الجامعـــة الإسلاميـــة للتكنولوجيا
UNIVERSITE ISLAMIQUE DE TECHNOLOGIE
ISLAMIC UNIVERSITY OF TECHNOLOGY
DHAKA, BANGLADESH
ORGANISATION OF ISLAMIC COOPERATION

"Techno-economic assessment of a stand-alone solar photovoltaic system at IUT campus"

A thesis submitted to the department of mechanical and chemical Engineering (MCE), Islamic University of Technology (IUT), in the partial fulfillment of the requirement for diploma in mechanical engineering.

Prepared By:

SOIBAHADINE MOHAMED THANI (141301)

SAIDOU MAMADOU DAVID (141314)

ABDIRAZAK ABDALLAH (141316)

Supervised By: Md.Mustafizur Rahman

(Lecturer MCE department)

Department of Mechanical and Chemical Engineering

Islamic University of Technology

CERTIFICATE OF RESEARCH:

The thesis title submitted by SOIBAHADINE MOHAMEDTHANI (141301), SAIDOU MAMADOU DAVID (141314),ABDIRAZAK ABDALLAH (141316)

"Techno-economic assessment of a stand-alone solar photovoltaic system at IUT campus", has been accepted as satisfactory in partial fulfillment of the requirement for Diploma in mechanical Engineering.

Signature of the Supervisor

Mr.Md.MustafizurRahman

(Lecturer MCE Department)

Department of Mechanical and Chemical Engineering

Approved by

Prof.Dr.Md.N.A.Chowhdury

Head, Department of MCE, IUT

CANDIDAT’S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the Candidates

____________________ ____________________

Soibahadine Mohamedthani **Saidou Mamadou David**

Student ID: 141301 **Student ID: 141314**

____

Abdirazak Abdallah

Student ID: 141316

Signature of the Supervisor

____

Mr.Md.Mustafizur Rahman

(Lecturer, MCE Department)

Islamic university of technology(IUT),OIC

Board Bazar, Gazipur Bangladesh.

Table of Contents

ACKNOWLEDGMENT:

We express our heartiest gratefulness to Almighty Allah for his divine blessings, which made us possible to complete this thesis successfully.

First and foremost, we feel grateful and acknowledge our profound indebtedness to **Mr. Md. Mustafizur Rahman**, Lecturer, Department of Mechanical and chemical engineering, IUT. His endless patience, scholarly guidance, continual encouragement, constant and energetic supervision, constructive criticism, valuable advice at all stage has made it possible to complete this project. We would also like to offer thanks to all who contributed in many ways during the project work. We acknowledge our sincere indebtedness and gratitude to our parents for their love.

We seek excuse for any errors that might be in this report despite of our best effort.

Abstract

Renewable energy resource is considered as clean, it can reduce the emission of greenhouse gases (GHG_s) which become a big concern around the world. Electricity produced using solar energy which is one of the renewable energy sources, can be an attractive from economic and environmental perspective. This study presents a techno-economic assessment by developing a bottom-up data-intensive spread-sheet-based model. The study estimates the electricity produced by a 96.8kW_p stand-alone solar photovoltaic in the south hall residential at Islamic university of technology (IUT) campus.

The unit cost of electricity by solar radiation was found to be \$0.456/kWh with a net present cost of \$267729.42.for the components, batteries were found to be the most expensive of the PV system.

I. Introduction.

Energy is a Measure of the ability of a body or system to do work or produce a change, expressed usually in joules or kilowatt hours (kWh). No activity is possible without energy and its total amount in the universe is fixed. In other words, it cannot be created or destroyed but can only be changed from one type to another. The two basic types of energy are:

- Potential: energy associated with the nature, position, or state (such as chemical energy, electrical energy, nuclear energy).
- Kinetic: energy associated with motion (such as a moving car or a spinning wheel) (1)

1. Why do we need energy?

Energy is very important in today's world. For example, we use different energy sources to generate the electricity we need for our homes, schools, businesses and factories. Electricity powers our TVs, computers, air conditioners, cell phones and washing machines - just to mention a few. We also use energy to run cars, planes, trains, buses and motorcycles. (9)

Energy sources can be categorized as renewable or nonrenewable:

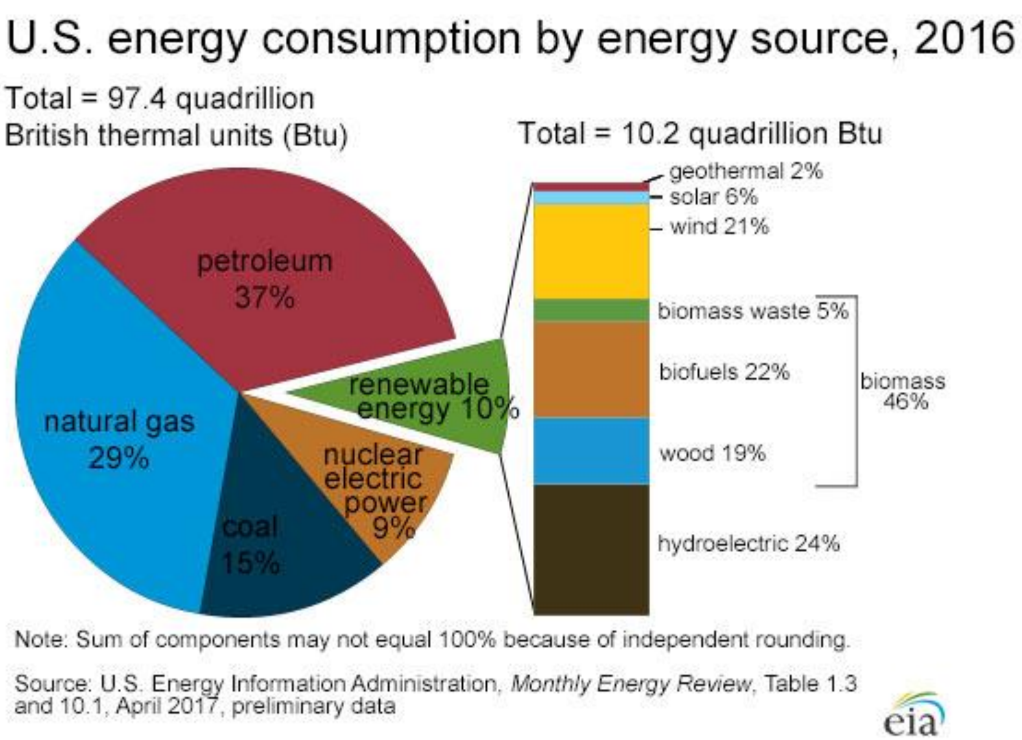
When people use electricity in their homes, the electrical power was probably generated by burning coal, by a nuclear reaction, or by a hydroelectric plant on a river, to name just a few sources. Therefore, coal, nuclear, and hydro are called energy sources. When people fill up a gas tank, the source might be petroleum refined from crude oil or ethanol made by growing and processing corn.

Energy sources are divided into two groups:

- Renewable (an energy source that can be easily replenished)

- Nonrenewable (an energy source that cannot be easily replenished)

Renewable and nonrenewable energy sources can be used as primary energy sources to produce useful energy such as heat or used to produce secondary energy sources such as electricity.



The chart above shows the energy sources used in the United States. Nonrenewable energy sources accounted for about 90% of all energy used. Biomass, which includes wood, biofuels, and biomass waste, is the largest renewable energy source, and it accounted for about half of all renewable e and about 5% of total U.S. energy consumption.(2)

2. What is Renewable Energy?

Renewable energy is energy generated from natural resources—such as sunlight, wind, rain, tides and geothermal heat—which are renewable (naturally replenished). Renewable energy technologies range from solar power, wind power, hydroelectricity/micro hydro, biomass and biofuels for transportation.

Renewable energy is energy that is generated from natural processes that are continuously replenished. This includes sunlight, geothermal heat, wind, tides, water, and various forms of biomass. This energy cannot be exhausted and is constantly renewed.(3)

3. Why is it important to use renewable energy?

Fossil-based fuels (oil, coal, and natural gas) currently provide about 85% of all the energy use both in US and worldwide. We all know that these resources are being constantly depleted and can't be replaced within any practical time span. People often wonder how long exactly would they last. The remaining amount of a particular resource is often characterized by so-called Reserves-to-Production ratio (R/P). In plain language, R/P basically gives us the length of time the reserves would last if their usage continues at the current rate. Here are estimated world total R/P ratios for the main conventional fuels: oil - 46 years, natural gas - 58 years, coal - 118 years. Of course, the usage is constantly changing and once in a while new deposits are found. That's why the above numbers are corrected every year.

Aside from being finite, energy production from fossil fuels results in by-products of combustion, or emissions. These emissions affect our environment and may be causing the climate change. In contrast, renewable energy (RE) resources, as the name implies, are constantly replenished naturally and will never be exhausted.

Their use generally has a much lower environmental impact than that of conventional fuels. That is why the technologies that utilize them are often called "green". (4)

By using renewable energy sources like solar energy, we also reduce our dependence on fossil fuel gas and oil reserves, which are becoming more expensive and difficult to find. It also reduces our dependence on imported fossil fuels, improving our energy security. (5)

4. Solar energy:

Solar energy is a renewable free source of energy that is sustainable and totally inexhaustible, unlike fossil fuels which are finite. It is also a non-polluting source of energy and it does not emit any greenhouse gases when producing electricity. The solar electricity that is produced can supply your entire or partial energy consumption. (6)

Solar energy is the most abundant and promising renewable energy resources with higher potential to gain energy than any other sources.

It can be used in two ways known as thermal route and photovoltaic route.

In thermal route the heat from solar energy is used for various purposes like heating, water purification, power generation, etc.

On the other hand in photovoltaic route the light in solar energy is converted into electricity, which can be used in lighting, pumping and power supply in rural areas where grid electricity is not reachable.

5. Solar photovoltaic:

This technology converts sunlight directly into electricity using photovoltaic (PV) cells. The solar PV cells are combined in panels. They can be put on rooftops, integrated into building designs and vehicles, or installed by the thousands across fields to create large-scale solar power plants.

Fig: A view of Solar panels

6. Solar thermal:

This technology converts sunlight into thermal energy (or heat), which in the past has been used mainly for space heating or to heat water (such as in a solar hot water system). (7)

The main benefit of solar energy is that it does not produce any pollutants and is one of the cleanest sources of energy. It is a renewable source of energy requires low maintenance and is easy to install. The only limitation that solar energy possess is that it cannot be used at night and amount of sunlight that is received on earth is depends on location, time of day, time of year, and weather conditions.

7. Characteristics of solar energy.

1: Solar energy is a completely free source of energy and it is found in abundance. Though the sun is 90 million miles from the earth, it takes less than 10 minutes for light to travel from that much of distance.

2: The earth gets 174 Pet watts of incoming solar radiation in the upper atmosphere. About 30% is reflected back to space and the rest is absorbed by oceans, clouds and land masses.

3: Solar energy is being recognized as the future of alternative energy sources as it is nonpolluting and helps combat the Greenhouse effect on global climate created by use of fossils fuels.

4: Solar energy produce no pollution, have no environmental effects and is ecologically acceptable.

5: Solar energy is one of the most widely used renewable source of energy. One can use renewable energy technologies to convert solar energy into electricity.

6: Solar energy could prove to be the major source of renewable energy because of its massive potential and long-term advantages

7: The earth receives about 1,366 watts of direct solar radiation per square meter.

8: Solar panels are virtually maintenance free since the batteries require no water or other regular service and will last for years. Once, solar panels are installed, there are no recurring costs.

9: Solar power can significantly reduce the electricity bills. Moreover, there are many tax incentives and rebate programs designed to spur the use of solar, and save home owners money at the same time.

10: Solar power is noise pollution free. It has no moving parts, and does not require any additional fuel, other than sunlight, to produce power

11: Though solar energy is used on a wide scale, it only provides a small fraction of the world's energy supply

12: Solar energy is used in many applications including Electricity, Evaporation, Biomass, Heating water and buildings and even for transport.

13: Large investment is one the primary reason why solar energy is not still not used by many people all over the world. (8)

8. Why do we need sustainable solar energy?

The world population is growing and increasing numbers of people aspire to higher standards of living: we need more and more energy and food. We can only do this by producing energy and food in a sustainable way, which means creating less waste and lowering CO_2 emissions. The sun is a source of energy that fulfills these conditions.

The world population has more than doubled in the last 60 years. In 2011 there were 7 billion people on the planet. The United Nations Food and Agriculture

Organization predict that this growth will continue and that in 2050 the population will have reached 9 billion. (10)

And by using solar energy we can fulfill the demand of that population increasing day by day.

There have been a few studies that conduct the techno-economic assessment to generate electricity from renewables for remotely located areas. Most of the studies

Worked on the feasibility of hybrid renewable energy system.

A rural village from the Siyambalanduwa region in Sri Lanka inhabiting approximately 150 households resulting approximate daily electricity demand of 270 kWh has been studied. Several electricity generating technologies including solar, wind and diesel gen sets have been studied and the total net present cost of each system configuration has been calculated for 20 years of lifetime of system to examine the lowest energy cost option. It has been found that the combination of wind turbines, PV system, a battery bank and a diesel generator creates the optimum hybrid system following the rated capacities, wind - 40 kW, PV - 30 kW, battery bank - 222 kWh and the diesel generator - 25 kW. This system can supply electricity at an approximate levelized cost of 0.3$/kWh.[11]

A techno-economical study is done by A.K.M. Sadrul Islam *et al*. [12] for a hybrid combination of PV, Wind and Diesel energy. A set of systems are analyzed to find optimum configuration for 78 kwh day^{-1} primary load. Sensitivity analysis is done to see the effect of solar radiation, PV investment cost, wind speed and Diesel fuel price on the optimum result. Golbarg Rohani and Mutasim Nour [13] have evaluated different combinations of wind turbines, PV, batteries and generators in order to determine the optimal combination of the hybrid system based on the lower Net Present Cost method. The reduction in CO_2 emission achieved in the study for the 500 kW optimal hybrid system was found to be 37% compared to the conventional diesel generator only power system. In [14], Alireza Maheri has designed an optimal standalone wind-PV-diesel hybrid system with cost and reliability as optimizing parameters. In [15], Shafiqur Rehman *et al*. have designed a hybrid wind-PV-diesel system for a village in Saudi Arabia. The designed hybrid power system resulted in avoiding addition of 4976.8 tons of GHG equivalent of CO_2 gas in to the local atmosphere of the village and conservation of 10,824 barrels of fossil fuel annually.

Kusakana and Vermaak [16] studied the feasibility of stand-alone PV and stand-alone wind systems in the rural regions of the Democratic Republic of Congo. The authors found that a stand-alone PV and a stand-alone wind system can satisfy the load demand for the location at the cost of $0.39/kWh and $0.54/kWh, respectively.

There are some studies that conduct techno-economic assessment of hybrid energy systems but study of stand-alone PV system is very limited.

The objective of this study is to design a solar PV system and develop a spread-sheet-based bottom-up data intensive techno-economic model to calculate the cost of electricity, generation using solar energy at IUT campus particularly in south hall.

II. Methodology:

The objective of this study is to design a stand-alone photovoltaic system that can meet the electricity demand for a residentially hall at Islamic university composed by 150 rooms ,30 toilettes and 5 levels. the cost of electricity was also calculated.

The following figure represent the methodology developed for calculating the cost of electricity from solar energy.

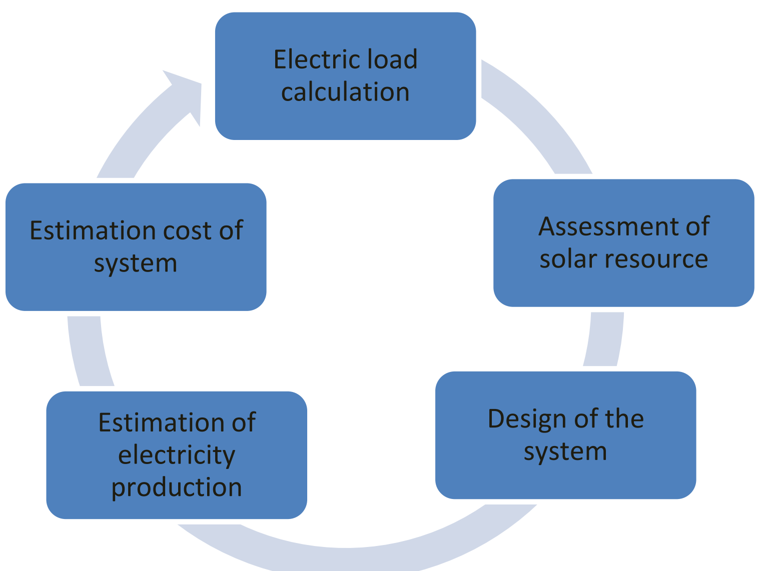


Fig: Techno-economic modeling methodology for this study

The main components of solar PV system are solar PV panel, charge controller, battery and inverter.

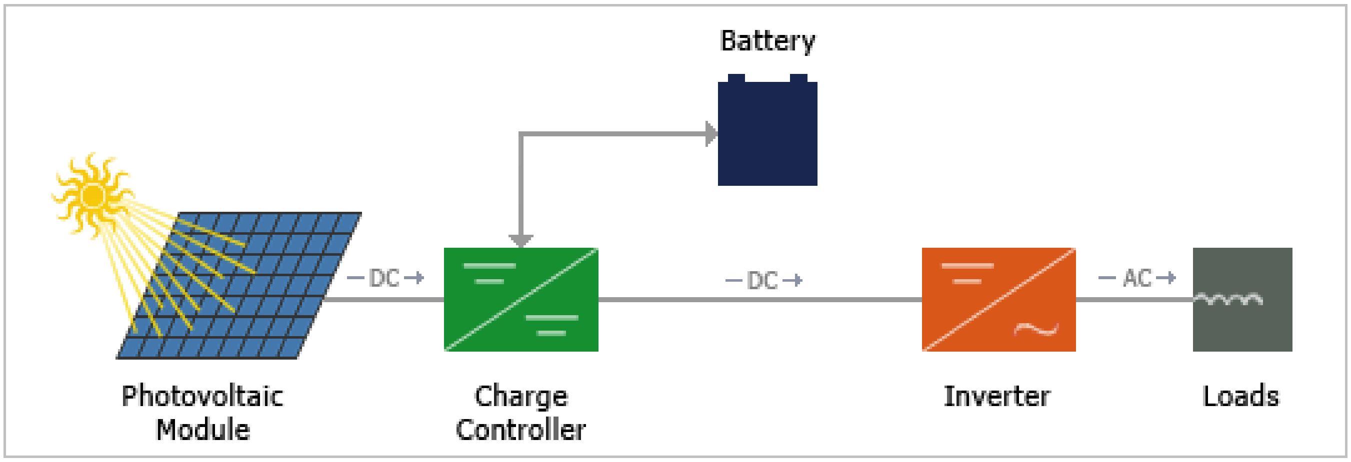
The system boundary is presented in the following figure and shows the scope of research.

Solar PV: Solar cells, also called photovoltaic (PV) cells by scientists, convert sunlight directly into electricity. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the *PV effect.*

Charge controller: A charge controller is an essential part of nearly all power systems that charge batteries, he basic functions of a controller are quite simple. Charge controllers block reverse current and prevent battery overcharge. Some controllers also prevent battery over discharge, protect from electrical overload, and/or display battery status and the flow of power. Let's examine each function individually.

Battery: A battery is an electrochemical cell (or enclosed and protected material) that can be charged electrically to provide a static potential for power or released electrical charge when needed.it is used to store the electricity produced by the solar panels and supply back to the system at night or during a raining day.

Inverter: A solar inverter, or converter or PV inverter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network.



When the panel is exposed to the sunlight, it absorbs and converts the solar radiation to an electric direct current, this electric current will be controlled by the charge controller and then send either to the battery to be stored or to the load by passaging through the inverter where it will be converted from DC to AC.

III. Electric load Calculation:

Islamic university of technology (23° 56' 52" N and 90° 22' 44" E) is a university situated in Gazipur district in Bangladesh. In this study, one hall residential containing 5 levels, each level contains 30 rooms, 6 toilettes, hallway was considered.

Considering that there are 3 students in each room, and 60 % of the students have laptops of 60W (average) and 40% have Desktops of 160W (average).and in each room there are 3 LED tube light of 16, 2 Fans of 24W.The daily operating hours for lighting and for the computer in each room were considered as 6h and 5h respectively irrespective of any season. On the other hand, Fans are used in summer only during 15h.

In the toilettes, considering that ,there are 3 LED tube light of 16 W .The daily operating hours for lighting in each toilette were considered 13h .

Each hallway contains 9 LED bulbs light of 3W, and the daily operating hours were considered 6h. .

To determine the load consuming in the hall , lets first determine the energy consuming in one room , one toilette and one hallway, and then summarized for the hall.

1. Load consuming in one room per day:

Energy of fans (in summer) = number of fan x power consuming by

The fan x daily working hours

= 2 x 24W x 15h

Energy of fans (in summer) = 0.72 kWh /day

Energy of (Desktop & **laptop**) = number of PC x power consuming by one PC x daily working hours

Considering that 60% of the students in south hall are using laptop and 40% are using Desktop,

So the power consuming by the Laptop and Desktop is:

= 3 x (0.6 x 60W+ 0.4 x 160W) x 5h

=1.5 kWh/day

Energy of Desktop & **Laptop** = 1.5 kWh /day

Energy of light = number of light x power consuming by one daily working = 3x 9W x 6h

Energy of light = 0.162 kWh/day

As the fans are used only in summer during 15h per day, the load consuming in one room has to be determine according to the season (summer and winter)

Energy consuming in one room (in summer) = energy of light + energy of Desktop + energy of fans

= 0.162 kWh + 1.5 kWh +0.72 kW

Energy consuming in one room (in summer) = 2.382kWh/day

In winter fans are not used, so the load consuming by the fans will not be included

Energy consuming in one room (winter) = energy for light + energy for Desktop

= 0.162kWh/day + 1.5 kWh /day

Energy consuming in one room (winter) = 1.66 kWh/day

2. Load consuming in one hallway per day:

One hallway contains 9 LED tubes light of 3W, and working during 6hours a day.

Energy for one hallway = number of tube light x power consuming by one tube light x working hours

= 9 x 3W x 6h

Energy for one hallway = 0.162kwh/day

3. Load consuming in one toilette:

One toilette contains 4 LED bulbs light of 3W, and the daily operating hours were considered 13. So the energy consuming in on toilette is:

Energy for one toilette = number light in the toilette x power of each light x daily operating hours

= 4 x 3W x 13h

Energy for one toilette = 0.156 kwh/day

4. Load consuming in one level:

One level contains 30 rooms, 6 toilettes and one hallway, so the load consuming in one level is determined by the following formula.

Load consuming in one level (in summer)= number of room in one level **x** Energy consuming in one room in summer **+** number of toilette in one level **x** Energy consuming in one toilette **+** number of hallway Energy consuming in the hallway

= 30 x2.382 kWh/day **+** 6 x 0.156kwh + 0.162kwh

Load consuming in one level in summer = **72.558kwh/day**

Load consuming in one level in winter = number of room in one level x Energy consuming in one room in winter **+** number of toilette in one level **x** Energy consuming in one toilette **+** number of hallway Energy consuming in the hallway

= 6 x 0.156kwh + 0.162kwh + 30 x 1.66kWh/day

Load consuming in one level in winter =50.898kWh/day

5. Load consuming in the Stairway:

The hall has 6 stairways on witch ,each stairway from level one to level 5 ,contains 4 tubes light of 3W,and the daily operation hours were considered 6. So the load consuming in the stairway by 24 tubes light in the whole building has to be determined using the following formula

Load consuming in the Stairway = number of stairway x number of tube light on each stairway x power consumed by each tube light x daily operating hour

= 6 x 4 x 3W x 6h

Load consuming in the Stairway = 0.432 **kW/day**

6. The total load consuming:

The totally load consumed in the sought hall has to be determined depending to the season, as in winter the fans are not used. In Bangladesh, the summer starts from April to October, and winter from November to March.

The peak energy requirement during summer = load consuming during summer in one level x the number of level + load consuming in the stairway

=5 x 72.558 kwh/day + 0.432 kW/day

The peak energy requirement during summer season =**<u>0.363MWh/day</u>**

The peak energy requirement during Winter = load consuming during Winter in one level x the number of level + load consuming in the stairway

= 5 x 50.898 kWh/day + 0.432 kW/day

The peak energy requirement during winter = **<u>*0.2549*MWh/day</u>**

7. The peak load:

The peak load is the maximum load of electrical power demand. And it is the sum of the power present in the system. Our system contains 2 fans of 24W, 3 Desktops of 160W (average) and 3 LED tube light of 16W for 150 rooms. Also 3 LED tube light of 16W in 30 toilettes. Again 5 hallways where each has 9 LED bulb lights of 3W.

It contains also 6 stairways where each one has 4 LED tubes light of 16W.

- The power of fans = 2 x 150 x 24 = 7.2kW

- The power of Desktop = 3 x 150 x 0.4 x 160 = 28.8kw

- The power of Laptop = 3 x 150 x 0.6 x 60 =16.2 kW

- The power of LED bulb light in the rooms= 3x 150 x 9 = 4.05kW

- The power of the LED bulb light in the toilettes = 4x 3 x 30 =0.36kW

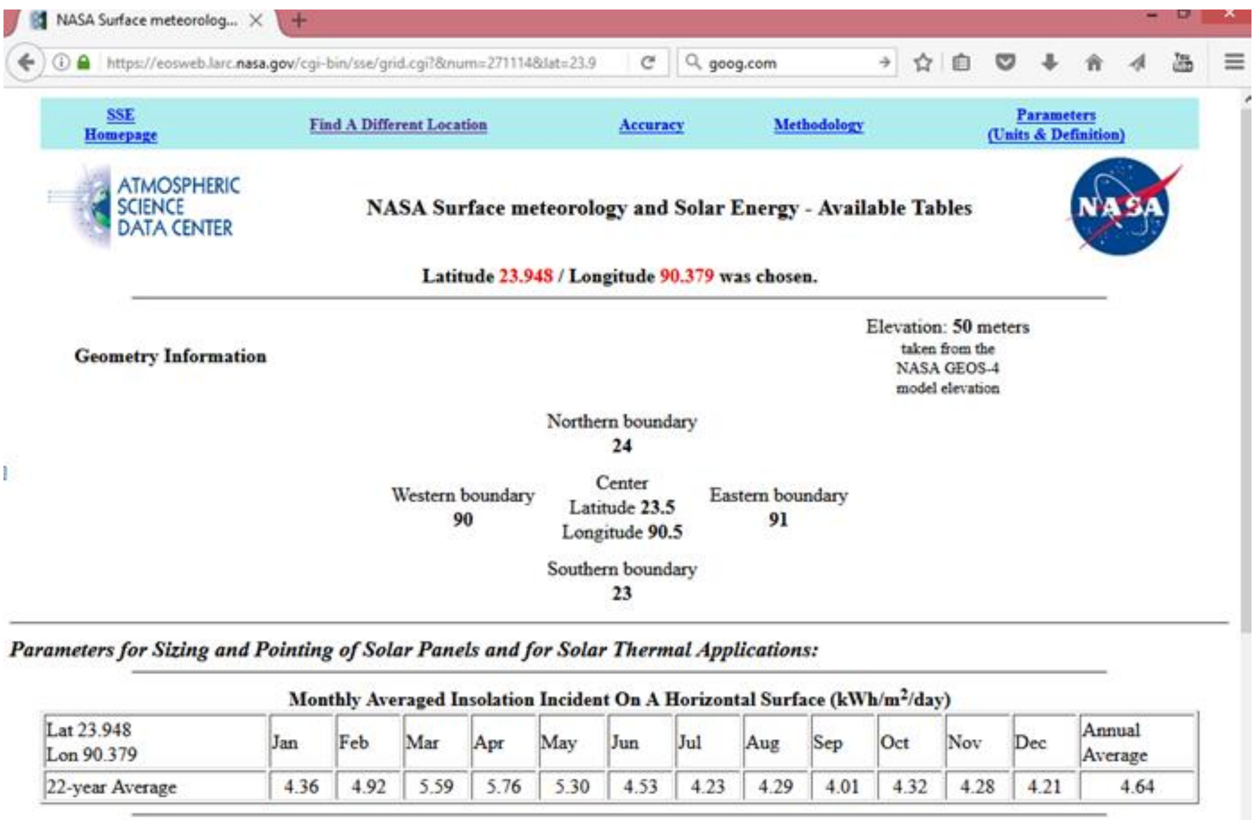
- The power of light in the stairways = 4 x 6 x 3 =0.072kW

- The power light in the hallways = 5 x 9 x 3 = 0.135KW

The peak load = **<u>56.817 kW</u>**

IV. Assessment of solar Resource

The solar radiation data for the location (Islamic university of technology) were obtained from NAZA website [17] based on the latitude and longitude of the location (23° 56' 52'' N and 90° 22' 44'' E). For accuracy, average data for 22 years were used.



NASA Surface meteorolog...

https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?&num=271114&lat=23.9

SSE Homepage | Find A Different Location | Accuracy | Methodology | Parameters (Units & Definition)

ATMOSPHERIC SCIENCE DATA CENTER

NASA Surface meteorology and Solar Energy - Available Tables

Latitude 23.948 / Longitude 90.379 was chosen.

Geometry Information

Elevation: 50 meters taken from the NASA GEOS-4 model elevation

Northern boundary 24

Western boundary 90

Center Latitude 23.5 Longitude 90.5

Eastern boundary 91

Southern boundary 23

Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications:

Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m²/day)

Lat 23.948 Lon 90.379	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	4.36	4.92	5.59	5.76	5.30	4.53	4.23	4.29	4.01	4.32	4.28	4.21	4.64

The average daily solar radiation was taking to be 4.64kWh/m^2/day.

The following figure represents the monthly average solar radiation data for the location (IUT).

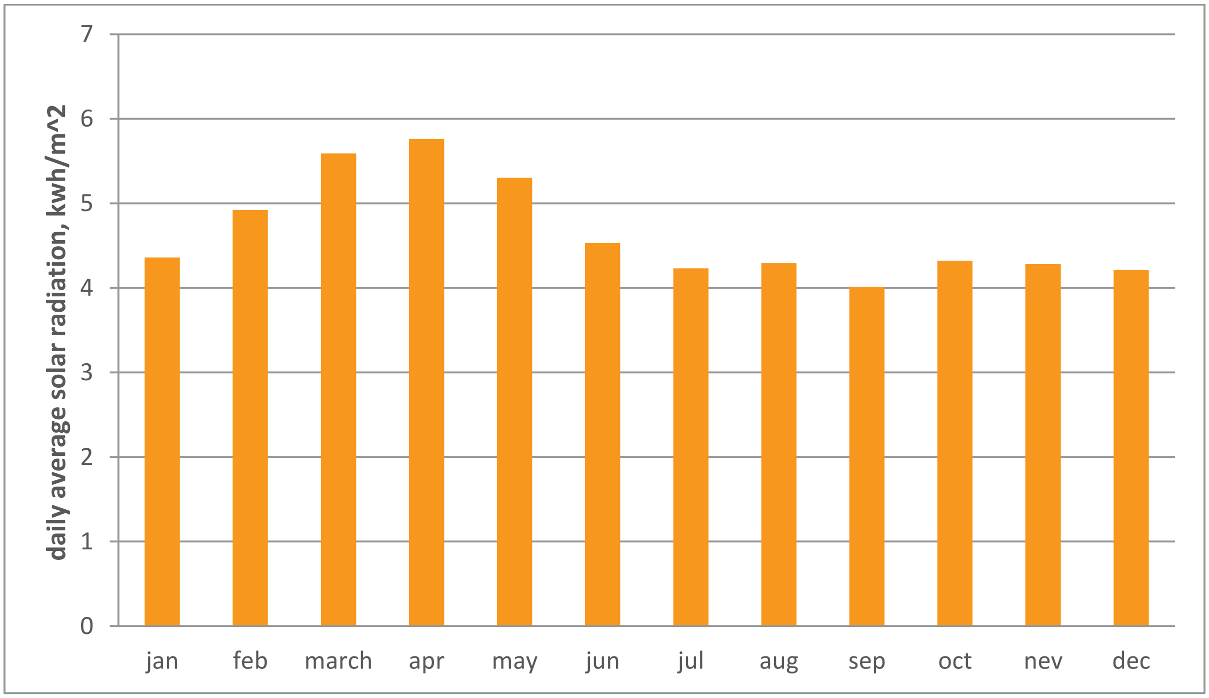


Fig: Monthly average solar radiation

V. Design of the solar photovoltaic (PV) system

1. Number of PV panel

To determine the number of PV panel which will be used to produce the electricity needed, we have to determine the Arrow Size.

Arrow Size:

The arrow size allows us to determine the number of panels, it calculated using the following formula.

Array size (kWp) = [(energy in summer) / (solar hour)] /Derate factor

- **Energy in summer = 0.363 MWh/day**
- **Solar hour per day in Bangladesh = 5h**
- **Derate factor = 75%**

Array size = [(0.363 MWh/day)/ (5h/day)] / 0.75

= 0.0968MWh/day

Array size = 96.8 KWp

- **Number of PV panels:**

The Pv panels choose for the system is the polly-cristyline Suntech for its higher efficiency and low cost. It has a nominal power of 290Wp

1 PV panel → **0.29KWp**

N panels → **96.8 KWp**

Number of panels = 96.8/0.29

Number of panels =334

The system is designed using 334 photo voltaic panels, to produce enough electricity in the system. When there is no solar radiation in a rainy day or at night, batteries are required to store the energy and supply it back to the system.

For cost-effective design of a system appropriate size of battery is important

2. Battery capacity

Battery capacity required for the system was calculated using the following formula:

Battery capacity (Ah) = D x E / (DOD X ηc x V)

Where:

D: the peak electric load (Wh/day)

E: Days of autonomy (days)

DOD: depth of discharge (%)

η_c: efficiency of charging (%)

V: nominal voltage of each battery

A battery **BD-TECH** type open lead acid has been choose to store the energy produced by the photo voltaic panels.

Battery	BD-tech
Type	open lead-acid
Nominal voltage (v)	12
Capacity (Ah)	130
Depth of discharge (%)	80
Charging efficiency (%)	85

The peak electric load D is 56817W and the days of autonomy which are the days that we will not get solar radiation, was considered to be 1. During these days the batteries will have to support and supply electricity in the system.

Battery capacity = 56817 x 1 / (0.8 x 0.85 x 12)

Battery capacity = <u>6962.87 Ah</u>

The number of strings of the system:

1 battery → 130 Ah

Strings → 6962.87Ah

Number of strings = 6962.87/ 130 = 53.6

Number of strings is calculated to be 54.

The system was designed for 1 day of autonomy, 54 batteries strings are required for the system. Each spring will contain 12 lead-acid batteries of 12V.the batteries are connected in series to offer a nominal voltage of 144V.

A charge controller is basically a voltage and/ or current regulator to keep the battery from overcharging, safe , keep it from electrically overload. Some controllers are also prevent battery over discharge .its regulate the voltage and current going to the battery. In our system a Maximum Power Point tracking solar charge controller of 96Am-150V was considered. To overcome the voltage produced by the solar panels, 4 MPPT charge controller are used.

An inverter is required to convert the direct electricity of 144V (DC) from the battery to a utility frequency alternating current (AC) of 220V.

The peak load of our system is 56.817 kW, for 20% of factor of safety the inverter will be designed to be:

56.817+0.2 x 56.817 = 68.18 kW

An inverter of 68.18kW is designed, but for its availability in the market, an inverter of 70kW was considered

3. The electricity produced by the system in one year:

The electricity produced in one year is calculated by using the following formula;

Electricity = Average solar radiation x efficiency of PV panel x efficiency of inverter x area of PV panel

- Average solar radiation = 4.64kWh/m^2/day
- Efficiency of PV panel = 13%
- Efficiency of the inverter = 95%
- Length of PV panel = 1956 mm
- Width of PV panel = 992mm

Area of PV panel = 1.956 x 0.992

= 1.945 m^2

Electricity = 4.64 x 0.13 x 0.95 x 1.94

Electricity = 1.115 kWh/day

Which is the electricity produced by 1 PV panel in one day.

In one year, 334 panels will produced: 1.115 kWh/day x 365days x 334 panels

The electricity produced by 334 panels in one year will be 135.9 MWh/year.

The system will not be able to produce the same amount of electricity each year. Therefor an annual performance reduction of 0.5% was considered.

We have to determine the amount of electricity that the system can generate in each year, compare to 135.9MWh produced at the first time considering 0.5% of performance reduction of the system.

1st year: 135.9 MWh

2nd year: 135.9 – 0.005 x 135.9 = 135.2205 MWh

3th year: 135.2205 -0.005 x 1352205 = 134.544 MWh

4th year: 134.544 – 0.005 x 134.544 = 133.8717

.

.

.

.

20th year: 124.17 – 0.005 x 124.17 = 123.549 MWh

So For 20 years of lifetime the total electricity was estimated to be2592.66MWh.

The above data are plotted in the following figure, which present the electricity produced over 20years lifetime of the PV system with an annual performance reduction of 0.5%.

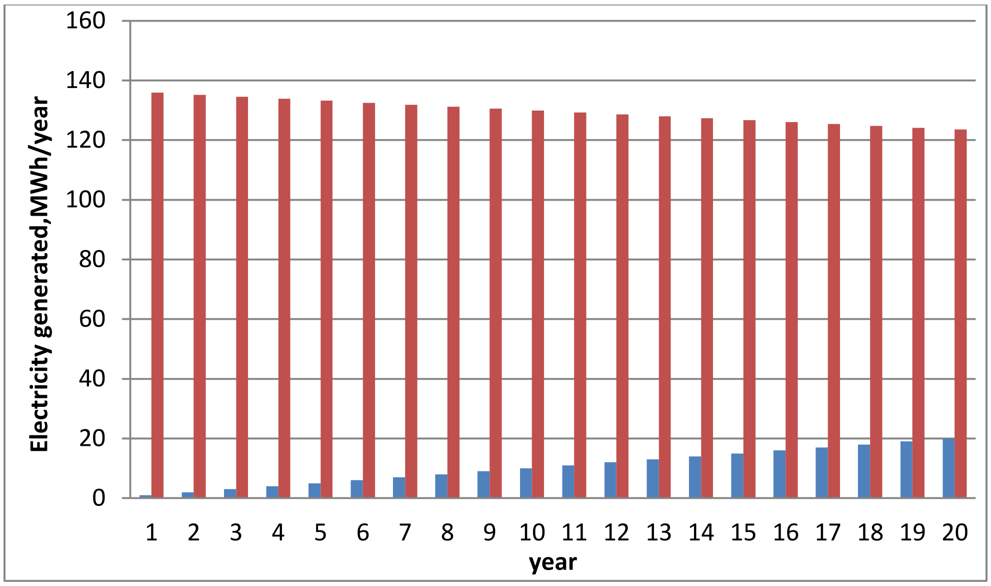


Fig: Estimated energy production during Cycle of the PV system

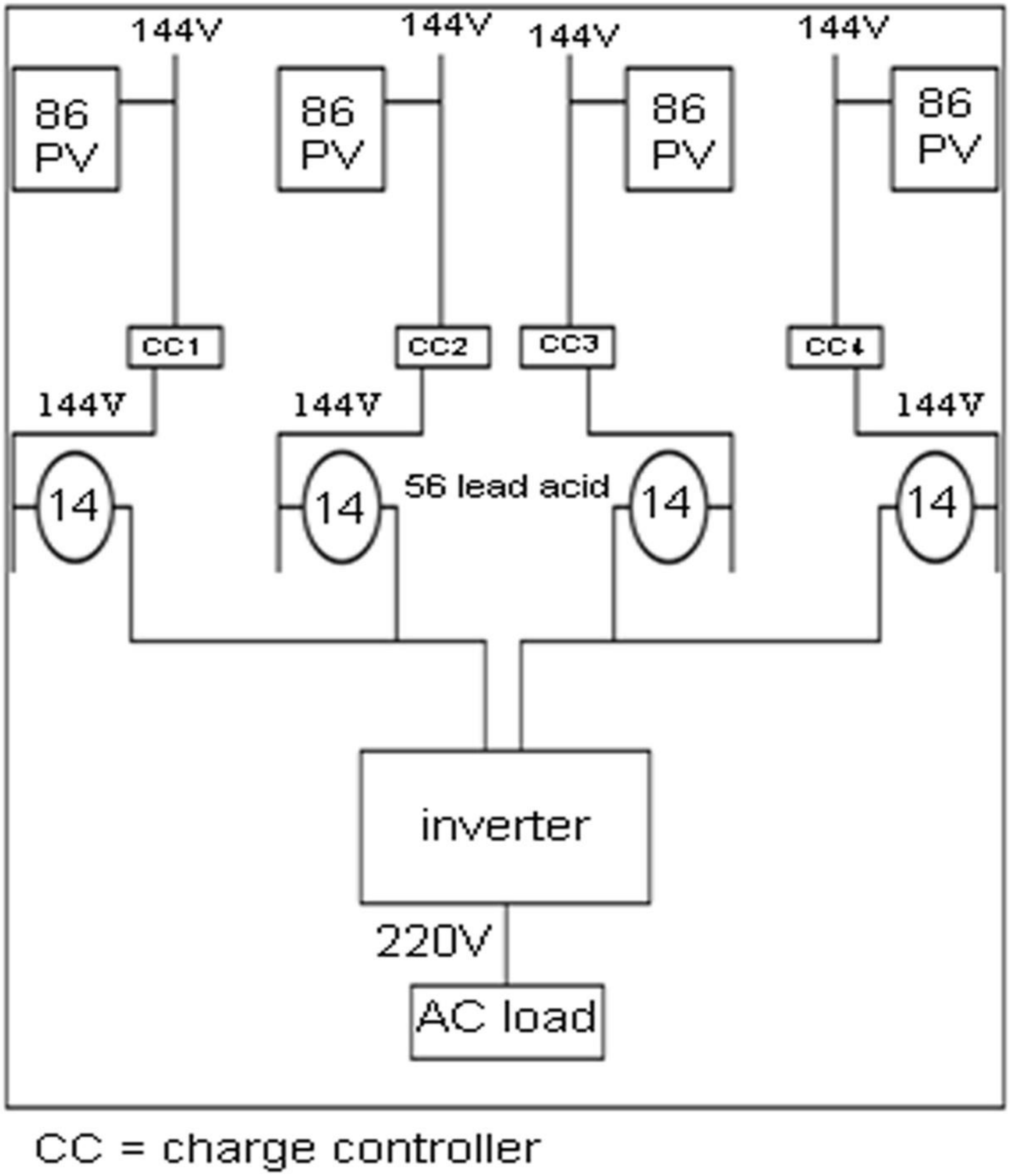


Fig: Circuit diagram of the stand –alone PV system

VI. Techno-economic Assessment:

After designing the different components of the system, a techno-economic assessment was conducted in order to determine the capital cost each components and the cost of electricity of the system.

An interest rate of 10% was assumed .All the capital cost were amortized over the lifetime of the components of the PV system, to determine the annual cost of each components, supporting structure (steel), copper cable testing and installation and the yearly maintenance cost.

Testing and installation cost ,and the yearly maintenance cost were assumed to be 3.75 and 2.00% of the total capital cost respectively.

1. panel:

Interest rate = 10%

Lifetime = 20years

Capital cost = 1.27 $/Wp

The Array size of the system was calculated to be 96.8 kWp.

Capital cost = 1.27 $/year x 96.8 x 1000 Wp = 122936 $

Capital cost = 122936$

The annual cost is calculated by using the interest table, with interest 10% and life time 20 years. The interest factor is 0.117.

10%			Compound Interest Factors						10%
	Single Payment		Uniform Payment Series				Arithmetic Gradient		
n	Compound Amount Factor Find *F* Given *P* *F/P*	Present Worth Factor Find *P* Given *F* *P/F*	Sinking Fund Factor Find *A* Given *F* *A/F*	Capital Recovery Factor Find *A* Given *P* *A/P*	Compound Amount Factor Find *F* Given *A* *F/A*	Present Worth Factor Find *P* Given *A* *P/A*	Gradient Uniform Series Find *A* Given *G* *A/G*	Gradient Present Worth Find *P* Given *G* *P/G*	n
1	1.100	.9091	1.0000	1.1000	1.000	0.909	0	0	**1**
2	1.210	.8264	.4762	.5762	2.100	1.736	0.476	0.826	**2**
3	1.331	.7513	.3021	.4021	3.310	2.487	0.937	2.329	**3**
4	1.464	.6830	.2155	.3155	4.641	3.170	1.381	4.378	**4**
5	1.611	.6209	.1638	.2638	6.105	3.791	1.810	6.862	**5**
6	1.772	.5645	.1296	.2296	7.716	4.355	2.224	9.684	**6**
7	1.949	.5132	.1054	.2054	9.487	4.868	2.622	12.763	**7**
8	2.144	.4665	.0874	.1874	11.436	5.335	3.004	16.029	**8**
9	2.358	.4241	.0736	.1736	13.579	5.759	3.372	19.421	**9**
10	2.594	.3855	.0627	.1627	15.937	6.145	3.725	22.891	**10**
11	2.853	.3505	.0540	.1540	18.531	6.495	4.064	26.396	**11**
12	3.138	.3186	.0468	.1468	21.384	6.814	4.388	29.901	**12**
13	3.452	.2897	.0408	.1408	24.523	7.103	4.699	33.377	**13**
14	3.797	.2633	.0357	.1357	27.975	7.367	4.996	36.801	**14**
15	4.177	.2394	.0315	.1315	31.772	7.606	5.279	40.152	**15**
16	4.595	.2176	.0278	.1278	35.950	7.824	5.549	43.416	**16**
17	5.054	.1978	.0247	.1247	40.545	8.022	5.807	46.582	**17**
18	5.560	.1799	.0219	.1219	45.599	8.201	6.053	49.640	**18**
19	6.116	.1635	.0195	.1195	51.159	8.365	6.286	52.583	**19**
20	6.728	.1486	.0175	.1175	57.275	8.514	6.508	55.407	**20**

The annual cost = 122936 x 0.1175 = 14444.98 $/year

Annual cost of solar panel = $14444.98/year

2. Battery:

Capital cost (a30Ah-12V each)= 155.84$

Lifetime = 4 years

Each battery, the capital cost is 155.84$ /the PV system is composed of 672 batteries.

Capital cost = 672 x 155.84 = 104724.48$

Capital cost = 104724.48 $

The annual capital cost is calculated using the interest table, with 4years lifetime.

The interest factor in this case is 0.3155.

10%	Compound Interest Factors							10%
	Single Payment		Uniform Payment Series				Arithmetic Gradient		
n	Compound Amount Factor Find F Given P F/P	Present Worth Factor Find P Given F P/F	Sinking Fund Factor Find A Given F A/F	Capital Recovery Factor Find A Given P A/P	Compound Amount Factor Find F Given A F/A	Present Worth Factor Find P Given A P/A	Gradient Uniform Series Find A Given G A/G	Gradient Present Worth Find P Given G P/G	n
1	1.100	.9091	1.0000	1.1000	1.000	0.909	0	0	1
2	1.210	.8264	.4762	.5762	2.100	1.736	0.476	0.826	2
3	1.331	.7513	.3021	.4021	3.310	2.487	0.937	2.329	3
4	1.464	.6830	.2155	.3155	4.641	3.170	1.381	4.378	4
5	1.611	.6209	.1638	.2638	6.105	3.791	1.810	6.862	5

The annual cost = 104724.48 x 0.1355 = 33040.57 $/year

Annual cost of batteries = $33040.57/year

3. Inverter:

Lifetime = 10 years

Capital cost =258.23 $/kW

The system is designed to use an inverter of 70 kW.

Capital cost = 70kw x 258.23 $/kw = 18076$

Capital cost of a 70kW inverter = 18076 $

The annual cost was calculated using the interest table ,with 10 years lifetime .the interest factor is 0.1627.

10%	Compound Interest Factors								10%
	Single Payment		Uniform Payment Series				Arithmetic Gradient		
n	Compound Amount Factor Find *F* Given *P* *F/P*	Present Worth Factor Find *P* Given *F* *P/F*	Sinking Fund Factor Find *A* Given *F* *A/F*	Capital Recovery Factor Find *A* Given *P* *A/P*	Compound Amount Factor Find *F* Given *A* *F/A*	Present Worth Factor Find *P* Given *A* *P/A*	Gradient Uniform Series Find *A* Given *G* *A/G*	Gradient Present Worth Find *P* Given *G* *P/G*	n
1	1.100	.9091	1.0000	1.1000	1.000	0.909	0	0	1
2	1.210	.8264	.4762	.5762	2.100	1.736	0.476	0.826	2
3	1.331	.7513	.3021	.4021	3.310	2.487	0.937	2.329	3
4	1.464	.6830	.2155	.3155	4.641	3.170	1.381	4.378	4
5	1.611	.6209	.1638	.2638	6.105	3.791	1.810	6.862	5
6	1.772	.5645	.1296	.2296	7.716	4.355	2.224	9.684	6
7	1.949	.5132	.1054	.2054	9.487	4.868	2.622	12.763	7
8	2.144	.4665	.0874	.1874	11.436	5.335	3.004	16.029	8
9	2.358	.4241	.0736	.1736	13.579	5.759	3.372	19.421	9
10	2.594	.3855	.0627	.1627	15.937	6.145	3.725	22.891	10

The annual cost = 18076.1$ x 0.1627 = 2940.98$/year

The annual cost of an inverter of 70kW = $2940.98 /year

4. Charge controller:

Life time =5 years

Capital cost = 608 $ each controller

4 charges controller were considered.

Capital cost = 608$ x 4 = 2432$

Capital cost of the charge controller = 2432 $

The annual control cost was calculated using the interest table ,with 5 years lifetime. The interest factor for 5 years of lifetime and 10% interest rate is 0.2638.

10%	Compound Interest Factors								10%
	Single Payment		Uniform Payment Series				Arithmetic Gradient		
	Compound Amount Factor Find *F* Given *P*	Present Worth Factor Find *P* Given *F*	Sinking Fund Factor Find *A* Given *F*	Capital Recovery Factor Find *A* Given *P*	Compound Amount Factor Find *F* Given *A*	Present Worth Factor Find *P* Given *A*	Gradient Uniform Series Find *A* Given *G*	Gradient Present Worth Find *P* Given *G*	
n	*F/P*	*P/F*	*A/F*	*A/P*	*F/A*	*P/A*	*A/G*	*P/G*	*n*
1	1.100	.9091	1.0000	1.1000	1.000	0.909	0	0	1
2	1.210	.8264	.4762	.5762	2.100	1.736	0.476	0.826	2
3	1.331	.7513	.3021	.4021	3.310	2.487	0.937	2.329	3
4	1.464	.6830	.2155	.3155	4.641	3.170	1.381	4.378	4
5	1.611	.6209	.1638	.2638	6.105	3.791	1.810	6.862	5

The annual cost = 2432$ x 0.2638 = 641.56$/year

The annual cost of charge controller = $ 641.56/year

5. Supporting structure:

Capital cost = 740.26 $/MT

Lifetime = 20years

Determination of the material required of the system, (562Kg steel for 4.2kWp system).

The Array size of the system is 96.8kWp, so the material requirements of the system = (996.8kWp x 562Kg)/ 4.2kWp = 12952.76Kg

Material requirements = 12.95 MT (Metric ton).

Capital cost of the supporting structure = 740.26 x 12.95 = 9586.36$

Capital cost of the supporting structure = 9586.36$

The annual cost was calculated using the interest table, with 20 years of lifetime, the interest factor is 0.1175

10%				Compound Interest Factors					10%
	Single Payment		Uniform Payment Series				Arithmetic Gradient		
n	Compound Amount Factor Find *F* Given *P* *F/P*	Present Worth Factor Find *P* Given *F* *P/F*	Sinking Fund Factor Find *A* Given *F* *A/F*	Capital Recovery Factor Find *A* Given *P* *A/P*	Compound Amount Factor Find *F* Given *A* *F/A*	Present Worth Factor Find *P* Given *A* *P/A*	Gradient Uniform Series Find *A* Given *G* *A/G*	Gradient Present Worth Find *P* Given *G* *P/G*	n
1	1.100	.9091	1.0000	1.1000	1.000	0.909	0	0	1
2	1.210	.8264	.4762	.5762	2.100	1.736	0.476	0.826	2
3	1.331	.7513	.3021	.4021	3.310	2.487	0.937	2.329	3
4	1.464	.6830	.2155	.3155	4.641	3.170	1.381	4.378	4
5	1.611	.6209	.1638	.2638	6.105	3.791	1.810	6.862	5
6	1.772	.5645	.1296	.2296	7.716	4.355	2.224	9.684	6
7	1.949	.5132	.1054	.2054	9.487	4.868	2.622	12.763	7
8	2.144	.4665	.0874	.1874	11.436	5.335	3.004	16.029	8
9	2.358	.4241	.0736	.1736	13.579	5.759	3.372	19.421	9
10	2.594	.3855	.0627	.1627	15.937	6.145	3.725	22.891	10
11	2.853	.3505	.0540	.1540	18.531	6.495	4.064	26.396	11
12	3.138	.3186	.0468	.1468	21.384	6.814	4.388	29.901	12
13	3.452	.2897	.0408	.1408	24.523	7.103	4.699	33.377	13
14	3.797	.2633	.0357	.1357	27.975	7.367	4.996	36.801	14
15	4.177	.2394	.0315	.1315	31.772	7.606	5.279	40.152	15
16	4.595	.2176	.0278	.1278	35.950	7.824	5.549	43.416	16
17	5.054	.1978	.0247	.1247	40.545	8.022	5.807	46.582	17
18	5.560	.1799	.0219	.1219	45.599	8.201	6.053	49.640	18
19	6.116	.1635	.0195	.1195	51.159	8.365	6.286	52.583	19
20	6.728	.1486	.0175	.1175	57.275	8.514	6.508	55.407	20

The annual cost = 9586.36 x 0.1175 = 1126.4$/year

The annual cost of the supporting structure (steel) = $1126.4/year

6. Copper Cable:

For copper cables:

The capital cost =50.24$/Kwp

Array size =96.8KWp

For 96.8Kwp, the copper cables will be 50.24x96.8= 4863.232$

the life time of copper cables is 20year.

Then the annual cost= 4863.232x0.1175= 571.43$/year.

The annual cost of copper cables= 517.43$/year.

Total capital cost:

The different costs are:

• Solar panels	122936$
• Batteries	104724.48$
• Inverter	18076.1$
• Charges controller	2432$
• Supporting structures steel	9586.36$
• Copper cables	4863.232$

The total cost= summation of the different cost

= 262618.172$

The total cost is 262618.172$

7. Testing and installation cost:

The testing and installation cost was assumed to be 3.75% of the total cost, that is: 262618.172x0.075= 9848.18$

So for 20years lifetime of the system is: 9848.18x0.1175=1157.16$/year

The testing and installation= 1157.16$/year.

8. Yearly maintenance cost:

The yearly maintenance cost also is considered to be 2% of the total cost, that is: 262618.172x0.02= $5252.36/yr

Yearly maintenance cost= $5252.36/yr.

9. Cost of electricity

The electricity cost **COE** ($/KWh) **= A/E**

Where: **A** is the annualized cost of the system ($/year) and **E** is the annual average electricity (KWh/year).

A= 59176.44 $/year

E= 129.633MWh/year

=129633KWh/year

COE=**A/E**=59176.44($/year)/129633(KWh/year)

= 0.456$/KWh

Using a factor of 0.0124 to convert **BDT** to **USD** we will have:

COE= 0.456($/KWh)/0.0124$/1BDT

= 36.81 BDT/KWh

So, the cost of electricity= 36.81 BDT/KWh

VII. Result and Discussion.

A design of a solar photo-voltaic system in IUT campus provides a total capital cost and unit cost of electricity of $267729.42 and $0.465/kwh respectively. The annual average electricity was found to be 129.633MWh/year, not for whole campus but only in south hall residence building. A peak load of 56.81KWp capacity produce by 334 PV panels is required to satisfy the load demand. The cost of PV panels, batteries, charge controllers, inverter, supporting structure, copper cable and testing and installation were estimated to be $122936, $104724.48, $ 2432, $18076, $9586.36, $1126.4, $9848.18, respectively. Testing and installation cost and yearly maintenance cost was assumed to be 3.75% and 2% of the capital cost respectively. For the compensation of the system, the interest rate was assumed to be 10% with an inflation rate of 7.3%.

Table: Annual and capital cost of the various components of the PV system.

parameter	*Life time(year)*	*Annually cost($/year)*	*Capital cost($)*
Solar panel	20	14444.98	122936
Battery	4	33040.57	104724.48
Charge controller	5	641.56	2432
Inverter	10	2940.98	18076
Supporting structure	20	1126.4	9586.36
Copper cable	20	571.43	1126.4
Testing and installation	//	1157.16	9848.18
Total	//	**53923.08**	**267729.42**

From the table above, it can be observe that the total annualized cost of the system was found to be $53923.08. The system can generate 129.633MWh electricity per year.

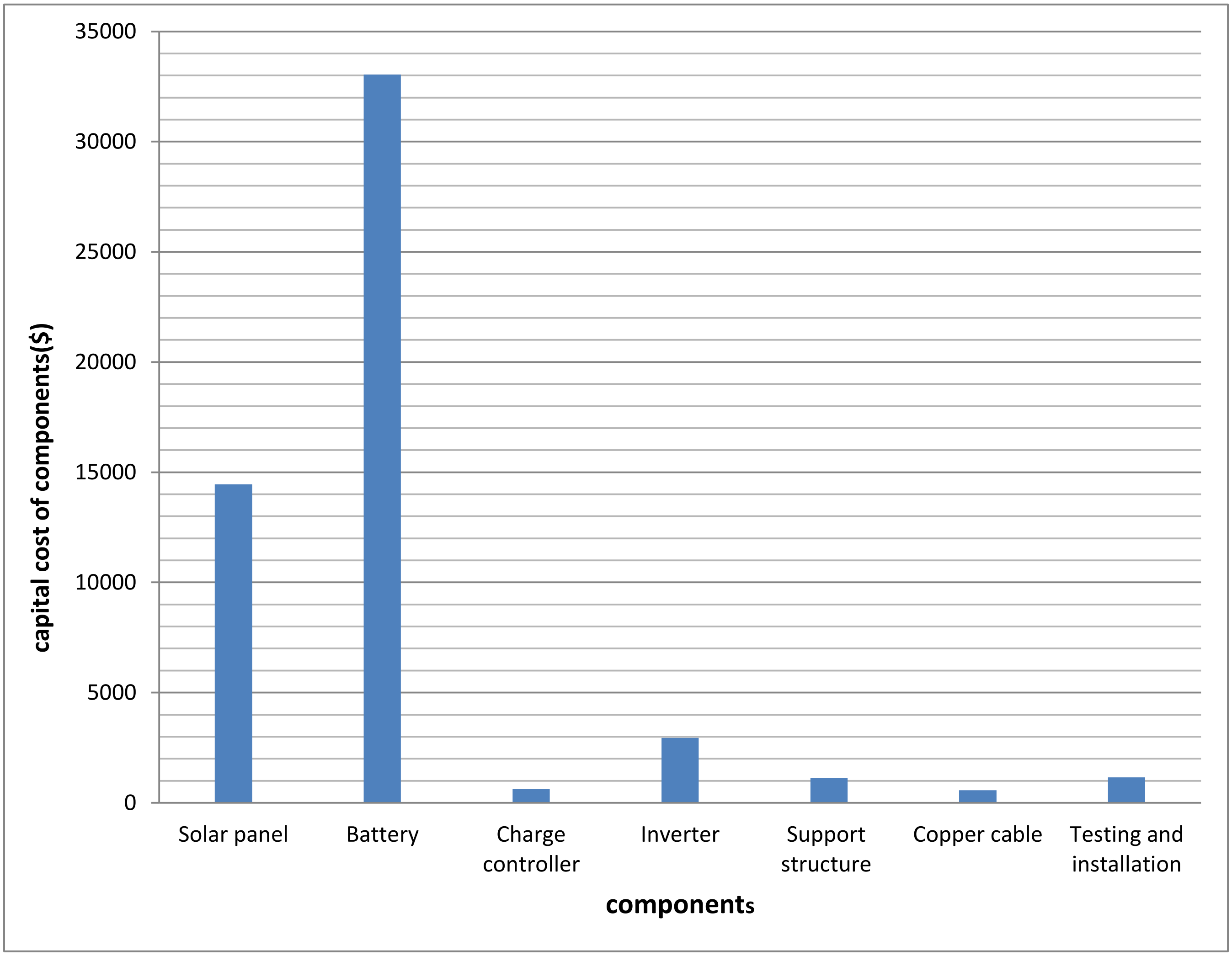


Fig: Capital cost distribution for the solar PV system.

For this system, the most expensive component is battery with a cost of $33040.57/year, this due to its high capital cost and lower life time compare to others components.

The percentage distribution of the components of the PV system to the total annualized cost is shown in figure below.

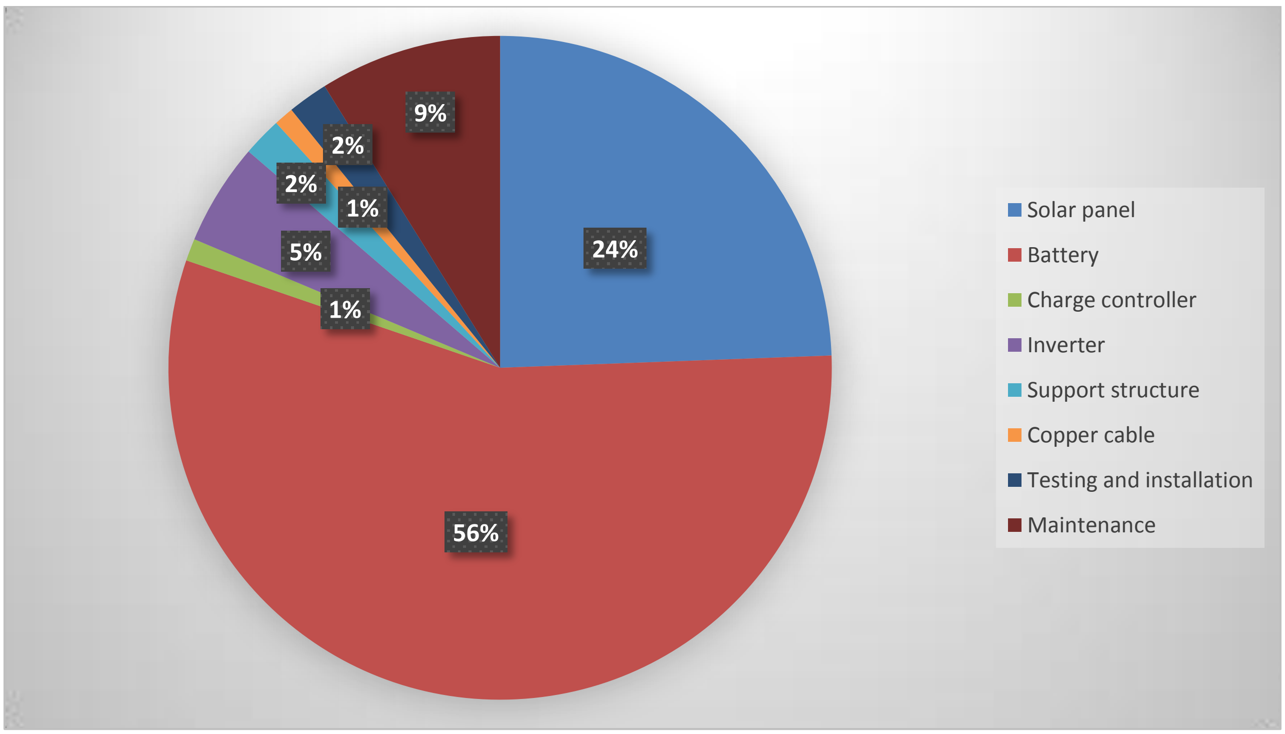


Fig: Percentage contribution of the components to the total annualized cost of the system.

VIII. Conclusion

In this study of the techno-economic assessment of a stand-alone solar photovoltaic system at IUT campus, our objective was to design a PV system for a specific building in the campus (south hall residence). The analysis was based on the different components which are the principles element of the design. So our result clearly confirm that depending on the number of rooms, toilets, hallways and stairways of the whole building requires a maximum load of **56.81KW** which needs **334 PV** panels and result to a total and unit cost of **$267729.42** and **$0.465/year** respectively of electricity. Comparing with the other energy sources, this system does not only improve the natural environment health of the university but will also reduce the recycling cost even though it is more expensive to build the system. In general the system is said to be expensive but it is eco-friendly and comfortable compare to other conventional energy system (eg: fossil fuels: coal, petroleum, and natural gas…) which make it an important tool for the future investigation.

References:

(1) https://www.eia.gov/energyexplained/index.cfm?page=about_home

(2) http://extension.psu.edu/natural-resources/energy/what

(4). http://www.renewable-energysources.com/

5) https://www.uswitch.com/solar-panels/guides/renewable-energy-facts/#step3

(1) 6. http://www. http://www.businessdictionary.com/definition/energy.html

energymatters.com.au/education/

[7]. https://arena.gov.au/about/what-is-renewable-energy/solar-energy/

[8]. http://www.conserve-energy-future.com/various-solar-energy-facts.php

[9]. http://www.dep.pa.gov/Citizens/JustForKids/Energy/Pages/Why.aspx

[10] http://www.biosolarcells.nl/en/zonne-energie/waarom-is-duurzame-zonne-energie-nodig/

[11]**Techno-economic analysis of off-grid hybrid renewable energy system for Sri Lanka**

Available from: http://ieeexplore.ieee.org/document/7069572/

[12] *Sadrul Islama, A.K.M., Mustafizur M.R., Alam, M.H.M, & Firoz, A. (2012). Hybrid energy system for St. Martin Island, Bangladesh: An optimized model, Procedia Engineering, 49, 179–188. DOI: 10.1016/j.proeng.2012.10.126*

[13] Rohani, G. & Nour, M. (2014). Techno-economical analysis of stand-alone hybrid renewable power system for Ras Musherib in United Arab Emirates, Energy, 64, 828–841. DOI: http://dx.doi.org/10.1016/j.energy.2013.10.065 .

CrossRef | Web of Science® Times Cited: 17

[14] *Maheri, A. (2014). Multi-objective design optimisation of standalone hybrid wind-PV-diesel systems under uncertainties, Renewable Energy, 66, 650–661. DOI: http://dx.doi.org/10.1016/j.renene.2014.01.009*

CrossRef | Web of Science® Times Cited: 13

[15] *Shafiqur, R., Mahbub Alam, M., Meyer, J.P., & Al-Hadhrami, L.M. (2012). Feasibility study of a wind-pv-diesel hybrid power system for a village, Renewable Energy, 38, 258–268. DOI:10.1016/j.renene.2011.06.028*

CrossRef | Web of Science® Times Cited: 45

[16] K. Kusakana and H.J. Vermaak, "Hybrid renewable power systems for mobile telephony base stations in developing countries", *Renewable Energy*, vol. 51(0), pp. 419-425, 2013.

[17] NASA Surface Meteorology and Solar Energy. [cited 2017 May 16]; Available from: https://eosweb.larc.nasa.gov/sse/.