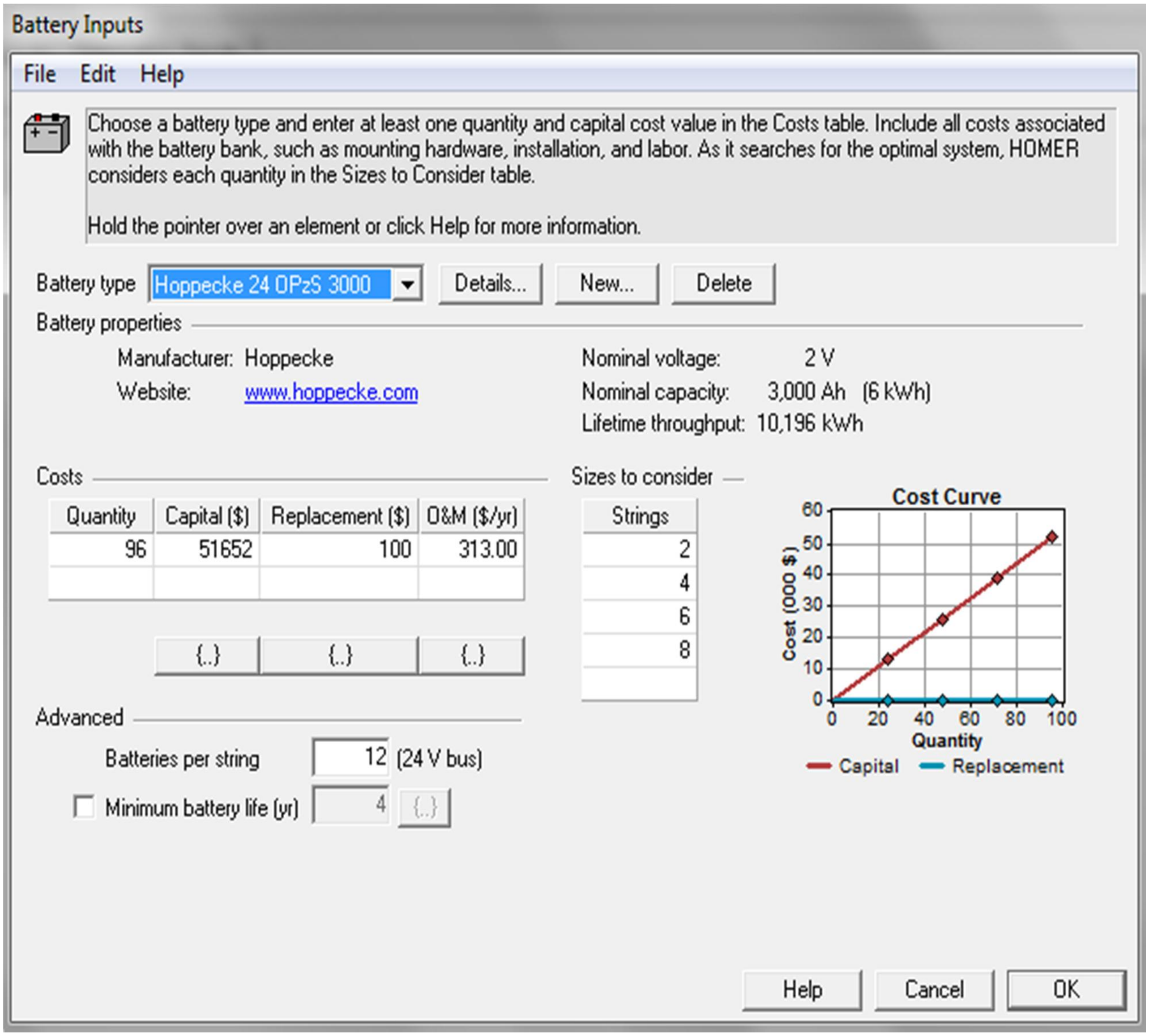

Fig.4.5. Storage batteries input

Photovoltaic System: for the site under analysis we considered 300W, 24V polycrystalline modules combined in 184 strings of 70KW at a cost of US$ 110476 per string (this value is valid for capital cost, it does not include shipping, training and installation which will be added in the additional capital costs in order to determine the financial indicators for the renewable solution). We assumed for the photovoltaic panels a derating factor of 80% and expected lifetime of twenty years. Solar panels do not require extensive maintenance; usually it is only required to remove dust from the panels twice a year so the O&M cost has been calculated as one-day of labor plus transport. The overall analysis of photovoltaic system input is illustrated in figure 4.6.

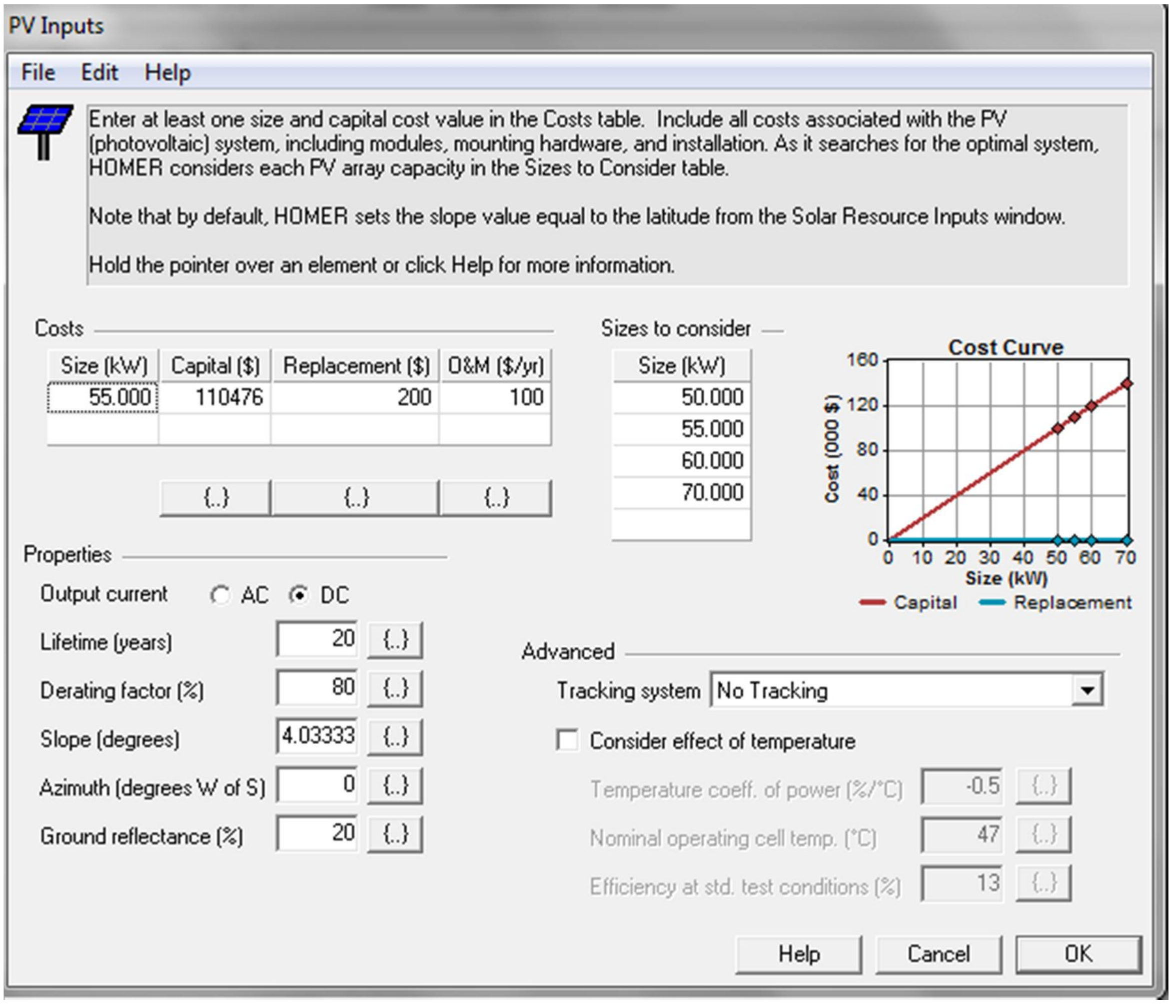

Fig.4.6. Photovoltaic solar input

4.3. Simulation Analysis

Calculation Results: By clicking the Calculate button, HOMER calculates the different permutations of possible designs based on the inputs provided and simulate the power system. A consistent business case for an off-grid site should compare the existing solution (or standard operator solution in case of a new site) to the preferred renewable option. In addition by introducing the sensitivity analysis on the primary load we are able to evaluate the financial and renewable indicators of the different models under numerous scenarios. The overall analysis of step 5 is illustrated in Appendix -E.

Optimization Results: the optimization result panel shows the list of configurations available basing on the input data we have introduced and ordered by the total NPC (Net Present Cost). It is possible to display the entire list of configurations or to show only the best solutions (from an economic perspective) per system design. The plot section in the hourly plot label enables to compare over two layer graph the most relevant variables of the selected configuration. In the figure to the right the graph on top shows the electrical production of photovoltaic system, while the below graph displays the battery state of charge throughout the year. The Simulation Results window include other relevant data concerning renewable equipment details (i.e. electrical production, hours or operation, etc.), batteries performances , emissions, etc.

Sensitivity Results: The Sensitivity Results label shows through different graph types the system dependency from the sensitivity variables. The effect of the primary load has a huge impact on several variables including the Total Net Present Cost. By increasing the power load the installing and operating costs of the system rise accordingly.

Simulation Results: By clicking on each of the displayed solution we can access a comprehensive set of data providing high level of detail on each system component. In addition it is possible to display many economical information essential to run a thorough business case.

The following analyses are related to the solution having the following system architecture: 70kW photovoltaic system,24KW inverter (refer Appendix E), eight 24V strings of twelvehoppecke24op$_z$s 300 batteries and critical primary load at 251kWh/d. The electrical tab in the Simulation Results window gives a useful overview of the overall and monthly electric production of the various sources of the system, excess electricity produced, etc. There is also a considerable waste of energy caused by the unutilized excess electricity. Adding more battery strings would allow to optimize the usage of excess electricity and to increase the overall autonomy of the system. By adding more battery strings and increasing the size of the photovoltaic system. We improved the system performances but at the same time we were increasing the capital expenditures of the overall system and we may not have adequate space on site for the additional equipment (i.e. an average 5.1kW PV system has ~ 43 m^2 footprint). Therefore the choice of the right configuration is a complex trade-off among financial, renewable, technical and design requirements. By clicking the Details button in the Cash Flow label the nominal and discounted total cost of ownership are displayed, providing for each configuration item capital, replacement, and salvage and operating cost for the entire lifetime of the project. The detail simulation results of the cash flow, monthly average electrical production, PV output, inverter output & battery are indicated in Appendixes F, G, H, I &J respectively.

4.4. Model Hardware Implementation Result

The following table (table 4.5) summarizes the capacities and/or the quantities of PV devices which we have applied for the model implementation system to operate for 2 hours.

Table 4.5 Results of capacities of PV devices for the model project.

System design	Operating time				
	Case-I	Case-II	Case-III	Case-IV	Case-V
	24hours	12hours	6hours	4hours	2hours
Total load energy demand (KWh)	5.232	2.616	1.308	0.872	0.436
AC losses (KWh)	1.8312	0.9156	0.4578	0.3052	0.1526
Daily system energy requirment (KWh)	7.0632	3.5316	1.7658	1.1772	0.5886
Daily system charging requirment (KAh)	0.5886	0.2943	0.14715	0.0981	0.04905
System design charging current (KA)	0.095814021	0.04790701	0.02395351	0.015969	0.00798
Number of module required (300Wp each)	12.52470865	6.26235433	3.13117716	2.08745144	1.04373
Required system battery capacity (KAh)	1.1772	0.5886	0.2943	0.1962	0.0981
Array input rating (KA)	0.128378264	0.06418913	0.03209457	0.02139638	0.0107
Inverter rating (KW)	0.2725	0.2725	0.2725	0.2725	0.2725

Based on the case-V column ('2 hours') of the above table, we have selected and used the following solar PV devices and cables for our model implementation.

- 1 PV module
- 1 charge controller
- 1 storage battery
- 1 solar PV inverter
- 40 meter 1.5mm^2 wire and 5 meter 2.5mm^2 cable

PV module**:** The PV module used in the model implementation is REW135QJ and its electrical specifications which are provided by the manufacturer are as listed below.

Peak power=135 Wp

Voltage at maximum power (Vmp) =17.6V

Current at maximum power (Imp) =7.65A

Open circuit voltage (Voc) =22V

Short circuit current (I_{SC}) =8.2A

Charge controller: The charge controller we have obtained from the result of the table is 10.7A; hence we applied a charge controller having a current capacity of 20A which is greater than 10.7A, for the model implementation.

Storage Battery: The solar storage battery resulted from the table is 98.1Ah, so we selected a battery of 100Ah (100Ah>98.1Ah) Daily charging capacity for this model.

Inverter: The Capacity of the inverter resulted from the design table is 295w, we have used 300 watt inverter for the model project, because a value greater than or equal to 295w is possible.

Wires/ cables**:** 40 meter, 1.5 mm^2wires was used for wiring of the incoming DC voltage section and 5 meter, 2.5 mm^2cable was used to transport the outgoing AC voltage section from the inverter output to the loads.

Once we have interconnected the PV devices, we connected 1 lamp & 1 computer across the PV source and we observed the following results:

The PV output varies automatically with variation of sun light intensity.

The charge controller indicates the state of charge SOC of the battery.

The two loads operate properly by the solar PV system.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Renewable energy sources like solar PV power system are current issues of our world for their contribution in reduction of global warming. So we want to begin our conclusion by saying that our study can be articulated as a multi-purpose project. The key element of our study is the system design that has been developed using the excel software. The design is subdivided in to a number of worksheets which are used to determine capacities of solar PV devices. This design method is also applicable for another off-grid PV power system, just like the one we have studied. The only thing that has to be done while designing another PV power system is adjusting the load profile worksheet. This can be done by resetting either one or more of the following items; quantities of appliances, power ratings of appliances, operating hours of appliances the respect to the load profile of the site under study.

This thesis/ project, Design and Implementation of Solar PV Power system for ASTU ICT Building, includes complete designs, descriptions and quantities of materials with their specifications and individual & overall costs for implementation of not only the model but also for the real site, server room of ASTU ICT Building. While studying the case, nothing is done by guess; each and every data is collected actually. Generally to design a solar PV power system, there are two alternative methods; one of these methods is the watt-hour method and the second one is the ampere-hour method. In this project we used the ampere-hour method, because it takes the real world behavior of PV modules and batteries. The amount of sun light which is technically termed as insolation value or peak sun hour value influences the generation capability of the PV panel. Fortunately, we have obtained an instrumentally recorded data of this peak sun hour or insolation value from a nearby meteorological station, National meteorological Agency, Adama branch. This data optimizes the reliability and feasibility of our project. In addition to excel software, we have also applied HOMER software for our thesis system simulation. The HOMER software uses the results of the excel design as its inputs, and finally it calculates sensitivity and optimization results of the system by taking the maintenance and operating costs in to account.

The implementation of the real project will highly reduce the problem of data misuse and the necessity of data reconfiguration caused by power interruption in the server room of ASTU ICT Building. This study can be implemented either by totally replacing the grid power system or as a back up by replacing the generator. This solar PV power system does not need a mechanical start up mechanism unlike a diesel generator.

5.2. Recommendations

For the server room of ASTU ICT Building, one can implement this project design simply by purchasing the solar PV devices and installing them accordingly; because all the specific design is completed in this work with the required cost analysis. Different design alternatives, both for full loads and for critical loads are considered in the design either to use as a stand -alone system for 24 hours or as a backup for 12 hours, 6 hours and 4 hours. If it is to be implemented as a backup, there is a need of installing a control system that makes it standby so that the system will be started automatically as soon as the grid line is interrupted.

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Appendix-A Result of capacities of solar PV devices for the full load

System Design	Operating time			
	Case-I	Case-II	Case-III	Case-IV
	24hours	12hours	6hours	4hours
Total load energy demand (KWh)	1412.448	706.224	353.112	235.408
AC losses (KWh)	494.3568	247.1784	123.5892	82.3928
Daily system energy requirment (KWh)	1906.8048	953.4024	476.7012	317.8008
Daily system charging requirment (KAh)	79.4502	39.7251	19.86255	13.2417
System design charging current (KA)	12.9331348	6.4665674	3.2332837	2.15552247
Number of module required (300Wp each)	1035.479168	517.739584	258.86979	172.579861
Required system battery capacity (KAh)	132.417	66.2085	33.10425	22.0695
Array input rating (KA)	17.12423673	8.56211837	4.2810592	2.85403946
Inverter rating (KW)	73.97	73.97	73.97	73.97

Appendix- B Cost analysis result of the full load with different operating hours

B	C	D	E	F	G	H	I	J	K
					Costs of full load at different operating hours				(in Birr)
Component	specification	quantities	unit	unit price	24h	12h	8h	6h	4h
PV panel	300Wp,24V	1035	pcs	12600	13041000	6520500	4347000	3260250	2173500
Inverter	5KW,24V	15	pcs	8333.3	125,000	125,000	125,000	125,000	125,000
Storage battery	2KAh,24V	66	pcs	92000	6072000	3036000	2024000	1518000	1012000
Charge controller	1kA, 24V	17	pcs	10294	175000	150000	125000	100000	75000
Sub- Total					19412999.5	9831499.5	6621000	5003250	3385500
Cabel, accesseries & contengency 14% of the above sub-total					2717819.93	1376409.93	926939.9	700454.9	473969.9
G-Total					22130819.43	11207909.4	7547939	5703704	3859469

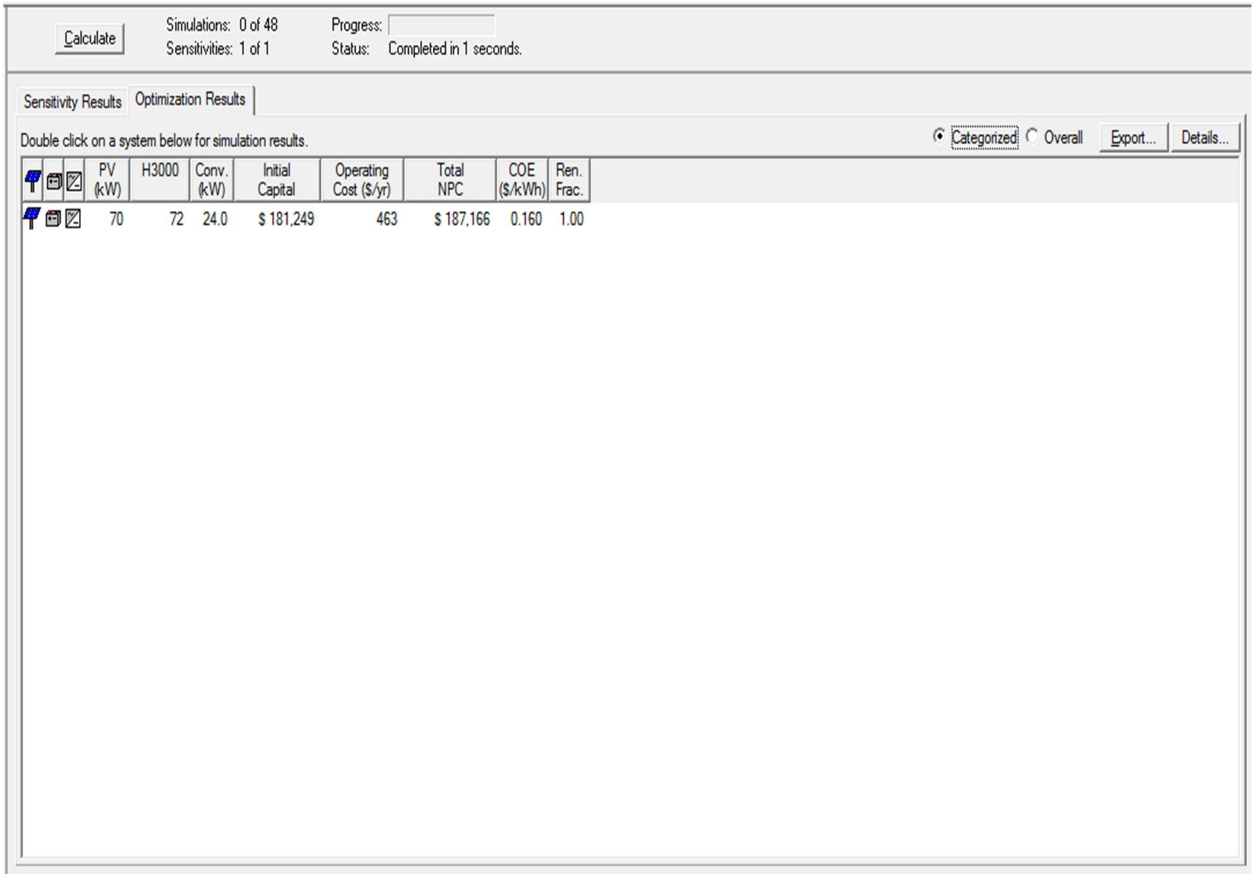
Appendix-C Result of capacities of solar PV devices for only critical loads

System Design	Case-I	Case-II	Case-III	Case-IV
	Operating time			
	24hours	12hours	6hours	4hours
Total load energy demand (KWh)	503.04	251.52	125.76	83.84
AC losses (KWh)	176.064	88.032	44.016	29.344
Daily system energy requirment (KWh)	679.104	339.552	169.776	113.184
Daily system charging requirment (KAh)	28.296	14.148	7.074	4.716
System design charging current (KA)	4.606105238	2.30305262	1.1515263	0.76768421
Number of module required (300Wp each)	368.7834458	184.391723	92.195861	61.4639076
Required system battery capacity (KAh)	47.16	23.58	11.79	7.86
Array input rating (KA)	6.098756235	3.04937812	1.5246891	1.01645937
Inverter rating (KW)	26.2	26.2	26.2	26.2

Appendix–D Cost analysis result of only the critical loads

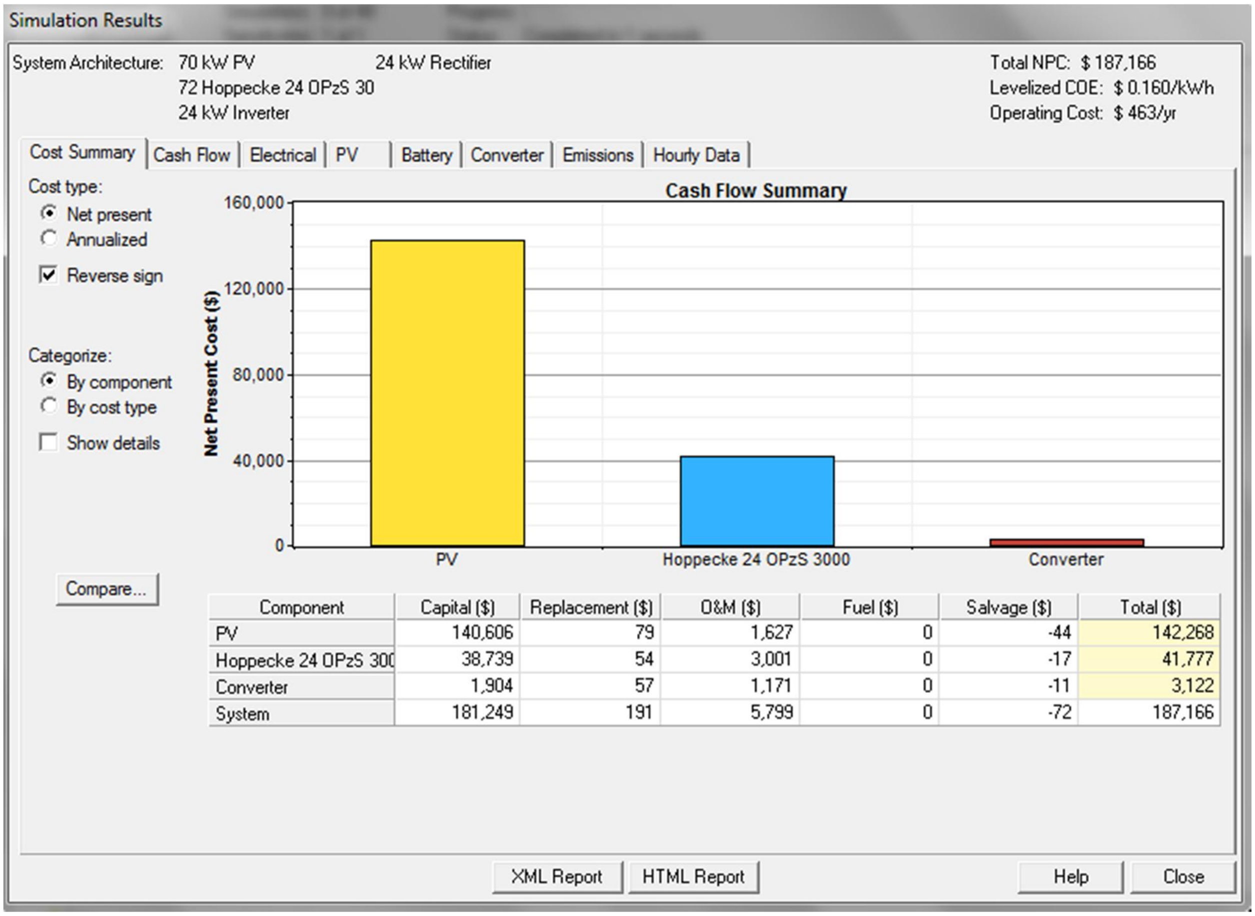
B	C	D	E	F	G	H	I	J	K
					Costs of full load at different operating hours				(in Birr)
Component	specification	quantities	unit	unit price	24h	12h	8h	6h	4h
PV panel	300Wp,24V	369	pcs	12600	4649400	2324700	1549800	1162350	774900
Inverter	5KW,24V	5	pcs	8333.3	41,667	41,667	41,667	41,667	41,667
Storage battery	2KAh,24V	23	pcs	92000	2116000	1058000	705333.3	529000	352666.7
Charge controller	1kA, 24V	6	pcs	10294	175000	150000	125000	100000	75000
Sub- Total					6982066.5	3574366.5	2421800	1833017	1244233
Cabel, accesseries & contengency 14% of the above sub-total					977489.31	500411.31	339052	256622.3	174192.6
G-Total					7959555.81	4074777.81	2760852	2089639	1418426

Appendix-E Calculated results of sensitivity and optimization for the critical load



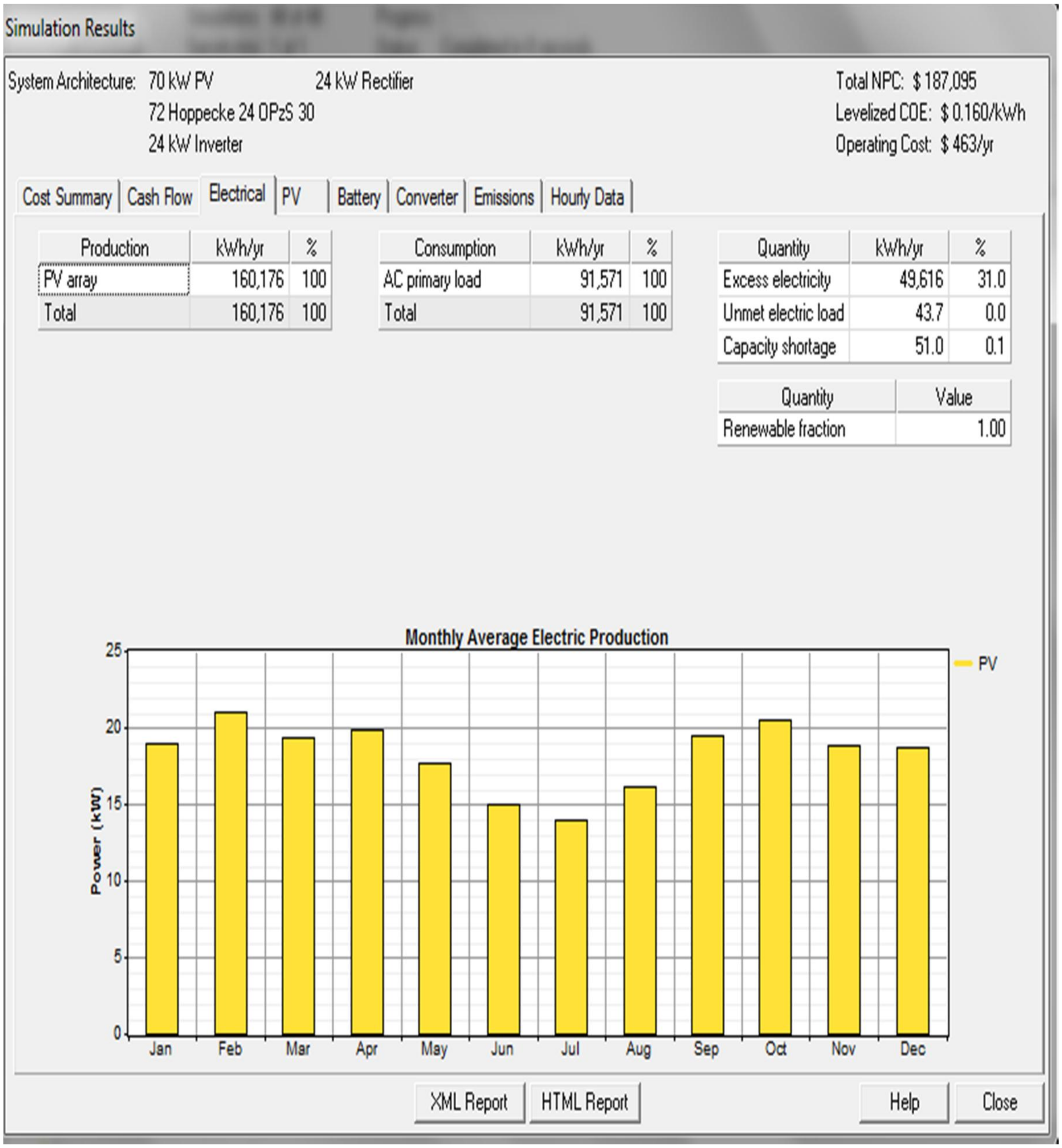
			PV (kW)	H3000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
			70	72	24.0	$ 181,249	463	$ 187,166	0.160	1.00

Appendix–F Simulation results of Cash flow summary

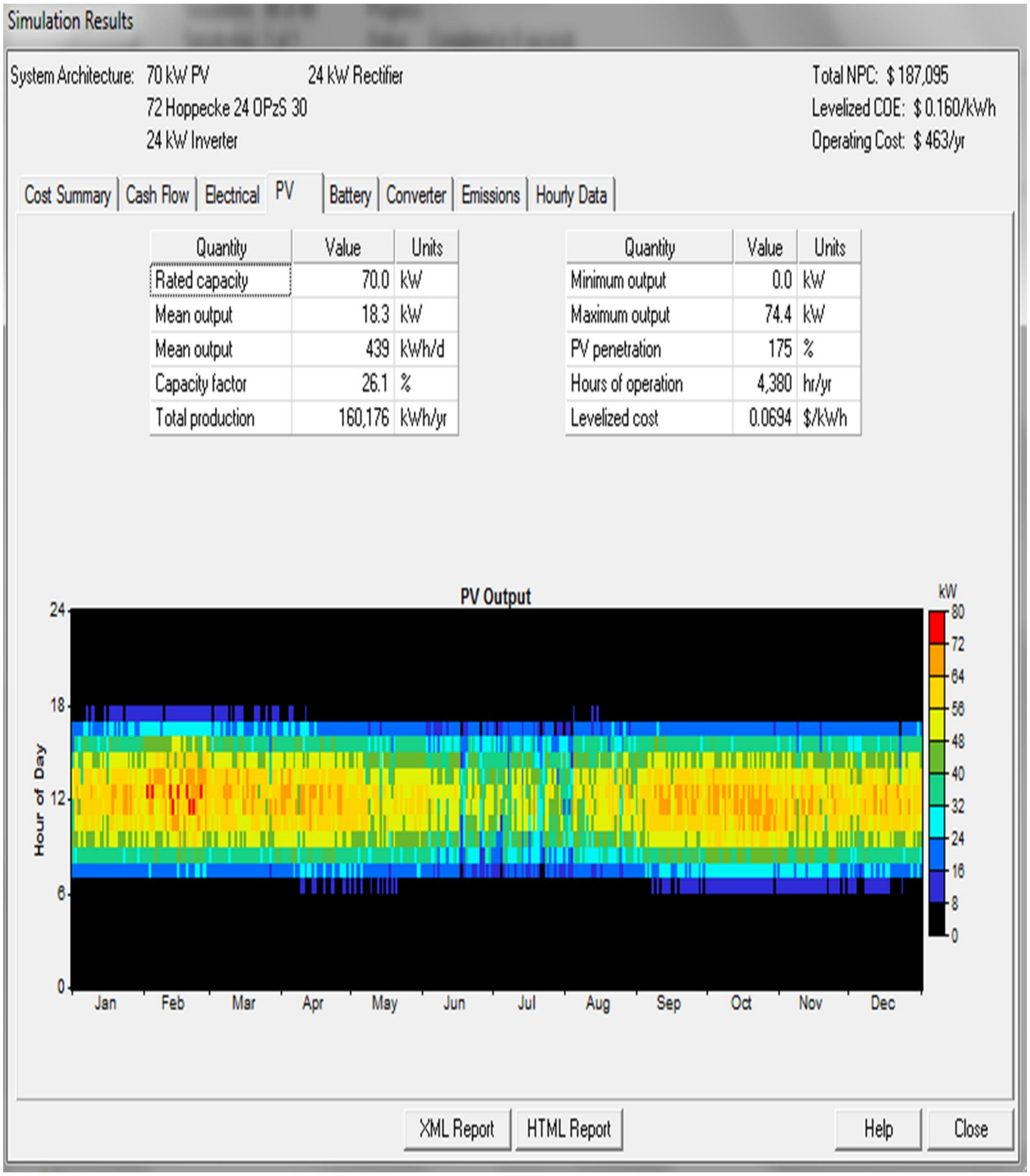


Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	140,606	79	1,627	0	-44	142,268
Hoppecke 24 OPzS 300	38,739	54	3,001	0	-17	41,777
Converter	1,904	57	1,171	0	-11	3,122
System	181,249	191	5,799	0	-72	187,166

Appendix–G Simulation results of Monthly Average Electrical production



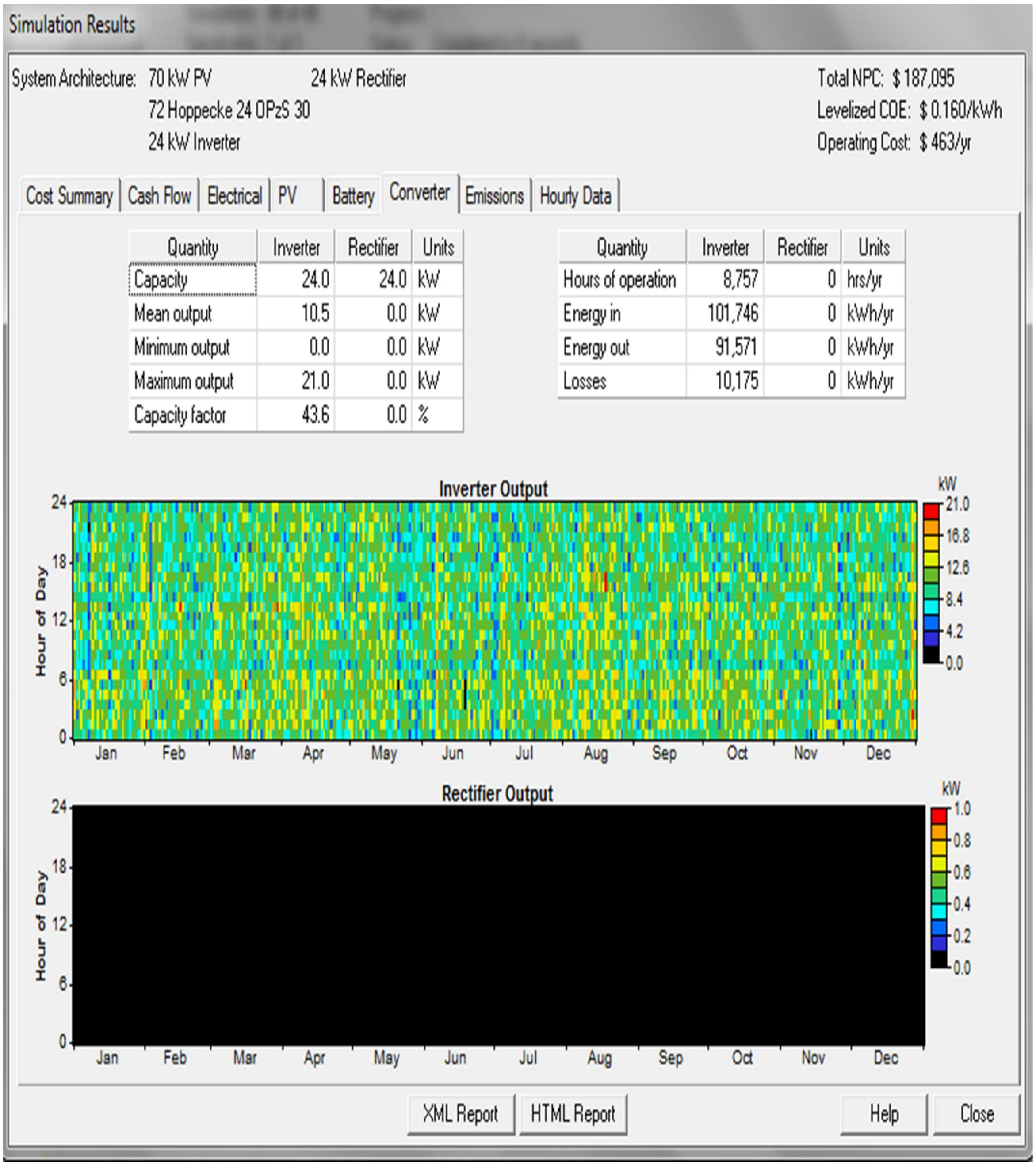
Appendix –H Simulation results of PV output



Quantity	Value	Units
Rated capacity	70.0	kW
Mean output	18.3	kW
Mean output	439	kWh/d
Capacity factor	26.1	%
Total production	160,176	kWh/yr

Quantity	Value	Units
Minimum output	0.0	kW
Maximum output	74.4	kW
PV penetration	175	%
Hours of operation	4,380	hr/yr
Levelized cost	0.0694	$/kWh

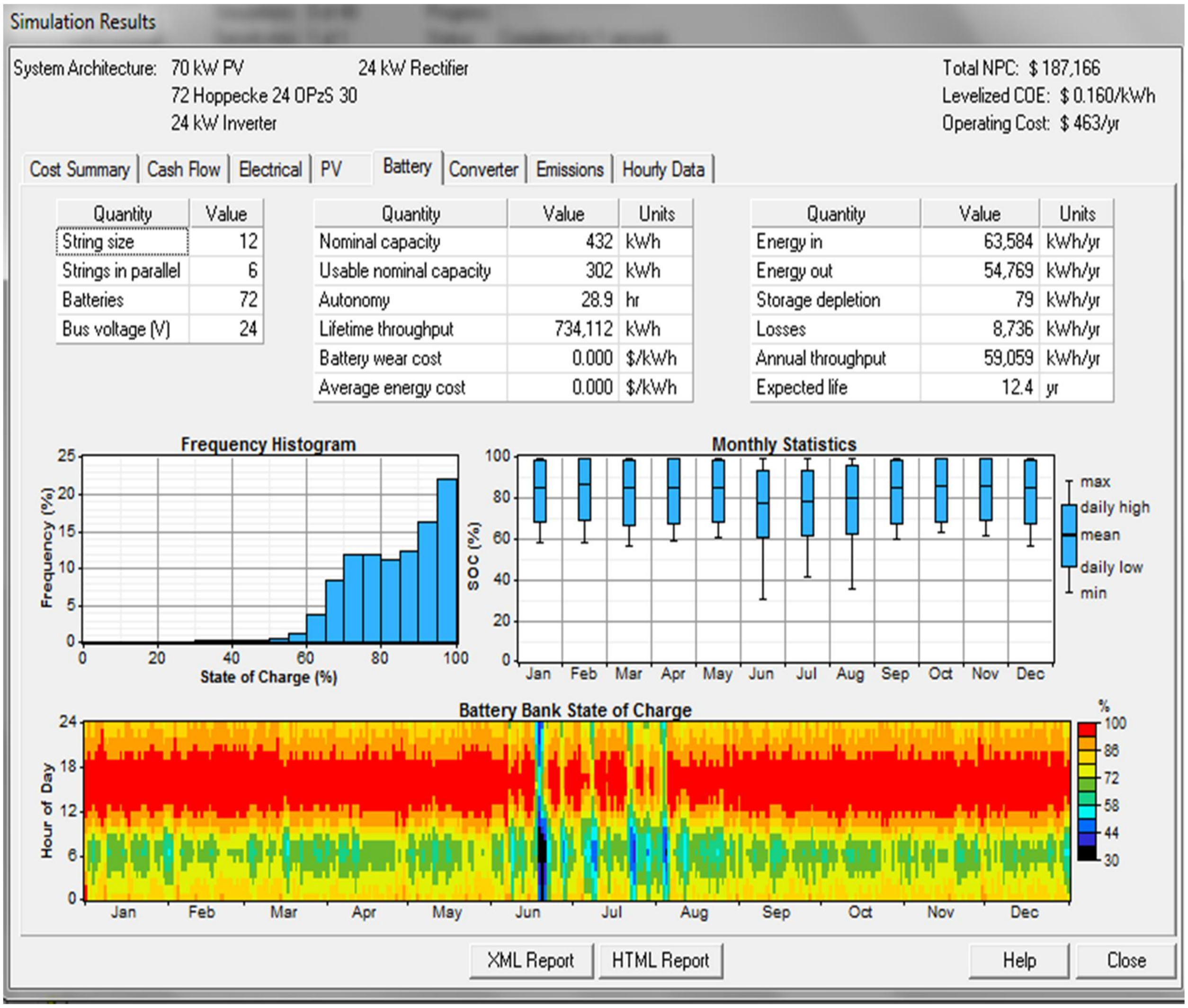
Appendix-I Simulation results of Inverter output



Quantity	Inverter	Rectifier	Units
Capacity	24.0	24.0	kW
Mean output	10.5	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	21.0	0.0	kW
Capacity factor	43.6	0.0	%

Quantity	Inverter	Rectifier	Units
Hours of operation	8,757	0	hrs/yr
Energy in	101,746	0	kWh/yr
Energy out	91,571	0	kWh/yr
Losses	10,175	0	kWh/yr

Appendix –J Simulation results of battery



Appendix-K Prototype