ANALYSIS OF THE SOLAR IRRADIATION PATTERN OF BANGLADESH FOR ELECTRICITY GENERATION

This thesis submitted in partial fulfillment of the requirements for the Award of Degree of

Bachelor of Science in Electrical and Electronic Engineering

Submitted By

Md. Yasir Arafat

152-33-2608

Ifran Mahmud

152-33-2671

Supervised by

DR. M. SHAMSUL ALAM

Professor, Faculty of Engineering

Daffodil International University

Department of Electrical and Electronic Engineering

DAFFODIL INTERNATIONAL UNIVERSITY

October 2019

Certification

This is to certify that this thesis entitled "**ANALYSIS OF THE SOLAR IRRADIATION PATTERN OF BANGLADESH FOR ELECTRICITY GENERATION**" 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.

Countersigned

Dr. M. Shamsul Alam

Professor

Department of Electrical and Electronic Engineering

Daffodil International University

Signature of the candidates

Name: Md. Yasir Arafat

ID: 152-33-2608

Name: Ifran Mahmud

ID: 152-33-2671

Dedicated to

Our Beloved

Parents

CONTENTS

List of Tables

List of Figures

List of Abbreviations

SHS	Solar Home System.
PV	Photovoltaic
AC	Alternating Current
DC	Direct current.
UV	Ultra Violet.
GDP	Gross Domestic Product.
NGO	Non-Governmental Organization.
IDCOL	Infrastructure Development Company Limited.
STC	Standard Test Condition.
OPC	Operational Condition.
BUET	Bangladesh University of Engineering and Technology.
GS	Grameen Shakti.
IRE	Institute of Renewable Energy
KWp	Kilowatts peak.
BRAC	Bangladesh Rural Advancement Committee
BAEC	Bangladesh Atomic Energy Commission
BPDB	Bangladesh Power Development Board
BCSIR	Bangladesh Council of Scientific and Industrial Research
DU	Dhaka University
DLR	Research and Development
NREL	National Renewable Energy Laboratory

PGCB	Power Grid Company of Bangladesh Limited
DESCO	Dhaka Electric Supply Company Limited
NWPGCL	North-West Power Generation Company Limited
LNG	Liquefied Natural Gas
GIZ	German Development Cooperation
Kreditanstalt für Wiederaufbau	Reconstruction Credit Institute of Germany
ADB	Asian Development Bank
EU	European Union
IDB	Islamic Development Bank
BSREA	Bangladesh Solar & Renewable Energy Association
MIST	Military Institution of Science and Technology
IUT	Islamic University of Technology

Acknowledgment

First of all, we give thanks to Allah for his diving blessing to make us possible to complete this thesis successfully.

We want to express our sincere gratitude to our honorable thesis supervisor Professor Dr. M. Shamsul Alam, Professor; Dept. of EEE Faculty of Engineering Daffodil International University (DIU).He extended his helping hand by providing us encouragement, support, facilities, the research, analysis and valuable feedback throughout the course of this thesis.

We would like to thanks our loving families for all their support throughout this entire process. Also, we would like to convey our best regards to all our friends and teachers for their support, without which it could be impossible for us to come out with this thesis paper. We offer our unconditional apology for any inadvertent mistake.

ABSTRACT

Power crisis along with environmental pollution generated from power production is the major concern for the developing country likes Bangladesh. Using irradiation and power data, we can easily understand that power projects are an awareness of increased benefits between customers and suppliers, and the proper use of the solar home system. Solar energy is one of the cheapest energy types that are rapidly increasing worldwide used. Bangladesh is among those countries in which sun warms the periphery all through the year and therefore has a faithful potential for solar power generation. The following research paper is based on performance analysis the solar irradiation pattern of Bangladesh for electricity generation. Irradiation and power area unit mentioned with their optimum capability. Solar Home System (SHS) is playing a vital role especially for rural electrification and coastal areas in Bangladesh both off grid and on grid system. The fundamental point of our research is to find out the irradiation of sun in Dhaka city in the month of November and December so that the power generation by the solar panel can be assessed. And we gather the solar irradiation and the maximum power data in Dhaka for (November and December) two months and analyze the data to get average irradiation and discover the connection between solar production by solar home system and make a standard form of power generation of solar home system in 2018.

CHAPTER 1

INTRODUCTION

Bangladesh is now a populated country in the world. Bangladesh has one of the highest numbers of the population living poverty in South Asia. In Bangladesh, there are numerous natural assets like as coal, gas, petrol. Bangladesh has been facing an electricity crisis for many years. The Bangladesh government takes many steps to reduce the electricity crisis as mean as the load-shedding problem. Most of the energy sectors are dependent on natural gas. PDB, PGCB, DESCO, and other companies are unable to generate extra electricity that is required due to the shortage of gas. Natural resources are decreasing with time when the demand is continuously increasing. Bangladesh is presently a quickest developing creating nation on the world. There is a rising demand for the energy sector for fast industrialization, urbanization, high population growth, rising a better way of life, etc. Bangladesh's economy has been becoming relentlessly in the course of recent years. Economic growth is highly correlated with energy demand or energy consumption. So now, remain the states to require being established big projects like industry, transport, etc. Renewable Energy sources to help overcome the situation. In the current world, maximum developing countries are depending more and more renewable sources and they want to produce clean energy to save their future generation. A large portion of the urban individuals doesn't approach power. Natural gas is the main source of generating electricity in Bangladesh. Without access to power, families can't have the essentials of lighting, refrigeration, utilization of family apparatuses, and access to the web, to give some examples.

Introducing the solar PV units on Rooftop would be a cleaner and less expensive vitality arrangement. We know that topographically Bangladesh is in the semi-tropical locale of the northeastern part in South Asia, we get the direct sunlight for the entire year that is truly ideal for solar photovoltaic-based power creation. Understanding the future prospect and numerous chances of sun based technology. The solar home system would be a potential positive alternative in providing affordable electricity and it's easy to the installation process. The government provides supported the development of rooftop solar-based plants on manufacturing plants and other business structures. With certain offices on huge plants expected to produce a megawatt or all the more each. With such solar-based plants, a huge number of processing plants in Bangladesh ought to have the option to meet their very own power needs, and contribute surplus capacity to the national grid.

World energy utilization is multiplying every 16 years. The pace of increment is significantly higher in America, where 6 percent of the total populace expends 33% of the world's vitality [1]. Some point or another, the exhaustion of energy resources will compel us to change the energy consumption behavior. The solution to the energy crisis in the future is partly dependent on the use of nuclear energy. The safety of reactors has already become an issue. It is contended that the crisis center cooling arrangement of the reactors has not been tried and along these lines there is no assurance that it will function true to form in a genuine crisis.

There is a huge capability for solar power. It is so huge that the total energy needs of the whole world can be satisfied by the solar resource. The possibility and utility of renewable sources of energy should be studied with due discretion. It is requisite because of the fear of shortage in traditional energy sources. This is easily understood when we place statistics on energy resource availability, consumption, and dependability on the import of fuel. Renewable energy resources can help our economy with decreases in reliance on petroleum products and reduce pressure on grid electricity. That are the significant things that we need to achieve a sustainable human improvement is energy freedom, which must be guaranteed through the satisfaction of the energy require of the country.

1.1 Energy Classification

Energy can be classified into different types:

1. Primary and Secondary Energy
2. Renewable Energy and Non-renewable Energy
3. Commercial and Non-commercial Energy

1.1.1 Natural Gas

Natural gas is that the fundamental stock of power age in Bangladesh. Our gas is incredibly pure, with concerning ninety fifth to ninety nine alkanes and virtually no Sulphur. In any case, the restricted gas stores cannot satisfy the stipulations of each residential, modern, and business requests, significantly requests for power age for long around 4200 MW whereas the power demand is 6000 MW. Therefore, we have a bent to stand live able to generate exclusively 63% of our total electricity demand. Due to shortage of electricity, not exclusively we have to face load shedding across the country but in addition, the industrial sector is badly affected. Leading to diminished industrial output and reduced export earnings.

Total Number of gas Field: 27

Total GIIP in TCF: 39.8Tcf

Proved + Probable+ Possible: 30.82Tcf

Remaining Reserve in TCF (As of January, 2019):11.47Tcf

Source: Petro Bangla

1.1.2 Coal

Coal is another natural resources in our country. We are 5 coal fields so far discovered, that's are Khalaspir, Phulbari, Barapukuria, Jamalganj and Dighipara. If initiatives are taken for exploration all over the country, there are enough possibilities to discover more coal mines. The government has an arrangement to produce more than 10,000 MW of power from coal power plants by 2021 and 20,000MW by 2030 under its proposed coal part groundbreaking strategy [2].

Reserve of coal (Bituminous Coal): 3100 million tons

Table 1: That are energy generated in Bangladesh by different resource with different years (2012-2018)

Year	Hydro	Natural Gas	Furnace Oil	Diesel	Coal	Power Import	Renewable Energy	Total(GWh)
2012-13	894	28119	5568	745	1156	0	0	36482
2013-14	588	28661	6516	1228	1038	2265	0	40296
2014-15	566	29731	7415	1704	941	3380	0	43737
2015-16	962	35822	8673	2067	847	3822	0	52193
2016-17	982	38052	9950	2627	1009	4656	0	57276
2017-18	1024.3	39804	10849.7	4520.3	1693	4782.7	3.79	62678

Source: Bangladesh Power Development Board

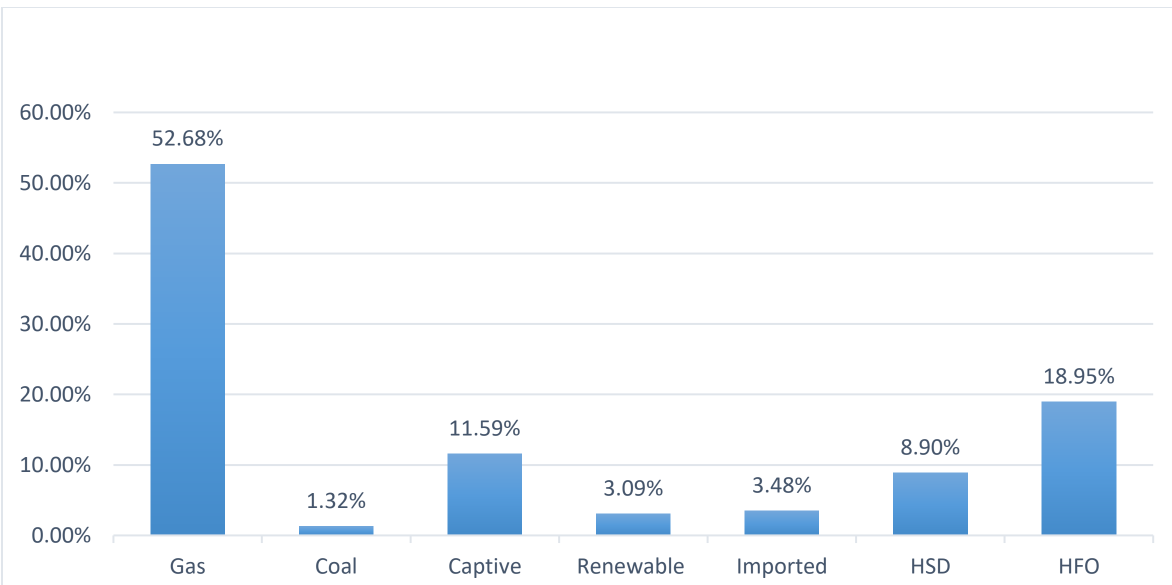

Figure 1.1: Electricity Generation Mix

Source: Bangladesh Power Development Board

1.1.3 Nuclear Power

Nuclear powers is characterized by extremely huge number of investment, technical complexity, and significant technical, market and regulatory risks, but have very low operating costs and can deliver large amount of based load electricity while producing almost no CO2 emissions. Typical construction time's area unit between five and eight years from initial concrete poured. Government of Bangladesh has marked a general contract with Russia on December 2015 for the development and necessity of the country's first nuclear plant (2*1200 MW) at Rooppur in Pabna at the 12.65 billion dollars of its cost [3].

1.1.4 Renewable Energy

Renewable Energy is a natural energy that founds from renewable resources including wind, sunlight, biomass and biogas, geothermal, waves and tides with natural resources. A large portion of these renewable energies rely on the solar light, hydroelectric and wind. In 2018, 171 GW of renewable energy capability was additional globally, in step with to new information discharged by the International Renewable Energy Agency (IRENA) [4].

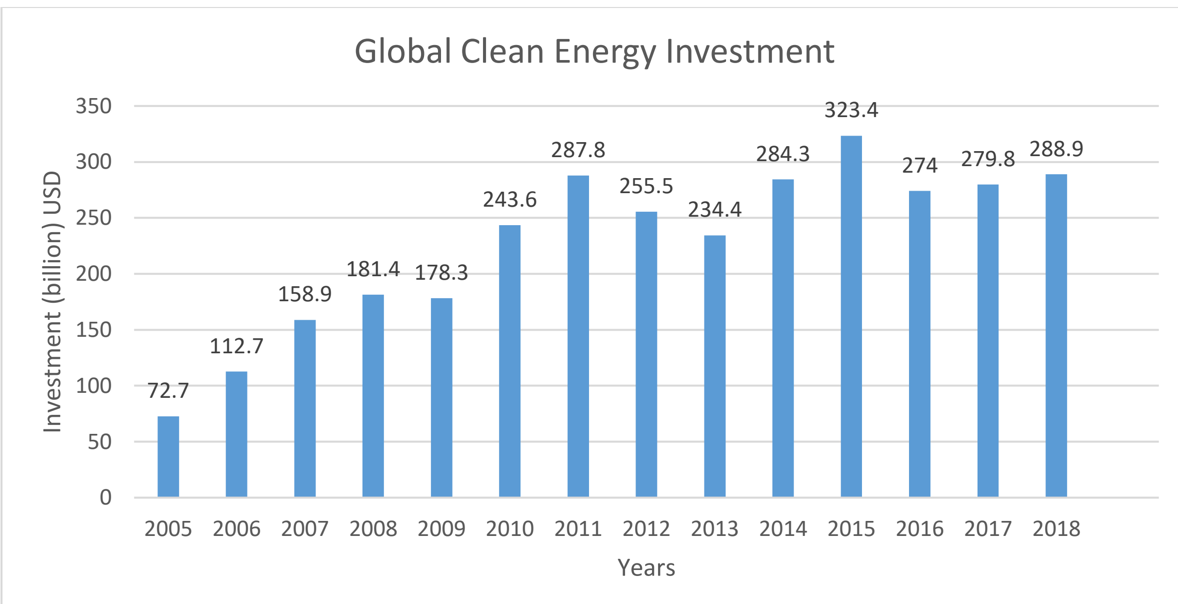

Figure 1.2: Global Clean Energy Investment

Source: UN Environment, Bloomberg New Energy Finance

Renewable energy is better for the environment. Renewable energy is clean and free from greenhouse gases, which cause environmental change-nor contaminating discharges. The worldwide power sector gradually transitions from conventional thermal power-generating sources toward renewable energy technologies. The development of sustainable power has picked up force in the previous decade in different nations, helped by a strong arrangement and administrative structure, the decreased expense of inexhaustible power age achieved because of innovative advances, rising power request, vitality security, and ecological concerns.[5]. Renewable energy reduces the dependency of fossil fuels, which produce greenhouse gas rise with global temperatures.

Bangladesh's case of SHS development to more than 1.9 million families in provincial territories has drawn the consideration of both donors and governments of other countries. The sensational inclusion of such development inside a brief timeframe has been conceivable to some degree in view of the appropriation given by donors to encourage SHS selection in remote and off-grid areas. Arrangement of moderate SHS with support administrations has turned into a national program of the government supported by the World Bank and different givers by setting up a self-sufficient and autonomous body known as the Infrastructure Development Company Restricted (IDCOL). In spite of national endeavors for advancing charge, Bangladesh's jolt rate has been just 55 percent for the country all in all and just 42.5 percent in rural areas. One conceivable arrangement, maybe a stop-hole one, is in this manner to supply power through sunlight based photovoltaic units under a specific financing plan presented through IDCOL. Most of the rural people have no access electricity. Solar home system may be an effective option for off grid electrification of those rural people.

Table 2: Bangladesh Renewable Energy generate with off grid and grid connected (June 2019).

Technology	Off-Grid	On-Grid	Total
Solar	295.74	56.37	352.11
Wind	2	0.9	2.9
Hydro	-	230	230
Biogas to Electricity	0.63	-	0.63
Biomass to Electricity	0.4	-	0.4
Total	298.77	287.27	586.04

Source: Bangladesh Power Development Board

1.1.4.1 Types of renewable energy

1. Wind Energy
2. Solar Energy
3. Geothermal

4. Biogas and Biomass

5. Hydropower

1.1.4.2 Wind Energy:

The wind is a form of solar energy which wind is used to produce electricity. A wind turbine converts the wind power to electricity by rotating the blade. A wind turbine converts the kinetic energy into mechanical energy and a generator converting the mechanical energy into electrical energy as means that electricity.

Denmark leads the field with 41%; Ireland is the second country, with 28% of its power from wind energy last year. Bangladesh government is projecting to generate electricity about 1153MW from wind and will set up 150MW capacity wind power plant in Chandpur, Inani Beach and Khulna by 2021 which each turbines will be generated power capacity between 5-7MW. In Bangladesh areas such as Anwari, Kutubdia, Feni and Teknaf average wind speed is 5-6 m/s.

Fig 1.3: Wind Power

1.1.4.3 Solar Energy:

Solar power is sustainable for renewable resources that clean inexperienced electricity generated from daylight or heat from the sun throughout the day. it's additionally free from the greenhouse and non-polluting sources of energy. Its take into account as inexperienced technology. Solar power will play a big role within the future. Radiation is powerfully obsessed on atmospherically conditions, the angle of incident of sunrays on the layer (panel placement), time of year, temperature and different geographical. Now a day, most of the solar battery potency of energy rating between 10-15 %. Bangladesh is positioned between 20.30- and 26.38-degrees north latitude, 88.04, and 92.44 degrees east that is a perfect position for conserving solar energy [6].

Figure 1.4: Solar Energy

1.1.4.4 Geothermal:

Geothermal energy is the heat from the earth, which is naturally inviting vitality sources. It is a clean and sustainable source of power. It is the underground heat leftover from the liquefied rocks that shaped Earth billions of years past, and it is tapped to heat building and generate electricity [7] .Geothermal energy is generally more affordable particularly when straightforwardly utilized, for example, as a source of heat in greenhouses.

1.1.4.5 Hydropower

Hydropower is generated to the flowing of water through the turbine which flowing of water pressure rotates the turbine blades convert the mechanical energy to change over into electrical energy. The total hydropower potential of Bangladesh in the three locations (Kaptai, Sangu and

Matamuhuri) is about Gwh/year (755MW) of which 1000GWh/year (230MW) has been harnessed at Kaptai through 5 operational units of hydropower plants. Hydropower is the largest energy source of renewable energy, which generates 6.7% of worldwide electricity [8]. Hydropower plants are usually located near rivers, canals, or has a water source. The world's largest hydropower plant the 22.5 gigawatts Gorges Dam in China that generates 80-100 terawatt-hours per year. Hydropower is one of another sort of elective wellspring of vitality that requires both water flow and stature to produce useful power.

Figure 1.5: Hydropower Plant

1.1.4.6 Biogas and Biomass:

Biogas and Biomass is the most rising demand to generate electricity. Biogas produced through anaerobic digestion of residues. The U.S. biogas industry is increasing systematically, now a day has around 2200 sites, which produce electricity in 50 states. Biomass is created without carbon power while likewise decreasing ozone depleting substance discharges and offering the most trustworthy renewable power sources.

1.2 World Renewable Energy Scenario

Developing countries target toward low carbon and nuclear-free future as means that they want to produce clean energy for their next generation. Many countries set to goals within the next decade they will become 100% renewable country. Sweden is aiming to be the first petroleum derivative free nation inside 2040.In the course of recent years Costa Rica has accomplished 95% of power created from renewable power source [9].

Nicaragua is aiming their power 90% originates from solar, wind and geothermal inside 2020. Germany is a world chief for sustainable power source nations. Now Germany around 50% of electricity is generated from renewable energy. Germany has a target to set reaching 65% of electricity generated from renewable energy by 2030. Denmark got 42% of electricity comes from wind energy by 2015.China, USA, India are leading the renewable energy revolution, according to the world economic forum, February 2018. The International Energy Agency's (IEA) electricity forecast report 2016 says that which predicts renewable energy capacity will expand by 43% – or more than 920 gigawatts – by 2022 [10].

China is solar energy generation leading country in the world [11].

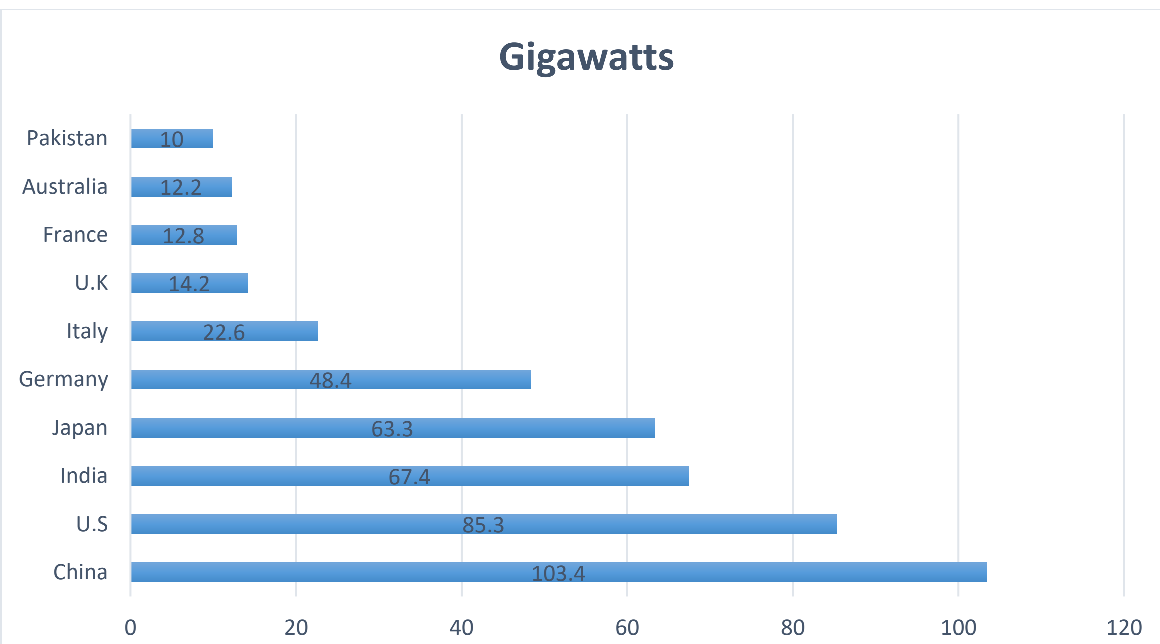

Figure 1.6: World top solar energy generation country 2018

1.3 Government Policy of Renewable Energy

Solar energy choosing is a big investment for a long time.64 percent of people live in a rural area in percent of the total population; according to the World Bank, report 2016. 37.2percentage of the population is urban. Only 12.9 percent of rural households in Bangladesh had electricity connection in the 1996-98 period, which saw an almost five-overlap increment to 58.6 percent lately [12]. The government has undertaken projects to construct transmission lines, enhance its capabilities, decrease hassle and bring more people that are rural under the coverage. Currently, 76 percent of people are enjoying electricity. Bangladesh government has a plan to increase power generation capacity to 24,000 megawatts in 2021, only 10 percent of total production energy comes from renewable sources and 40,000MW in 2030 [13]. In 2009, the total electricity generation capacity of Bangladesh was 4,942 MW (MW), which stood at 20,133 MW until the end of September 2018.

Bangladesh's power plants are heavily reliant on natural gas. The Government of Bangladesh intends to diminish reliance on natural gas because of the gas deficiency and move towards coal with designs to create 50 percent of all out power utilizing coal-based power plants within 2030.The Bangladesh government is planning to electricity import from India, Nepal, and Bhutan, Myanmar. Moreover, our government are importing liquefied natural gas as mean as LNG from abroad, and expanding the use of renewable resources, including solar and wind energy. Organizing land for large-scale solar PV project is very challenging since the Government of Bangladesh does not allow agricultural lands to be used purpose for sun based Photovoltaic task improvement.

In recent years, Bangladesh is arranging a few LNG-based power plants and Bangladesh has effectively figured out how to actualize a huge scale Solar Home System (SHS) venture with over 4.12 million SHSs introduced across the country. Government 230MW electricity produced by hydroelectric power plants [14]. The Bangladesh government takes some steps to improve renewable energy like that soft loan of a solar home system, a large investment of solar energy.

A few days ago, Saudi Arabia based Alfanar Company and Electricity Generation Company of Bangladesh (ECGB) have signed an agreement for a build on the 100MW solar power plant in Feni. In addition, the joint venture by Japanese firm Eiki Shoji Company Ltd having 95.1% offers in the project and our local company Sun Solar Power Plant Ltd having 4.9% offers will set up the

5MW plant from a grid-tied PV solar power project Gwainghat, Sylhet. Sirajganj 7.6 MWp (NWPGCL) and Kaptai 7.4MW (BPDB) Grid-associated Photovoltaic Solar Power Plant venture [15].

1.4 Problem Statement

Bangladesh is a small over populated creating nation on the world. Land will be the biggest problem for our country due to majority land are use of agricultural purposes .Government cannot agricultural land allow to use for rapid expansion of grid solar energy generation. Moreover panel, charge controller, inverter and battery quality are not good enough for high efficiency. In addition, the power factor of the loads does not take into consideration. Most of the people in Bangladesh live in rural area where they badly need of energy. We are only little few percent of energy produce from solar energy system, it's not highly sufficient for total our energy demand .We are some challenges that need to be mitigated to made the solar home system viable and cost effective for the better future.

1.5 Objectives

Specific objective of the present study are listed below

i. To collect rooftop solar irradiation data in Dhaka and analyze these data.
ii. To know the present situation of solar system in Bangladesh.
iii. To learn about rooftop solar photovoltaic system with its advantage and disadvantage and limitation.
iv. To compare the different month of data and its facility.

1.6 Scopes

In this thesis work to help known about of solar system. We work in our university's roof top areas. Actually, experimental data taken sunrise to sunset using of photovoltaic panel analyzer for taking data 45w, 60w, 100w panels. This work monitoring through the panels' analyzer, which is Voc (open circuit voltage), Isc (short circuit current), maximum power output (Pmax) of the solar cell with temperature and irradiation to measure and recorded all the data with using IV-400 meter.

That is a German project. The calculations were done based on the institute's geographical location, corresponding weather data and daily demand information.

1.7 Thesis Outline

Chapter 1: Introduction, Energy Classification, Types of Renewable Energy, World Renewable Energy Scenario, Government Policy of Renewable Energy, Problem Statement, Objectives and Scopes.

Chapter 2: Why use Solar Energy, Solar Energy in Bangladesh, Present Status of Bangladesh, Review of Solar Energy, The Associations working on Rural Solar Electrification, Challenging Rural Electrification and Economy, Energy Research.

Chapter 3: What are Solar Cells?, The Equivalent Circuit of Solar Cell, Cell Manufacturing , The major categories are solar panels, Components of a solar PV system, Different Function Load Calculation, Types of Solar Plant. Maximum Power Point Tracking System.

Chapter 4: Description of Study Areas , System Design, Equipment of Data Measurement, Research Machineries & Tools, I-V 400 W Calibration, Flow Chart , Data Collection Process.

Chapter 5: Solar Data Analysis, Comparison of Solar Irradiation Data among Different Year and Summary.

Chapter 6: Conclusion and Future Scope.

CHAPTER 2

LITERATURE REVIEW

2.1 Why use Solar Energy

Solar energy is that the power provided by the sun controlled through a technology known as electric photovoltaic cells that flip directly sunlight into electricity. Throughout the years, power costs have been rising and the cost of energy is expected to continue to increase over time .Homeowners around the nation and urban communities around the world are introducing solar panel systems on their roofs to exploit this spotless, renewable way to generate power. Solar energy is generated from daylight, not sunlight. So even on cloudy, rainy days, your panels are operating to provide energy. All that energy accumulates within the morning and afternoon hours, the complete time that the sun is up, producing more electricity than you can use. There are a unit several reasons why we should always all use solar panels to produce a source of clean, cheap and renewable energy for our homes. I think the main reason why we should use solar panels at home is that its energy is actually is taken from the sun that means that it's natural and less harmful for our planet therefore it might keep our surrounding clean. Another reason why we must always use solar panels is that; this can reduced your electricity bill.

2.2 Solar Energy in Bangladesh

Daily average solar radiation varies between 4 to 6.5 KWh per square meter. Maximum amount of radiation are available in the month of March-April and minimum in December-January. The availability of energy is affected by location (including with latitude and elevation), season and time of date.

Government utilities are associated with large-scale grid-connected renewable energy- power based project development. The electricity produced by a photovoltaic solar panel system is powered by its rated power output. Yet, it is dependent on the other factor these include panel efficiency, temperature sensitivity, shading and the angle of your roof. A roof’s angle, however, has the effect of Top production occurs when solar panels face south a tilt angle of 30degree to 45degree. The quality of solar panels (purity of silicon) affects the efficiency of the output.

2.3 Present Status of SHSs in Bangladesh

In this present scenario, solar photovoltaic is the best alternative source of renewable energy. It is a great source of unraveling the emergency in this circumstance. Photovoltaics system increment the quality of life, produce salary, improve children education by providing great nature of light, and diminish health hazard and reducing the risk of fire by kerosene burning. Bangladesh is very well situated, as far as radiation and marginal source of the sun so it's a decent spot to have a sun based program available where individuals can get the solar power for electricity. At that time, SHS had a staggering expense and low mindfulness among the people of Bangladesh. Two different organization model are implemented SHS program throughout the country one REB and another IDCOL. Every month around 50000 SHSs has been installed under IDCOL‘s SHS developing program.Solar Photovoltaics installation rates are rapidly increasing in Bangladesh. Solar Home system (SHS) has become more popular due to its soft loan from different private organization and another decreasing price of solar equipment and rooftop sunlight PV based mini-grid system to pump water, for motioning of railway, to control refrigerators, so forth.

Grameen Shakti is one of the major implementer and fastest-growing rural-based renewable energy companies in Bangladesh. BRAC Foundation, Srizony Bangladesh and DESHA, are the other private agencies implementer of the sun based solar home system (SHS) in rural Bangladesh. Grameen Shakti began to install SHS in the rural villages of Bangladesh since 1996. Grameen Shakti has developed successful market-based programs. There are around 10000 smaller scale utility system installation by Grameen Shakti in provincial commercial centers. Grameen Shakti in Bangladesh has implemented at around over 1.5 million Solar Home Systems (SHSs) through a micro-finance scheme. Around 10 million people are getting profits by these solar home systems, and in excess of 350,000 tons of CO2 are saved each year [16].

About 4.13 million SHSs have been installed under the program in the remote areas in Bangladesh where the grid expansion is costly and challenging [17]. IDCOL is providing soft lone for SHS and saves consumption of 3.60 million tons of kerosene worth USD 1300 million.

Program Target: 6 million SHSs by 2021

Number of Beneficiaries: About 18 million people by IDCOL and BREB distributed about 30 thousand SHS throughout the country

Fossil Fuel Saving 250000 ton/year

Direct Job Creation: Over 30000 people

IDCOL Investment: About USD 696 million

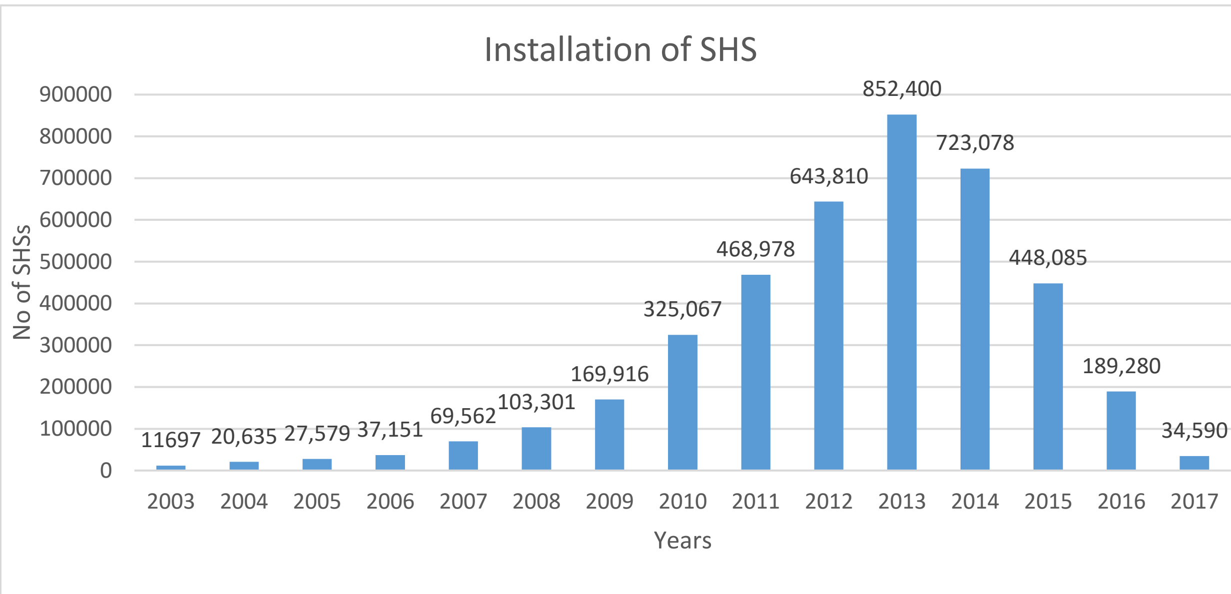

Figure 2.1: Year wise installations of SHSs in Bangladesh by IDCOL

Grameen Shakti and IDCOL aim to reduce the initial investment costs (down payment) of SHS to each household/consumer. SHS users then pay 10% 25% of the all-out SHS price as an initial down payment. The remaining 75% - 90% of the loan amount has to be reimbursed in up to 42 equal monthly installments [18] .The SHSs have ended up being dynamically well known among clients since they present an economically viable alternative to traditional power due to no need for costly fuel, low maintenance costs, and relative simplicity of establishment. No of solar home system (SHS) user is decreasing last few years remote areas due to the users get as grid connection. The most common SHS is to use light up places such as homes, shops, and clubs. The other use of solar power is to run radios, televisions, charge cell phones and other electrical devices. SHS is easy to install and comes with low maintenance cost and no monthly payments and long life warranty.

IDCOL has been essential in promoting SHS in Bangladesh through its accomplice associations, the record for the vast majority of the SHSs introduced up until now – Grameen Shakti, BRAC, and RSS. The World Bank, German Development Cooperation (GIZ), Kreditanstalt für Wiederaufbau (Reconstruction Credit Institute of Germany), ADB, EU, IDB, and multi-contributor trust support, GPOBA, have supported the IDCOL program. In addition, in contrast to the IDCOL framework, REB itself claims SHSs introduced by REB, while the clients just pay a fixed month-to-month charge for utilizing the system.

The information up to February 2013 indicates that just one PO, Grameen Shakti, accounted for 56 percent of the SHS that have been installed.

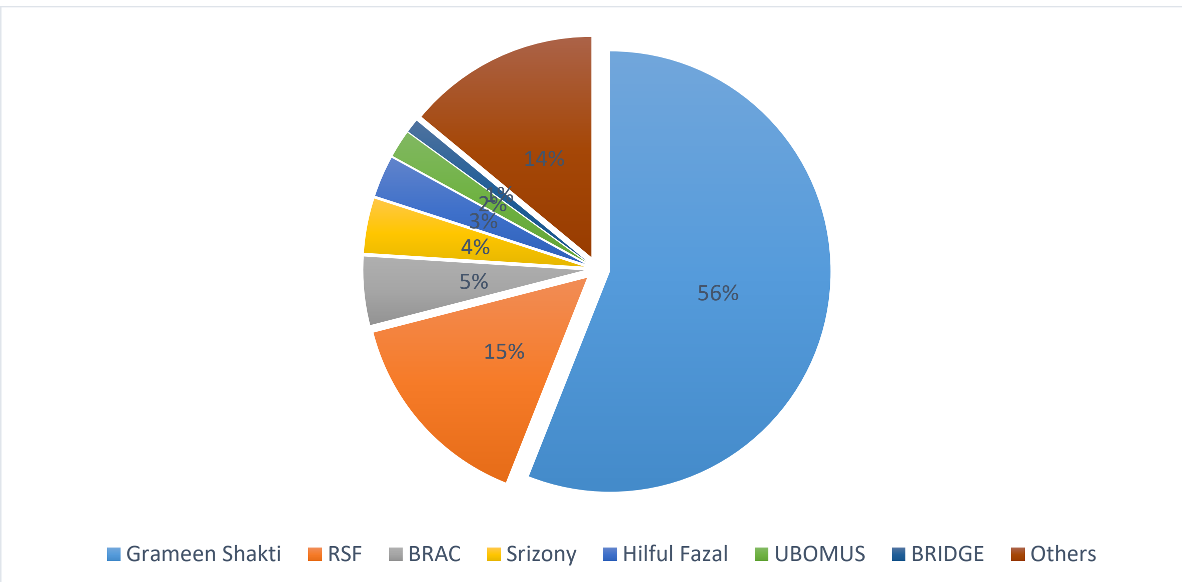

Figure 2.2: Installation of SHSs market Share

2.4 Review of Solar Energy

Shahidur R. Khandker, Hussain A. Samad, M. Asaduzzaman, Mohammad Yun [19], They analysis their research decreasing the solar home system cost between 2004 to 2012 around 10 percent which was about of the average price 25 percent in 2004 . Also showing that the demand for SHS is price-inelastic. This means POs will charge a better value for a system at its price (i.e., without any subsidy) perhaps without substantial reduction of market demand for SHS. SHS assumption increases evening study hours of both boys and girls; reduces fuel collection time of women and reduces women's and children's morbidity from respiratory diseases by reducing kerosene consumption. SHS adoption additionally promotes house welfare by increasing per capita expenditure.

Kevin DeGroat, Joseph Morabito, Terry Peterson, and Greg P.Smestad, for their explaining solar energy to a wide range of decision makers and to the public. It emphasizes two major, related challenges in achieving widespread, one are rapid adoption of solar energy technologies in time with global energy and environmental problem impact widespread that was facilities by a "Smart Grid" infrastructure. Moreover, another to continue to drive down manufacturing and deployment costs for solar energy systems expand manufacturing capability in order to accelerate deployment of solar energy systems [20]. PV modules are created by assembling many types of materials into an integrated package that must withstand long-term outdoor exposure.

S. Hossain, M.F. Hossain, and M.J. Uddin their study researches whether sun-based business industry should actualize a typical technique to situate itself in everywhere throughout the nation. There working are expanding mindfulness among the clients and providers of the advantages and SHS should be used of the correct and also there research of the project with Data satisfaction with the solar energy system, Duration of using solar energy, Service of solar panel providing company. Finally This data analysis indicates that performance of solar energy systems is much better as it needs very little maintenance [21] .Their result the benefits of using solar energy and the prospect concerning alternative energy system in Bangladesh still the because the issues with reference to this sector.

Sara MacAlpine, archangel Deceglie, Sarah Kurtz Birinchi Bora, O.S. Sastry, Yogesh Kumar Singh, Rashmi Singh, and Supriya Rai [22].They measurements in 2014 indicate that the small morph modules area unit underperforming their datasheet. STC power rating by 6-9% at NREL, and by 5-6% at NISE. CdTe modules at NREL additionally underperform by 5-6%, whereas at NISE.The CIGS modules at each sites underperform by 4-11%. several of those numbers fall outside of the datasheets' such as binning bounds (which permit modules to underperform by 2-5%), however most area unit among the quality “90% performance at ten years” warrantee tolerances. during this section, high irradiance information area unit those recorded around 1000W/m2, and low irradiance information area unit recorded around 500 W/m2, each +/- five-hitter. “Summer” months area unit June-September, whereas “winter” month’s area unit December-March. One will see that they exhibit the next fill issue each with lower temperature and with lower irradiance, with variance of roughly a pair of attributed to every. In distinction, the CIGS modules have the next fill issue beneath high irradiance in operation conditions, and with lower temperatures. during this case, the motive force is that the current; the magnitude relation of most electric receptacle current to tangency current is higher beneath the high irradiance conditions, implying that reduction in fill issue attributable to shunting is a lot of vital than series resistance for these modules.

Narima Amin, Richard Langendoen [23] work together to research about of rural electrification solving. They see financial resources that were made available to Grameen Shakti for reinvestment by selling carbon offsets on the global carbon exchange market .This helped to make the installations of the renewable technologies even more affordable assisted that significant growth rate. The Grameen Shakti model has started to be imitated in a few different nations. The execution of the Grameen Shakti replication will accomplish the objective of all inclusive vitality access by 2030.

2.5 The Associations working on Rural Solar Electrification

1. Bangladesh Rural Electrification Board (BREB)
2. Infrastructure Development Company Limited (IDCOL)
3. Greemen Shakti (GC)
4. BRAC Solar
5. Bangladesh Solar & Renewable Energy Association (BSREA)
6. Greenfinity Energy Limited etc.
7. BRIDGE
8. Mukti Cox’s Bazar
9. Coast Trust

2.6 Challenging Rural Electrification

Electricity generation with solar energy highly depends on Photovoltaic and heat engines. In the case of as we are finding an answer for urban power shortage problem. Here in urban area wind, sea, hydropower and so forth are impractical to be utilized as a type of sustainable power source to generate electricity and among the rest, we are going to work with Solar, as it is already being popular in our country.

Bangladesh economy was dependent on agriculture, which used to contribute about fifty percent its total national output (GDP), until recently as services and industries ((manufacturing) sector contributions rising, it has gone down to 15.1%. Economy was not affected much by the recent recession of World economy. Availability of electric energy is the driving force in any economic development. So production, consumption etc. each relate to the economic indicator of the nation.

Majority of the families in the rural areas will not be able to bear the cost of solar cells for their home. Moreover, Bangladesh doesn't have the essential innovation and crude materials to produce the photovoltaic cells (PV), reflectors and other auxiliaries, all of which will have to be imported [24] .Maintenance and repairing will also be an issue due to the absence of experience of the experts in this sector. A solar power plant will require many hectares of the zone cleared for its advancement, which will normally effects, affect nature. Security is also a concern PV's are over the top expensive and is probably going to be stolen at the essential probability from the rooftop of a building, from the streetlights and from other installations, which are within public reach. Also throughout the winter, season and some of the times during the season of monsoon cloud to cover increases radically thereby limiting sunlight accessibility and in this way may influence the age scheme. All our country's limitations aside, photovoltaic cells have very low efficiency.

Families, paying little heed to their SHS reception, are principally subject to lamp oil and biomass for their energy requirements. Around 80 percent of the family units use fuelwood or non-fuel wood biomass for Cooking and related exercises. While 62 percent of the SHS family units use lamp fuel, the frequency is essentially higher, at 99 percent, among the non-SHS families. Conversely, other sources of energy vary between 53 percent among the SHS families to 64 percent among the non-SHS family units. Although a huge portion of families utilizes different sources, vitality utilization from these sources is low. Bangladesh government has a target to set up with replacing diesel-operated pumps by the solar irrigation system.

One of the primary employments of the SHS is for lighting. Depending on the limit of the SHS boards, family units would have 2-5 lighting focuses. The additional lighting focuses a family unit has, the lower the use of kerosene for lighting, which is generally used in rural areas. While other potential uses of kerosene incorporate cooking, this is an exorbitant option in contrast to biomass cooking fuel and consequently is now and again saw in rustic family units. Given that there are about 1.9 million SHS family units in rural Bangladesh, the decrease in kerosene consumption amounts to utilization adds up to more than 40 million liters of kerosene saved every year due to SHS selection. Electricity can supply for three crop irrigations on 20 acres of land by each solar pump.

2.7 Energy Research

Different government and Non-government associations take many necessity stapes improving renewable technology and they provide a large investment of this project with working separately or jointly. The Singapore national research foundation and Singapore Economic Development Board and the National University of Singapore support Solar Energy Research Institute of Singapore. Researches are being completed out globally to increase the efficiency level of solar cells. Recently, it has been reported by researchers in Japan had set a new record for the efficiency of mass-produced solar panels, bringing the efficiency level of their solar panels to 26 percent [25]. Various research activities on renewable energy of our country are being arranged by many institutes like BUET, BRAC University, Renewable Energy Research Center (RERC) of DHAKA University, United International University, MIST, IUT, Daffodil International University and many others.

CHAPTER 3

SOLAR PV EQUIPMENT

Solar panels are devices that convert photons light into power through the utilizing sun based photovoltaic (PV) impact. The Solar panel are made parcel of little sun powered cells. Each sunlight-based cell is a little plate of a semiconductor like silicon. Solar panel generate vitality to utilization of direct transformation of daylight into solar power or electricity, this panel use of semiconductor layer, most commonly use silicon.

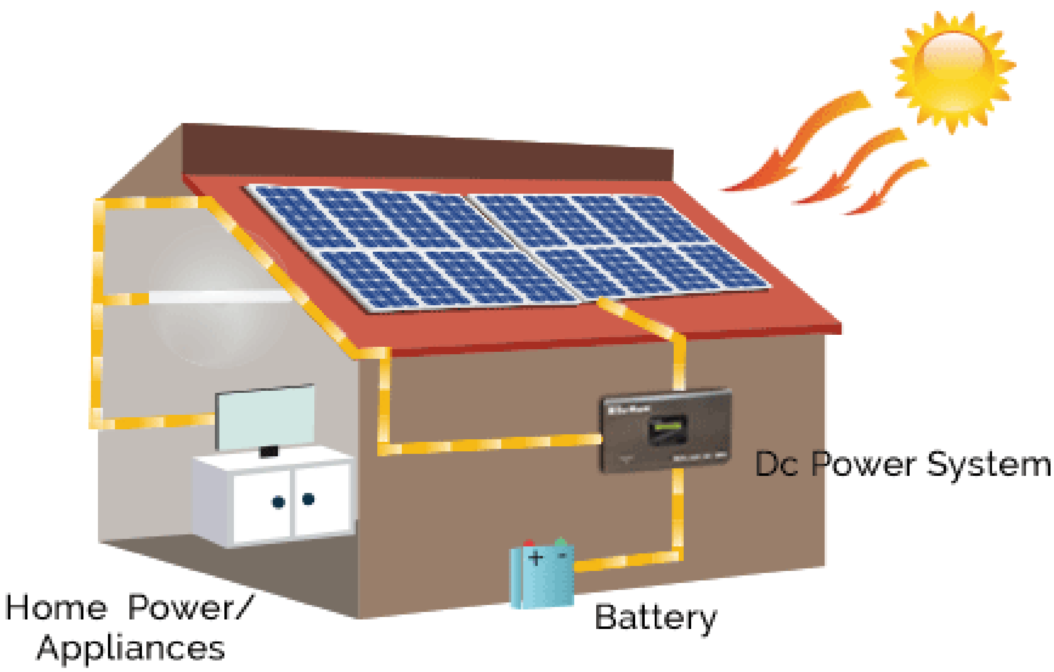

Figure 3.1: Off-Grid Solar Home System

3.1 What are Solar Cells?

There are many materials that can be used to make solar cells, but the most common is the element silicon. (This isn't to be mistaken for "silicon", a synthetic polymer.). Silicon is the second most copious component in the Earth's outside layer, next to oxygen, and silicon and oxygen together make quartz or common sand. It is therefore very abundant, as well as non-toxic and safe. This is the same silicon that is utilized to make PC chips, and some of the processing steps involved in making solar cells are similar to the steps in making computer devices. However, solar cells are much larger than typical individual computer circuits, and they must be much less expensive. A typical solar cell used for terrestrial (Earth-based) applications is 3-6 inches in diameter and costs only a few dollars. The conversion process occurs instantly whenever there is lightly falling on the outside of a cell. Moreover, the output of a cell is proportional to the input light: the more light, the greater the electrical output. The cell does not use up any internal "fuel" for the conversion process. The solar resources are more uniformly distributed over the Earth's surface than other renewable sources of energy light wind or hydro.

3.2 The Equivalent Circuit of Solar Cell

Figure 3.2 demonstrates the single diode equal circuit of a sun-powered cell. The photocurrent of a sun-based cell that is under consistent radiation won't change. In the model, I (L) can be considered as a constant current source.

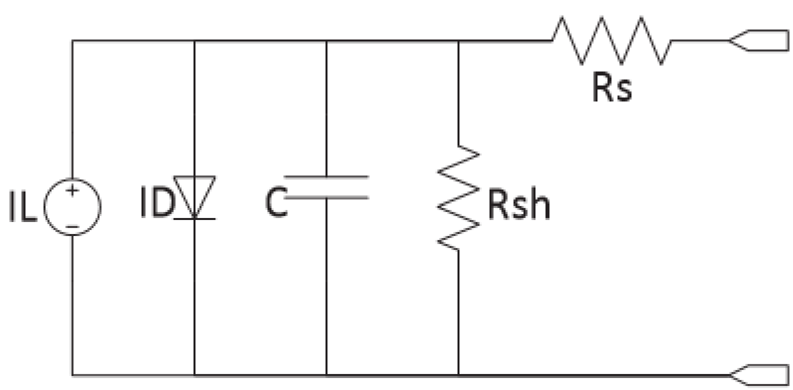

Figure 3.2: The Single Diode Equivalent Circuit of Solar Cell

3.3 Cell Manufacturing

- Cell manufacturing steps
- Diffuse with phosphorous to make N-type layer

- Doping penetrates both sides and edges
- Remove edge layer
- Deposit anti-reflective coating of TiO
- Print silver grid patterns on front and back
- Back grid allows with silicon and neutralizes back N-type layer

3.4 The major categories are Solar Panels

We present here a brief discussion of the most common competing solar cell technologies in the field today.

1. Monocrystalline Solar Panels
2. Polycrystalline Solar Panels
3. Thin-film Solar panels

3.4.1 Monocrystalline Solar Panels

Monocrystalline solar panels also are known single crystalline silicon. This solar cell is high purity of silicon, effectively conspicuous from the uniform dark look, and adjusted edges. Monocrystalline solar panels have the highest rate of solar panels efficiency (around 15%-20%) and high lifetime value but it is the most expensive solar panels. Monocrystalline solar panels provide the highest output performance in high temperature as means as more heat tolerant and space-efficient.

3.4.2 Polycrystalline Solar Panels

Polycrystalline solar cells are consisting of many small silicon grains. These solar cells are made by pouring molten silicon into square molds, where it cools and cuts into a perfectly square wafer. Polycrystalline solar cells are simpler, cheaper, and better in shaded. These panels are lower efficiency (around 13%-15%) because of lower silicon purity and it’s a shorter lifespan and also affordable. These solar panels are generally accessible and affordable.

3.4.3 Thin-film Solar Panels

Thin-film solar panels efficiency around 7%-13%.These panels are easy to produce; less cost, lightweight, portable but to have a shorter life expectancy. These thin-film solar panels have different types. Thin-film solar panels are larger and have a uniform, solid black appearance and normal use of small electronic appliances.

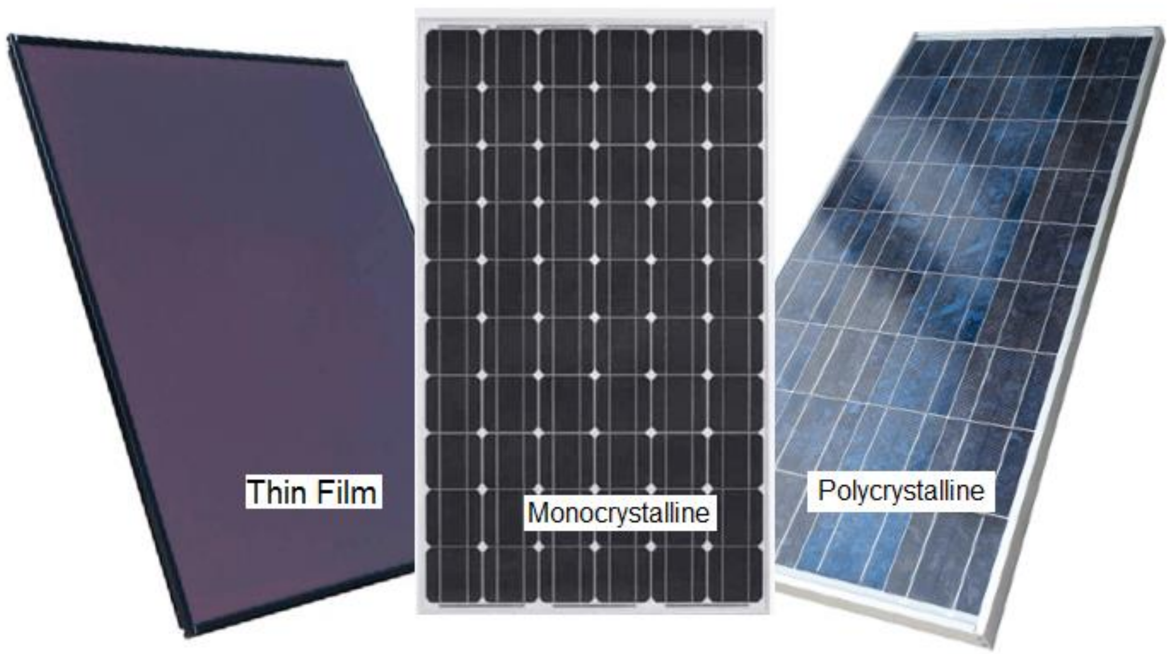

Figure 3.3 :Solar Panel Types

3.5 Components of a solar PV system

The rooftop solar photovoltaic system consists of charge controller and batteries. The overall efficiency will also depend on the type of battery and inverter used in the system. It is important to choose the right parts for the most effective use of Solar PV systems.

3.5.1 Charge Controller

A solar charge controller is the main function to prevent overcharging of the battery due to the consistent of electrical energy is transfer to the batteries and ensure that backup batteries don't release back through the system at night and provide load control function. The charge controller is also known as a charge regulator to maintain the battery is charging the balance.

Figure 3.4: Charge Controller

3.5.2 Batteries

The solar power system generates electricity during the daytime at the point when the sun is flaming. The battery produces DC current and voltage. When solar panels produce more electricity, the battery is needed to store this excess energy. The stored energy can be used when the electricity does not produce from solar panels, which are used such as rainy days and night.

Figure 3.5: Batteries

3.6 Different Function of Load Calculation

We are calculated to our data using by short circuit current, open circuit voltage, maximum current and maximum voltage, irradiance, Fill Factor, Efficiency.

3.6.1 Short Circuit current (Isc)

The photovoltaic module will create its maximum current when there is no opposition in the circuit. There is a short circuit between its positive and negative terminals. The greatest current is known as the short circuit current. Right when the module is shorted, the voltage in the circuit is zero.

3.6.2 Open Circuit Voltage (Voc)

The maximum voltage in a photovoltaic module is produced when there is a break in the circuit. It is known as the open-circuit voltage (Voc).Under this condition, the resistant is infinitely high and there is no current since the circuit is incomplete.

3.6.3 Maximum Power (Pmax)

The power accessible from a photovoltaic module anytime along the curve is expressed in watts (W). Watts are calculated by multiplying the voltage times the current (W = VA). At the short circuit current point, the power output is zero, since the voltage is zero. At the open-circuit voltage point, the power yield is moreover zero, since the current is zero. The maximum power is the result of current maximum power times the voltage at maximum power [26].

Pmax = Vmpp*Impp

3.6.4 Current at Maximum Power (Impp)

The maximum power current is the current when the output power is the greatest.

3.6.5 Voltage at Maximum Power (Vmpp)

The maximum power voltage is the voltage when the output power is the greatest.

3.6.6 Fill Factor

The fill factor is the relationship between the maximum power that the array can really give under normal operating conditions and the result of the open-circuit voltage times the short circuit current (V0c*Isc). This fill factor value gives an idea of the quality of the array and the closer the fill factor is to 1 (unity), the more power the array can give. For a good panel, FF is between 0.7 to 0.8 while for bad panel it may 0.4 [27].

3.6.7 Efficiency

Efficiency is characterized as the proportion of vitality yield from the sun-powered cell to enter vitality from the sun. Effectiveness is the most normally utilized parameter to look at the presentation of one solar cell to another. Efficiency depends on the solar band spectrum, the intensity of light and the temperature of the sun-powered cell.

3.6.8 Load

The electrical machines or hardware associated with the solar Photovoltaic framework, for example, lights, TV, PC's, and so on. It could be AC or DC machines.

3.7 Types of Solar Plant

Solar Plants are divided into two types based on storage systems.

- **Off Grid Solar Plant**
- **Grid Connected Solar Plant**

3.7.1 OFF Grid Solar Plant

An off-grid solar home system isn't associated with the local areas or the utility grid. Off-grid systems require maintenance and more care however can give a strong sense of independence, so one is never again being exposed to the danger of lost power from the utility grid. Off-grid solar systems where the solar energy is created and expended in the same place meaning it does not interact with the main grid at all.

- **Advantage of Off-Grid Solar Plant**

1. The off-grid solar system is suitable for energy storage that can be used later as a backup power.
2. These systems are great as far as expandability.
3. This system is highly cost effective and much safer.
4. There has no electricity bills.

- **Disadvantage of Off-Grid Solar Plant**

1. It has higher initial cost.

2. Solar energy storage is limited due to cloudy weather or rainy day or natural disaster.

3. It has no higher efficiency energy.

3.8 Maximum Power Point Tracking System (MPPT)

The output power of a selected solar panel is said to two inputs: the irradiation intensity and the temperature of the solar cell. At the outside atmosphere, the irradiation intensity and the temperature of the solar cell are ever changing all the time. It will cause the move of the I-V and P-V yield of the sun-oriented cell, which will change the maximum power point position. Without MPPT, the solar power system may never operate at the maximum power point, which will increase losses.

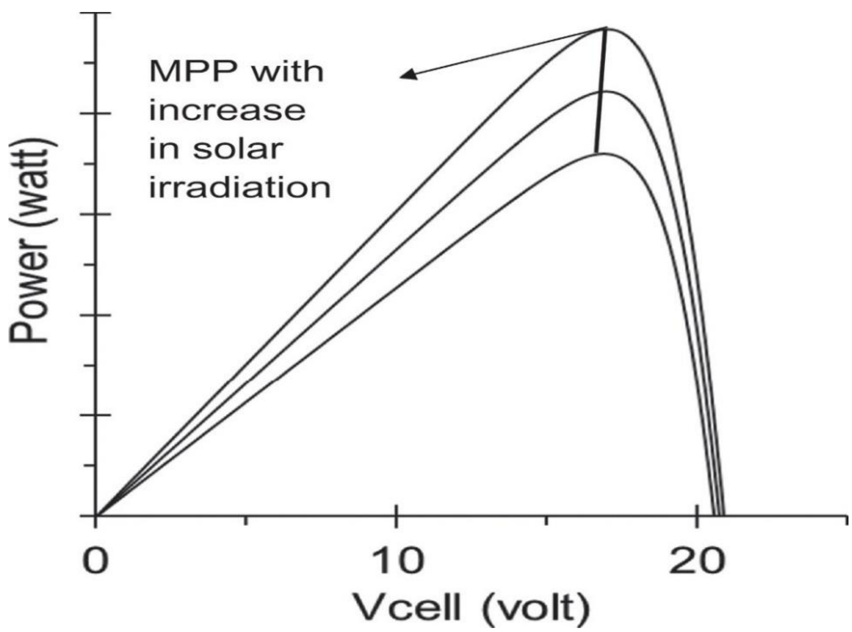

Figure 3.6: Solar PV power Characteristics with different solar irradiation level [28]

CHAPTER 4

METHODOLOGY

Bangladesh receives an average daily solar irradiation 4-6.5 kWh/m2. Irradiation varies from district to district .The research design is then presented and methods for determining the rooftop sample set, calculating incoming solar radiation and analyzing rooftop points are discussed in detail. The final section presents the methods for performing statistical analysis to generate the equations needed for extrapolation to estimate total PV potential for the study area. We started our project work from November month. Two types are data collection

I) Primary Data

II) Secondary Data

I) Primary Data

The primary data collection for the research was done at the time of field study.

We are data measured every day sunrise to sunset for a few months of the year.

II) Secondary Data

- Through the internet
- Book
- Research paper
- Company website

4.1 Description of Study Areas

The study area covers Dhanmondi in Dhaka district, the central point of Bangladesh. The study was conducted at Daffodil International University-Main Campus of AB building Rooftops. Solar radiation over different months, daily power measured. We find out average monthly output, different yearly output and related graphs are a plot showing variation in the different seasons and time. We analyzed the monthly load from November 2018 to December 2018.

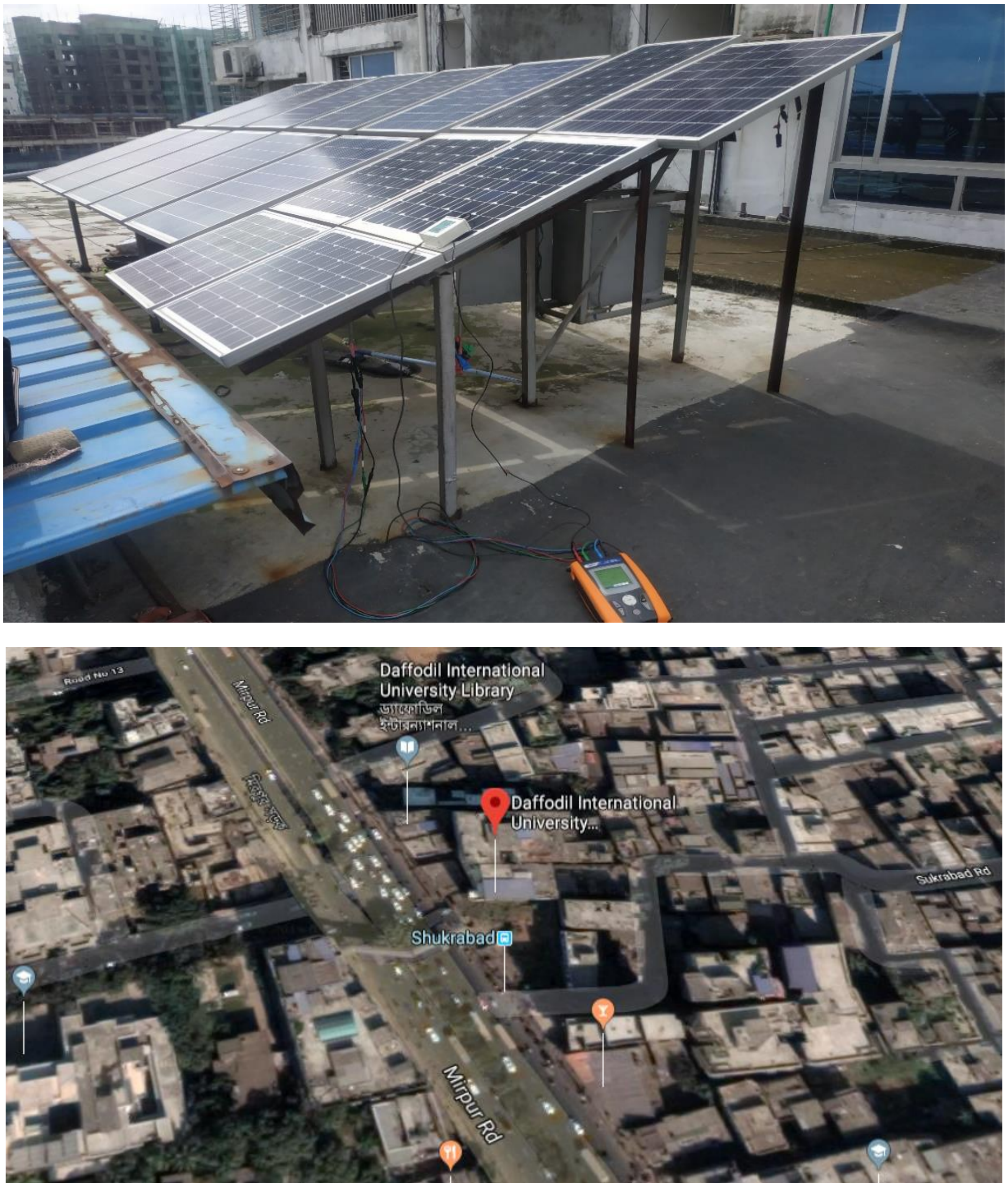

Figure 4.1: a) Actual view of the Rooftop   b) Google earth view

4.2 System Design

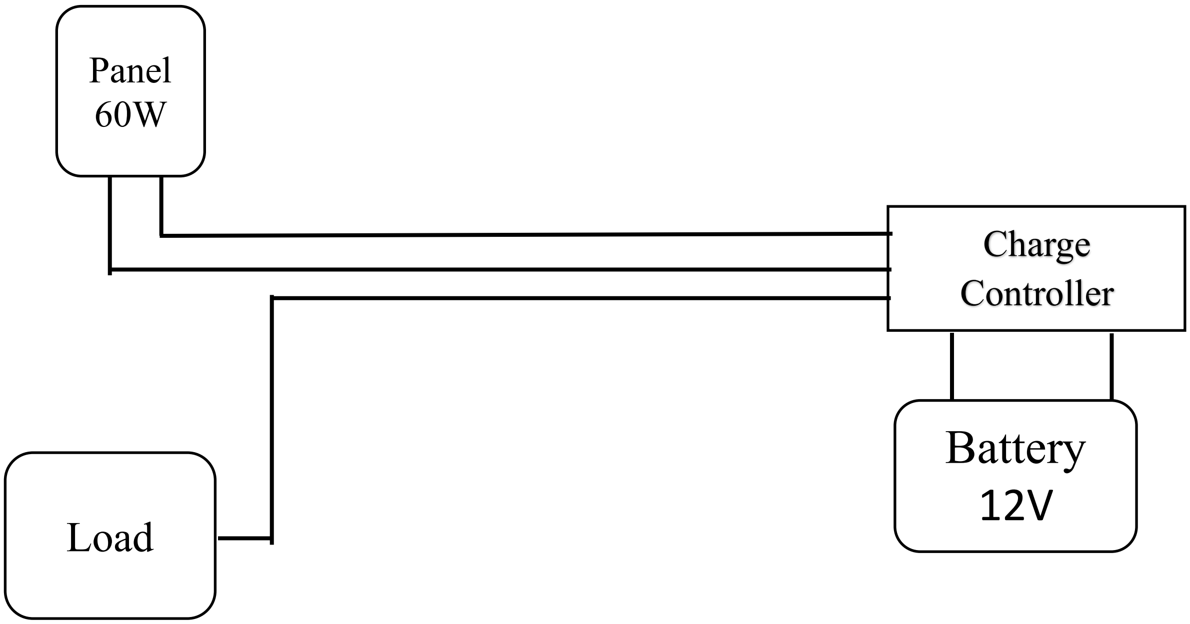

Figure 4.2 System Design

4.3 Equipment of Data Measurement

We are used to data measurement with different equipment. We measure different data on this project. There are the irradiance, the temperature, the open circuit voltage, short circuit current, voltage at maximum power, current at maximum power, maximum power and fill factor. We used four equipment on this project.

i) Photovoltaic Panel Analyzer (I-V 400W)

ii) Irradiance Meter

iii) Temperature Sensor ((HT304N)

iv) 60 W Solar Panel

Figure 4.3: Data Measuring System

4.4 Research Machineries & Tools

Some tools have been used to collect data such as I-V 400W, temperature sensor, 60W solar panel, irradiation sensor (HT304N).

4.4.1 Selecting the PV solar panel

We are selecting the 60W Solar Cell. This cell is made in Germany. This area is 0.44m^2.

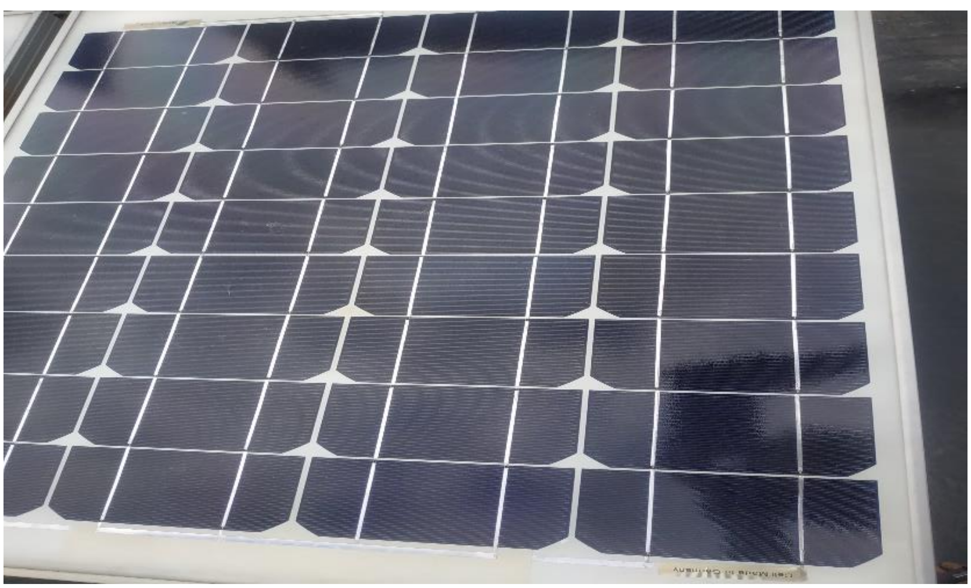

Figure 4.4: 60 W Solar Cell

4.4.2 Electrical Specifications

- Maximum Power (Pmp): 60W
- Open Circuit Voltage (Voc): 21.5V
- Short Circuit Current (Isc): 3.76A
- Voltage at Maximum Power (Vmp): 17.5V
- Current at Maximum Power (Imp): 3.46A
- Module dimension: 805*550*35mm
- Module weight: 5.9KGS±3%

4.4.3 Photovoltaic Meter (I-V 400W)

I-V400W permits field recognition of I-V Curve a of the primary trademark parameters both of a solitary module and of series of modules for PV establishments up to a limit of 1000V and 15A.For measuring I-V Curve, I-V 400W manages an internal database of the modules that are monitoring the data. It provides numerical and graphical display of Characteristic. It can measurement of solar irradiation (W/m2) with reference cell. This Analyzer has six standard AA batteries for power and internal memory for data saving.

Figure 4.5: Photovoltaic Panel Analyzer (I-V 400W)

4.4.3.1 Electrical Specifications

Table 3: Parameter, Range

Parameter	Range (V)
VDC Voltage @ OPC	5.0 - 999.9
IDC Current @ OPC	0.10 - 15.00
Max Power @ OPC (Vmpp >30V, Impp>2A)	50 - 9999
VDC Voltage (@ STC and OPC), IVCK	5.0 - 999.9
IDC Current (@ STC and OPC), IVCK	0.10 - 15.00
Max Power @ STC (Vmpp>30V, Impp>2A)	50 - 9999
Irradiance (with reference cell)	1.0 - 100.0
Temperature of module (with auxiliary PT1000 probe)	-20.0 - 100.0

4.4.3.2 General Specifications of I-V 400 W

- Display and Memory of IV 400:

Features: 128x128pxl custom LCD with backlight

Memory capacity: 256kbytes

Saved Data: 249 curves (I-V curve test), 999 IVCK

- **Power Supply:**

SOLAR I-V internal power supply: 6x1.5V alkaline batteries type LR6, AA, AM3, and MN 1500

Approx. 120 hours (yield test)

SOLAR-02 power supply: 4x1.5V alkaline batteries type AAA LR03

SOLAR-02 max recording time (@ IP=5s): approx. 1.5h

- **Output Interface**

PC communication port: optical/USB

Interface with SOLAR-02: wireless RF communication which max distance is 1m

- **Mechanical Features**

Dimensions: 235 x 165 x 75mm

Weight (batteries included): 1.2kg

- **Environmental Conditions:**

Reference temperature: 23°C ± 5°C

Working temperature: 0° ÷ 40°C

Working humidity: <80%HR

Storage temperature (batt. not included): -10 ÷ 60°C

Storage humidity: <80%HR

4.4.4 HT Instruments PT300N Temperature Measurement Probe

It is used for cell temperature measurement.

Figure 4.6: Cell Temperature Measurement

4.4.5 HT Instrument KITKELVIN probe

- HT Instrument KITKELVIN is used with I-V400w in AUTO mode, this set of cables allows quick I-V curve tracing.
- Test Leads for Pv Tester
- Banana Diameter of 4mm
- Banana Color Blue, Red, Black and Green
- 15cm Tip Length

Figure 4.7: HT Instrument KITKELVIN

4.4.5.1 General Specifications of HT Instrument KITKELVIN

Table 4: General Specifications of HT Instrument

Electrical protection	CAT II 1000V AC, CAT II 1500V DC
Measurement Range	1500V / 15A DC
Cable length	1.5m
Tip length	15cm
Banana Diameter	4mm (blue/red and black/green)

4.4.6 Irradiance Meter (HT304N)

- It is the Double input for connection to Single or Poly crystalline modules
- Irradiation measurement up to 1400 W/mg
- HT304N is a passive sensor and do not require any power supply
- Do not apply any voltage to instrument’s outputs

Figure 4.8: Irradiance Meter

4.4.6.1 Technical Specifications of Irradiation Sensor

Table 5: Irradiation

Range [W/m2]	Accuracy
50 - 1400	±3.0% of readings

4.4.6.2 General Specification

Available reference cells: MONO Crystalline and MULTI Crystalline Silicon

- **Guidelines Safety**

IEC/EN 61010-1

Technical literature: IEC/EN 61187

Calibration: IEC/EN 60904-2

Mechanical protection: IP65 in compliance with IEC/EN 60529

Pollution degree: 2

- **Mechanical Characteristics**

Dimensions (LxWxH): 120x85x40 mm

Weight: 260g

- **Environmental Conditions**

Working temperature: -20°C ÷ 50°C

Storage temperature: -20°C ÷ 60°C

4.4.7 Connection Cable for HT304

It is used for connection with Irradiance and Photovoltaic meter.

Figure 4.9: Cable for HT304

4.4.8 Temperature Sensor

It senses temperature from the solar cell and sends data to the I-V 400W.

Figure 4.10: Temperature Sensor

4.5 I-V 400 W Calibration

Before starting the measurement, we must have to calibrate I-V 400 W. For I-V 400 W calibration parameters has given below Table: 6

Table 6: I-V 400 W Calibration

Pmax	50W
Voc	21.42V
Vmpp	17.10V
Isc	3.20A
Impp	2.92A
Toll-	1.0W
Toll+	1.0W
Alpha	0.033 %/°C
Beta	-0.34 %/°C
Gamma	-0.42 %/°C
Noct	45 °C
Tech	STD
Rs	1 Ω
Degr	0.0 %/Yr.

4.6 Work Flow

A variant is a type of image that represents a workflow or process. Flanked arrows show boxes of numerous types and steps as their order box. We use flowcharts (Fig 4.11) in a process or program analysis, documentation or management in different fields.

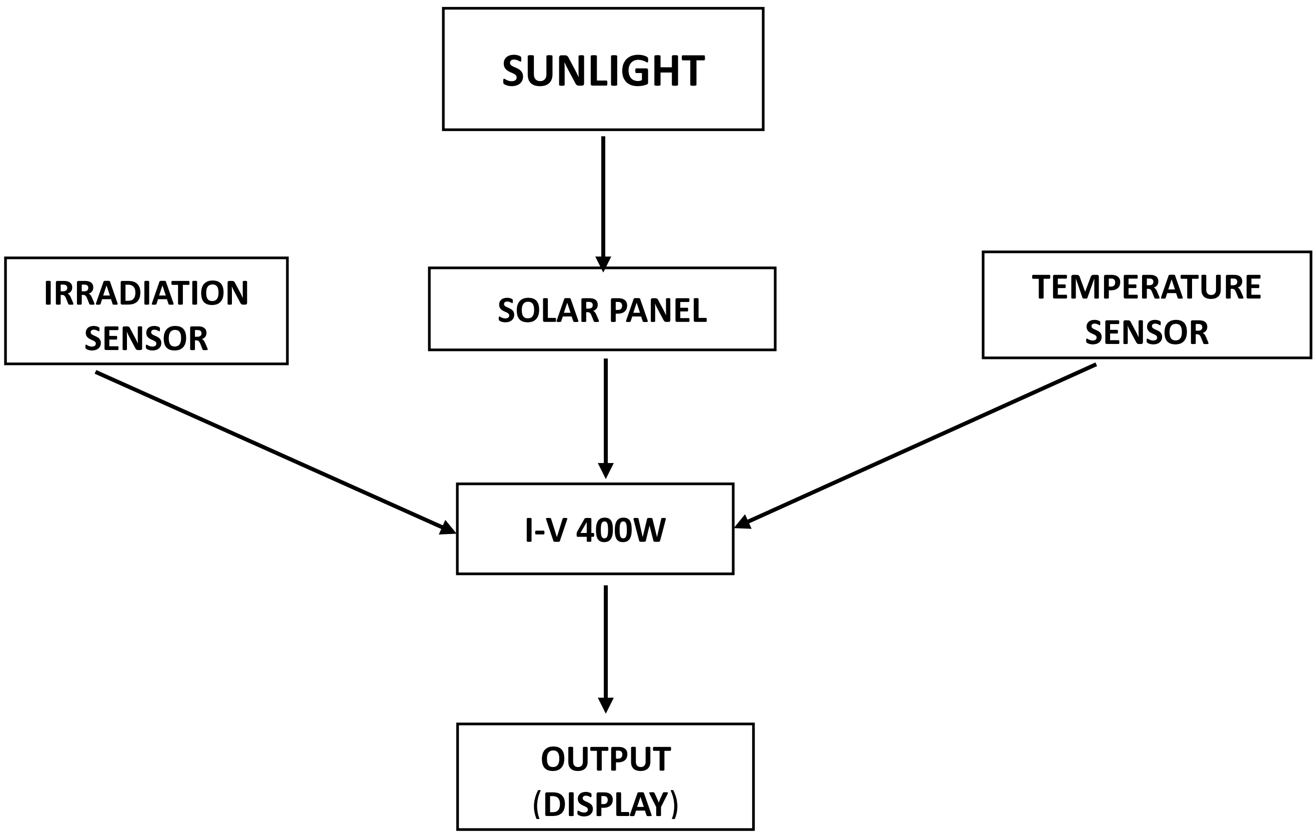

Figure 4.11: Work Flow

4.7 Data Collection Process

Our data collection process was easy. We collect the data from sunrise to sunset for every hour (sunrise to sunset). It depends on the irradiance and sun light. Firstly, we connect the 60W solar panel with photovoltaic meter and irradiance meter. Photovoltaic meter connect the temperature sensor. Then we are monitoring the data. We take a picture to monitoring data, which show the photovoltaic meter. It is suitable for a sunny day. Every day we measure all data from sunrise to sunset in rainy day, low light, winter. If the sun irradiance is low, we cannot found data on this moment. Finally, we keep the all data, after put up the data into the Google sheet.

Table 7: Measured Data of Solar System on 11 November 2018

Single day shit

SL	Time (Sunrise to Sunset)	Irradiance (W/m2)	Voltage (V)	Current (I)	Vmpp (V)	Impp(I)	Fill factor	Pmax (W)	Area of Panel (m2)	Efficiency (%)
1	6:10	0	0	0	0	0	0	0	0.44	0
2	7:10	98	19.2	0.63	16.2	0.36	0.52	5.832	0.44	13.44%
3	8:10	143	19.9	0.9	16.5	0.53	0.52	8.745	0.44	13.81%
4	9:10	490	20.4	1.58	16.8	1.4	0.73	23.52	0.44	10.84%
5	10:10	614	19.9	1.96	15.8	1.78	0.72	28.12	0.44	10.35%
6	11:10	540	20.2	1.74	16.2	1.55	0.71	25.11	0.44	10.50%
7	12:10	748	19.7	2.48	15.5	2.23	0.71	34.57	0.44	10.44%
8	13:10	752	19.8	2.23	16.7	2.01	0.72	30	0.44	15.30%
9	14:10	290	20	1.01	16.4	0.87	0.8	14.27	0.44	11.11%
10	15:10	257	19.8	0.85	16.2	0.75	0.72	12.15	0.44	10.68%
11	16:10	147	19.3	0.46	16.5	0.37	0.69	6.105	0.44	9.38%
12	17:10	45	19.2	0.32	16.1	0.25	0.71	4.025	0.44	20.20%

Starting from sunrise to sunset.

Where,

Voc = Open circuit voltage

Isc = Short circuit current

Vmpp = Maximum power at voltage

Impp = Current at Maximum power

Pmax = Vmpp*Impp

FF = Fill factor

Efficiency= Pmax/ Irradiance* Panel Area

CHAPTER 5

ANALYSIS OF THE DATA & RESULTS

The best proportion of ‘sunshine’ is to measure solar irradiation. This number was looked at two-month (November and December) irradiance and power. Not all the sunlight that falls on a PV panel is converted into electricity. A solar panel efficiency is the percentage of energy from sunlight is converted. The efficiencies of most solar panels range from 11-15%, however this varies for different types of solar panels. Solar energy is not available at night, winter, and rainy day so, energy storage should priority.

5.1 Solar Data Analysis

60-Watt Solar Panel has been established in the top floor of DIU and area is 0.44 m2. The focus of this thesis is the measurement of solar irradiation, and the corresponding power generated by this panel. There are some parameters such as irradiance, Equivalent power, Pmax. Equivalent power is the multiplication between irradiance and panel area. Furthermore, Equivalent power is the input power of total solar panel (60W) & Pmax is the output-generated power (Table-7). We have measured the data by I-V 400W Photovoltaic Panel analyzer (Operational Condition). The time duration of this experiment was 2 months (November and December 2018).

We can classification November and December 2018 between sunny and rainy day. This characterization discovers clear examination among irradiance and power.

We have estimated our required information model (Table-7) 11 November 2018 from sunrise to sunset (time 6:10 to 17:10). In time, (6:10) irradiance was zero and for the explanation, we got most extreme power zero. Then again, time (7.10) irradiance was 98 W/m2 and greatest power created 5.832 W. Since we have sunlight between time 6:10 and 7:10 that produces irradiance. We gather our information each 1 hours.

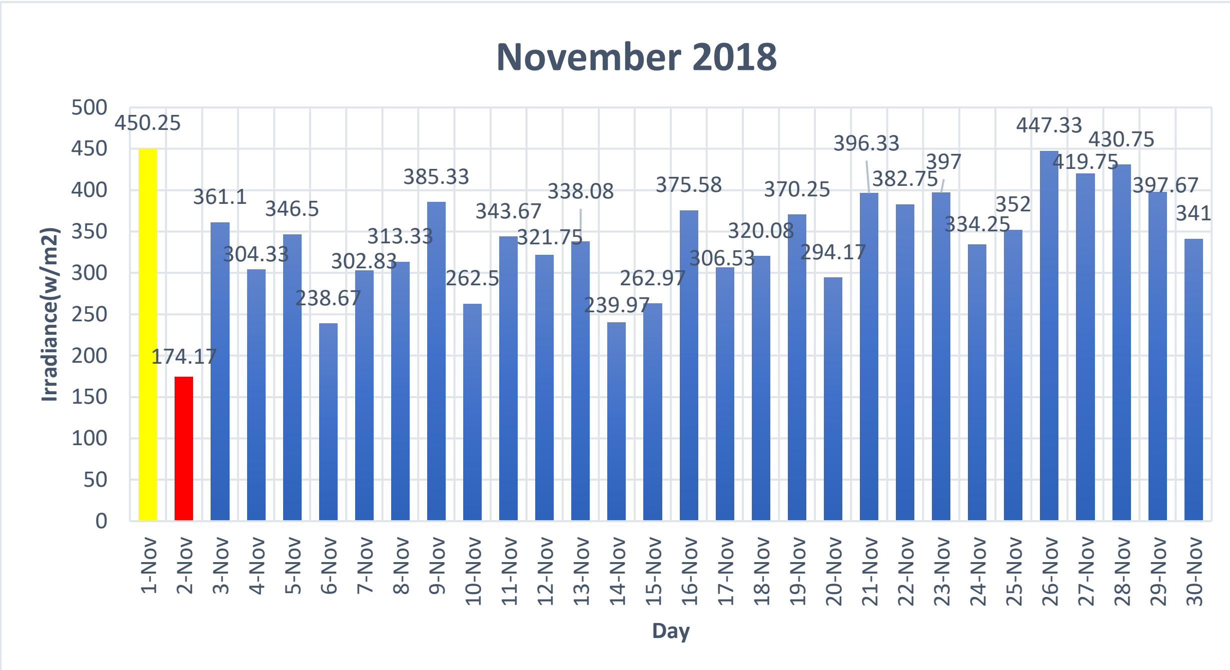

Figure 5.1: Solar Irradiance, November 2018

Figure-5.1 shows the information of solar irradiance of November 2018. On 01 November 2018, the most noteworthy estimation of sunlight based irradiance was estimated that was 450.25 W/m2 and on 02 November 2018, the least estimation of irradiance was recorded that was 174.17 W/m2 and the principle purpose for this circumstance was a sunny day and rainy day. During the sunny day, we have gotten the highest and for rainy day, we have gotten the lowest value. Additionally, monthly average irradiance 340.36W/m2 or 8.17kWh/m2/day was recorded November 2018.

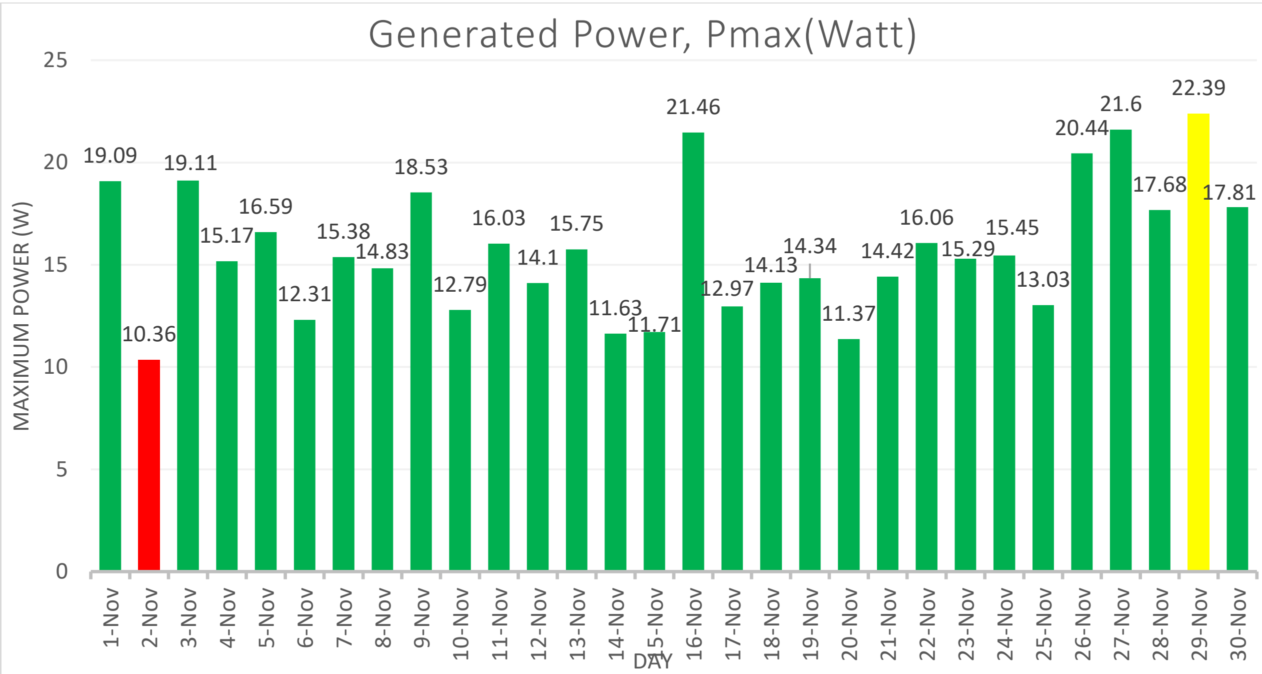

Figure 5.2: Maximum Power, November 2018

Figure-5.2 represents the maximum power generation curve of 60W solar panel in November 2018. On 29 November 2018, we have discovered the highest value of maximum power (22.39W) and the lowest value of minimum power (10.36W) in 02 November 2018. Monthly average power is 15.72 W.

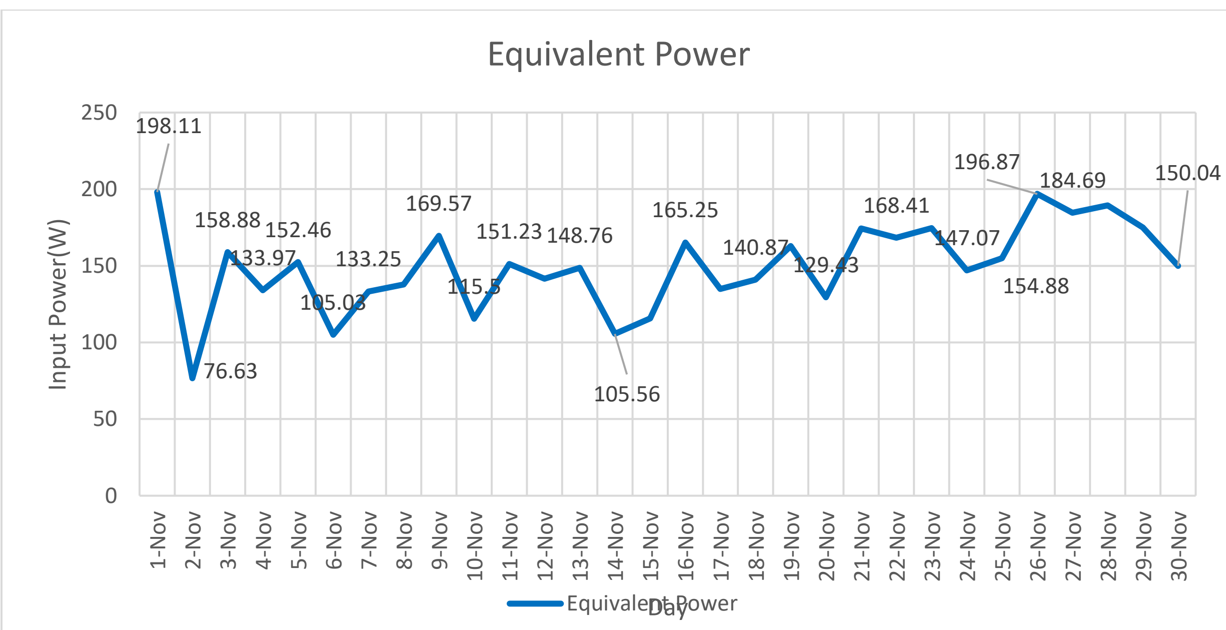

Figure 5.3: Equivalent Power of Solar Panel (60W), November 2018

Figure-5.3 shows the equivalent power of solar panel (60W). On 01 November 2018, the highest value of equivalent power is 198.11 W and 02 November the lowest value of equivalent power is 76.63 W were found.

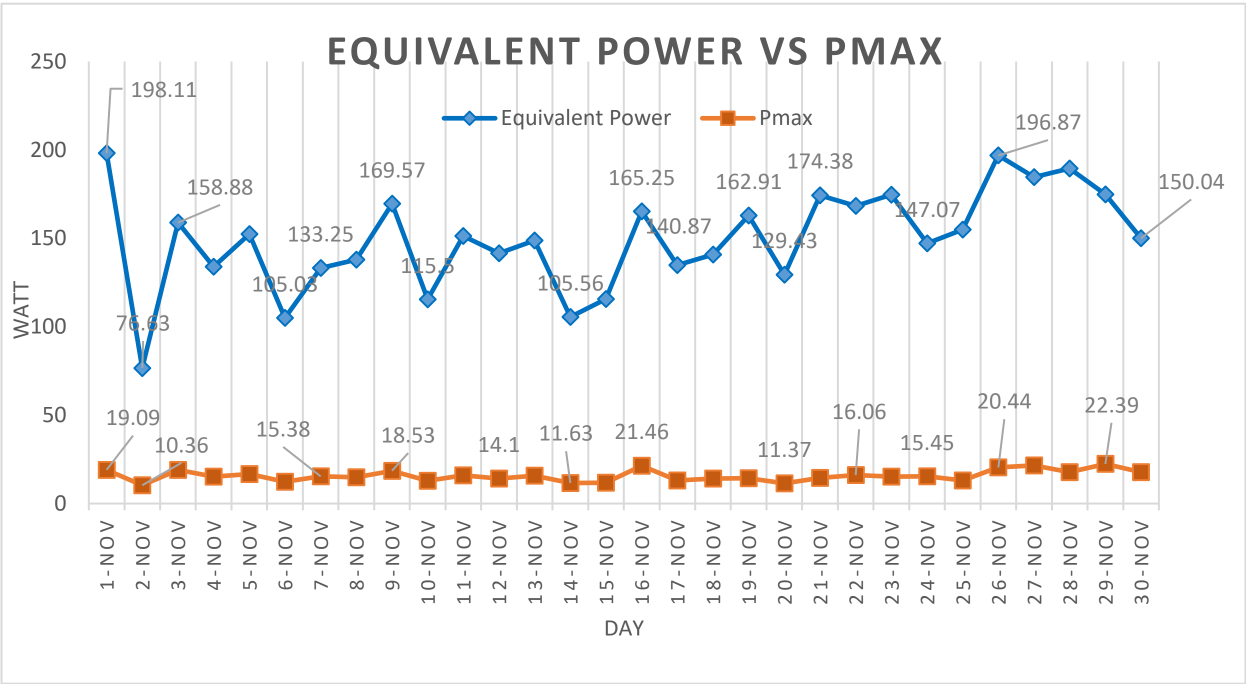

Figure5.4: Equivalent Power Vs Pmax Generation Curve Solar Panel (60W), November 2018

Figure-47 represents the input and output curve of solar power panel (60W). When equivalent power is high (198.11 W) then we get the output power Pmax is high (22.39 W) and when equivalent power is low (76.63 W) then we get the lowest output power Pmax (10.36W). In this manner, we can say that equivalent power and Pmax is proportional. In November 2018, the efficiency of solar panel (60W) is around 10.5%.

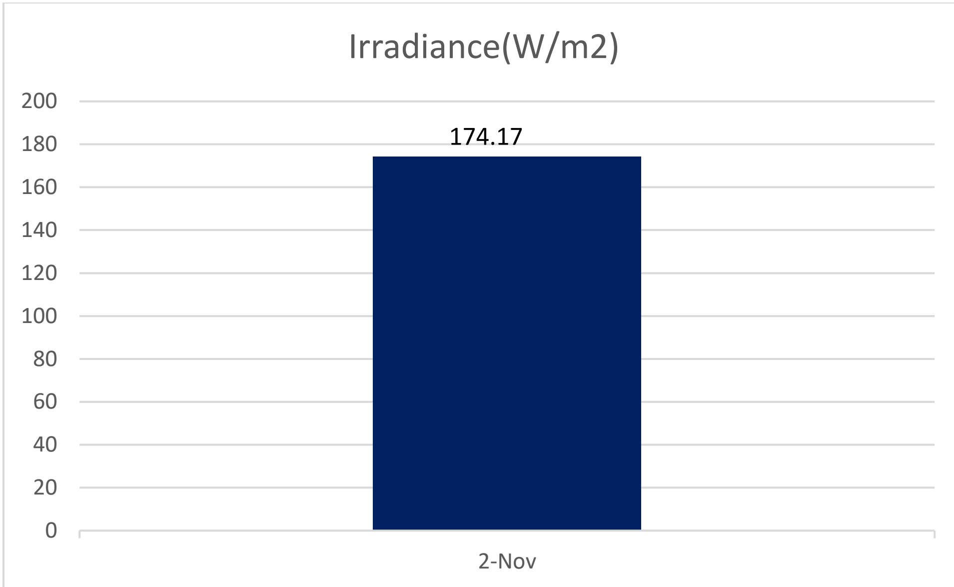

Figure 5.5: Rainy Day Irradiance November 2018

Figure 5.5- shows only one rainy-day irradiance in November 2018: on a rainy day, irradiance is 174.17 W/m2. In rainy days, maximum time, we cannot measure our required data in time. Rainy Day maximum power, we have found 10.36W and average rainfall in Dhaka November 2018 was recorded 34.4 mm.

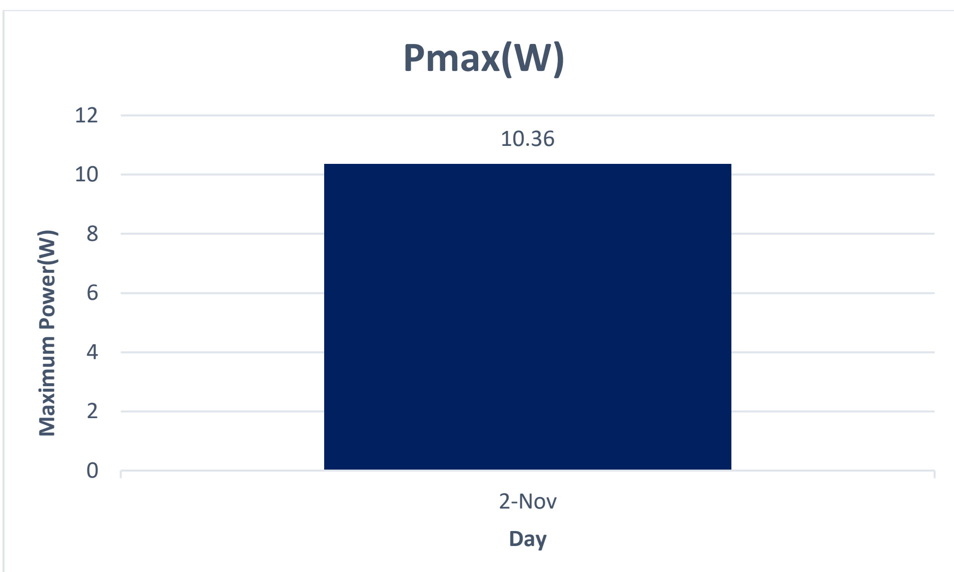

Figure5.6: Only Rainy-Day Maximum Power, November 2018

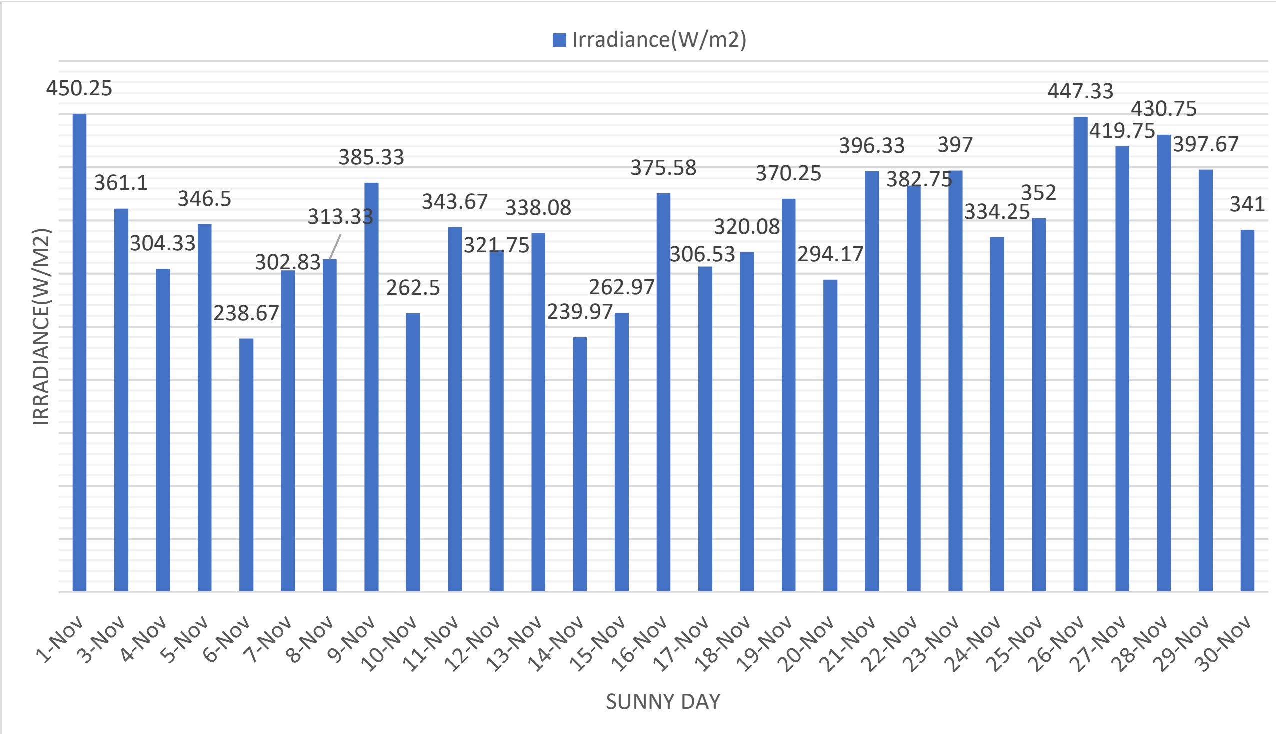

Figure5.7: Sunny Day Irradiance November 2018

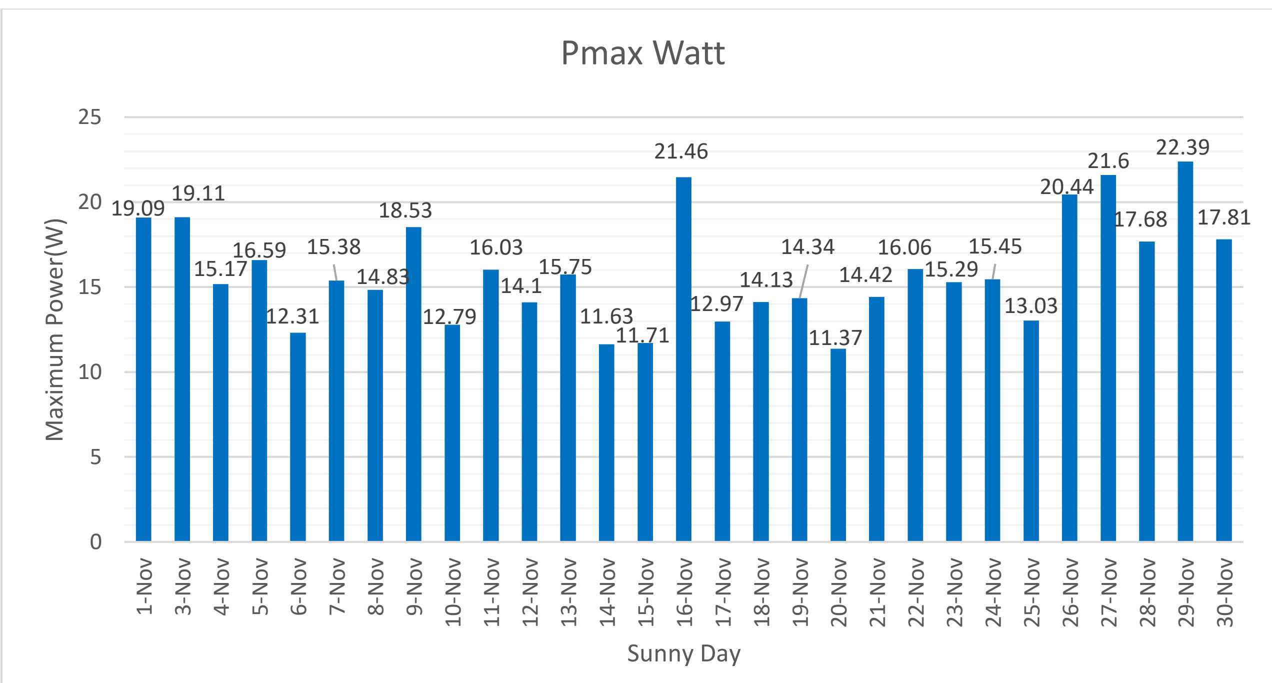

Figure 5.8: Sunny Day Maximum Power November 2018

On 1 November 2018, the measured irradiance was 450.25 W/m2 and the comparing force created by that panel was 19.09 W. However, the matter of worry that, on 29 November 2018, the measured irradiance was 397.67 W/m2 but the power created by the panel was 22.39 W, which was the highest power of November 2018.Figure 5.2 shows only rainy-day irradiance in November 2018: on a rainy day, average irradiance is 174.17 W/m2 and power 10.36 W. On rainy days, maximum time, we can't gauge our required information in time.

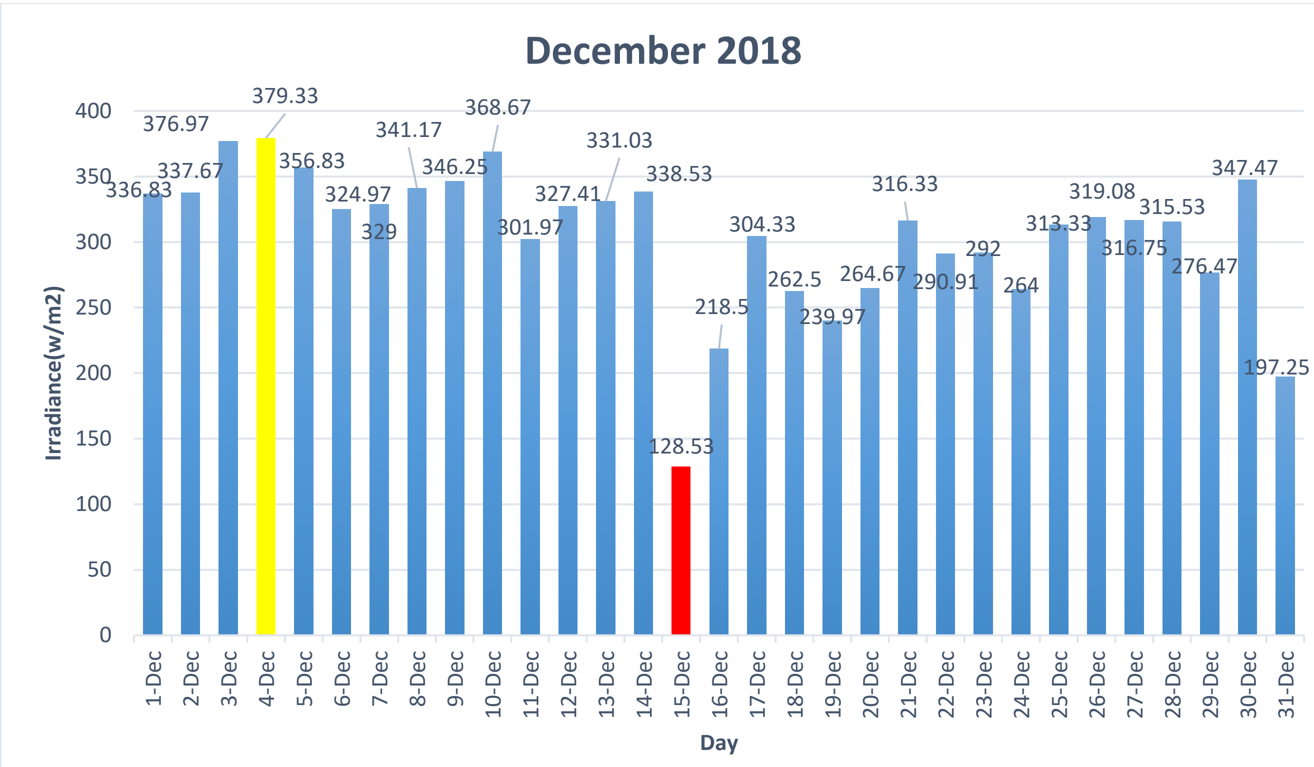

Figure 5.9: Solar Irradiance, December 2018

Figure-5.9 shows the data of solar irradiation of December 2018. On 4 December 2018, the highest value of solar irradiance was measured that was 379.33 W/m2 and on 15 December 2018, the lowest value of irradiance was found that was 128.53 W/m2 and the main reason behind this situation was a sunny day and rainy day. During a sunny day, we have gotten the highest value and for a rainy day, we have the lowest value. Moreover, December 2018 monthly average irradiation is 304.85W/m2 per day or 7.32 kWh/m2/day.

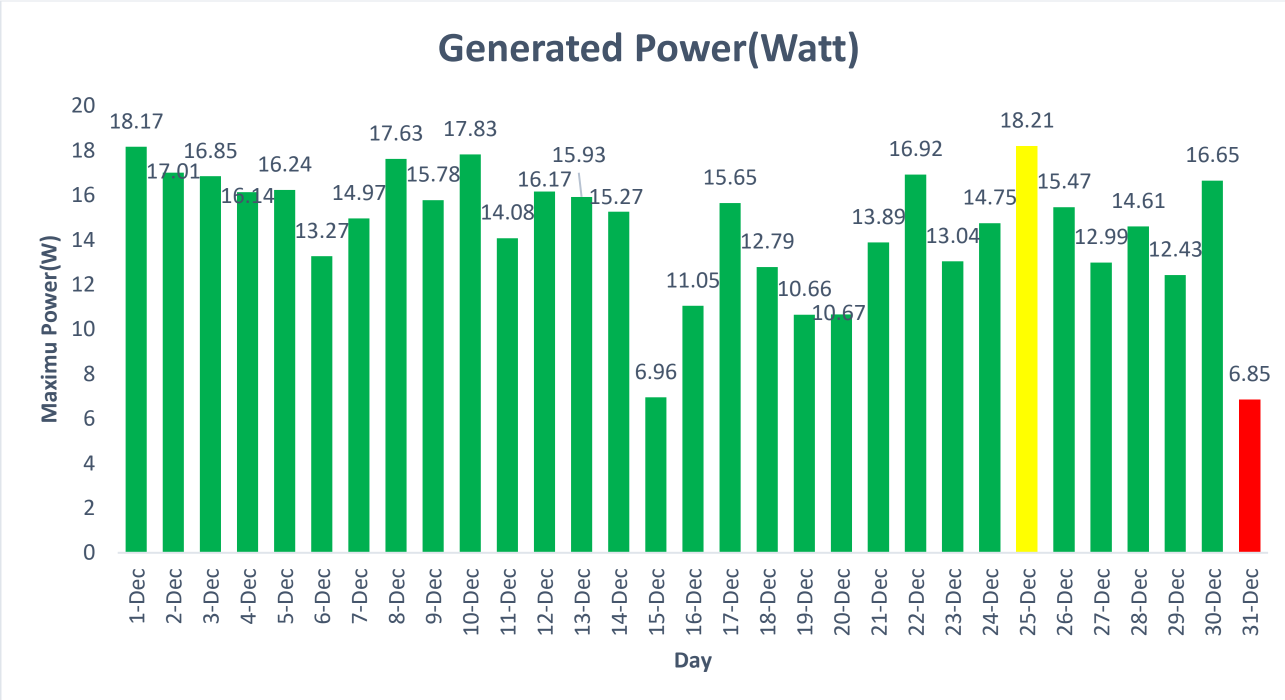

Figure 5.10: Maximum Power, December 2018

Figure-5.10 represents the maximum power generation curve of 60W solar panel in December 2018. On 25 December 2018, we have found the highest value of maximum power (18.21W) and the lowest value of minimum power (6.85W) in 31 December 2018. Monthly average power is 14.48 W.

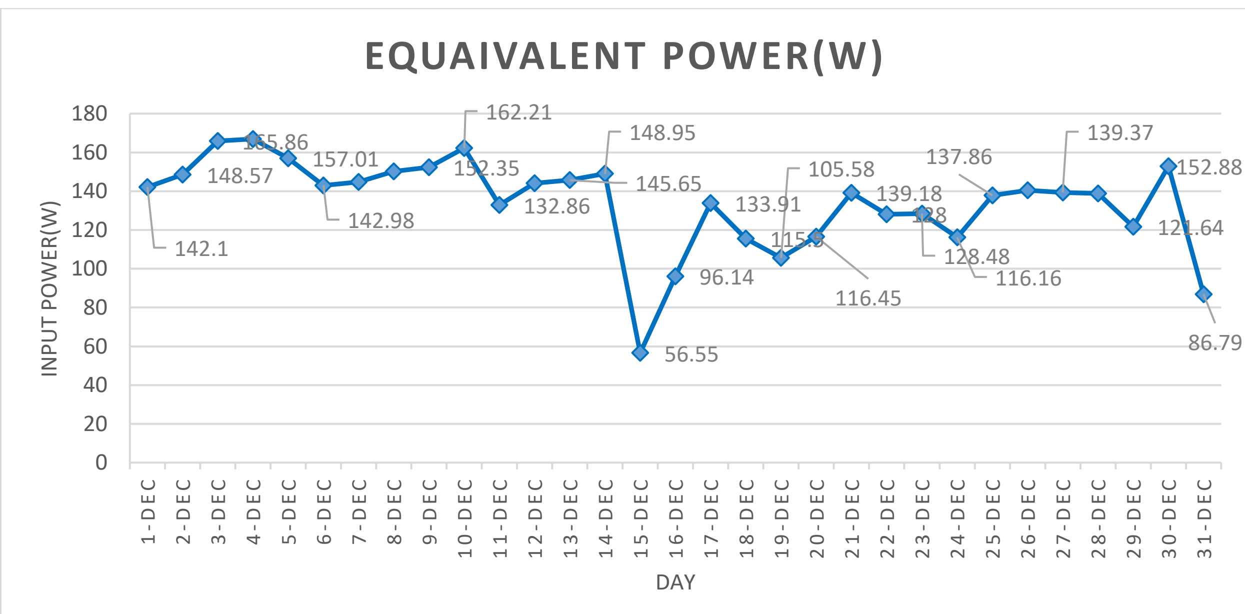

Figure 5.11: Equivalent Power of Solar Panel (60W), December 2018

Figure-5.11 shows the equivalent power of solar panel (60W). On 04 December 2018, the highest value of equivalent power is 166.91 W and the lowest value of equivalent power is 56.55 W were found in 15 December 2018.

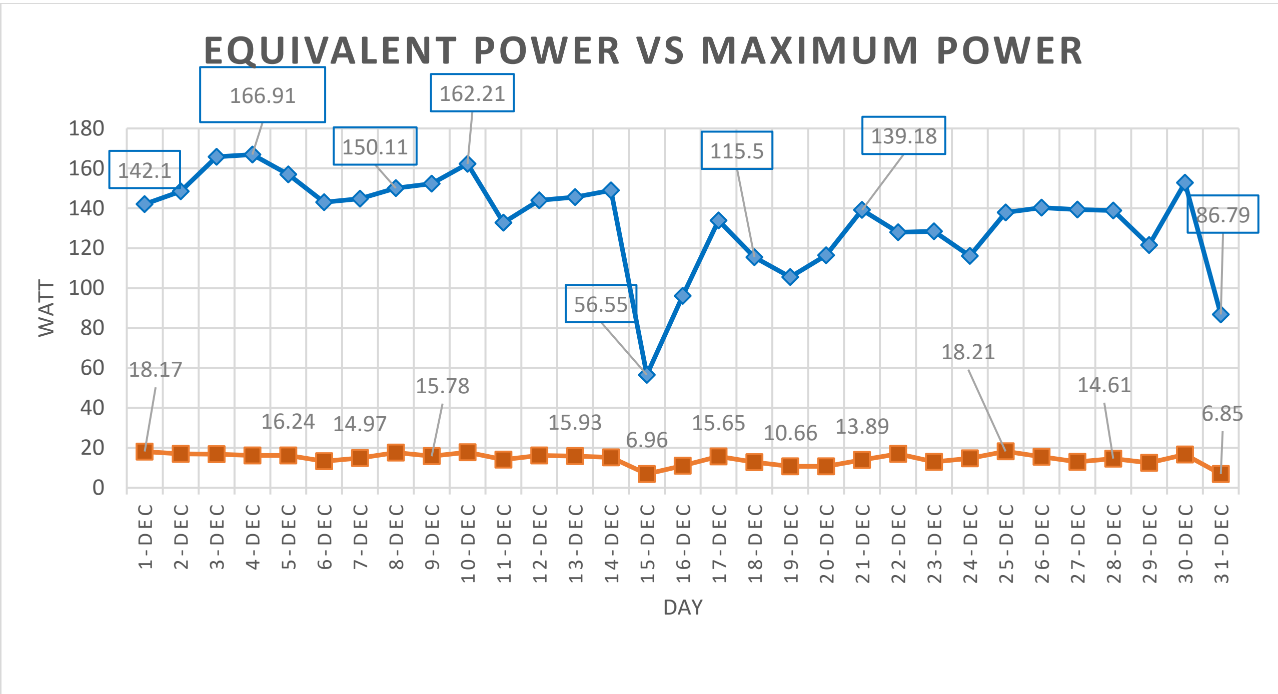

Figure 5.12: Equivalent Power Vs Pmax Generation Curve Solar Panel (60W), December 2018

Figure-5.12 represents the input and output power curve of solar power panel (60W). When equivalent power is high (166.91W) then we get the output power Pmax is high (18.21W) and when equivalent power is low (56.55W) then we get the lowest output power Pmax is (6.85W). Therefore, we can say that equivalent power and Pmax is proportional. On December 2018, the efficiency of solar panel (60W) was around 10.7%

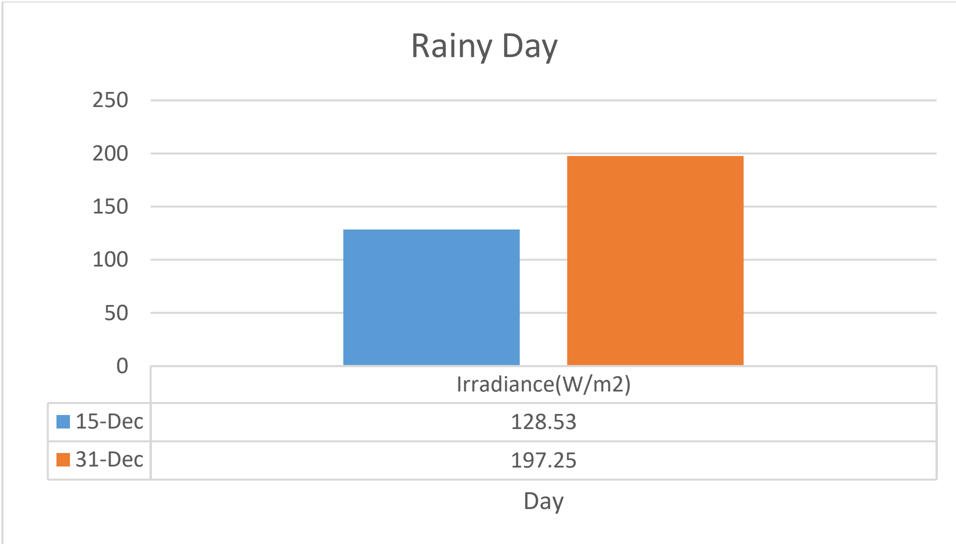

Figure 5.13: Only Rainy Day Irradiance December 2018

Figure- 5.13 shows only rainy-day irradiance in December 2018: in rainy day, average irradiance is 162.89 W/m2. We got the highest & lowest irradiance 197.25 W/m2 & 128.53W/m2 respectively. In rainy day, maximum time, we cannot measure our required data on time.

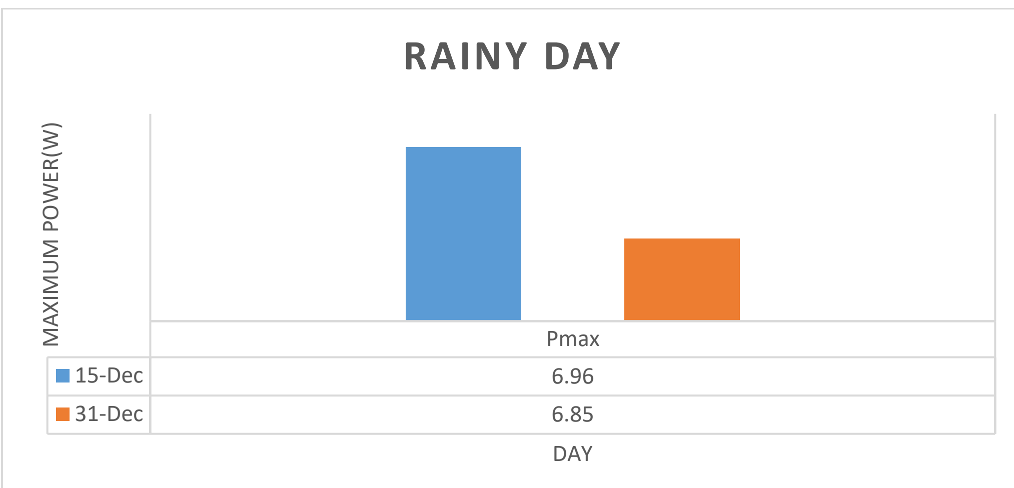

Figure 5.14: Only Rainy Day Maximum Power December 2018

Figure- 5.14 shows only rainy-day maximum power in December 2018: in rainy day, average power is 6.91W. We got the highest & lowest power 6.96 W& 6.85 W respectively and average rainfall in Dhaka December 2018 was recorded 12.8 mm.

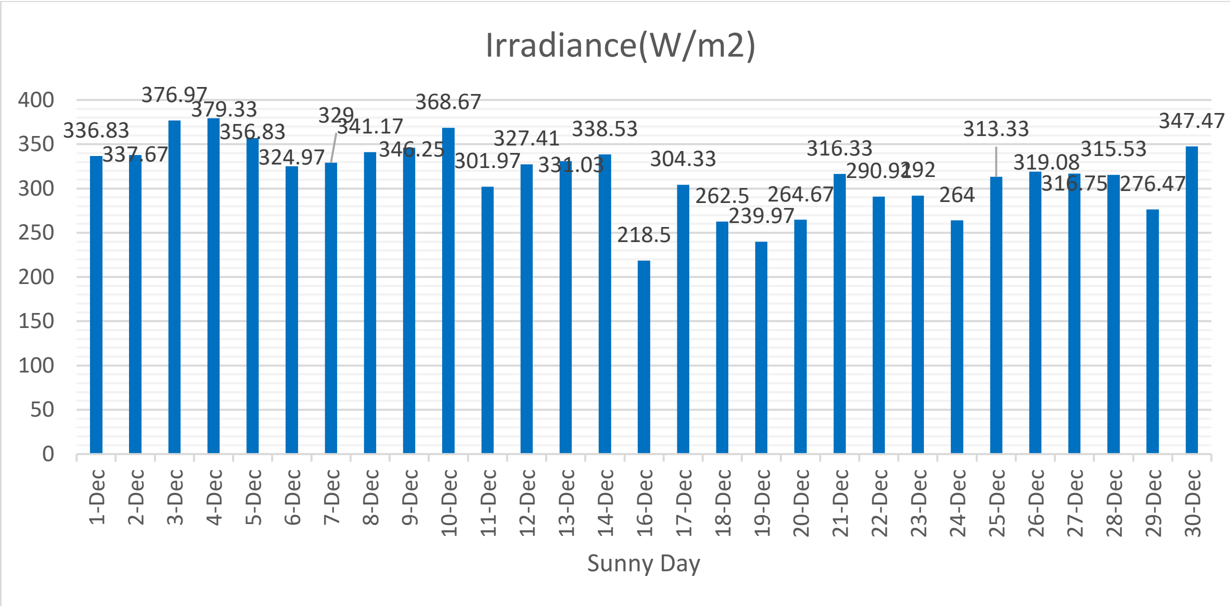

Figure 5.15: Sunny Day Irradiance, December 2018

Figure-5.15 shows the data regarding the solar irradiance of sunny day in December 2018: the average irradiance in sunny day is 314.63W/m2. In sunny day, we recorded our data every hour.

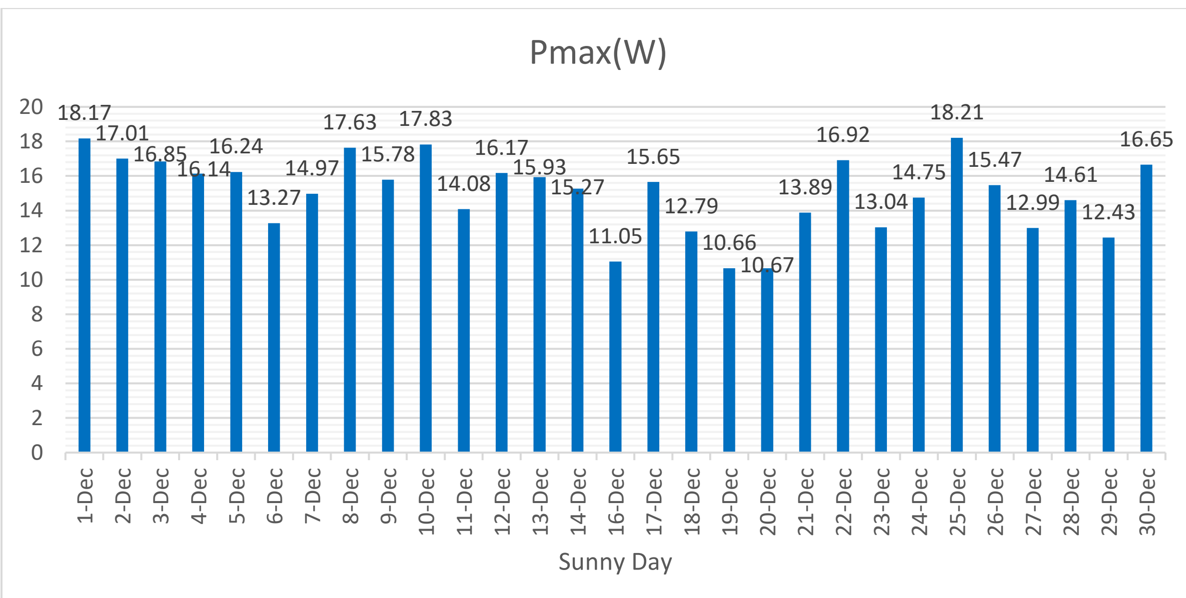

Figure 5.16: Sunny Day Maximum Power, December 2018

Figure-5.16 shows the data regarding the solar irradiance of sunny day in December 2018: the average power in sunny day is 15W. In sunny day, we recorded our data every hour.

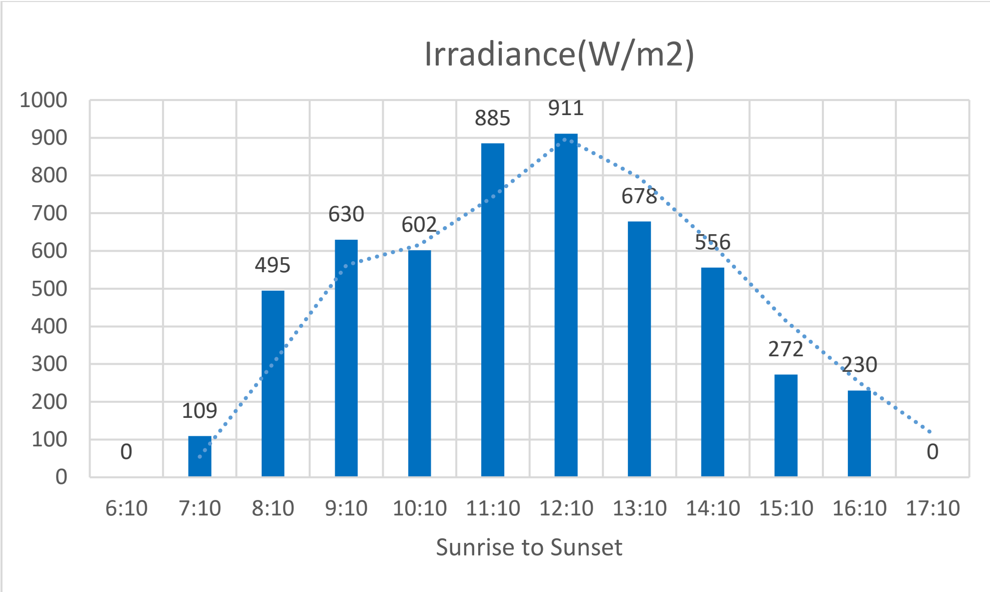

Figure 5.17: Daily irradiance sunrise to sunset (26 November) Sunny Day, November 2018

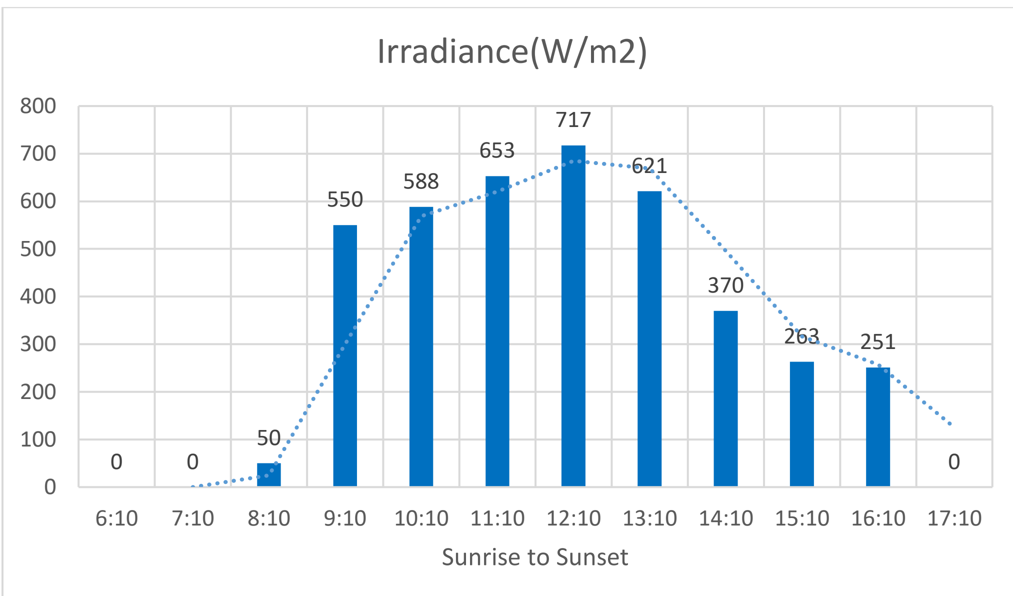

Figure 5.18: Daily irradiance sunrise to sunset (14 December) Sunny Day, December 2018

the peak sun hours in a certain region is 4-5 hours, this does not mean that there are only 4 or 5 hours of sunlight per day but that there was an equivalent of 4 to 5 hours of sunlight with an irradiance of around 500-900 W/m2(with weather variation). In order to calculate the output of a solar system, the peak sun hours should be considered. As peak sun hours would also vary over different times of the year, an average for the region is taken and used in calculations [29] the average and maximum hourly values were determined. From the monthly measurements set, daily and hourly data were built for the solar irradiation and maximum power. Daily average for each month and peak daily solar irradiation for complete years are shown in Figure-5.17 & 5.18.The month of November 2018 had the highest monthly daily average irradiation of 911 W/m² but the month of December 2018 shows the highest daily average peak in solar irradiation of 717 W/m². In this study, 6:10-7:10 and 17:00 time we couldn't found any irradiation values due to the sky covered by clouds and foggy. In winter, there are foggy and misty days in December, which might also restrict solar insolation to reach the surface, and November is post-monsoon autumn season. November and December 2018 had the lowest monthly average daily solar irradiation of 109W/m² and 50W/m2.

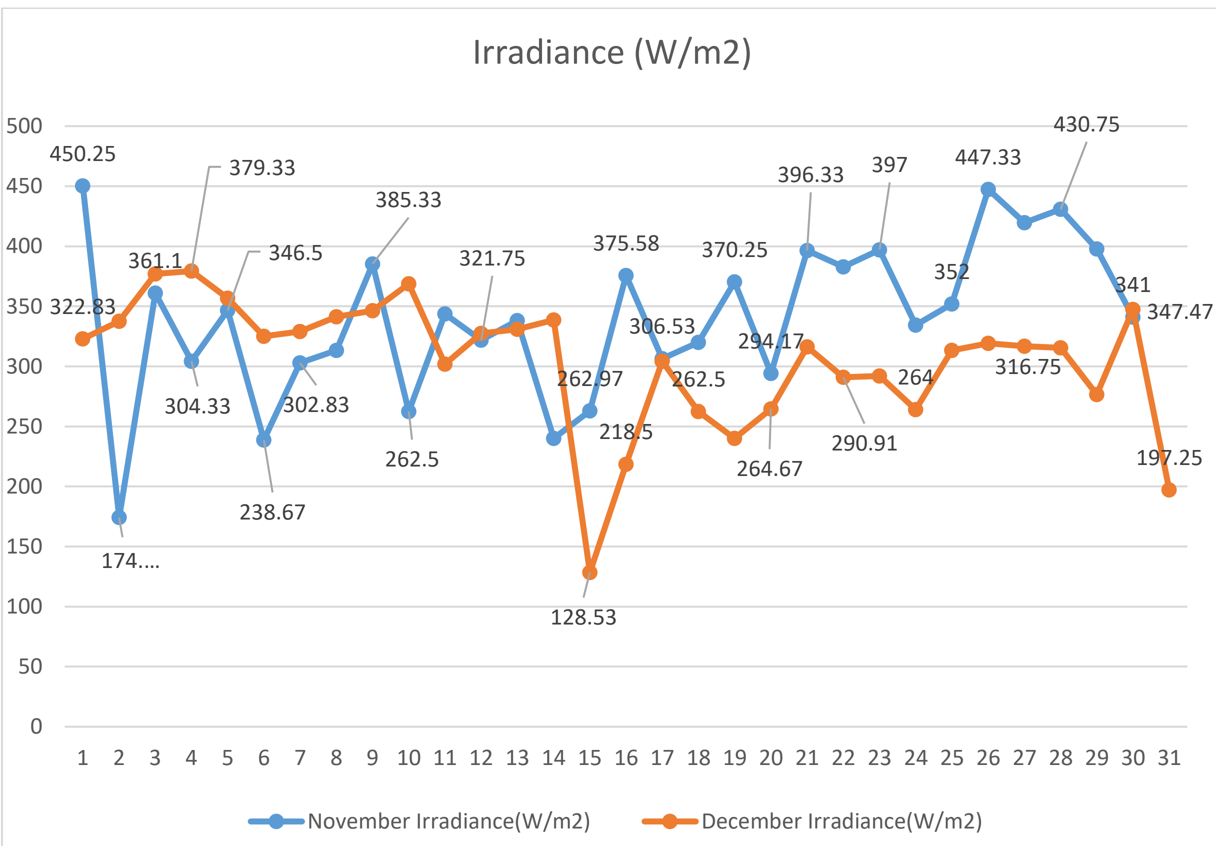

Figure 5.19: November vs December 2018 Irradiance (W/m2)

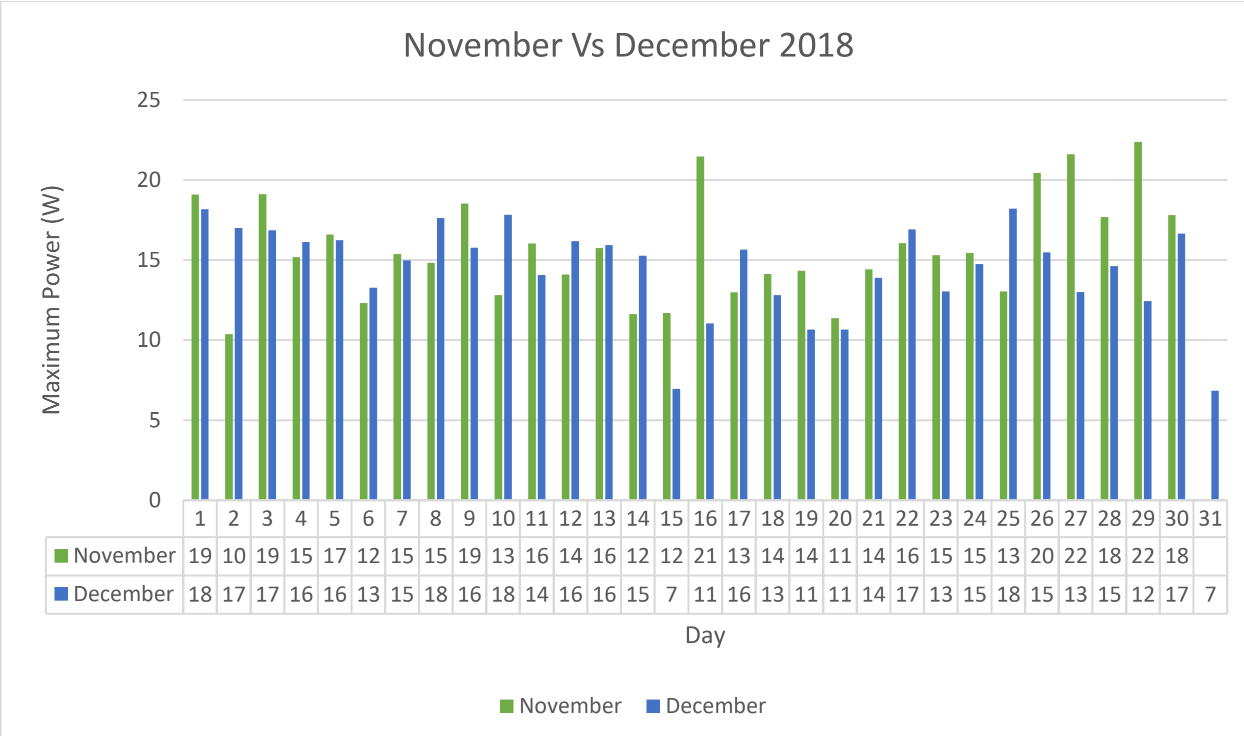

Figure 5.20: November vs December 2018 Maximum Power (W)

Figure 5.15 &5.16: we comparison between November and December 2018 Irradiance (W/m2) and Maximum Power(W). We have to see that the figure Maximum time irradiance of November is greater than December irradiance. November is better than the December. November 2018 average Irradiance is recorded 340.36W/m2 and December 2018 is recorded 304.85W/m2. Average 15.72 W of November 2018 is maximum power and December 2018 is 14.48W.

Table 8: Irradiance and Pmax in two month (November and December 2018)

	November	November	December	December
Date	Irradiance(W/m2)	Pmax(W)	Irradiance(W/m2)	Pmax(W)
1	450.25	19.09	322.83	18.17
2	174.17	10.36	337.67	17.01
3	361.1	19.11	376.97	16.85
4	304.33	15.17	379.33	16.14
5	346.5	16.59	356.83	16.24
6	238.67	12.31	324.97	13.27
7	302.83	15.38	329	14.97
8	313.33	14.83	341.17	17.63
9	385.33	18.53	346.25	15.78
10	262.5	12.79	368.67	17.83
11	343.67	16.03	301.97	14.08
12	321.75	14.1	327.41	16.17
13	338.08	15.75	331.03	15.93
14	239.97	11.63	338.53	15.27
15	262.97	11.71	128.53	6.96
16	375.58	21.46	218.5	11.05
17	306.53	12.97	304.33	15.65
18	320.08	14.13	262.5	12.79
19	370.25	14.34	239.97	10.66
20	294.17	11.37	264.67	10.67
21	396.33	14.42	316.33	13.89
22	382.75	16.06	290.91	16.92
23	397	15.29	292	13.04
24	334.25	15.45	264	14.75
25	352	13.03	313.33	18.21
26	447.33	20.44	319.08	15.47
27	419.75	21.6	316.75	12.99
28	430.75	17.68	315.53	14.61
29	397.67	22.39	276.47	12.43
30	341	17.81	347.47	16.65
31			197.25	6.85

5.2 Comparison of Solar Irradiation Data among Different Year

Table 9: Data of Monthly Average Solar Irradiance in 2008, 2009 & 2010

Month	Solar Irradiance(W/m2) (2008)	Solar Irradiance(W/m2) (2009)	Solar Irradiance(W/m2) (2010)
January	164.9	165.6	151.5
February	209.8	219.1	186.7
March	225.7	228.3	238.2
April	283.3	273.1	236.7
May	261.1	235.1	225.8
June	212.4	210.3	176
July	176.2	197	201.6
August	174.1	177.5	166.3
September	189.6	166.8	165.5
October	179.7	189.1	175.2
November	208.1	164	168
December	123.7	142.5	159.2
Annual average Irradiance(W/m2)	209.05	197.36	187.55
Annual Average (kWh/m2/day)	5.01	4.73	4.50

In the year 2008, annual average solar irradiation was 5.01 kWh/m2/day, the value of irradiation in 2009 was decreased, and that was 4.73 kWh/m2/day. There was also a declining trend in solar irradiation value in between 2009 and 2010 because in 2010, only 4.50 kWh/m2/day irradiation was measured as shown in Table 9.

Solar radiation data were collected from Renewable Energy Research Center (Dhaka University), National Renewable Energy Laboratory and Development and Research is given in Table 10. Most of these solar radiation data were collected from DU for Dhaka with different cities in Bangladesh.

Table 10: Collected Data from 1985-2005, 2008-2010, 2018 and Compare Irradiance (kWh/m2/day) Among them were Presented Below.

Month	NREL (1985-91)	RERC (1987-89)	RERC (1992)	DLR (2000-2003)	RERC (2003-2005)	RERC (2006)
January	4.18	4.29	3.34	4.58	3.16	3.4
February	4.68	4.86	4.05	4.81	4.46	3.79
March	5.55	5.53	5.24	5.31	4.88	5.04
April	5.65	5.23	6.02	5.84	5.28	5.06
May	5.58	5.67	5.76	5.21	5.46	5.09
June	4.48	5.13	5.39	3.85	4.22	4.8
July	3.9	3.87	4.2	3.76	4.48	3.84
August	4.12	3.92	4.87	4.11	4.12	4.73
September	3.96	4.5	5.38	3.76	3.78	5.15
October	4.7	4.61	4.93	4.19	3.57	3.18
November	4.25	4.22	3.72	4.47	3.92	3.35
December	4.06	3.89	3.39	4.34	3.19	2.84
Annual Average(kWh/m2/day)	4.59	4.64	4.69	4.52	4.21	4.45

In the year 1985-1991, annual average solar irradiation was 4.59 kWh/m2/day and it was increased to 4.64 kWh/m2/day in 1987-89. But in 2000-03, annual average irradiation was 4.52 kWh/m2/day, which was decreased into 4.2 kWh/m2/ day in 2003-05. In 2006, irradiation was increasing, and the value was 4.45 kWh/m2/day.

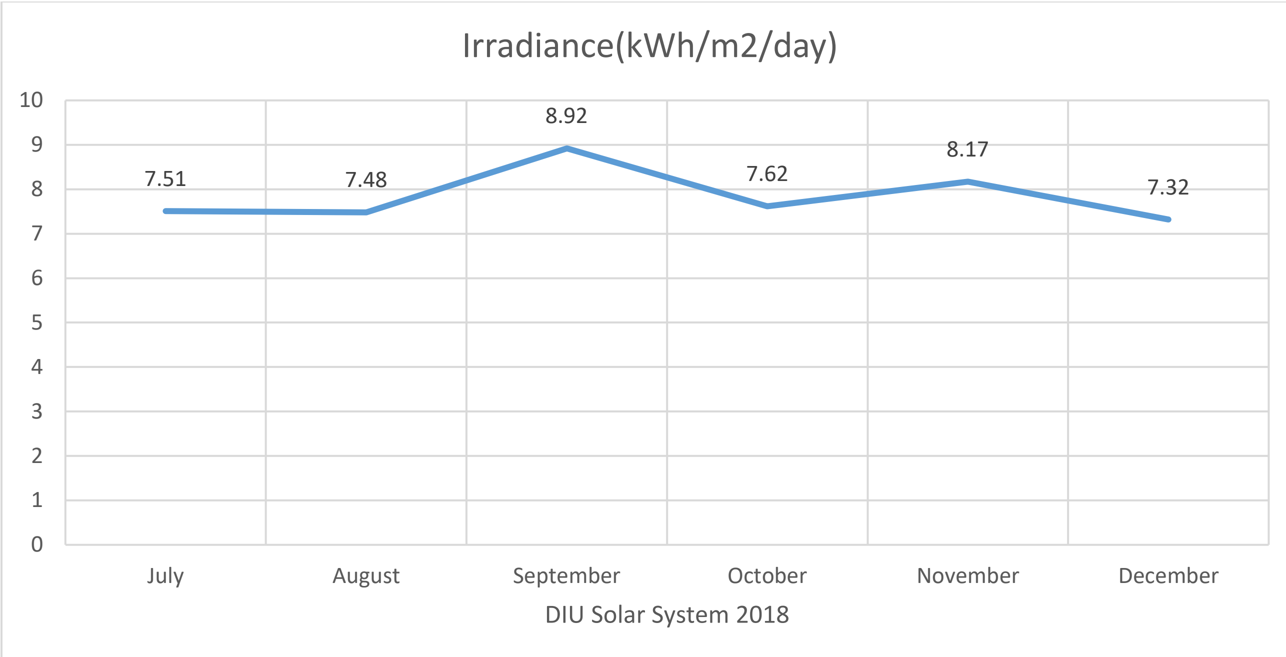

Figure 5.21: DIU Solar System Irradiance from July to December 2018

Figure 5.21, It is clear that the monthly (July to December) average solar irradiation in Dhaka (Dhanmondi area) over the course of the year 2018 is 7.84kWh/m2 /day. Within six month, the higher irradiance in September 2018 is 8.92kWh/m2 /day and lowest in December 2018 is 7.32kWh/m2/day due to it's winter season. Overall, we receive moderate amount of average solar irradiation 7.84kWh/m2/day (July to December) that can be proved very significant for a sustainable power sector.

Table 11: Difference Years Irradiance on November &December

Year	Month	Irradiance kWh/m2/day
1985-91	November	4.25
	December	4.06
1987-89	November	4.22
	December	3.89
1992	November	3.72
	December	3.39
2000-2003	November	4.47
	December	4.34
2003-2005	November	3.92
	December	3.19
2006	November	3.35
	December	2.84
2008	November	4.99
	December	2.95
2009	November	3.94
	December	3.41
2010	November	4.03
	December	3.82
2018	November	8.17
	December	7.32

.

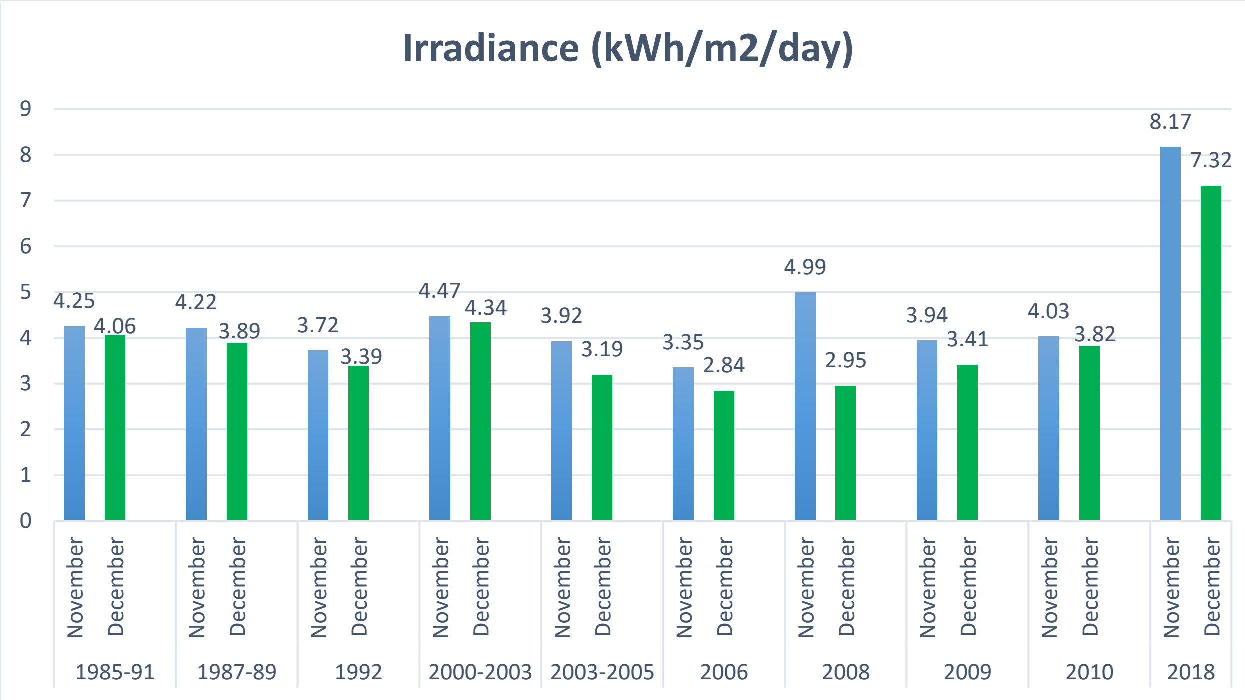

Figure 5.22: Difference Years Irradiance (November &December)

Figure 5.19, after analyzing the data we can say that in the month of November, we got the highest amount of Irradiance than December. In the year 1985-1991, November & December average solar irradiation was recorded 4.25& 4.06 kWh/m2/day and it was decreasing into 4.22& 3.89 kWh/m2/day in 1987-89 and next 1992 also decreasing into 3.72 &3.39. But in 2000-03, November & December average irradiation was recorded 4.47 &4.34 kWh/m2/day, which was decreasing into 3.92&3.19 kWh/m2/ day in 2003-05. In 2008, irradiation was increasing, and the value was 4.99 & 2.95 kWh/m2/day. In 2009, that was the value of irradiation 3.94 & 3.41. Again in 2010, irradiation was the value of 4.03 &3.82 kWh/m2/day. Moreover, in 2018, irradiation was increasing, and the value of 8.17 & 7.32 kWh/m2/day. Monthly average temperature was recorded at maximum 29.6 degree (C) and minimum19.2 degree (C) in November 2018.And monthly average temperature was recorded at maximum 26.4 degree (C) and minimum 14.7 degree (C) in December 2018.

5.3 Summary

In this data analysis chapter, we describe our thesis work. We work on 60 w solar panel in Dhanmondi area in Dhaka. Here we measure every day solar irradiation and Pmax for November &December. We got monthly average solar irradiance for November is 340.36 w/m2 and 304.85

w/m2 for December. And we also got monthly average maximum power (Pmax) for November is 15.72 W and 14.48 W for December. We also measured independently average irradiation and maximum power (Pmax) for sunny and rainy days for both month November and December. By measuring both November and December we analyze that the average irradiation and maximum Power (Pmax) of November is better than December. Additionally, we measure DIU solar system irradiance contrast July to December. Finally, we say that the Irradiance is higher than the previous year, for that causes alarming of global temperature and climate change.

CHAPTER 6

CONCLUSION

Renewable energy, which is environment friendly, inexhaustible and sustainable, can be considered as one of the significant alternatives source and it can play a significant character in the energy sector of our developing country. Worldwide renewable energy demand and research are rising and our government taking necessary steps for green energy especially solar energy. Solar irradiation is strongly dependent on the atmospheric condition, time of year, the angle of incidence of sunrays on the earth surface and other related geographical aspects. Geographically Bangladesh has enough well position. Recently solar technology has become very popular in our neighboring country India.

To use solar energy more effectively, due to the change in the radiation of the sun over time, it is very important to measure the radiation of that country. In this thesis, our main objective was to find sun radiation in Dhaka in November and December in order to estimate solar power generation and using this information, we can easily understand the electricity production and create a standard form of power generation of SHS in 2018. Here we find that the average irradiation of November 8.17 kWh/m2/day and December was 7.32 kWh/m2/day and corresponding power Solar insolation is the most abundant renewable energy source of Bangladesh produced by 60W solar panel was 15.72 W and 14.48 W respectively. Moreover, average sunshine was recorded 8 hours and 9 hours in November and December 2018.

Therefore, by ensuring the prospects we will solve our energy crisis and ensure provide a green environment for the future generations. Especially an off grid area based on solar PV system can solve our irrigation problem as well as will ensure a better life for the rural people. From this study, it can be concluded that solar irradiation intensity remains favorable from November to December throughout the Dhaka area. The analysis shows that solar irradiation intensity greater than 300

W/m2 was observed, from November to December 2018 in Dhaka city. In this study, solar irradiation (2018) was measured to get a better view of the solar power potential in Dhaka city than in recent years.

6.1 Future Scope

In Future, work cost analysis can be made by calculating the power output from different photovoltaic panel changing the inclination angle on a monthly basis and also work on dust and without dust of solar system.

REFERENCE

[1]. Stephen Eule. “A Look at IEA's New Global Energy Forecast.” Global Energy Institute https://www.globalenergyinstitute.org/look-ieas-new-global-energy-forecast.

[2] Sourcewatch.org. (2019). Bangladesh and coal - Source Watch. [Online] Available at: https://www.sourcewatch.org/index.php/Bangladesh_and_coal [Accessed 1 June. 2019].

[3] http://www.rooppurnpp.gov.bd [4 June 2019]

[4] Hydro Review. (2019). IRENA reports renewable energy now accounts for a third of global power capacity - Hydro Review. [Online] Available at: https://www.hydroworld.com/articles/2019/04/irena-reports-renewable-energy-now-accounts-for-a-third-of-global-power-capacity.html [Accessed 5 June. 2019].

[5] G. Energy and G. Energy, "Renewable energy to reach 22.5% share in global power mix in 2020",(16 July 2018) Power Technology | Energy News and Market Analysis, 2019. [Online]. Available: https://www.power-technology.com/comment/renewable-energy-reach-22-5-share-global-power-mix-2020/.

[6] http://www.sdnbd.org/wind.htm

[7] Metcalfe, T. What is geothermal energy? [2019, January 29]. Available: https://www.nbcnews.com/mach/science/what-geothermal-energy-ncna963996

[8] Hydro Power | Student Energy. Available: https://www.studentenergy.org/topics/hydro-power

[9] 12 Countries Leading the Way in Renewable Energy", Click Energy, 2019. [Online]. Available: https://www.clickenergy.com.au/news-blog/12-countries-leading-the-way-in-renewable-energy/.

[10] "Follow the Leader: How 11 Countries Are Shifting to Renewable Energy", Climate Reality, 2019. [Online]. Available: https://www.climaterealityproject.org/blog/follow-leader-how-11-countries-are-shifting-renewable-energy.

[11] "Top 10 Solar Energy Producing Countries 2018", Dcsolarx.in, 2019. [Online]. Available: https://www.dcsolarx.in/2019/01/top-10-solar-energy-producing-countries.html.

[12] "Bangladesh increases rural access to electricity five-fold in two decades", Dhaka Tribune, 21 April 2019.[Online].Available:https://www.dhakatribune.com/bangladesh/powerenergy/2019/04/21/bangladesh-increases-rural-access-to-electricity-five-fold-in-two-decades.

[13] D. Bss, "90pc electricity coverage by 2018", The Daily Star, (16 July 2013). Available: https://www.thedailystar.net/city/90pc-people-under-electricity-coverage-2018-1252828.

[14] "টেকসই ও নবায়নযোগ্য জ্বালানি উন্নয়ন কর্তৃপক্ষ", Sreda.gov.bd, 2019. [Online]. Available: http://www.sreda.gov.bd/index.php/site/re_present_status. [Accessed: 18- June- 2019].

[15] Md. Saidun Nabi. "Can Bangladesh Meet Its 10% Renewable Energy Target by 2020?", Dhaka tribune[Online] https://www.dhakatribune.com/bangladesh/power-energy/2019/01/12/can-bangladesh-meet-its-10-renewable-energy-target-by-2020.

[16] Mr. Abser Kamal, Dr. M Shahidul Islam, Mr. Mohammad Mahmodul Hasan, Grameen Shakti "Solar Home Systems with Micro Credits" CASE STUDY – Bangladesh. Available: http://www.inforse.org/asia/pdf/Pub_Bangladesh%20solar%20home%20system_2014.pdf

[17]"Infrastructure Development Company Limited (IDCOL)", Idcol.org, 2019. [Online]. Available: http://idcol.org/home/solar. [Accessed: 4 July- 2019].

[18] https://cdm.unfccc.int/[Accessed: 14 July- 2019].

[19] Hussain A. Samad, Shahidur R. Khandker, M. Asaduzzaman, Mohammad Yun, "The Benefits of Solar Home Systems an Analysis from Bangladesh ".

[20] Kevin DeGroat, Joseph Morabito, Terry Peterson, and Greg P. Smestad, "Systems Analysis and Recommendations for R&D and Accelerated Deployment of Solar Energy". January 2009

[21] M.F. Hossain, S. Hossain, and M.J. Uddin Renewable energy: "Prospects and trends in Bangladesh".

[22] Macalpine, S., Deceglie, M., Kurtz, S., Bora, B., Sastry, O. S., … Rai, S. (2016). "Analysis of a Single Year of Performance Data for Thin Film Modules Deployed at NREL and NISE". doi: 10.2172/1313608

[23] Amin, N., & Langendoen, R. (2012). Grameen Shakti: "A Renewable Energy Social Business Model for Global Replication". 2012 IEEE Global Humanitarian Technology Conference. doi: 10.1109/ghtc.2012.50

[24] Energy Scenario of Bangladesh 2017-18, Energy and Mineral Resources Division Ministry of Power, Energy and Mineral Resources, January 2019.

[25] Express, T. (2019). Trend in renewable energy use in Bangladesh. [Online] The Financial Express. Available at: https://thefinancialexpress.com.bd/special-issues/power-energy/trend-in-renewable-energy-use-in-bangladesh-1504082323

[26] Microgrid-Trainers-Handbook -page34. Available at: http://isolaralliance.org/docs/Microgrid-Trainers-Handbook.

[27] Alternative Energy Tutorials. (2019). Solar Cell I-V Characteristic and the Solar Cell I-V Curve. [Online] Available at: http://www.alternative-energy-tutorials.com/energy-articles/solar-cell-i-v-characteristic.html

[28] Haque, A. (2014)." Maximum Power Point Tracking (MPPT) Scheme for Solar Photovoltaic System". Energy Technology & Policy, 1(1), 115–122. doi: 10.1080/23317000.2014.979379

[29] Ecowho.com. (2019). Peak Sun Hours. [Online] Available at: http://www.ecowho.com/defn/p/Peak+Sun+Hours/f536b

[30] (2019). ADB Annual Report 2018. ADB Annual Reports. doi: 10.22617/fls190058

[31] Bdnews24.com. (2019). Bangladesh eligible for UN 'developing country' status. [Online] Available at: https://bdnews24.com/bangladesh/2018/03/17/bangladesh-eligible-for-un-developing-country-status

[32] (2019, April 21). Bangladesh increases rural access to electricity five-fold in two decades. Available at: https://www.dhakatribune.com/bangladesh/power-energy/2019/04/21/bangladesh-increases-rural-access-to-electricity-five-fold-in-two-decades

[33] Solar energy reduces rural poverty, The Daily Star (March 11, 2019)

Available at: https://www.thedailystar.net/business/solar-panel-in-bangladesh-reduces-rural-poverty-1713181

[34] Growth of grid solar power in Bangladesh. New Age Bd (2018, June 2). Available at: http://www.newagebd.net/article/42618/growth-of-grid-solar-power-in-bangladesh

[35] Iea.org. (2019). Renewables 2018: Key Findings. [Online] Available at: https://www.iea.org/renewables2018

[36] Oas.org. (2019). CHAPTER 1. RENEWABLE ENERGY OVERVIEW. [Online] Available at: https://www.oas.org/dsd/publications/Unit/oea79e/ch05.htm

[37] Hydro Review. (2019). IRENA reports renewable energy now accounts for a third of global power capacity - Hydro Review. [Online] Available at: https://www.hydroreview.com/2019/04/03/irena-reports-renewable-energy-now-accounts-for-a-third-of-global-power-capacity/

[38] Energy, G. and Energy, G. (2019). Renewable energy to reach 22.5% share in global power mix in 2020. [Online] Power Technology | Energy News and Market Analysis. Available at: https://www.power-technology.com/comment/renewable-energy-reach-22-5-share-global-power-mix-2020/

[39] Council, C. and Council, C. (2019). 11 countries leading the charge on renewable energy - Climate Council. [Online] Climate Council. Available at: https://www.climatecouncil.org.au/11-countries-leading-the-charge-on-renewable-energy/

[40] World Economic Forum. (2019). Three countries are leading the renewable energy revolution. [Online] Available at: https://www.weforum.org/agenda/2018/02/countries-behind-global-renewable-energy-growth/

[41] Studentenergy.org. (2019). Hydro Power | Student Energy. [Online] Available at: https://www.studentenergy.org/topics/hydro-power

[42] The Globe and Mail. (2019). Opinion: The greenprint: Checking up on Germany's transition to renewable energy. [Online] Available at: https://www.theglobeandmail.com/opinion/article-the-greenprint-checking-up-on-germanys-transition-to-renewable/

[43] Irena.org. (2019). Hydropower. [Online] Available at: https://www.irena.org/hydropower

[44] Greenmatch.co.uk. (2019). All You Need to Know about the Solar Panels | GreenMatch. [Online] Available at: https://www.greenmatch.co.uk/blog/2016/02/information-on-solar-panels

[45] Energy Informative. (2019). Which Solar Panel Type is Best? Mono-, Polycrystalline or Thin Film?. [Online] Available at: https://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/

[46] Union of Concerned Scientists. (2019). Rooftop Solar Panels: Benefits, Costs, and Smart Policies. [Online] Available at: https://www.ucsusa.org/clean-energy/renewable-energy/rooftop-solar-panels-benefits-costs-policies

[47] Energy Informative. (2019). Which Solar Panel Type is Best? Mono-, Polycrystalline or Thin Film?. [Online] Available at: https://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/

[48] Alternative Energy Tutorials. (2019). The 7 Components of Your Solar Power System. [Online] Available at: http://www.alternative-energy-tutorials.com/energy-articles/7-components-of-your-solar-power-system.html

[49] Cleanenergyauthority.com. (2019). Components of A Residential Solar Electric System | Cleanenergyauthority.com. [Online] Available at: https://www.cleanenergyauthority.com/solar-energy-resources/components-of-a-residential-solar-electric-system

[50] Express, T. (2019). Trend in renewable energy use in Bangladesh. The Financial Express. Available at: https://thefinancialexpress.com.bd/special-issues/power-energy/trend-in-renewable-energy-use-in-bangladesh-1504082323

[51] Somiron Mistry ,Thesis paper "PROSPECT OF SOLAR ENERGY USE IN BANGLADESH", Dept. Mech. Eng. (BUET) 2009.

[52] Iberglobal.com. (2019). [online] Available at: http://www.iberglobal.com/files/2018/renewable_trends.pdf

[53] Dhaka Tribune. (2019). Three wind power plants with 150MW capacity by 2021. [Online] Available at: https://www.dhakatribune.com/business/2019/03/20/three-wind-power-plants-with-150mw-capacity-by-2021

[54] https://www.accuweather.com/en/bd/bangladesh-weather

[55] Google Map

[56] Private sector now a major player in power generation | theindependentbd.com. (2019). Private sector now a major player in power generation. [Online] Available at: http://m.theindependentbd.com/post/176937