DESIGN, IMPLEMENTATION AND FEASIBILITY STUDY OF A SOLAR HOME SYSTEM

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DECLARATION

This is to certify that the thesis titled "DESIGN, IMPLEMENTATION AND FEASIBILITY STUDY OF A SOLAR HOME SYSTEM" is the demonstration of the thesis work supervised by the respectable Chairman and Professor Dr. Shahidul Islam Khan, Department of Electrical and Electronic Engineering (EEE), BRAC University, Dhaka. The declaration also includes that this is an authentic work and this paper was not submitted for the award of any other degree or diploma or publication.

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ABSTRACT

Electricity is one of the greatest blessing of the world. It has made impossible things possible. Regrettably there are approximately 1.3 billion people who are deprived of this blessing. Most of these people are the people from the underdeveloped and developing country. Being a developing country, Bangladesh is facing the same problem. Solar Home System (SHS) can resolve this problem as a renewable energy. The aim of this project is to study and implement a Solar Home System (SHS). This project can be divided two portions. Firstly, the implementation of the thesis project was done by designing and installing a 100 watt-peak solar home system. The further works were divided by the simulation process through software.

This study also includes Data logging, Cost Efficiency, analysis by RETscreen 4.0 and PVsyst to monitor the viability of this project. The information of the solar panel output voltage, efficiency of the panel, load pressure on panel, daily solar irradiation can be obtained from data logging. Phocos CXN charge controller has data logging capacity whilst being a charge controller. The cost effectiveness of SHS is the first and foremost concern for engineers. While calculating cost efficiency including geographical and representation of the cost of this system over the life cycle. Before implementing the system, PVSyst software has been used for simulation of the project and so the viability of the system has been assured virtually. These data were compared with other existing systems to increase the system efficiency, bearing the cost and geographical information in mind. The illumination of flood light has been observed to get profound data to implement this system in urban and rural residential area.

The load we used in the system have lower capacity than the actual capacity of the system. In fact, the load was provided with sufficient energy form the panel and there was no loss of load. More than 60% energy was unused. The utilization of this unused energy can be ensured by controlling more loads to the system in future.

ACKNOWLEDGEMENT

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DEDICATION

To Our Beloved Parents

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CHAPTER-1

INTRODUCTION

1.1 Significance of Renewable Energy

Renewable energy is the energy that is produced from natural sources, which are also renewable. Sunlight, wind, water tides, waves, biomass are example of renewable energy source. This energy and its resources are alternative to those degradable fossil fuel resources. This energy causes no harm to environment. The alarming rate of global warming, emission of CO_2 is causing harm to Ozone layer. Thus, our environment is in a great danger. To solve this very common worldwide problem we need to rely on such a source, which does no harm to environment along with the comforts we need to fulfil our demands. As power plants, nuclear reactor and fossil fuels cause environment pollution, renewable energy is the hope of light to resolve this issue.

The population of Bangladesh is increasing day by day. The growing population of the country need more electricity. We use natural gas as our main source to generate electricity. To meet the demand of electricity, the country needs to generate more electricity than ever. In order to fulfil the increasing demand of electricity we need another method to generate more power. To produce electricity by using nuclear reactor is very costly and without proper maintenance, it can cause a great damage to the environment by emitting greenhouse gases. Besides, all other fossil fuels, coals are decreasing and they are not environment friendly. Thus, usage of renewable energy can solve this problem. Renewable energy is sustainable. It reduces greenhouse gas emissions and lessens the uses of oils, coals, and fossil fuels, which pollute our environment. So it is eco-friendly and cost efficient than the nuclear reactor for a developing country like Bangladesh. The source of this renewable energy systems are Bio-Power (BIO-Gas & Bio-Mass), Water turbines or Hydro-Power, Solar Power and Wind-Power or Wind turbines of vertical & horizontal axis. Moreover, these energies can provide a great help in time of environmental detrition like desertification, biodiversity inanition and natural calamities.

Among the renewable energy the solar home systems uses the energy from sun. As the sun is the storehouse of energy and this energy is free, we utilize this energy through process. Besides the energy we can get from sun in an hour is enough to run the energy demand of one year. In fact, it can supply power to off-grid households. This method is more applicable for rural area where there is no grid connection to supply electricity. All this systems need are a photovoltaic (PV) module having solar cells, charge controllers and a battery. Here, the PV modules use sunshine to generate the electricity. The charge controller performs the task by delivering power to the battery and by protecting the battery. The battery stores energy and use it during night or when there is less sunshine to deliver enough power. The charge controller plays a significant role to switch the power connection from solar cells to battery. As it is a renewable energy, so it does not use all those materials, which causes pollution.

1.2 Previous Works on Solar Technology

Many research works are going for the solar technologies. This is one of the major components of the green technology. Improvements are obviously needed in every part of solar technology in order to get the best out of it. This does not leave our country Bangladesh in the dust. Indeed our country is also improving in this specific region to improve and to be a part of the green family of the world as well. As the world is progressing towards a greener future with the solar systems, there are more than 35[1] companies those who are doing business around the globe in improving and implementing the ideas about solar technologies.

Not only that, university students around the globe are also interested about the solar technologies as well. The university students of AUST (Ahsanullah University of Science and Technology) also designed a solar system for their own university.

In addition, the university students of the Rajamangala University of Technology Thanyaburi of Thailand had installed a photovoltaic system in their university to promote solar energy as a project work.

The scientists of Korea and California had developed a different way in order to boost the efficiency of the solar systems by introducing plastic solar panels [2]. Nowadays, people are installing solar systems on the commercial buildings, houses, offices and factories just to obtain the green energy.

Solar energy is mainly a site based energy-harnessing project. Therefore, there are many key factors, which actually determines where the best outcome of the energy is.

<u>Site and load based:</u>

The solar system is mostly location based. This means the best outcome comes in a specific region where the solar system is put, mainly the photovoltaic panel. For houses and apartments, the PV panels can be used on the roof top, garden, lawn in order to get the best outcome. Besides that, the solar panels are designed for a particular maximum load or maximum power output. This can be said for Sarnia Photo-Voltaic power plant of Canada, which delivers 80MW of power [3], Olmedilla Photovoltaic Park of Spain delivers 60MW of power [4].

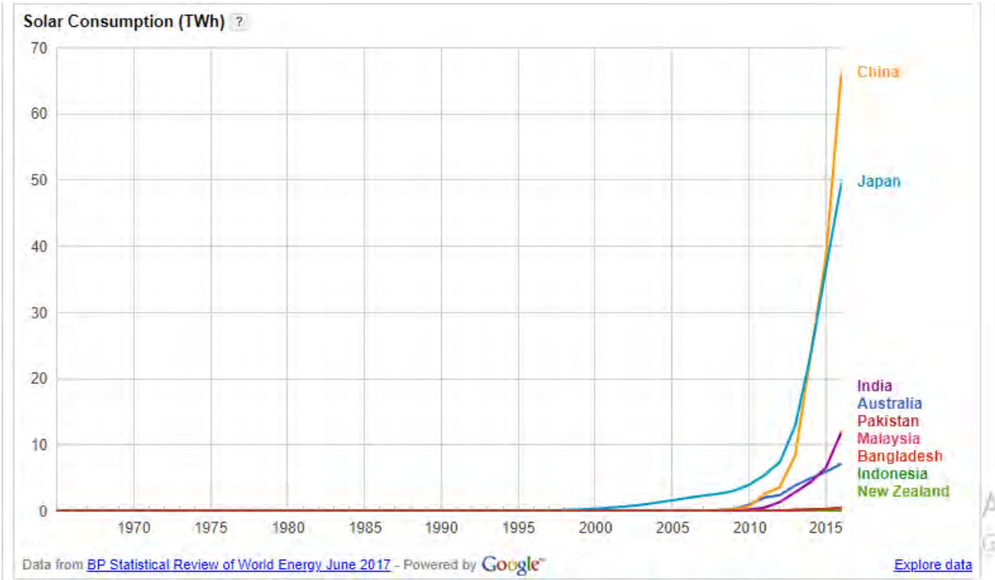


Figure 1.1: Consumption of solar energy around the world

1.3 Importance of Renewable Energy in Bangladesh

In 1980, the average electricity generation of Bangladesh was 3.75 million kilowatts with a minimum of 1 million kilowatts. This generation increased rapidly and in year 2014 it became 8.62 kilowatts [5]. Immobile power cuts and low authenticity of the power supply many households suffers. The energy supplied, is not sufficient in fact less in comparison with the countries having same economic condition. Again, to become a moderate-income country by 2020 Bangladesh need to triple the energy generation. At the same time, we need to mitigate the large share of industrial and household wastages. Under these circumstances, Solar Home Systems (SHS) can also play a vital role in urban areas along with the rural areas. About 75% citizens of Bangladesh lives in rural areas [5]. In urban areas, it can also be used as an alternative option when there is blackout or no grid connections, in common which is known as load shedding. In this case switching between the grid and PV module through the charge controller can solve this problem. In fact, this switching can also be done when there is less sunshine due to cloudy weather or in night.

Solar Home System can also provide power to industrial work. There are many industries in Bangladesh. They consume a huge amount electricity from power plants. This is another reason for which load shedding occurs. If large industries use solar power, an enormous amount of electricity can be saved. It is cost effective for those industries and factories.

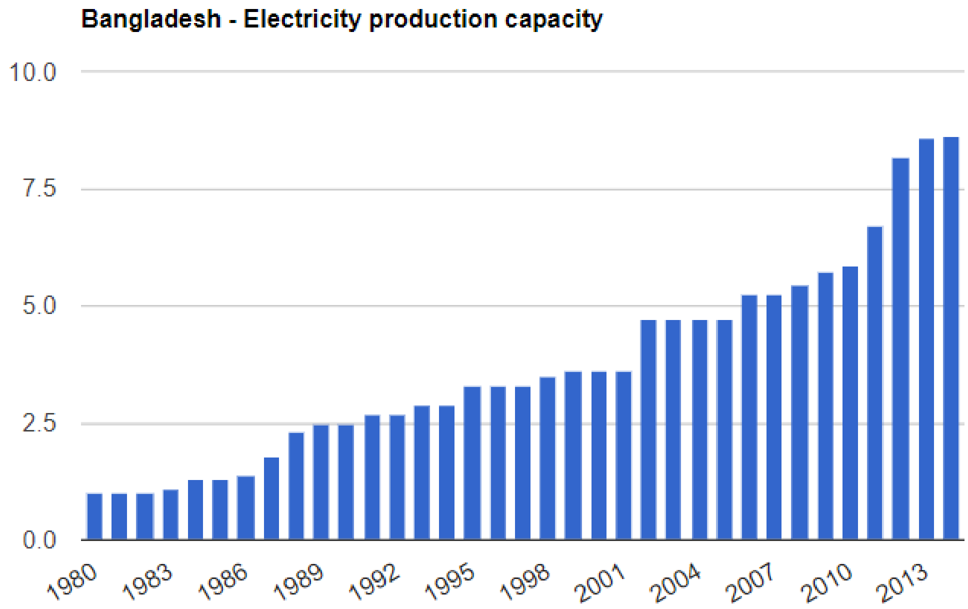


Figure 1.2: Electricity production in Bangladesh

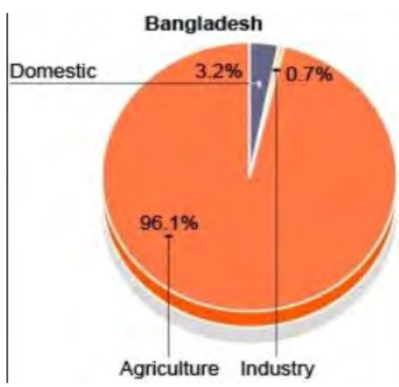


Figure 1.3: Electricity consumption in Bangladesh

1.4 Usage of Solar Home System and Solar Energy

Affluence of solar energy is worldwide. It is one of the important renewable energy after wind and hydro, which makes it third most reliable renewable energy. In this system, conversion of solar energy done by a solar PV panel to supply power. Solar Home System (SHS) is a standalone system. This system supplies power to the load in a cost effective method. As this system can supply power without grid connection, it can also be called off-grid photovoltaic system. People living in remote rural areas where there is no grid connection, gets advantage from this system.

This system is a great blessing for them to get electricity with the benefit of having low maintenance cost. This system can work at rated voltage of 12V DC (direct current) and can supply electricity to low power DC applications. It can also provide power to large appliances having 240VAC rating. This can be done by cabling. Mounting, switching, power conditioner or inverters.

However, not every place is appropriate for solar PV panel. It is because of solar incentive. The countries where sun shines brightly are the privileged ones. Incentives can make solar power reasonable. It is not necessary to have higher insolation for PV panel installation. There are many countries around the world does not have sophisticated amount solar insolation yet installed a good number solar power system and using it. According to a survey solar photovoltaic panel having more than 100GW was installed in 2012. These photovoltaic powers has the ability to produce 110TWh electricity. [5]

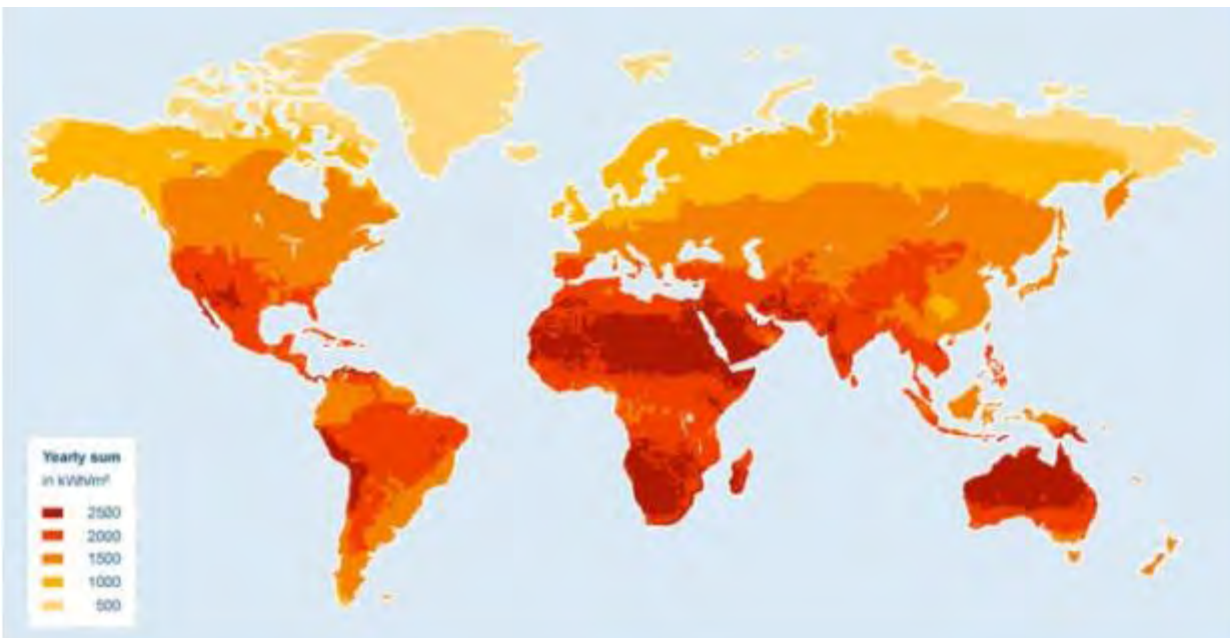


Figure 1.4: Openness and density of solar energy around the world

The picture in above shows the availability solar energy around the world. Different colors are indicating the variation of solar energy density in different regions. The warmer the color higher density of solar energy (insolation, solar radiation, sunlight). From the map, it is noticeable that insolation gets higher when we get closer to the equator and in equator it is higher than other places. It is because sun incidents fall directly to the surface of earth in the regions of equator.

Germany has installed highest PV power in the world. The capacity of their solar power is 32,411MW, which is almost 31%. In the year 2012, more PV panels were connected and the capacity of power became 76GW for year 2012. In the same year Germany produced electricity of 23TWh (terra watt-hour) by only using solar panels. After that, it only enclosed 3% of country's total consumption. Some market experts hope that by 2050 solar power will cover the 25% of the total consumption in Germany. Although Germany is not blessed with extents of solar energy, it has a great setting effort for solar power to compete in the market.

Many European countries have started implement and use solar power. Italy is the second highest capacity of solar power country in the world. In 2012, it added 3.4 GW solar power capacity. Other countries of Europe such as France, UK, Greece and Bulgaria are also implementing solar technologies. With a capacity of 1GW, Spain became world leader in solar thermal power (CSP) in the year 2012, which exemplified 65% of total installed CSP.

US has capacity of 7.8GW solar PV. China 8.3 GW solar PV. California has solar power of 1.6 GW. New Jersey, New Mexico and Arizona are not lagging behind. [6]

Table 1.1: EPIA's annual Global Market Outlook [5]

Ranking	Country	Installed PV (MW)
1	Germany	32,411
2	Italy	16,361
3	China	8,300
4	USA	7,777
5	Japan	6,914
6	Spain	5,166
7	France	4,003
8	Belgium	2,650
9	Australia	2,650
10	Czech republic	2072

1.5 Advantages of Solar Home Systems

- The energy we get from this technique is renewable
- It saves our money by deducting electricity bill
- It can be used in various application
- It requires low cost maintenance

1.6 Objective

The objective of this thesis study includes the following steps-

- To study the cost efficiency of solar system as a renewable energy.
- Widespread implementation of solar home system as renewable and green energy.
- To study about the components required for this system and their desired size specification for the system
- To know about the features of solar PV system and available tools a brief research has been done.
- To do some tests through simulation.
- To maintain the standard procedure of the design and implement it.
- To know more details about the best use of solar home system and its importance

1.7 Site Selection

This thesis project is performed under BRAC University. BRAC University has seven buildings. We chose the rooftop of Building 4 for thesis work. Building 4 of BRAC University is south facing and it has 16 levels including the rooftop. As it is south facing it has the advantage for sun rays falling on it easily and it gets solar radiation from east, south and west until the sun sets. This is the main reason for selecting the particular site. Another reason is that the wiring can easily be done. The red marked area on top of the zoomed in area is the location of panel installation.

Figure 1.5: Site location (Marked Red) of our thesis project (BRAC University Building 4)

Chapter-2

Literature Review of Solar Energy

2.1 Solar Energy

We know that heat and light are one kind of energy. In addition, solar energy is the energy that is radiated from the sun and arrives at the earth in form of light and heat energy. Solar energy is one of the important source of renewable energy and plays significant roles to produce electricity. The electricity we get or generate by using the solar radiation is called solar power. There are two types of technology for solar energy. These technologies are active solar technology and passive solar technology. In passive solar process, the energy of sun is used by not converting it. Moreover, in active solar system the energy of sun is converted into electricity by using outside sources. The active solar technology is a great renewable energy as it reduces the uses of fossil fuels to produce electricity. [7]

The potential of solar energy is very huge, huge enough to fulfill the requirements of the world. The total energy consumption of the whole world back in 2008 was around 474 exajoules (1EJ=10^18 joules) or approximately 15TW(1.504* 10^13Watts)[8]. Almost 80-90% of this energy came from the fossil fuels [9].

The amount of energy that the earth receives from the sun is about 3850000 EJ[5], which is more over equivalent to 174 petawatts (1PW=10^15W). The earth does not hold all of the energy as it reflects it back to outer space. The remaining power after the reflection is about 89PW. Of this huge amount of energy, only 0.02% of it is enough to replace the fossil fuels and nuclear power supply in the world. Considering all the greenhouse gas effects, and environmental effects we can certainly say that solar systems has the greatest source of energy for the betterment of the earth

2.2 Background of Photovoltaic System

The effect in which some materials absorb photons from light and separate electrons is called photoelectric effect or process. This photoelectric effect also takes place in photovoltaic solar cell. In 1839, scientist Edmond Becquerel noticed this phenomenon for the first time. He was then doing an experiment with electrolytic cell. He suddenly noticed that certain material generates a small amount of electric current in presence of light.

However, William Gryll, a professor of London and his student Richard Evans Day in 1876, observed the first photovoltaic effect. They generated electrical current by exposing selenium to light. They were able to come to a conclusion that solid materials can produce electricity by using sunlight. However, they could not produce enough current from sunlight but it was the base concept of photovoltaic cell.

Charles Fritts invented the first functioning solar cell in 1883. It was selenium coated with a thin layer of gold. It could convert a very small amount of light into electricity with an efficiency of 1%. It was used on the world's first rooftop solar array in 1884 in New York City. Due to the high cost of Fritts solar cell, it was not accepted in wide scale.

In 1905, Albert Einstein gave proper explanation to photo-electricity through his theory. In his theory he explained how photons from light can produce electricity if it is connected to a circuit.

The photovoltaic cell, which converted enough solar light to produce electrical current to run electrical equipment, was silicon PV (photovoltaic) cell. The U.S. scientists Daryl Chapin, Calvin Fuller and Gerald Pearson developed the first silicon PV cell at Bell Lab in 1954. The efficiency of this cell was 6% [10].

Silicon solar cell was being improved through research, which resulted in 1963 as mass production of solar cells. The use of solar cell in space industry made the cost go down. It became more popular in 1970 when the oil crisis rose. As a result, scientist did more research on it for to make it cheaper for non-space technology. Thus, it gained recognition as a source of power for household and industrial purpose.

2.3 Solar Cells, Modules and Arrays

A photovoltaic solar system is a system, which includes silicon solar panel. The solar panel is made of photovoltaic solar cells. It produces higher voltages, currents and power points if we attach them in series or parallel circuit. A photovoltaic cell is in genuine made of semiconductor material, specifically silicon made. By arranging these cells in series or parallel, a photovoltaic module is created. Again, by attaching photovoltaic modules in series or parallel connection solar arrays are designed. Inside a photovoltaic module, the photovoltaic cells are kept in such a way so that no harm can cause by environment; for example, it is watertight with shielding laminate. Photovoltaic panels may have one or modules. These modules are assembled by a pre-wiring field installable unit[11].

The performance of solar PV module and array depends on their rated condition. This rating is done according to the Standard Test Condition (STC). The STC temperature of a PV module is 25^{o} C and in Fahrenheit it is 77^{o} F. The air mass is 1.5 spectral and the solar irradiance is 1000 W/m^2 as per to the STC rating.

Nowadays, photovoltaic modules are reliable source of power generation having low failure rates with a lifetime expansion of 20 to 30 years.

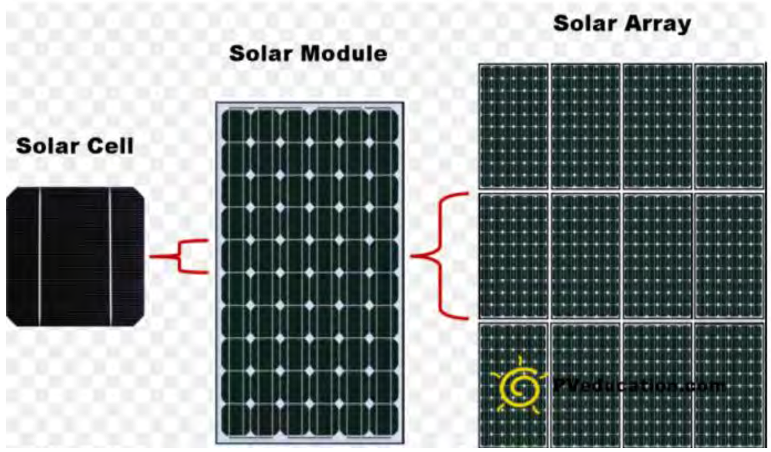


Figure 2.1: Solar cell, module and array

2.4 Photovoltaic System

The device, which converts light into electricity, is known as solar panel and the process or system through which light is converted into electricity is known as photovoltaic system. Photovoltaic means light-electricity. Solar panels of photovoltaic system has small cells on it known as solar photovoltaic cells. These photovoltaic cells can be arranged in two ways in a solar panel. One way to connect it is in series and the other way is in parallel. A Solar Photovoltaic cell converts solar energy into electricity. A photovoltaic cell is a semiconducting material composed of silicon. When the sunrays fall on it, it interacts with photons and generates small current.

The semiconducting material or semiconductor of solar cells have minimum two layers, known as wafer. These semiconductors are doped with boron and phosphorus. One of the layer of the material is positively charged and the other one is negatively charged. Thus, the positive layer is P-type or works as a hole and the negative layer is N-type. The silicon layer that is doped with Boron is P-type and the other one that is doped with Phosphorus is N-type. As two different type of charge (positive charge & negative charge) is present in a solar cell, an electric filed is created. This electric field is called P-N junction. Semiconductors absorb photon from light and separate the electrons. The P-N junction make available direction to the separated electrons. These released electrons flow to the negative layer to positive layer and a loop of hole is created. Therefore, a one directional current is created which in actual is a DC current.

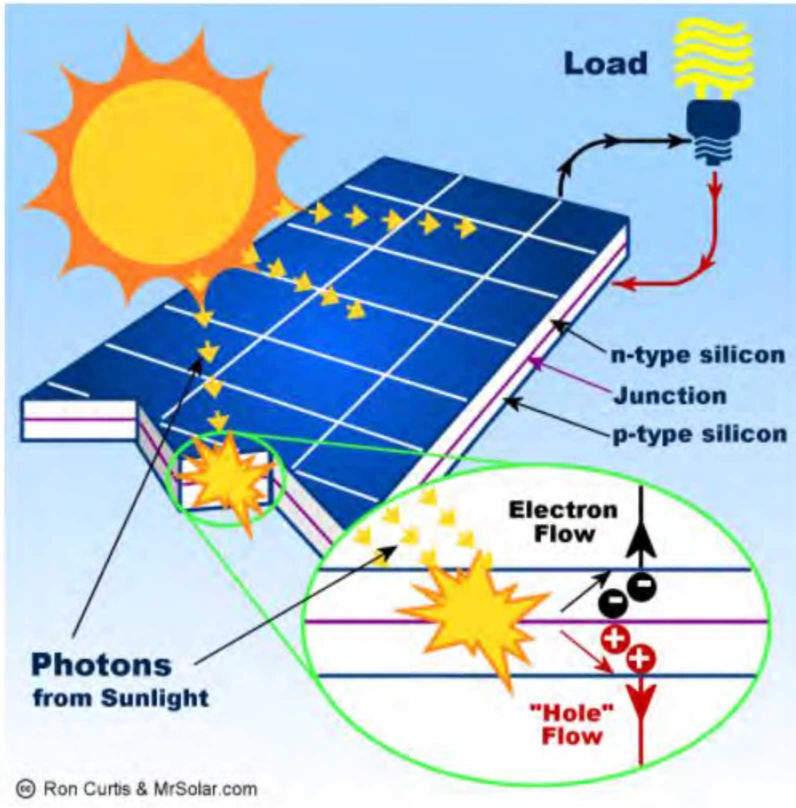


Figure 2.2: Conversion of electricity from sunlight

2.5 Solar PV Technology

Many studies and analysis have done to meet the demand of electrical current through solar PV technology. The existing technologies are developing with time. Hence, the solar system we have at the present can generate more electricity than the previous one. Four types of solar PV technology subsists. They are-

- Single crystalline or mono crystalline
- Multi crystalline or poly crystalline
- Thin film
- Amorphous silicon

Single Crystalline or Mono Crystalline

Mono crystalline silicon cells are the most efficient solar cells than the other cells. It can be found easily. If we calculate the power generation per square foot of module, it generates the supreme power. In a mono crystalline PV cell, a single crystal of silicon is cut from each cell. In a solar panel the number of cells are increased by cutting the wafers in a rectangular shape.

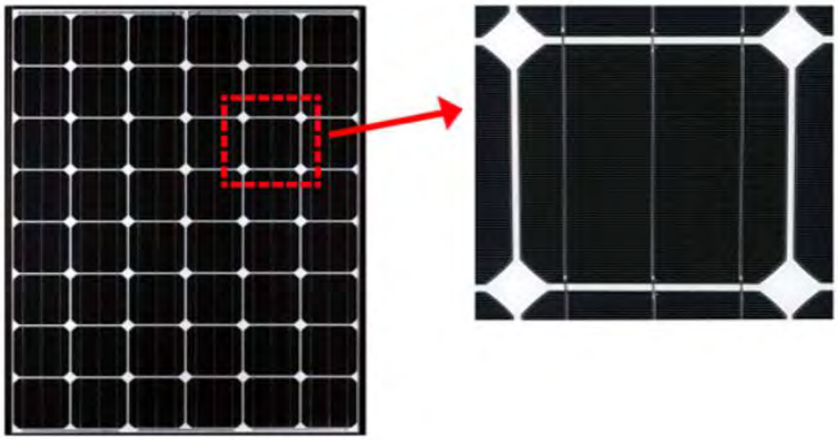


Figure 2.3 (a): Mono Crystalline Photovoltaic Solar Cell

Multi Crystalline or Poly Crystalline

Polycrystalline cells are made in the same manner; just the difference is that they need go through the melting procedure and then transferred into a mold. Hence, the formation of single crystalline does not take place. In this technology, the mold takes form of square blocks which then turns into square wafers. One advantages of this system is that it wastes fewer materials than mono crystalline technology.

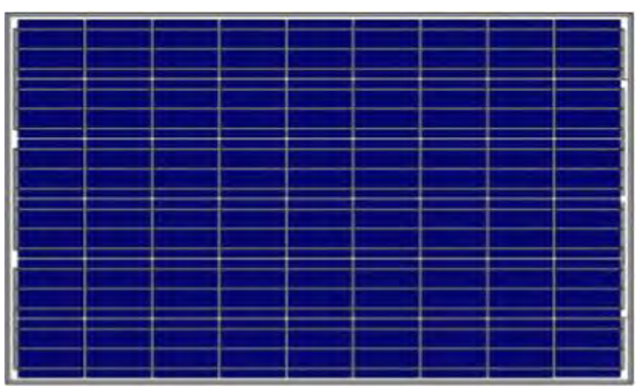


Figure 2.3(b): Poly Crystalline Photovoltaic Solar Cell

Thin Film Panel

Thin film technology is new in the solar cell technology. It is very thin. To be specific, it is of a few micrometer or less than that. This technology includes thin film supplies or materials of Copper Indium, Cadmium Telluride and Gallium Arsenide. They are all accumulated together on glass, stainless steel or in other materials to make a substrate. Few of them can give better performance where there is less light compare to the crystalline silicon.

Figure 2.3(c): Thin Film Solar Cell

Amorphous Silicon

Amorphous silicon is a thin film technology. Nevertheless, it is the very latest solar thin film technology. Amorphous silicon is nothing but a silicon in non-crystal form. This technology includes vaporization of amorphous silicon. The silicon vapor is gathered or deposited on thick amorphous films, which I couple of micrometer and after that, accumulated on stainless steel rolls in this technology only 1% material is used.

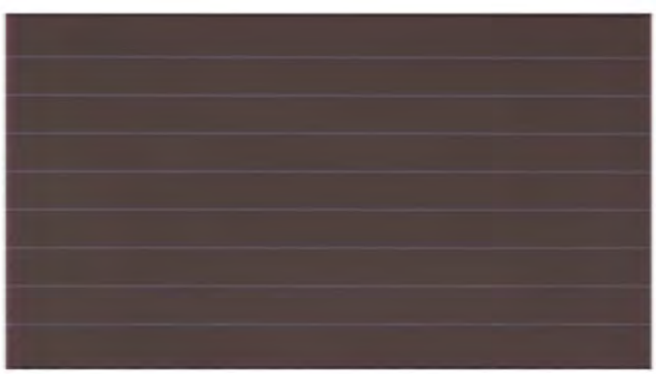


Figure 2.3(d): Thin Film Solar Panels -3.8V 30µA Amorphous Silicon Solar Cell

Table 2.1: Effectiveness of different solar technology

Cell type	Efficiency	Strengths	Weakness
Mono Crystalline	12-20%	Space efficient, Durability up to 25 years	Expensive, sensitive to ambient temperature, got sensitive issues towards shading, snow and dirt, Manufacturing process is spendthrift
Polly Crystalline	12-18%	Cost efficient, simple manufacturing, less wasteful than mono crystalline, intolerance to high ambient light	Has impurities, less efficient than mono crystalline, got less space, trade is energy extensive
Thin Film	8-10%	Cost efficient and simple manufacturing, flexible configuration for installation, high tolerance to ambient temperature and shading	Low efficiency, does not have sufficient space, high degradation rate
Amorphous Silicon	6-8%	More thin film, cost efficient, simple manufacturing, flexible configuration for installation, high tolerance to ambient temperature, only 1% material is used	Low efficiency, not enough space, high degradation rate

2.6 Components of PV System

The arrangement of Solar Photovoltaic system has several components such as

- **Solar Panel (PV) Module:** Solar panel is the most important component of Solar Home System. This is the device, which converts light energy to electrical energy. A solar panel is an array of solar cells arranged in a series or parallel way.
- **Charge Controller:** Charge controllers ensures when to charge or discharge the batteries. It is mainly a voltage or current controller. It protects the battery so that it does not get damaged because of overcharging or discharging for a long period. The solar charge controllers can be of different sizes and have features and cost. Charge Controllers have ranges of 4.5A (ampere) and up to 60 A to 80 A.
- **Battery:** Battery, another mandatory component of solar home system. The solar home system can only convert the solar energy into electricity in day light. However, at night when there is no sunlight, it produces electricity with the help of battery. In case of solar irradiation and over cast weather loads takes power from battery. A better solar system requires a good battery with longevity. The efficiency of a battery or how good a battery is, can be measured through the following features-
  (i) Capacity,
  (ii) Cycle life,
  (iii) Performance,
  (iv) Size,
  (v) Space requirement,
  (vi) Ah efficiency,
  (vii) Self-discharge rate,
  (viii) Installation,
  (ix) Price.
- **Cables & Accessories:** Solar Home System is an outdoor application. Hence, we need cables, which does not get damaged easily and can ensure low voltage drop along with low power losses.
- **Inverter:** Inverter plays a great role where solar home system supplies electricity along with the grid connection. We get DC current through photovoltaic system. We might need AC current for some rare case. Under those circumstances, the inverter converts the DC (direct current) to AC (alternative current).

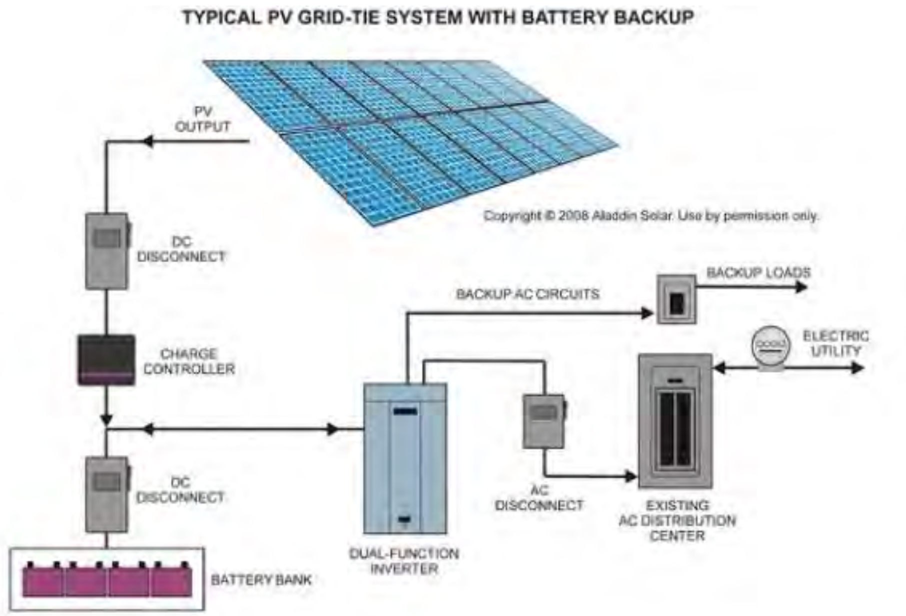


Figure 2.6: A Typical Solar PV system

2.7 Types of Solar Panel Design

A solar system can be implemented in various ways. Thus, it can be varied according to its functional and operational configuration. Generally, it has three basic design-

- Grid tied
- Standalone system
- Hybrid system

Grid tied PV system

In grid tied system a simple solar installation is needed which uses a standard inverter. It does not require any battery storage. This system is perfect for those who already using grid supply or want to use grid power and solar power both. Grid tied PV system design is very simple than other and cost effective as it does not require many components. The main goal of this system is to lower the electricity bill and proper use of solar energy. Here, the PV array operates in parallel with the grid. In day the loads takes power from the PV system. At night and in overcast weather the load energies by using grid power. One disadvantage of this system is that the power and system goes out together as they are parallel connected.

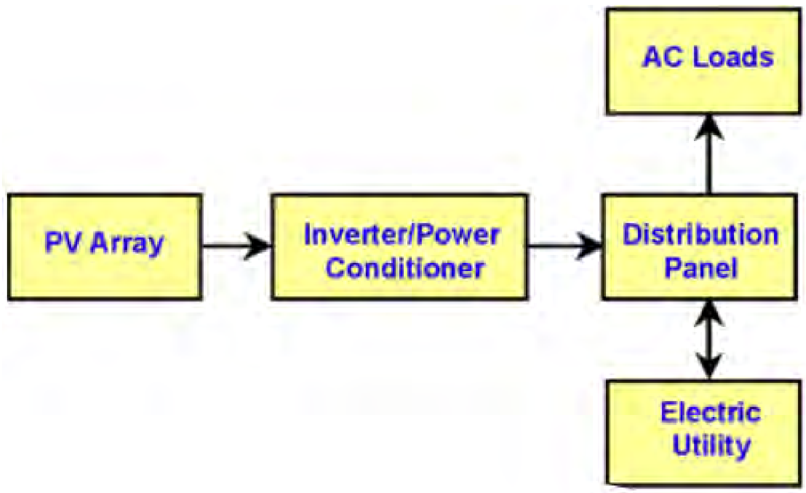


Figure 2.7: Block diagram grid tied solar PV system

Standalone PV System

Standalone PV system does not require electrical utility grid, it can operate independently without a utility gird. Generally, it takes power from solar module or array. A standalone PV system supply power to the DC or AC load or can supply power to both DC and AC loads. It uses battery to supply power to the loads at night and during rainy day or when there is not enough sun light to produce electrical current. This system also includes a charge controller to protect the battery from damage. In rural areas or in the areas where there is no grid connection, this system plays a vital role to electricity. Common uses of standalone PV system include electrical fan, lights, water-pumping system etc.

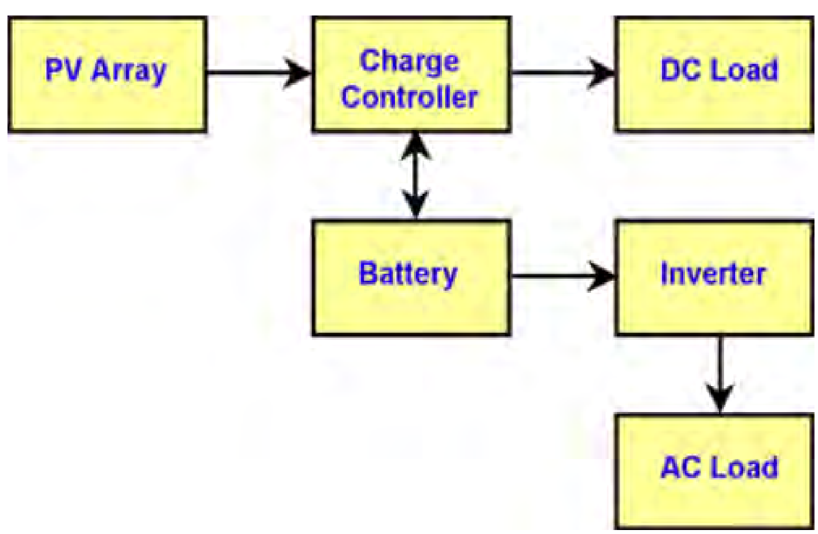


Figure 2.8: Block diagram of standalone PV system

There is another type of standalone PV system where a DC load can directly be connected with the DC output of a PV module or array. It is known as direct-coupled system and this sort of standalone PV system is the simplest one. In direct coupled system there is no battery to store energy. Hence, the load only work during the daylight when the sun shines.

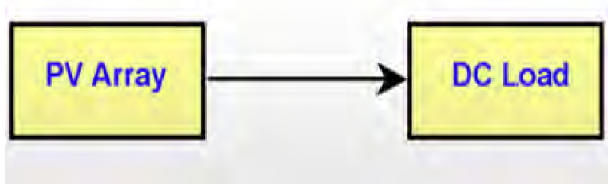


Figure 2.9: Direct-coupled PV system

Hybrid System:

It is same as grid tie solar PV system but includes batteries to store energy. As this system stores energies, it is also used during blackouts like a UPS (uninterruptible power supply).

Generally, the word hybrid refers to the combination of two source. The combination of hybrid system includes solar and battery storage connected to the grid electricity as an auxiliary power source. Wind, engine generator can also be used as an auxiliary power source [12].

Figure 2.10: A typical hybrid solar system

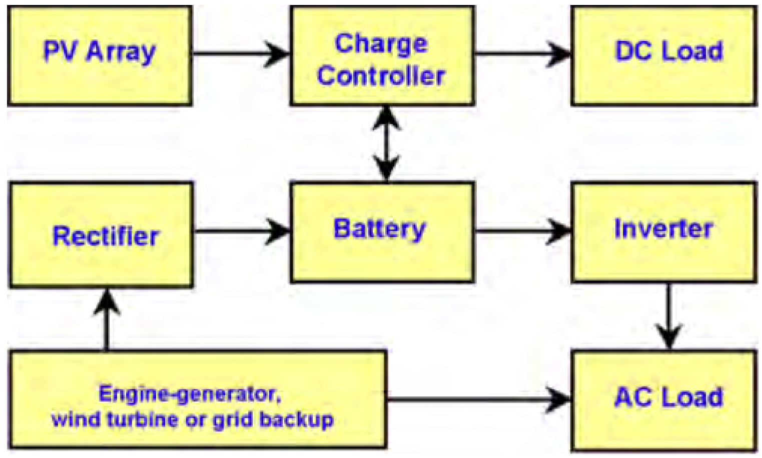


Figure 2.11: Block diagram of a hybrid solar system

2.8 Solar Radiation

The energy we get from sun is solar energy. Solar energy is a short wavelength. The ultra-violate rays, radio frequency and visible waves are different form of solar radiation. These radiations are great solar resource. It is a resource, which is easily available, and no cost is needed for it. Every day earth receives a huge amount of solar rays. This ray is the main base to solar panel. Not every sphere of earth gets same amount of solar radiation. It is because-

- Geographic position
- Solar rays varying with time
- Different season caused by annual rotation
- Changes of weather

The earth, being imperfectly round, has elliptical shape. Therefore, sunrays radiates at different angle. These angles can vary between 0° to 90^0 [13]. When the sun radiates over the horizon then angle is 0^0. Again, when the sunshine perpendicularly over the panel then it is 90^0. Earth's surface gets most of the energy emits from sun as soon as it is in vertical position. In addition, the region where slanted sunrays fall gets less amount of solar energy. It is because slanted rays diffuse and gets scattered. Solar panel is the technology, which converts solar radiation into electrical current. As a result, it is very important to set a suitable location for installing solar PV panel so that maximum sun rays. Not only that, the setting of solar panel also required some necessary measurement such as angle, altitude, mounting etc. The installment of a PV solar panel needs to be positioned by means of two angles known as azimuth angle and zenith angle. Another important parameter for the installment is the tilt angle. These parameters are part of solar geometry.

2.9 Solar Geometry

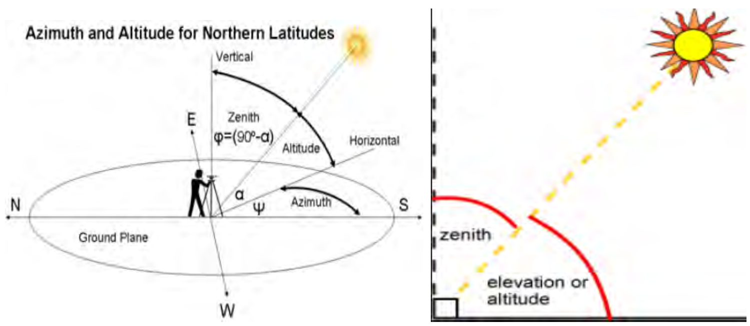
The position of sun has effects on the enactment of solar panel. A brief description of solar geometry is given is below:

Azimuth Angle:

Azimuth angle can be defined as a horizontal angle. The angular distance of an object horizontally with the location of the object. It is generally measured from north to east by means of horizon. It is denoted with α.

Zenith Angle:

The zenith angle is the angle which is measured vertically amid with sun. Zenith angle is a 90° angle as it is measured with vertical axis.



(a) (b)

Figure 2.12: (a) Picture of azimuth angle along with sun
(b) Difference between zenith angle and elevation angle

Solar elevation angle:

Elevation angle is also known as altitude angle. It is 0^0 when the sun rises and 90^0 when the sun shines in equator [14].

Tilt angle:

The angle, which is measured by using solar panel and horizontal plane, is known as tilt angle. A solar panel is set according to its tilt angle. Tilt angle is very important. Because tilt angle is the angle where the panel can get most of the sunshine. Tilt angles may vary with sides. A south facing building have different tilt angle than a north facing building.

Air Mass:

Air mass is a body of air having contents of temperature, humidity and pressure. Air masses cover many hundreds or thousands square of miles. Sunrays have to pass through this air mass. Air mass defines what amount sunrays the surface will receive. Air mass has a relation with zenith angle. If the zenith angle increases, air mass increases. It is because the height and path get longer. Nevertheless, it decreases if the elevation angle increases. Because the thickness of the decreases.

Table 2.1: Air mass for some values of solar elevation angle [15]

Elevation angle along with Sea	Air Mass
90^0	1
45^0	1.15
30^0	1.41
20^0	2
15^0	2.92

CHAPTER-3

METHODOLOGY & SYSTEM DESIGN

3.1 Methodology

Our project starts with complete observation of solar photovoltaic system. Our system begins with the enumeration of the type and synopses of elements required for installing the system, after that with a general analysis (using PVSyst and RET Screen software) to conclude an idea how much energy the system will be generate and calculating cost benefit of the system economically.

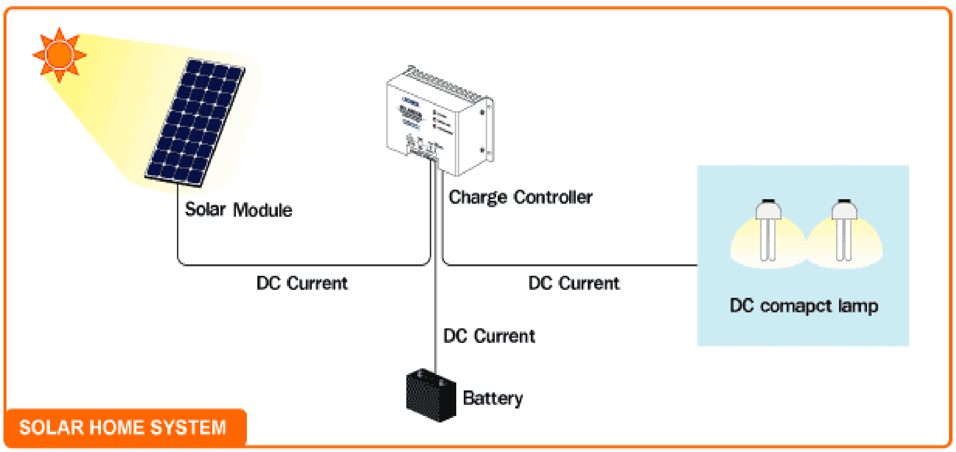


Figure 3.1: Solar Home System

To determine system specification, construction and components we will follow the steps given below:

1. In this part of the design, the place where the system will be placed is where the sunlight reaches well. It is very important because the entire value of the system will depend on it. To calculate the locations solar radiation we can take data from SPARRSO (Bangladesh Space Research and Remote Sensing Organization) AND NASA (The National Aeronautics and Space Administration) and PVsyst software what will help us to calculate the amount of solar radiation we will get on our site.
2. Considering all data and flexibilities, we concluded Building no. 4 is suitable to build the system. Our initial target was to build a home system that will give enough energy to power a DC LED light and a DC fan. However, it was narrowed down to power a flood light that will turn on after 6 PM and glow for 4 hours.
3. Finding the correct place on building roof that can be utilized for the project based on a minimum roof area, roof orientation, slope /pitch.

4. Using PVSyst software we simulated the solar system comprising load and assessed system parameters (including panel tile, wire length near shading etc.)
5. We collected additional information from local dealers. Our information includes, cost, size, weight, etc.
6. Initially, we designed the layout of the system for the selected target load and building.
7. Using RETScreen, we analyzed the total cost and simulate probable breakeven period.

We followed the draft procedure to design our 60Wp off-Grid solar PV system for BRAC University. Overall simulation of the economic performance and technical data was conducted by using planning and simulation PC software packages. PVSyst, developed by the group of Energy of the institute for science of Environment of the University of Geneva in Switzerland and RETScreen clean Energy project Analysis Software, developed by Natural resources Canada.

3.2 Design of a 100Wp off-grid PV System

To design the 100Wp off-grid PV System we followed previous method developed previously. We get solar radiation data searching on online resources and built-in resources of PVSyst software. At the end, radiation data was collected from the software provided by the solar path for this position.

3.2.1 Site Selection

In this part of the design, the location where the system can be built, the availability of sunlight, these issues are well reviewed. Because the entire value of the system will depend on sunlight. Depending on the size of the panel, how much space it will need is decided. The performance of the system is always good for the PV panel in which the sunlight is readily available throughout the year, it cannot be constrained by any obstacle. Considering these factors and visiting the site properly, the solar panel orientation and position is selected.

3.2.2 Calculation of load

It is very important to have a proper understanding of the case of designing any solar system. The size of the components of the system depends on the electricity demand. So the whole system designing is dependent on the amount of load. If there is no correct information about the load, the initial cost will increase, the PV array or the battery size will be slashed, and the system will not work effectively. Therefore, the load type and size should be determined carefully so that the performance of the whole system is maximum.

Before designing the system, we needed to calculate how much time it would run. For our project we use DC flood light and DC fan.

Table 4.1: Table for Load

Equipment	Quantity	Rated power (watt)	Operating hour	Watt-Hour
DC Flood light	1	20 x 1=20 watt	7	20 x 7= 140
DC Fan	1	40 x 1 =40 watt	7	40 x 7 = 280
	Total	**60 watt**		**420 watt-hour**

Now in Summer, Autumn and Spring for 420 watt-hour load for a 12 volt DC system, daily ampere-hour calculated as follows:

Watt- hour/voltage = (voltage x ampere x hour)/ voltage

= (420/12) ampere-hour

= 35 ampere-hour

Again, in winter, as people does not use fan, 140 watt-hour daily ampere-hour is calculated as follows for our system:

Watt- hour/voltage = (voltage x ampere x hour)/ voltage

= (140/12) ampere-hour

= 11.667 ampere-hour

At this point load calculation is completed.

3.2.2 Battery Capacity Calculation

Battery is used to save energy produced by the solar home system and to use it when needed. The rechargeable batteries are used for this. In a solar home system, mainly lead acid battery is used. There are different types of batteries. It is a very important task to choose which type of battery is suitable.

Battery used in the solar home system can usually run on a shallow cycle or cloudy day or deep cycle in winter. The cost of battery is limited to a small battery charge. But the charge on the dip cycling is 50 percent or more. The batteries used in the solar home system should have the following characteristics:

a. Legibility for deep cycle,
b. Low maintenance,
c. Maximum charging capacity,
d. Can be fully discharged,
e. Reliability,
f. For greater fluctuation of temperature, low fluctuation of efficiency.

3.2.3 Battery Selection

Battery is selected for the Solar Home system in the following manner:

A) How much time the battery will be used for.

B) The quantity of storage of the average ampere (Ah), this is equivalent to the number of days of daily life, and the number of hours of battery used.

C) We need to collect the acceptable level of discharge from the battery manufacturer. Then we need to divide the Ampere-Hour with the discharge level. For example, if the amount of discharge is 80%, 0.8 should divide Ah. Thus, the correct and usable Ah can be found.

D) There should be no susceptible type for discharge rate. If necessary, we need to collect data from manufacturer again.

E) The requirement of the temperature correction factor should be checked. If necessary we need to follow procedure C and D again.

In our solar home system we are using 55 Ampere-Hour Battery to power the demand for summer, autumn and spring is 35 Ampere-Hour and for Winter 11.667 Ampere-Hour. So our battery fulfills our demand for designing a solar home system. We can add further load in our system in future.

Table 4.2: Summary of the initial design parameters for the 60 Watt-off-grid PV system

Meteor Data	
Daily horizontal radiation	5.07 kWh/m2/day
Building Orientation	
Number of buildings Selected	1 (One)
Total Roof Area	Adequate
Roof Pitch	Horizontal
Roof orientation	South
Module-Controller Details	
Module Type	Polycrystalline (Kyocera SM-85ksm)
Module Capacity	55Wp
Module Efficiency	Module Efficiency 14.00%
Number of Panels	1 (One)
Controller Capacity	10 Ampere
Number of Controller	1 (One)
Type of Controller	PWM series controller

CHAPTER-4

SIMULATION RESULTS

4.1 Technical Analysis by PVSyst

This is software package that allows a user to precisely study and analyze a full-featured PV project to evaluate the results and identify the best conditions in different configurations. The software enables a user to simulate a PV System while evaluating its sizing, pre-feasibility and financial analysis. The system can be grid-connected, stand alone, pumping or DC grid system. A large group of highly qualified professionals are mainly responsible for the existence of PVsyst software. To meet this requirement PVsyst trains the interested on Photovoltaic Technologies and the software. Designing a PV system in an optimal and reliable way is essential for cost recovery and feasibility of the system. This is where this software comes to help by allowing people to simulate different design configurations and discovering the right system setup for their need. The Author and founder of PVsyst software is a Swiss Physicist named André Mermoud. He began developing the tools for 3D Shading constructions, stand-alone system simulation, pumping PV systems and database for the components to work in conjunction.

PVsyst, being a commercial software, offers its users a trial version for one month only. Since the software is available for use only for one month, different computers were used after the end of each trial periods. PVsyst 6.57, 6.65 and finally 6.70 was used one after another for the simulation and evaluation of this project.

4.2 General Features

PVsyst 6.70 provides three different levels of study, in the development of a project in simple stages. The levels are:

4.2.1 Database:

The PVsyst software has advanced data management for meteorological data and PV components. PVsyst Software Company collects the needed Meteo data from other sources across the world. Hourly values are gathered from the likes of Meteonorm, Solar Prospector, Helioclim-3, SolarGIS climData. These sources provide the data for mostly the USA, but 3Tiers provides hourly data for any location on earth through satellite. On the other hand, Meteonorm, NASA-SSE, SolarGIS iMaps, PVGIS-ESRA, Helioclim-1, Retscreen gathers monthly data, which are supported in PVsyst. The software takes the most reliable data for the selected site by the user and uses the data to virtually detect the intensity of solar irradiance on the desired PV panel. [16]

4.2.2 Preliminary Design:

Monthly values are taken and performed in this level for quick system evaluation, specifying only a few general system parameters without defining the actual components with a rough estimation of system cost. Grid-connected, stand-alone and pumping systems can be simulated with necessary parameters and results are generated without the advanced simulation result consisting of generated monthly data.

4.2.3 Project Design:

This level of the software performs a thorough system design and thereby generates detailed hourly simulation data. A user has to define and choose specific system components while the softwares suggests the rating of a component that should be used. In the next step, a user can define more detailed parameters and overview the effects of thermal behavior, wiring, module quality, mismatch and incidence angle losses, horizon (far shading), or partial shadings of near objects on the array and such. A rather complex CAO 3D construction of the system is required in the Near Shading feature of the software if the system has objects that causes partial shading of the panel.

The algorithms in the application checks the consistency of all parameters after every system component specification. It produces orange warings if the parameters are not defined correctly or red warnings if there is a components missing in the design. Orange warning allows simulation while the red one does not. If there is no red warning in the system, the simulation can be carried on which can generate up to dozens of data. The data can be shown in hourly, daily or monthly values containing important diagrams like loss diagram, performance factor, solar fraction and so on. [16]

The simulation calculates energy distribution of a whole year. The main results are:

1. The total energy production [MWh/y] is essential for the evaluation of the PV system's profitability.
2. The Performance Ratio (PR [%]) describes the quality of the system itself.
3. The specific energy [kWh/kWp] is an indicator of production based on the available irradiation (location and orientation).

Another notable feature of PVsyst is Measured Data Analysis. This feature permits to import any measured data in ASCII format to perform comparison of simulated model and gathered data. This helps to identify very small irregularities of a system and analyzation of the running parameters.

A block diagram of the procedure to use the project design feature of the software has been given on the next page.

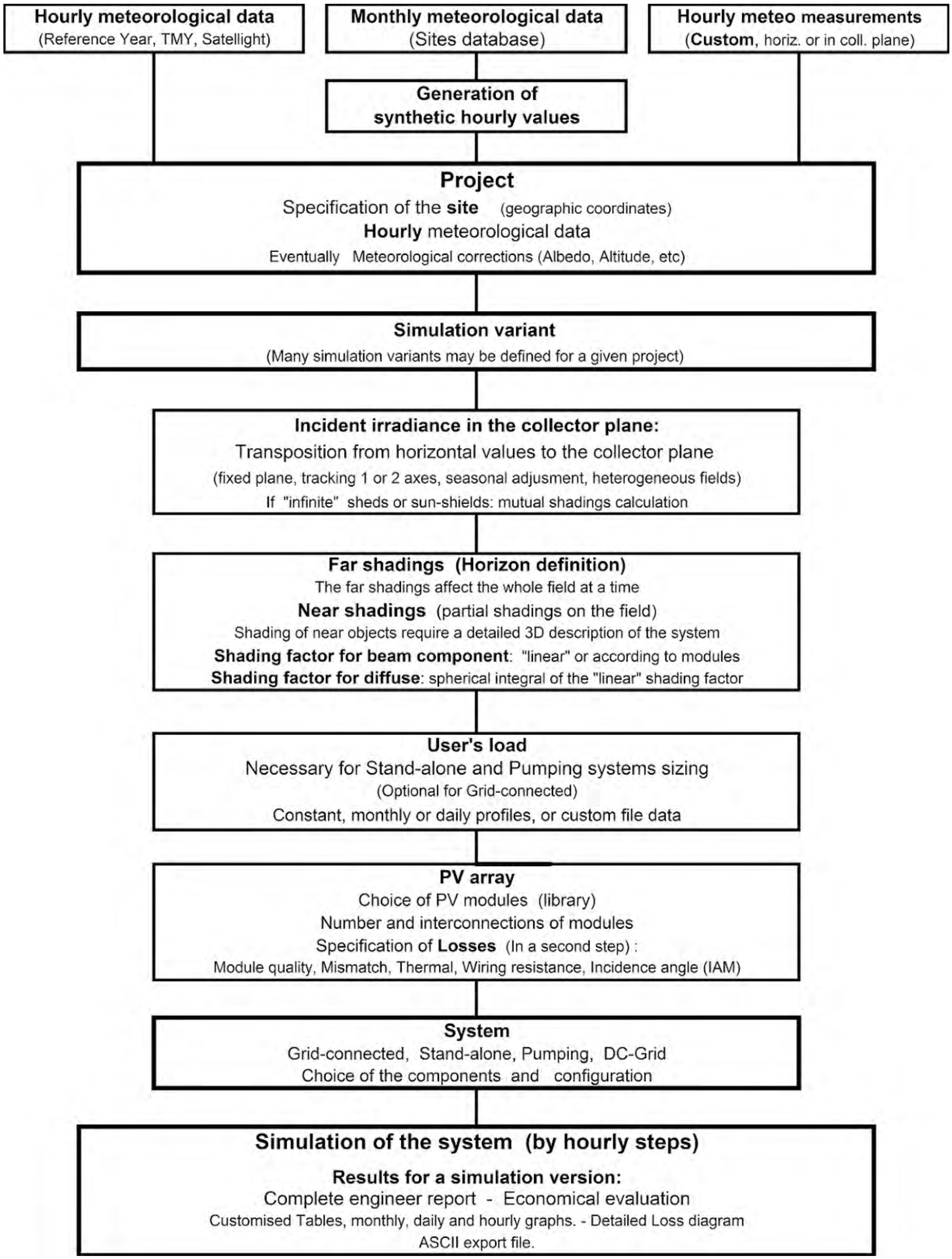


Figure 4.1: A block Diagram of the process of a Standalone project

4.3 Acquisition of Necessary Data for this Project

For a stand-alone system, mandatory model parameters needed for simulation model are the following:

- Geographical site information
- Monthly meteorological data for horizontal global irradiance and temperature.
- Database of PV components like PV modules, Charge Controllers, Batteries etc.

The databases are available within the software that can be exported if needed. Importing data feature ASCII format is available in this programme if the preloaded data are not sufficient. For this project, the meteo data, global irradiance and geographical data of our location is available as ‘Dacca’. However, the PV panel, Charge controller and battery was not available in the software. Similar rating components were used in this case, as there are no ASCII data available for the uncommon components we used.

4.3.1 Acquisition of Site and Meteo Data

The system was implemented on the rooftop of BRAC University Building 4 situated in Mohakhali, Dhaka. The Meteo database for this location as well as the entire Dhaka city is available as ‘Dacca’ in the software. The site’s latitude and longitude is 23.78 degree North and 90.40 degree East respectively with an altitude of 30 meters. The average annual Horizontal Global Irradiance for the building is 5.07kWh/m2 per day.

Table 4.1: Meteo and incident energy data for project site obtained from PVSyst

Meteo and incident energy

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	WindVel m/s	GlobInc kWh/m²	DifSInc kWh/m²	Alb Inc kWh/m²	DifS/GI
January	130.5	48.4	17.37	0.0	157.4	54.81	0.444	0.000
February	130.3	58.6	20.77	0.0	147.6	63.38	0.444	0.000
March	177.6	72.7	25.14	0.0	191.2	76.61	0.605	0.000
April	177.2	84.8	27.19	0.0	180.1	86.03	0.604	0.000
May	177.8	100.9	27.88	0.0	173.0	99.35	0.605	0.000
June	147.9	97.8	27.55	0.0	142.5	95.09	0.503	0.000
July	152.9	94.1	28.04	0.0	147.3	92.00	0.520	0.000
August	140.4	96.3	28.25	0.0	137.8	94.90	0.478	0.000
September	144.8	80.9	27.47	0.0	150.6	82.60	0.493	0.000
October	140.2	70.3	26.60	0.0	154.4	74.39	0.477	0.000
November	139.2	42.7	22.71	0.0	167.8	48.71	0.474	0.000
December	130.3	38.0	19.02	0.0	162.9	44.56	0.444	0.000
Year	1789.1	885.5	24.85	0.0	1912.7	912.44	6.092	0.000

4.3.2 Orientation and Horizon

For our site, the best panel tilt angle on a yearly basis was chosen 36^0 fixed tilt position with an azimuth of 8^0 as the Transposition Factor is 1.10 (Highest) and Loss by respect to optimum is -0.1% (Lowest) in this setup. Transposition Factor is the ratio of the incident irradiation on the plane, to the horizontal irradiation. This determines how much energy is gained or lose by tilting the panel meaning the highest is better. Whereas, Loss by respect to optimum means how much solar irradiance are not used or lost by a fixed plane orientation, which elaborates lower values, are better. The tilt angle and the azimuth angle are chosen by the optimization data for the selected meteo site as shown below in the snapshot of the software.

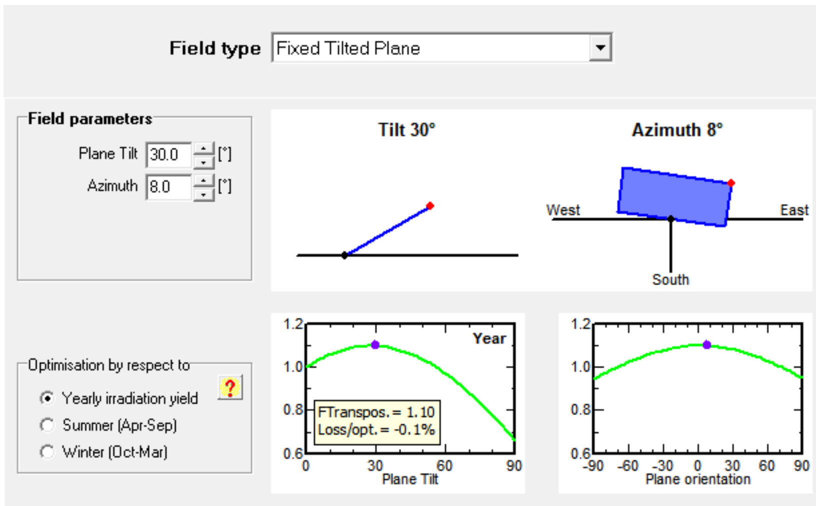


Figure 4.2: Panle orientation and tilt angle

The horizon diagram for the proposed site that was obtaioned in the software is given below:

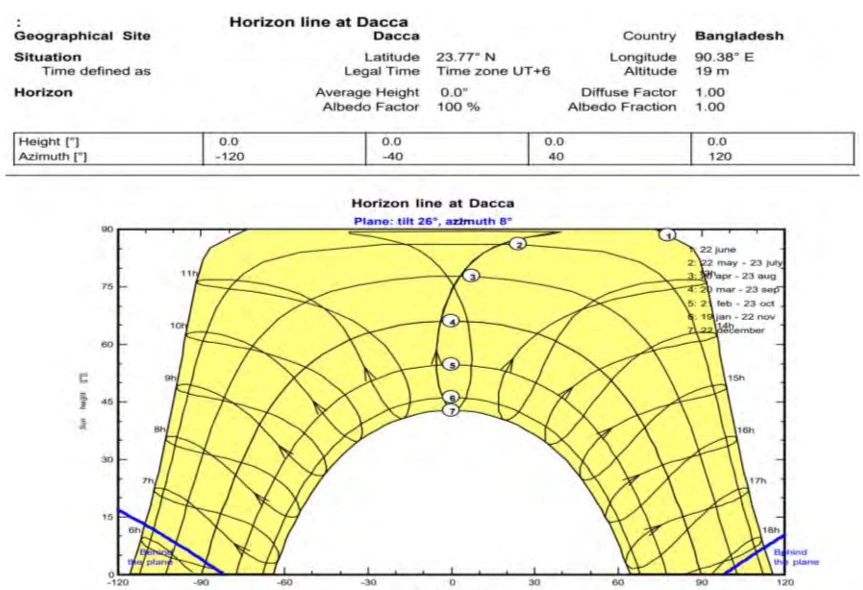


Figure 4.3: Horizon of our site location

4.3.3 Near Shading

Near shading feature of this software are necessary for the determination of precise solar panel gathered energy if the panel is partially shaded by one or more nearby object. The reconstruction of the exact geometry of the PV field and its environment can be built in the 3D-space of the software if needed. There are sufficient templates and object injected in the software for an accurate 3D representation of the site. The program can develop a shading factor as a function of sun's height and azimuth. At the time of simulation, the hourly shading factor are calculated very fast by interpolation. In this project there are no nearby object that obstructs the solar ray either partially or totally. Hence, no sheading was defined in the software as per the site environment.

4.3.4 Battery Size Calculation

The battery size should be defined according to the load and the system. According to our available resources, we selected our system panel to be 100Wp while the load is a 20W flood light for security purposes. However, in our simulation model, one LED Light of 20W and a 40W DC fan are selected to compensate the cost recovery years. A fully charged battery, without any solar input must be able to back up the system to meet the requirements. The autonomy is defined in such a way. As calculated, one 12V battery with 55Ah rating is chosen for this case. This rated battery can give full support for the user needs throughout the year except for monsoon season in our country.

4.3.5 Solar Panel and Charge Controller Selection

Sequentially, the PV panel and the charge controller can be defined inside the system tab, according to the user preference. There are a wide variety of components that are available for selection. However, every component model is different in specification and manufacturer that should be chosen wisely. Not every manufacturer produces components with the same performance. Unfortunately, the components that we used in our system are not available in the software but fortunately same specified components with very little differences was available. 100Wp module from Xunlight corporation and a 10-10 Ampere 12-24V charge controller from Steca were chosen from the database.

4.4 Simulation & Report

The software enables a user to simulate a selected project and generates a full report accordingly with full access but restricted modifying option of the database in the Trial period of a month. After the trial period, the software does not let a user create a new simulation variant, but still gives access to the previously created simulation variants without the ability to save the work. As part of our project was prepared completely with the help of this software, simulation report is very important for the whole project. The report includes:

I. **Simulation Parameters:** Based on the selected components and parameters, the report includes necessary details on the report. The parameters are – PV orientation, array characteristics, PV loss factors and system parameters including panel, battery, charge controller and user needs. It is attached in appendix A.

II. **Detailed User Needs:** this section of the report contains detailed data of the user defined hourly load usage. As per our report, a seasonal load modification was used. Except for winter season, the light and the fan runs for 7 hour per day. In winter, only the light is in use according to the hourly distribution for our report. A percentage average of hourly profile throughout the year are also included in a graph representation. It is attached in appendix B.

III. **Main Results:** this part of the report includes total system production and loss of load. It shows normalized productions (per installed kWp) of Available Energy, Used Energy, Excess (unused) Energy, Performance Ratio PR and Solar Fraction SF in numerical values as well as in graphical form. Loss of Load section includes the time fraction and missing energy in numerical values only. Detailed monthly results of the complete main report are available in a tabular form also. It is attached in appendix C.

IV. **Loss Diagram:** the loss diagram includes every energy loss components in numerical value as well as percentage value. This part contains four section that are Horizontal global irradiation, Effective irradiance on collectors, Effective energy at the output of array, energy supplied to the user and finally the energy used by the user.

4.5 Necessary Graphs Obtained from the Simulation Result

At the end of the simulation a few important graphs from the software was obtained which are worth mentioning in here. Moreover, the software's detailed report option enables the user to examine other necessary graphs that may give extra insight of the simulation report. The graphs generated by the Main Simulation Result followed by the detailed results of the simulation that are not available in the main result are represented and discussed on the next page.

Graph of Normalized Production and Loss Factors:

The graph below shows the unused energy, PV-array loss, system and battery loss and used energy in percentage comparison. In the winter season, the unused energy is much higher as in that period the load demand is lower. Whereas, on other seasons, there is no unused energy detected.

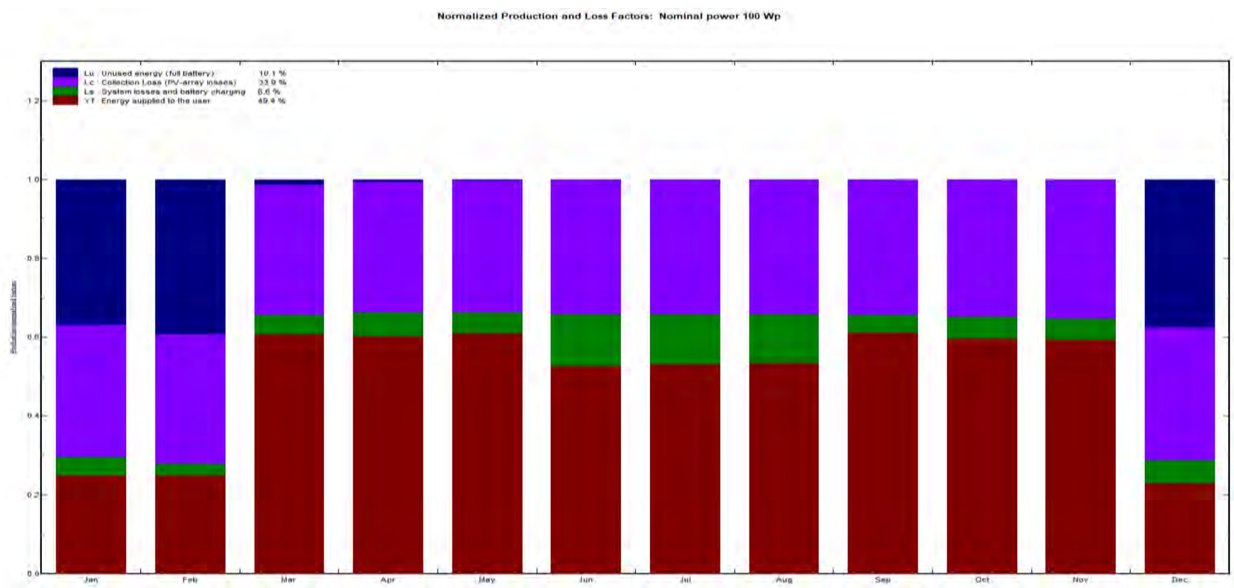


Figure 4.4: Graph of Normalized Production and Loss Factors

Graph of Performance Ratio PR and Solar Fraction SF:

PR represents the ratio of the effectively produced (used) energy, with respect to the energy which would be produced by a "perfect" system. Whereas, SF is a ratio of the system output and required energy. In our simulation, both PR and SF are healthy except with differences of PR in winter season because of less usage of load. [17]

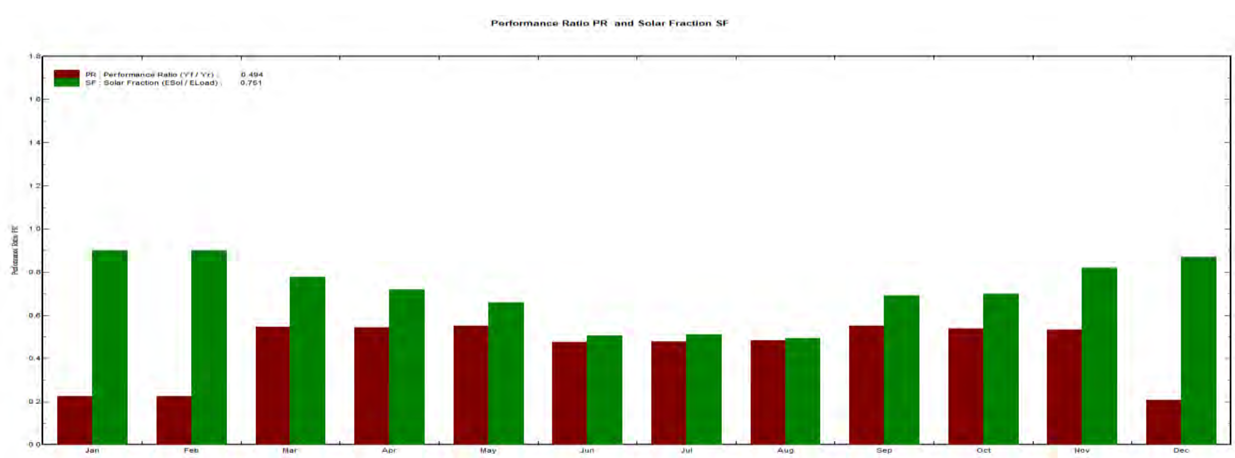


Figure 4.5: Graph of Performance Ration and Solar Fraction

Graph of Available Energy against Our Need:

As it was evident that during the monsoon season, in the month of June, July, August, our need exceeded the available solar energy due to rain and less sunlight.

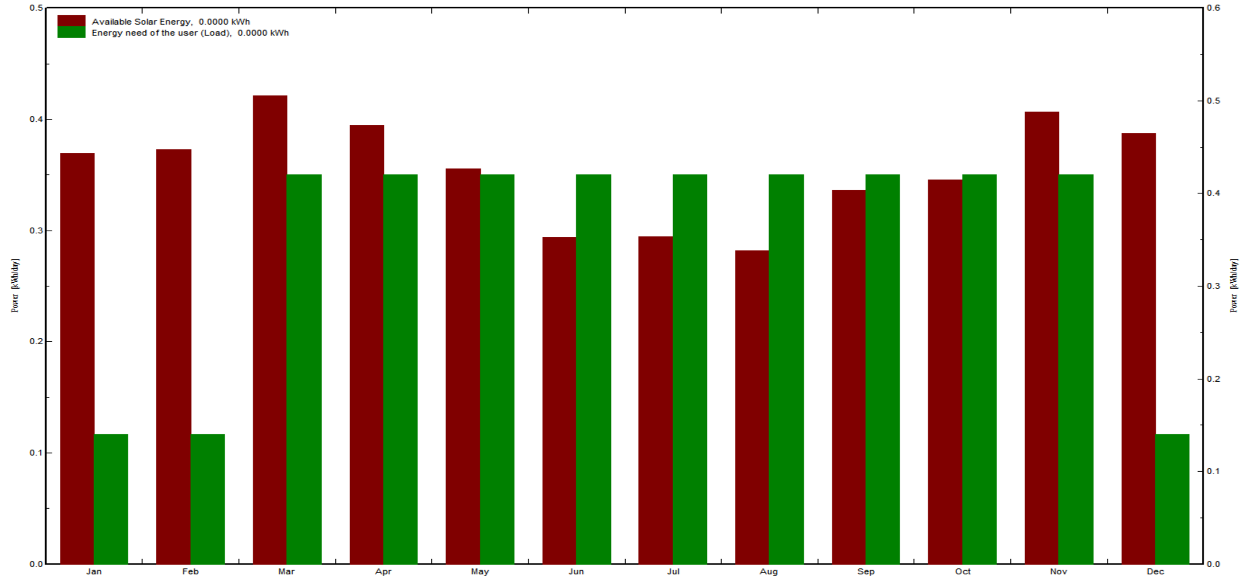


Figure 4.6: Graph of Available Energy against Our Need

Graph of Average State of Charge against Probability of Loss of Load (LOL)

This graph describes the probability of the amount of the user load will be inadequate for the system to supply against the state of charge of the battery. In this project, the battery is inadequate for a probable 7% of the user needs on an annual basis.

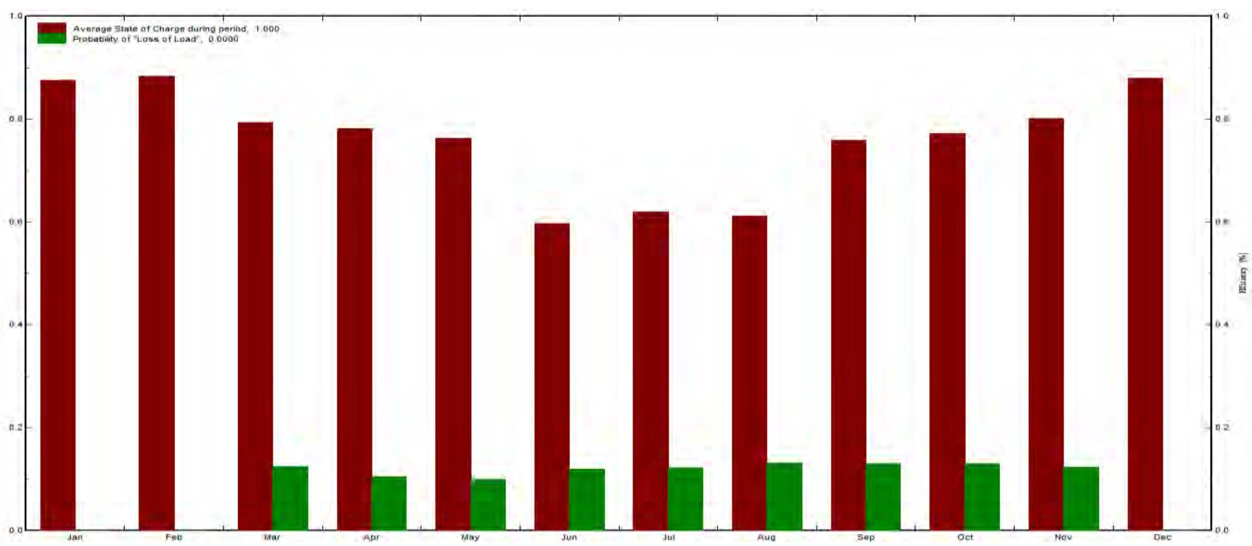


Figure 4.7: Graph of Average State of Charge against Probability of Loss of Load (LOL)

Loss Diagram of Initial Project Design:

This diagram illustrates different system losses due to significant factors in comparison to an ideal system. The efficiency of the panel was 6.33% at Array Nominal Energy. However, the missing energy of 36.4% in this diagram elaborates the need of another battery for our system. As the resources available to us required us to work with only one battery, we used it, even though the software recommended higher rating battery.

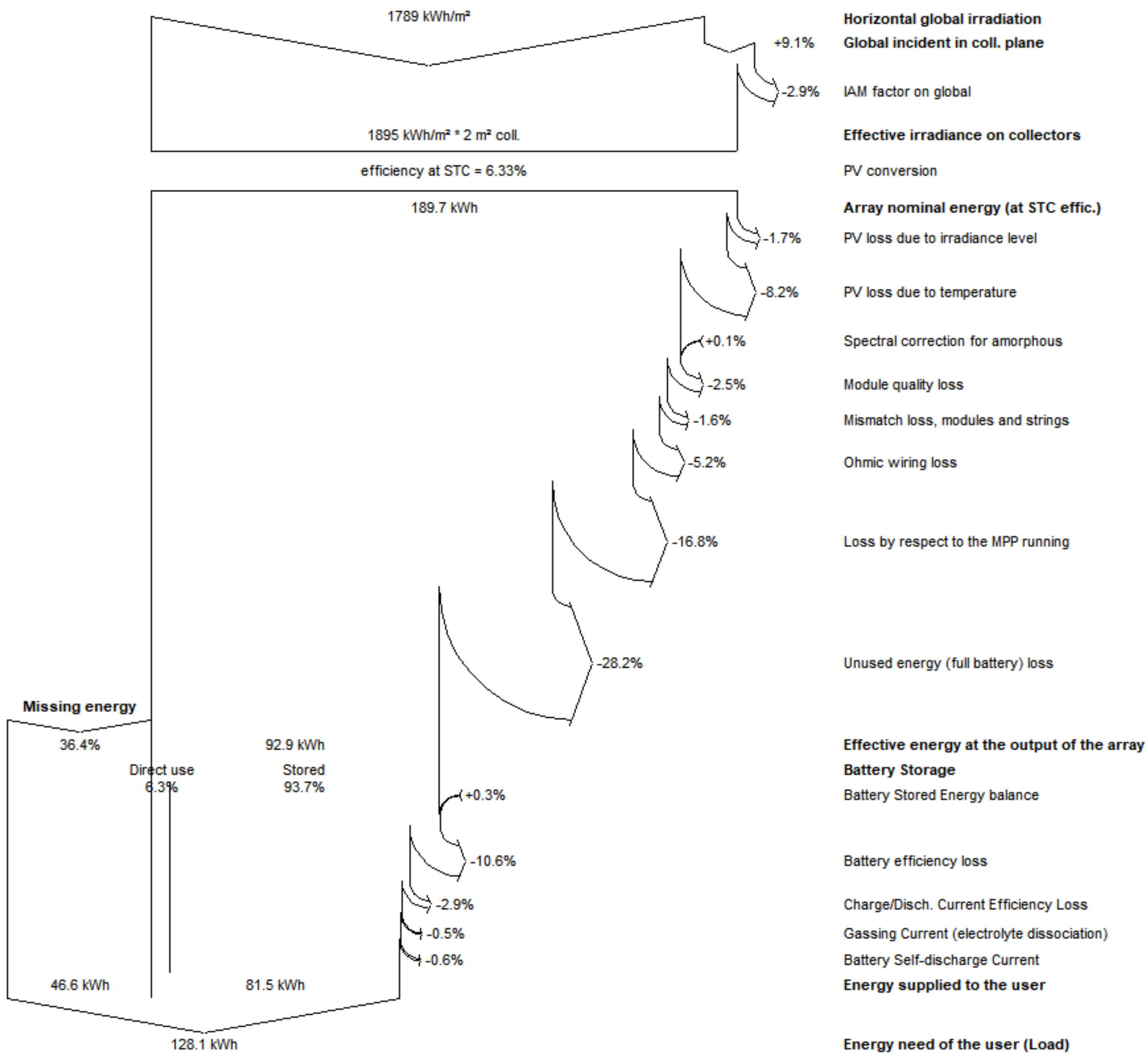


Figure 4.8: Loss Diagram of initial Project Design

Financial Analysis by RETScreen 4.0

4.6 Economics of PV Installation

One of the first barriers against PV installation is it's costing which reduces the attraction for PV installation or having a Solar Home System. The huge amount of cost arises at the beginning (initial cost) and it becomes impossible for the disadvantaged class of people. In developing countries like Bangladesh, SHS is a crying need in some parts of the country where grid connection is a daydream for them but they cannot have SHS only because of high initial cost and less efficiency in using different types of loads. Besides, life cycle costing distribution is not perfect in sales and distribution section in these countries.

The life cycle costing can be sorted out in two basic portions: initial cost & future costs. After that, there are two types of calculation that has been used for expressing the future cost or benefit of its present worth. The first is used to calculate the present worth of a single payment. The second is used to calculate the total net present worth of a recurring cost, such as annual fuel or maintenance costs. The parameters should be remembered before calculations:

- Period of analysis: the lifetime of the longest lived system under comparison. Usually, it is considered 20 years.
- Excess Inflation (i): The rate of price increment of a component above general inflation.
- Discount Rate (d): The rate (relative to general inflation) at which money would increase in value if invested (typically 8-12%).
- Capital cost: The total cost while buying and installing the system, containing only the initial components costs.
- Fuel costs: The annual fuel bills of the base case such as annual Kerosene consumption bills or electricity bill when grid connection is the base case.
- Replacement Costs: The cost of replacing each components at the end of its lifetime. Most of the time batteries are replaced after every 3-4 years because of their limited life span and decreasing efficiency and amp-hours.

$$\text{Present worth of a single payment, Pr} = \left(\frac{1+i}{1+d}\right)^N$$

$$\text{Present worth of an annual payment, Pa} = \frac{\left(\frac{1+i}{1+d}\right)\left(\left|\frac{1+i}{1+d}\right|^N - 1\right)}{\frac{1+i}{1+d} - 1} \quad [27]$$

- Single Payment:
  For a single future cost Cr, payable in N years time, the present worth is given
  PW=Cr* Pr

- Annual Payment:
  For a payment Ca occurring annually for a period N years the present worth is,
  PW=Ca*Pa

- Life cycle cost (LCC) :

For different payments made during the life time of the system, the present can be calculated by applying discount rate (d) in these provided equations, Pr and Pa. LCC is the sum of all PW's of the system.

- Annualized life Cycle Cost (ALCC):

LCC is divided with the value of Pa to get ALCC containing discount rate, inflation rate of the system and provides the information in BDT/year format.

- Unit Electricity Cost (UEC):

This is the most used parameter when it comes to comparison among systems or between grid and solar system or hybrid system. UEC is calculated by,

$$\text{UEC (BDT/kWh)} = \frac{ALCC\left(\frac{BDT}{year}\right)}{Electricity\ Supplied\left(\frac{kWh}{year}\right)}$$

Electricity per year= $I*AE_m*E_s*365$ KWh

Where I = average annual irradiation in kWh/m^2 day

A= array area in m^2

E_m = module efficiency

E_s =system efficiency. [27]

4.7 Financial Analysis by RETScreen 4.0

Calculating all these information and getting the desired value is difficult and the process is lengthy. Hence, the Government of Canada has introduced a software named RETScreen Clean Energy Project Analysis to provide the necessary data and to make the calculating process easier. This software is provided free of cost to take an integrated approach in addressing climate change and reducing pollution. It is an Excel based software kit which has embedded formulas and information and so it can display the graphical representation and yearly accumulated data. It determines the financial viability of potential renewable energy, energy efficiency and hybrid (multiple renewable or grid connected) projects. It conducts five basic analysis based on provided information and these are as follows : Energy Analysis, Cost Analysis, Emission Analysis, Financial Analysis, Risk Analysis. Here, this software was used for checking the financial viability of the system with different amount of loads. For financial analysis, method 2 type was defined which is a built in method in the software. After necessary specifications were put in for the software, the energy model was built for the system. [28]

4.7.1 Energy Model

Energy Model was built in RETScreen software as follows:

A. Load

a. At first, 60W load is selected randomly to watch out the financial approach of the system containing 20W DC flood light and 40W DC fan as load replacing 36W CFL bulb and 80W AC ceiling fan respectively. Small amount of load is assumed considering the one room electricity requirement in isolated areas and towns and so stand-alone off-grid system will be implemented.

b. After that, 2400W load is selected to be replaced by the system for large application of SHS in Urban Commercial buildings and so lighting and cooling load is selected such as 400W DC LED light (20X20W) and 840W DC fan (12X70W) replacing 1000W CFL bulbs (40X25W) and 1400W (14X100W) AC ceiling fan respectively. This proposed amount of load is selected based on assumption considering commercial cum academic building of BRAC University Building -4 where large amount of load is required while peak hours relentlessly.

B. Tariff for kW-hr:

5.36 taka per unit [29] (as it was calculated that monthly energy need is not less than 100 kW-hr and not more than 300kW-hr) for small load assumption and 10.5 taka per unit [29] for large amount of commercial multipurpose building load.

C. Other system specifications as obtained were also given as input. The detail energy model is provided at this chapter.

4.7.2 Cost Analysis

For this analysis, a total implementation cost of 22,500 taka without any loan was estimated. Yearly maintenance cost was estimated at 500 taka and a onetime cost of 6200 taka after every five years (for battery and other parts replacement) was also considered for small system. For large load, BDT 450,000 was estimated considering the local market price for required components and a periodic cost of BDT 100,000 is estimated for the replacement of battery or other components after every five years.

4.7.3 Financial Analysis

Financial analysis was carried out so that cash flow and break-even point can be identified from graphical representation. Fuel cost escalation rate was considered as 5.9% [30] and inflation rate as 5.6% [30]. After generating cash flow graph, it was seen that the break-even point would be reached at the middle of 8 years for small load and at the beginning of 4 years for large level loads. Here, it can be noticed from different types of loads that larger the load, faster the break-even year. Hence, it would be beneficial for the large amount of loads, leading towards the concept of DC micro grid system, independent from the grid connection to avoid the load shedding for essential loads like office lighting and so on.

4.8 RETScreen 4.0 report analysis

For low level load demand (home system/ lighting system for small business):

RETScreen Energy Model - Power project

Power project

Base case power system

Grid type		Off-grid
Technology		Grid electricity
Fuel rate	BDT/kWh	5.360
Capacity	kW	2.50
Annual O&M cost	BDT	1,000
Electricity rate - base case	BDT/kWh	7.257
Total electricity cost	BDT	3,825

Load characteristics

○ Method 1
⦿ Method 2

Description	AC/DC	Intermittent resource-load correlation	Base case load W	Hours of use per day h/d	Days of use per week d/w	Proposed case load reduction %	Proposed case usage time reduction %
80W ceiling Fan AC	AC	Positive	80.00	14.00	7	50%	0%
36W CFL Bulb	AC	Positive	36.00	9.00	7	44%	0%

	Unit	Base case	Proposed case
Electricity - daily - DC	kWh	0.00	0.00
Electricity - daily - AC	kWh	1.44	0.74

☐ **Percent of month used**

		Base case	Proposed case	Energy saved
Electricity - annual - DC	MWh	0.000	0.000	
Electricity - annual - AC	MWh	0.527	0.270	49%
Peak load - annual	kW			

Proposed case power system

Inverter

Capacity	kW	0.0	Peak load - annual - AC

Battery

Days of autonomy	d	4.0	
Voltage	V	13.2	
Efficiency	%		
Maximum depth of discharge	%		
Charge controller efficiency	%		
Temperature control method		Ambient	
Average battery temperature derating	%	0.5%	
Capacity	Ah	55	#DIV/0!
Battery	kWh	1	

Technology Photovoltaic

Resource assessment

Solar tracking mode	Fixed
Slope	26.0
Azimuth	8.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity delivered to load MWh
January	4.36	5.65	#DIV/0!
February	4.92	5.83	#DIV/0!
March	5.59	6.00	#DIV/0!
April	5.76	5.63	#DIV/0!
May	5.30	4.89	#DIV/0!
June	4.53	4.11	#DIV/0!
July	4.23	3.89	#DIV/0!
August	4.29	4.10	#DIV/0!
September	4.02	4.06	#DIV/0!
October	4.32	4.84	#DIV/0!
November	4.28	5.37	#DIV/0!
December	4.21	5.62	#DIV/0!
Annual	**4.65**	**5.00**	**0.00**

Annual solar radiation - horizontal	MWh/m²	1.70
Annual solar radiation - tilted	MWh/m²	1.82

Photovoltaic

Type		mono-Si
Power capacity	kW	0.10
Manufacturer		
Model		
Efficiency	%	
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.40%
Solar collector area	m²	#DIV/0!
Control method		Clamped
Miscellaneous losses	%	1.0%

See product database

Summary

Capacity factor	%	0.0%	
Electricity delivered to load	MWh	0.00	0.0%

Peak load power system

Technology	Not required

SHS Thesis Project
Dhaka

14/Sat/4/2018
RETScreen4-1

RETScreen Cost Analysis - Power project

Settings		
⦿ Method 1	⦿ Notes/Range	Notes/Range
○ Method 2	○ Second currency	None
	○ Cost allocation	

Initial costs (credits)	Unit	Quantity	Unit cost		Amount		Relative costs
Feasibility study							
Feasibility study	cost	1			BDT	-	
Subtotal:					**BDT**	-	0.0%
Development							
Development	cost	1	BDT	22,500	BDT	22,500	
Subtotal:					**BDT**	**22,500**	97.8%
Engineering							
Engineering	cost	1	BDT	200	BDT	200	
Subtotal:					**BDT**	**200**	0.9%
Power system							
#N/A	kW	0.00			BDT	-	
Road construction	km				BDT	-	
Transmission line	km				BDT	-	
Substation	project				BDT	-	
Energy efficiency measures	project				BDT	-	
User-defined	cost				BDT	-	
					BDT	-	
Subtotal:					**BDT**	-	0.0%
Balance of system & miscellaneous							
Spare parts	%		BDT	0	BDT	-	
Transportation	project	3	BDT	100	BDT	300	
Training & commissioning	p-d				BDT	-	
User-defined	cost		BDT	-	BDT	-	
Contingencies	%		BDT	23,000	BDT	-	
Interest during construction			BDT	23,000	BDT	-	
Subtotal:		Enter number of months			**BDT**	**300**	1.3%
Total initial costs					**BDT**	**23,000**	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost		Amount	
O&M						
Parts & labour	project	1	BDT	500	BDT	500
User-defined	cost				BDT	-
Contingencies	%		BDT	500	BDT	-
Subtotal:					**BDT**	**500**

Annual savings	Unit	Quantity	Unit cost		Amount	
Fuel cost - base case						
Electricity	MWh	1	BDT	7,257.317	BDT	3,825
Subtotal:					**BDT**	**3,825**

Periodic costs (credits)	Unit	Year	Unit cost		Amount	
User-defined	cost	5	BDT	6,200	BDT	6,200
					BDT	-
End of project life	cost				BDT	-

RETScreen Financial Analysis - Power project

Financial parameters

General

Fuel cost escalation rate	%	5.9%
Inflation rate	%	5.6%
Discount rate	%	
Project life	yr	20

Finance

Incentives and grants	BDT	
Debt ratio	%	

Income tax analysis ☐

Annual income

Electricity export income

GHG reduction income ☐

Net GHG reduction	tCO2/yr	0
Net GHG reduction - 20 yrs	tCO2	6

Customer premium income (rebate) ☐

Other income (cost) ☐

Clean Energy (CE) production income ☐

Project costs and savings/income summary

Initial costs

Development	97.8%	BDT	22,500
Engineering	0.9%	BDT	200
Power system	0.0%	BDT	0
Balance of system & misc.	1.3%	BDT	300
Total initial costs	**100.0%**	**BDT**	**23,000**

Annual costs and debt payments

O&M	BDT	500
Fuel cost - proposed case	BDT	0
Total annual costs	**BDT**	**500**

Periodic costs (credits)

User-defined - 5 yrs	BDT	6,200

Annual savings and income

Fuel cost - base case	BDT	3,825
Total annual savings and income	**BDT**	**3,825**

Financial viability

Pre-tax IRR - equity	%	14.1%
Pre-tax IRR - assets	%	14.1%
After-tax IRR - equity	%	14.1%
After-tax IRR - assets	%	14.1%
Simple payback	yr	6.9
Equity payback	yr	7.3
Net Present Value (NPV)	BDT	54,500
Annual life cycle savings	BDT/yr	2,725
Benefit-Cost (B-C) ratio		3.37
GHG reduction cost	BDT/tCO2	(8,724)

Yearly cash flows

Year #	Pre-tax BDT	After-tax BDT	Cumulative BDT
0	-23,000	-23,000	-23,000
1	3,523	3,523	-19,477
2	3,732	3,732	-15,745
3	3,954	3,954	-11,791
4	4,189	4,189	-7,602
5	-3,704	-3,704	-11,306
6	4,702	4,702	-6,604
7	4,981	4,981	-1,622
8	5,277	5,277	3,655
9	5,591	5,591	9,246
10	-4,768	-4,768	4,479
11	6,276	6,276	10,754
12	6,649	6,649	17,403
13	7,044	7,044	24,446
14	7,462	7,462	31,909
15	-6,134	-6,134	25,775
16	8,376	8,376	34,151
17	8,873	8,873	43,024
18	9,401	9,401	52,425
19	9,959	9,959	62,385
20	-7,885	-7,885	54,500

Cumulative cash flows graph

For large level load demand(commericial lighting system/ academic building load system):

RETScreen Energy Model - Power project

Power project

Base case power system

Grid type		Off-grid
Technology		Grid electricity
Fuel rate	BDT/kWh	10.500
Capacity	kW	100.00
Annual O&M cost	BDT	5,000
Electricity rate - base case	BDT/kWh	10.976
Total electricity cost	BDT	115,376

Load characteristics

○ Method 1
⊙ Method 2

Description	AC/DC	Intermittent resource-load correlation	Base case load W	Hours of use per day h/d	Days of use per week d/w	Proposed case load reduction %	Proposed case usage time reduction %
Light 220V 36W	AC	Positive	1,000.00	12.00	7	60%	0%
FAN 220V 80W	AC	Positive	1,400.00	12.00	7	60%	0%

	Unit	Base case	Proposed case
Electricity - daily - DC	kWh	0.00	0.00
Electricity - daily - AC	kWh	28.80	11.52

☐ **Percent of month used**

		Base case	Proposed case	Energy saved
Electricity - annual - DC	MWh	0.000	0.000	
Electricity - annual - AC	MWh	10.512	4.205	60%
Peak load - annual	kW			

Proposed case power system

Inverter

Capacity	kW		Peak load - annual - AC

Battery

Days of autonomy	d	4.0	
Voltage	V	13.2	
Efficiency	%		
Maximum depth of discharge	%		
Charge controller efficiency	%		
Temperature control method		Ambient	
Average battery temperature derating	%	0.5%	
Capacity	Ah	300	#DIV/0!
Battery	kWh	4	

Technology Photovoltaic

Resource assessment

Solar tracking mode		Fixed
Slope	°	26.0
Azimuth	°	8.0

☒ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity delivered to load MWh
January	4.36	5.65	0.36
February	4.92	5.83	0.32
March	5.59	6.00	0.36
April	5.76	5.63	0.35
May	5.30	4.89	0.36
June	4.53	4.11	0.32
July	4.23	3.89	0.32
August	4.29	4.10	0.33
September	4.02	4.08	0.32
October	4.32	4.84	0.36
November	4.28	5.37	0.35
December	4.21	5.62	0.36
Annual	**4.65**	**5.00**	**4.08**

Annual solar radiation - horizontal	MWh/m²	1.70
Annual solar radiation - tilted	MWh/m²	1.82

Photovoltaic

Type		mono-Si	
Power capacity	kW	4.00	See product database
Manufacturer			
Model			
Efficiency	%	12.0%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	33.3	
Control method		Clamped	
Miscellaneous losses	%	6.0%	

Summary

Capacity factor	%	13.5%	
Electricity delivered to load	MWh	4.08	97.1%

Peak load power system

Technology	Not required

RETScreen Cost Analysis - Power project

Settings		
⦿ Method 1	⦿ Notes/Range	Notes/Range
O Method 2	O Second currency	None
	O Cost allocation	

Initial costs (credits)	Unit	Quantity	Unit cost		Amount		Relative costs
Feasibility study							
Feasibility study	cost	1			BDT	-	
Subtotal:					**BDT**	**-**	0.0%
Development							
Development	cost	1	BDT	450,000	BDT	450,000	
Subtotal:					**BDT**	**450,000**	97.8%
Engineering							
Engineering	cost	1	BDT	8,000	BDT	8,000	
Subtotal:					**BDT**	**8,000**	1.7%
Power system							
#N/A	kW	0.00			BDT	-	
Road construction	km				BDT	-	
Transmission line	km				BDT	-	
Substation	project				BDT	-	
Energy efficiency measures	project				BDT	-	
User-defined	cost				BDT	-	
					BDT	-	
Subtotal:					**BDT**	**-**	0.0%
Balance of system & miscellaneous							
Spare parts	%		BDT	0	BDT	-	
Transportation	project	2	BDT	1,000	BDT	2,000	
Training & commissioning	p-d				BDT	-	
User-defined	cost		BDT	-	BDT	-	
Contingencies	%		BDT	460,000	BDT	-	
Interest during construction			BDT	460,000	BDT	-	
Subtotal:		Enter number of months			**BDT**	**2,000**	0.4%
Total initial costs					**BDT**	**460,000**	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost		Amount	
O&M						
Parts & labour	project	1	BDT	1,000	BDT	1,000
User-defined	cost				BDT	-
Contingencies	%		BDT	1,000	BDT	-
Subtotal:					**BDT**	**1,000**

Annual savings	Unit	Quantity	Unit cost		Amount	
Fuel cost - base case						
Electricity	MWh	11	BDT	10,975.647	BDT	115,376
Subtotal:					**BDT**	**115,376**

Periodic costs (credits)	Unit	Year	Unit cost		Amount	
User-defined	cost	5	BDT	100,000	BDT	100,000
					BDT	-
End of project life	cost				BDT	-

RETScreen Financial Analysis - Power project

Financial parameters

General

Fuel cost escalation rate	%	5.9%
Inflation rate	%	5.6%
Discount rate	%	
Project life	yr	20

Finance

Incentives and grants	BDT	
Debt ratio	%	

Income tax analysis ☐

Annual income

Electricity export income

GHG reduction income ☐

Net GHG reduction	tCO2/yr	6
Net GHG reduction - 20 yrs	tCO2	125

Customer premium income (rebate) ☐

Other income (cost) ☐

Clean Energy (CE) production income ☐

Project costs and savings/income summary

Initial costs

Development	97.8%	BDT	450,000
Engineering	1.7%	BDT	8,000
Power system	0.0%	BDT	0
Balance of system & misc.	0.4%	BDT	2,000
Total initial costs	**100.0%**	**BDT**	**460,000**

Annual costs and debt payments

O&M	BDT	1,000
Fuel cost - proposed case	BDT	0
Total annual costs	**BDT**	**1,000**

Periodic costs (credits)

User-defined - 5 yrs	BDT	100,000

Annual savings and income

Fuel cost - base case	BDT	115,376
Total annual savings and income	**BDT**	**115,376**

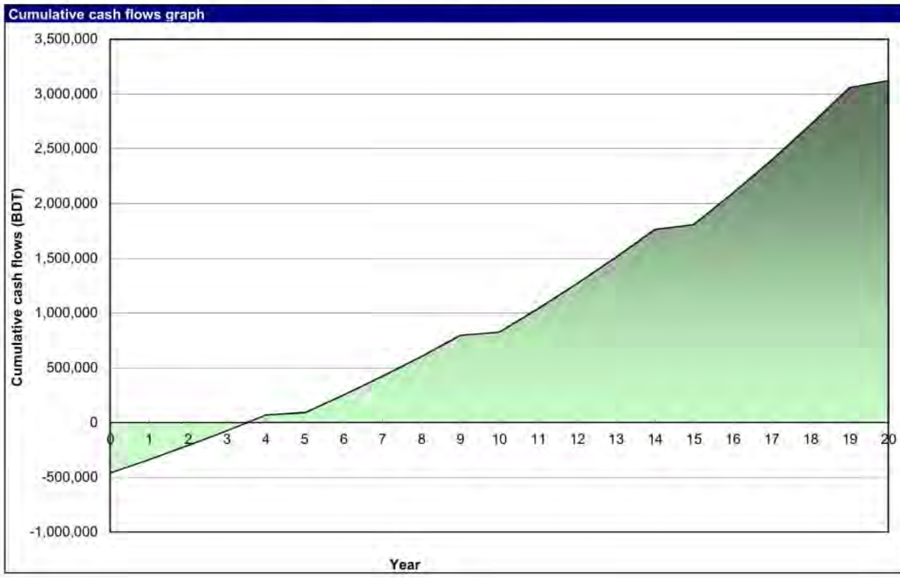
Financial viability

Pre-tax IRR - equity	%	28.8%
Pre-tax IRR - assets	%	28.8%
After-tax IRR - equity	%	28.8%
After-tax IRR - assets	%	28.8%
Simple payback	yr	4.0
Equity payback	yr	3.5
Net Present Value (NPV)	BDT	3,121,789
Annual life cycle savings	BDT/yr	156,089
Benefit-Cost (B-C) ratio		7.79
GHG reduction cost	BDT/tCO2	(25,056)

Yearly cash flows

Year #	Pre-tax BDT	After-tax BDT	Cumulative BDT
0	-460,000	-460,000	-460,000
1	121,127	121,127	-338,873
2	128,277	128,277	-210,596
3	135,849	135,849	-74,747
4	143,867	143,867	69,120
5	21,042	21,042	90,162
6	161,352	161,352	251,514
7	170,876	170,876	422,390
8	180,962	180,962	603,353
9	191,644	191,644	794,996
10	30,515	30,515	825,511
11	214,935	214,935	1,040,446
12	227,622	227,622	1,268,068
13	241,057	241,057	1,509,125
14	255,286	255,286	1,764,410
15	43,911	43,911	1,808,321
16	286,311	286,311	2,094,633
17	303,211	303,211	2,397,844
18	321,108	321,108	2,718,952
19	340,061	340,061	3,059,013
20	62,776	62,776	3,121,789

Cumulative cash flows graph



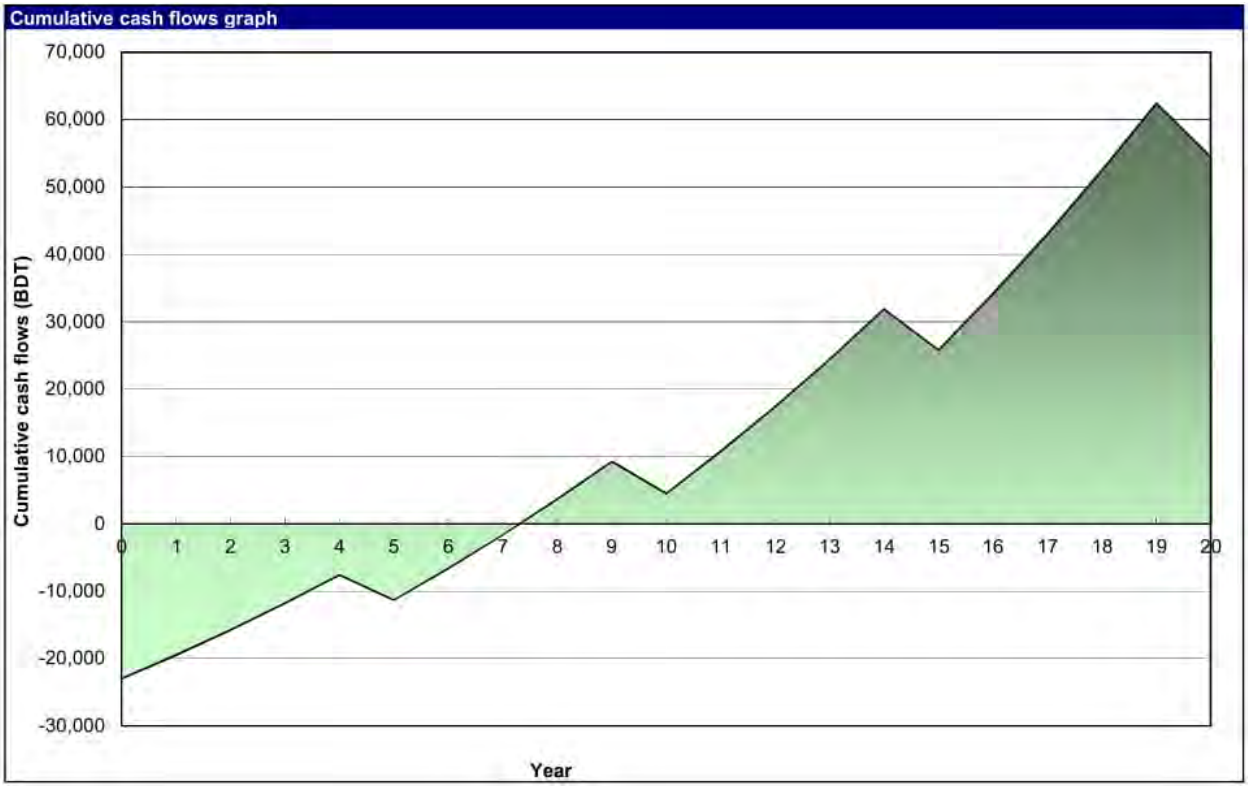


Figure 4.9: Cash Flow graph for low level load demand (home system)

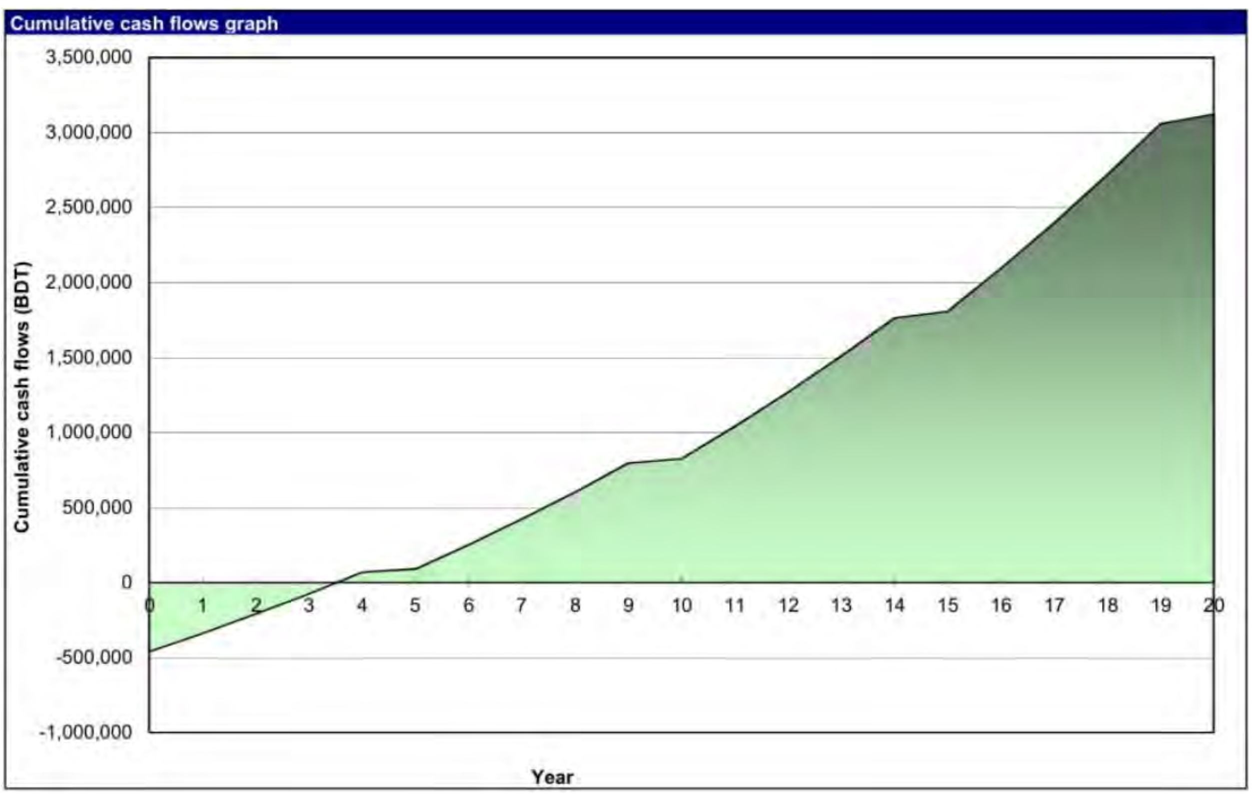


Figure 4.10: Cash Flow graph for large level load demand (commercial system)

It can easily noticed that larger the load, more feasible the system. Initial costs and periodic costs play vital role in deciding the break even point. In small system, it takes almost 8 years to reimburse the investment through energy saving and cost minimization. This is comparatively risky for the customers as they invest large amount of money while installion of this project only for home lighting purposes. Hence, considering the uncertainity , consumers lose attraction of having an SHS. Meanwhile, for large system, it is feasible to implement as the break-even point is nearer, within 4 years and can have large amount of loans from banks for impleneting green electricity. Therefore, it is highly appreciated to have a solar lighting system in commercial rising buildings , using the rooftop area.

CHAPTER-5

IMPLEMENTATION OF THE PROJECT & DATA LOGGING

5.1 Implementation

After gathering necessary simulation results and ground study as discussed in earlier chapters, implementation of the project as per specification started. As per initial parameters, it was determined that a system with exact specification as found during initial study needs some adjustments. As a result, system specification needed to be adjusted to match the available resources keeping scopes for future modification of the system if necessary. The main objective of building a solar home system was to increase our depth of knowledge regarding practical aspects of a solar system. Therefore, the initial assessment was scaled down to complete the project within the resources available to us. Since this is a feasibility study of a PV System, data logging is an important part for it. To meet this requirement a charge controller with data logging capability and automatic load switching capability was used. A complete site demonstration in picture form is very difficult as our project took place on top a 15-storied building of BRAC University. A 3D model of the system has been created using a professional but easy to work on software called SketchUp. The latest demo version of the software was used for this case.

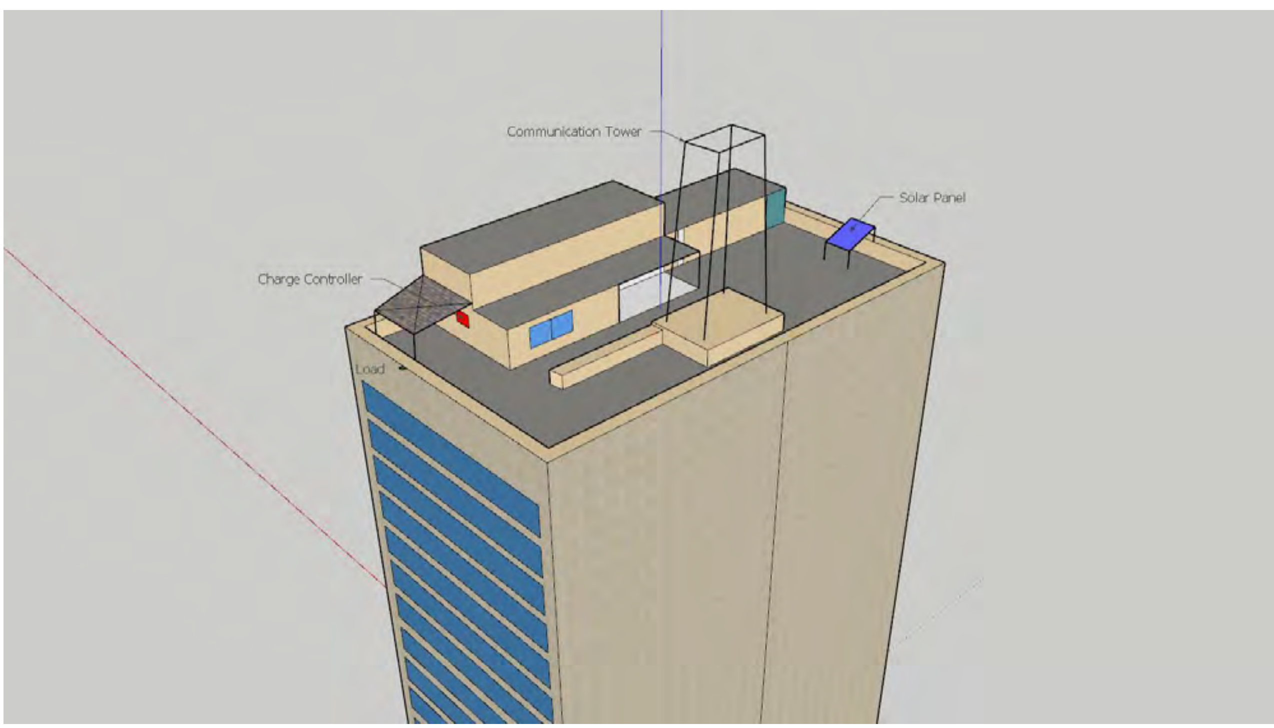


Figure 5.1: 3D representation of our project site.

5.1.1 Solar Panel Setup

In this project, Model – ESM100W (100Wp) from EverExceed Corporation, acquired from Grammen Shakti, a prominent solar products vendor in Bangladesh. The panel was already setup at a tilt angle of 15^0 and azimuth of 8^0 as this panel was subject to previous study of different projects. The panel has been marked as Blue in the 3D representation near the back side of the building in Figure 6.1. However, as necessary shading of system components was not available near the solar panel and keeping in mind that the load is a security flood light which needs to be situated at the front of the building, the system's charge controller was located on the front of the building. The distance between the panel and charge controller is 60' 5".

Figure 5.2: Photograph of Solar Panel Mounted on the Roof

5.1.2 Installation of Charge Controller, Battery and Measuring Meters

The Charge Controller is marked Red in the 3D representation in Figure 6.1, which illustrates that installation in the front side of the building of this portion of the project is beneficial for additional load as well as providing for necessary sheading of equipments and battery. However, as the distance from the panel to charge controller is notable, a voltage drop of 0.3V was measured for I^2R loss between the panel and charge controller location. A single 55Ah Rahimafrooz Solar Battery and Digital DC Voltmeter & Ammeter was used for measuring voltages and currents. For Safety purposes of the system, a fuse for each connection has been implemented. Battery was just below the wooden panel for charge controller and measuring meters.

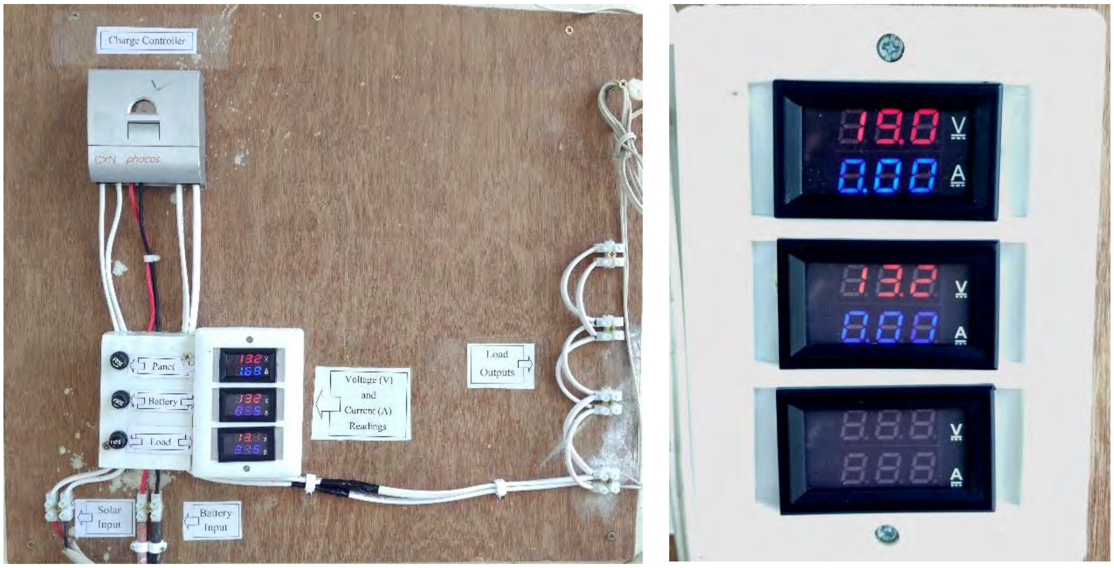


Figure 5.3: Photograph of Charge Controller & Measuring Devices Mounted on a Wooden Board (Left) and Measuring Devices at Daytime When Battery is at Full Charge, Not Charging and Load is Off (Right)

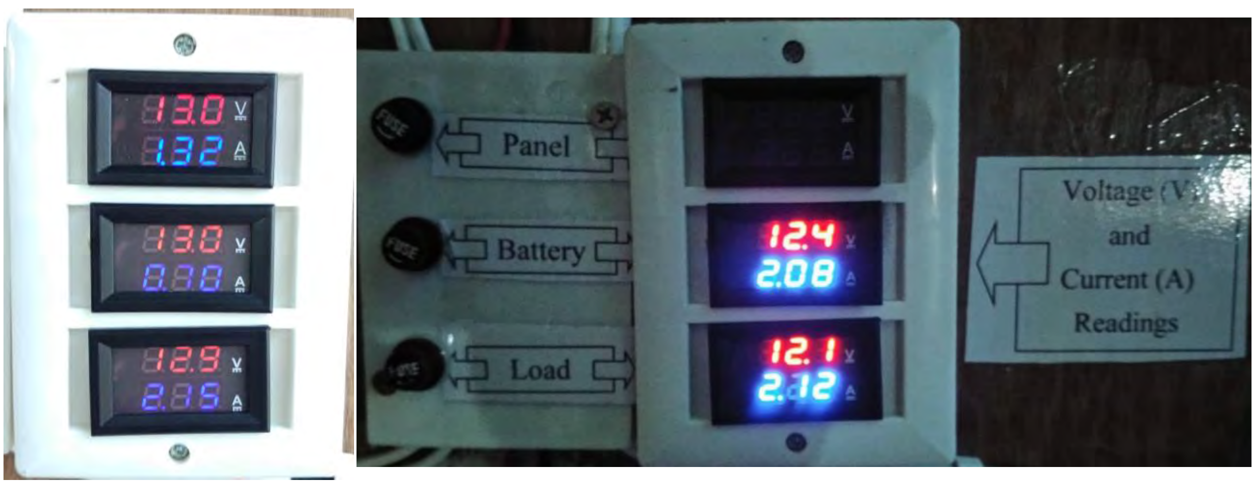


Figure 5.4: Measuring devices at daytime when load is on and consuming current from both the Panel & Battery (Left), at nighttime when load is on, panel voltage is low; load is consuming current only from battery.

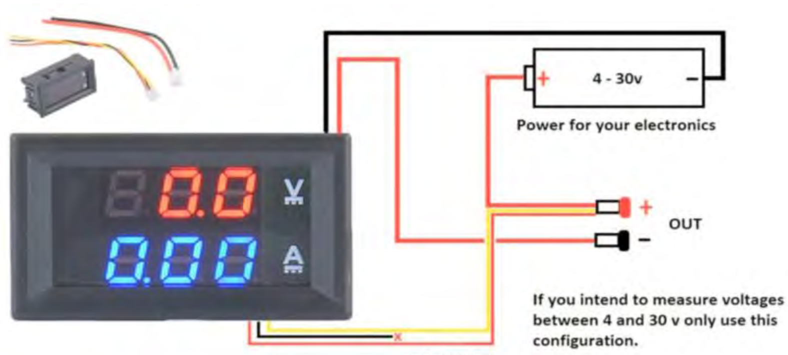


Figure 5.5: Schematic connection diagram of measuring device

5.1.3 Installation of Loads and Wiring

DC Flood Light was used as a replacement of AC lights to reduce energy consumption, loss of inverter and overall cost. Features of this Light is given in appendix E. For wiring purposes, IDCOL Pamphlet were followed for sola r system.

Table 5.1: Wire Gauge Table

Charge Controller to Solar Panel	70
Charge Controller to Loads	40
Charge Controller to Battery	6-10RM

Voltage drop at each end of the connection did not exceed 3% as for long solar panel to charge controller connection a higher diameter wire was used.

Figure 5.6: Zoomed in Photograph of the load at night taken from the bottom of the building.

5.2 Data Logging

Data logging or acquisition is the process of collecting and storing data over a period of time often used in scientific experiments or record the data-based events/actions of a system. data logging strongly depends on digital processor based systems with built in or external sensors.

5.2.1 Significance of Data Logging in a PV System

In any type of renewable energy system, data logging is an important part for future improvement and analyzation of the acquired data. As solar energy is becoming more accepted across the world as a sustainable renewable energy, it is becoming more and more important to monitor the performance of the system after installation. [18] Many factor can affect a systems performance such as bad wiring, faulty equipments, inconsistency of PV Panel output, environmental factors, accidental damage as well as manufacturing defect. It is vital for Return On Investment period of a system to be quicker for any solar system which is strongly related to the system's ability to maintain a minimum quality. [19]

However, the most significant side of data logging in a PV System is studying the system's behavior over different conditions and specifications. In fact, data logging is the main structure in the developing of softwares like PVsyst and RETScreen. Years of data logging made it possible for mankind to develop a relation between factors of solar array energy production like tilt angle, environment and shading effect. In this project, the purpose of data logging is not different from the discussion above.

5.2.2 Acquisition of Data

With the revolution in technology, it has become easier to implement data logging in any system. In or case, we used a charge controller with data logging capacity for our convenience. A germen made product, Phocos CXN10 was used in our case. It can acquire data daily for up to a week and replaces previous day data with the new one. After that, it takes the average of gathered data of a week and produces weekly data for a month. With the average of the weekly data, it can produce monthly data for a year. Apart from data logging, it has a built in night light function in which, a user can set a time for the load to automatically turn on or off at night with flexibility of setting a time within the night. This function is mainly directed for studying the behaviors of a PV System.

Figure 5.7: Phocos CXN Charge Controller

5.2.3 Communication of Phocos with a Computer

In a data logging process, it is even more vital to collect data than storing it. If the logged data can be taken out from a device, it helps the entire studying process a much more convenient. In this particular device, a week of data is stored in the charge controller with replacement of oldest data with a new one. Hence, data should collected every week. The collection is fairly easy process as there is a device named MXI for communication between the CXN and a Computer. A software is available for this in the name of CXCOM in which all the extra feature of the controller can easily be accessed with the data logging feature as well.

Figure 5.8: MXI Communication Device for Phocos
CXN

The connection of MXI module with the controller is fairly easy as diagram describes below. There are other accessories for the charge controller available like CXM for real time monitoring of voltages and currents of the system. However, the MXI and CXM both cannot be connected at the same time. Moreover, the charge controller can be controlled using several button combinations with one push button. The schematic of the process is given in appendix H.

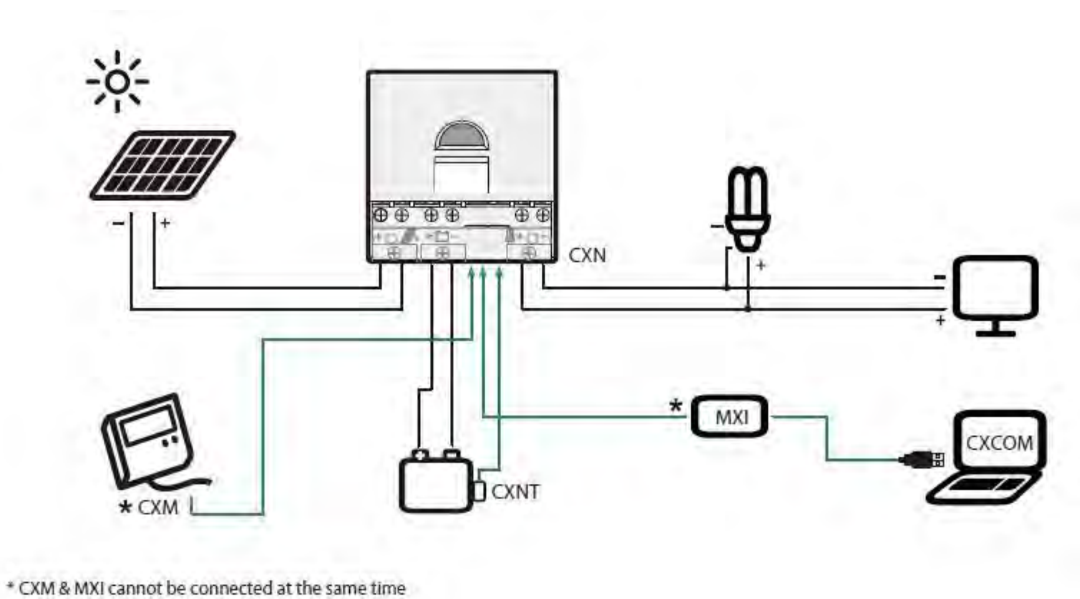


Figure 5.9: Connection Schematic Diagram of Phocos working in conjunction with MXI

5.2.4 Acquired Parameters from Data Logging

The charge controller measures all possible parameters that can be generated from the given connection of PV Panel, Battery and Load. Moreover, it has the functionality to disconnect load if the battery voltage falls short. It displays detailed data of battery max-min voltage, State of Charge, PV & Load Amperehours, PV & Load maximum current and so on. A typical data set for a week has been demonstrated in Figure 5.10 below.

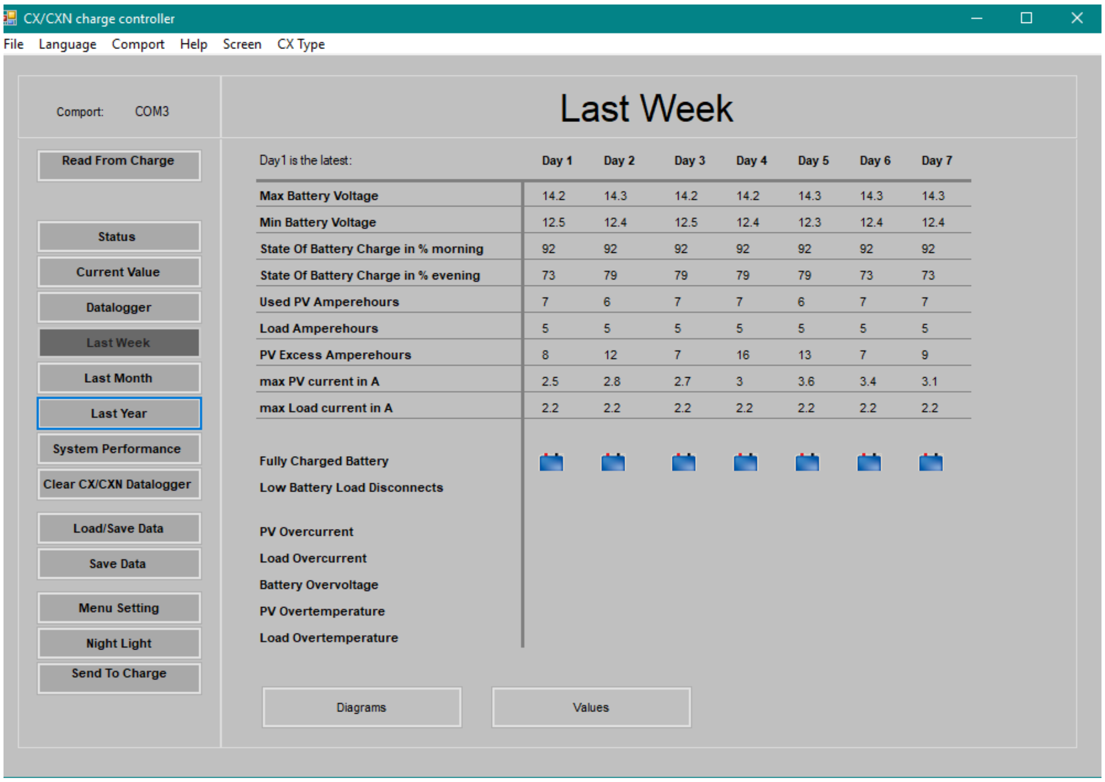


Figure 5.10: A typical data set for a week collected from the charge controller.

We utilized the Night Light function of the controller in our study by setting the function to turn on load after 6.00 PM & turn off at 10.00 PM. Which describes why the State of Charge of battery is different in comparison with morning and evening.

CHAPTER-6

Drawback and opportunities

6.1 Drawbacks

Like every power generation system, this home system has its negative aspects discussed below in brief:

- **Expensive Semiconductor Material**:

To generate electricity from sunlight, semiconductor factories need clean industrial environments and are expensive to build & maintain. It will take many years to invent new materials and methods of producing solar panels cost effectively. How many years it takes depends on how much time and money is invested into solar energy research by both government and private industries. Installing solar panels on a house is costly and requires skilled people. Currently Solar home systems use fixed solar panels since alignment systems are very expensive for the average homeowner. The primary investment cost is a significant factor concerning why there is a lack of support for solar power from consumers.

- **Low Efficiency:**

Solar cells efficiency of currently ranges from around 20% up to a height range of around 40%, although this is improving. The rest of the sunlight that falls in the panel is spoiled as heat. More photovoltaic cells that are efficient have been discovered (up to 43% efficient) but these are new discoveries and are expensive to produce industrially. [20]

- **Dust:**

Maintenance costs and time can sum up since solar panel must be kept clean and clear of relics for them to operate at their most efficiently. Solar panels efficiency drops significantly even when a small portion is blocked by fallen relics or a film of dust. In Bangladesh street light project failed due to high level of dust in Dhaka city.

Figure 6.1: Dust ridden solar panel

❖ Limited sunray:

The basic problem with solar energy that has suppressed its use is the fact that energy production only takes place when the sun is shining. Large storage systems need to be built to provide a continuous and reliable source of electricity when the sun is not shining at night or a cloudy weather. [21]

❖ DC Equipment:

We need to make wiring the home separately because a solar home system supplies DC voltage and grid supplies AC voltage. It increases the overall cost of the system. It is another reason consumers are not interested to install solar home system.

❖ Redesigning of Rooftop:

Installing solar panels on a rooftop can be very difficult to the overall structure so roof range need to be in our consideration. As we know that most of the houses in our rural area are tin shed & their structure are not strong enough to install a big solar panel. Installers need to calculate how many years a roof can support it, whether the installation will need to be replaced completely, or the structure needs to be re-enforced and how the extra weight of a solar panel installation may affect the roof's overall strength. Now a days solar panels often boast lifespans of 20 years, but if the roof needs replacement before that, the homeowner may just be opening themselves up to more hazards. On older homes, it may simply be that the roof is not in any situation to clench the additional weight that a solar panel may introduce.

Figure 6.2: Rooftops of ruler areas after installation of solar system

→ Moisture:

Moisture can also create hazards on a roof with solar panels if installers are not aware about where they run wires and racks. In many cases, defective installed systems can cause water to dam up and even run back up the roof. Shingles are effective at keeping water from seeping underneath them when then water is sliding down.

Figure 6.3: Moister on a solar panel

→ Birds:

Another solar panel installation problem can be caused by damage from birds. Racks and panels can create good nesting spots for birds, which leads to damaged wires and hardware. Increased bird presence on a roof means damage from bird stool as well. There is not much that can be done to stop birds from finding solar arrays welcoming.

Figure 6.4: Bird stool on solar panels

6.2 Opportunities

Although a PV system has its disadvantages, it has benefits as well that are discussed below:

6.2.1 DC Power

Solar home system provides DC current and there are many advantages of using DC instead of AC supply.

- A DC system has no inductance as a result the voltage drop in DC system is less than that of AC system for same load and hence a better voltage regulation. [22]
- A DC system has no skin effect so we can utilize entire cross section area of the line conductor
- A DC system requires less insulation than an AC system because of less potential stress for same working voltage.
- Absence of capacitance in DC system leads to less power loss because there is no need for charge and discharge of capacitance.
- DC system reduces the amount of resistance in the line.
- DC system allows us to use non-conventional energy like solar energy.

6.2.2 Economic Benefit

→ **Global warming:**

Solar power helps to slow/stop global warming. Global warming threatens the survival of human civilization, as well as the existence of countless other species. Solar panel systems creates electricity without pollution responsible for global warming. Solar power is now very clearly one of the most important solutions to the global warming crisis. Solar Home system will reduce dependency on fossil fuel.

→ **Self-reliance:**

Solar home system provides its owners self-reliance on energy. If grid fails or the price of electricity increases due to any economic crisis, solar home system helps the consumer to be reluctant. On the other hand, in our country many areas like the islands, riverside remote areas where supplying electricity is a challenge solar home system is an excellent solution.

→ **Secure Investment:**

The utility companies are axiomatic for their flutter and unreliable electricity prices. With solar panels and simple math, we can calculate how much electricity will be generated, and most importantly, at what price, for at least the next 20 years. Therefore, Solar Home System is a secure investment. [23]

CHAPTER-7

RESULTS & DISCUSSIONS

7.1 Results

The actual project did not follow the initially simulated specifications that were calculated due to some adjustments made to complete with the resources available. However, adjustments were made in a manner that allows future improvements with little financial involvement. After completion of the project, we compared the data collected from the charge controller with the simulation variant. Below is the collected data of a typical sunny week in spring (March 2018):

Table 7.1: Collected Data of a Sunny Spring Week

Day1 is the latest:	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Max Battery Voltage	14.2	14.3	14.2	14.2	14.3	14.3	14.3
Min Battery Voltage	12.5	12.4	12.5	12.4	12.3	12.4	12.4
State Of Battery Charge in % morning	92	92	92	92	92	92	92
State Of Battery Charge in % evening	73	79	79	79	79	73	73
Used PV Amperehours	7	6	7	7	6	7	7
Load Amperehours	5	5	5	5	5	5	5
PV Excess Amperehours	8	12	7	16	13	7	9
max PV current in A	2.5	2.8	2.7	3	3.6	3.4	3.1
max Load current in A	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Fully Charged Battery							

As the system specification changed, further simulation taking into account the new adjustments had to be analyzed. The graphs are shown below:

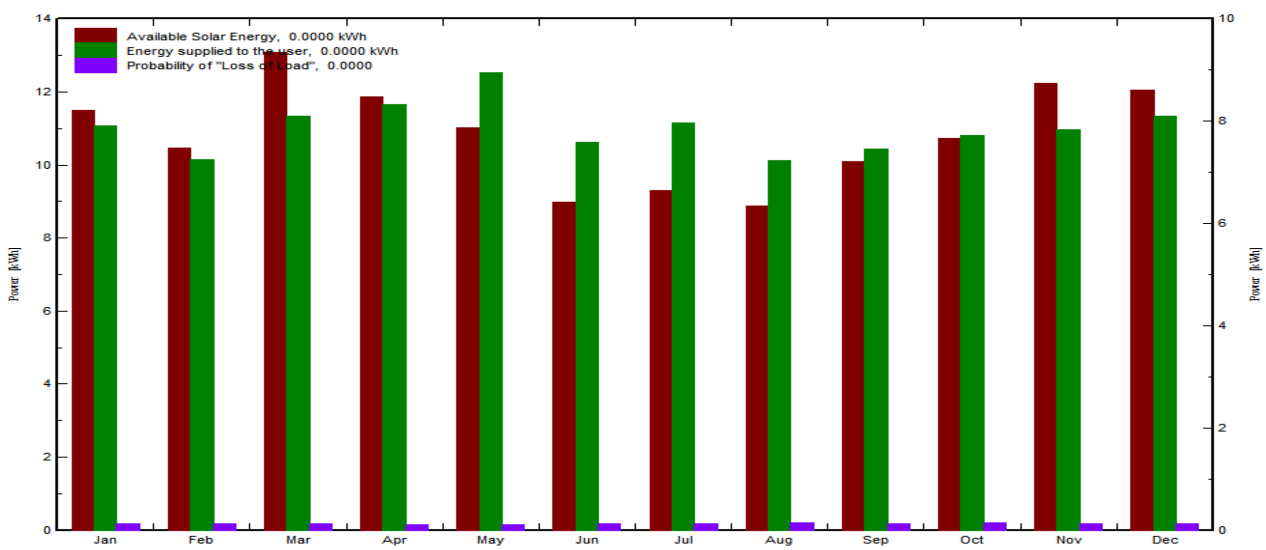


Figure 7.1: Annual average solar energy, Energy supplied to the user and probability of loos of load (LOL)

The loss diagram of actual system is given below:

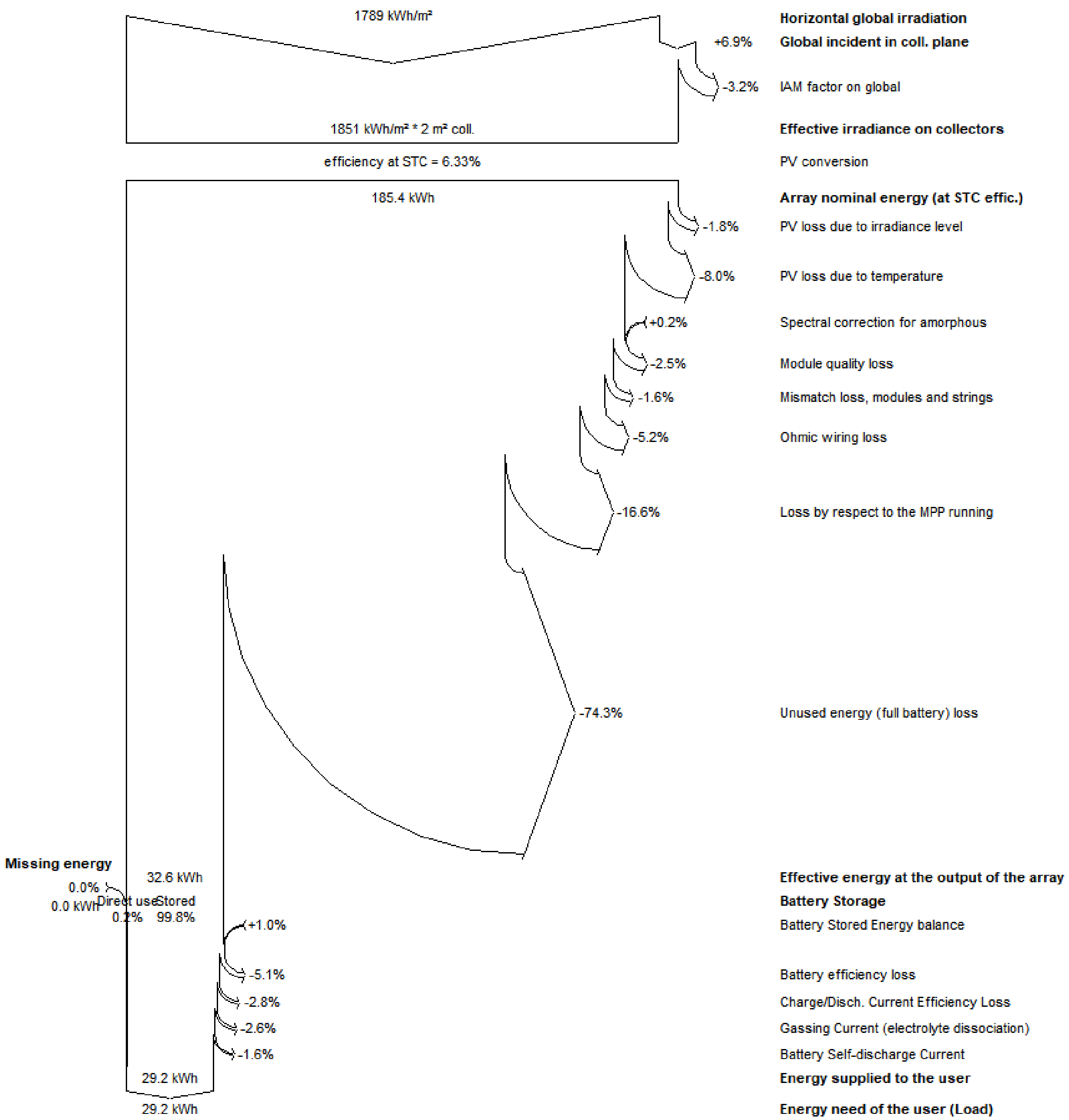


Figure 7.2: Loss Diagram of the Actual System

The diagram elaborates that system has ample energy to supply the user with significant unused energy. The big percentage of unused energy can be utilized by installing more loads in future improvements.

7.2 Comparison between the Simulated Data and Logged Data

The PVsyst Software provides us with more than ample amount of simulated data to study with. However, not all of the data parameters generated from the charge controller matches with the parameters of the simulation variant. Below are the comparison between them that does match:

5 State of Charge (SOC) of the battery comparison:

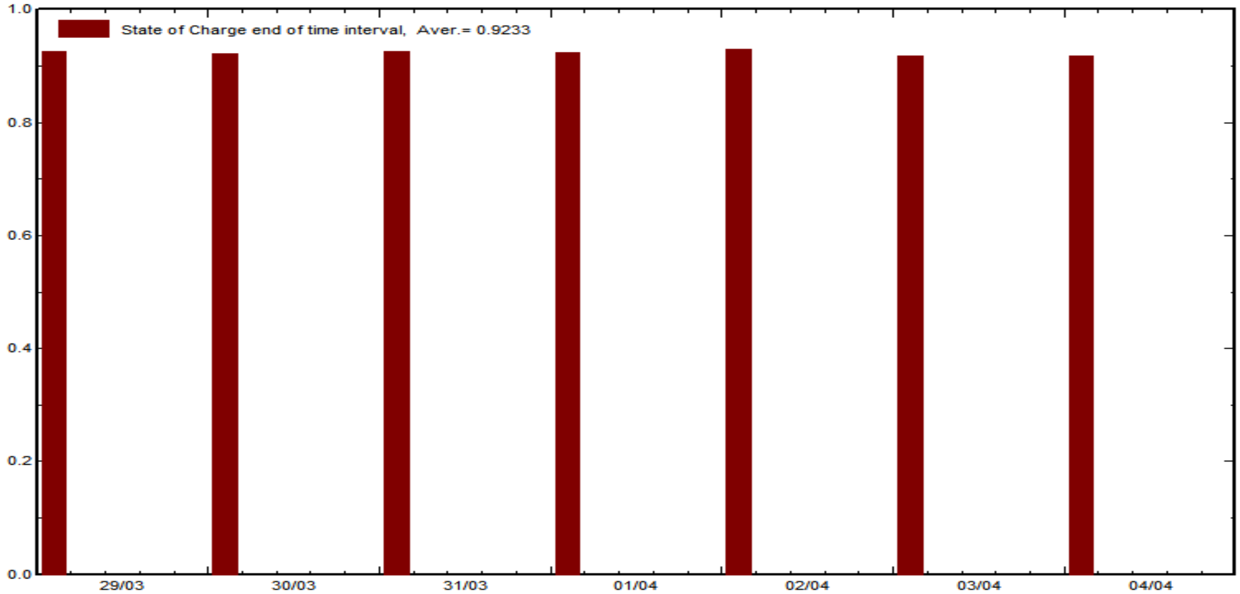


Figure 7.3: SOC of Battery in PVsyst Simulation from 29th March, 1990 to 4th April, 1990

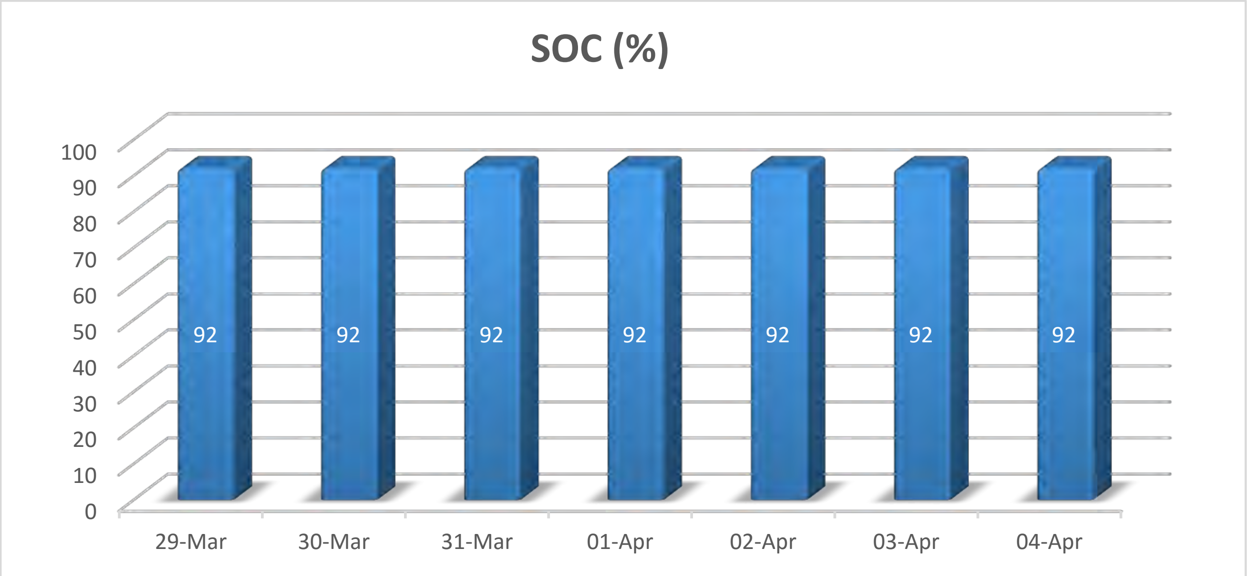


Figure 7.4: SOC of Battery from Data Logging from 29th March, 2018 to 4th April, 2018

From the graphs, the average SOC in the given time periode is 92 percent for both the simulation variant and data log. It illustrates that the value from simulation in comparison to data log is acurate even though the meteo data is 28 years old from the logged data period. It elaborates that the meteo data, while still old is ample for a simulation model.

6 Average Battery Voltage Comparison

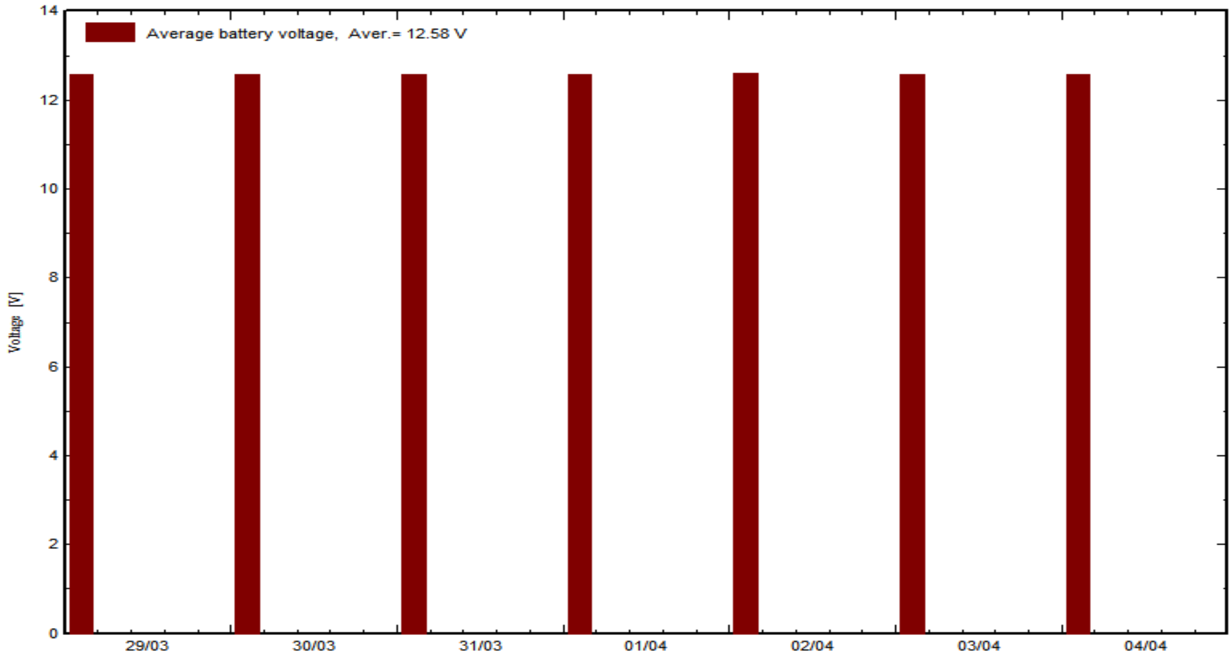


Figure 7.5: Average Battery Voltage in PVsyst Simulation from 29th March, 1990 to 4th April, 1990

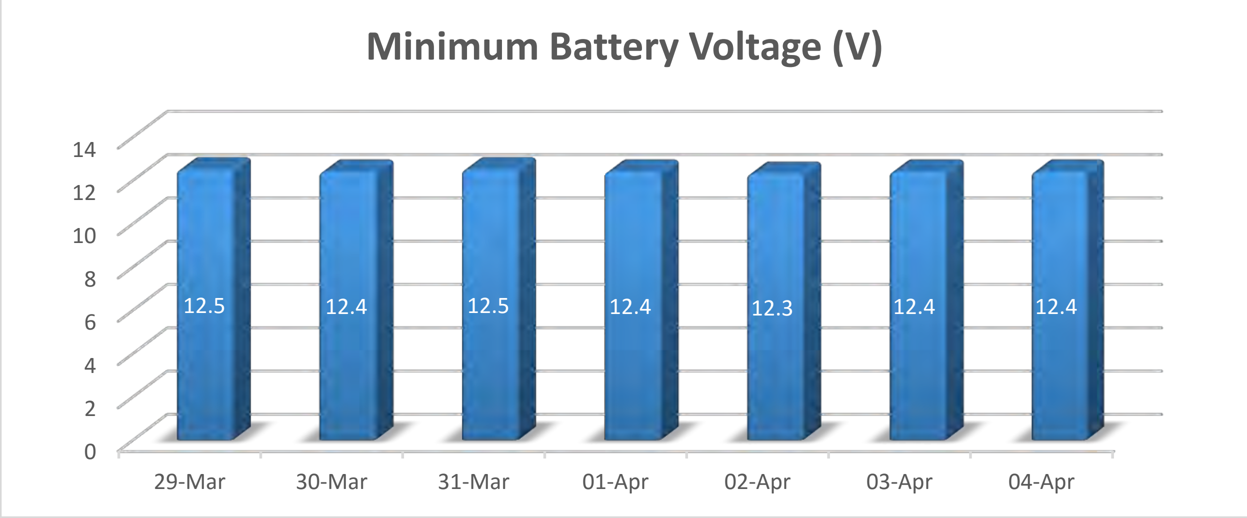


Figure 7.6: Minimum Battery Voltage from Data Logging from 29th March, 2018 to 4th April, 2018

There is no average voltage parameter in the data logging software nor there is any minimum voltage parameter available in the simulation software. However, the minimum voltage parameter and average voltage parameter data matches almost exactly. PVsyst takes hourly data to produce the average battery voltage data for a day whereas, data logger only logs the minimum battery voltage. Which may be the main reason why the data are close but not the same in comparison with each other. Another reason might be that the simulation battery model and the implemented battery is not the same. Nonetheless, both are still battery voltage readings which is why the comparison is shown.

7 PV Amperehour Comparison

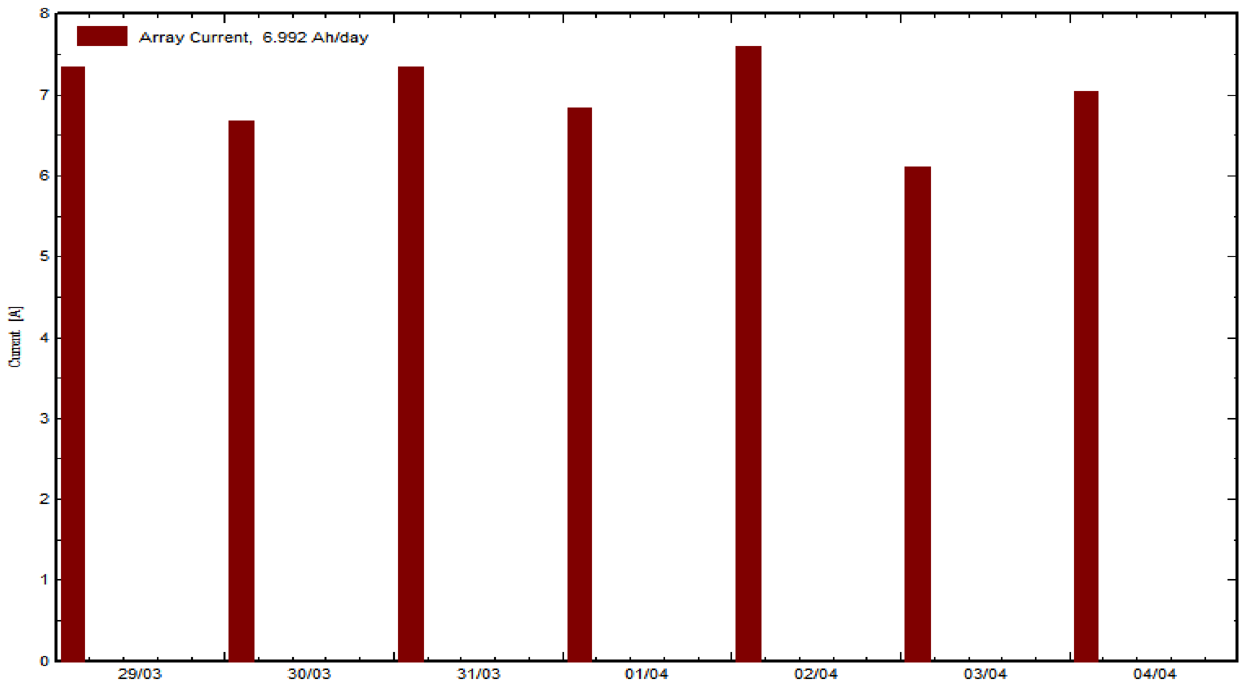


Figure 7.7: PV Amperehour in PVsyst Simulation from 29th March, 1990 to 4th April, 1990

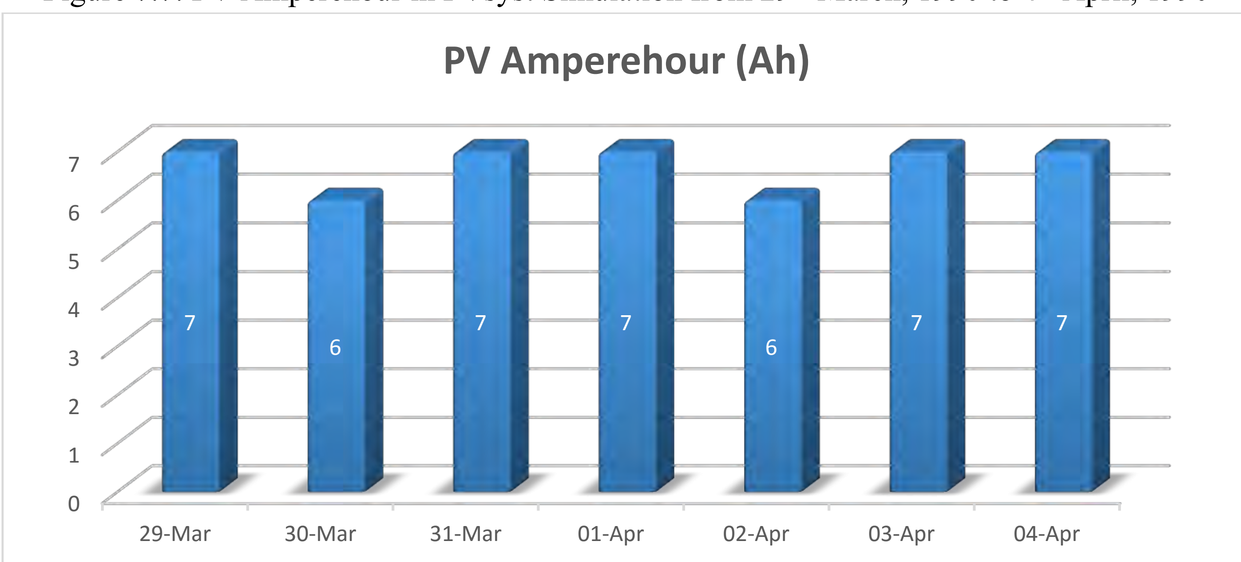


Figure 7.8: PV Amperehour from Data Logging from 29th March, 2018 to 4th April, 2018

The measured average PV amperehour from the simulation model and data logging model are 6.99Ah/day and 6.71Ah/day accordingly. It describes the current generated from the panel in simulation model is very close with the gathered data from the charge controller. Which again proves the feasibility of simulation before implementing a project even though the meteo data is old from the execution period.

7.3 Discussions

7.3.1 Power Generation

It was assumed to have a load of 420 watt-hour daily but to adjust the system within confined budget the load was reduced to 20W, which would provide 60 Watt-hour daily. The flood light of 20W 12V was placed on the top of 4th building of BRAC University to observe the night mode function of the charge controller Phocos. It lit the surrounding from 6pm-9pm. The power generated from the panel was sufficient for at least 30 watts and so it achieve the desired illumination 10W flood light DC was added to the system with changing the charge regulator or panel.

7.3.2 Cost of the PV System

Local market price was surveyed through surfing in websites and making phone calls to Navana Renewable Energy limited, Ensysco Bangladesh and so on in order to determine system cost. Monocrystalline solar panel of $100W_p$ was used because of availability in thesis lab which has higher efficiency than polycrystalline.

7.3.3 Cost & Maintenance of Battery

In our system, deep cycle lead-acid battery was used that allows for partial discharge and allows for deep slow discharge. These batteries are costly and constitute around 60% of the overall system cost for buying and maintenance. For the actual system, a single battery of 55 Amp-h was used which is sufficient to meet adjusted load demand. One big issue with these batteries is that they need supervision and maintenance. They need to be topped up every three months and their life span is also short. For the financial analysis of 60W small system, it was considered that every after 4 years battery is changed.

7.3.4 Temperature Effect

Efficiency of the solar panels are calculated in standard condition meaning 25^0C but solar panel lose efficiency due to the temperature increment. In order to increase the efficiency, the panels should be cooled down by placing the panel in such a way that it gets natural air circulation. Air cooling fan can be installed with maximum 1 or 2 watt rating to ensure better efficiency.

7.3.5 Break-even point

It was observed from the different system cash flow analysis that the larger projects can reach the break-even point early and become efficient for urban uses. Initial cost and base system plays vital role in deciding the feasibility of an SHS. Larger system require less initial cost compared to small systems and by this time larger systems face bigger amount of tariff rate in base case grid electricity. As a result, it becomes feasible using solar power for variety of loads, even for AC loads using inverters. Ultimately, the break-even point is reached within 3-6 years. On the other hand, smaller systems face larger amount of initial cost compared to the outcome of the project and hence the base case system unit electricity cost and SHS unit electricity cost becomes similar.

Therefore, it requires more time to reach break-even point, losing the attraction of having an SHS for the customers.

7.4 Difficulties Faced During the Project

7.4.1 Troublesome PVsyst Software

PVsyst, while being a tremendously useful tool for solar system performance simulation, the software is not free of fault. While using the software, it crashed with an error report several amounts of time during system setup. Especially when viewing detailed graphs of the simulation and scaling axis of the graphs for best understandable representation. Every time it crashed, the simulation variant needed to be changed each time as it was in demo mode.

7.4.2 Difficulties Installing MXI Driver

The MXI module is a mandatory component for the Phocos CXN charge controller to communicate with the computer. However, the driver software which is a must for windows to understand the MXI module established in 2009 was outdated for a new version of windows like windows 10 to work with. Nonetheless, after a hefty amount of research on the internet a difficult but not impossible workaround was followed. Which included turning off the operating system's signature verification of a driver software and manual installation of the driver. After following the process the CXCOM software worked correctly.

7.4.3 Charge Controller Improper Working

At first, the charge controller was not communicating correctly with the computer and the data was incorrect from the device. Nevertheless, resetting the controller using the button combinations for the push button helped resolve the problem. The process of resetting the controller is given in appendix H.

7.4.4 Measuring Device Installation

Installing the measuring device and connecting with the components were difficult, as the DC Voltmeter Ammeter does not follow the conventional voltmeter and ammeter connection. Moreover, fitting the modules with the wooden board was troublesome as we had to use normal plastic switch board and cut it to precise measurement using a heated up warm knife.

7.5 Future improvements

SHS is used for isolated places, hilly tracts and islands where grid connection is almost impossible. Therefore, small home lightening system with few watt loads like DC powered television, fan, mobile charger etc. are sufficient with single or double solar panels. Irony is that the initial cost for the small loads become unbearable for the disadvantaged class people and it requires 5-8 years to recover the investment. Hence, the business for SHS is facing difficulties around the whole world and annual reports indicate the downward direction slope of their business due to less attraction for SHS. This problem leads to the newer future of solar home system, showing the path for DC mini grid system for isolated areas and Smart Home System for urban areas.

Firstly, DC micro grid system is one of the greatest opportunities of solar home system. It requires setup of kW level DC power production from solar systems and the DC transmission lines along with proper protection and security. It is beneficial for the isolated areas where grid connection is not available at all and the economy of the society is not that well. The important thing is customers do not need to bear the whole burden of initial costs rather they will pay for UEC. This becomes easier to bear the cost for electricity compared to candlelight, kerosene and they can easily trade-off.

Secondly, smart home system is the other idea that arises from the solar home system. In smart home system, solar electricity can be used as back up or solar electricity can be used with grid connection that will reduce the electricity bill as well. Different types of communicating systems with grid connection and solar power can make the power system more stable and efficient.

Lastly, loans for implementing SHS should have different approach. In African countries, solar home system has got economic boom because of financial support from loan providing NGO's and different international organizations who work to provide electricity for the socio-economic development. In Bangladesh, BRAC, a non-governmental organization, Grameen Shakti and others in total 47 organizations work together under the umbrella of IDCOL to establish solar home system. For example, Grameen Shakti provide microcredit loans with 8-15% flat interest over one to five years. These interest rates are decided compared with the price of kerosene. These loan policies can be made flexible and innovative considering the availability of grid connection in near future such as Grameen Shakti offers additional warranties for a fee and will buy back the system if grid connection becomes available.

CHAPTER-8

CONCLUSION AND RECOMMANDATION

8.1 Conclusion

Solar Home System can fulfill fundamental energy requirements (i.e., lighting), particularly in off-grid rural areas in Bangladesh. Solar Home System has immense and deep economic, socio-cultural, and demographic influence on day-to-day life of the urban people in Bangladesh. Nearly all the users of Solar Home system are satisfied with its performance. [24] It is possible to make Solar Home System making cheaper & reducing down payment options combined with micro credit we can make it more popular to the poorer people. Larger-capacity Solar Home System can be introduced to the local people to install small business and boost the local economy. Maximum users did not have the adequate technical knowledge to maintain their Solar Home System to get maximum benefit and longer period of service life. Ensuring training about how to solve minor technical problems, cleaning the panel to the users with a Effective support service will ensure the continued service life of Solar Home System. [25] It is very important to ensure after sells service to the customers because Solar Home System in an interlocked system and any of the devices components is damaged the overall system will fail. If after-sales service is not ensured, [26] this could have a negative effect on growth of the Solar Home System market. Trained technicians are another significant hindrance for after-sales services. There are presence of many manufacturers both local and foreign, standard component testing is highly Preferred. Maintaining a standard quality will increase the service life of Solar Home Systems and will make it more popular.

It is very important to find out the economic benefit of Solar Home System for the rural areas users. The purpose is to calculate convenience to compare and contrast with the expenditure of acquiring a solar unit. Analyzing a large household survey data from Bangladesh, we can decide the effectiveness of Solar Home System on a diverse of household and intra-household behavioral result. We figure it out that Solar Home System assumption increases evening study hours of both boys and girls. Helps promote women's decision-making power and information sharing; [24] and reduces women and children malady from respiratory diseases by decrement kerosene burning. Solar Home System adoption also raise household prosperity by increasing per capita consumption. High cost of buying a unit plus the grant subsidy combined with each unit, we calculated that the convenience saved to households benefited the cost of buying a solar unit. This Proves Solar Home System is cost-effective for rural users. Therefore, government can concentrate to give subsidiary on other issues like health education when the amount of subsidiary reduces in power sector.

8.2 Future Enhancement

→ **Data Logging:**
Now we are collecting data daily basis using PVSyst & RET Screen but in future, we can gather data more effectively and efficiently by collecting data on hourly basis. This will help us to decide how to make our system more efficient.

→ **More Parameters:**
We can add more parameters like unused PV hours, unable to supply loads (hours) etc. in the data logger.

→ **GSM Module:**
Currently our system is using night light function to power our load but we can make it more efficient using GSM module and micro controller for controlling remotely to supply our loads. Our system is interfaced with Windows 10 but it can be interfaced with a GSM module to collect data remotely.

→ **Grid Connection:**
Connecting with the grid, we can switch connection in between grid and battery and even we can develop a system to sell extra power to the grid.

→ **Real Time Data Analysis:**
In future our charge controller can be installed with data-logging facility and this will allow us to gather real time data continuously and analyze them using simulation software to get an idea about actual performance.

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সাপ্লাই কোম্পানি লিমিটেড (ডেসকো). [online] Available at:

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Appendix A
SIMULATION PARAMETERS FOR PVSYST

Stand Alone System: Simulation parameters

Project : **Off Grid SHS Project in BRACU**

Geographical Site		**Dacca**	Country	**Bangladesh**
Situation	Latitude	23.77° N	Longitude	90.38° E
Time defined as	Legal Time	Time zone UT+6	Altitude	19 m
	Albedo	0.20		
Meteo data:	**Dacca**	MeteoNorm 7.1 station - Synthetic		

Simulation variant : **Solar Home System**

Simulation date 12/04/18 15h39

Simulation parameters	System type	**Stand-alone system**		
Collector Plane Orientation	Tilt	26°	Azimuth	8°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm

PV Array Characteristics

PV module a-Si:H tripple	Model	**XR12-100**		
Original PVsyst database	Manufacturer	Xunlight Corporation		
Number of PV modules	In series	1 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	1	Unit Nom. Power	100 Wp
Array global power	Nominal (STC)	**100 Wp**	At operating cond.	94 Wp (50°C)
Array operating characteristics (50°C)	U mpp	18 V	I mpp	5.1 A
Total area	Module area	**1.6 m²**		

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	62 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	3.4 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.5 % (fixed voltage)
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

System Parameter	System type	**Stand Alone System**		
Battery	Model	**Enersol 78**		
	Manufacturer	Exide Classic		
Battery Pack Characteristics	Voltage	12 V	Nominal Capacity	55 Ah
	Nb. of units	1		
	Temperature	Fixed (25°C)		
Controller	Model	SLX 1010		
	Manufacturer	Steca		
	Technology	uP, Shunt transistor	Temp coeff.	-5.0 mV/°C/elem.
Battery Management control	Threshold commands as	Battery voltage		
	Charging	14.2 / 12.5 V	Corresp. SOC	0.92 / 0.75
	Discharging	11.6 / 12.2 V	Corresp. SOC	0.19 / 0.45

User's needs :	Daily household consumers	Seasonal modulation
	average	0.4 kWh/Day

Appendix B

DETAILED USER NEEDS FOR PVSYST

Stand Alone System: Detailed User's needs

Project : **Off Grid SHS Project in BRACU**

Simulation variant : **Solar Home System**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	26°	azimuth	8°
PV modules	Model	XR12-100	Pnom	100 Wp
PV Array	Nb. of modules	1	Pnom total	**100 Wp**
Battery	Model	Enersol 78	Technology	Lead-acid, vented, plates
User's needs	Daily household consumers	Seasonal modulation	Global	128 kWh/year

Daily household consumers, Seasonal modulation, average = 0.4 kWh/day

Summer (Jun-Aug)

	Number	Power	Use	Energy
Lamps (LED or fluo)	1	20 W/lamp	7 h/day	140 Wh/day
Domestic appliances	1	40 W/app	7 h/day	280 Wh/day
Total daily energy				420 Wh/day

Autumn (Sep-Nov)

	Number	Power	Use	Energy
Lamps (LED or fluo)	1	20 W/lamp	7 h/day	140 Wh/day
Domestic appliances	1	40 W/app	7 h/day	280 Wh/day
Total daily energy				420 Wh/day

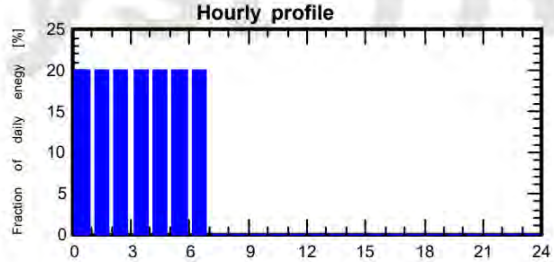
Winter (Dec-Feb)

	Number	Power	Use	Energy
Lamps (LED or fluo)	1	20 W/lamp	7 h/day	140 Wh/day
Total daily energy				140 Wh/day

Spring (Mar-May)

	Number	Power	Use	Energy
Lamps (LED or fluo)	1	20 W/lamp	7 h/day	140 Wh/day
Domestic appliances	1	40 W/app	7 h/day	280 Wh/day
Total daily energy				420 Wh/day

Hourly profile



Appendix C

MAIN RESULTS OF PVSYST

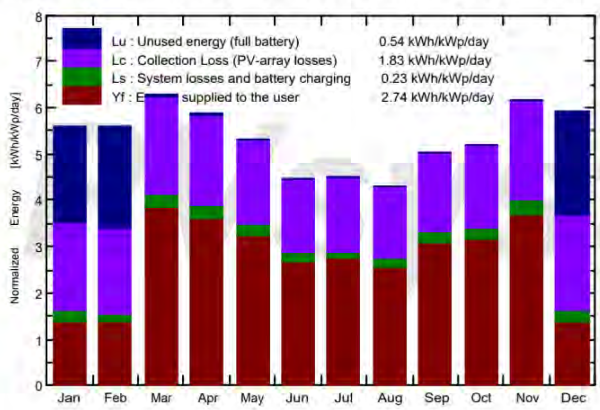
Stand Alone System: Main results

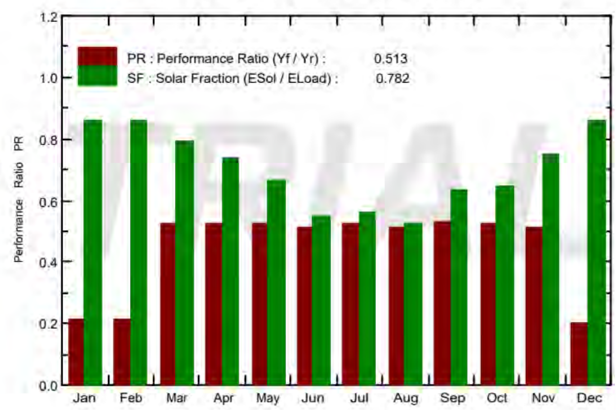
Project : **Off Grid SHS Project in BRACU**

Simulation variant : **Solar Home System**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	26°	azimuth	8°
PV modules	Model	XR12-100	Pnom	100 Wp
PV Array	Nb. of modules	1	Pnom total	**100 Wp**
Battery	Model	Enersol 78	Technology	Lead-acid, vented, plates
User's needs	Daily household consumers	Seasonal modulation	Global	128 kWh/year

Main simulation results				
System Production	**Available Energy**	**128.5 kWh/year**	Specific prod.	1285 kWh/kWp/year
	Used Energy	100.2 kWh/year	Excess (unused)	19.8 kWh/year
	Performance Ratio PR	51.32 %	Solar Fraction SF	78.21 %
Loss of Load	Time Fraction	11.8 %	Missing Energy	27.9 kWh/year





Solar Home System

Balances and main results

	GlobHor kWh/m²	**GlobEff** kWh/m²	**E Avail** kWh	**EUnused** kWh	**E Miss** kWh	**E User** kWh	**E Load** kWh	**SolFrac**
January	130.5	169.5	11.46	6.413	0.000	4.34	4.34	1.000
February	130.3	152.6	10.44	6.139	0.000	3.92	3.92	1.000
March	177.6	190.2	13.02	0.238	1.040	11.98	13.02	0.920
April	177.2	171.2	11.74	0.087	1.800	10.80	12.60	0.857
May	177.8	158.9	10.88	0.000	2.900	10.12	13.02	0.777
June	147.9	129.2	8.66	0.000	4.549	8.05	12.60	0.639
July	152.9	133.9	8.98	0.000	4.488	8.53	13.02	0.655
August	140.4	128.1	8.58	0.000	5.040	7.98	13.02	0.613
September	144.8	146.0	9.99	0.007	3.320	9.28	12.60	0.737
October	140.2	156.3	10.61	0.000	3.220	9.80	13.02	0.753
November	139.2	180.0	12.08	0.000	1.560	11.04	12.60	0.876
December	130.3	178.8	12.01	6.896	0.000	4.34	4.34	1.000
Year	1789.1	1894.6	128.46	19.780	27.918	100.18	128.10	0.782

Legends:				
	GlobHor	Horizontal global irradiation	E Miss	Missing energy
	GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
	E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
	EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

Appendix D

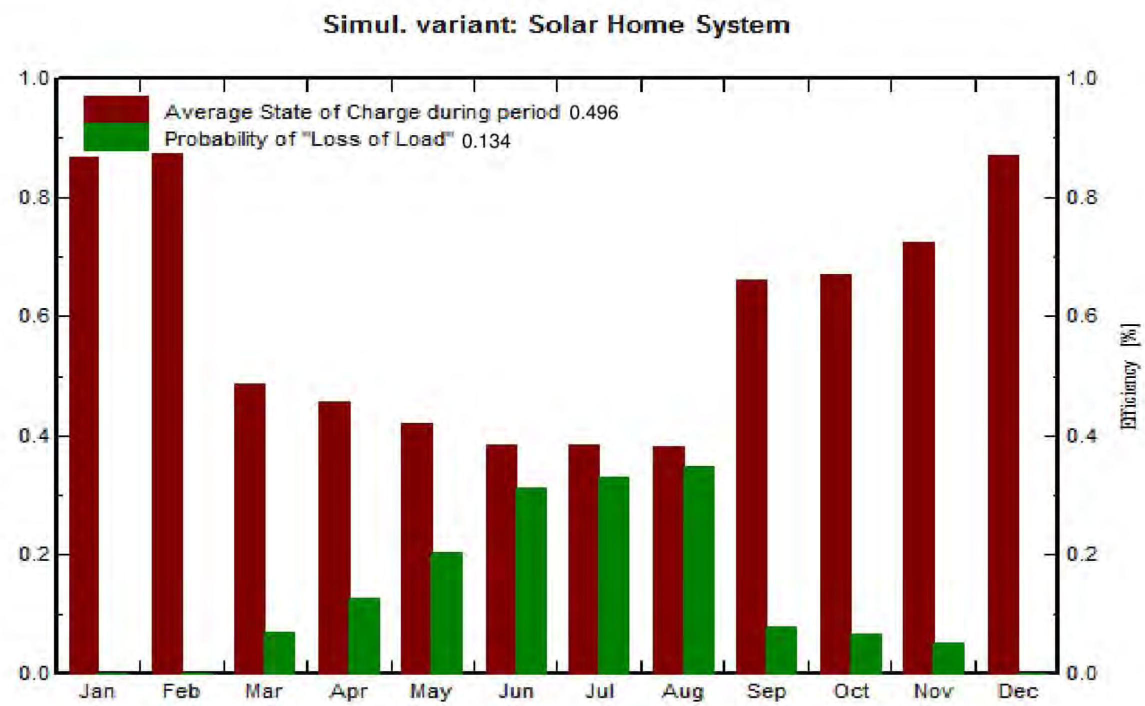
SPECIFIC RESULTS OF PVSYST

Stand Alone System: **Specific Results**

Project : **Off Grid SHS Project in BRACU**

Simulation variant : **Solar Home System**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	26°	azimuth	8°
PV modules	Model	XR12-100	Pnom	100 Wp
PV Array	Nb. of modules	1	Pnom total	**100 Wp**
Battery	Model	Enersol 78	Technology	Lead-acid, vented, plates
User's needs	Daily household consumers	Seasonal modulation	Global	128 kWh/year

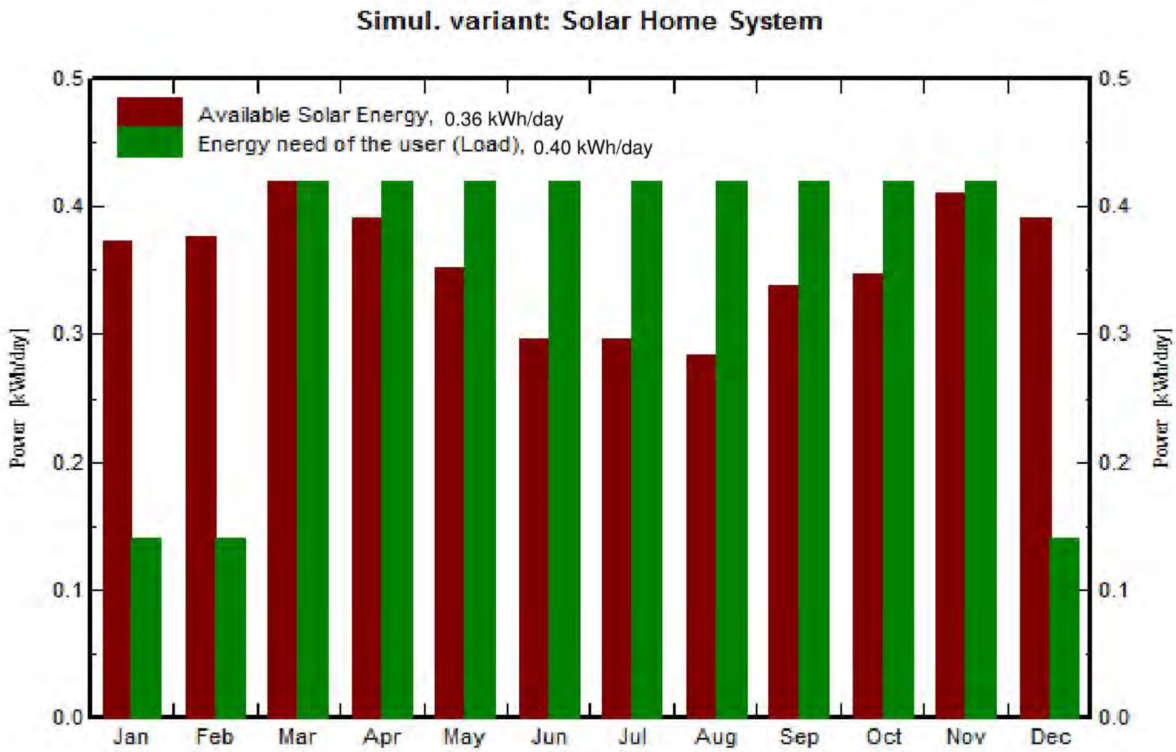


Stand Alone System: **Specific Results**

Project : **Off Grid SHS Project in BRACU**

Simulation variant : **Solar Home System**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	26°	azimuth	8°
PV modules	Model	XR12-100	Pnom	100 Wp
PV Array	Nb. of modules	1	Pnom total	**100 Wp**
Battery	Model	Enersol 78	Technology	Lead-acid, vented, plates
User's needs	Daily household consumers	Seasonal modulation	Global	128 kWh/year



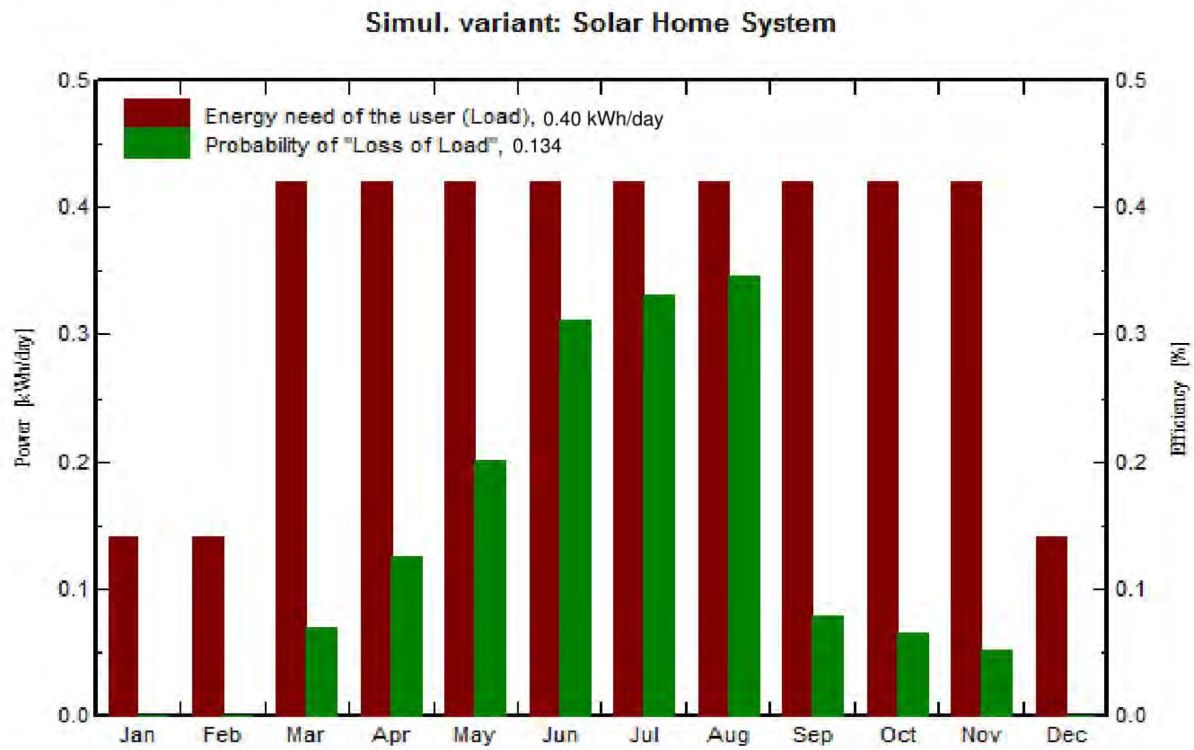
PVSYST V6.70		12/04/18	

Stand Alone System: **Specific Results**

Project : **Off Grid SHS Project in BRACU**

Simulation variant : **Solar Home System**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	26°	azimuth	8°
PV modules	Model	XR12-100	Pnom	100 Wp
PV Array	Nb. of modules	1	Pnom total	**100 Wp**
Battery	Model	Enersol 78	Technology	Lead-acid, vented, plates
User's needs	Daily household consumers	Seasonal modulation	Global	128 kWh/year



Appendix E

LOSS DIAGRAM OF PROJECT SIMULATED BY PVSYST

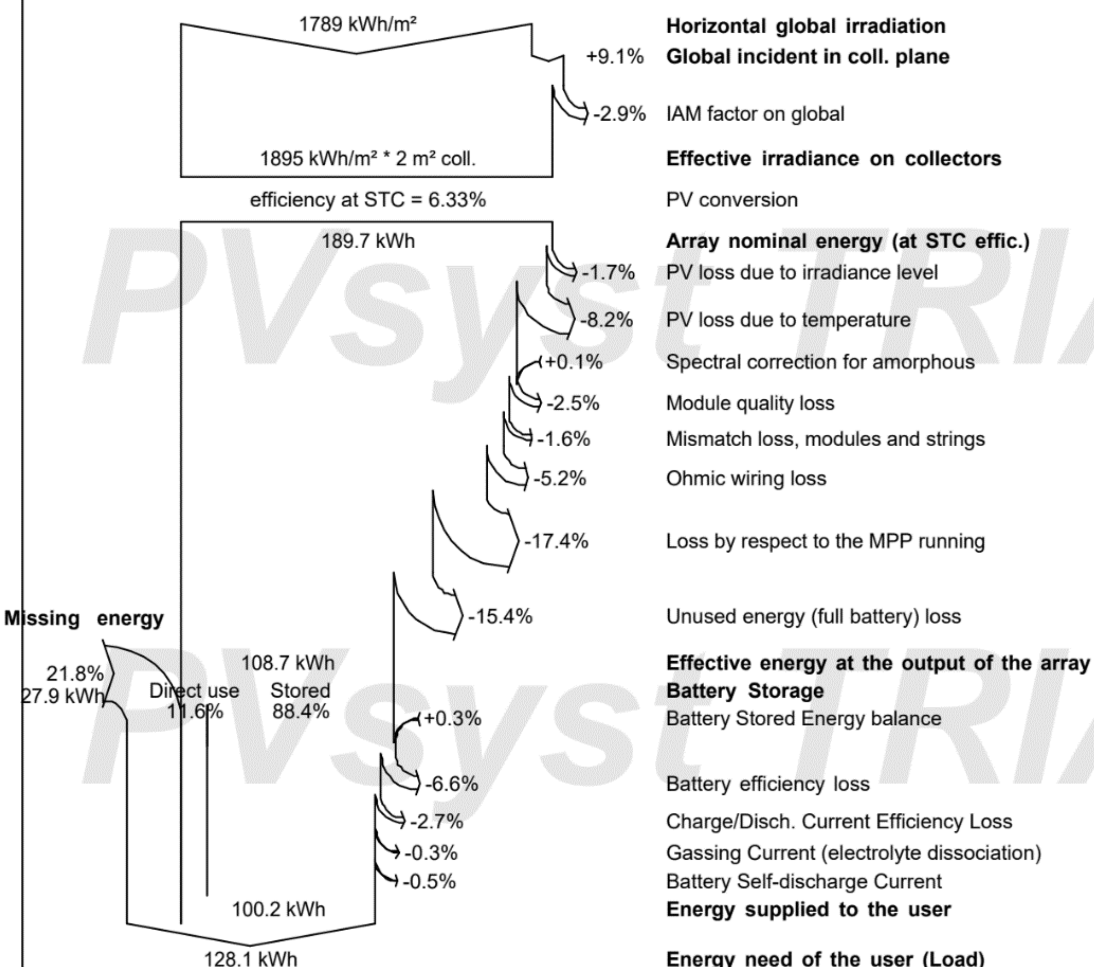
Stand Alone System: Loss diagram

Project : **Off Grid SHS Project in BRACU**

Simulation variant : **Solar Home System**

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	26°	azimuth	8°
PV modules	Model	XR12-100	Pnom	100 Wp
PV Array	Nb. of modules	1	Pnom total	**100 Wp**
Battery	Model	Enersol 78	Technology	Lead-acid, vented, plates
User's needs	Daily household consumers	Seasonal modulation	Global	128 kWh/year

Loss diagram over the whole year



Appendix F

CHARACTERISTICS OF A PV MODULE (XUNLIGHT XR-12-100)

Characteristics of a PV module

Manufacturer, model : **Xunlight Corporation, XR12-100**

Availability : Prod. from 2012

Data source : Manufacturer 2013

STC power (manufacturer)	**Pnom**	**100**	**Wp**	**Technology**		**a-Si:H tripple**	
Module size (W x L)		0.889 x 1.779	m²	Rough module area	Amodule	1.58	m²
Number of cells		1 x 12		Sensitive area (cells)	Acells	N/A	m²

Specifications for the model (manufacturer or measurement data)

Reference temperature	TRef	25	°C	Reference irradiance	GRef	1000	W/m²
Open circuit voltage	Voc	27.0	V	Short-circuit current	Isc	6.35	A
Max. power point voltage	Vmpp	20.0	V	Max. power point current	Impp	5.00	A
=> maximum power	Pmpp	100.0	W	Isc temperature coefficient	muIsc	7.0	mA/°C

One-diode model parameters

Shunt resistance	Rshunt	45	ohm	Diode saturation current	IoRef	1989.59	nA
Serie resistance	Rserie	0.28	ohm	Voc temp. coefficient	MuVoc	-83	mV/°C
				Diode quality factor	Gamma	6.05	
Specified Pmax temper. coeff.	muPMaxR	-0.23	%/°C	Diode factor temper. coeff.	muGamma	-0.001	1/°C

Special parameter for amorphous modules

Rshunt exponential	Rsh(G=0)	540	ohm	Exponential parameter	Rsh exp	5.5	
Recombination parameter	di² / mu tau	1.82	1/V	Spectral correction enabled		Yes	

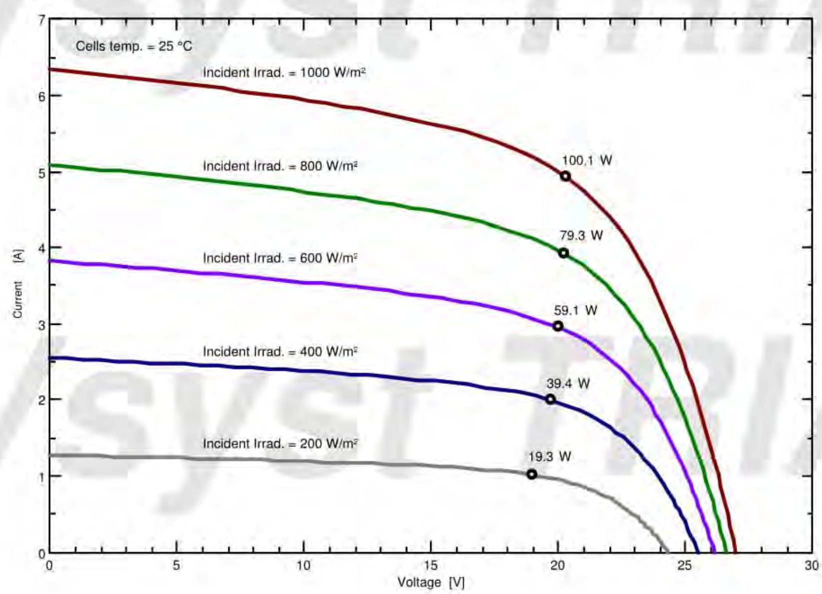
Reverse Bias Parameters, for use in behaviour of PV arrays under partial shadings or mismatch

Reverse characteristics (dark)	BRev	3.20	mA/V²	(quadratic factor (per cell))	
Number of by-pass diodes per module		12		Direct voltage of by-pass diodes	-0.7 V

Model results for standard conditions (STC: T=25°C, G=1000 W/m², AM=1.5)

Max. power point voltage	Vmpp	20.4	V	Max. power point current	Impp	4.92	A
Maximum power	Pmpp	100.1	Wc	Power temper. coefficient	muPmpp	-0.18	%/°C
Efficiency(/ Module area)	Eff_mod	6.3	%	Fill factor	FF	0.584	
Efficiency(/ Cells area)	Eff_cells	N/A	%				

PV module: Xunlight Corporation, XR12-100



Appendix G
CHARACTERISTICS OF A REGULATOR
(STECA SOLARIX PR 1510)

Characteristics of a controller for stand-alone

Manufacturer, model : **Steca Solarix, Solarix PR 1510**

Data source :

General features

Technology / Data display capability	uP, Series transistor	LCD	
Nominal battery voltage	Switchable bi-voltage	12 V	24 V
Maximum input current	I PV Max	10 A	
Maximum output current	I load max	10 A	
Current self-consumption	Night / Running	13 mA /	13 mA
Battery temperature compensation	Internal sensor		
Associated Battery Pack technology	Lead-acid, sealed, Gel		

Running Thresholds

		Per cell	Whole battery
Charging thresholds (PV charging)	Triggering OFF (Vmax)	2.23 V	13.4 V
(overcharging protection)	Triggering ON	2.09 V	12.5 V
Load Disconnecting threshold	Triggering OFF (Vmin)	1.92 V	11.5 V
(deep discharge protection)	Triggering ON	2.04 V	12.2 V
Corrections according to battery temperature		-5.0 mV/°C	-30.0 mV/°C
Reference temperature		20 °C	

Remarks and Technical features

Hybrid regulator

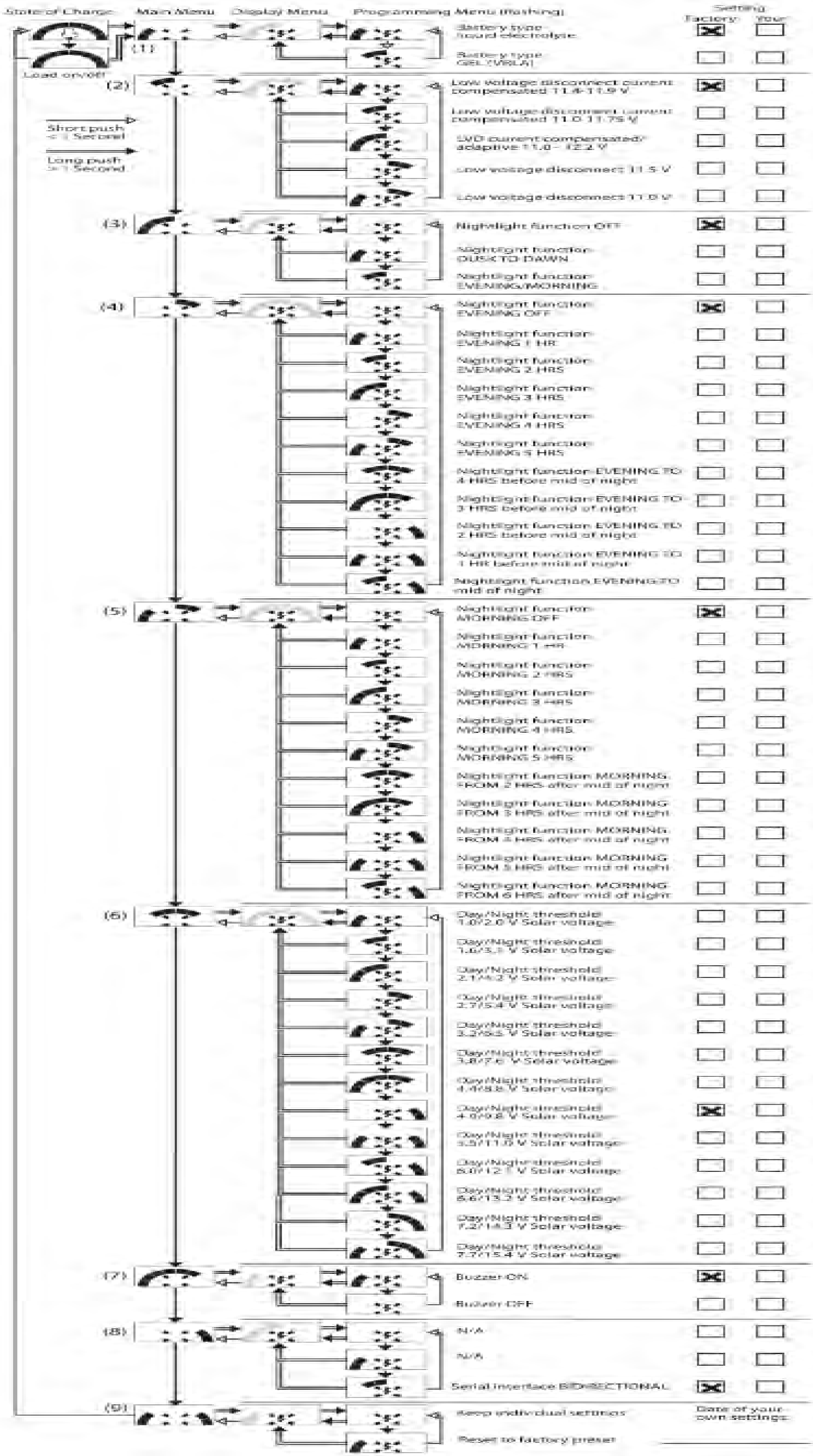
SOC determination using Steca Atomic

Graphic display

Sizes:	Width	187 mm
	Height	44 mm
	Depth	96 mm
	Weight	0.30 kg

Appendix H

PHOCOS PUSH BUTTON COMBINATION FOR CONTROLLING WITHOUT A COMPUTER


State of Charge
Main Menu
Display Menu
Programming Menu (flashing)
Setting
Factory
Your
Load on/off
(1)
Battery type liquid electrolyte
Battery type GEL (VRLA)
(2)
Low voltage disconnect current compensated 11.4-11.9 V
Low voltage disconnect current compensated 11.0-11.75 V
LVD current compensated/ adaptive 11.0 – 12.2 V
Low voltage disconnect 11.5 V
Low voltage disconnect 11.0 V
Short push < 1 Second
Long push > 1 Second
(3)
Nightlight function OFF
Nightlight function DUSK TO DAWN
Nightlight function EVENING/MORNING
(4)
Nightlight function EVENING OFF
Nightlight function EVENING 1 HR
Nightlight function EVENING 2 HRS
Nightlight function EVENING 3 HRS
Nightlight function EVENING 4 HRS
Nightlight function EVENING 5 HRS
Nightlight function EVENING TO 4 HRS before mid of night
Nightlight function EVENING TO 3 HRS before mid of night
Nightlight function EVENING TO 2 HRS before mid of night
Nightlight function EVENING TO 1 HR before mid of night
Nightlight function EVENING TO mid of night
(5)
Nightlight function MORNING OFF
Nightlight function MORNING 1 HR
Nightlight function MORNING 2 HRS
Nightlight function MORNING 3 HRS
Nightlight function MORNING 4 HRS
Nightlight function MORNING 5 HRS
Nightlight function MORNING FROM 2 HRS after mid of night
Nightlight function MORNING FROM 3 HRS after mid of night
Nightlight function MORNING FROM 4 HRS after mid of night
Nightlight function MORNING FROM 5 HRS after mid of night
Nightlight function MORNING FROM 6 HRS after mid of night
(6)
Day/Night threshold 1.0/2.0 V Solar voltage
Day/Night threshold 1.6/3.1 V Solar voltage
Day/Night threshold 2.1/4.2 V Solar voltage
Day/Night threshold 2.7/5.4 V Solar voltage
Day/Night threshold 3.2/6.5 V Solar voltage
Day/Night threshold 3.8/7.6 V Solar voltage
Day/Night threshold 4.4/8.8 V Solar voltage
Day/Night threshold 4.9/9.8 V Solar voltage
Day/Night threshold 5.5/11.0 V Solar voltage
Day/Night threshold 6.0/12.1 V Solar voltage
Day/Night threshold 6.6/13.2 V Solar voltage
Day/Night threshold 7.2/14.3 V Solar voltage
Day/Night threshold 7.7/15.4 V Solar voltage
(7)
Buzzer ON
Buzzer OFF
(8)
N/A
N/A
Serial interface BIDIRECTIONAL
(9)
Keep individual settings
Reset to factory preset
Date of your own settings: