DESIGN, SIMULATION AND FEASIBILITY ANALYSIS OF A SOLAR ROOFTOP PV SYSTEM FOR ACADEMIC BUILDING 4 OF DAFFODIL INTERNATIONAL UNIVERSITY

A Project and Thesis submitted in partial fulfillment of the requirements for the Award of Degree of
Bachelor of Science in Electrical and Electronic Engineering

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Certification

This is to certify that this project and thesis entitled "**DESIGN, SIMULATION AND FEASIBILITY ANALYSIS OF A SOLAR ROOFTOP PV SYSTEM FOR ACADEMIC BUILDING 4 OF DAFFODIL INTERNATIONAL UNIVERSITY**" is done by the following students under my direct supervision, and this work has been carried out by them in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering. The presentation of the work was held on 27th June 2021.

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The project and thesis entitled **"DESIGN, SIMULATION AND FEASIBILITY ANALYSIS OF A SOLAR ROOFTOP PV SYSTEM FOR ACADEMIC BUILDING 04 OF DAFFODIL INTERNATIONAL UNIVERSITY,"** submitted by **Name: A.S.M. Shahriar Habib, ID No: 171-33-439, & Name: Md. Nazim Uddin, ID No:171-33-444** Session: Spring 2017 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** on 27th June 2021.

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Dedicated to

Our Parents

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List of Abbreviations

HOMER	Hybrid Optimization Model for Electric Renewables
PV	Photovoltaic
LPG	Liquefied Petroleum Gas
LNG	Liquefied Natural Gas
LED	Light Emitting Diodes
BCF	Billion Cubic Feet
MT	Mega Ton
AC	Alternating Current
DC	Direct Current
BIPV	Building Integrated Photovoltaic
PWM	Pulse Width Modulation
MPPT	Maximum Power Point Tracker
HP	Horse Power
UPS	Uninterruptible Power Source
PSE	Pressure Safety Element
SI	International System of Units
AB4	Academic Building 4
GHI	Global Horizontal Irradiance
BDT	Bangladeshi Taka
STC	Standard Test Conditions
RMS	Root-Mean-Squared
NPC	Net Present Cost
COE	Cost of Energy

List of Symbol

Ω	Resistance (Ohm)
CO_2	Carbon-di-Oxide
N_2O	Nitrous Oxide
CH_4	Methane
η	Efficiency
$°C$	Degree Celsius
U_c	Thermal Constant Component
U_v	Wind Velocity

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ABSTRACT

Electricity is a vital element of the economic development of a country and quality of living. The energy sector of Bangladesh is entirely dependent on natural gas. However, natural gas reserves are depleting. As a result, it is essential to reduce reliance on natural gas. Besides, burning fossil fuels is one of the primary sources of the greenhouse effect and climate change. Solar power is the most viable option for reducing dependency on gas and reducing greenhouse gas emissions as this is clean energy. Every day, Daffodil International University uses a lot of energy. Almost all of the electricity is supplied from the national grid. So, a feasible solar project will aid in the reduction of grid supply. The architecture, simulation, and feasibility study of a solar project are presented in this article. The most critical step in creating a solar project model is calculating the load at various times of the year, measuring the rooftop and its productive location. These data have been measured at the beginning. The average load for full and reduced load is 9737.57 kWh/day and 3037.3 kWh/day, respectively. The project's effective area is 1845 m^2 which was measured practically. PVSYST was used to determine the number of solar panels and the highest capacity. Besides, different losses are also mentioned in this section. The solar panels have a maximum capacity of 298 kW to generate electricity. To visually reflect the project, Sketchup Pro is used. In this thesis, HOMER is the leading simulation software here. Two simulations are performed. One is for the whole building's loads, and the other is for the classroom, washroom, and corridor loads. The cost of energy is BDT 8.95 for full load and BDT 8.12 for the reduced load. So, when the load is reduced, the cost also decreases. So, reduced load results in a much feasible system.

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Bangladesh is a tiny country with a large population. About 149.77 million people live here, and the population is increasing day by day [1]. So a massive amount of electricity is needed to meet her demand. At this stage, the government is focusing on renewable energy [1]. They are taking initiatives to motivate people to use renewable energy. Among the renewable resources, solar energy is the most popular and cheapest resource. Daffodil International University is a Bangladeshi University situated at Ashulia in Dhaka. It requires much energy every day. Our challenge is to construct a solar project on the rooftop of Academic Building 4. As it needs a huge of energy, it is necessary to find out the most feasible way.

1.2 Literature Reviews

The base of the whole thesis work is constructing a solar project at the rooftop of Academic Building 4 of Daffodil International University. To complete this thesis work correctly, we used various sources of information and researches. We have collected some experimental data by surveying the site. Besides, We have used calculations that take into account both current conditions and values. Moreover, We used PVSYST and Sketchup pro for designing the solar project. HOMER is working here as the simulation software. We used HOMER to determine the most feasible way to implement the project at the rooftop for different loads. At the end of the article, we have made a distinction. We have tried to suggest which is the best and feasible way to construct the project.

1.3 Objectives

This research work aims to concentrate on the use of both solar and grid power at the same time to power loads of the Academic Building 4 of Daffodil International University. The objectives of this are:

i. To study the present renewable energy conditions of Bangladesh.

ii. To measure the rooftop of Academic Building 4 of Daffodil International University.

iii. To find out the loads for different times of a day of both Summer and Winter.

iv. To find out the system power using PVSYST.

v. To assess techno-economic feasibility of the system using the HOMER model

1.4 Thesis Outline

The following is the structure of this project/thesis:

Chapter 1 presents the introduction.

Chapter 2 introduces the background.

Chapter 3 represents solar power and photovoltaic technology.

Chapter 4 indicates the components of a solar PV system.

Chapter 5 describes the solar system design.

Chapter 6 is the load survey of the building.

Chapter 7 shows the measurement of the rooftop.

Chapter 8 is the analysis and simulation.

Chapter 9 represents feasibility analysis.

Chapter 10 is the conclusion and future works.

CHAPTER 2

BACKGROUND AND MOTIVATION

2.1 Introduction

Natural gas meets most of the energy demand of Bangladesh. Oil, coal, biomass, and other forms of energy are essential. Our country has a large coal reserve, but coal is less produced and less used. On the other hand, natural gas has a small reserve. However, it has the highest output and use of all the available commodities. Aside from that, the authority uses imported oil and LPG to meet energy demand. Furthermore, the government has begun importing LNG to meet rising gas demand.

Renewable energy is being used instead of gas, coal, and oil worldwide. It is critical for long-term sustainability and environmental protection by reducing carbon emissions. Bangladesh uses renewable energy as well, but it is of only a tiny amount. The government has introduced several moves to increase the use of renewable energy in the future, including installing solar home systems, solar irrigation systems, and the Rooppur nuclear project, etcetera.

2.2 Global Energy Crisis

Energy has been an indispensable part of our everyday lives as well as the world economy. Now It has turned into a vital part of our everyday needs. However, about 770 million people do not have access to modern energy facilities [2]. If they achieve a reasonable standard of living by relying on conventional fossil fuels, the effects would be catastrophic for the world. Furthermore, as the world's population and living standards continue to rise, global energy demand is projected to increase significantly.

Between 2012 and 2040, global energy demand can increase by nearly half. According to the EIA, developed world demand will increase by 18 percent. In comparison, developing country demand will increase by 71 percent, with demand in India, Southeast Asia, and Africa more than doubling [3].

For one thing, much of today's energy use is unsustainable due to the corporate pattern of profit maximization over resource conservation. Until the finiteness of capital is known, wasteful habits will have to change.

The present system would have disastrous results. In terms of global climate change, carbon dioxide emissions associated with burning fossil fuels are a top concern for foreign policymakers. Furthermore, there are increasing worries regarding supply stability, shortages, and the effects of energy prices.

The initiative to the energy shortage is to reduce the world's reliance on non-renewable fuels while still increasing overall sustainable development. Fossil fuels are the creator of much of the industrial age. However, other forms of renewable energy, such as water, solar, and wind, are also considered to be used in technology. The world policymakers are also concerned about this issue and trying to take initiatives. According to the "Global Energy Outlook 2020," Renewables will meet 80% of global energy demand growth by 2030 [4].

To eliminate power scarcity, we must therefore use less energy than we did previously. We will do that by upgrading and modernizing electricity infrastructures like smart grids and green infrastructure. It is also essential to upgrade outdated equipment with energy-efficient alternatives, such as Light Emitting Diodes (LED) instead of conventional light bulbs.

2.3 Energy Crisis in Bangladesh

Electricity has brought the earth a more modern and unique way of living. It is challenging to view a civilized society without electricity. One of the significant issues of Bangladesh is the power crisis. The distance between demand and supply is increasing every day. Nowadays, it has become a severe problem. The following are among the reasons for the reduced availability:

i. Many plants are not repairable, reconstruction, and overhaul.

ii. Age has derated the capacity of some plants.

iii. Fuel shortage.

Transmission losses, equipment losses, distribution losses, and corrupt management are all factors that are responsible for the power crisis. Usage, pricing, and collections losses, on the other hand, are non-technical failures. As the need for electricity grows, new power plants must be constructed to satisfy the growing demands. However, it is unlikely that the government can create many new power plants in our country because of insufficient funds. On the other hand, the old power plants have come to the end of their expected life. In that case, either of the modules or even the whole station may have gone down severely. As a result, the national grid is disrupted, and the entire country is plunged into darkness. [5].

It is time to consider renewable energy sources to substitute to prevailing renewable resources to solve them partially. Sunshine, wind, and tidal power are only a few green energy options available to us in nature. These tools, unlike fossil fuels, can be used for a long time. Science proposed the concept of collecting the vast amounts of energy that exist in the universe.

2.4 Installed Capacity in Bangladesh

Bangladesh's power sector is highly dependent on fossil fuels. Natural gas and coal serve as the country's primary power generation sources. Bangladesh's generated electricity comes from natural gas is 51.68%. In comparison, 27.51% comes from furnace oil, 5.87%

is from diesel, 8.05% from coal, 1.05% is from hydro, 5.28% comes from power import, and 0.56% is from renewable energy [6].

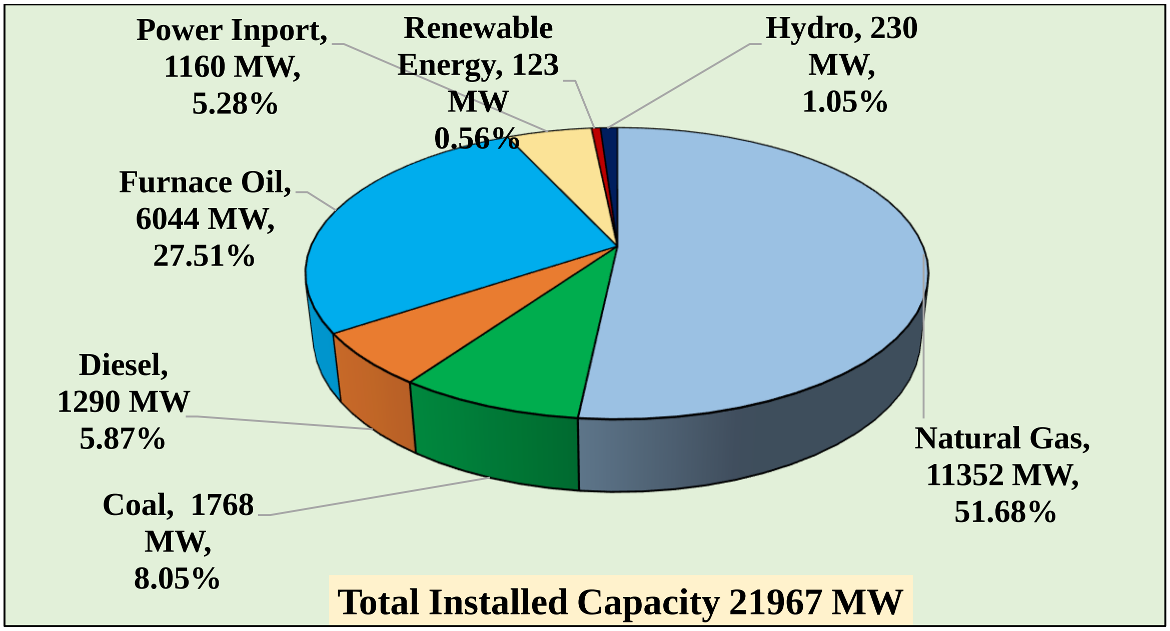

Figure 2.1: Resource-based installed capacity and percentage of Bangladesh.

2.5 Energy Reserve of Bangladesh

The country's energy reserves are deficient, with only a little oil, coal, and countable natural gas reserves. The country faces an internal energy crisis, as gas-fired thermal power plants account for nearly all of the country's power generation. However, gas is also necessary for the industrial sector. Therefore, the country has to make some compromises between power production and development continuously. The present reserve of different resources are as follows:

2.5.1 Natural Gas

Since the first discovery in 1955, the country has discovered 26 gas fields, 24 onshore and two offshore. One offshore gas field depilated after 14 years of output, while another offshore field was not viable for production due to a limited reserve [7].

Table 2.1: The present condition of natural gas [7].

Fuel	Reserve
Gas Initially Place (Proven + Probable)	40,092.19 BCF
Recoverable (Proven + Probable)	30055.40 BCF
Remaining Reserve	11,736.10 BCF

2.5.2 Coal

Given the uncertainty of long-term energy supply from natural gas, it is essential to diversify its primary energy sources. Domestic coal may be a significant alternative energy source for energy security [8] .

Table 2.2: Field-wise Coal Reserve in Bangladesh [7].

Coal Basins	Proved (MT)	Indicated (MT)	Inferred (MT)	Total (MT)
Barapukuria	114.32	211.33	21.06+(43-64)	346.71+(43-64)
Phulbari	288	226	58	572
Khalashpir	-	297.57	225.92	523.49
Jamalganj	-	-	1053.9	1053.9
Dighipara	-	105	495	600
Total	402.32	839.9	1896.88-1917.88	3139.10-3160.10

2.5.3 Peat

Bangladesh's peat deposits are found in low-lying areas of the alluvial plain, submerged for a significant portion of the year. Peat is available in Baghia-Chanda beel in Madaripur and Gopalganj districts, Kola Mouza in Khulna district, Chatal beel in Moulavibazar district, Pagla, Dirai, and Shalla in Sunamganj district, Chorkai in Sylhet district, and

Brahma beel in Brahmanbaria Sadar Upazila of Brahmanbaria district and Mukundapur area of Habiganj district [9].

Table 2.3: Reserve of Peat in Bangladesh [8].

Fossil Fuel	Reserve
Peat	146.36 MT

2.6 Renewable Energy Sources in Bangladesh

Renewable energy is generated by humans utilizing renewable resources such as daylight, wind, waves, and geothermal heat. It is also known as clean energy. It is derivable from natural sources or processes refilled regularly. For example, sunlight or wind continue to shine and blast, even though time and temperature limit their availability. However, renewable energy will remain annexed to the existing energy genesis by non-renewable traditional means for the near future. Table 2.4 represents the contribution of renewable energy to power generation in Bangladesh. Figure 2.2 shows the total capacity share from renewable energy.

The present contribution of renewable resources are given in Table 2.4 and the current state of renewable energy resources in Bangladesh are shown in Figure 2.2 [10]:

Table 2.4: The present contribution of Renewable Resources.

Technology	Off-grid (MW)	On-grid (MW)	Total (MW)
Solar	346.58	143.6	490.18
Wind	2	0.9	2.9
Hydro	0	230	230
Biogas to Electricity	0.63	0	0.63
Biomass to Electricity	0.34	0	0.4
Total	349.61	374.5	724.11

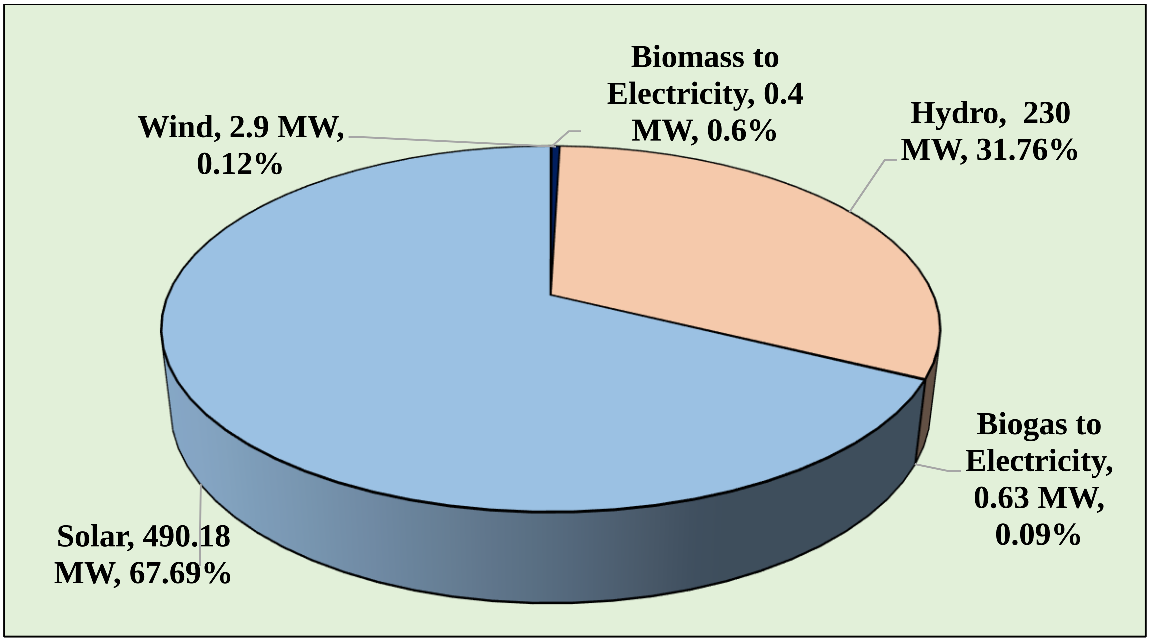

Figure 2.2: Bangladesh's current renewable energy resources situation.

2.6.1 Solar Energy

We can get thermal or electrical energy by conversion of solar energy. It has been used in several ways by people all over the world for thousands of years. The main benefits of solar energy are that it has no pollution, inexhaustible and ideal for deserts and isolated areas where other outlets are unavailable. As the cost of solar materials is low, solar energy has the eligibility to play a significant role in the future.

The average daily isolation of 4-6.5 kwh/m^2 falls about 300 days per year. With the most amount of irradiation accessible in March-April and the smallest amount of irradiation usable in the months of December-January, Bangladesh has a high potential for solar energy [9].

The photovoltaic power potential map of Figure 2.3 describes the whole situation [11].

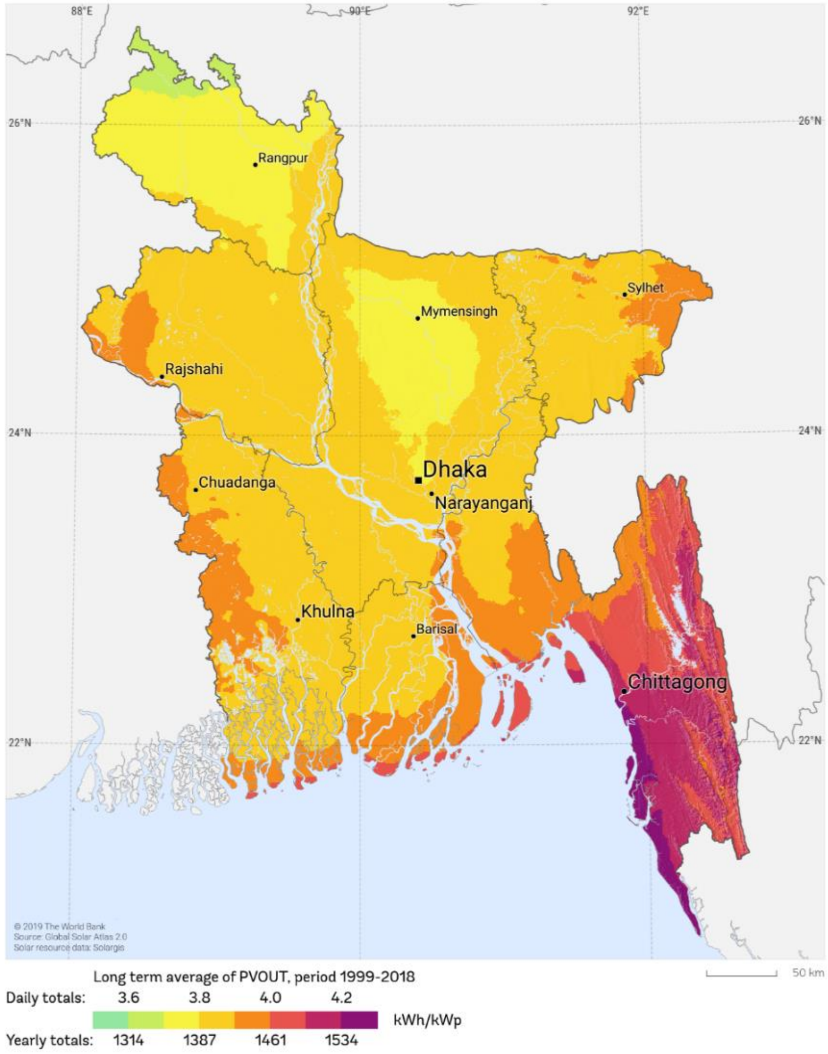

Figure 2.3: The photovoltaic power potential of Bangladesh.

2.6.2 Wind Energy

The electricity produced from the wind's strength is regarded as wind energy. The rotor and generator commonly obtain the energy. Firstly, The rotor turns dynamic energy into mechanical energy, converted into electrical energy by the generator. Wind energy has lots of benefits. It uses a local, good for the environment, and lengthy fuel supply. By limiting energy produced from fossil fuels, wind turbines can also help decrease gross air pollution and carbon dioxide emissions. In Bangladesh, we do not use wind energy correctly. In 2019, the government pursued foreign firms' participation in constructing wind power projects at Mongla, Inani in Cox'Bazar, and Kachua in Chandpur. Envision Energy expressed an interest in developing plants in Mongla and Inani [12].

The typical wind speed of different places in Bangladesh is given in Table 2.5, and the mean wind speed of different places are shown in Figure 2.4 [13]:

Table 2.5: Normal wind speed of Bangladesh

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka	1.23	1.60	2.59	4.21	3.80	3.70	3.64	3.21	2.24	1.28	0.93	0.92
M.singh	1.07	1.45	2.18	3.21	3.21	3.21	3.01	2.68	2.10	1.32	0.87	0.78
Tangail	1.23	1.44	2.08	3.17	3.23	3.29	3.19	2.65	1.12	1.26	0.97	0.90
Faridpur	1.26	1.43	2.42	3.92	4.06	3.76	3.62	3.31	2.66	1.53	1.09	1.12
Madaripur	0.84	0.94	1.53	2.40	2.22	2.03	2.21	2.09	1.38	0.83	0.59	0.60
C.gram	2.54	3.27	5.03	7.54	7.44	8.77	8.87	7.92	5.56	3.06	2.14	2.11
Sandwip	1.27	1.78	3.10	4.19	4.20	4.91	4.90	4.51	2.87	1.75	1.09	1.10
Sitakunda	1.12	1.57	2.56	3.21	3.21	3.70	3.54	3.19	2.19	1.21	0.86	0.83
R.mati	1.26	1.51	2.31	2.90	2.60	2.54	2.54	2.12	1.62	1.26	1.10	1.09
Cumilla	1.16	1.58	2.81	4.30	4.36	4.64	4.73	4.10	2.69	1.44	0.89	0.88
Chandpur	0.85	0.96	1.92	2.80	2.22	2.21	2.12	1.87	1.36	0.92	0.72	0.67
M_Court	0.71	1.08	1.81	2.91	2.84	3.41	3.45	3.01	1.98	1.08	0.71	0.60
Feni	0.84	1.26	1.97	2.95	2.75	3.17	3.43	3.02	2.01	1.00	0.70	0.63
atiya	2.33	2.53	3.57	5.14	4.02	5.81	5.64	4.67	3.38	2.06	1.63	1.65
C.Bazar	3.60	3.85	4.30	4.84	5.36	6.15	6.41	5.75	4.20	3.15	2.93	3.13
Kutubdia	2.52	2.64	3.38	3.88	4.02	5.40	5.40	4.78	3.13	2.19	1.72	1.93
Teknaf	1.93	2.44	2.54	2.15	2.27	2.39	2.48	2.27	1.49	1.29	1.21	1.16
Sylhet	2.18	2.68	3.25	3.25	2.82	2.56	2.39	2.18	1.84	1.84	1.98	2.07
Srimangal	0.46	0.91	1.63	1.83	1.53	1.42	1.63	1.21	0.87	0.58	0.36	0.30
Rajshahi	1.64	1.77	2.26	3.40	3.73	3.55	3.24	2.90	2.45	1.53	1.45	1.66
Ishurdi	1.57	1.75	2.64	4.62	4.92	4.73	4.23	3.85	2.89	1.58	1.34	1.53
Bogra	1.29	1.58	2.17	3.07	3.12	2.90	2.65	2.38	1.90	1.20	0.96	1.05
Rangpur	1.25	1.59	2.50	3.40	3.01	2.93	2.77	2.60	2.14	1.63	1.46	1.25
Dinajpur	0.98	1.20	1.72	1.99	1.76	1.74	1.62	1.43	0.18	0.81	0.66	0.69
Sayedpur	2.67	3.14	4.60	4.76	4.00	3.73	3.56	3.05	2.74	2.12	2.04	2.24
Khulna	1.34	1.61	2.48	3.72	3.74	3.34	3.20	3.25	2.23	1.27	0.97	1.07
Mongla	1.86	2.05	2.71	3.96	4.17	3.98	3.70	3.46	2.71	1.87	1.45	1.50
Satkhira	1.54	1.81	2.50	3.75	3.72	3.16	2.83	2.56	2.05	1.51	1.40	1.47
Jessore	1.38	1.85	3.42	6.00	6.25	5.41	4.84	4.29	3.37	1.71	1.19	1.11
Chuadanga	0.82	0.95	1.57	2.47	2.44	2.31	1.99	1.71	1.55	0.94	0.62	0.66
Barisal	0.64	0.96	1.85	3.11	3.00	2.92	2.84	2.45	1.62	0.83	0.54	0.56
Patuakhali	1.61	1.77	2.72	3.93	4.02	3.69	3.59	3.23	2.42	1.51	1.24	1.16
Khepupara	1.75	2.19	3.63	5.64	5.92	5.72	5.58	4.96	3.36	1.77	1.36	1.37
Bhola	0.61	0.93	1.65	2.81	2.40	2.19	2.21	1.87	1.28	0.65	0.47	0.52

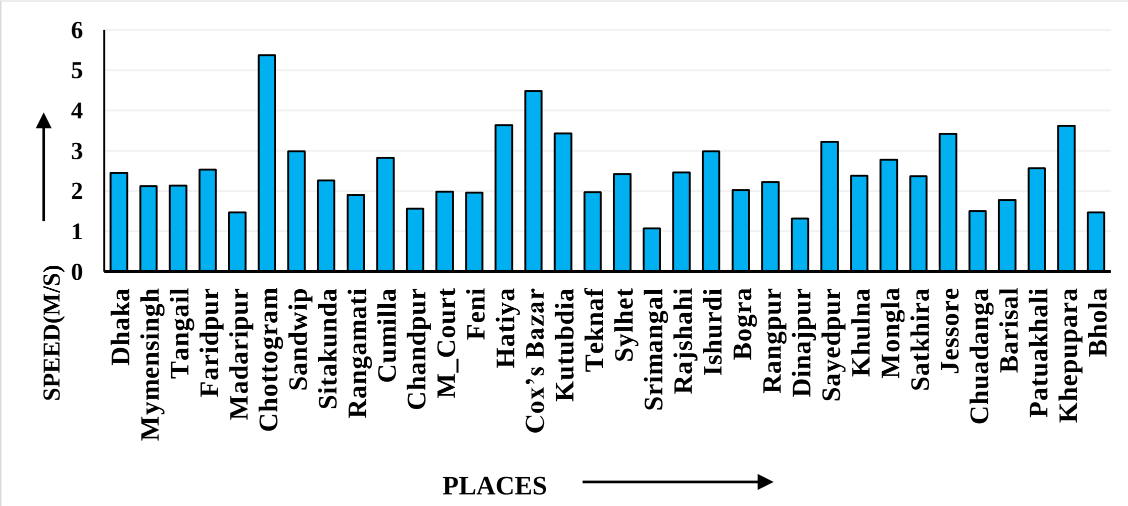

Figure 2.4: The mean wind speed in various parts of Bangladesh.

2.6.3 Hydraulic Energy

Hydraulic energy is the energy generated by water collected in high-altitude reservoirs and lakes. When the water moves to a lower level, kinetic energy is produced and afterward into electrical energy in the hydroelectric plant. The main advantage of a hydraulic power plant is having high efficiency, no fuel charge, high production rate capacity, pollution-free, etcetera. The main disadvantage of a hydraulic power plant is its high initial cost and longer commissioning time. However, we can offset these disadvantages by the low cost of generation and the control of floods, and increased irrigation facilities. For the generation of hydraulic power, it is necessary to construct a dam at a suitable place.

Moreover, this dam, during the rainy season, can reserve a large amount of water. When the authority opens the dam, the water rushes through the penstock with much kinetic energy. The penstock sends the water to the turbine. After that, the turbine transforms the water's potential energy into mechanical energy, then transformed it into electrical energy.

In Bangladesh, the only hydropower plant was constructed in 1962, named "Karnafuli Hydropower station," and Bangladesh's most significant water resource development projects. The first phase of construction began in 1957 and finished in 1962. By this time, the government had installed the reservoir, drainage system, penstock, and two 40 MW generators for the power plant. They also established a 50 MW power plant in August 1982. In October 1988, the 4th and 5th production units were equipped, each with 50 MW turbines, taking the total electricity production to 230 MW [14].

2.6.4 Geothermal Energy

Geothermal energy is energy that we receive from the earth's base. It is created by the heat produced during the planet's initial development and neutron absorption. However, The energy is deposited in the earth's core by rocks and fluids. In Bangladesh, Madhyapara of western Rangpur, Boropukuria of Thakurgaon, Madhupur, Singra, Kuchma, Chittagong-Tripura, and Bogra zone has substantial eligibility for Geothermal energy [15].

2.7 Summary

In this chapter, we have discussed the energy crisis of the world and Bangladesh. Then, the installed capacity and the sources of energy of Bangladesh were overviewed. After that, a study was made on the energy reserves of Bangladesh. Finally, the renewable energy sources of Bangladesh were discussed. Significantly, the solar irradiation map of Bangladesh was included here.

CHAPTER 3

SOLAR POWER AND PHOTOVOLTAIC TECHNOLOGY

3.1 Introduction

Sun is the foundation of energy on earth. The energy of the sun is very much crucial for life. It not only allows life to survive, but it also provides the majority of the energy used by humans. The sun is the source of biomass, fossil fuels, and renewable energy like wind and solar power. Fossil fuels preserve solar energy in a secondary form. In a word, both animals and plants cannot survive without the sun's existence.

3.2 Solar Energy

Solar energy is the transformation of energy present in the sun. It is the most environmentally friendly and plentiful renewable energy source currently available. The majority of sunlight that passes through the earth's atmosphere is visible light and infrared radiation. Solar energy can be used for various uses, including electricity production, illumination, a pleasant indoor environment, and boiling water for domestic, business, or industrial use. Plants convert solar energy into sugar and starches by photosynthesis.

3.2.1 Types of Solar Energy

We can divide solar energy into two categories based on conversion mode and the type of energy it produces [16]. These are as follows:

i. Active solar energy.

ii. Passive solar energy.

3.2.1.1 Active Solar Energy

Active solar energy is an arrangement that improves the efficiency of solar panels by using mechanical or electrical equipment. We often use these processes to convert the energy into electrical or mechanical energy. We can classify them into three types:

- Solar thermal energy.
- Photovoltaic solar power.
- Concentrating solar power.

3.2.1.2 Passive Solar Energy

Passive solar energy is the process of capturing the sun's power without any mechanical equipment. The design, planning, and building of the home have a significant impact on it. For heating and cooling, passive energy systems use the sun's energy. Passive solar systems do not need any external components to function. To transform rays into the sunlight, they employ passive collectors.

3.2.2 Benefits and Challenges of Solar Energy

There are some benefits and challenges of solar energy.

3.2.2.1 Benefits

The benefits of solar energy are as follows:

i. It is the cleanest form of energy. There is no emission of greenhouse gas in solar projects.

ii. As long as the sun exists, there is plenty of energy available on earth.

iii. Since it is possible to store energy in the batteries or supply to the grid, there is no loss.

iv. As we can capture it quickly, it is called free energy.

v. Utility prices are low.

3.2.2.2 Challenges

Disadvantages of solar energy are as follows:

i. During the Winter and on cloudy days, production is limited.

ii. The initial cost of the goods, as well as the installation, is also excessive.

iii. It consumes a lot of space.

3.2.3 Potential of Solar Energy

The vitality of the sun has no limits. The surface of the earth receives 343 w/m^2 of solar energy at an average [17]. The surface of the area is about $5 \times 10^{15}\ m^2$ [17]. If we multiply this with the average solar energy, we will find that the value is 1715$\times 10^{14}$w. However, since the earth reflects 30% of them and only 30% of the earth's surface is above sea level, we can obtain the available solar energy on the land surface is about 360$\times 10^{14}$ w. But all of the earth's surface is not suitable for solar PV projects. Besides, forests cover such significant places. It is not possible to cut down trees for implementing solar panels. So, we reduce the area by one-half for measurement. By this, we can see that this amount of solar energy adds up to 66$\times 10^{22}$ Joules over a year. In 2019, the energy consumption of the world was 583.90$\times 10^{18}$ joules [18]. It accounts for less than 0.1 percent of the solar energy that we can harvest on the ground. So, we cannot make a dent if we get all of our energy from the sun. The capacity is enormous, about 10,000 times what the planet needs [17]. By this, we can easily understand the great potential of solar energy.

3.3 Why use Solar Power

Fossil fuels and nuclear power plants are the primary foundations of global energy production. Fossil fuels are gas, oil, and coal. By burning fossil fuels, Carbon-di-Oxide (CO_2) is emitted. Besides, a small amount of methane (CH_4) and nitrous oxide (N_2O) are also emitted [19].

Carbon pollution causes climate change, which traps heat in the atmosphere. The global temperature is frequently rising. Icebergs are shrinking, snow on waterways and lagoons has cracked up formerly. Besides, plant and animal patterns have changed, and plants are flourishing earlier. The results of global climate change are just what scientists predicted in the past. Deterioration of icebergs, dramatic sea-level rise, and longer, more intense extreme heat are possible outcomes [20]. We have shown different sources of Greenhouse gas emissions in Figure 3.1.

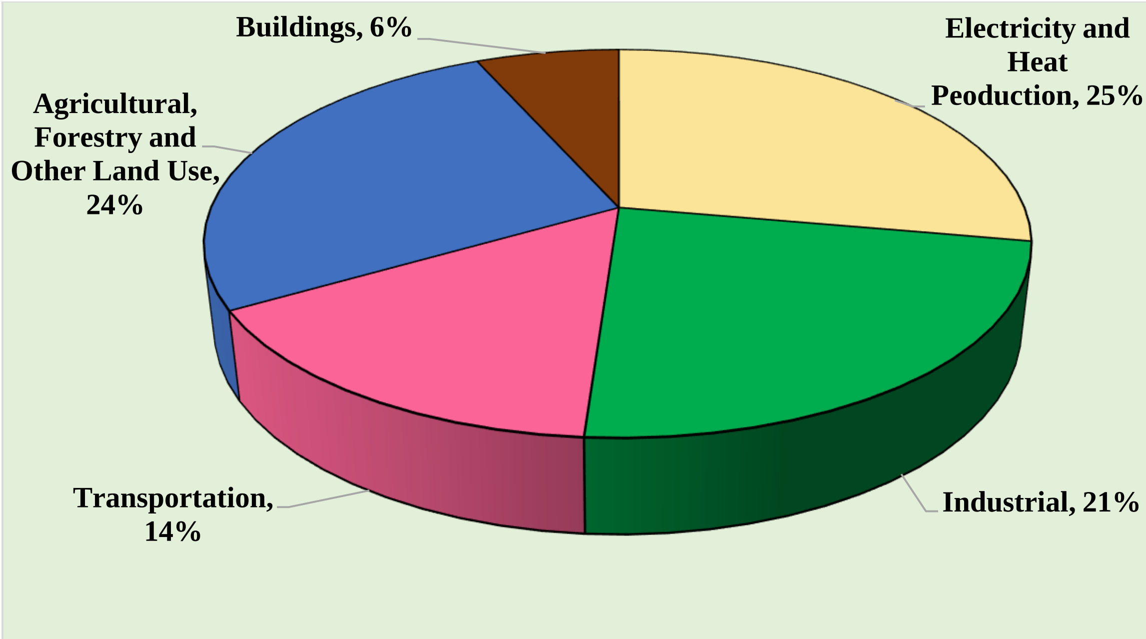

Figure 3.1: Greenhouse gas emissions by economic sector [19].

About 25% of global greenhouse gas emissions occur due to electricity generation by burning fossil fuels. There is no alternate way of using renewable resources as the primary source of generating electricity in this situation. Nuclear power also emits a minimal amount of greenhouse gas, but it is risky because of radioactive elements. Wind and hydro are also advantageous. However, this is not possible to implement these plants at any place. In this situation, solar can be the best alternative way to overcome this situation. People can implement solar panels at any location. Mass people can use solar power to meet their daily demands.

3.4 Works on Solar Technology around the World

Many countries and regions have built massive solar power capacity into their electrical grids to provide an alternative to traditional energy sources.

In 2020, the world added over 260 gigawatts of renewable energy power. The total installed capacity of renewable energy power was 2799 GW [21]. Solar dominated with

127 GW of new capacity among the other renewable resources has settled its position just after hydropower [21]. The share of installed capacity of different renewable energy is as follows [22] :

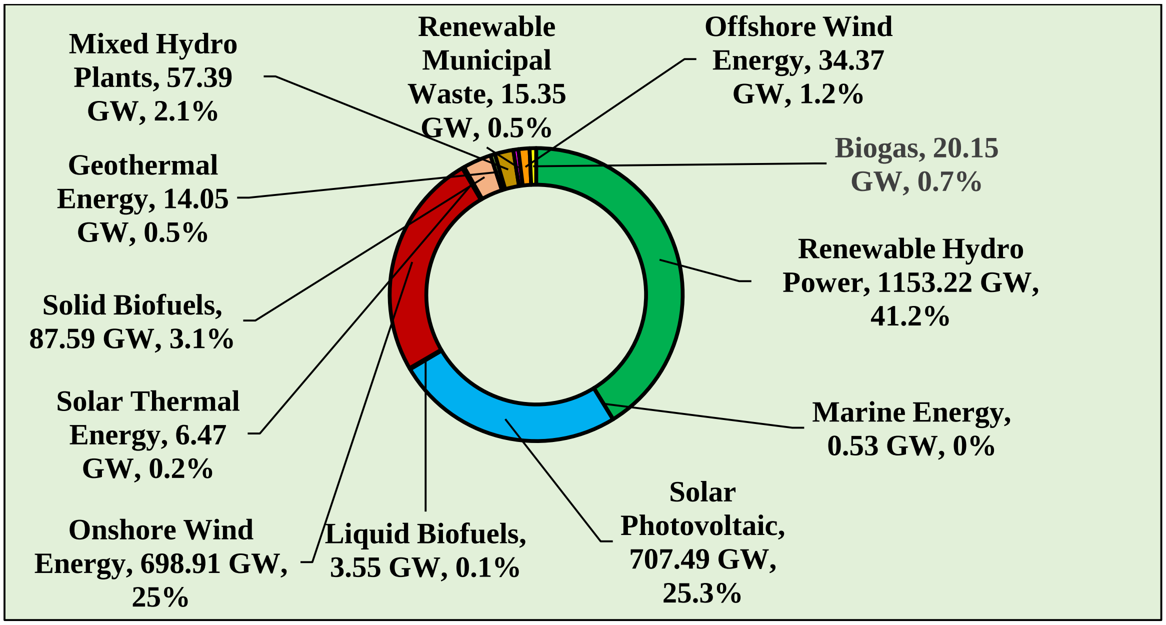

Figure 3.2: Global Total Installed Capacity by Different Renewable Energy Resources.

Due to the expansion of Asia in 2020, the entire solar capacity has now touched a similar quantity as wind capacity. China and Vietnam have increased their capability significantly. India and the Republic of Korea added over 4 GW of solar power, while Japan added over 5 GW. The United States of America increased its capacity by 15 GW [21]. The increment of using solar energy all over the world is included in Figure 3.3 [23].

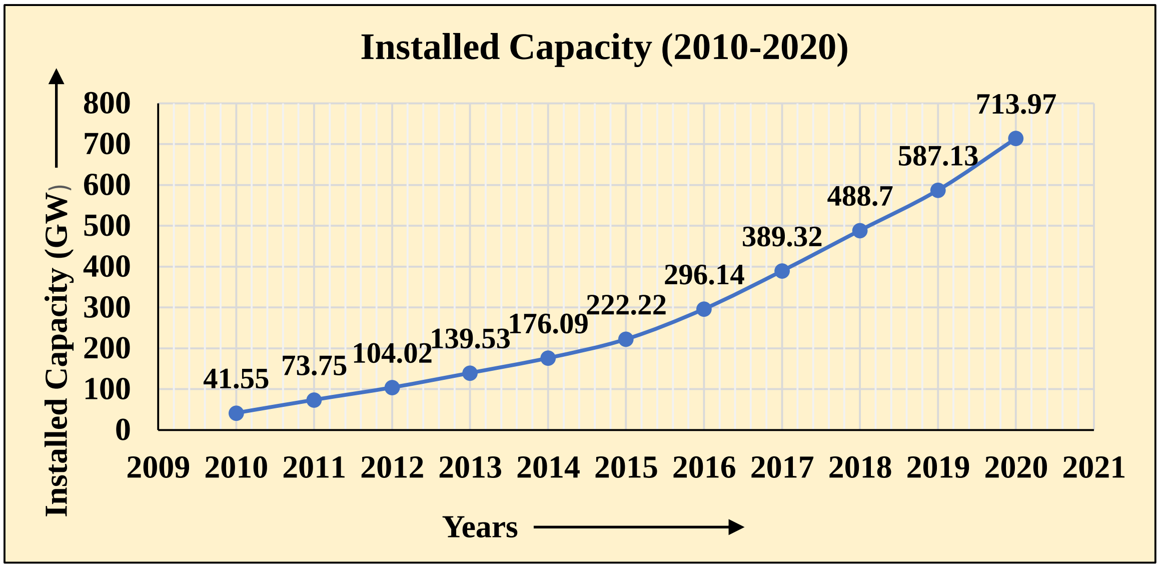

Figure 3.3: Increment of installed capacity by renewable resources over the years.

The countries with the largest installed capacity so solar power are included in Table 3.1 [24]:

Table 3.1: Countries with enormous solar power installed capacity.

Country	Installed Capacity (GW)
China	254.355
United States of America	75.57
Japan	66.99
Germany	53.78
India	39.21
Italy	21.60
Australia	17.63
Vietnam	16.50
Republic of Kores	14.57
Spain	14.09

3.5 Photovoltaic Technology

A PV cell is an electronic system that produces electricity when photons or light particles are attracted. The photovoltaic effect, named after French physicist Edmond Becquerel, was first discovered in 1839 [25].

3.5.1 What is Photovoltaic Technology?

Photovoltaics is the direct conversion of light into energy at the atomic level. The photoelectric effect is a function of some substances that enables them to consume light photons and unleash electrons. As these free electrons are found, an electric current is produced, which can produce electricity.

3.5.2 Solar PV Modules Constructions

A solar cell is a junction diode, but it differs significantly from conventional p-n junction diodes in terms of structure. A weak sheet of p-type semiconductor is grown on a thicker n-type semiconductor. The technologists add a few more thin electrodes on top of the p-type semiconductor plate.

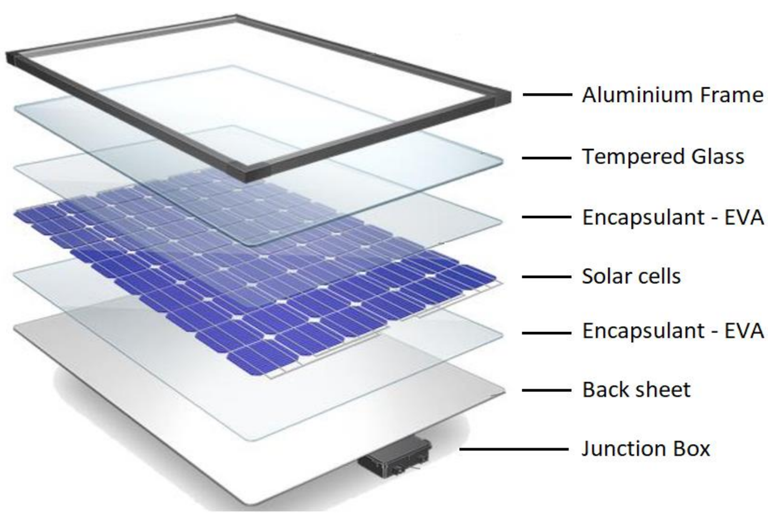

Figure 3.4: Typical construction of PV modules [26]

3.5.3 How Does it Work

The photovoltaic effect is generated by solar cells. A p-n junction is formed when two different types of semiconductors are combined in these solar cells. There are p-type and n-type semiconductors, respectively. Electrons transfer to the positive p-side of the molecule, while holes relocate to the negative n-side. As these two types of semiconductors merge, an electric field is generated in the junction region. This field causes negatively charged particles to travel in one direction and positively charged ions to shift in the other position. Light is a form of photons, which are small packages of electromagnetic radiation or electricity. The photovoltaic layer absorbs these photons. In the p-n junction, energy from a photon is transferred to an atom of a semiconducting substance. As light falls on these cells, it causes them to glow. The power is directly converted to the electrons in the material. As a result, the electrons shift to a more energetic state known as the conduction band. The electron leaped up and pierced the valence band, leaving a vacuum due to the increased momentum—the electron travels, resulting in two charge carriers, an electron-hole pair.

When electrons are not activated, they create connections with the atoms around them, which lock the semiconducting substance together and prevent it from moving. However, in their excited state in the conduction band, these electrons are free to flow through the material. The p-n junction's electric field allows electrons and holes to move in opposite directions, as predicted. Rather than being attracted to the p-side, the liberated electron continues to move to the n-side. The movement of the electron in the cell generates an electric current. When an electron moves into a medium, it creates a "hole." This hole will follow in the footsteps of the p-side but in the opposite direction. [27]. Figure 3.5 shows a diagram of this operation:

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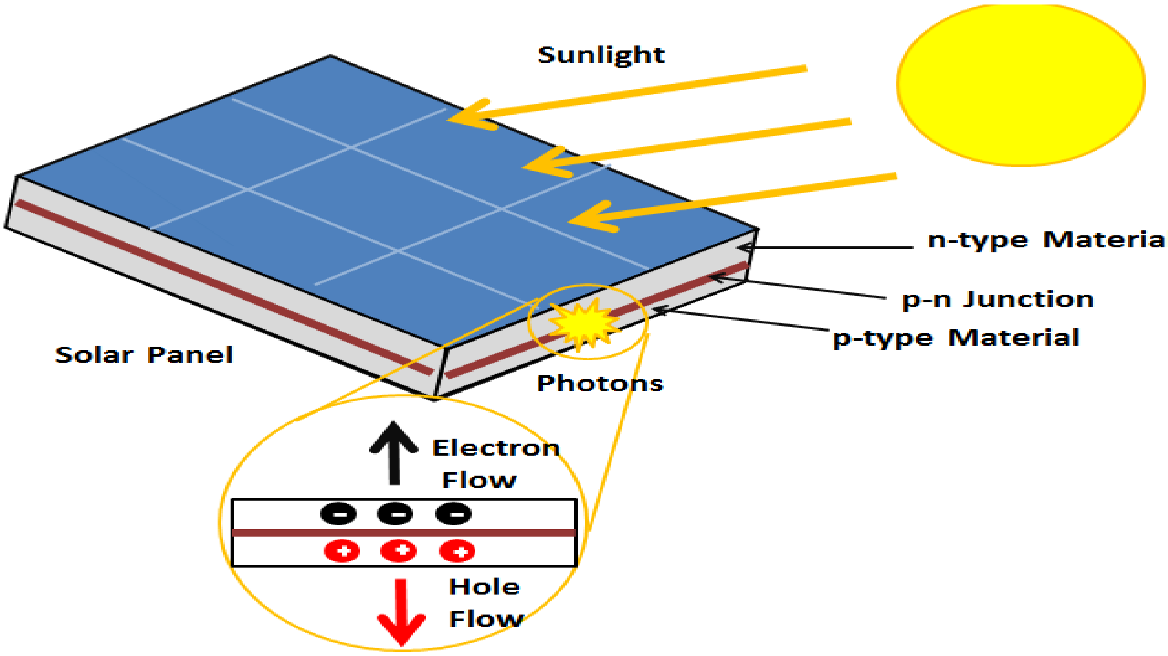


Figure 3.5: Photovoltaic Effect [28]

3.6 Summary

This chapter is about solar power and photovoltaic technology. At first, solar energy is described. The classifications, advantages, and disadvantages are also included here. Besides, it is described that why we should use solar energy. The necessity of using solar energy is the leading issue. Moreover, the usage of solar energy worldwide is also discussed. Finally, photovoltaic technology and its working procedure are represented.

CHAPTER 4

COMPONENTS OF A SOLAR PV SYSTEM

4.1 Introduction

A solar photovoltaic system works by converting solar energy to electrical energy. Nevertheless, it is not possible with only a single component. It needs some components to fulfill every step. We have discussed these elements in this chapter.

4.2 Solar Panels

The sun is the source of solar energy. Solar panels transform sunlight into electricity that we can use to power electrical loads. People operate solar panels by using photovoltaic cells to absorb sunlight, generate direct current, and transform it into usable alternating current using inverter technology. The alternating current then proceeds through the house's electrical system and is transmitted as indicated.

4.2.1 Types of Solar Cells

Solar panels are mainly of three types [29]:

i. Monocrystalline cells.

ii. Polycrystalline cells.

iii. Thin-film solar cells.

4.2.1.1 Monocrystalline Cells

Monocrystalline solar panels are solar panels composed of crystalline silicon solar cells. These cells are made from single crystalline silicon. Since the cells are permanently colored and cylindrical, they have a distinct look. Monocrystalline cells have four corners that are cut out to keep costs low and productivity at their peak.

Figure 4.1: Monocrystalline cells [29].

Advantages:

i. Because of their high performance, they take up less room than other varieties.

ii. It can work well when the light is low.

iii. It has the highest level of efficiency at 15-20%.

Disadvantages:

i. The productivity level suffers due to the increment of temperature.

ii. There are many wastages during construction.

iii. The costliest solar cells on the market.

4.2.1.2 Polycrystalline Cells

Polycrystalline or Multi crystalline are solar panels involving numerous silicon crystals in a single PV cell. People build polycrystalline solar panels of wafers created of several silicon fragments melted together. The surface of these solar panels looks like a mosaic. These solar panels are four-sided.

Figure 4.2: Polycrystalline cells.

Advantages:

i. The manufacturing process is cheaper.

ii. It reduces the amount of silicon waste.

iii. It can work well in low temperatures.

Disadvantages:

i. These panels have lower effectiveness.

ii. It solar panels have a lower purity of silicon.

iii. It has lower productivity rates. So, it needs a lot of space.

4.2.1.3 Thin-film Solar Cells

The constructor builds thin-film solar cells of micron-thick photon-absorbing material layers distributed over a flexible layer and transforms light energy into electrical energy. There are numerous sorts of thin-film solar cells. The material used for the PV layers determines how they vary from one another. The classes are given below :

●Amorphous silicon

●Cadmium telluride

●Copper indium gallium selenide

●Organic PV cells.

Figure 4.3: Thin-film solar cells [29].

Advantages:

i. Shading similarly reduces their efficiency.

ii. People make them versatile, allowing them to use in many situations and building styles.

iii. It is simple to achieve mass production.

Disadvantages:

i. They are not suitable for domestic use due to their large size.

ii. Though these panels have a shorter lifetime, and their warranty periods are often shorter.

iii. Due to missing frames, the installation is challenging.

4.2.2 Efficiency of Different Solar Panels

The intensity of light hits a solar panel's surface, and Solar panel efficiency measures solar energy conversion into electrical energy.

The effectiveness of various types of solar cells is given in Table 4.1.

Table 4.1: The performance of various classes of solar cells [29] [30].

Cell type	Efficiency, η
Monocrystalline	17%-22%
Polycrystalline	15%-17%
Thin film	10%-13%

4.2.3 Efficiency comparison of different solar panels

Among the three types of solar panels, Thin-film solar panels have the lowest efficiency. So, this is not wise to implement this kind of solar panel. The efficiency of monocrystalline and polycrystalline are almost the same. A monocrystalline cell has slightly higher efficiency. However, the price is higher than the polycrystalline. So, we can say that if there is no tight budget, monocrystalline will be the best option to implement a solar project.

4.3 Inverter

A power electronic system that converts direct current to alternating current is referred to as an inverter. We determine the frequency of the resulting AC by the system used. Inverters work in the opposite manner of converters, massive electromechanical devices that convert AC to DC.

4.3.1 Necessity of an Inverter

An inverter is used to convert that converts DC voltage to AC voltage. We may create the inverter stand-alone for solar power applications or use it as a backup power source with batteries charged separately. The solar panel produces direct current electricity. Most household and industrial devices, on the other hand, require AC capacity. As a result, inverters are needed in solar systems.

4.3.2 Applications of Inverter

The inverter is used in various applications, including remote car connections, home or business applications, and large grid configurations.

- Indestructible energy sources.
- Inverters can operate independently.
- In solar energy platforms.
- As part of a switched-mode power supply installation.

4.3.3 Classifications of inverter

We can classify the inverter into two types. These are:

i. Stand-alone.

ii. Line-tied or utility-interactive.

4.4 Batteries

From small handheld devices to large-scale industrial applications, batteries are the most popular power source. A battery consists up of one or more electrolytic cells that can transform chemical energy into electrical energy. An anode, a cathode, and some electrolytes are the three essential components of all batteries. There are two kinds of Batteries:

i. Primary Batteries.

ii. Secondary Batteries

●SMF Battery.

●Lithium (Li) Battery.

●Nickel, Cadmium (NiCd) Battery.

●Lead Acid Battery.

In the store, there are various types of batteries. None of them, however, are compatible with solar PV technology. The most popular organic arrangements used in home-based storing energy are lead-acid, lithium-ion, and saltwater batteries. In most cases, lithium-ion batteries are the better option for a solar panel battery. The best long-term alternatives are iron/chromium redox and zinc/manganese batteries.

4.5 Charge Controller

When we use a battery in a system, a charge controller becomes essential. A charge controller controls the power from the solar array that goes into the battery bank. It is like a regulator connecting the PV array to the system's loads and the battery bank. When the battery bank is nearly complete, the controller reduces the charging current to retain the necessary voltage for completely charging and topping off the battery. The charge controller protects the battery by being able to regulate the voltage. Solar cells generate much voltage on a bright sunny day, which can harm batteries. A charge controller aids in maintaining the battery's balance while charging. PWM and MPPT are two different technologies for solar charge controllers.

4.6 Other Materials

Array Mounting Racks, Grounding Equipment, Surge Protection, Meters, and Instrumentation are also needed for a solar project [31].

4.7 Summary

This chapter is about the components of a solar PV system. The different elements of a solar PV system are discussed here. At first, different types of solar panels, their advantages, and disadvantages are described here. After that, inverters, batteries, and charge controllers are included in the same way.

CHAPTER 5

SOLAR SYSTEM DESIGN

5.1 Introduction

A solar power system is something that converts sunlight into usable energy using photovoltaics. It is made up of several components. Solar panels absorb and turn sunlight into power. A solar inverter transforms direct current to alternating current, charging, cabling, and other electrical accessories.

5.2 Typical Solar PV Arrangement

A representative solar PV system consists of solar panels, charge controllers, batteries, inverters, and load. The diagram of Figure 5.1 shows the system:

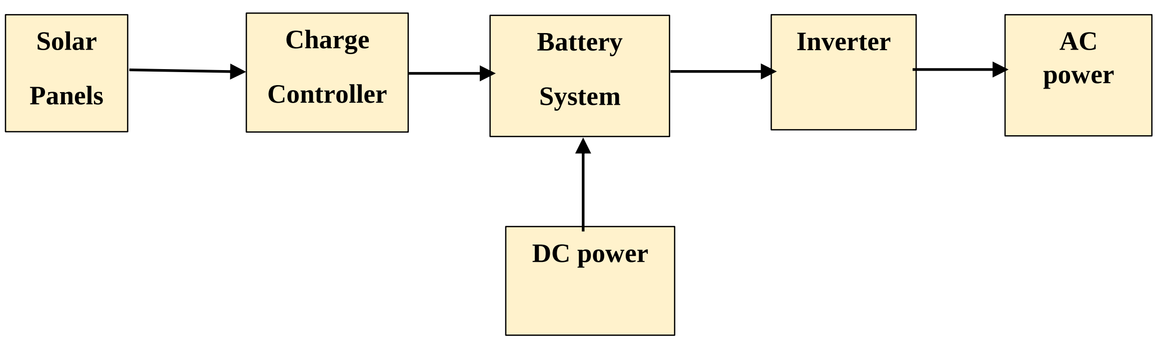


Figure 5.1: Typical solar PV system

5.3 Types of Solar System Design

Photovoltaic power systems are categorized based on their functional and operational specifications, component configurations, and how they are related to other power sources and electrical loads. There are four types of solar system design. These are:

i. Off-grid.

ii. Grid-tied.

iii. Grid-tied with battery-backup system

iii. PV direct.

5.3.1 Off-grid

Off-grid systems, also known as stand-alone systems, are planned to be self-contained from the power grid. When the sun is not available, such as on cloudy days or at night, we can use batteries to store energy. Battery electrolyte levels and terminal corrosion would need to be monitored regularly in this type of system.

Batteries are necessary for this circumstance. An off-grid system also includes a more considerable initial investment as well as higher installation costs. However, this is not a reasonable price to pay for electricity self-sufficiency. These are usually paired with a backup generator and are suitable for isolated areas that the grid has not yet electrified.

5.3.2 Grid-tied

PV systems of this kind are the most popular. They are also known as grid-inter tied, grid-direct, or on-grid networks. They produce solar energy and send it to the loads and the grid. It reduces the amount of power used. The PV array and inverter are the two main components of this system. Grid-connected systems are identical to traditional electric methods, which is the cheapest option of the three options for implementing a solar project.

Besides, it requires less maintenance. Since there is no need to use batteries in grid-direct systems, they are much efficient.

5.3.3 Grid-tied with Battery-backup System

In terms of configuration and parts, this system is quite similar to an off-grid system. However, it still has a power grid eliminating the need for the system to supply electricity all of the time. In this case, when the grid goes down, specified loads have electricity.

Suppose the battery consumes more electricity than the home requires. In that case, the surplus is sold back to the utility rather than wasted like it would be in a stand-alone device until the capacity of batteries is complete on a sunny day. However, because of their efficiency losses, batteries reduce device output. Besides, a grid-direct system is more costly.

5.3.4 PV Direct

These are the most basic solar PV systems, consisting of just two components: solar panels and a load. They can only fuel them while the sun is shining, and they do not have batteries or connections with the grid. They are suitable for a few things, including water pumping and attic cooling fans.

5.4 Mounting

Solar panels are mounted on roofs, building facades, and the ground using photovoltaic mounting systems. It is also called solar module racking. The constructor may retrofit the panels on roofs or part of the building using these mounting systems. There are numerous types of mounting of solar panels that can be done. Depending on the location and design, we build different kinds of mounting. We have described them below:

5.4.1 Pole Mounting

Where usable roof space is inadequate or inappropriate, pole-mounted solar panels are helpful. Solar panels may be mounted on poles to provide the most sunlight penetration. It requires a significant amount of land to be set aside for the solar installation. As a result, it is beneficial to use pole-mount for industrial or agricultural facilities and vast private properties. It does not need any roof penetration.

Figure 5.2: Pole Mounting.

There are three types of pole-mounting [32]:

i. Top of Pole Mount Systems.

ii. Side of Pole Mount systems.

iii. Adjustable Tilt Pole Mount Systems.

5.4.2 Roof Mounting

The most popular method of installation is roof mounting. In this case, the solar racking is mounted directly on the roof. It is possible to attach the panels to concrete, shingle, or rubber roofs, whether smooth or tilted. These mounting constructions allow the system to be fitted parallel to the roof for the best visual solution for pitched roofs.

Figure 5.3: Roof Mounting [33].

Roof mounting is of two types [34]. These are;

i. Flat Roof Mounting.

ii. Sloped Roof Mounting.

Flat roof mounting is of three types.

● Attached: This category needs penetration and connection to the framing.

●Ballasted: In this type, it does not need penetration.

●Hybrid: It is a combination of the ballasted and structural system.

Sloped Roof Mounting is of three types.

● Flush mount

● Angle mount

● Fin Mount

5.4.3 Ground Mounting

When the panels are attached to the ground with steel beams or a metal plate, a ground mount is appropriate. In this case, it is necessary to attach the panels to a rack framework. Implementing a ground mount as a carport over a parking lot or in an open field is possible. It is practicable to place ground mount anywhere the best solar conditions exist. So, this is a perfect option for those who do not have enough open roof space or do not want panels on the roof.

Figure 5.4: Ground Mounting [32].

5.4.4 Building Integrated Photovoltaic (BIPV)

Solar power generation devices or structures embedded into the building envelope and structural components are known as building-integrated photovoltaics. The structural components can be roof, façade, or window. This device can transform solar energy into electricity. Besides, it also provides building envelope functions such as weather protection, thermal insulation, noise reduction, daylight exposure, and protection.

Figure 5.5: Building Integrated Photovoltaic [35].

5.5 Summary

This chapter is about solar system design. At first, a typical solar PV system arrangement is shown. There are some ways to implement a solar project. These are included here. Besides, different mounting processes are also described here.

CHAPTER 6

LOAD SURVEY OF ACADEMIC BUILDING 4

6.1 Introduction

To construct a solar project at the rooftop of Academic Building 4 of Daffodil International University, we need to calculate the building loads first. For this, we have to find out the total number of elements and their working hour. As there is a considerable difference between Winter and summer loads, we have to calculate it separately.

6.2 Load of an Electrical System

An electrical load is a power-consuming electrical part or section of a circuit. We can also extend the theory to a circuit's power consumption. An electrical load is a system that absorbs electrical energy in the current form. It converts it to heat, light, motion, and other types of energy. The electrical load could be resistive, inductive, capacitive, or a mixture of the three. We can use the expression 'load' to describe a variety of scenarios.

6.3 Overview of Academic Building 4

The Academic Building 4 of Daffodil International University is a 15 storied building including a ground floor for parking. There are classrooms, faculty rooms, guest rooms, library, laboratory, etcetera. The front view of AB4 is shown in Figure 6.1.

Figure 6.1: Front view of Academic Building 4

6.4 Different Elements of Academic Building 4

Table 6.1: Name of the elements with unit power consumption

Name	Power Consume (watt)
Light	18
Fan	65
LED Screen	300
Projector	320
Desktop	222
Air-conditioner	2500
Air-conditioner	1250
Server PC	1700
Exhaust Fan	30
Lift	20000
Water Pump	7460
Water Pump	2238
Water Pump	1492
3-Pin Socket	250
Router	200
Hyper-Flux	1700
CC TV	70
Data Center	7000
Data Center Rack	16000
Online UPS	38400
PSE	29000
Dehumidifier	40

6.5 Categorization of Different Elements

Table 6.2: Elements by category

Category	Name of the element	Total number of elements
Classroom, Faculty Room, and Library	Fan	1293
	Light	2466
	LED Screen	25
	Projector	120
	Desktop	384
	Air-conditioner (2 Ton)	100
	Air-conditioner (1 Ton)	70
Server Room	Fan	12
	Light	36
	Server PC	1700
Washroom	Light	490
	Exhaust Fan	128
Corridor	Light	450
Water Pump	10 HP	2
	3 HP	2
	2 HP	1

6.6 Load Calculations

Our final goal is to do a feasibility analysis for two different types of loads. So, it is necessary to calculate both loads.

6.6.1 Load Calculation of Whole Academic Building 4

We will calculate the loads for both Summer and Winter.

6.6.1.1 Daily Load Calculation of Summer

Table 6.3: Daily load calculations of Summer (Full building)

Time	Load (KW) (Weekdays)	Load (KW) (Weekends)	Time	Load (KW) (Weekdays)	Load(KW) (Weekends)
12.00 A.M.	70	70	**12.00 P.M.**	849	849
1.00 A.M.	70	70	**1.00 P.M.**	849	849
2.00 A.M.	70	70	**2.00 P.M.**	849	849
3.00 A.M.	70	70	**3.00 P.M.**	849	849
4.00 A.M.	70	70	**4.00 P.M.**	849	849
5.00 A.M.	70	70	**5.00 P.M.**	849	849
6.00 A.M.	70	70	**6.00 P.M.**	849	849
7.00 A.M.	70	70	**7.00 P.M.**	854	849
8.00 A.M.	91	91	**8.00 P.M.**	854	70
9.00 A.M.	849	849	**9.00 P.M.**	854	70
10.00 A.M.	849	849	**10.00 P.M.**	70	70
11.00 A.M.	849	849	**11.00 P.M.**	70	70

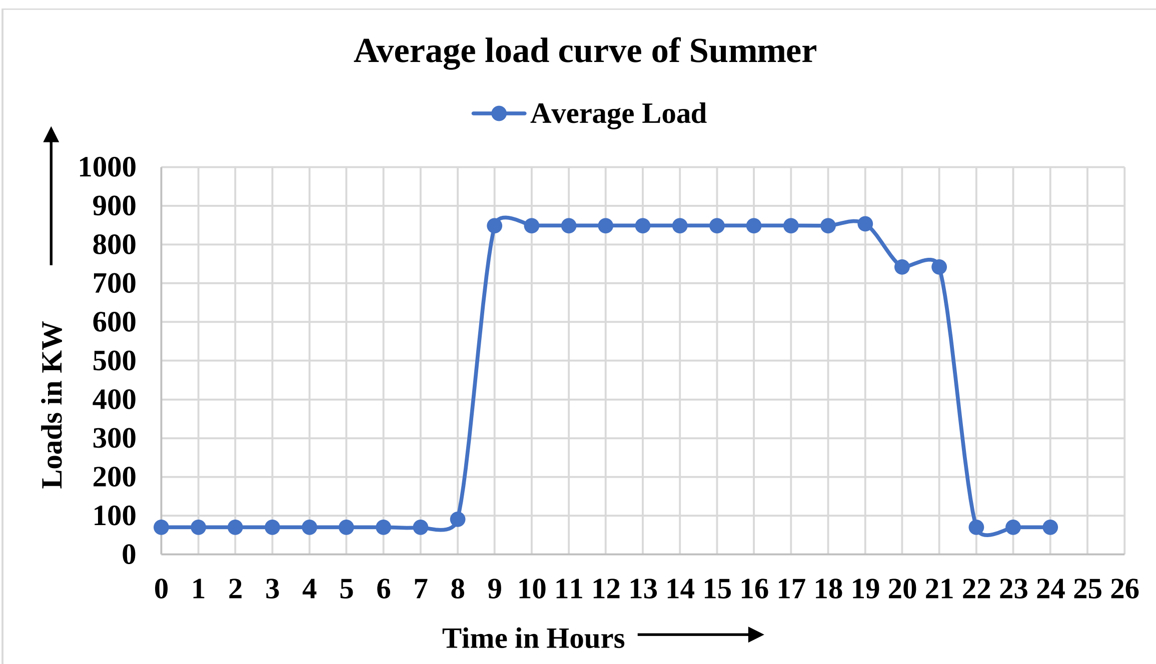


Figure 6.2: Average daily load curve of Summer (Full building)

6.6.1.2 Daily Load Calculations of Winter

Table 6.4: Daily load calculation of Winter (Full building)

Time	Load (KW) (Weekdays)	Load (KW) (Weekends)	Time	Load (KW) (Weekdays)	Load(KW) (Weekends)
12.00 A.M.	70	70	**12.00 P.M.**	427	427
1.00 A.M.	70	70	**1.00 P.M.**	446.5	446.5
2.00 A.M.	70	70	**2.00 P.M.**	446.5	446.5
3.00 A.M.	70	70	**3.00 P.M.**	446.5	446.5
4.00 A.M.	70	70	**4.00 P.M.**	427	427
5.00 A.M.	70	70	**5.00 P.M.**	427	427
6.00 A.M.	70	70	**6.00 P.M.**	427	427
7.00 A.M.	70	70	**7.00 P.M.**	432	70
8.00 A.M.	91	91	**8.00 P.M.**	432	70
9.00 A.M.	427	427	**9.00 P.M.**	432	70
10.00 A.M.	427	427	**10.00 P.M.**	70	70
11.00 A.M.	427	427	**11.00 P.M.**	70	70

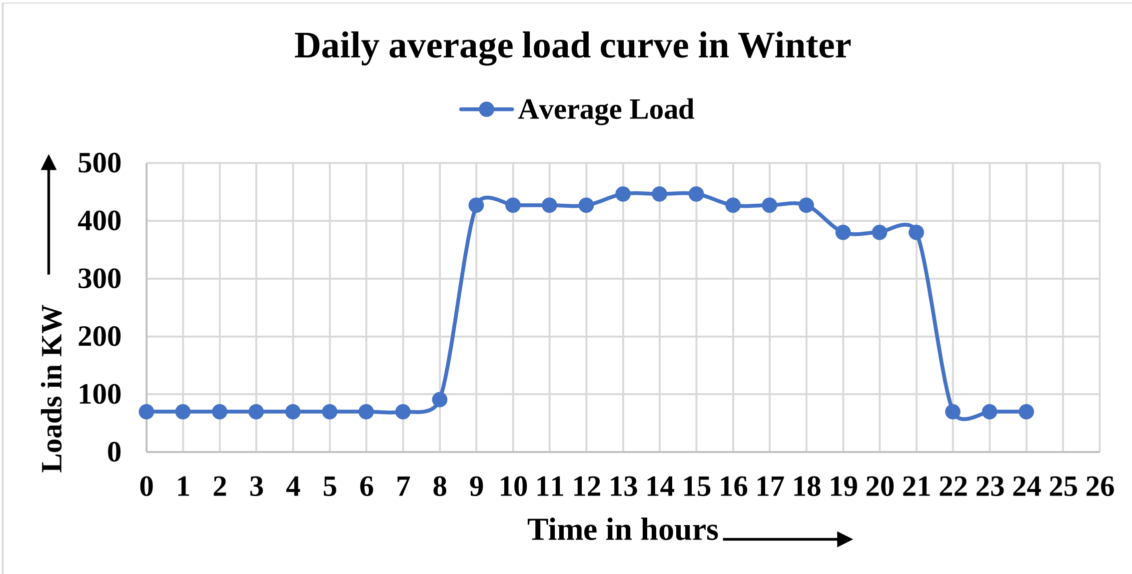


Figure 6.3: Average daily load curve in Winter (Full building)

6.6.2 Load Calculations of selected parts

To reduce the load for our project, we have selected the electrical elements of the classroom, washroom, and corridor.

6.6.2.1 Daily Load Calculations of Summer

Table 6.5: Daily load calculations of Summer (Reduced load)

Time	Load (KW) (Weekdays)	Load (KW) (Weekends)	Time	Load (KW) (Weekdays)	Load (KW) (Weekends)
12.00 A.M.	12.3	12.3	**12.00 P.M.**	260	260
1.00 A.M.	13	13	**1.00 P.M.**	275.2	275.2
2.00 A.M.	11.6	11.6	**2.00 P.M.**	272	272
3.00 A.M.	12	12	**3.00 P.M.**	263.2	263.2
4.00 A.M.	12.6	12.6	**4.00 P.M.**	262	262

5.00 A.M.	12.5	12.5	**5.00 P.M.**	273.2	273.2
6.00 A.M.	12.1	12.1	**6.00 P.M.**	267.6	267.6
7.00 A.M.	12.3	12.3	**7.00 P.M.**	280	280
8.00 A.M.	8.05	8.05	**8.00 P.M.**	285	12.1
9.00 A.M.	267.6	267.6	**9.00 P.M.**	275	12.5
10.00 A.M.	270	270	**10.00 P.M.**	12.3	12.5
11.00 A.M.	265.2	265.2	**11.00 P.M.**	12.3	12.1

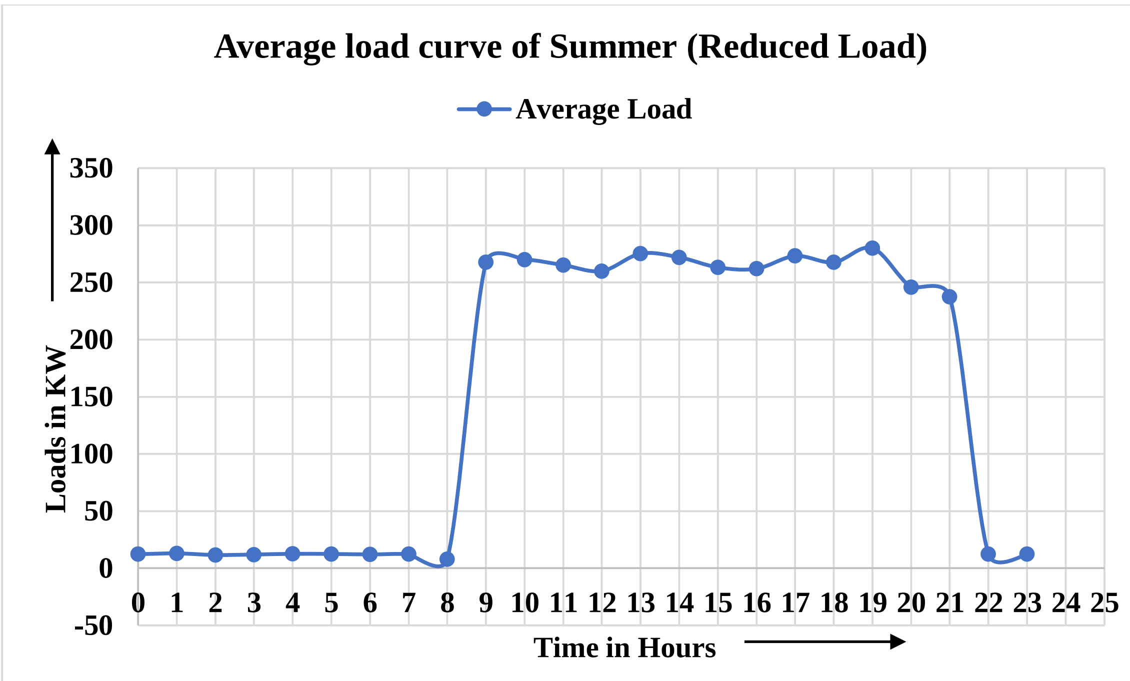


Figure 6.4: Average load curve in Summer (Reduced load)

6.6.2.2 Daily Load Calculations of Winter

Table 6.6: Daily load calculations of Winter (Reduced load)

Time	Load (KW) (Weekdays)	Load (KW) (Weekends)	Time	Load (KW) (Weekdays)	Load (KW) (Weekends)
12.00 A.M.	12.3	12.3	**12.00 P.M.**	145.6	145.6
1.00 A.M.	13	13	**1.00 P.M.**	166.6	166.6
2.00 A.M.	11.6	11.6	**2.00 P.M.**	170	170
3.00 A.M.	12	12	**3.00 P.M.**	163.2	163.2
4.00 A.M.	12.6	12.6	**4.00 P.M.**	145.6	145.6
5.00 A.M.	12.5	12.5	**5.00 P.M.**	150	150
6.00 A.M.	12.1	12.1	**6.00 P.M.**	141.2	141.2
7.00 A.M.	12.3	12.3	**7.00 P.M.**	196.3	196.3
8.00 A.M.	8.05	8.05	**8.00 P.M.**	200	12.5
9.00 A.M.	145.6	145.6	**9.00 P.M.**	192.8	12.1
10.00 A.M.	150	150	**10.00 P.M.**	12.3	12.3
11.00 A.M.	141.2	141.2	**11.00 P.M.**	12.3	12.3

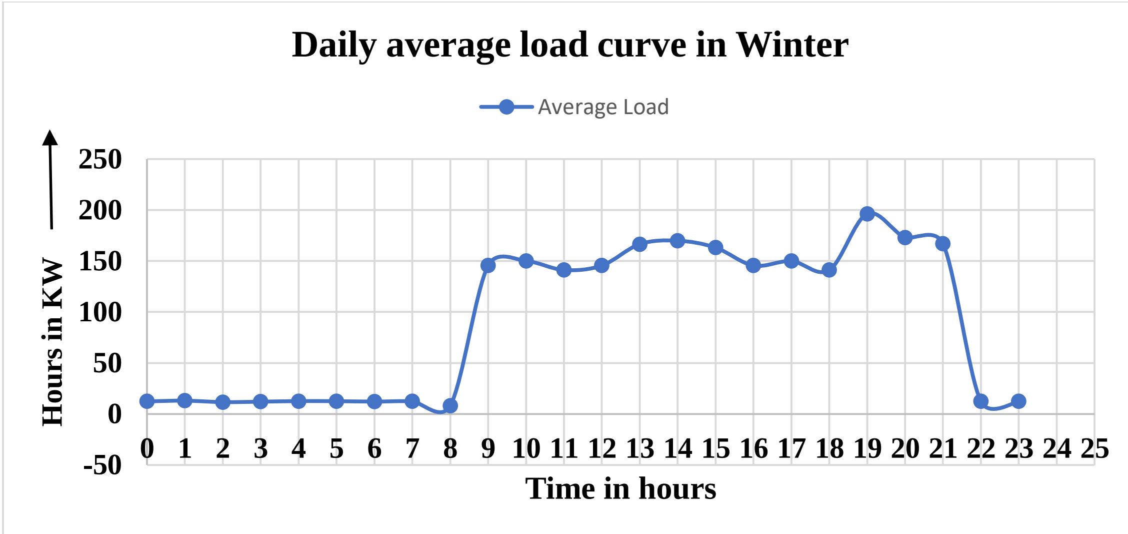


Figure 6.5: Daily average load curve in Winter (Reduced Load)

6.7 Summary

This chapter is about the load calculations of Academic Building 4. At first, we have described what load calculation is. Load varies from time to time for different parts of the year. So, we have calculated hourly load data for both Summer and Winter. For this project, we will need loads of some particular parts of the building. So, we have also measured hourly loads of this selected parts for both Summer and Winter.

CHAPTER 7

MEASUREMENT OF ROOFTOP

7.1 Introduction

To measure anything is to assign a numerical value to some aspect of it. Measuring something means converting the quantity into numbers. We use many different units to write measurements. There are seven vital units in the SI system: meter (m), kilogram (kg), second (s), kelvin (K), ampere (A), mole (mol), and candela (cd).

7.2 Site for Solar Project

The permanent campus of Daffodil International University is at Khagan, Ashulia, Savar, which is in Dhaka district. We used latitude and longitude and degrees of the academic building 4 for the solar project. Figure 7.1 is showing the rooftop of Academic Building 4 of Daffodil International University.

Figure 7.1: Top view of Academic Building 4

7.3 Measurement of Roof

The Academic Building 4 of Daffodil International University has two separate rooftops. These are:

i. North-south structure.

ii. East-west structure.

We measured the rooftops in square feet because square feet provide a standardized measurement regardless of the roof's configuration or form. Figure 7.2 shows the two rooftops of Academic Building 4:

Figure 7.2: Two parts of roofs of Daffodil International University academic building 4

7.3.1 North-south structure

The total area of North-South structure is,

Length = 199'

Width = 74'

Total area = 14726 square feet.

But we can not use total area. So, usable area is ,

Length = 187'10"

Width = 65'

Total area = 12209.16 square feet.

As there is a structure, so we cannot use a length of 31'. So, we will be able to use 64' width. There is an additional structure where we can implement solar panels. The length and width are 85'3" and 15'7", respectively.

The effective length = (187'10"-31') = 156'10"

The effective width = 64'

The effective area = 10037.33 square feet

The additional area = 1328.48 square feet

The total effective area = (10037.33+1328.48) square feet

= 11365.81 square feet

7.3.2 East-West Structure

The total area of East-West structure is,

Length = 194'11"

Width = 61'1"

Total area = 1190.16 square feet.

Due to some difficulties, we can only use 32'5" width to implement solar panels.

The effective length = 194'11"

The effective width = 32'5"

The effective area = 6318.55 square feet.

There is an additional space over the stair. The length and width of it are 84'6" and 26'2", respectively.

The area of this space = 2211.08 square feet.

The total effective area is (6318.55+2211.08) square feet.

= 8529.63 square feet.

=1845 m^2

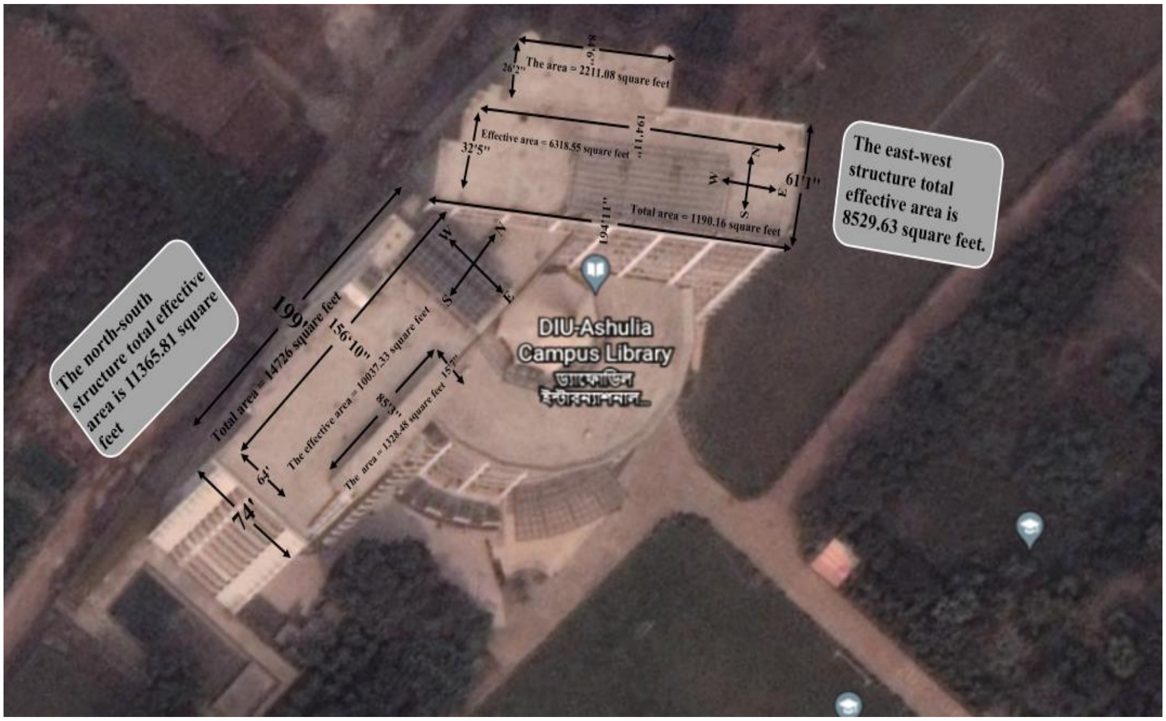


Figure 7.3: The orientation and total rooftop area of Academic Building 4

7.4 Practically and Theoretically Measurement of Solar Panels

The selective solar panel is of 265w maximum output.

Length = 5'4" and Width = 3'3"

Area = 17.33 square feet

= 1.6 m^2

North-south structure:

The number of solar panels in the main effective area is = (10037.33÷17.33) = 579.2 pieces.

However, it cannot be a fraction, so that we can take 572 pieces. So we will be able to implement the panel in 13 rows.

Number of panel in the additional structure = (1328.28÷ 17.33) = 76.65 pieces.

So we can implement 72 solar panels.

Total number of solar panels = (572+72) pieces

= 644 pieces.

East-west structure:

Number of solar panel in the main effective area = (6318.55÷17.33)

= 364.6 pieces.

However, it cannot be a fraction. So, we can take 352 pieces.

Now, the number of solar panel in the area over the northern stair = (2211.08÷17.33) pieces

= 127.58pieces

However, it cannot be a fraction. So, we can take 88 pieces.

Total number of solar panel in the east-west structure = (352+88) = 440 pieces.

Total number of implementable solar panels of Academic Building 04 = (644+440) pieces

= 1084 pieces.

7.5 Summary

This chapter is about the measurement of rooftops. There are two rooftops at Academic Building 4. One is the North-South structure, and another one is the East-West structure. The rooftop area is calculated for both of them. It is 1845 m^2 in total. Finally, We have estimated the number of solar panels.

CHAPTER 8

ANALYSIS AND SIMULATION

8.1 Introduction

We have discussed the basics of photovoltaic technology, load survey, and site descriptions in the previous chapters. We calculated them with practical values. According to the load and site data measurement, we shall design and determine the simulation results.

8.2 System Configuration

We have already discussed different solar system configurations. Each type of configuration has its benefits and drawbacks. We must select relevant system configurations based on the system requirements.

Initially, we listed two possible configurations for AB4 in our work. The first is a grid-connected solar PV system that does not have a battery. The second is a stand-alone solar PV system with a battery.

However, the building needs a tremendous amount of energy. So this is not possible to store energy in the battery. So, we have chosen a grid-connected solar PV system for our desired project.

8.3 Selecting the Components

The selection of the components is very much crucial for a solar project. The overall output and the lifetime of the project are entirely dependent on it.

8.3.1 PV Panels

We need massive power, but we do not have much space. As a result, we used monocrystalline silicon modules. We selected our modules based on the cost and reliability. Solar PV panels need significant initial investment.

The cost of modules accounts for about 60% of the overall device implementation cost. We determine The price of a PV panel by its performance and the material used to construct it. One of the essential considerations is productivity. Besides, temperature dependency also plays an important role. By considering these matters, We have decided to use a solar panel of LG technology.

Figure 8.1: LG265S1C-A3

Table 8.1: Details of the selected solar panels [36].

Name	General Data
Cells	6×10
Cell type	Monocrystalline
Dimensions (L x W x H)	1640 ×1000 × 35 mm
Frame	Anodized aluminum
Maximum power at STC (Pmax)	265
Operating temperature (°C)	-40 ~ 90
Module efficiency (%)	16.2

8.3.2 Inverter

Most of the electrical elements we use are dependent on Alternating Current. However, Solar panels produce Direct Current. So this is necessary to convert the AC into DC. We have chosen an inverter of Fronius.

Figure 8.2: Fronius Symo 20.0-3 480.

Table 8.2: Details of the selected inverter [37].

Name	GENERAL DATA
Dimensions (width x height x depth)	51.1 ×72.4 × 22.6 cm
Ambient functioning temperature range	-40 to 60 C
Max. permitted PV power	30.00 kW
Operating voltage range	200 - 1,000 V
Max. output power	19,995 VA
Max. efficiency	98.0 %

8.3.3 Combiner box

A combiner box is a tool that connects several strings of PV modules to the inverter by combining their output. People use it commonly in industrial and utility-scale PV power plants, usually more than 500 kW. As we are not sure about our capacity, we have primarily chosen a combiner box. It is of SMA company.

Figure 8.3: The SMA SCCB-10 combiner box.

8.4 Use of Software

We will use some software to design, calculate and simulate our estimated project. Mainly we shall use HOMER Pro to find out the cost analysis. Besides, we will use PVSYST and Sketchup Pro for different purposes.

8.5 Analysis and Simulation with PVSYST

PVsyst is a PC software kit used worldwide to study, scale, simulate, and analyze complete solar PV systems. PVSYST has various built-in mathematical models for different components such as photovoltaic modules, inverter, and other tools. We will use PVSYST to determine the maximum capacity, module sizing, and system losses in this project.

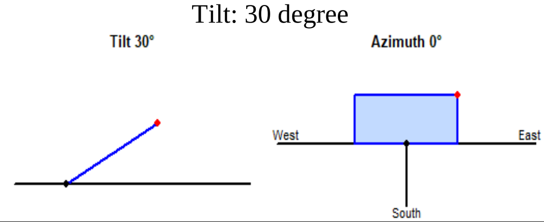
8.5.1 Design

This section contains various steps for designing such systems, including position, horizon, and machine sizing. We require many components to build a system, including module, battery, and inverter selection. A sizing array illustrates various modules linked in series and parallel. PVSYST allows users to add these components to create a realistic PV environment that we can simulate. Users get the test output after completing the simulation.

Input data

We completed our design first to acquire preliminary information and then planned a grid-connected device project for DIU AB4. We have specified our position, orientation, and horizon in this section. We selected our exact location. We chose a module. An inverter described our monthly energy consumption rates. It announced the expected power we want to produce because we want to build a PV system. We have mentioned the parameters in Table 8.3:

Table 8.3: Input data of PVSYST

Simulation parameters	Description
Geographical site	Academic Building 4, Daffodil International University
Position	Lattitude:23.88 °N Longitude:90.32°E, Altitude: 21m
Albedo	0.25
System parameter	System type: Grid-connected System
User's need	Unlimited load
Project Lifespan	25 years
PV field orientation	Fixed plane
Collector plane orientation	Tilt: 30 degree 
Horizon	Free horizon
Near Shading	No shading
PV module	LG265S1C-A3
Panel type	Si-mono
Unit nominal power	265 W
Module Area	1845 m^2
Cell area	1613 m^2
Inverter name	Fronius Symo 20.0-3 480
Unit Nominal Power	20 KW

8.5.2 Simulation and Result

The simulation and the simulation result is described below:

8.5.2.1 PV Array Characteristics

Table 8.4: PV array characteristics

Simulation parameters		Description
PV Module	Number of PV modules	1125 units
	Nominal (STC)	298 KW
	Modules	45 strings × 25 in series
	Power at operating conditions	267 KW
	The voltage at operating conditions	689 V
	Current at operating conditions	388 V
Inverters	Number of Inverters	12 units
	Total Power	240 KW
	Operating Voltage	200-800 V
	The nominal ratio of DC and AC	1.24

8.5.2.2 Array Losses

Table 8.5: Array losses

Simulation parameters		Description
Array soiling losses	Loss fraction	2 %
Series diode loss	Voltage drop	0.7
	Loss fraction	0.1%
Module mismatch losses	Loss fraction	2%
Thermal loss factor	Uc (constant)	29 W/m^2
	Uv (wind)	0 W/m^2
Light-induced degradation	Loss fraction	2%
Strings mismatch loss	Loss fraction	0.1%
DC wiring losses	Global array resistance	30 mΩ
	Loss fraction	1.5%
Module quality loss	Loss fraction	-0.8%
Module average degradation	Loss fraction	0.4%/year
Mismatch due to degradation	Current RMS dispersion	0.4%/year
	Voltage RMS dispersion	0.4%/year

8.5.3 Schematic Diagram

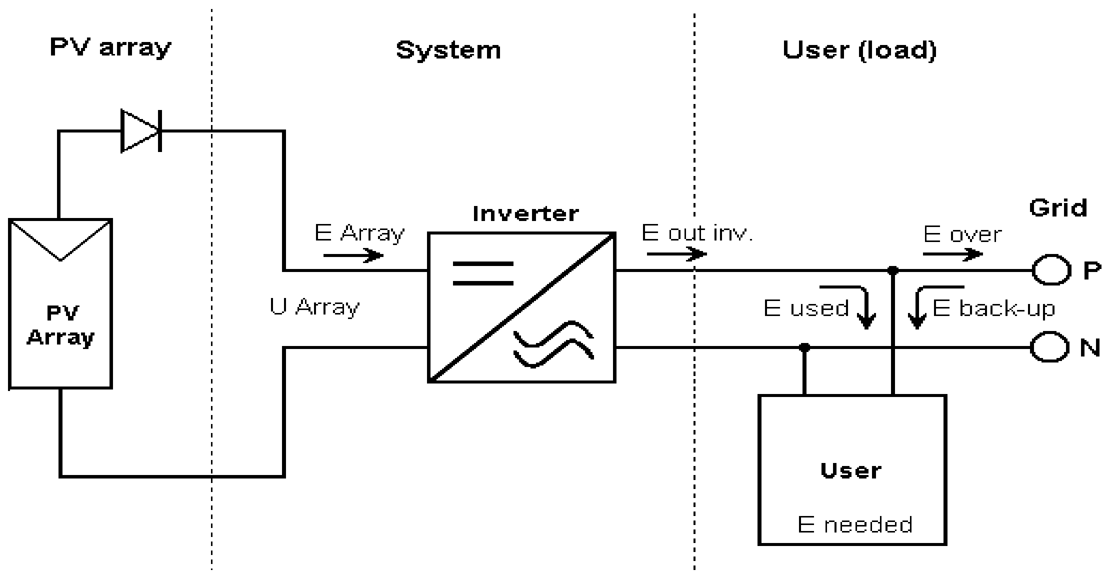


Figure 8.4: Simplified sketch of the system.

8.5.4 System Production

System Production

Produced Energy	403.3 MWh/year	Specific production	1353 kWh/kWp/year
		Performance Ratio PR	68.70 %

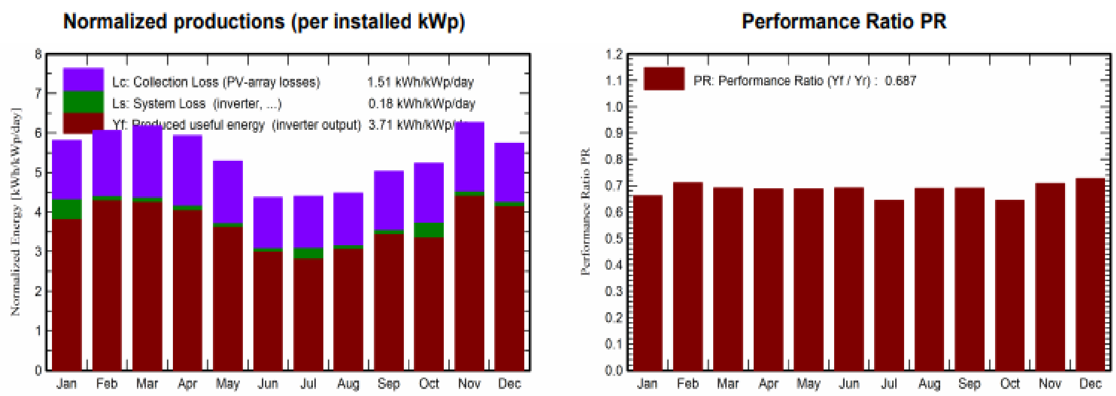


Figure 8.5: System Production

8.5.5 Loss Diagram

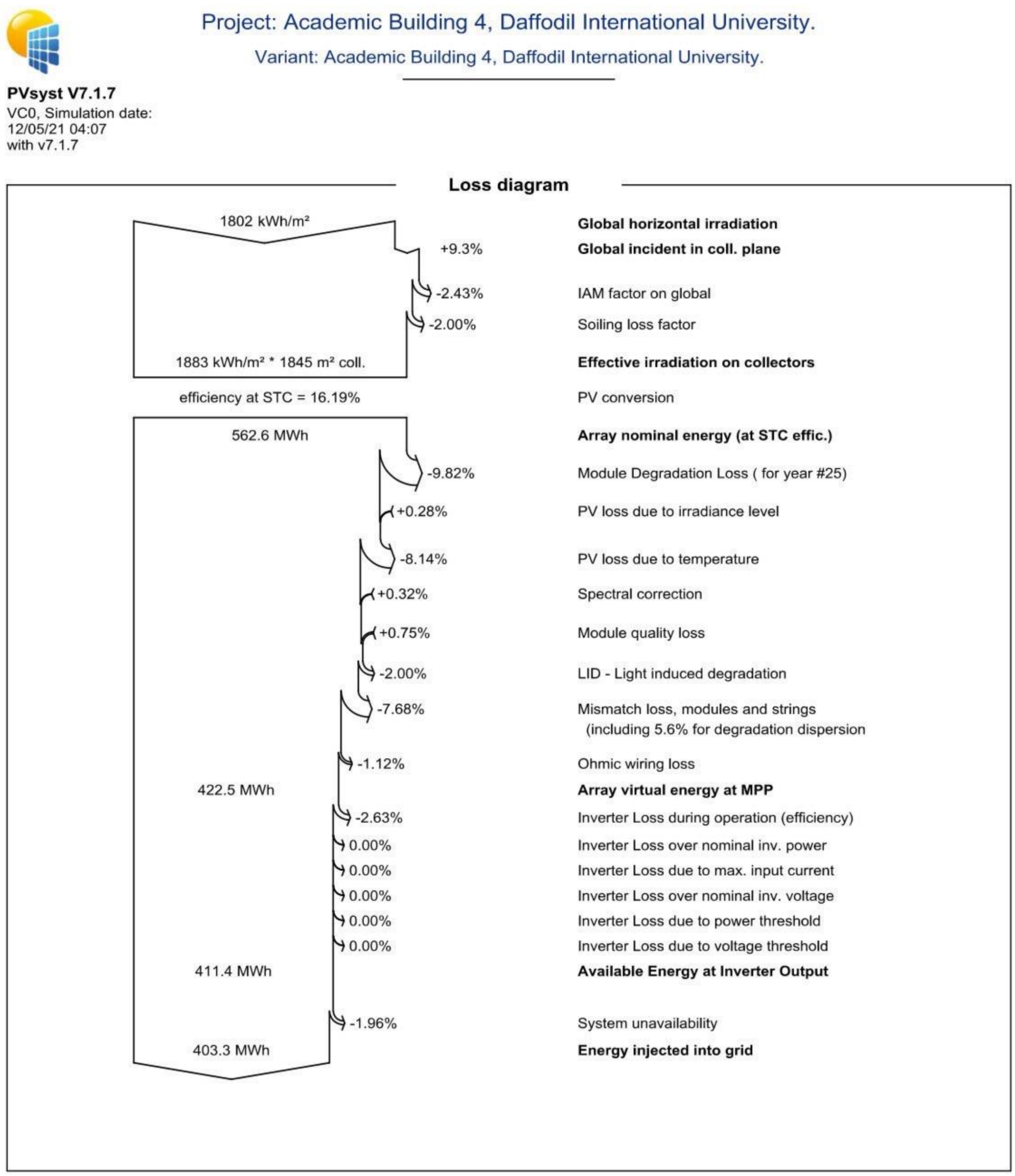


Figure 8.6: Loss diagram

8.6 Practical View of the Project

In our practical measurements, we have found that we can implement 1084 solar panels. Moreover, with the help of PVSYST, we have measured that we can implement 1125 solar panels. These data have very close values. We shall try to visualize our desired project in this section. We have used Sketchup Pro to draw the estimated view of the project.

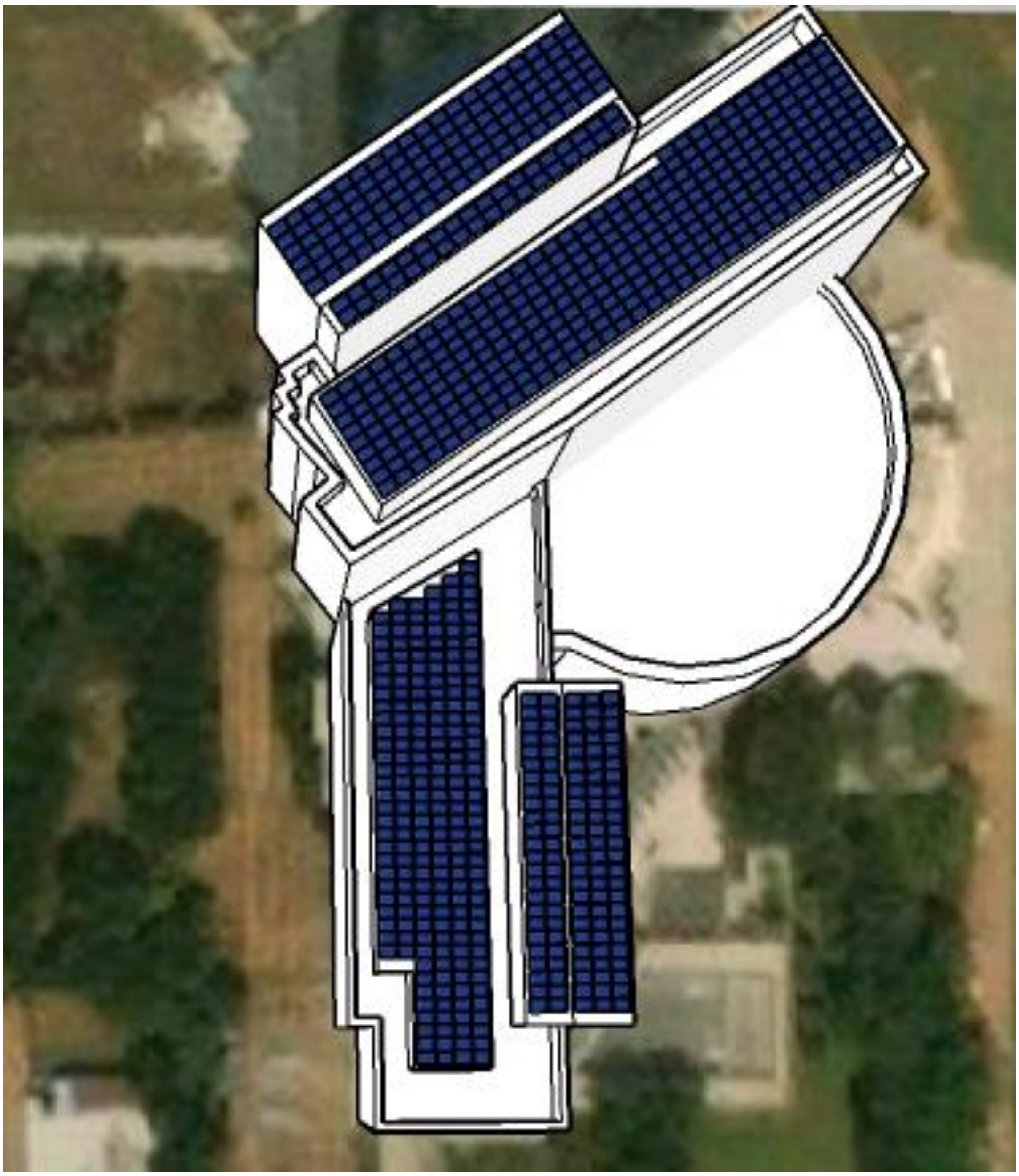


Figure 8.7: Estimated top view of the project.

8.7 Cost Analysis with HOMER

HOMER Energy's HOMER Pro microgrid application is the world standard for improving microgrid configuration in all fields. In this thesis work, we shall compare the economics for two types of loads.

8.7.1 Input Data

We have already calculated loads of different parts of the day. Besides, we needed some data to complete the simulation.

Table 8.6: HOMER input Data (Both loads)

Name	Properties		
Electric load	**Load**	**Full load**	**Reduced load**
	Scaled annual average load	9,737.573 kWh/d	`3,047.369kWh/d
	Scaled peak load	1,532.0077 kW	1,518.2858 kW
	Load factor	0.2652	0.2676
PV (LGElectronics265LG265S1W-A3)	Capital cost	BDT 104,110.38/KW	
	Replacement cost	BDT 0.00	
	Operation and Management cost	BDT 20/KW/Year	
	Sizes to consider	265 W	
	Derating factor	85%	
	Tracking	No Tracking	
	Lifetime	25 years	
Inverter	Capital cost	BDT 12,417.31	
	Replacement cost	BDT 12,417.31	
	Operation and Management cost	BDT 20/KW/Year	
	Sizes to consider	20 KW	
	Life span	10 years	
	Parallel with AC generator	Yes	
Economics	Annual interest rate	6%	
	Project lifetime	25 Years	

8.7.1.1 Solar GHI Resource

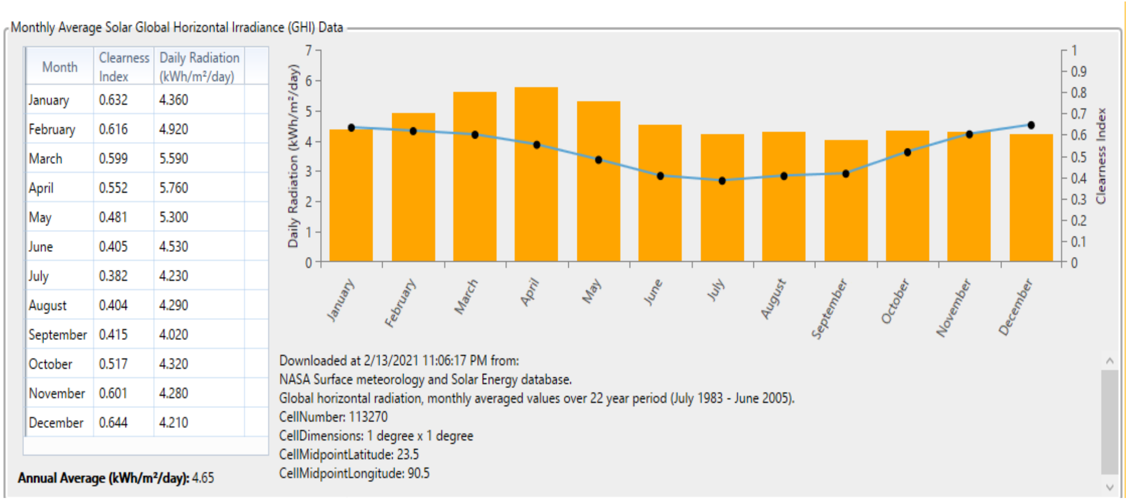


Figure 8.8: Solar GHI Data [13]

8.7.1.2 Wind Speed Data

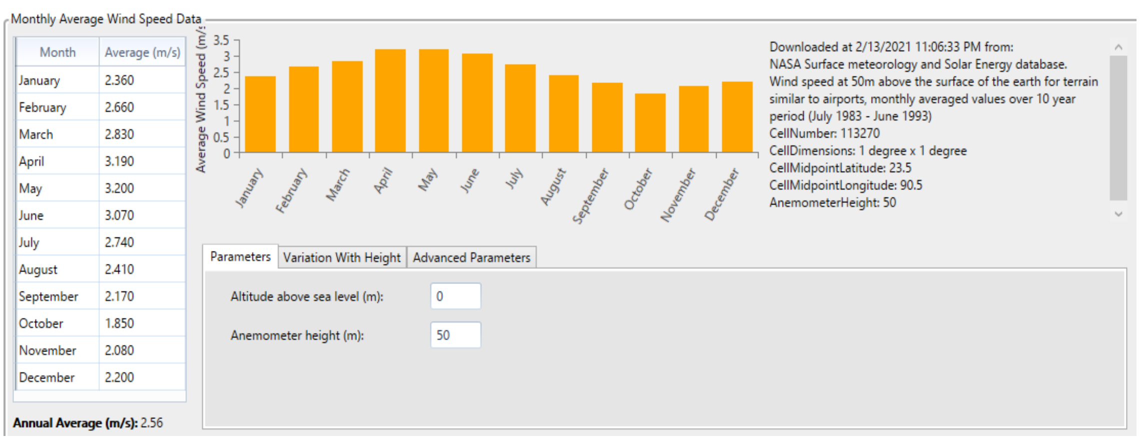


Figure 8.9: Monthly average wind speed data

8.7.1.3 Temperature data

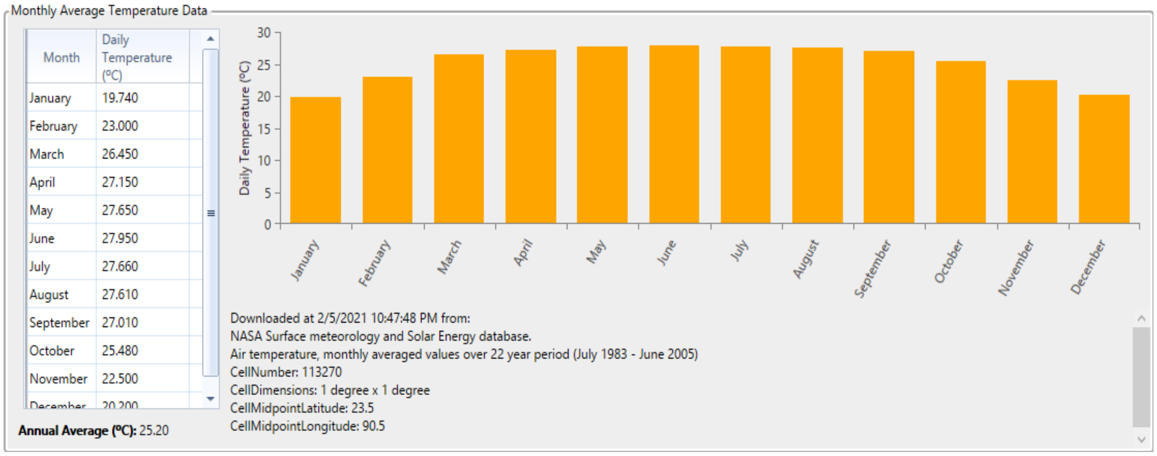


Figure 8.10: Monthly average temperature data

8.7.2 Design and Simulation Results for Full Load

This section covers the cost analysis based on loads of every element of the building.

8.7.2.1 Design

Schematic diagram

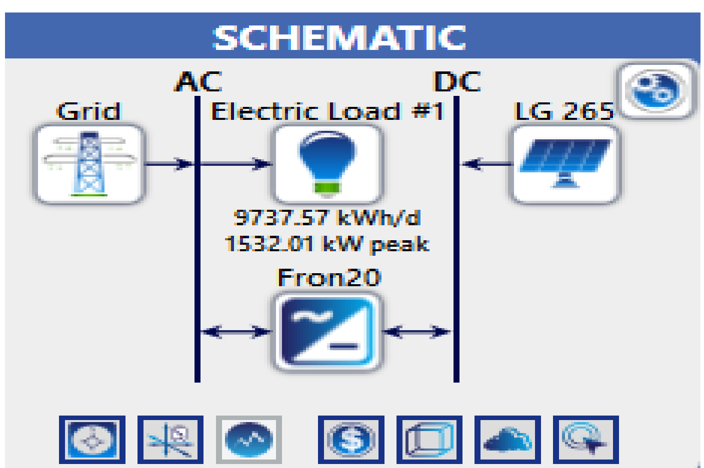


Figure 8.11: Schematic diagram of the project (Full load).

8.7.2.2 Simulation Result

i. Cost Summary

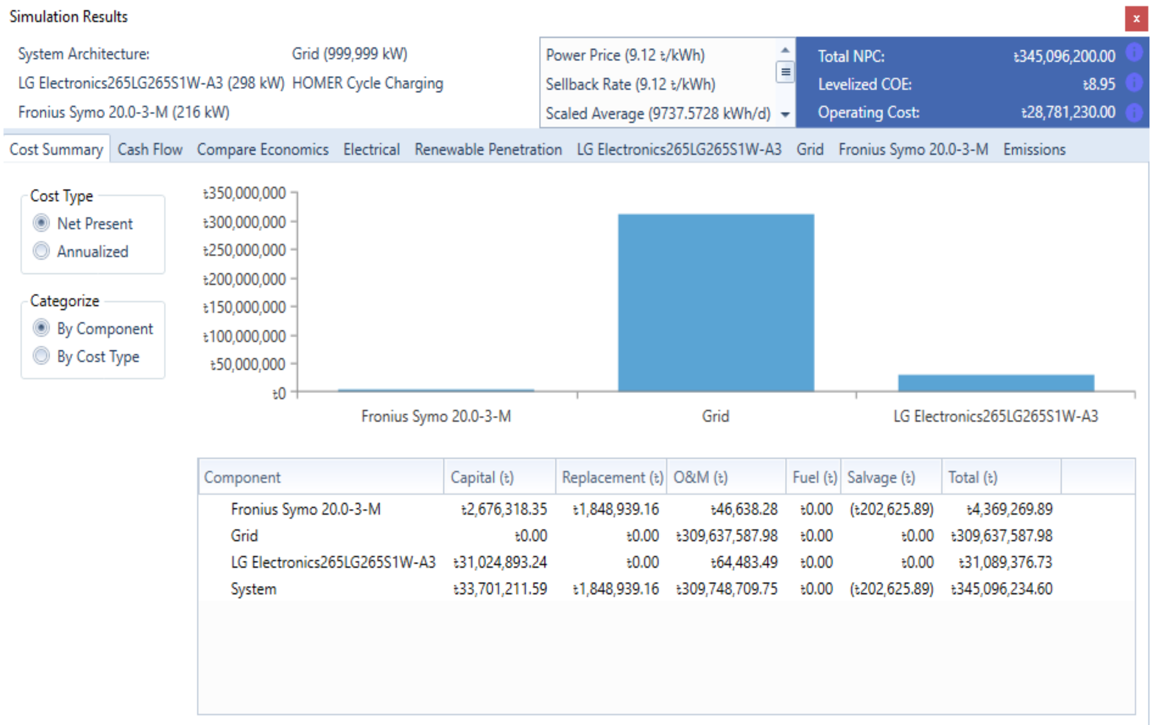


Figure 8.12: Cost Summary (Full load).

ii. AC Primary Load Monthly Average

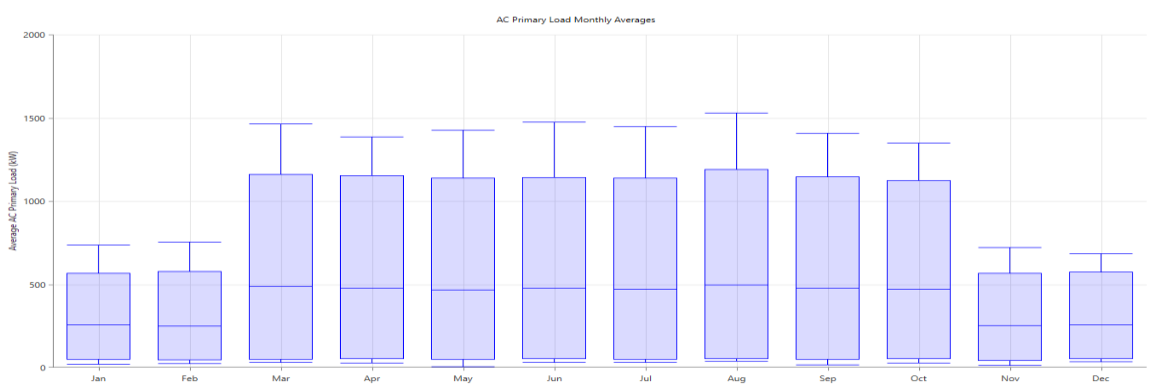


Figure 8.13: Month average AC load (Full load).

iii. Cash Flow

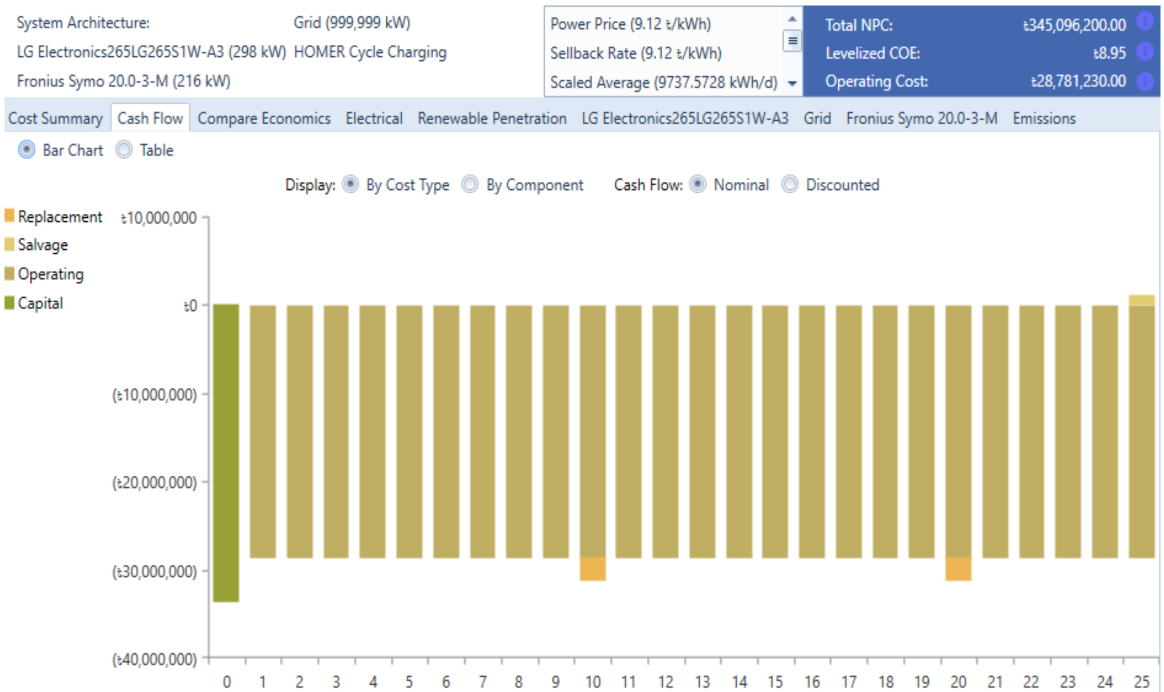


Figure 8.14: Cash flow (Full load).

iv. Electrical

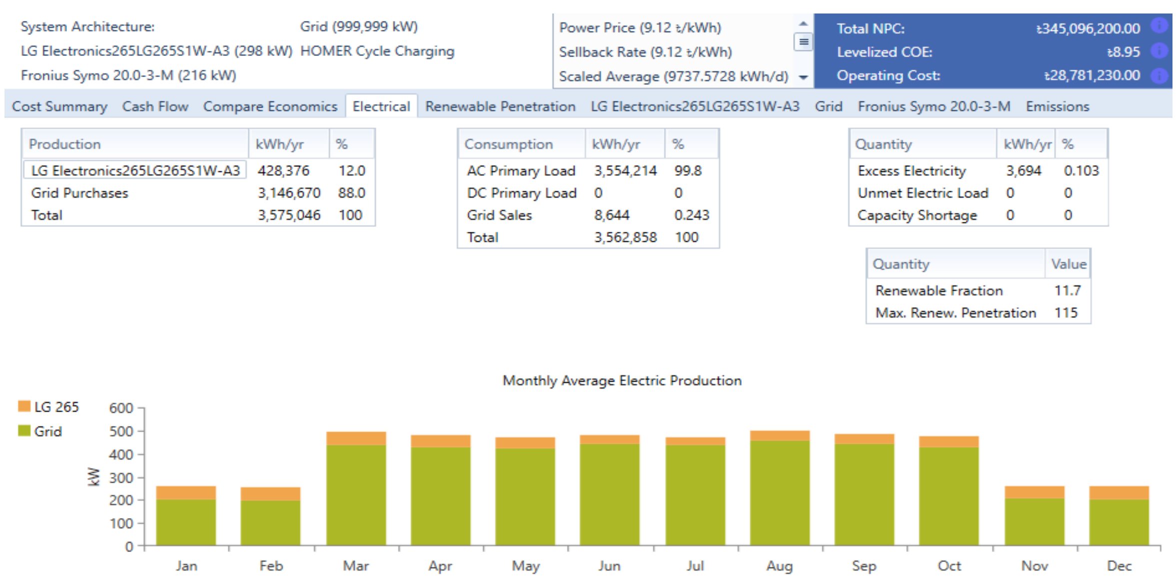


Figure 8.15: Electrical data (Full load).

v. Renewable Penetration

Figure 8.16: Renewable Penetration (Full load).

vi. Solar Panel Output

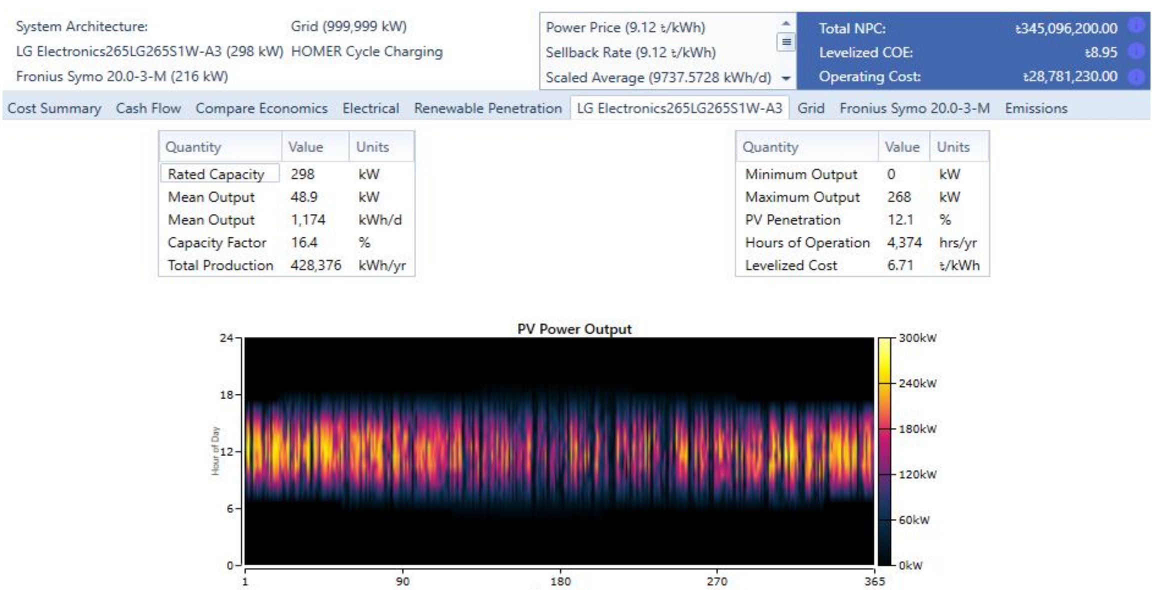


Figure 8.17: Solar panel output (Full load).

vii. Grid Result

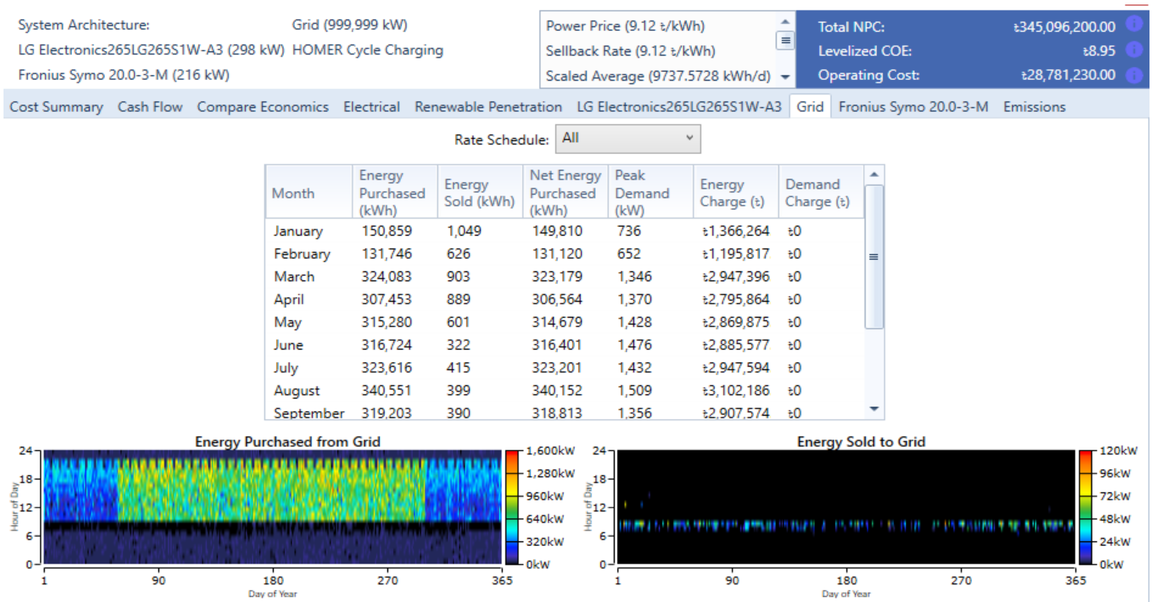


Figure 8.18: Grid result (Full load).

viii. Inverter Result

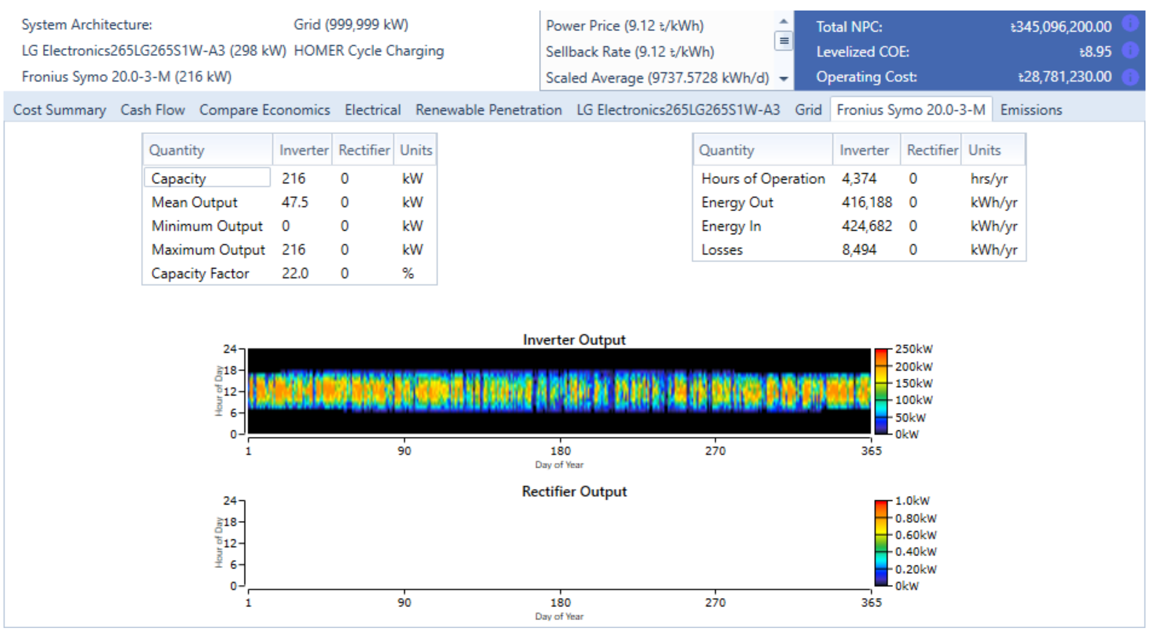
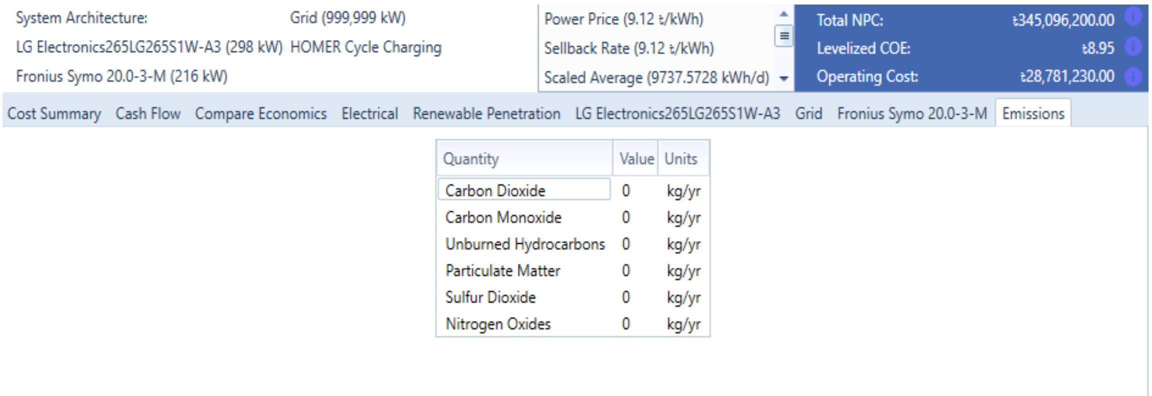


Figure 8.19: Inverter result (Full load).

ix. Emissions



Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Figure 8.20: Emissions result (Full load).

8.7.3 Design and Simulation Results for Reduced Load

This section covers the cost analysis based on loads of classrooms, washrooms, and building corridors.

8.7.3.1 Design

Schematic diagram

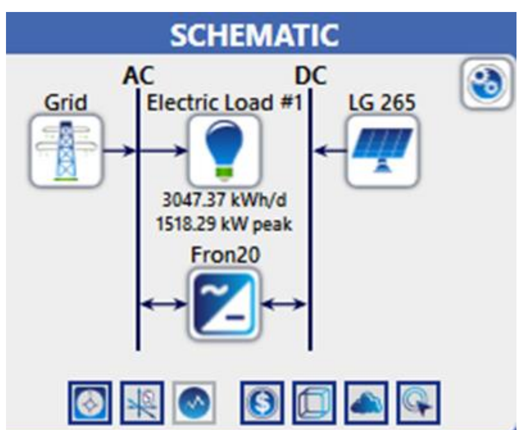


Figure 8.21: Schematic diagram of the project (Reduced load).

8.7.3.2 Simulation Result

i. Cost Summary

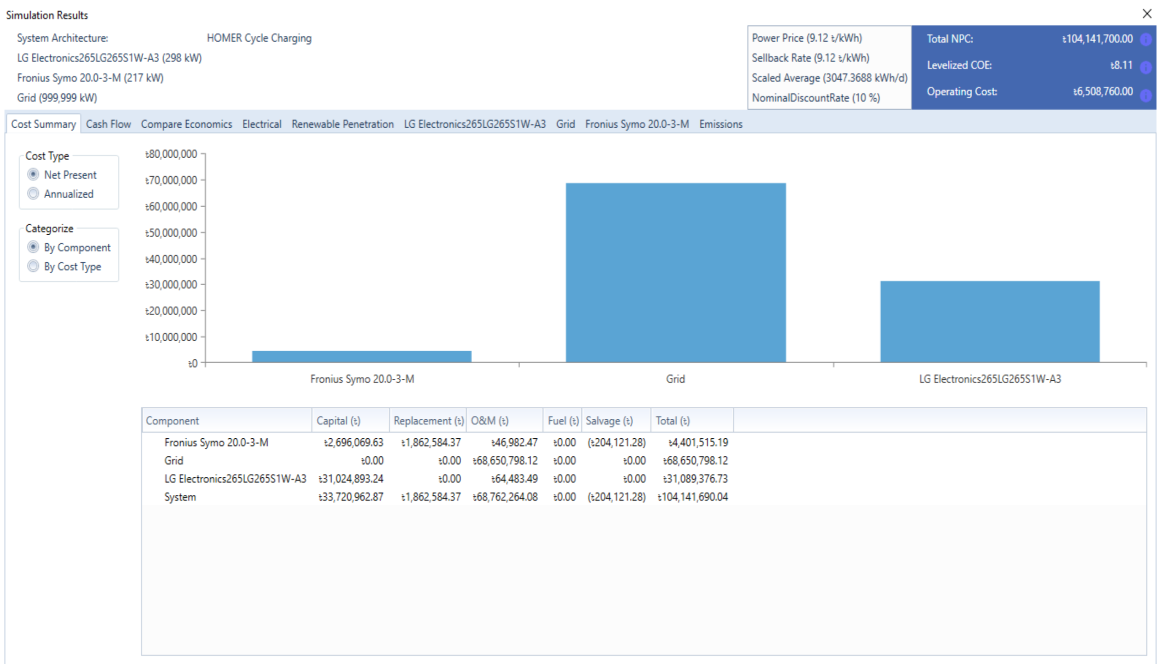


Figure 8.22: Cost Summary (Reduced load).

ii. AC Primary Load Monthly Average

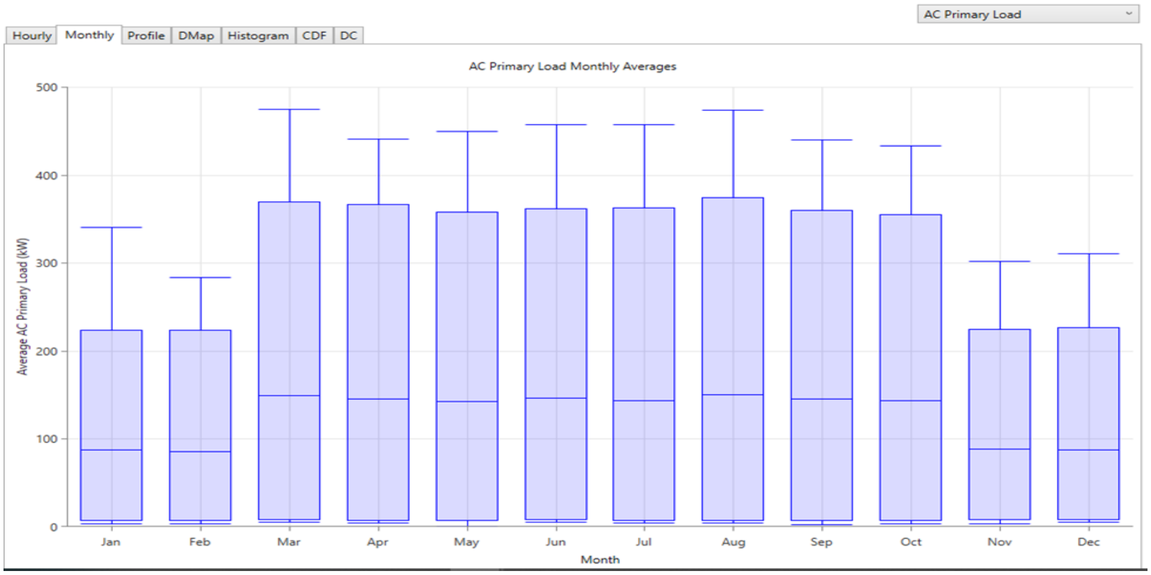


Figure 8.23: Month average AC load (Reduced load).

iii. Cash Flow

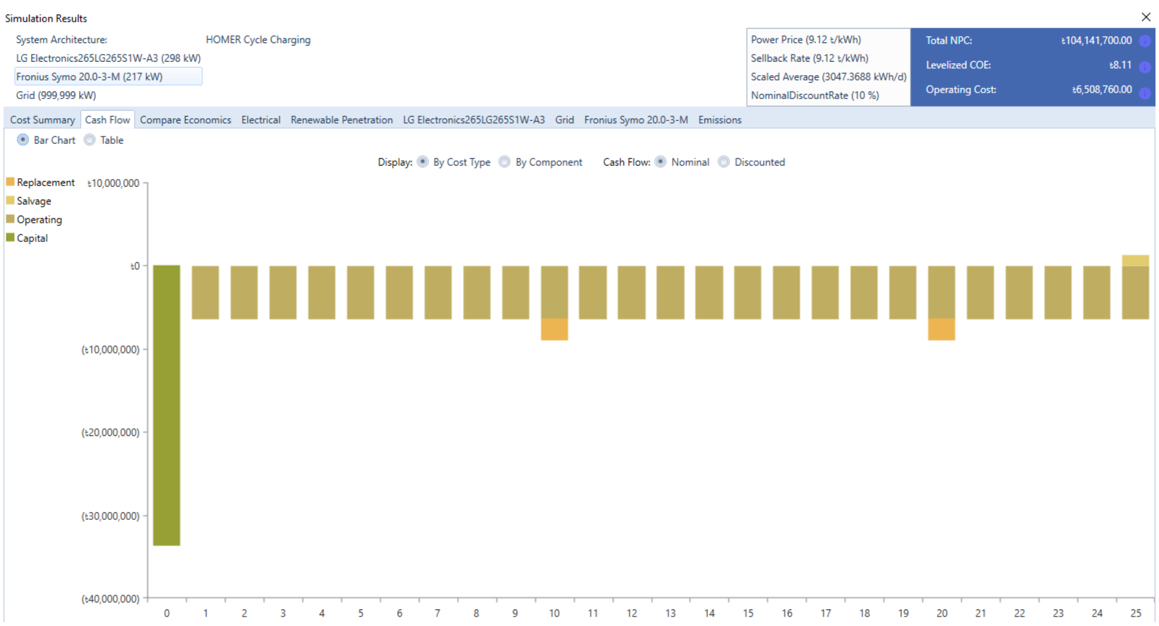


Figure 8.24: Cash flow (Reduced load).

iv. Electrical

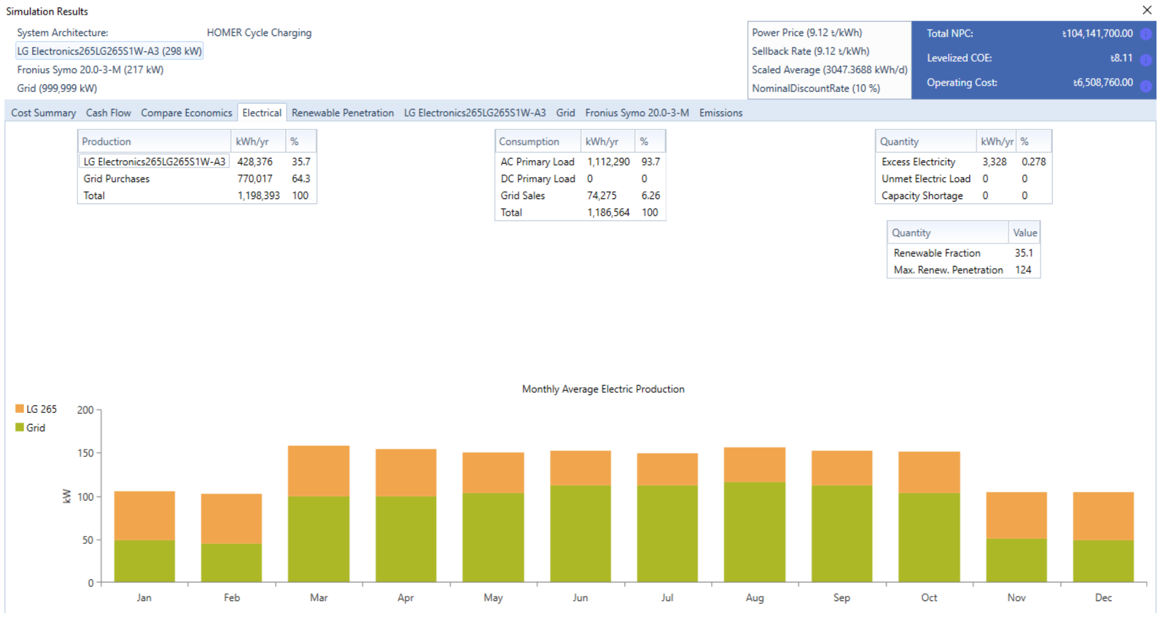
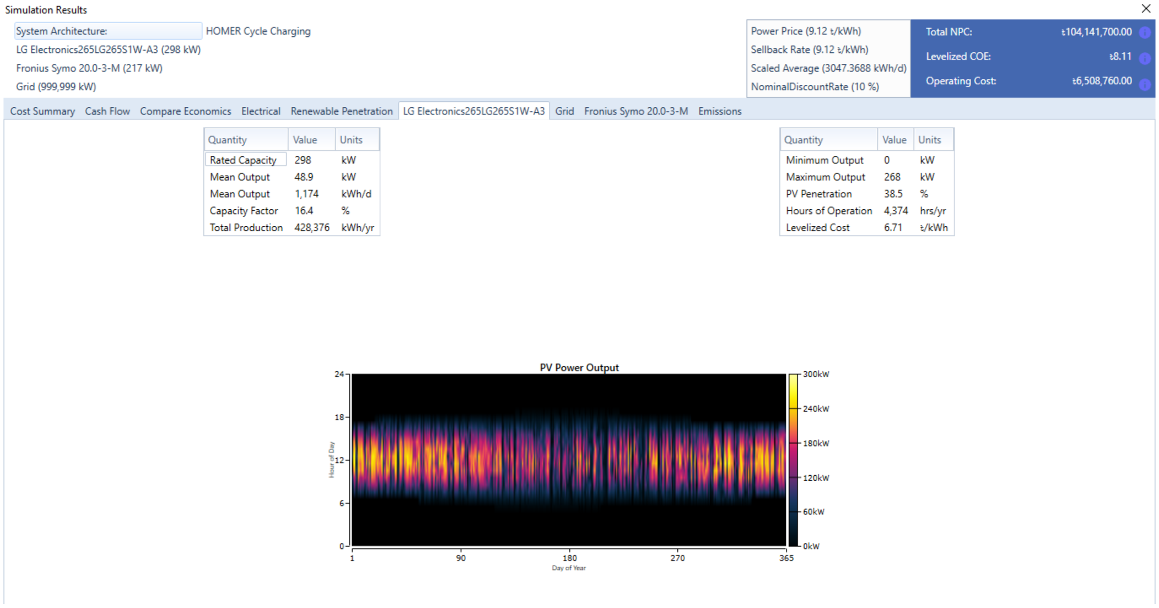


Figure 8.25: Electrical data (Reduced load).

v. Renewable Penetration

Figure 8.26: Renewable Penetration (Reduced load).

vi. Solar Panel Output

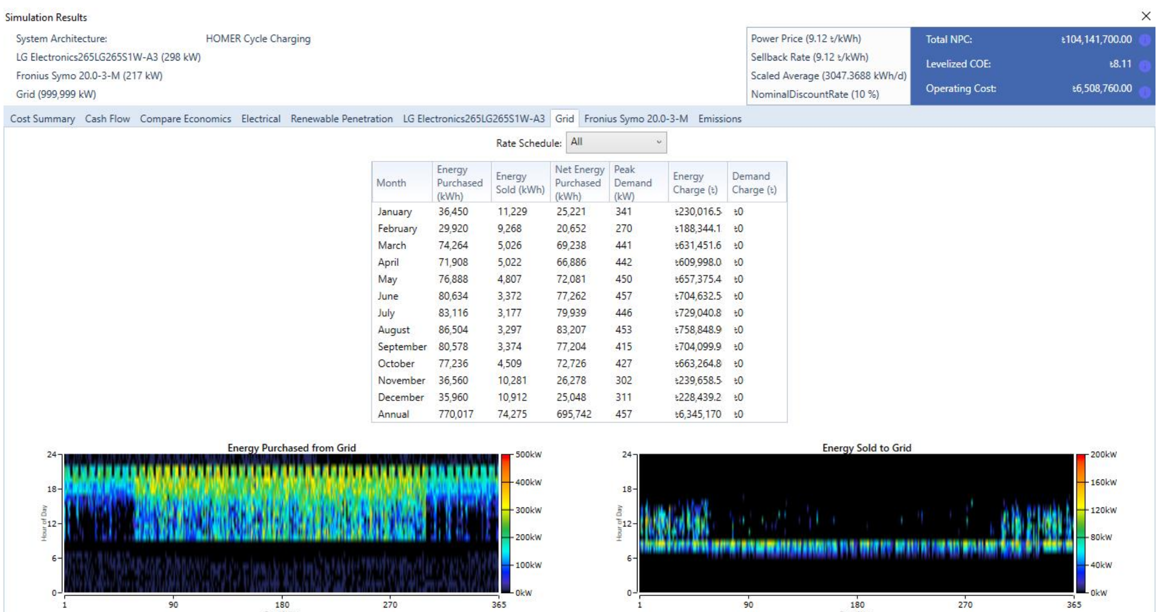


Quantity	Value	Units
Rated Capacity	298	kW
Mean Output	48.9	kW
Mean Output	1,174	kWh/d
Capacity Factor	16.4	%
Total Production	428,376	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	268	kW
PV Penetration	38.5	%
Hours of Operation	4,374	hrs/yr
Levelized Cost	6.71	৳/kWh

Figure 8.27: Solar panel output (Reduced load).

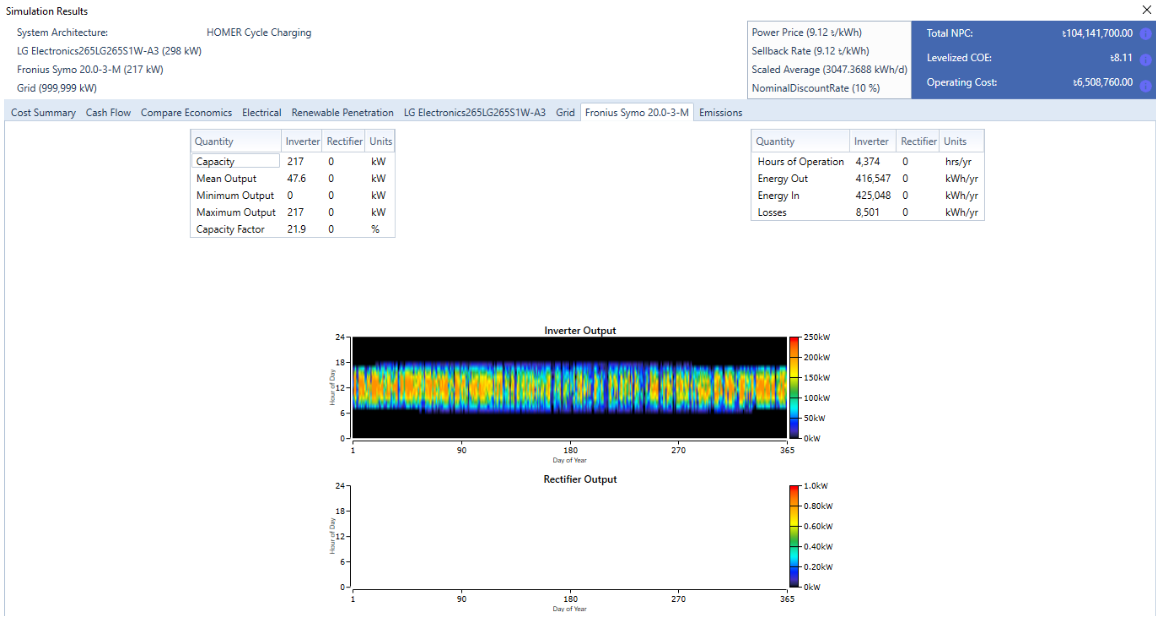
vii. Grid Result



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (৳)	Demand Charge (৳)
January	36,450	11,229	25,221	341	৳230,016.5	৳0
February	29,920	9,268	20,652	270	৳188,344.1	৳0
March	74,264	5,026	69,238	441	৳631,451.6	৳0
April	71,908	5,022	66,886	442	৳609,998.0	৳0
May	76,888	4,807	72,081	450	৳657,375.4	৳0
June	80,634	3,372	77,262	457	৳704,632.5	৳0
July	83,116	3,177	79,939	446	৳729,040.8	৳0
August	86,504	3,297	83,207	453	৳758,848.9	৳0
September	80,578	3,374	77,204	415	৳704,099.9	৳0
October	77,236	4,509	72,726	427	৳663,264.8	৳0
November	36,560	10,281	26,278	302	৳239,658.5	৳0
December	35,960	10,912	25,048	311	৳228,439.2	৳0
Annual	770,017	74,275	695,742	457	৳6,345,170	৳0

Figure 8.28: Grid result (Reduced load).

viii. Inverter Result

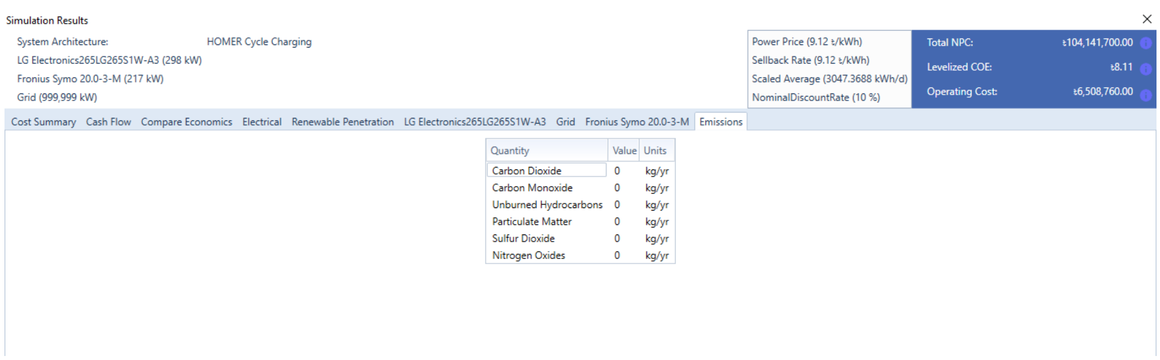


Quantity	Inverter	Rectifier	Units
Capacity	217	0	kW
Mean Output	47.6	0	kW
Minimum Output	0	0	kW
Maximum Output	217	0	kW
Capacity Factor	21.9	0	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	4,374	0	hrs/yr
Energy Out	416,547	0	kWh/yr
Energy In	425,048	0	kWh/yr
Losses	8,501	0	kWh/yr

Figure 8.29: Inverter result (Reduced load).

ix. Emission



Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Figure 8.30: Emissions result (Reduced load).

8.8 Summary

This chapter is about analysis and simulation. At first, the solar panels and the inverter have been selected. The maximum capacity has been measured with PVSYST by using their capacity and the area of the rooftop. The maximum capacity was 298 KW. After that, a visual representation has been created with Sketchup pro. Finally, we have done the simulation with HOMER pro. We have found a schematic diagram, net present cost, cost of energy, cost summary, Ac primary load monthly average, cash flow, electrical result, renewable penetration, solar panel output grid result, inverter result, and emission result. It has been calculated for full load and selected load.

CHAPTER 9

COMPARISON AND FEASIBILITY STUDY

9.1 Introduction

We have already analyzed our estimated solar project in the previous chapters. We have calculated it for both full load and reduced load. Now we shall try to find out the most feasible way in this chapter.

9.2 Comparison

Between the two models, the only difference we produced is the input load. The rooftop of our solar project was of exact area. There is not any extra space to implement more solar panels. So, we have included a comparison table of our two models in Table 9.1:

Table 9.1: Comparison of full load and reduced load.

Name	When Full load	When Reduced load
Scaled annual average load	9,737.573 kWh/d	3,047.369 kWh/d
Scaled peak load	1,532.0077 kW	1,518.2858 kW
Load factor	0.2652	0.2676
Total NPC	BDT 345096200	BDT 104141700
Levelized COE	BDT 8.95	BDT 8.11
Operating Cost	BDT 28781230	BDT 6508760

9.3 Feasibility Analysis

Our rooftop has a limited area. So, it was not possible to meet the demand of the building. Even when we took the classroom, washroom, and corridor load, we could not meet the demand several times. Nevertheless, let us look at the overall performance. We will see that when we reduce the load, the cost of per unit electricity also reduces. Besides, We found A reduced value of operating cost while we reduced the load. However, When we considered the whole load, we found the cost of BDT 8.95.

On the other hand, when we reduced the load, the cost per unit of electricity was reduced to BDT 8.11. So, the feasibility increases when the load decreases in this particular project. The reduced load increases the selling of the energy to the grid. So, there is no doubt that the project consisting of the reduced load is much feasible.

9.4 Summary

This chapter includes a comparison and feasibility analysis of this project. At first, we have a comparison between the results of full load and reduced load. Then, we have made a feasibility analysis. We have found that the energy cost for a full load and reduced load are BDT 8.95 and BDT 8.11, respectively. So, the system with reduced load is much feasible.

CHAPTER 10

CONCLUSION AND FUTURE WORK

10.1 Conclusion

This thesis work examines the design, simulation, and feasibility analysis of a solar rooftop PV system. In the concluding section of this research work, it can be seen that the outcome found was a productive one in favor of bringing the project into action. The project's initial goal of developing a feasible, practical framework was achieved. The area we measured was suitable for implementing this solar project. As there were not any other tall structures, there was not any problem with shading. The project lifetime was 25 years. So, the solar panel and inverter were selected based on efficiency and environmental condition. The number of PV panels we found was 1125 units, and they have a maximum capacity of 298 KW. It was not capable of meeting the total demand of the building. So, a grid-connected system was chosen. So, when the system needs electricity, it collects electricity from the grid. On the other hand, when the generation overflows the demand, it supplies electricity to the grid. As net metering is implemented, HOMER analyzed the simulation with grid power price and grid sell-back price. Both prices were BDT 9.12. Two simulations were done here, including the whole building's loads, classroom, washroom, and corridor loads. The cost of energy was BDT 8.95 for the full load and BDT 8.11 for the reduced load, which were lower than the grid power price. Among the two types of loads, the reduced load was more feasible than the full load. As the unit cost of energy of reduced load is lower than the cost of energy of grid and full load, it is the most feasible way to construct the project. This condition is applicable for any type of load at any place. So, to construct a grid-connected solar project, it is necessary to reduce the load to get higher efficiency.

10.2 Limitations

There were also some limitations. We have described them below:

i. Academic Building 4 is now under construction. So, there is a possibility of increment of load in future.

ii. The area of the rooftop was not large enough to implement a massive project.

iii. The solar irradiance data proves that this location has a lower value than other locations.

iv. HOMER can not take different values for flat, Off-peak, and peak.

v. The solar panels and inverter price is higher in Bangladesh than overseas.

10.3 Scope of Future Work

Though there are limitations, we can ignore them as the project was feasible. There is a vast space around the university area. The authority can also take steps to construct a larger project. Besides, the rooftops of other buildings are serviceable for implementing solar projects. By spread over more and more solar projects, the whole Daffodil smart city can meet its overall demand.

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Appendix A

Net Metering

Net metering is a billing mechanism that credits solar energy system owners for the electricity they add to the grid. When the solar panels generate more energy than usage, the consumer may send it to the grid in return for credits. Then, when the solar panels aren't producing enough during the day or at other times, the consumer takes electricity from the grid and utilizes these credits to subsidize the cost of that electricity.

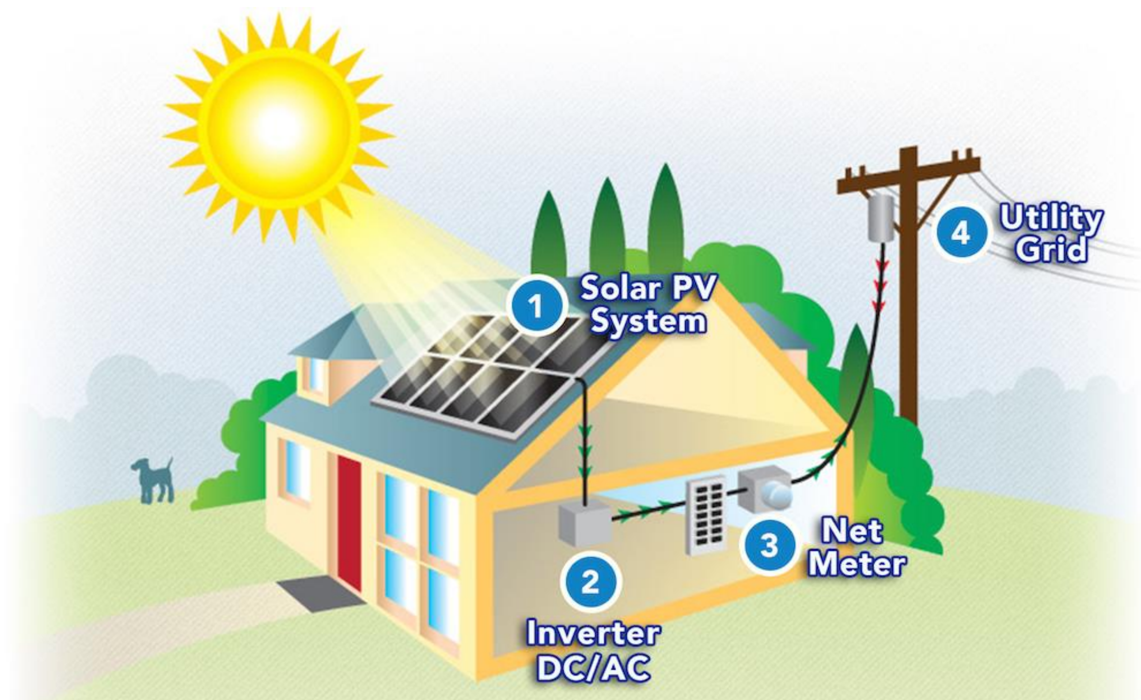

Figure: Typical net metering system [38].