An Approach Towards a Sustainable Urban City - Utilization of Existing Rooftop Solar Energy Panels by Making Use of DC Appliances

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A Thesis submitted to the Department of Electrical and Electronic Engineering in of partial fulfillment of the requirements for the degree of

Bachelor of Science in Electrical and Electronic Engineering

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Declaration

It is hereby declared that

1. The thesis submitted is my/our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Abstract

As with the growing GDP, developing market economy of Bangladesh is raising question on energy sustainability. Although having the infinite possibilities of harnessing solar energy, it could not be utilized properly as 90% of the urban rooftop solar panels are idle. The proposed system can work with the existing rooftop solar panels by using them as the source for powering the DC appliances of the apartments and store the excess energy in the 48V battery bank for later use. National grid connection is also kept as a backup source for powering the appliances when solar irradiance is unavailable and the batteries are all drained up. The reason of being exceptional of this project is use of DC appliances instead of converting the DC solar energy into AC which is inefficient and at the same time costly. This project successfully shows that those idle rooftop solar panels can utilized in the most effective and efficient ways while saving money and contributing to the nation's energy sustainability.

Keywords: Solar Panels, Battery, MPPT Charge Controller, Power Consumption, DC Appliances.

Dedication

We would like to dedicate our study to our parents and to the near one who have always motivated us to strive for achievement and their never-ending guidance at all phases has brought us so far. We would also love to dedicate this to our supervisor for all his support and encouragement in the development of the final work output.

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List of Acronyms

SHS	Solar Home System
BRAC	Bangladesh Rural Advancement Committee
BPDB	Bangladesh Power Development Board
DC	Direct Current
AC	Alternating Current
NGO	Non-Government Organization
MPPT	Maximum Power Point Tracking
SREDA	Sustainable and Renewable Energy Development Authority
DESCO	Dhaka Electric Supply Company Limited
NPC	Net Present Cost
CRF	Capital Recovery Factor
COE	Cost of Energy
MW	Mega-Watt
GDP	Gross Domestic Product
COP	Coefficient of Performance
SWERA	Solar and Wind Energy Resource Assessment
GHI	Global Horizontal Irradiance
CDM	Clean Development Mechanism
UNFCCC	United Nations Framework Convention on Climate Change
BERC	Bangladesh Energy Regulatory Commission

Chapter 1

Introduction

1.1 Foreword

Bangladesh is one of the world's most densely populated countries with a population of 160 million. Earlier the fundamental earning source of the people was agriculture. However, as the GDP rate increased with time Bangladesh entered the realm of the developing country. This stable economic growth and rapid development in the industrial sector has created a huge demand for energy. Though electricity is the most common form of energy which is consumed by both domestic and industrial sectors, this country has never been able to produce the adequate amount of electricity to meet the demand. It can be seen that, Bangladesh is generating electricity from fossil fuel, natural gas and coal. All of these natural resources are limited and will phase out very soon. However, to meet the demand, natural gas and fossil fuel consumption is getting high day by day. As a result, the natural resources will phase out quicker that the past. The future generation will not have the access to this natural resources. As a result, the urge of using renewable energy was never this much imperative before. Renewable energy such as solar power will play a vital role in meeting the demand for electricity, especially in the off-grid areas of the country. The geographical location of this country has shown some promising results for harnessing solar energy. Bangladesh is located between 20.30 – 26.38 degrees north latitude and 88.04 – 92.44 degrees east longitude. Daily average solar irradiation rate is 4to 6.5 kWh per square meter. Maximum amount of radiation is available on the month of March - April (6.5 hour/day) and minimum on December-January (4 hour/day). Solar power systems contribute a huge amount of energy so that it can mitigate the present energy crisis, especially in rural areas of Bangladesh. As the continuation of this idea, solar power is being used in the rural areas for powering homes known as solar home systems. This solar home program showed promising results to overcome the challenge of electricity deprivation problem in rural areas of Bangladesh. If this concept can be brought to the urban areas then power crisis can be reduced to a great extent. Despite being successful in rural areas by adopting the technologies of the solar home system, urban areas are far behind in this matter. Therefore, the government has made it mandatory for the urban buildings to produce 3% of the total power consumption through solar power in order to get the electricity connection. However, the real scenario differs dramatically from this imposed rule. The city dwellers do not understand the importance of renewable energy as such renewable energy can help to conserve the nation's natural resources. It can also provide reliable power supplies and fuel diversification, which enhance energy security and lower risk of fuel spills while reducing the need for imported fuels. Furthermore, it can also lower the prices of and demand for natural gas and coal by increasing competition and diversifying our energy supplies. That is why city dwellers needed to be motivated towards a green energy solution such as a solar home system. It will be an effective solution of the present energy crisis and to prevent the upcoming depletion of the present reserve of natural resources for a better future of urban areas. Furthermore, it can bring cleaner air into the cities by reducing the man-made carbon emission. Solar energy not only is environment friendly but also can be economically beneficent to the city dwellers as the power consumption is less and that power is produced through solar irradiance which is free of cost.

1.2 Background and Motivation

Bangladesh is world’s one of the most densely populated country. By 2014, Bangladesh stands at the 9th position in terms of population. However, it is considered as one of the fastest growing economies in the Southern-Asia. The country struggles with internal energy crisis because it is hugely dependent on fossil fuels for producing energy. Due to the growing economy energy has become the inevitable and basic need [9]. Unfortunately, around 70% people were deprived of having uninterrupted electricity and among them approximately 40% are living below the poverty line [14]. Furthermore, 80% people of this country live in village and only 32% of the total population are connected with national grid [12]. Though, the energy sector uses and covers varied products; electricity, petroleum products, natural gas, coal, biomass and solar, electricity is the used mostly, as it is the most common used form of energy in the country. Thus, because there is a continuous and rapidly widening gap between electricity supply and demand, therefore it is a major challenge for the energy sector in Bangladesh. The steady increase in GDP and sustainable economic growth not only brought a slight lift to the quality of life but also contributed heavily to the energy crisis. However, Bangladesh Power Development Board (BPDB) has shown some remarkable progress in energy production, the future of the energy crisis has not been secured yet. According to BPDB, current electricity generation capacity of Bangladesh is at around 17,752 megawatts (MW) with the target to produce 24,000 MW by 2021 (BPDB, 2017). According to a daily newspaper, "The Financial Express", to sustain 7.0 per cent Gross Domestic Product (GDP) growth, Bangladesh will require around 34,000 MW of electric power by 2030. But all of this power generation depends on the natural resources such as coal and natural gas. As a result, the natural gas reserve of the country is dwindling rapidly. If this heavy dependency soon does not get substituted with renewable sources, the energy crisis will hinder the economic development of this country. However, renewable energy sources have shown some promising data for producing electricity without any fuel [11]. United Nations Framework Convention on Climate Change (UNFCC) has taken some steps and initiatives for Clean Development Mechanism (CDM) [10]. In this context, the popularity of harnessing solar energy is increasing day by day. Hopefully, Bangladesh Rural Advancement Committee (BRAC), a Non-Government Organization (NGO) started a Solar Energy Program for sustainable development in 1997.

Bangladesh Power Development Board (BPDB) and other government organizations have done some worth noting projects such as Hill Tracts Electrification Project, 20.16 KW solar PV system at the office of the prime minister in December 2009 etc. Solar plants are growing rapidly and as these plants are producing DC power, appliances are also getting compatible with DC power [13]. Furthermore, the solar home system is playing a vital role for rural electrification. Furthermore, Bangladesh is trying to achieve SDG 7 (Affordable and Clean energy) within a certain period. Goal 7 of the SDGs aims to correct this enormous imbalance by ensuring everyone has access to affordable, reliable, and modern energy services. For achieving this goal emphasis on harnessing renewable energy is mandatory. The Power Division, Ministry of Power, Energy and Mineral Resources Government of the People's Republic of Bangladesh has made it mandatory for consumers to install permanent rooftop panels at their holdings for getting new connections [36]. The idea was to make sure that consumers are generating at least 3% of their demand on their own from the renewable source before they get connection from the national grid. This was an approach by the government for promoting the use of renewable sources of energy and ease pressure on the traditional non-renewable sources. This thesis paper is aiming on the same target by utilizing those unused rooftop panels. If the energy crisis is being overcome by utilizing the unused solar panels in urban areas of Bangladesh, then both rural and urban areas will have clean and affordable access to energy.

Our goal is to design and simulate an urban solar home system using the existing rooftop solar panels and using DC appliances which will consume less power in comparison with AC appliances. A recent survey was done by the Dhaka Electric Supply Company Limited (DESCO) in Gazipur's Tongi [36]. After the survey, they came to a conclusion that around 90% rooftop solar systems there were non-functional. However, the numbers of rooftop solar panels in Bangladesh are very huge. After seeing the report, motivation for working in this project came in our mind. Through the successful implementation of this proposed urban solar home system the power crisis can be deducted to some extent. Furthermore, limited natural resources can be stored and reserved for the upcoming generations. In addition, the urban consumers can reduce the net electricity bill through this proposed system.

1.3 Literature Review

Many researches have been done similar to ours but the idea is different. In our research the key difference is we are using only DC appliances instead of AC appliances in order to reduce the overall cost in the system as there is no need for an inverter which is very costly to buy. In Krishna Neupane's paper they have built a smart controller based solar-grid design which has the ability to generate the maximum output from the solar panel [1]. The key difference is there they used inverters and AC loads. In Amber Rasheed's paper they have compared the efficiency of AC and DC loads considering two topologies, one represents the comparison with a main PEC supplying all the loads another is the PEC is supplying separately to all the loads total four comparisons shown in this paper [2]. But in our research, we will compare the energy efficiency between AC and DC common appliances. In Tiago J. C. Sousa's paper analyzes three different possibilities that can be used to perform the interface between the AC power grid and a DC home: (i) AC-DC converter using a low frequency transformer; (ii) AC-DC and DC-DC converters using a high frequency transformer; (iii) AC-AC and AC-DC converters using a medium frequency transformer [3]. These three possibilities are compared in terms of efficiency, total power factor and total harmonic distortion of the AC power grid. But in our system, we are directly using solar panels along with only DC appliances where there is no use of any converter which is cost friendly to the system. In Jun Pan's paper introduces a MPPT charge controller which has some special features like improved solar tracking capabilities, optimal charging strategy which helps the battery to charge faster with a high state of charge ratio and overcharge blocking facilities [4]. We have adapted this type of thinking for implementing our MPPT algorithm for better efficiency and performance. In A. Iqbal's paper they have developed a DC compressor based cold storage which is very efficient rather than AC compressor because the coefficient of performance (COP) for DC compressor is 1.48 which is higher than AC compressor [5]. It's indicating that DC compressor is power efficient as well as it is reliable to use as our common appliances. In S. Pant's paper presents a MATLAB/Simulink based study of a PWPS which uses a permanent magnet DC (PMDC)motor driving a centrifugal pump under three conditions of solar irradiance (i.e., constant irradiance, varying irradiance and partial shading) [6]. Perturb and observe MPPT algorithm is applied for regulation of DC-DC boost converter duty cycle to provide maximum power from PV source to PMDC motor. We implemented a similar kind of technique in the simulation of a 48V 210W water pump in order to show it as a common appliance in a household. In S. Siddiqua's paper they have developed a double burner smart electric stove which runs by solar systems which consumes approximate 1520W which is very high to consider [7]. In our system we are considering only a single burner in order to reduce the power consumption. Our proposed solar stove will consume approximately 500W.

1.4 Problem Statement and Solution

In the last two decades Bangladesh has installed more than four million solar home systems which reflects a very promising potential of this country in terms of solar power harnessing. Unfortunately, these numbers often deceive the viewer from the real truth and works as a musk to hide the reality. According to a Former member of Sustainable and Renewable Energy Development Authority (SREDA) Siddique Zobair, 90% of the panels remain idle. He also added that most of the solar systems which had been installed previously in Dhaka and other divisional areas are now hardly of any use. Furthermore, a recent survey done by the Dhaka Electric Supply Company Limited (DESCO) near Tongi showed that 90% rooftop solar systems were non-functional. This is not only confined to the Tongi area rather this inconvenience occurs all over the country. The building owners set up those rooftop solar systems as a demo for only getting the grid connection. After getting the grid connection, the owners abandon the whole system. The unutilized solar panels remain idle over the rooftops covered with dust. As the day's past, without proper maintenance and proper usage these electrical device conditions deteriorate. Another common scenario is rooftop solar panels were being connected with faulty inverters and charge controllers. Behind this problem few influential key factors work as the root. Firstly, throughout the years, the electricity supply from the grid has improved a lot. The urban domestic electricity consumers find it more reliable to rely on the grid supply rather than depending on the solar power. As the electricity generation is increased the load shedding is being cut down. This results in creating unwillingness to use the solar panels. Furthermore, the buildings are now equipped with backup generators for supporting as a backup in case of load shedding. In addition to that, while converting the DC power to AC power through inverters energy loss is being observed. This affects the efficiency factor of the solar homes. Besides, the expenses of the inverters contribute to the unwillingness of using the solar home system in urban areas. Not to mention, the less availability of the DC appliances contributes largely to this problem. Finally, the expenses needed to set up fully working solar homes is quite high. Though, the capital which is invested in the solar home system can be retrieved over the years from the benefits it served, the payback period is not that much radical. These factors work as radical behind developing this problem to this huge extent.

For solving this problem, few suggestions and changes are discussed and applied in this paper. Instead of leaving the rooftop solar panels idle, abandoned and covered with dust, those can be utilized through proper arrangement. To begin with, the common appliances of the apartments such as the staircase lights, the caretaker's room's appliances, garage lights and fans, the water pumps etc. can be powered by the solar power panels generated power. Doing so, cost reduction can be obtained from each month's electricity bills. Furthermore, instead of using the expensive inverters the generated solar DC power can be directly fed to the DC appliances. This concept is discussed in detail in the upcoming chapters. Using DC appliances not only optimize the inverter power loss but also serves the purpose of electricity bill cost reduction as DC appliances tend to use one third of the power compared with AC appliances. In addition to that as the electricity billing cost is being reduced and the appliances cost is also being optimized the money which will be invested in the system can be recovered within a considerably small amount of time.

1.5 Thesis Objective

Bangladesh is a naturally gifted country of renewable energy sources. This country shows some promising opportunity of harnessing solar energy. Our goal is to design and simulate an urban solar home system which will contribute as a remedy to the power crisis and to utilize the non-functional rooftop solar systems. In our system, there are DC lights, DC fans, DC refrigerator, DC water pump and solar cooking stove which are the common electrical appliances in almost every urban apartment. Through the successful implementation of this proposed urban solar home system the power crisis will be reduced. One of the main benefits of this project is usage of DC appliances which tends to save more energy than AC appliances. Furthermore, limited natural resources can be stored and reserved for the upcoming generations.

A modern urban solar home system is designed in such a way so that the DC appliances will get power from the PV panels during day time and during night time the battery bank will provide necessary power to the appliances. In our system, solar panels can harness the solar energy and uses that energy to run the loads. In future, we will add net metering system in this project that will be more beneficial to our citizens. Net metering system is a system where Our citizens can sell the DC current to PDB and get some payment. While calculating cost efficiency including geographical and representation of the cost of this system over the life cycle. Before implementing the system, MATLAB/Simulink software has been used for simulation of the project and so the viability of the system has been assured virtually. A backup system is kept in the project for uninterrupted power supply. A manual switch is there for using the grid connection when all the battery juice is drained up and the sun does not give enough irradiance to produce electricity from the PV panels. Solar energy is a great source of abundant power. It is economically beneficent to the citizens of the city as after the first investment of installing the system, the power what people will get tends to be free of cost.

1.6 Overview of the Thesis Organization

This paper is divided into 6 chapters consisting of the introduction where necessary background information is provided. In the chapter 2, a site survey has been done for gathering the actual condition and real-life scenario of the existing rooftop solar panels in Dhaka city. Followed by the system design and simulation in the chapter 3. In this chapter, the whole system design, working principle, description about the individual components is written. Furthermore, in the chapter 4 the result and analysis are written such as no-load test, variable irradiance test, power consumption test and its effect. The economic feasibility studies and payback calculations are done in chapter 5. In this chapter, financial analysis report is written. The economic feasibility of the system, cost analysis, total expenditure and net worth of the system is presented here. And finally, the paper is being concluded in chapter 6 with areas of improvement and future works to be done in the conclusion chapter

Chapter 2

Real-life Scenario of Rooftop Solar Panels in Dhaka

2.1 Introduction

We know that the government of Bangladesh has created a law to install solar panels in every rooftop of the new apartments in order to get grid connection. They proposed to install a solar system that can generate at least 3% of the total load of the building. It was supposed to be monitored by the PDB whether the apartments are following the rule before giving the grid connection. Therefore, in order to get national grid connection every apartment started to install the solar panels. But the scenario became different after everyone got the national grid connection. Most of the rooftop solar panels are just remaining idle. Even in some cases people get their grid connection after showing a fake solar module to the inspection officer. In this chapter we will be showing the information of some random visited site across Dhaka. All these sites claim that their solar systems are fine but after analyzing their model it was clear that they have not been utilizing their solar panel system properly. Also, some of them do not even have a complete system still got the grid connection.

For gathering thesis related information, we visited 6 apartments located in different parts of Dhaka city. The visited sites are listed below:

1. The Apartment of Mohammadpur, Dhaka
2. The Apartment of Shyamoli, Dhaka
3. The Apartment of 60 Feet, Agargaon, Dhaka
4. The Apartment of Nakhalpara, Dhaka
5. The First Apartment of Faridabad, Old Dhaka
6. The Second Apartment of Faridabad, Old Dhaka

2.2.A. The Apartment of Mohammadpur, Dhaka

The location of this site is opposite of Mustakim, Camp Bazar, Mohammadpur, Dhaka. That is an 8 storied building on an approximately 45 decimal places. In total there are 40 flats in that building consisting of 5 flats on each floor. The people of that place claimed that their whole system is working properly and they have installed every equipment according to given instruction by DESCO. The system was designed by Moon Power Engineer (a firm who sells readymade solar equipment). But the real scenario was different. It was clear by the appearance of those equipment that they are being kept unmaintained and unused. Below, we will be showing their equipment with specification.

<u>Solar Panels:</u>

Figure 2.1: Solar Panels from apartment of Mohammadpur

These solar panels were located at the roof of the water tank of that building. They were placed in three rows consisting four panels in two rows and two panels in the third row. The rating of the solar panels is situated in the backside of the panel but due to high temperature the writings got a bit blurry. Moreover, the panels were covered with a lot of dust which is another sign of the panels not being maintained. The dust on the solar panels reflects that the solar panels are not being used properly. Moreover, the dust contributes to the shading effect of the panels

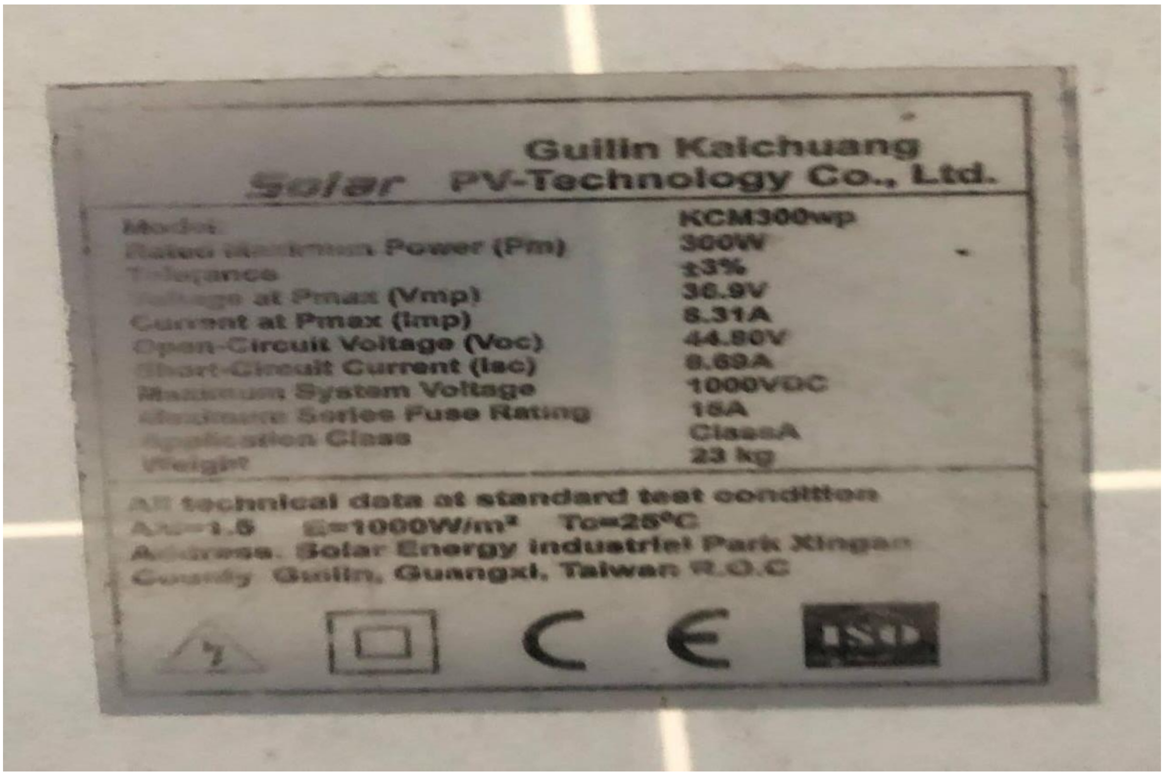


Figure 2.2: Solar Panels rating from apartment of Mohammadpur

which decreases the panel's efficiency. From the picture and the condition of the panels, it is very much clear that the rooftop solar system of this apartment is not working properly.

Solar Panels Ratings:

The rating for each panel is as below:

Model	KCM300wp
Rated Power Pm	300W
Tolerance	±3%
Voltage at Pmax, Vmp	36.9V
Current at Pmax, Imp	8.31A
Open circuit voltage, Voc	44.80V
Short circuit current, Isc	8.69A
Maximum System Voltage	1000VDC
Maximum Series Fuse Rating	15A
Application Class	Class A
Weight	23kg

Table 2.1: Solar Panel Ratings from apartment of Mohammadpur

All the panels were parallel connected. Therefore, the ratings of that array will be as:

Voltage rating = 36.9v

Current rating = (8.31 * 10) = 83.1 A

Power = (36.9 * 83.1) = 3066.39w ~ 3kw

Charge Controller:

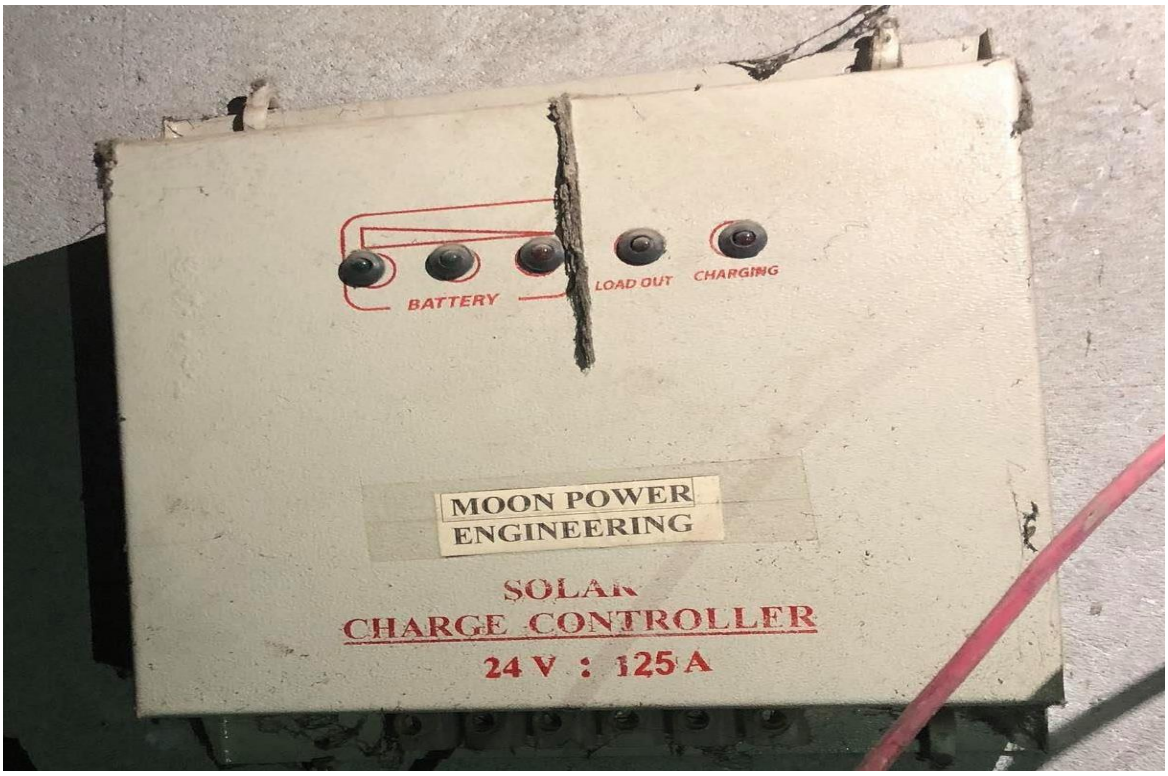


Figure 2.3: Charge Controller from apartment of Mohammadpur

The charge controller that they have used was of 24V and have a capacity of 125A current. Nothing else was written on that box. It would have been better to know the manufacturer and model number of that charge controller. One of the astonishing things about this charge controller was its size. As it had a dimension of 8inch*8inch*3inch. But a 125 A charge controller generally looks bigger than that. Moreover, as the manufacturer name was not mentioned anywhere in the charge controller it is very much certain that it was built by local electricians. Furthermore, the wiring connection was not clear. The house owner mentioned that the cables were connected with the charge controller inside from the wall as it was predesigned when the apartment was built but in real life these wires are connected in a more visible condition. So, the wiring condition was also a blunder.

Inverter:

Figure 2.4: Inverter from apartment of Mohammadpur

This inverter shown by the owner was 24V and 3500VA. No other data was written over this inverter for that reason it was not possible to be sure of its AC module ratings. Furthermore, generally on the inverter the tolerance level, maximum input/output current and voltage ratings, total capacity of loads are mentioned. Surprisingly in this inverter no such data was shown which gives birth to the question that whether or not this equipment works properly. That suspicion soon became very much obvious after seeing that there was no led for indicating the working condition of the inverter. Moreover, the place where it was kept was very dirty along with the inverter itself which proves that they don't utilize or take care of their equipment. The wiring condition was also very much confusing as the input output terminal and the load input terminals were not connected properly. The deeper the analysis was going; the more fake scenario was coming into sight from the system configuration.

Battery:

Figure 2.5: Battery from apartment of Mohammadpur

From the picture it is seen that the batteries are not in a working condition. No battery can work properly with dust loaded on those like this. It is not surprising that these batteries are left at this condition for long time. As the whole system is not working properly the need of batteries is also an absurd idea. That is why these batteries are left in this condition. Each battery has 12v 100Ah Volvo solar power battery. Two of the batteries were being used and the third one was damaged a few days ago of site visit. So right that moment the total battery array had the capacity to support 200Ah and the array was 24 volts as they were in parallel connection. It was hard to believe a working battery in that condition.

Loads:

Figure 2.6: Light bulbs from apartment of Mohammadpur

Figure 2.7: Calling Bell from apartment of Mohammadpur

According to the caretaker and one of the residents of that building the solar system has a load of 47 light bulbs each of 24 watts (16 bulb in the staircase. 1 bulb in rooftop and 30 in garage)

40 calling bells (1 for each flat so in total, 5 flat* 8 floors= 40).

Assumptions and Remarks:

The solar panel array provides 3KW. Assuming this to be the 3% of the total load we can assume the total load of that apartment.

Total load = $\frac{\text{solar panel output}}{3} * 100$

$= \frac{3\text{ kw}}{3} * 100$

= 100 KW

There are 40 flats in this apartment. So individual load of the flats will be = $\frac{100\text{ kw}}{40}$ = 2.5 KW

Therefore, according to that calculation, 3% of that building should have been 2.5 KW.

The solar array produces 83.1A of current. So, the charge controller must have a rating of at least

83.1 + (83.1 X 25%) = 103.88A ~ 105A

The Charge controller and converter that they have used were proper in case of specifications. But the number of batteries that they used were very low. The amount of load that they were supposed to be using is 3KW so the backup system needs improvement as well. For that site the energy being produced by the solar panel is going to waste because they are not being used properly. A 3KW solar panel array like that will hardly need two and half hours to charge both of those batteries. For the rest of the time the solar panel will remain idle. So, that site needs to add more batteries to their backup system for proper utilization of their existing system.

2.2.B. The Apartment of Shyamoli, Dhaka

This site is located in east Shyamoli. It is a 6 floored apartment having 2 flats in each floor. This apartment stands in a 5-decimal space. This building is almost new as the tenants started living just 8 month ago. The solar system of this apartment along with each component is described below.

Solar Panel:

Figure 2.8: Solar Panels from apartment of Shyamoli (upper view)

Figure 2.9: Solar Panels from apartment of Shyamoli (Front view)

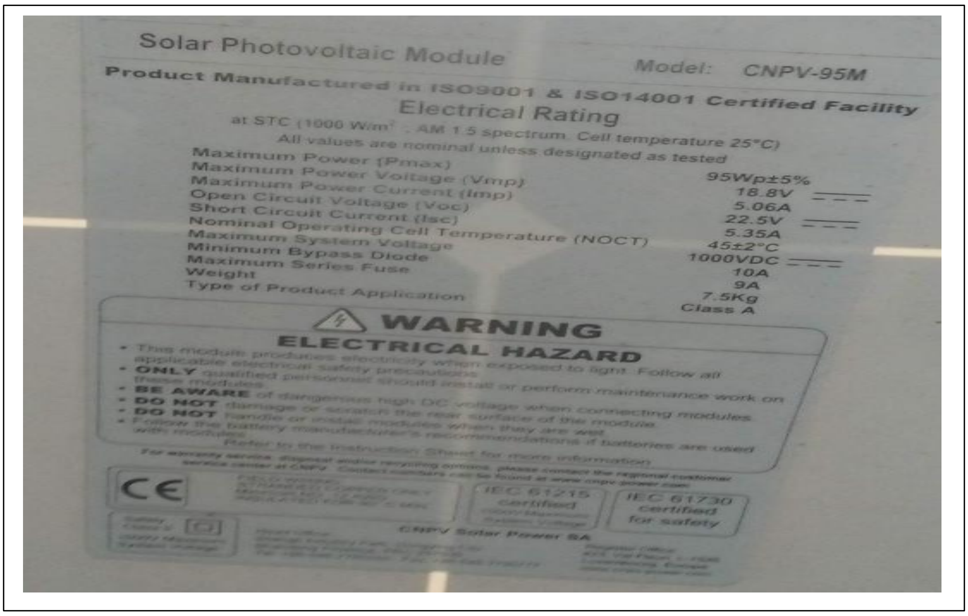


Figure 2.10: Solar Panels Rating from apartment of Shyamoli

The rating for each panel is as below:

Maximum Power P_{max}	95 Wp (±5)
Maximum Power Voltage V_{mp}	18.8V
Maximum power current I_{mp}	5.06A
Open Circuit Voltage V_{oc}	22.5V
Short Circuit Current I_{sc}	5.35A
Nominal operating cell temperature NOCT	$45(\pm2)^0$ C
Maximum System Voltage	1000VDC
Minimum Bypass Diode	10A
Maximum Series Fuse	9A
Weight	7.5kg
Type of product application	Class A

Table 2.2: solar panel rating from apartment of Shyamoli

They have placed the solar panels on the rooftop of the water tank. They have 26 panels in total. Two panels are in series connection and in that way 13 sets were connected in parallel. The specification of each solar panel is as below:

That means the specification of that solar panel array will be as follows:

Voltage rating = 18.8 * 2 = 37.6V

Current rating = 5.06 * 13 = 65.78A

Power = 37.6 * 65.78 = 2473.32W ~ 2.5KW

Charge Controller:

Figure 2.11: Solar Charge controller from apartment of Shyamoli

This is a charge controller by Anirban Company whose model is SN1000. As we can see in this figure that the charge controller has

Rated Voltage - 12v/ 24v

Rated Current- 30A

And it is a microcontroller-based charge controller.

In this charge controller all the wire connections seemed fine but the charge controller. Although the charge controller itself was not connected to the system. The signal bulbs which represent the on/off condition of the charge controller were not working. The major problem of this charge controller is that this has a limit of 30A which is not capable of regulating the 3% load of a building. This type of charge controller is used in rural solar home system which has a very small loads and are connected with a small solar PV arrays such as 500 to 900 watts. So, in the urban solar operation as the loads gets higher this charge controller is not capable enough to withstand the load. As soon as the charge controller is being to the load it is expected that the charge controller will burn out. So, it is very much clear that the charge controller is not working in this apartment so the solar system is expected not to work either.

Inverter:

The caretaker of this building refused to show the inverter while making excuse that it is being kept locked in a separate room and he didn’t have the keys to that room. After finding the reason of not showing the inverter pretty suspicious, we tried to extract some specific information about the inverter. After sometimes of interrogation, the caretaker finally confessed that few months back they have some technical issue in the inverter. After the fault they disconnected the inverter from the system and as a result it was kept separated in a room. As the charge controller was not working and capable with this arrangement and the inverter having technical fault the total solar system of this apartment was kept shut down.

Battery:

The guard of that building told us that the battery was locked in the same room where the inverter is being kept. As none of the equipment of this arrangement were working properly such as the inverter, the charge controllers so, the batteries were even not connected to the system. only the solar PV panels were there to showing off the system. By keeping the inverter and the batteries locked on the other end of the system without connected them, there is no doubt that this system is not working at all. As the system is there as a dummy for getting the electricity connection, we are pretty much sure that they do not even bother to buy the inverter and the batteries. To cover their act, they simply made excuse about keeping the batteries and inverter locked inside a room having no key for it. If they actually had any batteries or inverter, they could have at least show us.

Load:

According to the security guard the solar system is covering 22 light bulbs and 16 fans. In total they have 12 flats in that building. So, a light bulb and a fan of each flat is being powered by the solar system. Also, there are 6 light bulbs in the staircase. Rest of the 4 light bulbs and 4 fans are in the garage and security guard's room. But actually, none of the loads were powered by the solar power rather all of the loads were being powered by the grid AC connection.

Assumption and Remarks:

The solar panel array provides 2.5KW. Assuming this to be the 3% of the total load, we can assume the total load of that apartment.

Total load = $\frac{\text{solar panel output}}{3} * 100$

= $\frac{2.5\text{kw}}{3} * 100$

= 83.35 KW

There are 12 flats in this apartment. So individual load of the flats will be = $\frac{83.35 \text{ kw}}{12}$ = 6.94 KW ~ 7 KW

As the load consumption is very high for each of the flat, the required power from the 3% solar panel gets also very high. Therefore, they did not buy the required equipment rather just buy only the solar PV panels just for showcasing them and get the electricity connection. To work properly with this arrangement, a good charge controller is needed which in this case was not present. The charge controller was not compatible for this arrangement. The rating of the charge controller that they have used is far inferior.

Charge controller actual current rating should be = (13*5.35*1.3) = 90 A

In order to make that charge controller go with the system we can have to use at least a 90A charge controller. Also, it was a shady thing not to be able to show the battery and inverter physically.

2.2.C The Apartment of 60 feet Road, Agargaon, Dhaka

The location of this field is in 60 feet, Agargaon, Dhaka. That is an 8 storied building. There are 24 flats in that building. The solar system of this apartment along with each component is described below.

<u>Solar Panels</u>:

Figure 2.12: Solar Panels from apartment of Agargaon

By looking at the solar panels, the initial impression about those is very much clear that the panels are unused. The condition is similar to the apartment of Mohammadpur described earlier. Both of these apartments are not using the solar panels properly as there were thick layer of dust all over the panels. No panel can produce efficient amount of power with dust loaded all over them. There are a total 28 PV panels connected in series and parallel combination. There were 2 strings of parallel connected PV panels. Each parallel string contained 14 numbers of series connected solar panels. Then these 2 sets of 14 connected series connected solar panels were connected in parallel.

Figure 2.13: Solar Panels ratings from apartment of Agargaon

The rating for each panel is as below:

Model	Sun Gold
Rated Power Pm	150W
Tolerance	± 3 %
Voltage at Pmax, Vmp	17.28V
Current at Pmax, Imp	8.69A
Open circuit voltage, Voc	21.08V
Short circuit current, Isc	9.46A
Maximum System Voltage	1000VDC
Maximum Series Fuse Rating	10A

Table 2.3: solar panel rating from apartment of Agargaon

There are a total 28 PV panels connected in this system. There are 14 PV panels connected in series. Another 14 set of panels are connected in series similarly. Then these 2 sets of series connected PV panels are connected parallel with one another.

Therefore, the ratings of that array will be:

Voltage rating = 17.28*2 = 34.56 V

Current rating = 14*10 = 140 A

Power = 4200 W ~ 4.2 KW

Charge Controller:

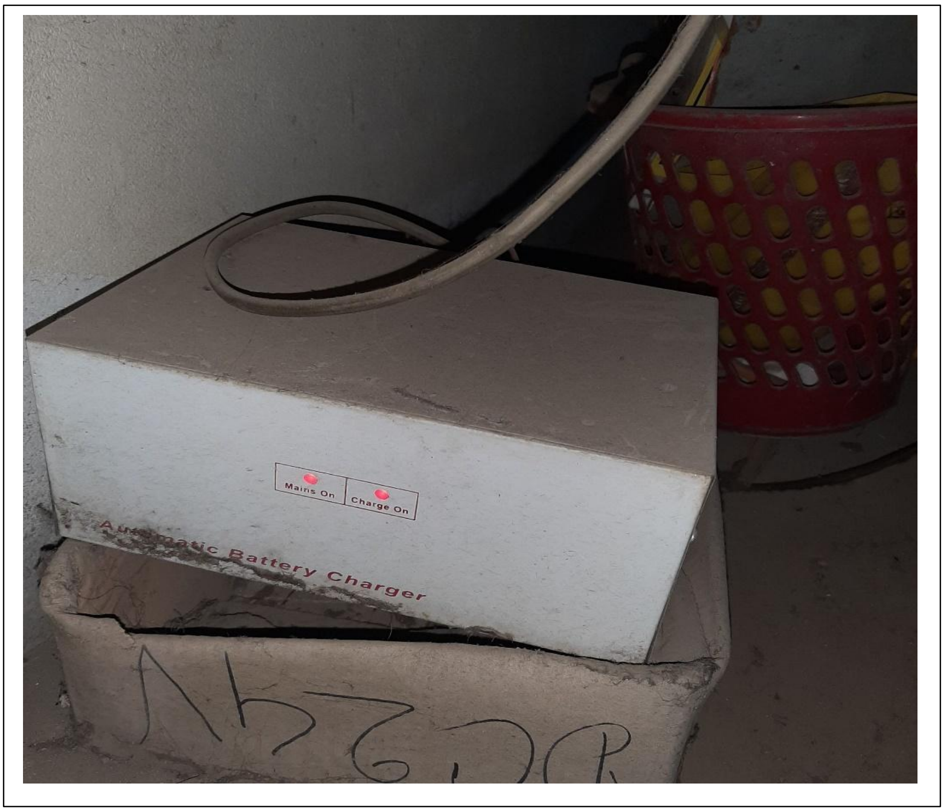


Figure 2.14: Solar Charge Controller from apartment of Agargaon

As seen in the picture, this is not a branded charge controller. There is no specific banding name on top of the charge controller. Furthermore, there is also no specific rating of current and voltage above the charge controller. This raises a great question of compatibility and credibility of the charge controller. This is a huge system providing an output of 4.2 KW. To withstand this much power the charge should have a greater dimension in terms of size but as seen in the picture that is not the case. In addition to that, the mounting condition of this charge controller is another sign of great unprofessionalism. It has been mounted on a fragile paper cardboard which has already been bended by the weight of the charge controller. The dust on top of the charge controller also adding much more suspicion about the working condition of this device. To work properly and for casting out the electrical hazard this device needs proper maintenance which is not done in this case. The insulation and safety operation backups such as circuit breaker were also missing. After talking with the caretaker of the apartment we came to know that this charge controller was actually made by a local electrician who has no professional expertise in this area. After seeing this kind of scenario, it is not a hidden fact anymore that this solar system is actually playing a role as a decoy to the fraud rather than serving the actual purpose.

Battery:

Figure 2.15: Battery from apartment of Agargaon

The batteries of this apartment are also not in a working condition. Furthermore, the batteries are completely isolated from the rest of the system. the battery bank is not connected to the charge controller. In addition to that, the required battery capacity to run the system successfully is not satisfied. As a result, they had thrown away the batteries and kept them beside generator. This reflects great act of unprofessionalism. Any kind of electrical hazard can occur at any time and compromise the total building security. There were two batteries each having the capacity of 12v 100Ah.

Inverter:

Their system has no inverter which was absurd. According to them they were running AC loads which is impossible without an inverter in their system. But they had always avoided talking to us in this matter. There were no inverters present in this apartment for solar system which makes it very much clear that they were not utilizing the solar system at all. As a result, there was dust all over the PV panels.

Load:

According to one of the residents of that building the solar system has a load of total 588 watts. But none of the loads were connected with the solar system.

12 light bulbs each of 24 watts = 288 watts

4 ceiling fans each of 75 watts = 300 watts

Total = 588 watts

Assumption and remarks:

The solar panel array provides 4.2 KW. Assuming this to be the 3% of the total load, we can assume the total load of that apartment.

Total load = $\frac{\text{solar panel output}}{3} * 100$

= $\frac{4.2\text{kw}}{3} * 100$

= 140 KW

There are 24 flats in this apartment. So individual load of the flats will be = $\frac{140\text{ kw}}{24}$ = 5.83 KW

It is clear by their system design that they were not following the government rules, instead they installed the system only to get the grid connection. After getting that they simply put their system in idle. None of the component of this system is bought and connected like the way it should be. For example, the actual charge controller rating should be 24 V, 130 A. Another serious violation of government rule is according to their PV installation calculation, they were supposed to produce 4.2 KW as their entire power consumption is 140 KW. But in reality, they are only using 588 watts of power from the solar which is ridicules. Only if they could actually produce the solar power through PV panels, they would have used and utilized more and more of that energy for powering their common appliances for saving the expenditure. We can see from the photos that the solar panels are very dusty which compromises the efficiency of the solar panels. Also, it proves that they are not maintaining their solar panels properly and the whole actual scenario is very much clear now.

2.2.D The Apartment of Nakhalpara, Dhaka

We started to explore East Nakhalpara, Tejgaon, Dhaka. In that area, apartments with rooftop solar panels are very rare to find because everyone is using generators as backup sources for load shedding. They got the electricity connection without implementing 3% of the solar home system in the apartment. They don’t even know about it. So, after searching a lot, we found an apartment in samiti bazar which was 10 storied and had 2 flats on each floor. The apartment which was newly constructed. The solar system of this apartment along with each component is described below.

Solar Panels:

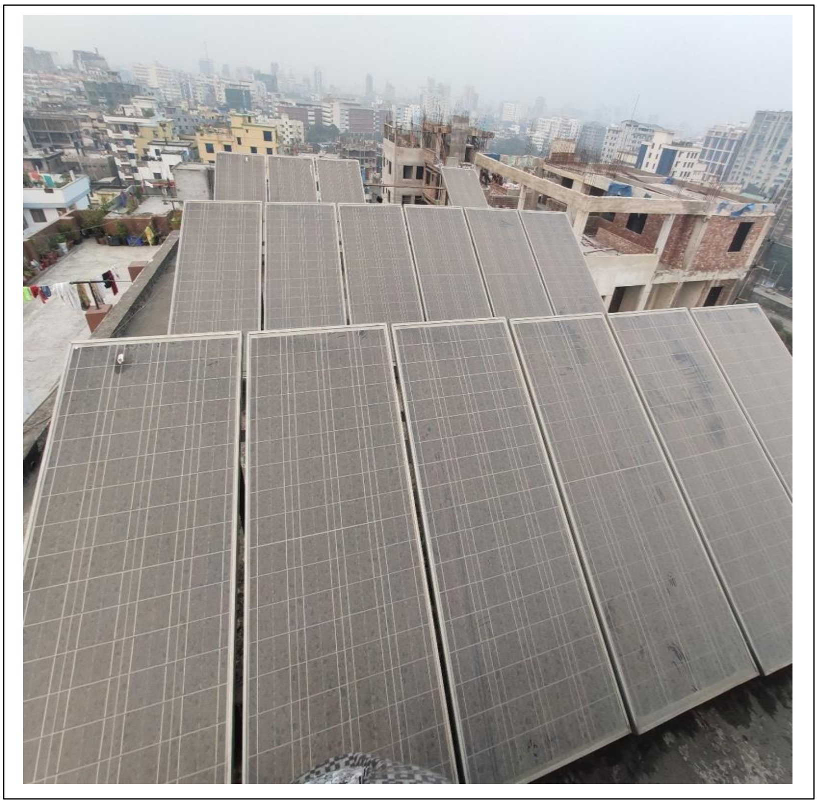


Figure 2.16: Solar Panels from apartment of Nakhalpara

As seen in the picture, the solar panels are very much dusty. It is very much clear that the panels are not being used for a long time. The dust over the panels dignifies that these solar panels are not being used and also, they did not spend any money or effort for maintenance of these solar panels. In order to get the electricity connection from the national grid they only put some dummy solar panels over the roof.

Figure 2.17: Solar Panel rating from apartment of Nakhalpara

The ratings of the solar panels are given below:

Model	Sun Gold
Rated Power Pm	250W
Tolerance	±3%
Voltage at Pmax, Vmp	30.5V
Current at Pmax, Imp	8.19A
Open circuit voltage, Voc	36.6V
Short circuit current, Isc	8.68A
Maximum System Voltage	1000VDC
Maximum Series Fuse Rating	20A

Table 2.4: solar panel rating from apartment of Nakhalpara

There was total 18 solar panels on the roof. There were 3 parallel strings each containing 6 numbers of series connected solar panels. Therefore, the ratings of that array will be:

Voltage rating = 30.5*3 = 91.5v

Current rating = 8.19 * 6 = 49.14A

Power = 250W * 18panel= 4.5 KW

Charge Controller:

According to the configuration of the solar panel, there should be a charge controller which can hold at least 60A of current in order to distribute the electricity among the loads. But the real scenario is different. There was no charge controller connected with solar panels which is a very shocking scenario. They only installed the solar panels according to the estimation given by DESCO. They somehow managed to get the grid electricity just by showing the panels. According to flat owner appearance it can be said that they bribed the inspection members who came to check the system when it was built.

Inverter:

There was no inverter present in the system. This is very much obvious as none of their components of the solar system was in a working condition rest of the components were not even present in the system. Only if the system was working, they would have needed a good quality inverter. As the sole purpose of those dummy PV panels was to only get the grid connection, they did not buy the rest of the components such a charge controller, inverter and even batteries.

Battery:

There was no battery in the solar system. After asking questions about the batteries the caretaker shamelessly answered that they did not even buy the batteries same as the charge controller and inverter.

Loads:

No loads were connected with the solar system. All of the loads of that apartment were being powered with the national grid connection. They not only violated the imposed rule about 3% power generation but also applied an unethical way for getting the national gird connection.

<u>Assumption and remarks:</u>

The solar panel array provides 4.5 KW. Assuming this to be the 3% of the total load, we can assume the total load of that apartment.

Total load = $\frac{\text{solar panel output}}{3} * 100$

= $\frac{4.5\text{kw}}{3} * 100$

= 150 KW

There are 20 flats in this apartment. So individual load of the flats will be = $\frac{150\text{ kw}}{20}$ = 7.5 KW

As the apartment was 10 stored. Each floor has 2 units of apartment, in total 20 units of apartment were there. According to load calculation, each flat consumes 7.5 KW power from the grid. So, in 20 flats, altogether they consume around 150KW power. According to the government policy in order to get the electricity, every building has to install 3% solar panels of the total power consumption. So, they should install a system of solar panels which can cover at least 4.5 KW power consumption. But in reality, they did not cover even a single watt. Another important demerit is without solar panels, they didn't install inverters, charge controllers, batteries in the system which was not desirable at all. So, the authorities should take proper steps in order to remove this kind of fraud system to eradicate the corruption in the power industry.

2.3 Sites with Net Metering

Among the 6 apartments visited by us for gathering actual field information, 2 of the sites has net metering facility. Net metering is an electricity billing mechanism which allows consumers who generate some or all of their own electricity by using solar power or wind power, to use that electricity anytime, instead of when it is generated. Moreover, the electricity which is surplus after consumption can be sold to the government. 2 of the apartments we visited at Faridabad, Old Dhaka were using net metering. Detail findings of those 2 apartments are written below.

2.3.A The First Apartment of Faridabad, Old Dhaka

This site is located in Faridabad, Old Dhaka. It is an 8 floored apartment having 4 flats in each floor. The net metering system of this building was new. The caretaker and building owner said that they had installed the system 8 months ago. The solar system of this apartment along with each component is described below.

Solar Panels:

Figure 2.18: Solar Panel from first apartment of Faridabad (upper view)

Figure 2.19: Solar Panel from first apartment of Faridabad (side-view)

Figure 2.20: Solar Panel rating from first apartment of Faridabad

The ratings of the solar panels are given below:

Model	Sun Gold
Rated Power Pm	250W
Tolerance	±3%
Voltage at Pmax, Vmp	30.5V
Current at Pmax, Imp	8.19A
Open circuit voltage, Voc	36.6V
Short circuit current, Isc	8.68A
Maximum System Voltage	1000VDC
Maximum Series Fuse Rating	20A

Table 2.5: solar panel rating from first apartment of Faridabad

There are parallel connected 6 rows of PV panels each having 5 series connected PV panels. They are connected in series. So, there are total 30 PV panels in the rooftop of this apartment. Each PV panel has Wp of 250Watts.

That means the specification of that solar panel array will be as follows:

Voltage rating = 30.5 * 5 = 152.2 V

Current rating = 8.19 * 6 = 49.14 A

Power = 250 * 30 = 7500 Watts = 7.5KW

<u>Inverter:</u>

They are using this inverter to convert the DC current to AC current. They used the Grandniow solar inverter which is very efficient for converting this DC power to AC power. After converting the DC power to AC, it is used in powering the AC loads in the apartment and rest of the unused power is sold to the PBD. From Inverter to loads there are circuit breakers for safeguarding electrical hazards such as short circuits, electrical arcs, irregular voltage tripping.

Figure 2.21: Solar Inverter from 1st apartment of Faridabad (Front view)

Figure 2.22: Solar Inverter from 1st apartment of Faridabad (Back view)

the specification of the inverter is given below:

Maximum DC Power	1.5KW
DC maximum input voltage	500V DC
DC operating voltage range	100-500V DC
DC MPPT voltage range	100-450V DC
Max DC power	4400 W
DC nominal operating voltage	360V DC
AC maximum frequency	50HZ
AC max output power	4000W
AC nominal output power	4000W
DC input voltage	1000V
Dc Maximum power	4400W
Maximum efficiency	97.5%
Rated AC voltage	230V

Table 2.6: Inverter specification from 1st apartment of Faridabad

Battery:

There was no battery in this system. As they are using AC loads and at time when solar power is unavailable, the national grid power is used no batteries seen in the system.

Meter:

The net meter is connected to measure the net electricity being produced, used and sold to PBD. As mentioned above, the extra power which is not consumed by the apartment loads is being sold to PDB. For measuring purpose, the meter is being connected with the system.

Figure 2.23: Meter from 1st apartment of Faridabad

Loads:

As load they are using 8 staircase lights and 2 lights in the garage. These light bulbs are getting power from the solar system. For such an expensive system the total load connected seems very much negligible. The system can produce 7.5 KW of energy but it is powering only 10 lights with that much power. After gathering the information from the building caretaker and from own experience each of the light was 24 watts AC light bulbs.

So, total load is (24 * 10) = 240 watts.

Figure 2.24: Staircase light from 1st apartment of Faridabad

Assumption and Remarks:

The solar panel array provides 7.5 KW. Assuming this to be the 3% of the total load we can assume the total load of that apartment.

Total load = $\frac{\text{solar panel output}}{3} * 100$

$= \frac{7.5 \text{ kw}}{3} * 100$

= 250 KW

There are 32 flats in this apartment. So individual load of the flats will be = $\frac{250 \text{ kw}}{32}$ = 7.81KW

Therefore, according to that calculation, 3% of that building should have been 7.81 KW. But this data is not reliable. Furthermore, by adding this much panel on the rooftop, the owner is only 240 watts as the 3% load. The whole system is fraud.

With that much power a building not only can manage it's 3% power consumption but also sell the unused power and get a handsome amount of bill reduction if net metering is properly used.

Furthermore, the building owner said that total cost of this installment is total 6 lakh taka. According to the owner, in winter season this system can store on average 6 KW/h electricity per day. So, in 1 month it can produce = 6KW/h * 30 =180 KW/h per month

Now if we do payback calculation, per unit of electricity cost for residential consumers is 8.42 tk.

In 1 month, the owner is getting 8.40*180= 1,512 BDT worth of electricity

At this rate it will take 30 years to get back the installation cost. But the lifetime of solar panels are 25 years. So, ultimately this system is not at all economically feasible.

2.3.B The Second Apartment of Faridabad, Old Dhaka

This site is located in Faridabad, Old Dhaka. It is a 9 floored apartment having 4 flats in each floor. The net metering system of this building was new. The solar system of this apartment along with each component is described below.

Solar Panels:

Figure 2.25: Solar Panel from second apartment of Faridabad (upper view)

Figure 2.26: Solar Panel from second apartment of Faridabad (lower-view)

The ratings of the solar panels are given below:

Model	Green Touch
Rated Power Pm	250W
Tolerance	± 3%
Voltage at Pmax, Vmp	34.23V
Current at Pmax, Imp	8.91A
Open circuit voltage, Voc	36.6V
Short circuit current, Isc	9.10A
Maximum System Voltage	1000VDC
Maximum Series Fuse Rating	20A

Table 2.7: solar panel rating from second apartment of

Figure 2.27: Solar Panel rating from second apartment of Faridabad

There are parallel connected 5 rows of PV panels each having 5 series connected PV panels. They are connected in series. So, there are total 25 PV panels in the rooftop of this apartment. Each PV panel has Wp of 250Watts.

That means the specification of that solar panel array will be as follows:

Voltage rating = 34.23 * 5 = 172 V

Current rating = 8.91 * 5 = 44.55 A

Power = 250 * 25 = 6250 Watts = 6.25KW

Inverter:

They are using this inverter to convert the DC current to AC current. They used the Grandniow solar inverter which is very efficient for converting this DC power to AC power. after converting the DC power to AC, it is used in powering the AC loads in the apartment and rest of the unused power is sold to the PBD. From Inverter to loads there are circuit breakers for safeguarding electrical hazards such as short circuits, electrical arcs, irregular voltage tripping. The inverter converts the DC to AC. The Inverter was connected with the meter and a Circuit breaker. According to the Electrician of that building from the last month bill they supply 150KW to the PDB.

Figure 2.28: Solar Inverter from 2nd apartment of Faridabad (Front view)

Figure 2.29: Solar Inverter from 2nd apartment of Faridabad (Back view)

the specification of the inverter is given below:

Max. DC Voltage	450 V	450 V
Max. DC Current	9 A	10 A
MPP(T) Voltage Range	180–450 V	180–450 V
Connectors	MC4	MC4
Output Data (AC)		
Max. AC Power	1 kW	1.5 kW
Output AC Voltage Range	190–270 V	190–270 V
Rated AC Voltage	230 V	230 V
Max. AC Current	4.5 A	6.8 A
Frequency	50, 60 Hz	50, 60 Hz
Power Factor (cosθ)	1	1
Distortion (THD)	< 3.5 %	< 3.5 %
No of feed-in phases	1	1
Max. Efficiency	97.5 %	97.1 %
Euro Efficiency	96.5 %	96.1 %

Figure 2.30: Inverter specification from 2^{nd} apartment of Faridabad

Battery:

There was no battery in this system. As they are using AC loads and at time when solar power is unavailable, the national grid power is used so no batteries seen in the system.

Meter:

The net meter is connected to measure the net electricity being produced, used and sold to PBD. As mentioned above, the extra power which is not consumed by the apartment loads is being sold to PDB. For measuring purpose, the meter is being connected with the system. The net metering connection was setup in the apartment in such a way that it can shows the total KW/h produced in one month. Total converted AC electricity was sent to the grid. The Grid will do the measurement and give them a total report of one month produced electricity. According to their information the Meter is switched off for the electricity repairing case. They informed me that they will repair the connection as soon as possible to work it fine.

Figure 2.31: Meter from 2nd apartment of Faridabad

Figure 2.32: Meter from 2nd apartment of Faridabad (night view)

Loads:

They did not connect any loads from their solar power. Their main target was to sell the solar electricity to PGCB or PDB.

Assumption and Remarks:

They claimed that in winter season this system can store on average 5 KW/h electricity per day. Furthermore, the building owner said that total cost of this installment is total 5 lakh taka, where the cost of solar panel is 4 lakh taka BDT and inverter cost is 80,000 taka and installation and other expenses were included.

So, in 1 month it can produce = 5KW/h * 30 =150 KW/h per month

Now if we do payback calculation, per unit of electricity cost for residential consumers is 8.42 tk. In 1 month, the owner is getting 8.40*150= 1260 BDT worth of electricity. At this rate it will take 30 years to get back the installation cost. But the lifetime of solar panels are 25 years. So, ultimately this system is not at all economically feasible.

2.4 Conclusion

The actual working rooftop solar system are very rare. From our site visit experience and report from the visit it is seen that among 6 sites none of the sites are working as suppose they should work. The building owners are not willing to set-up the actual system for various reasons. As a result, the unutilized idle solar panels end up as e-waste. None of the 6 sites we visited had all the required components. Some owners are unwilling to buy expensive inverters, some are using only dummy panels and what not. Every site we visited had one thing in common and that is they do not involve any kind of maintenance of the existing system. In the past few years, grid system has gone through some remarkable development. Furthermore, these days the backup generator is providing the necessary power in the load shedding hours. As a result, the owners are very much not willing to implement the idea of harnessing solar energy by using rooftop solar panels. In addition to that, the whole system cost is relatively high than other substitutes in this field. Generally, the net metering sites which we visited had the longest payback time of expenditure. although the total system was just an approach to get grid connection in the apartment, the high payback time problem always crosses an owner's mind even if someone is willing to implement the system. Also, the conversion process from DC to AC involves energy loss. As long as these issues are not fixed, the building owner will never be willing to implement rooftop solar system.

Chapter 3

System Design and Simulation

3.1 Introduction

Bangladesh has potential to harness solar energy and utilize it to reduce power crisis. In Dhaka city there are solar panels in almost every rooftop apartment. However, most of them are not working properly. Our goal was to design and implement such an urban solar home system which will work properly, efficiently and will provide benefits to the apartment owners so that every apartment which has existing rooftop solar panels on them can work to its full potential. Keeping this in mind we designed and simulated an urban solar home system which consists of solar panels, MPPT charge controller, batteries, DC power supply, and DC loads. This urban solar home project can successfully power up the 3% common load of an urban home. That means we will be dealing with a higher number of loads and a complex system. So, we must choose the components that we will be using very carefully so that they can withstand the required current and voltage. Various types of components serving different purpose are required to work together to run our desired system successfully. In this chapter, we will be elaborately discussing the interface of the components in this system. Also, with the help of the simulation tool (MATLAB/ Simulink) we will be simulating this system in our desired way.

3.2 Design of the Proposed System

The sole purpose if this system is to extract solar energy, supply it to the loads as well as keep storing energy for later use and have a secondary energy source as a backup for the whole system. PV solar panels are used to extract solar energy from the sun. An MPPT charge controller is used to extract maximum power from the sun and charge the batteries with a regulated voltage and current. While PV panels gets efficient irradiance and temperature, the energy which is harnessed by the panels are feed directly to the DC Loads and rest of the power is use to charge the battery bank. Common appliances such as fans, lights, cooking stoves, water pump and refrigerator are used as the load for this project. Grid connection is kept as a backup in this system in case of gloomy weather when solar irradiance will not be sufficient enough.

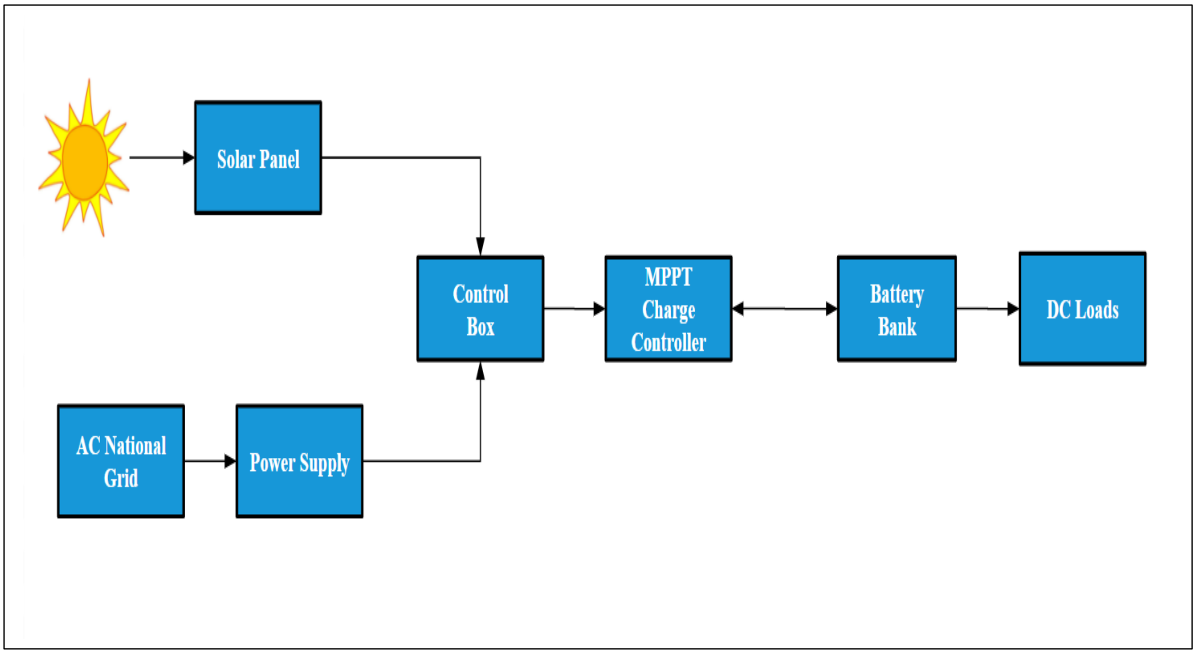


Figure 3.1: System Block Diagram

3.3 Working Principle of the System

In this section, working principle of the proposed system will be discussed. The urban solar home system which we designed has 3 main sections. First one is source, then the energy storage system and finally the output. Solar energy is the main energy source of this system. However, in the gloomy days or rainy season when the solar energy is not sufficient enough, grid power is brought into exercise as the backup energy source. After extracting the energy, a portion of that is used to charge the batteries and rest of the energy is used to power the loads.

There are in total 12 PV panels; each having maximum power of 200 Wp. These 12 panels are connected in such a manner so that voltage and current requirement is fulfilled. There are 2 series connected modules and then 6 of them are connected parallelly. From these solar panels solar power is being harnessed. Then this power is used to charge the batteries. But for charging the batteries with a regulated voltage and current for optimizing the battery health, MPPT charge controller is connected. This device tracks the maximum power point from the PV and IV graph and ensures maximum efficiency. Furthermore, it also keeps the battery charging current and voltage within a regulated range. After that the loads are being added with the 48 V battery bank. When the solar irradiance is sufficient, the loads will get power directly from the solar panels and rest of the power will be used to recharge the battery. But in case of low solar irradiance, the loads will get power from the battery bank.

Moreover, sometimes, we might not get enough solar irradiance for a longer time. At that moment the battery will require backup power to run the loads. A grid connection is present in the system as a backup. There is a converter in the power supply box which converts the whole AC 220V 50Hz electricity to the DC 48V electricity. The solar panels and national grid cannot work at the same time, rather only one can supply power. For this arrangement, a control box is connected before the charge controller so that it can take input from only one source at a time. A manual switch is there for the operation and switching the input sources. In this way the whole system is being operated.

3.4 Description of the Individual Components

In this section we are going to describe about the individual components which will be used in this project. In this project, we have used solar panels to extract solar energy. Batteries are used to store the energy. For backup source, national grid connection and power supply box is used. MPPT charge controller is there for better efficiency. Common electrical home appliances such as fans, lights, cooking stoves, water pump and refrigerator are used in this project as loads.

3.4.1 PV Panel

PV panels or solar panels are semiconductor based electrical device that converts sun light energy to electrical energy through the process of photovoltaic effect. The main material in PV panels is silicon. Solar panel plays very important role to the whole system because the efficiency of the panels has great impact over the total efficiency of the project. In this project simulation we have used 215Wp Soltech solar panels. The proposed system of this project is a 48V, 20 A system. For that reason, the solar panels must provide 48V and 20A constant supply. The total solar panel array should provide at least 4956Wh/day in order to fulfill the load demand.

So, if we connect 12 panels where each panel having 215W capacity then, Total energy we need from the panel = 4968*1.3 (System loss) = 6458Wh/day.

Total watt-peak from PV panel = 6458/panel generation factor

= 6458/4

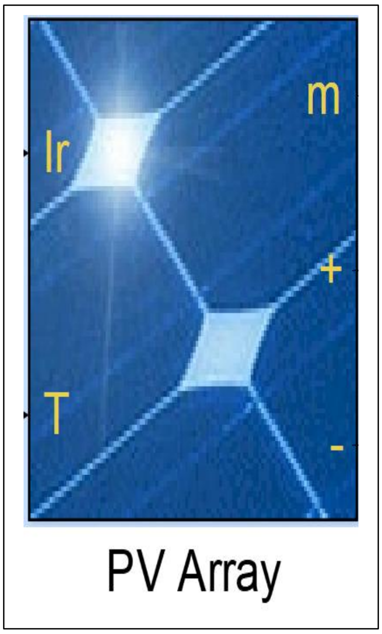
= 1615Wp.

Number of panels needed = 1615/ power rating of solar panel

= 1615/215= 7.5

In case of future load expansion, we are considering 12 panels in our system.

The solar panels have 2 inputs in the simulation. One is solar irradiance; another one is temperature. The solar irradiance data is collected from the final report of solar and wind energy resource assessment (SWERA) – Bangladesh. And the temperature data is from the “weatherspark.com”. Both of these data sets are very reliable.



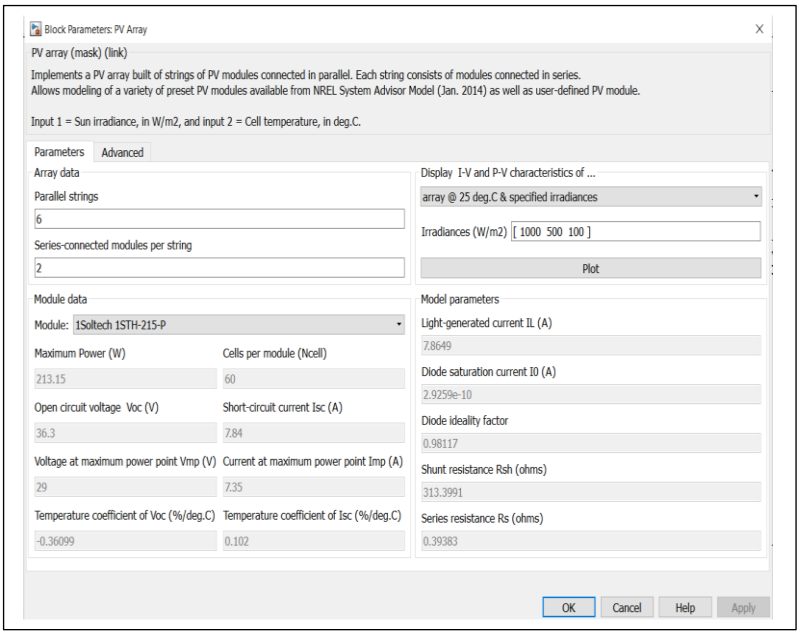


Figure 3.2: Solar Array in Simulink

Figure 3.3: Solar Array specifications in Simulink

3.4.2 MPPT Charge Controller

The MPPT (maximum power point tracking) charge controller serves a very important role in this project. As the solar irradiance varies greatly time to time depending on seasons and weather and also even hourly basis, the voltage and current it produces is inconsistent. If the voltage coming from the solar panels are more than the battery voltage or if due to bad weather the solar panels are not producing enough voltage and current to charge the battery then the battery health deteriorates very quickly. The MPPT charge controller prevents battery from getting damaged and also charges the batteries in efficient way. It tracks maximum power point from the PV and VI graph for maximum efficiency.

MPPT charge controllers work efficiently compared with other charge controllers because it can boost the voltage when solar irradiation is not enough to charge the batteries. Also, at times when panels produce higher voltage than the battery charging voltage limit, it bucks or steps down the voltage. First the MPPT block sense voltage and current from the PV panels. So, the input of this MPPT block will be current and voltage data from the PV panels. The output of this block will be duty ratio. The duty ratio will then be compared with the carrier signal to produce pulse width modulation signal. The signal will be then feed to the gate terminal of the MOSFET, the gate will act like a switch. The MPPT charge controller code is attached below:

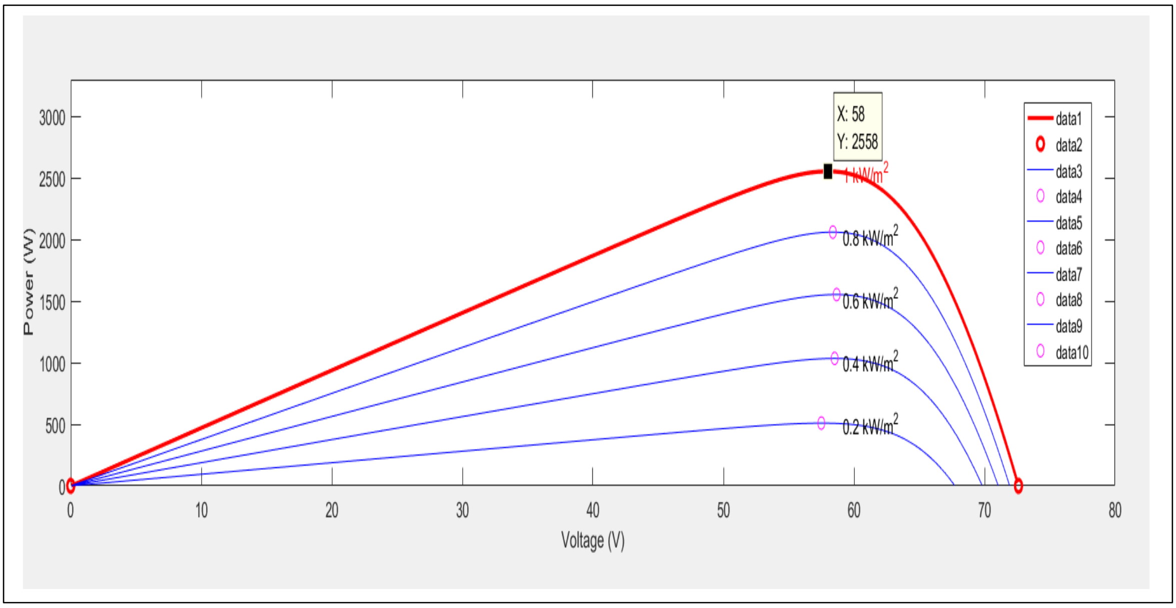


Figure 3.4: Maximum power tracking point

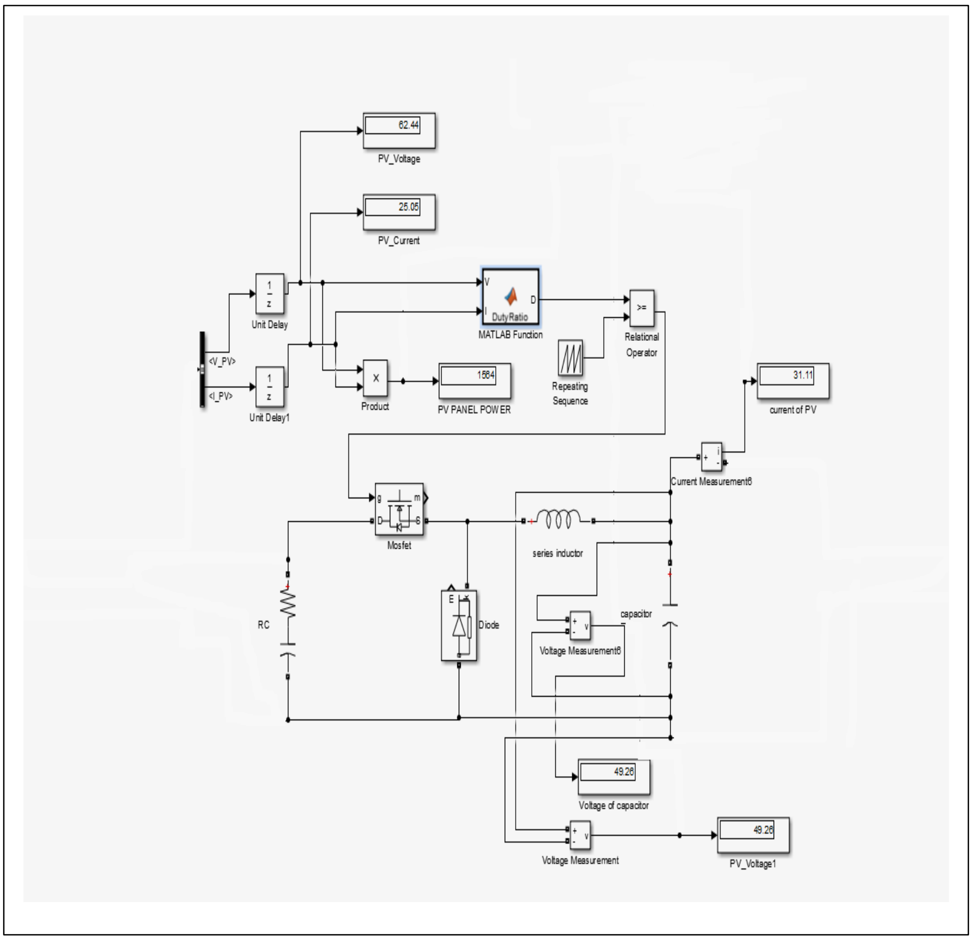


Figure 3.5: MPPT Charge Controller Block

MPPT Charge Controller Function block code:

```
function D = DutyRatio (V,I)
Dmax = 0.95;
Dmin = 0;
Dinit = 0.95;
deltaD = 0.00001;
persistent Vold Pold Dold;
dataType = 'double';
if isempty(Vold)
    Vold = 0;
    Pold = 0;
    Dold = Dinit;
```

```
end

P= V*I;
dV = V-Vold;
dP = P-Pold;

if dP ~= 0
   if dP<0
      if dV<0
         D = Dold - deltaD;
      else
         D = Dold + deltaD;
      end
   else
      if dV<0
         D = Dold + deltaD;
      else
         D = Dold - deltaD;
      end
   end
else D = Dold;
end

if D>= Dmax || D <= Dmin
   D = Dold;
end

Dold = D;
Vold = V;
Pold = P;
```

3.4.3 Battery

The batteries are connected with the charge controller. The arrangement is in such a way so that it shares the load power with the solar panel. When the appliances are on, one portion of the load current comes from the battery & the rest of the current comes from the solar panel. When the load is off, the PV panel charges the batteries.

Battery Specification:

48v battery & total power is 964W

So, battery have to supply,

P=V*I

964=48*I

Therefore, I= 20A

20A current will need to feed the load from the battery

We determined the battery size by doing the following calculation,

$$\text{Battery size} = \frac{\text{Total power consumption} * \text{Days of autonomy}}{\text{Depth of discharge} * \text{Efficiency} * \text{voltage of the battery}}$$

$$\text{Battery size} = \frac{4968 * 2}{0.6 * 0.85 * 48}$$

Battery size =400 AH

Current needed from the panel to charge the battery = total battery size * $\frac{1}{10}$ th of the battery size

Current needed from the panel to charge the battery = (400* $\frac{1}{10}$) A

Current needed from the panel to charge the battery = 40 A

We will use 48V 400AH Renewable Energy Lead acid Battery. The total amount of our battery will be 16. Arranging these 16 batteries in series and parallel connection we will get 48V 400AH.

In MATLAB, the total battery bank is represented with the one battery. In the MATLAB interface, the battery is configured as the calculation is done.

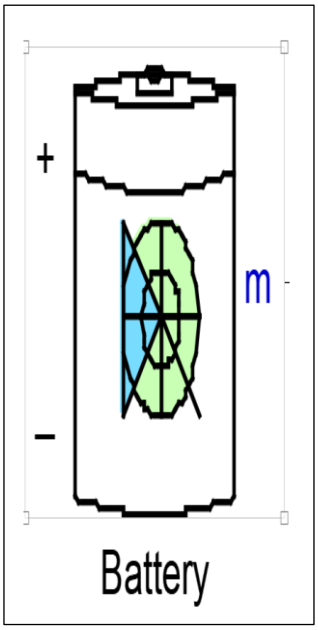


Figure 3.6: Battery Block

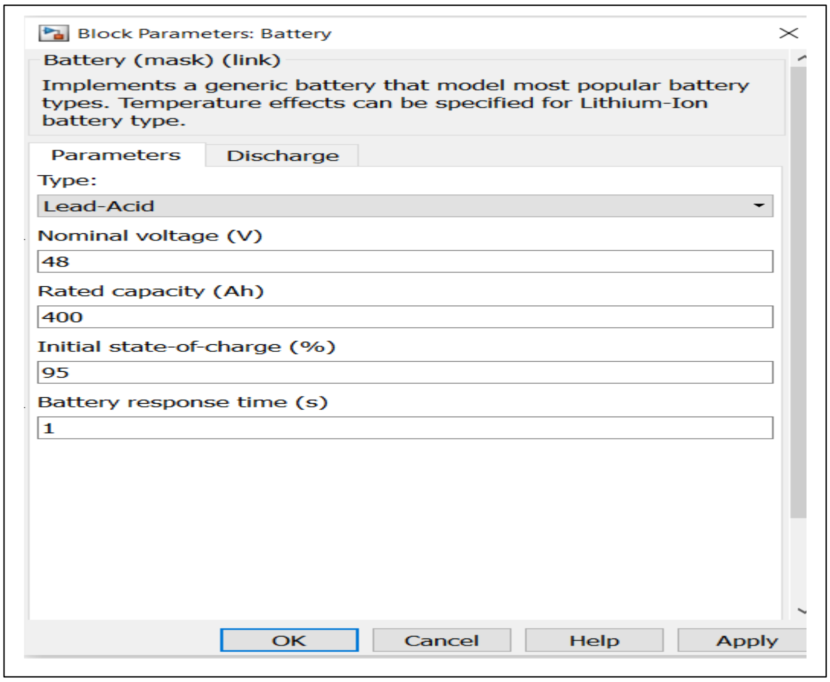


Figure 3.7: Battery Block Specification

3.4.4 Loads

We designed this project in such a way so that maximum cost reduction can be possible. In Bangladesh, most of the roof top solar panels remains unutilized because of the expensive inverter which converts solar DC power to Ac power and feed the appliances. In order to avoid that expense, we chose to use the DC power and DC appliances. This can be the ultimate motivation of urban citizens to use their idle solar panels and harness solar energy. We have used the 5 most essential appliances of every home. They are DC Light, DC Fan. Solar Water Pump, Solar Cooking Stove and Solar Refrigerator.

Name of The Appliances	Voltage (V)	Current (I)	Power (in watt)	Quantity	Power Consumption	Duration (Hours)	Power consumption (Wh/day)
DC Lights	12	1	12	12	144 watts	12	1728
DC Fans	12	1.6	20	4	80 watts	12	960
DC Water Pump	48	4.37	210	1	210 watts	2	420
DC Cooking Stove	48	10.5	500	1	500 watts	3	1500
DC Refrigerator	48	0.62	30	1	30 watts	12	360
Total			772	19	964 watts		4968 (Wh/day)

Table 3.1: Load Summery Table

3.4.4.A. DC Light

In this project, we used 12V DC LED lights. The name of the model we intimated in the project is Ensysco LED. The operating voltage of this LED is 12 volts. It consumes 1-amp current. The power consumption is 12 watts. This LED glows bright with 1080 luminosity which is high enough to illuminate any standard 100 square feet space. In below we can see the array of the DC lights. We have represented the DC bulbs with the diodes.

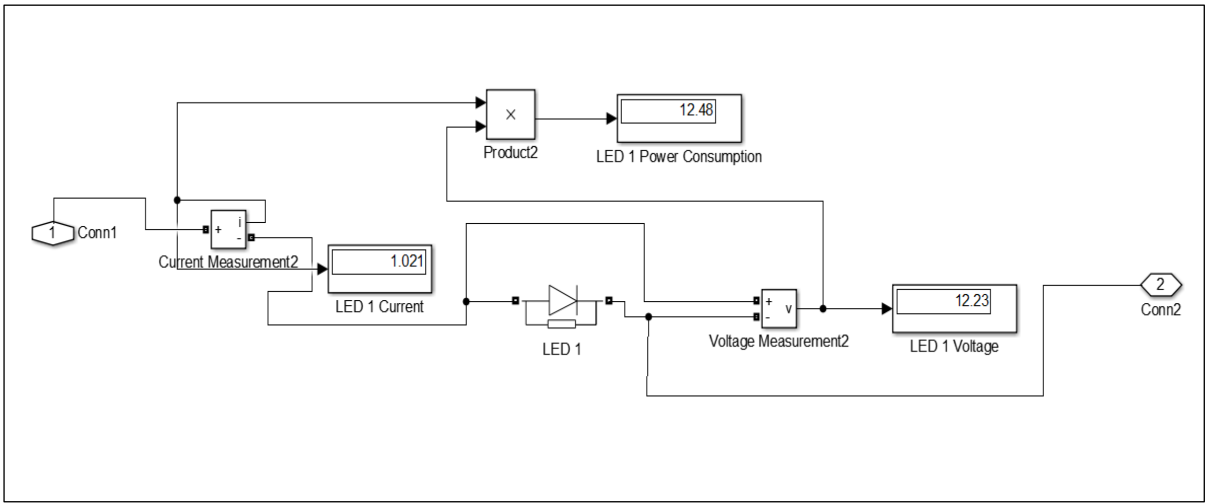


Figure 3.8: Simulation Block DC Light

Figure 3.9: DC Light (Actual)

3.4.4.B. DC Fan

A general DC motor from the Simulink library is used to represent the motor of the ceiling fan. The operating voltage of the fan is 12 volts and it requires 1.6 amps current. The power consumption of this unit is 20 watts. The actual model which we intimate is Ensysco Solar ceiling fan.

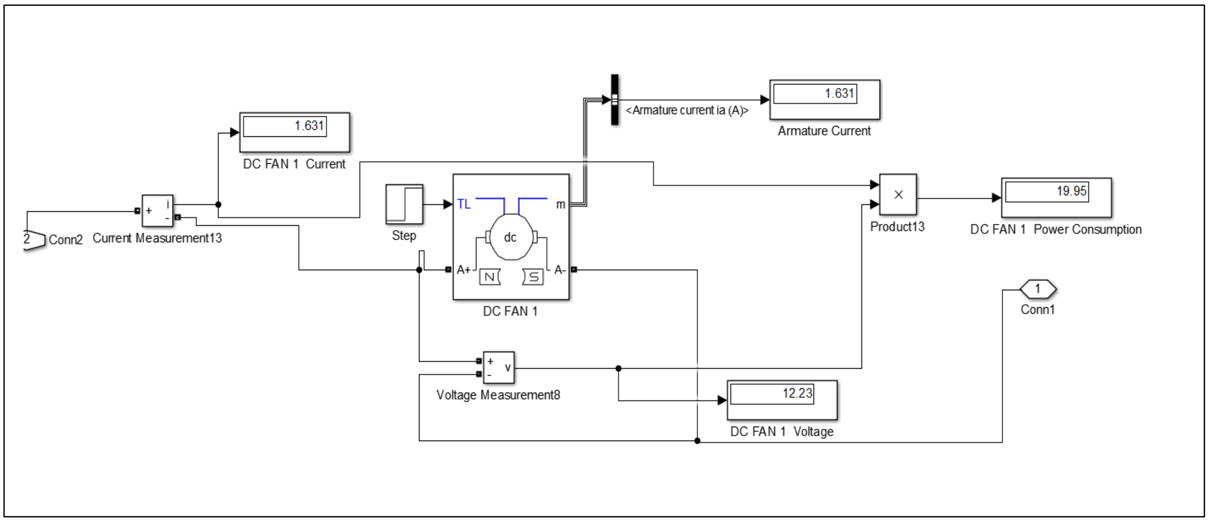


Figure 3.10: Simulation Block DC Fan

Figure 3.11: DC Fan (Actual)

3.4.4.C. DC Water Pump

This is a solar power water pump which runs with DC voltage and current. This pump is capable to push water upto25 meters by having a 25-meter water head. The name of the company is PNG Solar. The model of this water pump is SQB2.0/25-D24/210. Rated voltage is 24 volts of this pump and it requires 8.75 amps. The power consumption is 210 watts. We simulated a DC Motor Block in the simulation as it matches best with the real-life solar water pump. In the configuration block, the motor was configured in such a way so that it performs as a water pump. In the simulation, the motor is configured as 48V motor due to the simplification of the system as the whole system is a 48 volts system.

Pump Performance

Model	Pump		Solar Panels		Max.Flow (m^3/h)	Max. Head (m)	Outlet Dia. (inch)
	Voltage (V)	Power (W)	Voltage range (V)	Power (W)			
SQB2.0/25-D24/210	24	210	26-50	280-380	2	25	1x1
SQB2.2/35-D24/280	24	280	26-50	280-380	2	25	1x1
SQB3.0/50-D48/550	48	550	50-100	720-900	3	50	1x1
SQB3.0/50-D72/550	72	550	76-150	720-900	3	50	1x1
SQB3.0/60-D72/750	72	750	76-150	1000-1250	3	60	1x1

Figure 3.12: DC Water Pump specification

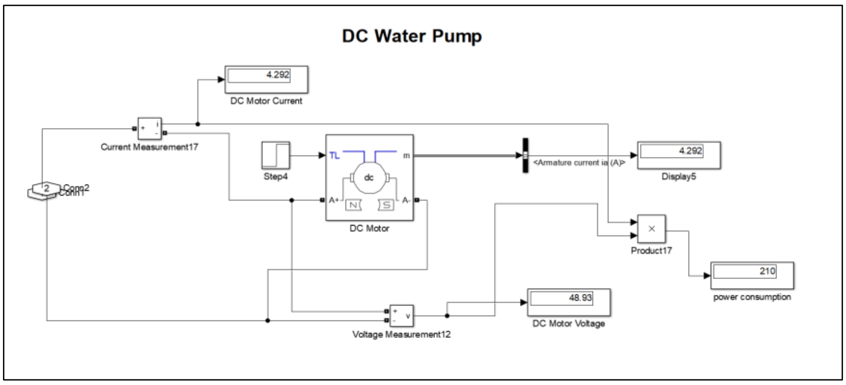


Figure 3.13: Simulation block DC Water Pump

Figure 3.14: DC Water Pump (actual)

3.4.4.D. DC Cooking Stove

This solar cooking stove is developed by the CARC (Control and Applications Research Centre). It is an efficient cooking system compatible with solar power. The rated voltage is 48 volts and required current is 10.5 amps. This solar cooking stove consumes 500 watts.

In simulation we have represented the stove with three resistors connected in parallel which represents the heating coil of the stove. In the actual solar stove, similar kind of 3 resistors were used to reduce the power consumption while serving almost the same amount of heat compared with the existing AC cocking stoves in the market.

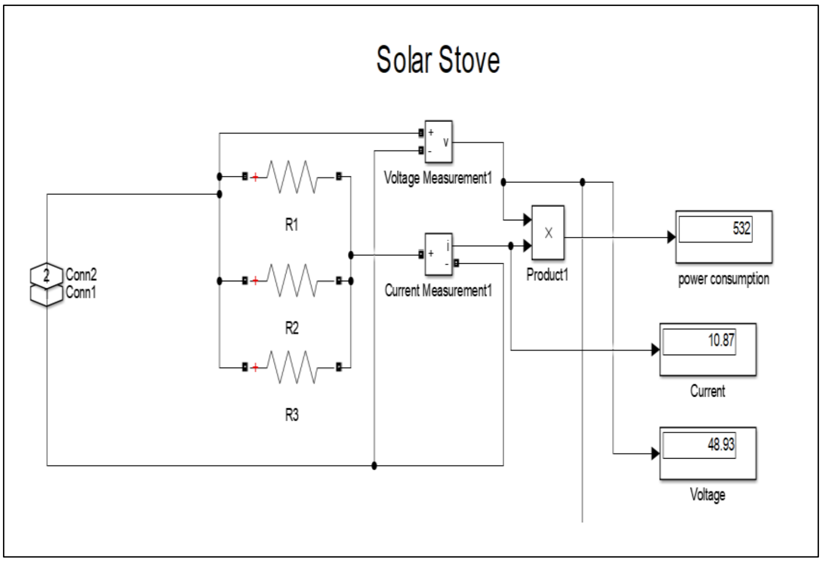


Figure 3.15: Simulation block DC Stove

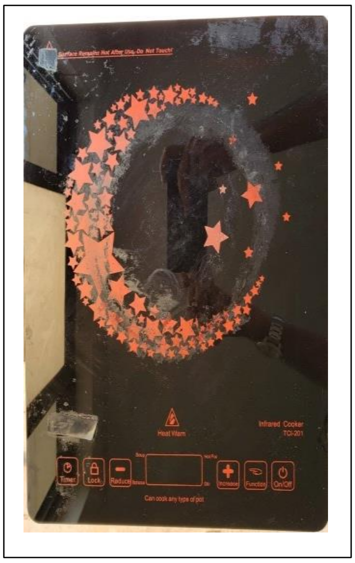


Figure 3.16: DC Stove (Actual)

3.4.4.E. DC Refrigerator

This solar refrigerator is also developed by CARC (Control and Applications Research Centre). There is a DC compressor and freezer. The DC compressor is powered by the DC voltage source. The cooling is done efficiently. The DC compressor is compatible with 24 V system. The operating voltage range of the compressor is 24V. It requires 4 amps current. The compressor consumes 30 watts at maximum condition. In the simulation, we used a DC motor which serves as the compressor which is shown in the figure. The motor parameters are selected and adjusted as the actual compressor which was used in refrigerator.

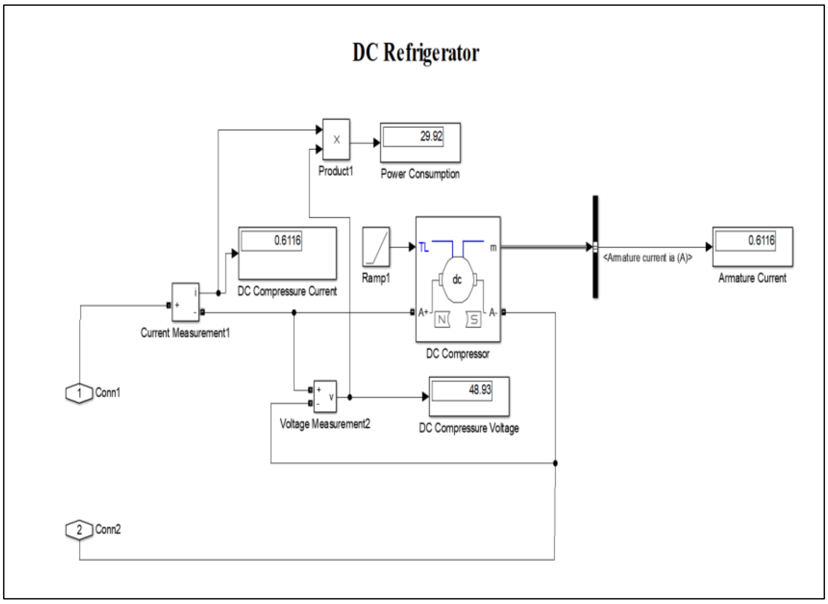


Figure 3.17: Simulation block DC Refrigerator

Figure 3.18: DC Refrigerator (Actual)

3.4.5. Power Supply

The power supply is kept as the backup in this project. Main purpose of the power supply is to work as a secondary source of power for charging the batteries. There could be many possible reasons for which solar panels cannot produce required current and voltage to charge the batteries such as weather issues and natural catastrophes. National grid can be brought into exercise as the backup source of power in those critical situations. But the national grid is a

220V AC, 50 Hz system which will not be compatible with our project. that is why a power supply is need to convert that 220 V AC into 48 V DC.

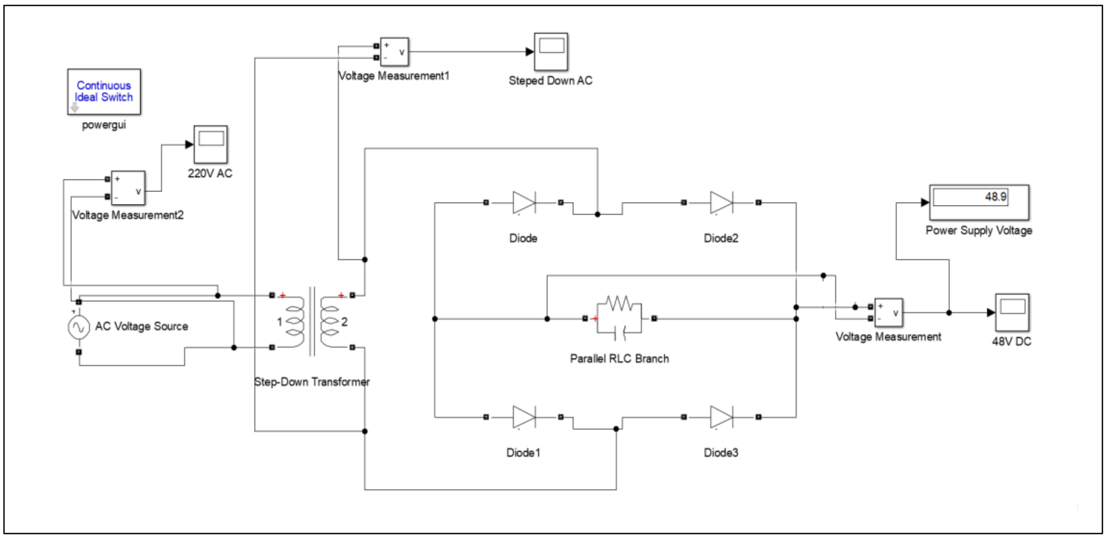


Figure 3.19: Simulation block of power supply

3.5 Modelling the system in MATLAB/Simulink Platform

We have designed and improvised our system in order to simulate it properly in MATLAB, Simulink. In this portion of the chapter, we will get to know how one device is syncing with the other device to run the system successfully.

The system that we have designed is capable of taking variable input. We know that the solar irradiance is not constant. Instead, it varies from time to time. At around 6 AM the solar irradiance is very small but it increases with time and reaches at peak point at around 12PM. Then the solar irradiance generally starts to decrease until the dusk. After that the solar irradiance is zero due to the absence of sun. This cycle continues daily but sometimes the day is longer or shorter, which varies with season. As input data for simulation, we have used data from the Final Report of Solar and Wind Energy Resource Assessment (SWERA) – Bangladesh. For better result and accuracy, we simulated the system for both summer and scenario. We have taken 12 pieces of 215-watt Soltech solar panels. The array is designed as 2 in series and 6 set of them in parallel. The whole array has been represented in the Simulation file with a PV array. The output of the solar panel is then feed into the charge controller. The charge controller safely charges the battery and provide the DC loads with regulated current and voltage. After all these, the refined and stable electrical signal goes to the battery and the load side. In our simulation we have represented 400Ah battery array in a single battery cell. The battery charging mechanism is controlled by the charge controller. The Battery will keep on charging until the SOC reaches to its maximum capacity. Moreover, the system is designed in such way that if there is energy production deficiency then the battery will co-operate with the solar panels to supply power to the load side. That makes the system to provide a continuous and uninterrupted power supply to the load.

The grid power is used in this system as a power backup system of the battery. We have installed a full wave rectifier at the grid side which will work as the power supply. The AC input of 220V 50Hz will be transformed into 48V DC output. We can always manipulate the output voltage value by varying the turn’s ratio of the transformer. As it is a simulation, thus it was quite convenient to do that easily. Load is connected at the same node of the battery and charge controller connection. From that single node all the five types of DC loads of the system are connected.

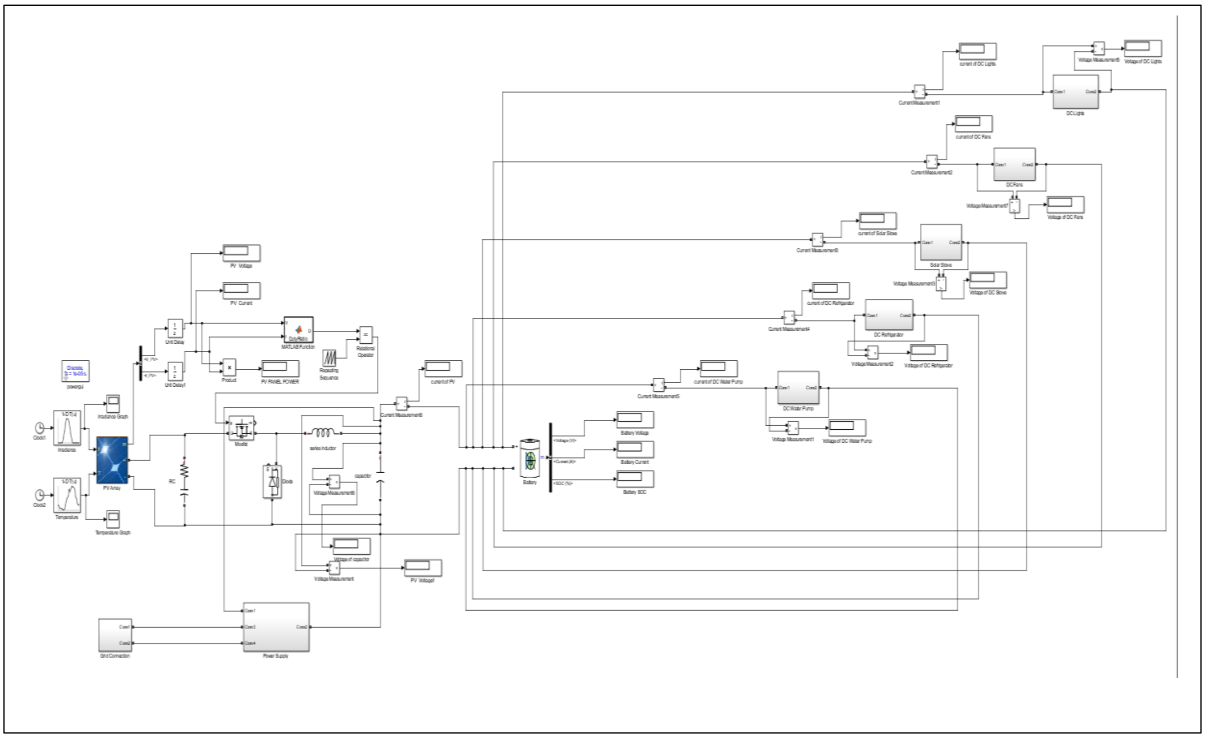


Figure 3.20: Simulation block of the total system

Chapter 4

Result and Analysis

4.1 Introduction

Several simulation-based tests and calculations are done in this project. In this chapter, those test results are discussed. In the second chapter, the present scenario of rooftop solar panels is discussed, and shown that the real-life implementation of rooftop solar systems in Dhaka city tends to zero. Through this project, how the actual and fruitful implementation can be done is shown here. Furthermore, how DC appliances can run with the project is also shown through simulation results in this chapter. Moreover, battery charging and discharging test, power consumption comparison between AC and DC appliances, and cost reduction in terms of electricity bill through this project is also being discussed with the result findings and analysis.

4.2 Solar Panels Utilization, Test and Result

This project simulation is done by assuming a 7 storied standard building in Dhaka city which consists of 14 flats. According to Mizanoor/Journal of System and Management Sciences Vol.7 (2017) No 4, 17-31, a survey found that the average consumption of electricity is 281 KWh/month for 4 room's flat, making the average daily electricity consumption 9.36 KWh/day. The total electricity consumption of this building for one day is 131.13 KWh/day. At least 3% of the total power consumption must be produced from solar energy which is 3.39 KWh/day. To fulfill this need, we used 12, 215 watts/panel solar panels which will provide roughly 2580 W. We used data from the final report of SWERA (Solar and Wind Energy Resource Assessment), project Bangladesh for increasing the accuracy of the simulation. They used the data from January 2003 to December 2005 and reported the mean monthly data. For having the actual 24-hour simulation of the solar energy, we used monthly average hourly GHI

(Global Horizontal Irradiance) data of the month April as summer data and December as winter data. How solar irradiance varies throughout the day and how it affects solar power harnessing is shown in this chapter.

The model of the PV panel that we used for our simulation is Soltech 1STH-215-P. We have used in total 12 Solar panels where 2 were in series connection and like that there was 6 set of parallel connection. It is an important issue to utilize the PV panel that we use in the best way possible because improving the efficiency array is only one way to extract more energy from the sun One of the ways to determine that is to make sure that the PV operates at MPP (Maximum Power Point) under a specific set of irradiance and temperature.

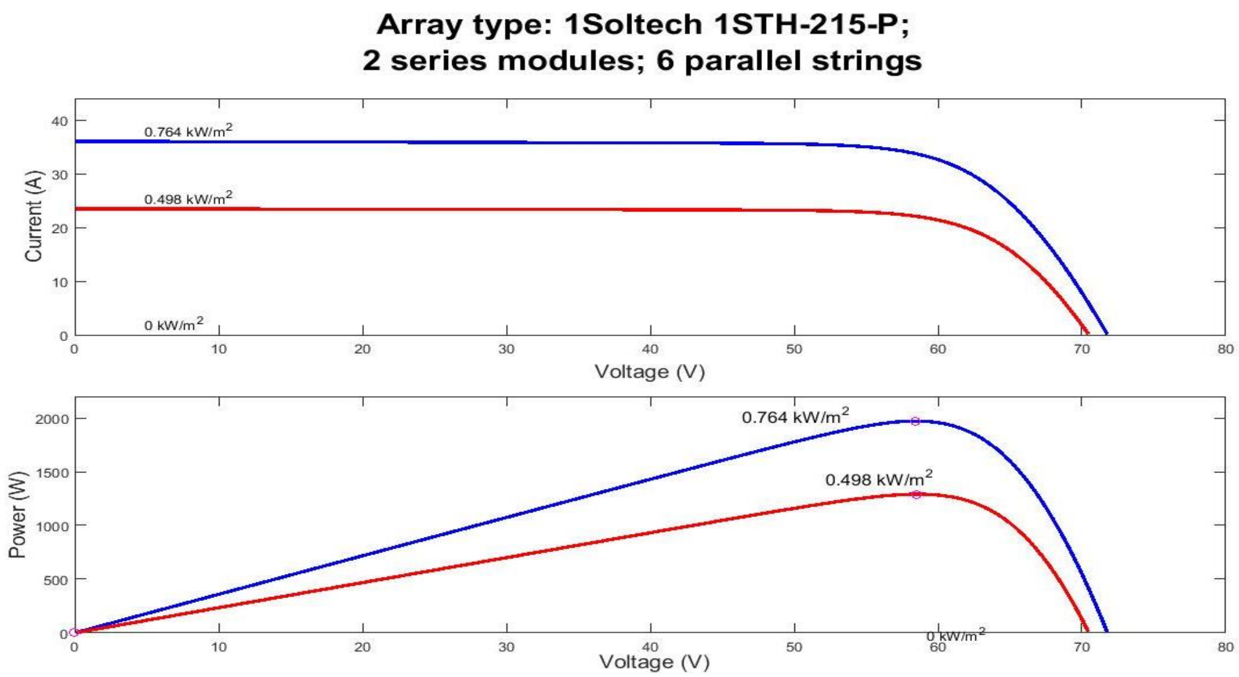


Figure 4. 2 I-V & P-V characteristics of PV array

We have plotted the I-V characteristics and P-V characteristics of our PV module for maximum irradiance using the average hourly GHI of winter and summer. We took 764W/m^2 as the maximum irradiance for summer and 498W/m^2 as the maximum irradiance for winter. When all parameters are constant, the higher the irradiance is the greater the output current and power will be. In fig: 4.1, we can see the effect of different irradiance values for output components. In summer we could get up to 36A of current where in winter we can get a maximum of 23.5A of current from the system. Also, the output power of the system varies for different irradiance values. We can see that the maximum MPP of the system will occur when it is operated in a 58V. On the contrary, the current output starts to diminish when the system rises above 50V. So, we can conclude that the solar array which is designed for this project is working perfectly. The relationship between irradiance and modules current and power can be expressed as the following:

$$\frac{G1}{G2} = \frac{I2}{I1} = \frac{P2}{P1}$$

Where G1 and G2 are the irradiances (in W/m^2), I1 and I2 are the modules' corresponding current (A), and P1 and P2 are the resultant power when irradiance changes (W).

4.3 System Results in Summer (April)

In summer we get the highest amount of possible irradiance which is beneficial for our solar home system, as we know that more irradiance means the PV array will work more efficiently. In this section of the chapter, we will be showing the result that we get from the system by varying the irradiance and loads.

4.3.1 Full Load Simulation

We have simulated the system by running it with varying irradiance data for 24 Hours. SWERA's average hourly GHI data were used in the system in the simulation. According to this data, in average we can produce up to 5.46 kWh-day by this much irradiance. From the load calculation of chapter 3, we saw that 5 kWh-day of energy production is required to run the load properly for whole day. The data we used is provided below in the table:

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Irradiance W/m^2	0	0	0	0	0	5	66	198	354	521	666	751
Time	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Irradiance W/m^2	764	693	553	402	237	72	4	0	0	0	0	0

Table 4. 9 Irradiance data of April by SWERA

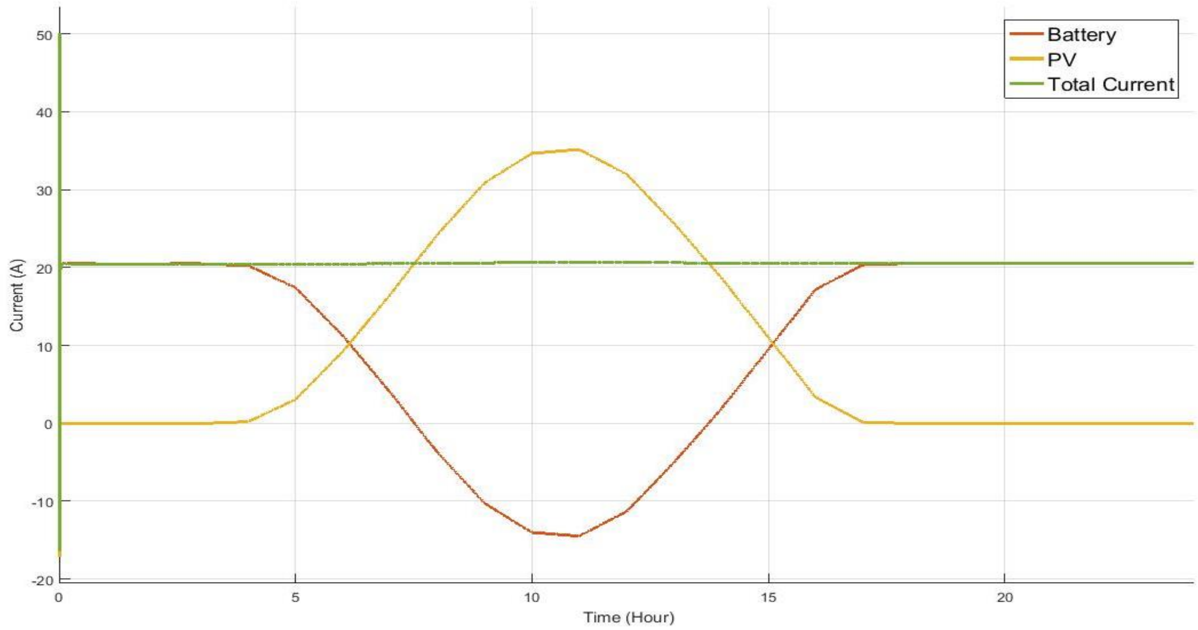


Figure 4. 10 Battery and PV current of summer

After simulating we got the graph as above. From this figure we can see that initially at night time while the irradiance is zero, the battery was providing current to the load. It was providing 20.6A to the loads to operate properly. But around 5 AM when the irradiance value started to increase, the solar PV cell started to generate power and provide current to the load side. The value of current produced from solar panels reached approximately 36A at noon when the irradiance is the maximum. As our load side needs total 20.6A to work, so rest of the current produced by the Solar PV is used to store charge on the battery array. When the irradiance value started to fall, the production of current by the PV also decreased, and eventually, the system started to rely completely on the battery array. We can notice one important thing here, that is the PV and Solar Panel were working together to provide sufficient current to the load side while required. When the battery current is negative the battery is taking charge for itself from the PV array after making sure that the PV array can sufficiently provide current to the load side.

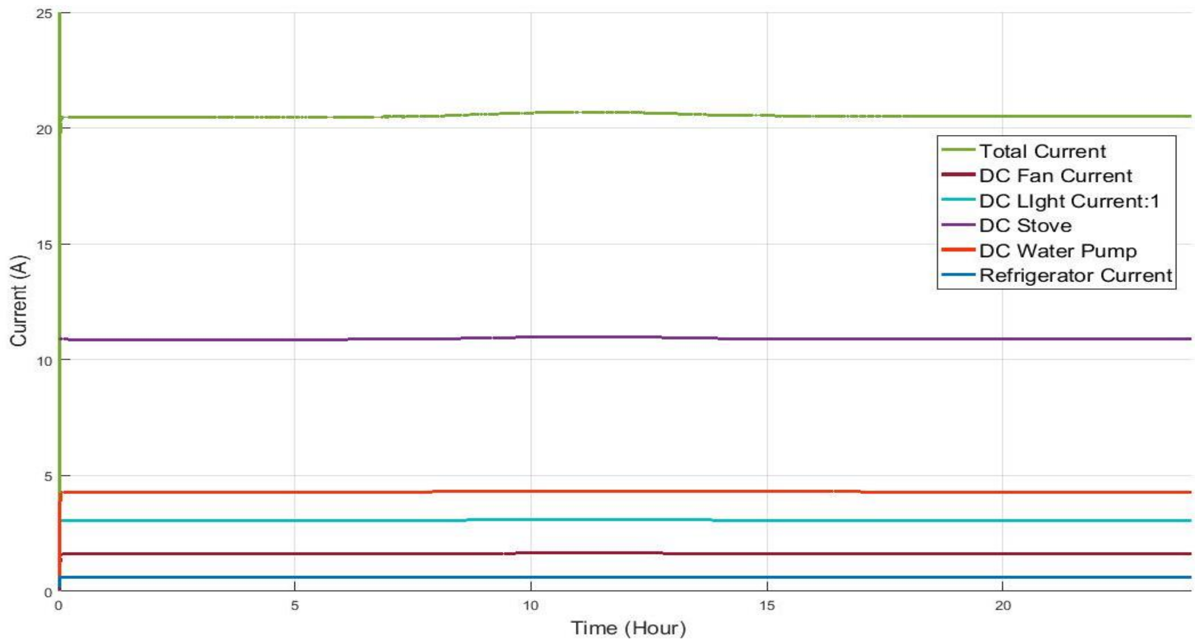


Figure 4. 11 System following Kirchhoff's current division law (summer)

In this figure, we can see that the total current provided by the battery and PV array combined, is distributed between the loads. So, that proves Kirchhoff's current law:

Total Current = DC Fan Current + DC light Current + DC Stove Current + DC Water Pump Current+ DC Refrigerator Current

= 1.6 + 3.1 + 11 + 4.3 + 0.6

= 20.6A

And the total current of battery and PV array is 20.6A as well.

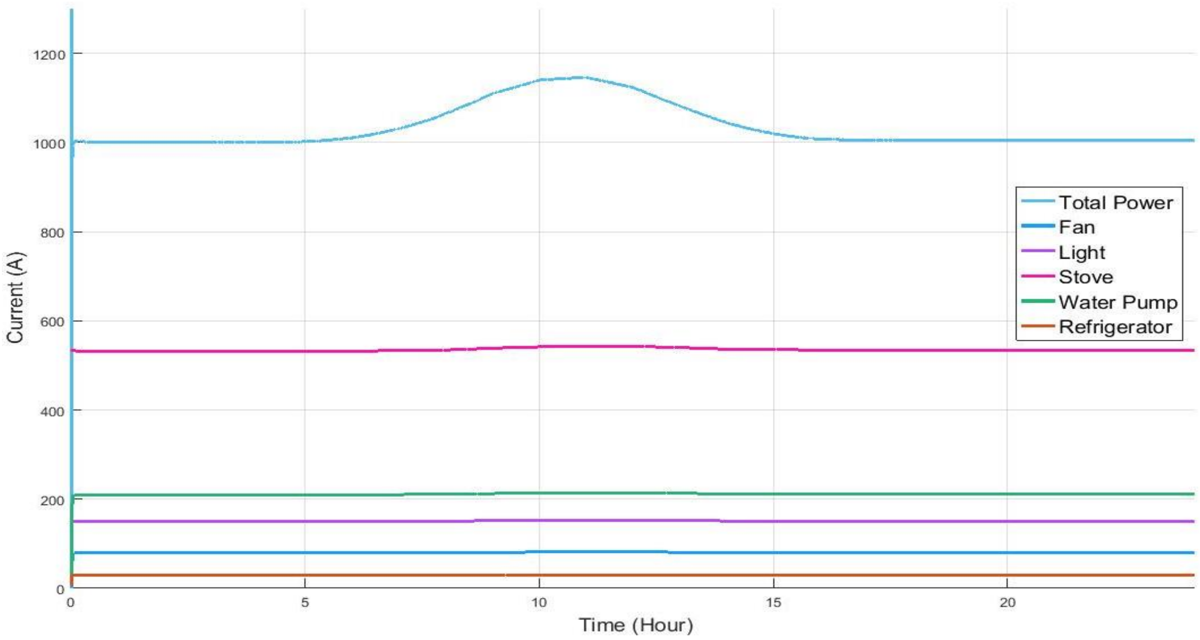


Figure 4. 12 Power division among loads (summer)

From this figure, we can see the total power produced by the PV array and consumed by the load side. The bump in the mid-day is the amount of extra energy that remains after transferring power to the battery. This graph is proof that it is a closed system and no power is being lost. Though, it is based on ideal values only because in practical values a different kind of power losses comes into consideration.

The total power produced by PV and battery at noontime around 12PM is 1145.9W.

Total Power = DC light Power + DC Fan Power + DC Stove Power + DC Water Pump Power + DC Refrigerator Power

= 153 + 81.4 + 543 + 214.3 + 30.5

= 1022.2W

So, at this time the power loss is (1145.9-1022.2) W= 123.7W

Aside from that time all the produced power is utilized properly.

4.3.2 No Load Simulation

In this section of the chapter, we will be discussing the no-load simulation part. That means we have simulated our system by unplugging the loads to see whether the nature of the current flow is affected by that.

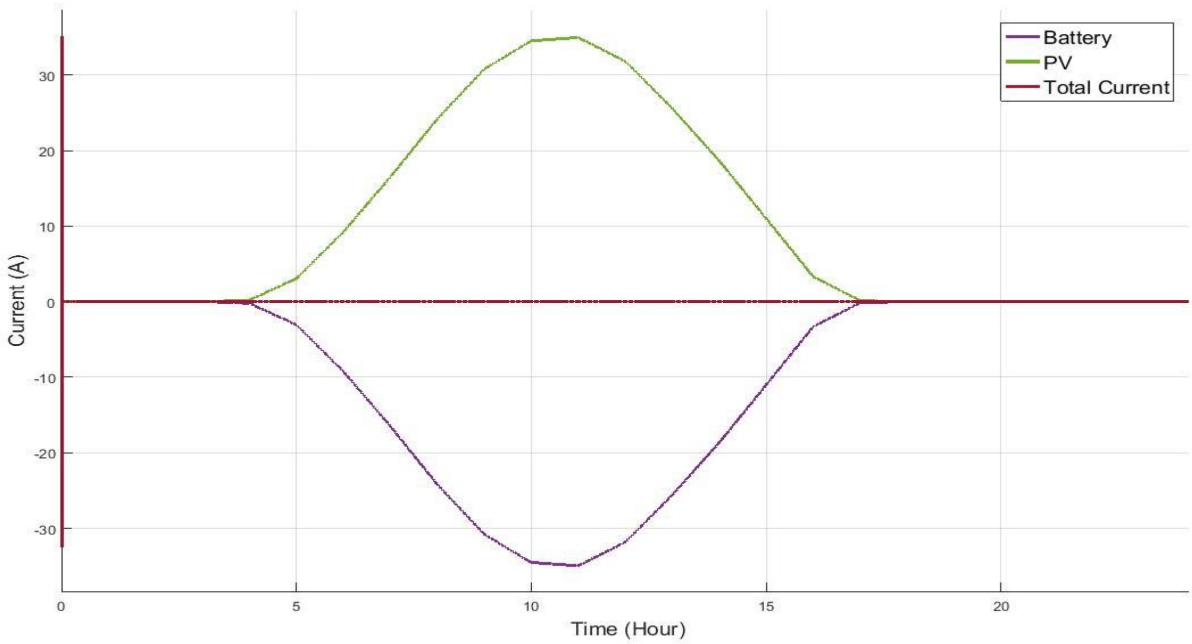


Figure 4. 13 No load test (summer)

As we can see the current value is zero from the beginning of the simulation as there was no irradiance. But, when the irradiance value started to rise, the current production of solar PV started. The produced current has been fully transferred to the battery as there were no loads.

The signal of the battery is under zero which signifies that the battery is recharging. The value peaks at the noontime around 12 PM (36A) and falls gradually with the decrease of irradiance value.

4.3.3 Maximum Irradiance

We have also simulated the system with maximum irradiance that we can achieve in summer for 24 hours. By doing this, we can check whether the system operates without the complete help of other sources or not. The irradiance that we used for this simulation is 764W/m2 and 340C.

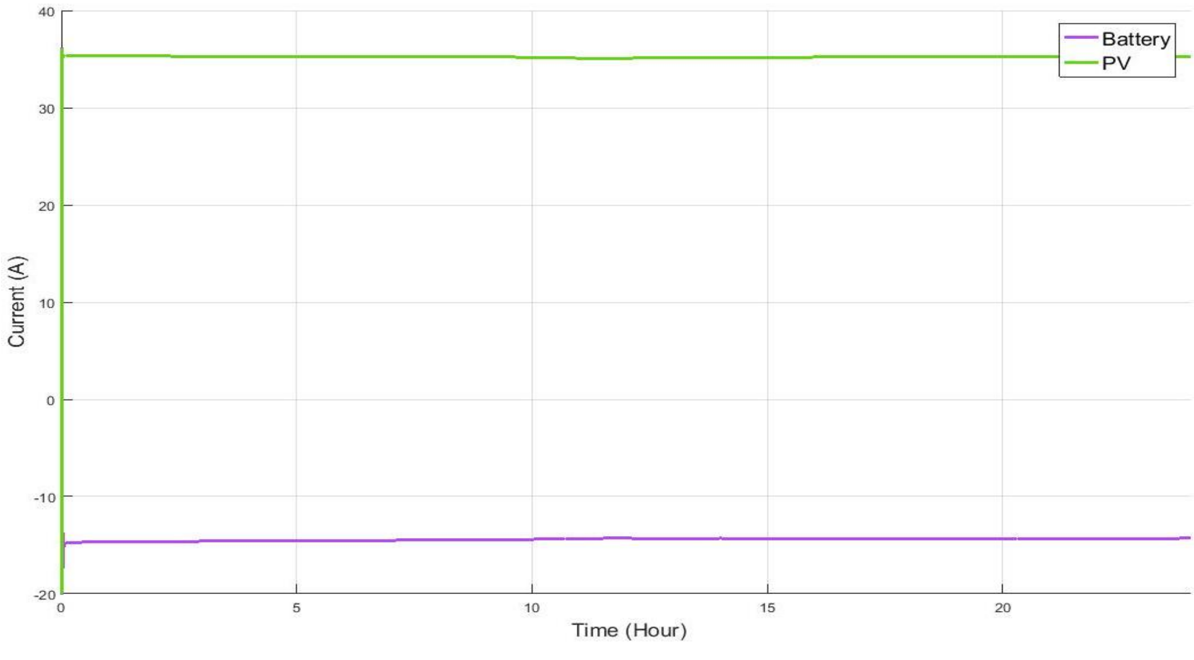


Figure 4. 14 Maximum irradiance test (summer)

It is clear from the above graph that for maximum irradiance the PV array continuously gives the maximum amount of output current which is 36A. So far, we know that the current load needs are 21A. The rest of the 15A is used to recharge the battery. One of the disadvantages of this simulation is that the battery keeps on draining energy from the PV array for the whole 24

Hours as here max irradiance is applied for 24 hours straight. Though, previously in full 24-hour real data simulation we saw that the battery helps the PV array after being fully recharged.

4.3.4 Minimum Irradiance

It would be interesting to see how the system will operate when the irradiance is minimum i.e. Zero. For that, we have kept the irradiance value of the simulation as $0W/m^2$ and the temperature value as 26^0C. Therefore, after simulating this for 24 hours we got the graph below:

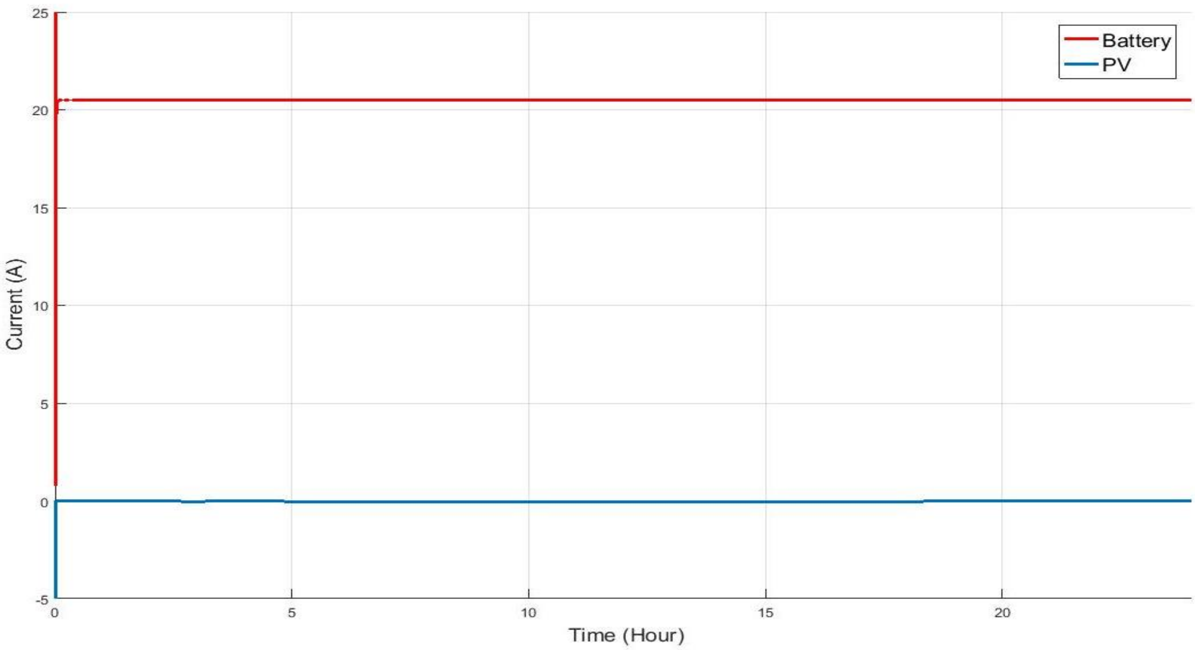


Figure 4. 15 Minimum irradiance test (summer)

The current value of the PV array of the graph above is zero because of zero irradiance. We can also see that the Battery is backing up the whole load side by providing 21A of current. We can assume that the battery is getting help from the third backup system grid here as the battery does not have enough storage to provide for 24 hours of nonstop current supply.

4.4 System Results in Winter (December)

For checking the reliability of the system, both summer and winter season-based simulation is done. We had operated the system in winter when the average irradiance value is very low. This will show whether the system is operable in full scale throughout the year or not.

4.4.1 Full Load Simulation

We have simulated the system by running it with varying irradiance data for 24 Hours. SWERA average hourly GHI data were used in the system in the simulation. According to this data, we can produce 3.17 kWh-day by this much irradiance but we need a total of 5 kWh-day of energy. Therefore, clearly, we will be lagging behind the demand by 2.8 kWh-day. The data we used is provided below in the table:

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Irradiance W/m^2	0	0	0	0	0	0	11	97	237	382	479	498
Time	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Irradiance W/m^2	489	426	309	189	54	2	0	0	0	0	0	0

Table 4. 2 Irradiance data of December by SWERA

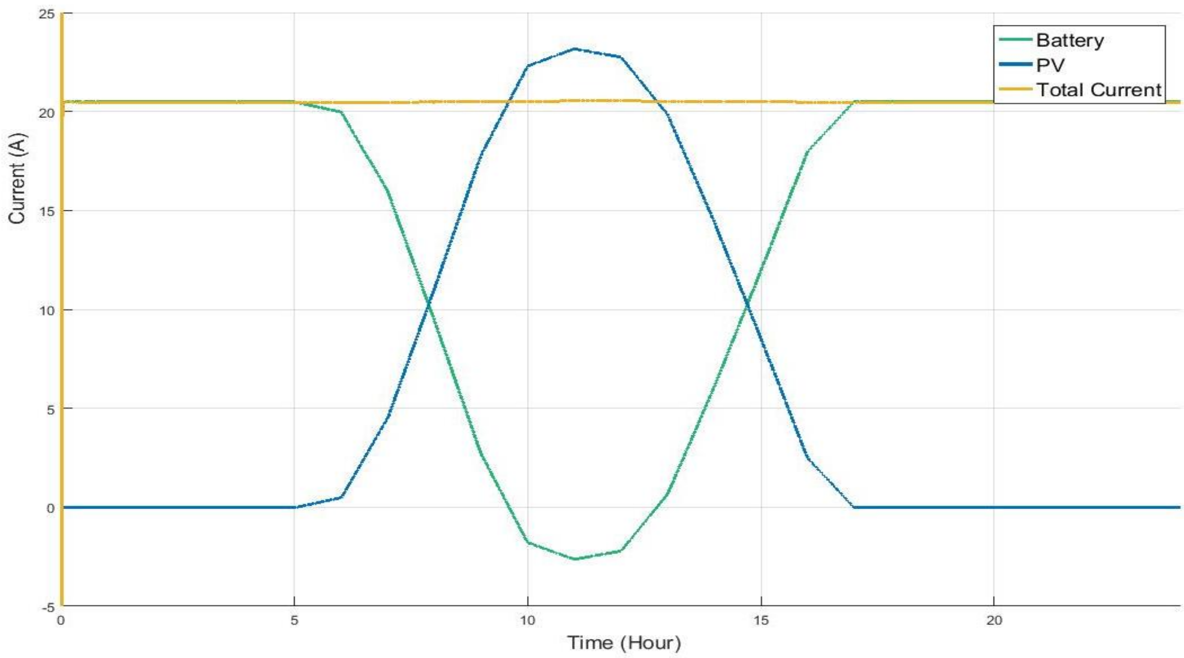


Figure 4. 16 Battery and PV current in winter day

In the above graph, we can see that just like summer time the PV array current rises with the increase of irradiance & temperature and gradually fall after the fall of irradiance value. Similarly, to run the load, a battery array is providing the system with backup power when the PV produces no power. The main difference of this curve with the summer graph is that the value of PV array current does not rise above 23.5A even at peak time. The load consumes 21 A of the system and if there is any remaining energy, then that will be transferred to the battery to recharge. This means the battery won't get enough charge from the PV current to charge completely. Thus, in winter the need for the third backup system i.e. grid is immense.

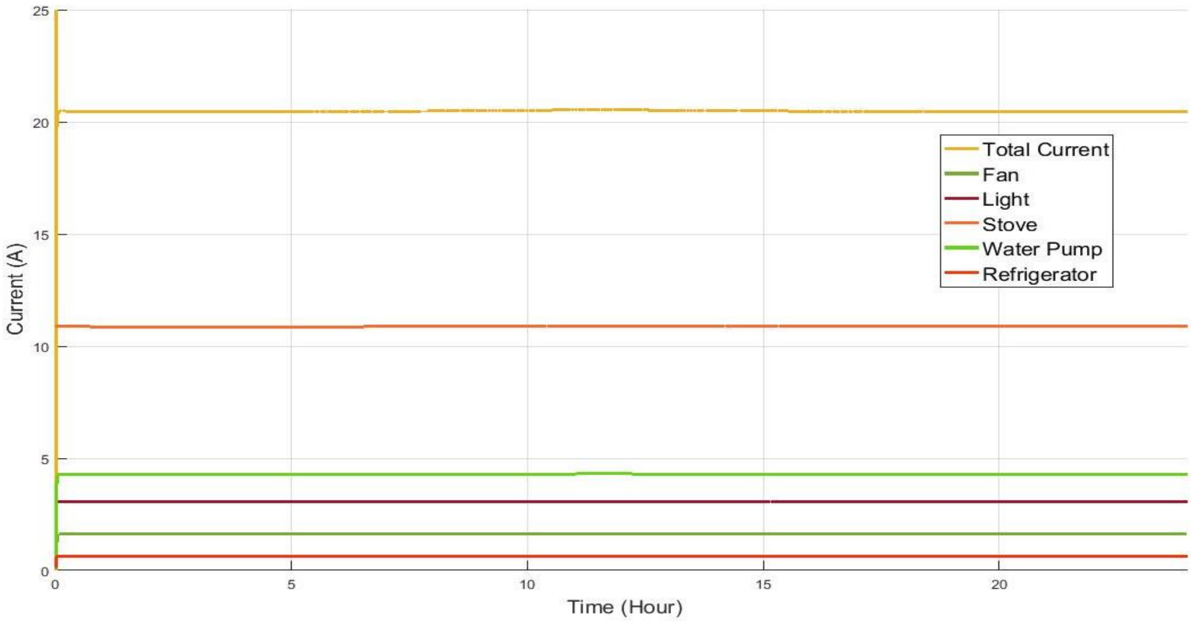


Figure 4. 9 System following Kirchhoff's current division law (winter)

The total current provided by the system to the load is 20.5A. As we have 5 different types of load connected to the system so according to Kirchhoff's current law the total current will be divided among the loads. We got,

Total Current = DC Fan Current + DC light Current + DC Stove Current + DC Water Pump Current+ DC Refrigerator Current

=1.6 + 3.1 + 10.9 + 4.3 + 0.6

= 20.5A

The total current we got from the simulation is also 20.5A which proves that the system abides by Kirchhoff's current law properly. Although in winter the system will have to depend on the backup system lot because of the least amount of power generation.

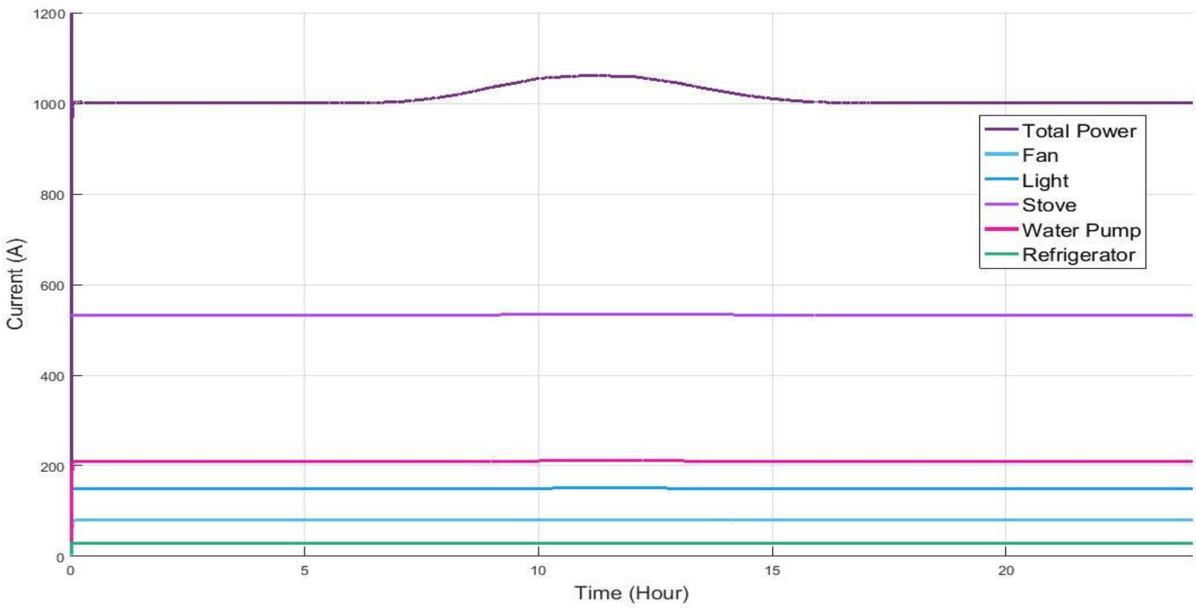


Figure 4.10 Power division among loads (winter)

Just like the summer simulation, we can also see a small bump in the total power output at noontime which signifies the loss off from the PV array at that time. Rather than that, almost everything is similar to the summer. Despite having lower power production of power in winter, we can still see that the loads are getting load anyhow. This happened because the battery is continuously being assisted by the grid power.

Total power produced by PV and battery noon time is 1060.1W.

Total Power = DC light Power + DC Fan Power + DC Stove Power + DC Water Pump Power + DC Refrigerator Power

= 150.7+80.2+535+211.2+30.1

= 1007.2W

So, the power loss at that period of time is (1060.1-1007.2) W = 52.9W.

4.4.2 No Load Simulation

This section was simulated with no load, rather we will be charging only the battery with all the power that the PV array harnesses throughout the day.

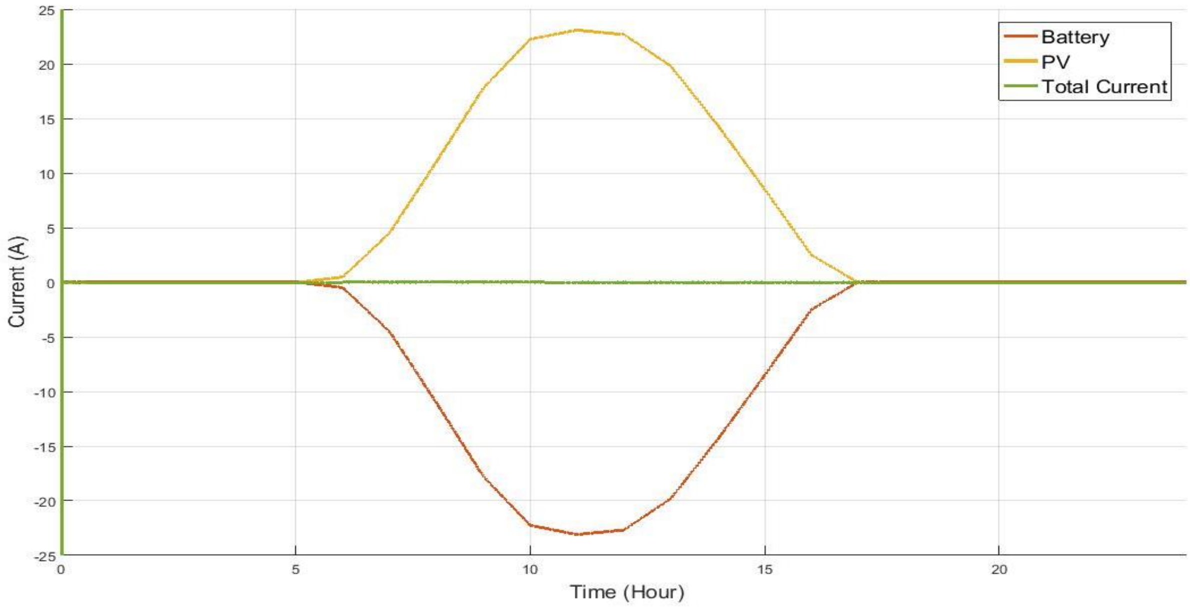


Figure 4.11 No load simulation (winter)

As we can see in the above figure that the total net current aligns to the x-axis that is because all the current produced by the PV array is transferred to the battery array. At noon the curve gains the maximum amplitude which is 23A due to the highest irradiance value. When the irradiance is zero the PV panel does not generate any energy and also the battery does not discharge anything as there are no loads.

4.4.3 Maximum Irradiance

Now we will see how the system will operate if it is provided with maximum irradiance for 24 hours straight. Here we have used the irradiance value as 498 W/m2 and temperature as 23.50 C. The reason is these values are highest for the December month that we took as reference data.

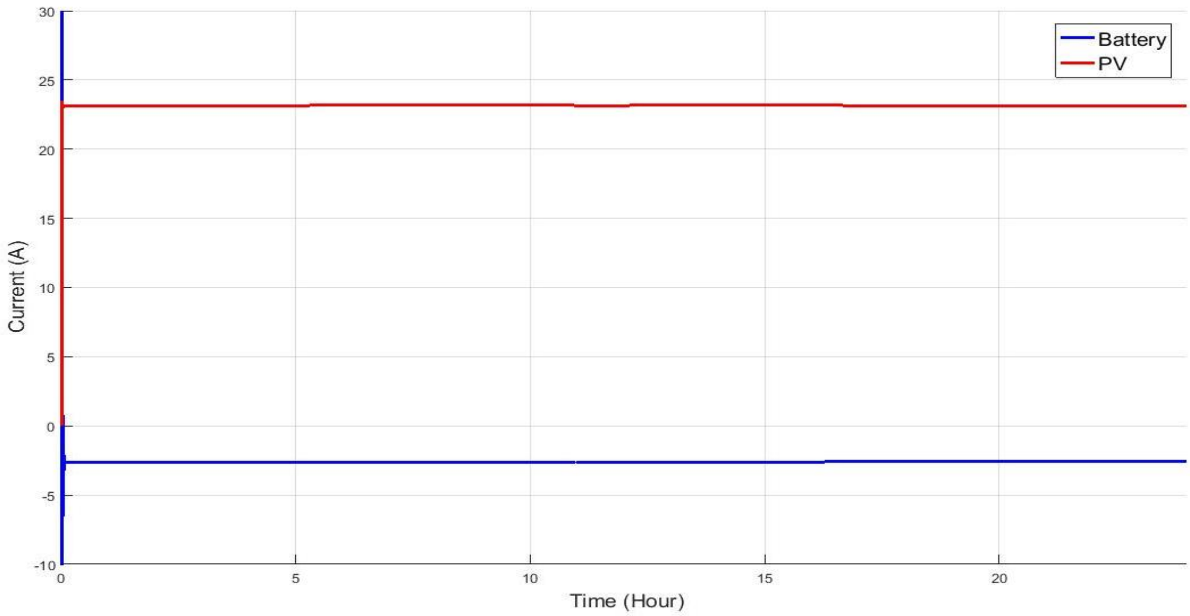


Figure 4. 12 Maximum irradiance simulation (winter)

We can see in the graph that the PV array is continuously generating electricity due to the maximum irradiance that's why the PV current curve is straight for all 24 hours. The value that it is producing is 23.6A. We know that the load will be consuming 21A so the rest 2.6A will be going to the battery array to recharge it.

4.4.4 Minimum Irradiance

This time we will use the least irradiance value possible for simulation which is zero. Also, the temperature that we will be using is 130C as it is the lowest value in December. By doing all this we will know how the system will work when there is no irradiance value for at least 24 hours.

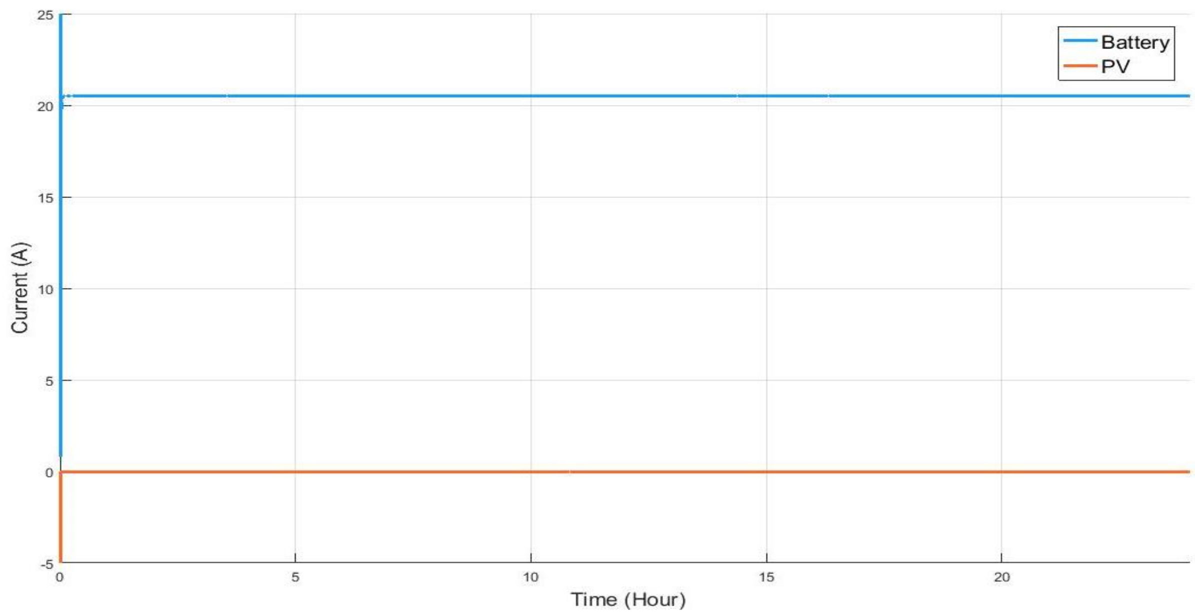


Figure 4. 13 Minimum irradiance simulation (winter)

The graph shows the current value of the PV array and the battery while the irradiance is minimum. We can see that the PV current is completely zero as there is no irradiance. At this moment, the backup system is successfully providing energy to the load. The current that the battery is providing is 21A which is equal to the load current. The battery array is not sufficient enough to provide power for all 24 Hour so the grid helps to maintain that by providing the rest of the energy through recharging process. This chart is almost similar to the graph that we got while simulating minimum irradiance for summer, but one thing which is different between this two is the temperature value. So by analyzing the graphs it is clear that the temperature does not affect the simulation result, wherein practical life things are different.

4.5 Efficiency Comparison Between AC and DC Appliances

One of the main motives behind this paper is to show that DC appliances are more efficient than AC appliances. For that, we have taken some common DC and AC appliance of a building as references to design our system. As we can see in the table below that the appliances do the same category of work by consuming a different amount of energy.

Name	DC	AC
Lights	Brand Name: Ensysco LED Rated voltage: 12 V Current: 1 amp Power consumption: 12 Watts Luminosity: 1080	Brand Name: Superstar Incandescent Rated voltage: 220 volts Current: 0.34 amps Power consumption: 75 watts Luminosity: 1100
Fans	Brand Name: Ensysco solar ceiling fan Rated voltage: 12 V Current: 1.6 amps Power consumption: 20 watts RPM: 320	Brand Name: Conion celling fan Rated voltage: 220 volts Current: 0.34 amps Power consumption: 75 watts RPM: 320
Water Pump	Brand name: PNG solar Model no: SQB2.0/25-D24/210 Rated voltage: 24 volts Current: 8.75 amps Power consumption: 210 watts Maximum Flow: 2 m^3/h Water head: 25 meters	Product name:Gazi, ACI-TJSW-1B Rated voltage: 220 volts Current: 2.27 amps Power consumption: 522.2 watts Maximum Flow: 1.8 m^3/h Water head: 20 meters
Cooking Stove	Rated voltage: 48 volts Current: 10.5 amps Power consumption: 500 watts	Brand name: Walton Model number: WI S37 Rated voltage: 220 volts Current: 9.54 amps Power consumption: 2100 watts
Refrigerator	Rated voltage: 24 volts Current: 1.2 amps Power consumption: 29 watts (DC compressor)	Product name: Walton WFE-3E8-GDXX-XX Rated voltage: 220 volts Current: 1.2 amps Power consumption: 130 watts (AC compressor, compressor model: V 0102)

Table 4.3: AC and DC appliance details

DC appliances tends to use less power and serve the same features of AC appliances. A side-by-side comparison table is made to illustrate the observation.

A power consumption comparison table is given below:

Name of the appliances	Quantity	DC power (W)	AC power (W)	Use (in Hour)	DC power consumption (Wh/day)	AC power consumption (Wh/day)
Light	12	153	224.4	12	1836	2692.8
Fan	4	81.4	74.8	12	976.8	897.6
Cooking stove	1	543	2100	3	1629	6300
Refrigerator	1	30.5	130	12	366	1560
Water pump	1	214.3	522	2	428.6	1044
Total power consumption =					5236.4	12494.4

Table 4. 4 AC and DC appliance power consumption data

$$\text{Efficiency} = \frac{Total\ AC\ power\ consumption - Total\ DC\ power\ consumption}{Total\ AC\ power\ consumption} * \ 100\%$$

$$= \frac{12494.4 - 5236.4}{12494.4} * \ 100\%$$

= 58.09%

From this chart we can see that we can save up to approximately 60% of the energy that we are using right now by switching to DC appliances.

4.6 Remark on Results

Our motive behind the project is to inspire people to properly utilize the solar rooftop panels and Switching to DC appliances. We believe that it will save a lot of power and also save the nature from harm we are causing to generate more power. So as power is saved so it will reduce our electricity bill . BY only using the common appliances we managed to save 57% energy, thus it may be possible to save a lot more by imcluding more applainces to this system. Based on the results that we have got it is possible to inspire more people because this paper shows that we can save a lot of energy even from inside our household. Aside from that, the results could be more appropriate if we could simulate the loads in real-time with respect to their daily use. That would have given more practical reports.

Chapter 5

Feasibility Analysis and Standard Impacts of The System

5.1 Introduction

A better system always needs to analyze its efficiency by doing the feasibility test. ‘Homer Pro’ finds best feasible systems from which the user can be more specific about what sizes should be considered viable for one’s project. In our system we will use the ‘Homer Pro’ software in order to know the total cost summary, operation cost, simulation results, annual electricity production, annual production of Generic flat plate PV. By analyzing the ‘Homer Pro’ simulation result we will be able to find out the financial and system feasibility of our whole system.

5.2 Economic Optimization Analysis Using HOMER Pro software

5.2.1 Introduction

The HOMER Pro is the global standard for optimizing microgrid design in all sectors from village power and island utilities to grid –connected campuses and military base. It allows user to simulate, optimize and also has the ability to do sensitive analysis on a system consisting of multiple energy sources like PV design, diesel generator, battery, grid calculation etc. Originally developed at the National Renewable Energy Laboratory, and enhanced and distributed by HOMER Energy, HOMER (Hybrid Optimization Model for Multiple Energy Resources) nests three powerful tools in one software product, so that engineering and economics work side by side. HOMER simulation is the best system design software and the optimization finds the best possible system configuration which gives the least total Net Present Cost (NPC) that satisfies user defined constraints. It can calculate the economic analysis, cost calculation, feasibility analysis and others etc. One of the main advantages of HOMER pro software is resource data (solar and wind) is provided via the tool from internal resource data. With over 200,000 users in 193 countries, HOMER is the established global leader for design optimization and feasibility, and HOMER Energy has grown to become a nexus for the microgrid market. One of the most significant updates is HOMER optimizer" which finds out the best feasible system from which the user can be more specific about what sizes should be considered viable for their proposed project.

5.2.2 Cost Analysis Procedure By HOMER

Step by Step Analysis Procedure is Given Below:

Net Present Cost: The net present cost of a component is the present value of total costs of installing and operating the component over the project lifelong divided by the present value of all the revenues that it earns through the project lifetime.

$$NPC = TAC/CRF(I, proj)$$

Here,

TAC = Total annualized cost

CRF=Capital Recovery factor

I=annual real discount rate (%)

Rproj = the project lifetime [25].

By Homer pro, after simulation we get the Total NPC (Net Present Cost) is $5708.47. we also get the capital recovery factor which is 6. The project lifetime we calculated is about 25 years as a single PV panel can generate electricity up to 25 years. So, if we put these values in the above equation, we will get the total annualized cost which is $34250.82.

1. **Total Annualized Cost:** The total annualized cost is the annualized value of the total net present cost.

$$C_{ann,tot} = CRF(i, R_{proj}) * C_{NPC,tot}$$

CNPC, tot = the total net present cost.

$C_{ann,\ tot}$ = The total capital recovery factor

From simulation, we get the total net present cost in 25 years is $5708.47 and we found the capital recovery factor from section 3 is 6. So, putting this value in the above equation, we also get the total annualized cost which is $34250.82.

2. **Capital Recovery Factor:** The capital recovery factor is a ratio used to calculate the present value of an annuity. (A series of equal annual cash flow)

$$CRF\ (i, N) = \frac{i(1+i)^N}{(1+i)^N - 1}$$

i=real discount rate

N = number of years [25].

We have considered the default 6% real discount rate provided by Homer pro software. So, considering it in the above equation we got the Capital recovery factor is 6.

3. **Real Discount Rate:** The real discount rate is used to convert between one-time costs and annualized costs.

$$i = \frac{i' - f}{1 + f}$$

i =real discount rate

i' =nominal discount rate

f =expected inflation rate [25].

Here, the nominal discount rate we get from the simulation is 12% and before simulation, we assumed the real discount rate by 6%. So, putting the values in the above equation we will get the expected inflation rate in 25 years which is 85.7%.

4. **Cost of Energy:** It is the average cost/kwh of useful electrical energy produced by the system.

$$\text{COE} = \frac{TAC}{Lprim, AC + Lprim, DC}$$

Here,

$L_{prim,AC}$ = AC primary load

$L_{Prim,DC}$ = DC primary load

In our system we are only considering DC load as our primary load. So, from the above equation, Lprim,AC will be omitted. So, putting the total annualized cost value ($5708.47) and the DC primary load consumption value (6.5KW), we will get the cost of energy of our system which is $0.88/KWh.

In this case we are going to calculate the net total operating cost, Operation and maintenance cost. In this section we are going to show the design, calculation and cost optimization result for each case using HOMER PRO and try to find out the better solution by comparing those results.

We are considering Dhaka as our default location in 'Homer pro' and we are considering the simulation for a single apartment where DC components will be use like LED bulb, Fan, water pump, cooking stove refrigerator. The total power consumption per day is around 5KW. The individual power consumption is given in the below chart which will be used in the Homer simulation.

Name of The Appliances	Voltage (V)	Current (I)	Power (in watt)	Quantity	Power Consumption	Duration	Power consumption (Wh/day)
DC Lights	12	1	12	12	144 watts	12	1728
DC Fans	12	1.6	20	4	80 watts	12	960
DC Water Pump	48	8.75	210	1	210 watts	2	420
DC Cooking Stove	48	10.5	500	1	500 watts	3	1500
DC Refrigerator	48	1.25	30	1	30 watts	12	360
Total			772	19	964 watts		4968

Table 5.1: DC Loads and Ratings at a Glance

The total power we needed per day is around 5KW but here we have to consider the system loss as well. So, we need 4968*1.3= 6.5 KW load which means PV panel should provide at least 6.5KW power in the system. So, we should build a schematic diagram in Homer Pro considering this issue.

5.3 Schematic Diagram of Proposed Model

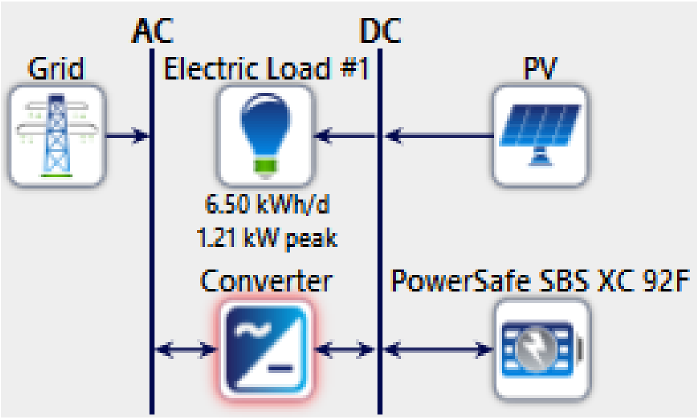


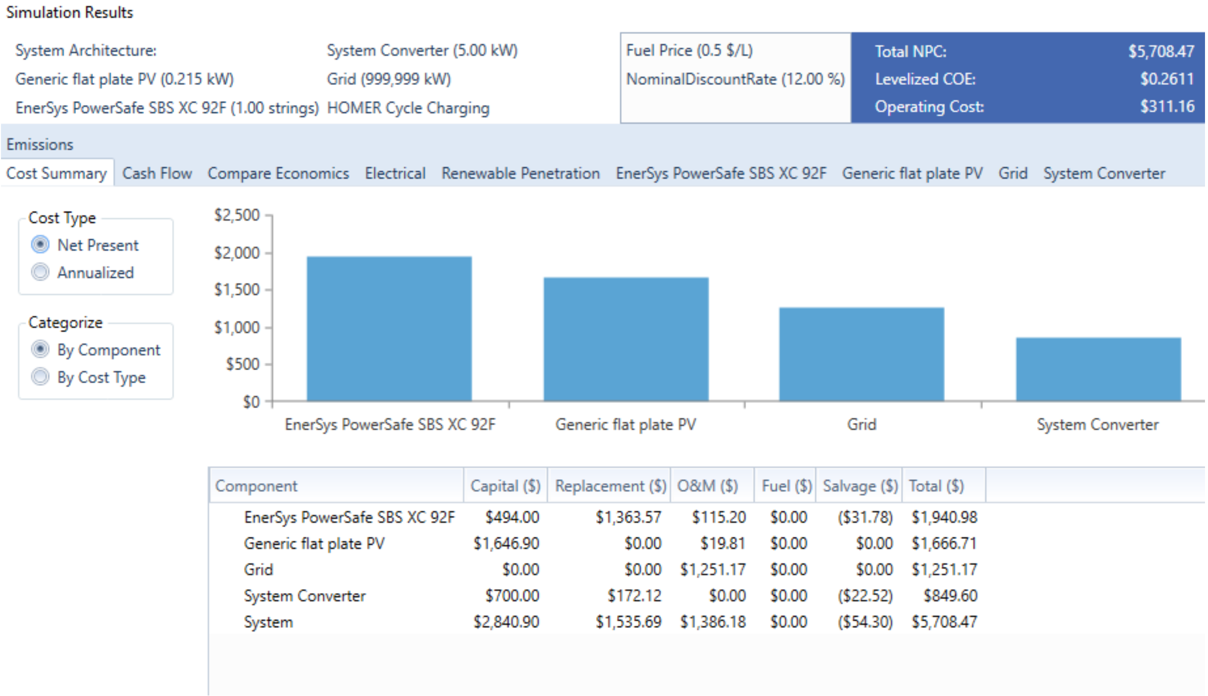
Figure 5.1: Schematic Diagram in HOMER Pro

Here, we can see we are getting the supply to the load of 6.5KW from 12 panel 215w PV panels as well as 16, 100AH 12v Battery (PowerSafe SBS XC 92F). If the PV panels and battery fails to provide the necessary power to the load, a grid is connected to back it up and a converter is doing the conversion of power from 220V AC to 48V DC and supplying it to the battery.

5.4 Simulation Results

5.4.1 Cost Summary

From the simulation, HOMER finds a total of 6.5KW PV panel and 16 batteries which is the best fit for our proposed system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
EnerSys PowerSafe SBS XC 92F	$494.00	$1,363.57	$115.20	$0.00	($31.78)	$1,940.98
Generic flat plate PV	$1,646.90	$0.00	$19.81	$0.00	$0.00	$1,666.71
Grid	$0.00	$0.00	$1,251.17	$0.00	$0.00	$1,251.17
System Converter	$700.00	$172.12	$0.00	$0.00	($22.52)	$849.60
System	$2,840.90	$1,535.69	$1,386.18	$0.00	($54.30)	$5,708.47

Figure 5.2: Total Cost Summary in HOMER Pro

From above figure it is seen that the total capital cost for the system is $2840.90 and the total net present cost (NPC), replacement cost, O&M cost over the 25 years lifetime period is given as $5708.47, $1535.69, $1386.18 respectively.

5.4.2 Cash Flow Chart

The below Cash flow chart is representing the income and expenses over the 25 years lifetime of our system. If we observe carefully, it's giving a clear idea about how much minimum capital we need initially in order to run the system which is approximately $2840.90 and every 3 years we will need some maintenance cost if something wrong happened in our system. The maximum amount we need for the replacement in 15 years is $1535.69.

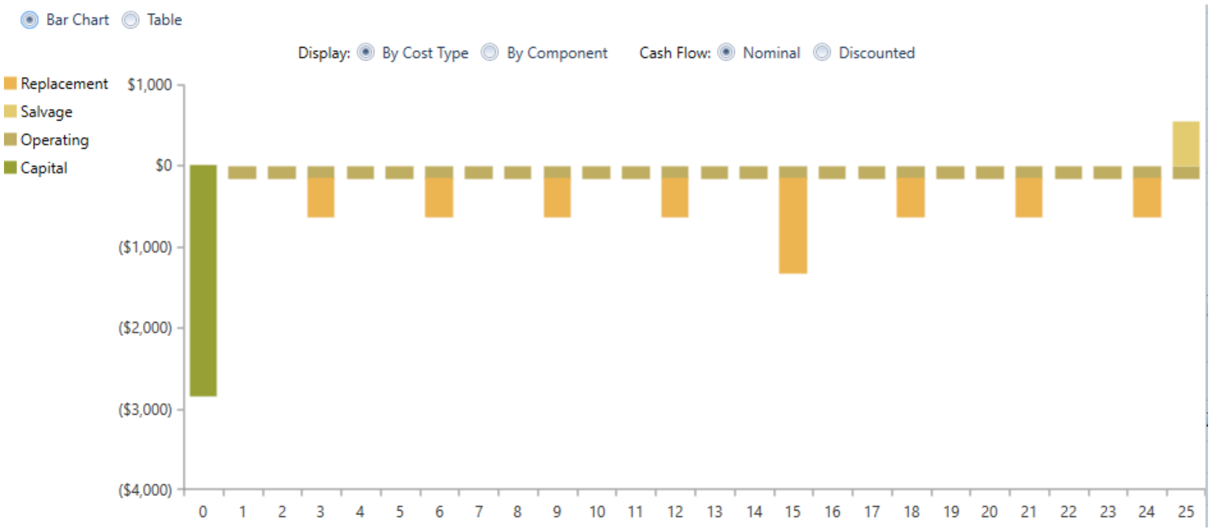
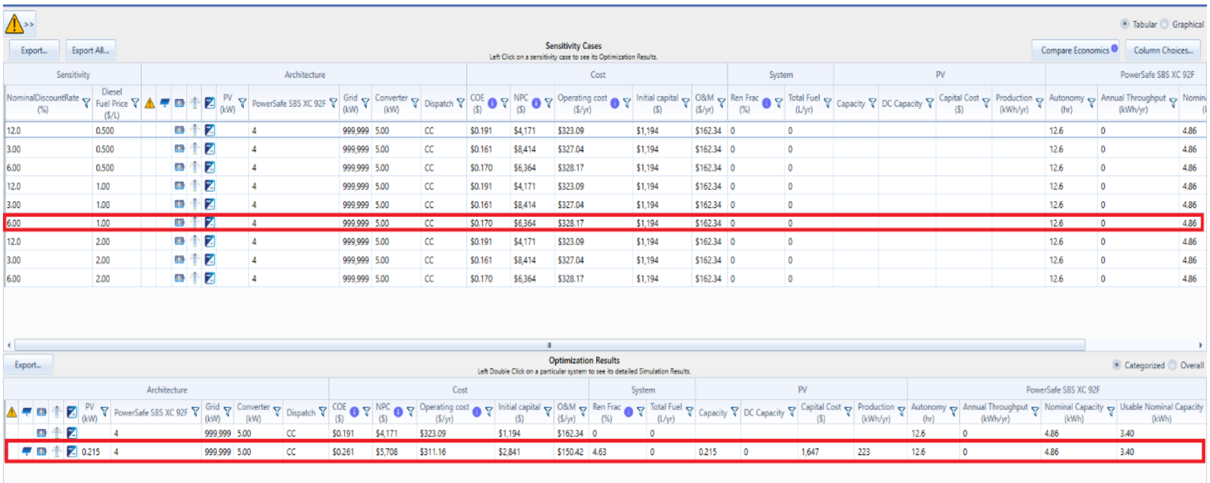


Figure 5.3: Cash Flow Chart

5.4.3 Simulation Results



Sensitivity Cases

Left Click on a sensitivity case to see its Optimization Results.

NominalDiscountRate (%)	Diesel Fuel Price ($/L)	PV (kW)	PowerSafe SBS XC 92F	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	O&M ($/yr)	Ren Frac (%)	Total Fuel (L/yr)	Capacity	DC Capacity	Capital Cost ($)	Production (kWh/yr)	Autonomy (hr)	Annual Throughput (kWh/yr)	Nomin
12.0	0.500		4	999,999	5.00	CC	$0.191	$4,171	$323.09	$1,194	$162.34	0	0					12.6	0	4.86
3.00	0.500		4	999,999	5.00	CC	$0.161	$8,414	$327.04	$1,194	$162.34	0	0					12.6	0	4.86
6.00	0.500		4	999,999	5.00	CC	$0.170	$6,364	$328.17	$1,194	$162.34	0	0					12.6	0	4.86
12.0	1.00		4	999,999	5.00	CC	$0.191	$4,171	$323.09	$1,194	$162.34	0	0					12.6	0	4.86
3.00	1.00		4	999,999	5.00	CC	$0.161	$8,414	$327.04	$1,194	$162.34	0	0					12.6	0	4.86
6.00	1.00		4	999,999	5.00	CC	$0.170	$6,364	$328.17	$1,194	$162.34	0	0					12.6	0	4.86
12.0	2.00		4	999,999	5.00	CC	$0.191	$4,171	$323.09	$1,194	$162.34	0	0					12.6	0	4.86
3.00	2.00		4	999,999	5.00	CC	$0.161	$8,414	$327.04	$1,194	$162.34	0	0					12.6	0	4.86
6.00	2.00		4	999,999	5.00	CC	$0.170	$6,364	$328.17	$1,194	$162.34	0	0					12.6	0	4.86

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

PV (kW)	PowerSafe SBS XC 92F	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	O&M ($/yr)	Ren Frac (%)	Total Fuel (L/yr)	Capacity	DC Capacity	Capital Cost ($)	Production (kWh/yr)	Autonomy (hr)	Annual Throughput (kWh/yr)	Nominal Capacity (kWh)	Usable Nominal Capacity (kWh)
	4	999,999	5.00	CC	$0.191	$4,171	$323.09	$1,194	$162.34	0	0					12.6	0	4.86	3.40
0.215	4	999,999	5.00	CC	$0.261	$5,708	$311.16	$2,841	$150.42	4.63	0	0.215	0	1,647	223	12.6	0	4.86	3.40

Figure 5.4: Simulation Results

We are considering that particular sensitive cases where the nominal discount rate is 6 and it's considering all the components together. By giving the 6% nominal discount, we get the net present cost as $6364, the operating cost as $328.17, initial capital as $1194.

In order to run our system in an optimal way we are considering the first optimization results where the net present cost is $5708.47, total operating cost is $311.16, initial capital is $2840.90, operating and maintaining cost is $1386.18and to construct the PV panel we need $1647.

5.4.4 Monthly Average Electricity Production

The monthly average electricity production (KWh) is shown in below:

Production	kWh/yr	%
Generic flat plate PV	2,409	90.9
Grid Purchases	242	9.11
Total	2,650	100

Consumption	kWh/yr	%
AC Primary Load	0	0
DC Primary Load	2,362	100
Total	2,362	100

Quantity	kWh/yr	%
Excess Electricity	210	7.91
Unmet Electric Load	10.5	0.441
Capacity Shortage	15.5	0.653

Quantity	Value
Renewable Fraction	89.8
Max. Renew. Penetration	1,148

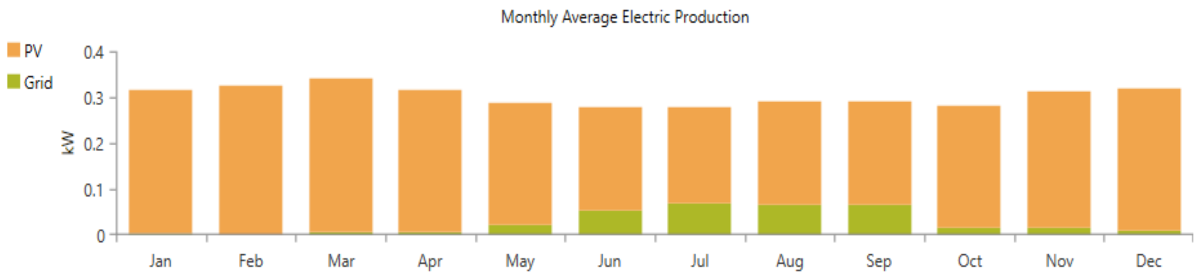


Figure 5.5: Monthly Average Electricity Production

The above figure shows that the annual average electricity production of Generic flat plate PV is 2409KWh and we need the grid supply in case of emergency is 242KWh and the annual electricity demand that is consumed by the load is 2362kWh. So, we will get the sufficient power supply from the PV panel as well as from the Grid supply in case of emergency without any issue. In the monthly average electric production chart, we can see in March, April the PV panel will provide the maximum output. If we look closely, we can measure the excess electricity, unmet electric load and capacity shortage by simulating our whole system in Homer Pro which is giving a general idea about how much electricity we will need if we face power shortage in extreme whether condition and the amount is 210KWh/year.

5.4.5 PV Panel Output

Quantity	Value	Units
Rated Capacity	2.08	kW
Mean Output	0.351	kW
Mean Output	8.42	kWh/d
Capacity Factor	16.9	%
Total Production	3,073	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	2.06	kW
PV Penetration	130	%
Hours of Operation	4,374	hrs/yr
Levelized Cost	0.0192	$/kWh

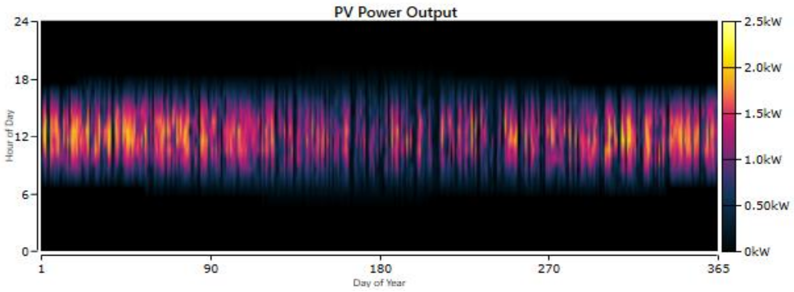


Figure 5.6: PV Power Output

If we look closely in the above figure, the rated capacity of PV panel is 2.08KW. The minimum and the maximum output it can give is 0.351 and 8.42 KWh/day which fulfilled our daily demand. In 24hr time format, we can see from 7 to 17hr, the PV panel is giving the output from the rage of 0.75 to 1.85KW per day.

5.5 Financial Analysis

Metric	Value
Present worth ($)	5,226.68
Annual worth ($/yr)	4,965.35
Return on investment (%)	39.7
Internal rate of return (%)	44.2
Simple payback (yr)	7.40
Discounted payback (yr)	9.20

Figure 5.7: Economical Analysis Chart for DC Load

After simulating our whole system in 'Homer Pro' we have come to know about the present worth of our system, annual worth after the usage, total return on investment, Simple payback after building the whole system in rooftop, if we give 6% discount what will be the discounted payback calculation which is $5226.68, $4965.35, $39.7%, 44.2%, 7.40 years and 9.20 years respectively. So, we have come to the conclusion that after building the project, approximately after 7 years and 5 months we will be able to recover our initial investment and the rest 17 years and 7 months we will be able to enjoy the free electricity which will be beneficial for both investors and consumers.

Metric	Value
Present worth ($)	$1,350
Annual worth ($/yr)	$172
Return on investment (%)	27.0
Internal rate of return (%)	31.8
Simple payback (yr)	13.03
Discounted payback (yr)	18.40

Figure 5.8: Economical Analysis Chart for AC Load

Now if we simulate our whole system where all the loads are AC type in 'Homer Pro' we have come to know about the present worth of our system, annual worth after the usage, total return on investment, Simple payback after building the whole system in rooftop, if we give 6% discount what will be the discounted payback calculation which is $1350, $172, $27%, 31.8%, 13.03 years and 18.4 years respectively. So, we have come to the conclusion that after building the project using AC load, according to Homer pro simulation result from the above figure, approximately after 13 years we will be able to recover our initial investment which is higher than DC load type and if we also considered 6% discounted payback then it will take approximately 18 years and 5 months which is again taking higher time to recover the initial investment. So, Using DC loads will be a smart choice rather than choosing AC loads.

5.6 Impact and Sustainability

5.6.1 Economic Sustainability

While developing the project, economic analysis plays a very valuable role which gives an idea to the investors that if the project will be economically feasible and sustainable. Solar energy is cost effective. Once installed without the maintenance cost, there is no significant expense is needed. The consumers can shortly realize that how much money can be saved by switching to solar energy. Which leads to economic self-reliance. Furthermore, power crisis can be reduced if the domestic consumers switch to the solar energy. As a result, the industrial consumer will have more electricity. This will help the nation to keep a steady growth of GDP. In addition to that, solar energy is inexpensive if compared with the grid electricity. Moreover, the local solar energy service provider will get opportunities to expand the business and more research and development would be done to the domestic solar energy solution companies. If the demand increases, the local companies for example 'Rohimafroz', 'Encysco' and 'Walton' would be interested to produce according to the native demand. This will also affect Bangladesh's economy and sustainability. We have used Homer Pro software which provides some financial parameters which includes inflation rate, discount rate, reinvestment rate, debt ratio, debt interest rate as input variables as shown in Table 6. The parameters are mentioned in the table below:

Financial Parameters	Unit
Discount rate	6%
Inflation rate	2%
Annual capacity shortage	5%
Project lifetime	25 years
salvage	$52
Initial cost	$5708.47
Operation and maintenance cost	$311.16
Total annual cost	$619.43

Table 5.2: Financial Input Variables

Financial Parameters	Unit
Payback Period	7.4 years
Return on investment	39.7%
Internal rate of return	44.2%
Total electricity production	3073KWh/year
Electricity cost	$0.06/KWh
Levelized cost	$0.0192/KWh
Annual Worth	$4965.35

Table 5.3: Financial Output Variables

5.6.2 Social Sustainability

Social and human development cannot be done without the proper access to energy. Access to sufficient energy not only flourishes economy but also leads to social sustainability. Renewable energy such as solar power can improve living standard by reducing expense of electricity bill and reutilizing it into other resources. Social life also gets benefitted by the easy access of solar energy. Moreover, people get aware of the advantages of the solar energy and play a role to reduce the environmental pollution caused by the fossil fuels. The contribution towards a green and healthy society can be made through this project.

5.6.3 Environmental Sustainability

The conventional ways for producing electricity in Bangladesh involves burning of fossil fuels and other natural resources. Due this continuous process, a huge amount of carbon di oxide is emitted to the atmosphere. Moreover, the natural resources are not abundant. If these resources are not utilized in a controlled manner within a very short period of time all of the resources will phase out. For example, the natural gas crisis in Bangladesh is getting more and more severe. However, due to the tropical position of this country, harnessing solar energy is very efficient and beneficent for this country. Through this project, carbon emission can be reduced. In addition to that, the global warming and climate change like global phenomena's can also be reduced at some extent. A chart of waste emission is given below:

Quantity	Value	Units
Carbon Dioxide	1,064	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	4.61	kg/yr
Nitrogen Oxides	2.26	kg/yr

Figure 5.9: Emission of Waste Particles Due to PV Panel Erosion

5.7 Applicable Standards and Codes

Bangladesh government has recently drafted a Bangladesh Energy Regulatory Commission (BERC) Regulation in 2016 which will be applied to all the renewable energy power plants including the solar home system. The draft says that BERC will be administrating all the terms & conditions, tariffs, etc. of the SHS. Also, the license for the plants will be provided by BERC if the protocols of the BERC act, 2003 and Renewable energy policy, 2008 are followed properly. On the contrary, no license will be required by plants installed for producing 5MW of energy, but in that case, those plants will need to collect a waiver certificate after being inspected with proper terms and conditions determined by BERC. The capability of our system is not that huge thus this system will not be required to have a license, rather a waiver certificate is enough.

BERC had formulated an electric grid code called “Grid Code”, according to which the appliance of SHS must follow IDCOL or any other international protocol to get approved of usage. Some of the protocols by IDCOL is as below:

I. The designed system must have the capability to run for at least two days without the need for any charge from the panels. The batteries used in the system must have at least 5 years of lifetime

II. It should have a convenient installation system so that the user can perform routine maintenance easily i.e. adding battery water, replacing appliances, changing fuses, etc.

III. PV panels used in the system must have a type-test certificate from any renowned organization. In the case of local panels, they should at least have the Technical Standard Committee (TSC) authorization.

IV. The PV module should be waterproof and framed with a proper mounting structure made of corrosion-resistant material.

V. The whole PV array must be able to resist up to 160 km/hour of wind force.

VI. The Minimum amount of clearance between the rooftop floor and panel must be 20 cm.

VII. The whole system must have proper safety and protection against battery overcharge/undercharge and excess water loss, excess discharge, short circuit protection, protection from reverse polarity, etc.

VIII. The wiring system must be insulated properly, some sample wire for the system is as followed:

From PV module to Charge Controller: 2.5 sq. mm/1.5 sq. mm

From Charge Controller to battery: 4.0 sq. mm

From Charge Controller to Socket Out-let: 4.0 sq. mm

From Charge Controller to all other loads: 1.5 sq. mm.

IX. The wires used in the system must have a warranty of at least 3 years and be approved by the TSC of IDCOL.

X. It is recommended by IDCOL to have at least 1 annual maintenance schedule with a complete check-up.

XI. An emergency shutdown procedure must be assigned to the system.

5.8 Ethical Consideration

Ethical consideration is one the most important term of a research work. The proposed system should not bring any harm to anyone and for this reason ethical consideration is done. We have done the ethical consideration by keeping in mind both the proponents/potential vendors and consumers point of view.

5.8.1 Ethical Consideration of Proponents/ Potential Vendors

While developing the project and later on commercializing it, all the standards and equipment codes should strictly be followed. Any kind of irregularities such a quality checking issues, faulty equipment must not be allowed. To avoid the electrical hazards such as arc hazards, short circuit hazards superior quality circuit breakers should be provided. Finally, while handing over to the consumers, a very standard and well explanatory operation manual and safety precaution guide book should be included.

5.8.2 Ethical Consideration of Consumers

The consumers should not try to save just a bit of money by bypassing the components with faulty and duplicate materials. The ethical concern about right and wrong on using the system is expected. After buying, people hardly do any maintenance to the solar system. This is a very common scenario in most of the apartments of Dhaka city. Consumers needed to maintain the system regularly for better performance and efficiency. Finally, huge concern should be given on the replacement units. If one equipment is not working properly, then the actual replacement unit should be bought and use rather than using inexpensive faulty equipment.

5.9 Risk Management

Installing solar system involves many risks so precautions are must while doing the task. Firstly, all the electrical equipment should be checked by the standards and approvals. Proper electrical certification is must while installing the system. For example, solar panels should be used from renowned companies for their professionalism and experience. Also, because they sell products by keeping the standards in mind. The batteries should be checked and used accordingly as batteries can be easily damaged and tend to explode. The wiring cables should be checked and follow the PDB instructions while giving connections as faulty wires leads to the short circuit hazard and compromises the whole system security. Furthermore, proper insulation and circuit breakers needed to be ensured to safeguard the system from different electrical hazards. Finally, the workers should be careful and advised to wear proper safety gears while installing the system.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

After one year of extensive research, the main objective of our research is to precisely motivate our citizens to use the existing solar panel of the rooftops. Only 59.6 percent of the people of Bangladesh have access to the national grid. In Bangladesh alone, 90 percent rooftop solar panels of ordinary residences or industrial sectors are kept idle [36]. Without keeping them idle, we can use this project to use our renewable resources. This project also includes battery and grid backup system to support it during gloomy days. One of the main reasons for the citizens to not use these rooftop PV panels is the expensive inverter. In this project, we have successfully shown that by using solar power we can save a huge amount of energy and monthly electricity bill. We also have a manual control box that gives the backup connection from the grid. We designed the whole system with DC appliances because they consume less amount of power than AC appliances. This project will inspire our citizens to properly utilize the solar panels without keeping them unutilized. It can save more than 58 % energy according to our calculation. In this way, the awareness of using solar energy will increase among our citizens. In addition, the total cost of this product easily proves the financial advantages rather than using other limited non-renewable resources [36].

For successful implementation and consequences of the project an extensive research is done to find out the problems of the existing systems and some improvements and the changes are done here. In this project, we have compared the economical and efficient aspects of both DC and AC appliances. In the future work we will use a voltage regulator which helps the existing system to work more reliably and seamlessly. Also, the energy efficiency analysis proves that the system is more user friendly than AC appliances. All the components that we have used in our system are available in the market which makes the system very feasible. The financial attainability report provides an overview of the project efficiency. Though the DC appliances in the market is not that much available yet, as new researches are done extensively in this field, soon the availability will increase. In case of glooming days for a longer period of time there is a manual switching system included in this project so that people of apartments get uninterrupted electricity.

6.2 Challenges and Future Development

There are some hard challenges that we faced while doing this project. Firstly, due to the covid-19 situation it was hard to gather the survey reports. Secondly, this project covers all the DC appliances which are hard to find in the Bangladeshi market. Some of the DC appliances that we used were successfully built by the Control Application of Research Centre (CARC) of BRACU.

However, we have successfully simulated the project and compared DC appliances vs AC appliances to show the total savings of power by using DC appliance. Moreover, we have used HOMER software for the cost calculation and feasibility test.

Our thesis has a higher vision for improvement with more extensive studies and analysis. Some of the possible place for improvement is given below:

- Automatic switching can be included between Grid connection and solar connection.
- In near future we will add the universal charge controller to easily use DC appliances of different voltage ratings.

- We proper voltage regulator can be developed for using various loads with different rated current and voltages.
- It will be better to add net-metering in this project because in that way we can share/sell excess produced energy with others.
- A practical pilot project will be more helpful to understand the system more extensively as we know that in case of simulation, we only get the ideal results but the practical results vary due to different factors.

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Appendix

Appendix A: Summer Data

Summer (April) Data

Time (24-hour format)	PV		Battery		Total load	
	Voltage V	Current A	Voltage V	Current A	Voltage V	Current A
0.1	48.96197	-0.01976	48.96197	20.45802	48.96197	20.43826
0.5	48.92188	-0.02062	48.92188	20.48803	48.92188	20.46741
1	48.90852	-0.02079	48.90852	20.48203	48.90852	20.46124
1.5	48.90554	-0.02148	48.90554	20.48149	48.90554	20.46001
2	48.90486	-0.02295	48.90486	20.48267	48.90486	20.45971
2.5	48.9047	-0.02406	48.9047	20.4837	48.9047	20.45964
3	48.90464	-0.02564	48.90464	20.48526	48.90464	20.45962
3.5	48.90494	0.093436	48.90494	20.36631	48.90494	20.45975
4	48.90546	0.212665	48.90546	20.2473	48.90546	20.45996
4.5	48.90956	1.638778	48.90956	18.82291	48.90956	20.46168
5	48.91595	3.064719	48.91595	17.39966	48.91595	20.46438
5.5	48.92736	6.151624	48.92736	14.31756	48.92736	20.46918
6	48.94177	9.241101	48.94177	11.23417	48.94177	20.47527
6.5	48.95835	12.87596	48.95835	7.60632	48.95835	20.48227
7	48.97604	16.5135	48.97604	3.976251	48.97604	20.48975
7.5	48.99463	20.38904	48.99463	0.108562	48.99463	20.49761
8	49.03087	24.26066	49.03087	-3.7481	49.03087	20.51256
8.5	49.126	27.57395	49.126	-7.02101	49.126	20.55294
9	49.21825	30.89165	49.21825	-10.2997	49.21825	20.59192
9.5	49.29681	32.79888	49.29681	-12.1737	49.29681	20.6252
10	49.36129	34.69654	49.36129	-14.0441	49.36129	20.65248
10.5	49.40535	34.92575	49.40535	-14.2546	49.40535	20.6712
11	49.43098	35.18018	49.43098	-14.4981	49.43098	20.68206
11.5	49.43167	33.55679	49.43167	-12.8743	49.43167	20.68246
12	49.41024	31.97512	49.41024	-11.3017	49.41024	20.67343
12.5	49.36515	28.82141	49.36515	-8.16694	49.36515	20.65447
13	49.2989	25.64501	49.2989	-5.01851	49.2989	20.6265
13.5	49.22207	22.19589	49.22207	-1.60184	49.22207	20.59405
14	49.13781	18.70119	49.13781	1.857247	49.13781	20.55844
14.5	49.1037	14.88252	49.1037	5.661322	49.1037	20.54384
15	49.08464	11.0239	49.08464	9.511871	49.08464	20.53577
15.5	49.06525	7.192761	49.06525	13.33481	49.06525	20.52758
16	49.04564	3.316613	49.04564	17.20267	49.04564	20.51928

Time (24-hour format)	PV		Battery		Total load	
	Voltage V	Current A	Voltage V	Current A	Voltage V	Current A
17	49.02237	0.143623	49.02237	20.36579	49.02237	20.50942
17.5	49.0176	0.073539	49.0176	20.43384	49.0176	20.50738
18	49.01561	-0.02729	49.01561	20.53383	49.01561	20.50654
18.5	49.01451	-0.02565	49.01451	20.53172	49.01451	20.50607
19	49.01372	-0.02414	49.01372	20.52987	49.01372	20.50573
19.5	49.01299	-0.02404	49.01299	20.52947	49.01299	20.50543
20	49.01228	-0.02379	49.01228	20.52892	49.01228	20.50513
20.5	49.01158	-0.02409	49.01158	20.52892	49.01158	20.50483
21	49.01088	-0.02373	49.01088	20.52827	49.01088	20.50454
21.5	49.01019	-0.02412	49.01019	20.52836	49.01019	20.50424
22	49.0095	-0.02368	49.0095	20.52763	49.0095	20.50395
22.5	49.00882	-0.02414	49.00882	20.5278	49.00882	20.50366
23	49.00814	-0.02365	49.00814	20.52702	49.00814	20.50338
23.5	49.00746	-0.02414	49.00746	20.52723	49.00746	20.50309
24	49.00679	-0.02363	49.00679	20.52644	49.00679	20.50281

Time (24-hour format)	Total load current A	Light current A	Fan current A	Stove current A	Refrigerator current A	water pump current A
0.1	20.43826	3.064418	1.608905	10.88044	0.612013	4.272489
0.5	20.46741	3.061733	1.630957	10.87153	0.611527	4.291668
1	20.46124	3.060839	1.630283	10.86856	0.611355	4.290205
1.5	20.46001	3.060639	1.630186	10.8679	0.61132	4.289965
2	20.45971	3.060593	1.630162	10.86775	0.61131	4.2899
2.5	20.45964	3.060582	1.630157	10.86771	0.611309	4.289886
3	20.45962	3.060579	1.630155	10.8677	0.611308	4.289881
3.5	20.45975	3.060599	1.630164	10.86777	0.611312	4.289906
4	20.45996	3.060633	1.630181	10.86788	0.611318	4.289952
4.5	20.46168	3.060908	1.630313	10.86879	0.611369	4.290302
5	20.46438	3.061336	1.630525	10.87021	0.611449	4.290861
5.5	20.46918	3.0621	1.630897	10.87275	0.611591	4.291848
6	20.47527	3.063065	1.631376	10.87595	0.611772	4.29311
6.5	20.48227	3.064175	1.631927	10.87963	0.611979	4.29456
7	20.48975	3.06536	1.632515	10.88356	0.6122	4.29611
7.5	20.49761	3.066605	1.633134	10.88769	0.612432	4.29774
8	20.51256	3.069032	1.634216	10.89575	0.61288	4.300681
8.5	20.55294	3.075402	1.637436	10.91689	0.614073	4.309137

Time (24-hour format)	Total load current A	Light current A	Fan current A	Stove current A	Refrigerator current A	water pump current A
9	20.59192	3.081579	1.64051	10.93739	0.615223	4.317219
9.5	20.6252	3.08684	1.643154	10.95485	0.616208	4.324155
10	20.65248	3.091158	1.64531	10.96918	0.617013	4.329823
10.5	20.6712	3.094108	1.646811	10.97897	0.617566	4.333744
11	20.68206	3.095825	1.647675	10.98466	0.617886	4.33601
11.5	20.68246	3.095871	1.647738	10.98482	0.617896	4.336137
12	20.67343	3.094436	1.647035	10.98005	0.617629	4.334279
12.5	20.65447	3.091416	1.645568	10.97003	0.617066	4.330385
13	20.6265	3.08698	1.643372	10.95531	0.616239	4.324595
13.5	20.59405	3.081835	1.640823	10.93824	0.615279	4.317877
14	20.55844	3.076192	1.638018	10.91951	0.614226	4.310491
14.5	20.54384	3.073909	1.636813	10.91193	0.613798	4.307391
15	20.53577	3.072632	1.636175	10.9077	0.613558	4.305704
15.5	20.52758	3.071334	1.635529	10.90339	0.613317	4.304005
16	20.51928	3.07002	1.634876	10.89903	0.613071	4.302286
16.5	20.51352	3.069112	1.634414	10.89602	0.612902	4.301078
17	20.50942	3.068462	1.634089	10.89386	0.61278	4.300225
17.5	20.50738	3.068143	1.633923	10.8928	0.61272	4.299794
18	20.50654	3.068009	1.633856	10.89236	0.612695	4.29962
18.5	20.50607	3.067936	1.633818	10.89211	0.612681	4.29952
19	20.50573	3.067883	1.633791	10.89194	0.612672	4.29945
19.5	20.50543	3.067834	1.633767	10.89178	0.612662	4.299387
20	20.50513	3.067787	1.633744	10.89162	0.612654	4.299324
20.5	20.50483	3.06774	1.63372	10.89146	0.612645	4.299263
21	20.50454	3.067693	1.633697	10.89131	0.612636	4.299202
21.5	20.50424	3.067647	1.633674	10.89115	0.612627	4.299141
22	20.50395	3.067601	1.633651	10.891	0.612619	4.299081
22.5	20.50366	3.067555	1.633628	10.89085	0.61261	4.299021
23	20.50338	3.067509	1.633605	10.8907	0.612602	4.298961
23.5	20.50309	3.067464	1.633583	10.89055	0.612593	4.298902
24	20.50281	3.067419	1.63356	10.8904	0.612585	4.298843

Appendix B: Winter Data

Winter (December) Data

Time (24-hour format)	PV		Battery		Total load	
	Voltage V	Current A	Voltage V	Current A	Voltage V	Current A
0.1	48.98194	-0.00454	48.96199	20.44281	48.96199	20.43827
0.5	48.92795	-0.00555	48.92194	20.47299	48.92194	20.46744
1	48.90993	-0.00581	48.90859	20.46708	48.90859	20.46127
1.5	48.90591	-0.0053	48.90561	20.46534	48.90561	20.46004
2	48.90501	-0.00521	48.90494	20.46496	48.90494	20.45975
2.5	48.9048	-0.00493	48.90479	20.46461	48.90479	20.45968
3	48.90475	-0.00513	48.90474	20.46479	48.90474	20.45966
3.5	48.90473	-0.00483	48.90472	20.46449	48.90472	20.45966
4	48.90471	-0.00483	48.90471	20.46448	48.90471	20.45965
4.5	48.90519	0.249661	48.90539	20.21027	48.90539	20.45993
5	48.90627	0.50327	48.90651	19.95714	48.90651	20.4604
6	48.91948	4.473373	48.92136	15.99329	48.92136	20.46666
6.5	48.93145	7.702134	48.93435	12.77	48.93435	20.47214
7	48.94653	10.93383	48.94967	9.544782	48.94967	20.47861
7.5	48.96256	14.27992	48.96583	6.205516	48.96583	20.48544
8	48.97902	17.63684	48.98233	2.855578	48.98233	20.49241
8.5	48.99344	19.88068	48.99592	0.617488	48.99592	20.49817
9	49.00553	22.13894	49.00806	-1.63563	49.00806	20.5033
9.5	49.03917	22.57504	49.04441	-2.05642	49.04441	20.51863
10	49.06021	23.02514	49.06347	-2.49842	49.06347	20.52672
10.5	49.07077	22.82173	49.07128	-2.29167	49.07128	20.53006
11	49.07118	22.62438	49.07084	-2.0945	49.07084	20.52989
11.5	49.05985	21.19212	49.05473	-0.66897	49.05473	20.52315
11.6	49.05473	20.90476	49.04909	-0.38399	49.04909	20.52077
12	49.03012	19.75666	49.02341	0.75327	49.02341	20.50993
12.5	49.00943	17.0404	49.00705	3.462562	49.00705	20.50296
13	48.99689	14.3204	48.99426	6.177144	48.99426	20.49754
13.5	48.98323	11.41222	48.98041	9.079474	48.98041	20.49169
14	48.96894	8.483125	48.96604	12.00249	48.96604	20.48562
14.5	48.95368	5.172951	48.95048	15.3061	48.95048	20.47905

Time (24-hour format)	PV		Battery		Total load	
	Voltage V	Current A	Voltage V	Current A	Voltage V	Current A
15.5	48.92572	0.966622	48.92429	19.50132	48.92429	20.46795
16	48.91964	0.071095	48.91862	20.39445	48.91862	20.46554
16.5	48.91644	0.036744	48.91617	20.42775	48.91617	20.4645
17	48.91549	-0.01481	48.91538	20.47897	48.91538	20.46416
17.5	48.91513	-0.01404	48.91509	20.47807	48.91509	20.46404
18	48.91499	-0.01326	48.91497	20.47724	48.91497	20.46399
18.5	48.9149	-0.01139	48.91488	20.47534	48.91488	20.46395
19	48.91483	-0.00955	48.91481	20.47347	48.91481	20.46392
19.5	48.91476	-0.00879	48.91474	20.47268	48.91474	20.46389
20	48.91468	-0.00829	48.91467	20.47215	48.91467	20.46386
20.5	48.91461	-0.00744	48.91459	20.47126	48.91459	20.46383
21	48.91454	-0.0066	48.91452	20.4704	48.91452	20.4638
21.5	48.91446	-0.00613	48.91445	20.4699	48.91445	20.46377
22	48.91439	-0.00578	48.91438	20.46951	48.91438	20.46374
22.5	48.91432	-0.00584	48.9143	20.46955	48.9143	20.4637
23	48.91424	-0.00602	48.91423	20.4697	48.91423	20.46367
23.5	48.91417	-0.00621	48.91415	20.46985	48.91415	20.46364
24	48.91409	-0.0064	48.91408	20.47001	48.91408	20.46361

Time (24-hour format)	Total load current A	Light current A	Fan current A	Stove current A	Refrigerator current A	water pump current A
0.1	20.4382697	3.064419	1.608905	10.88044	0.61201349	4.2724905
0.5	20.46743822	3.061737	1.630959	10.87154	0.61152722	4.29167343
1	20.46127251	3.060843	1.630286	10.86858	0.61135612	4.29021153
1.5	20.46003992	3.060644	1.630189	10.86791	0.61132134	4.28997173
2	20.45974772	3.060599	1.630165	10.86777	0.61131098	4.28990751
2.5	20.45968224	3.060588	1.63016	10.86773	0.61131044	4.28989368
3	20.4596623	3.060585	1.630158	10.86772	0.61130882	4.28988967
3.5	20.45965516	3.060584	1.630157	10.86772	0.61130937	4.28988802
4	20.45964922	3.060583	1.630157	10.86771	0.61130863	4.2898869
4.5	20.45993273	3.060629	1.630179	10.86786	0.61131731	4.28994454
5	20.46040489	3.060704	1.630216	10.86811	0.61133127	4.29004217
6	20.46665825	3.061698	1.630702	10.87141	0.61151661	4.29132959
6.5	20.47213521	3.062568	1.631129	10.8743	0.61167877	4.29245957
7	20.47860788	3.063594	1.631639	10.8777	0.61187026	4.2938014
7.5	20.48543785	3.064676	1.632177	10.88129	0.61207222	4.29521789
8	20.49241276	3.065781	1.632727	10.88496	0.61227849	4.29666484
8.5	20.49816978	3.066691	1.633184	10.88798	0.61244851	4.29786507
9	20.50330354	3.067504	1.633588	10.89068	0.61260031	4.29892935
9.5	20.51862622	3.069938	1.634786	10.89876	0.61305356	4.30209159
10	20.52671673	3.071214	1.635432	10.90299	0.61329321	4.30378426
10.5	20.53005991	3.071738	1.635707	10.90473	0.6133906	4.30449439
11	20.52988593	3.071708	1.635697	10.90463	0.6133859	4.30446351
11.5	20.52314679	3.070629	1.635186	10.90105	0.61318484	4.30309526
12	20.50992938	3.068532	1.63415	10.89409	0.61279415	4.30036181
12.5	20.50295804	3.067436	1.633583	10.89046	0.61258911	4.29889378
13	20.49754484	3.06658	1.633156	10.88761	0.61242841	4.2977661
13.5	20.49169075	3.065652	1.632695	10.88453	0.61225587	4.29655303
14	20.48561972	3.06469	1.632217	10.88134	0.61207588	4.29529388
14.5	20.47904744	3.063649	1.6317	10.87789	0.6118818	4.29393175
15	20.47214824	3.062555	1.631156	10.87426	0.61167753	4.29250104
15.5	20.46794575	3.061894	1.630817	10.87206	0.61155388	4.29161648
16	20.46554362	3.061515	1.630626	10.8708	0.6114829	4.29111643
16.5	20.46449631	3.061351	1.63054	10.87026	0.61145212	4.29089398
17	20.46416024	3.061298	1.630513	10.87008	0.61144223	4.29082322
17.5	20.46403778	3.061278	1.630503	10.87002	0.61143864	4.29079782
18	20.46398567	3.06127	1.630499	10.86999	0.61143708	4.29078687
18.5	20.46395078	3.061265	1.630496	10.86997	0.61143607	4.29077961
18.9	20.4639265	3.061261	1.630494	10.86996	0.61143535	4.29077457
19	20.46392055	3.06126	1.630494	10.86996	0.61143516	4.29077334
19.5	20.46389024	3.061255	1.630491	10.86994	0.61143427	4.29076705

Time (24-hour format)	Total load current A	Light current A	Fan current A	Stove current A	Refrigerator current A	water pump current A
20.1	20.46385275	3.061249	1.630488	10.86992	0.61143316	4.29075928
20.5	20.46382806	3.061245	1.630487	10.86991	0.61143243	4.29075416
21	20.46379755	3.06124	1.630484	10.86989	0.61143152	4.29074783
21.5	20.46376683	3.061235	1.630482	10.86988	0.61143062	4.29074146
22	20.46373582	3.061231	1.630479	10.86986	0.6114297	4.29073503
22.5	20.46370444	3.061226	1.630477	10.86984	0.61142877	4.29072852
23	20.46367266	3.061221	1.630474	10.86983	0.61142783	4.29072194
23.5	20.46364092	3.061215	1.630472	10.86981	0.61142689	4.29071535
24	20.46360931	3.06121	1.630469	10.86979	0.61142596	4.2907088