Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

Design, Manufacturing & Economic Analysis a Solar PV System for DTU Auditorium

Rohit Kumar
Student of Mechanical Engineering
Delhi Technological University,
Delhi, India

Suraj Kumar
Student of Mechanical Engineering
Delhi Technological University,
Delhi, India

Chander Prakash
Student of Mechanical Engineering
Delhi Technological University,
Delhi, India

Lokesh
Student of Mechanical Engineering
Delhi Technological University,
Delhi, India

Tarun Saxena (Alumni)
MS Energy Management
University of Texas at Dallas,
USA

Dr. J. P. Kesari
Faculty of Mechanical Engineering
Delhi Technological University,
Delhi, India

Abstract - Rooftop solar PV system provides several benefits like being self-reliant in electricity power requirement in a user-friendly manner, insurance against hike in electricity tariff in future, maintaining environmental sustainability, reduction in carbon footprint, utilizing free roof space, etc. The Government of India is encouraging the setting up of the rooftop solar PV system through net metering policy [1]. PV system design should meet the load supply requirements, make system low cost, consider the design of software carefully and prepare the general design in Google SketchUp software before drawing hardware design on the paper. To consider the design of PV system as an example, Paper mentions about the analysis of the design of system software and system hardware, economic benefits, basic ideas, concepts and steps for installation [4]. we have discussed the designing of the rooftop PV system & calculation and how our project helps the peoples and benefits given to the society and environment.

Keywords – Solar PV System; Design Concept; Modeling Methodology; Analytic Study; Future Availability; Renewable Energy; Environmental Friendliness.

INTRODUCTION

A photovoltaic system which is designed to convert solar power from sunlight to useful energy in the form of electricity. It is made up of many components such as solar panel which convert solar radiation into electricity, A solar inverter is a device that is used to convert Direct current to Alternate current as we get the output in form of direct current. As well as rails & splices, clamp & grounding, attachment and other accessories which make a running system. It can be used as a solar tracking system which is increased the overall efficiency of the entire system. The collection of several solar panels creates a solar array which is integrated with each other which makes a system.

PV systems are varied from small to large levels which include rooftop PV system or building-integrated systems which generates few to huge tens of kilowatt (kW) or megawatt (MW). Nowadays, solar PV system use are mostly of on-grid type, whereas off-grid or stand alone are very less used. The PV systems used are environmentally friendly because it has no moving part that's why it works quietly and has no environmental emission. These benefiting features raised the demand in the market for power generation. A rooftop solar system replenishes the cost of investment on the entire system within the 2 to 2.5 years and generates almost 96 percentages of total renewable energy within 25 years lifespan. On account of the hike up in the photovoltaic system, the price of the PV system has decreased suddenly as comparison to the starting of the PV system. However, the cost of the system varies according to the size of the system in the market. The cost of the solar PV system is very less than half of the overall cost of the system, and other costs included such as allowing, customer acquisition, installation labour cost, inspection, and miscellaneous costs. The photovoltaic system is classified in various types like on-grid, off-grid, stand-alone system, and PV based utilities. A solar PV system works as a solar array system for commercial, industrial, and residential. which is made by numbers of solar panels that are connected to each other and make a solar array and these components understand in brief as the Balance of System (BOS). The basic part of BOS are structures for mounting and power conditioning equipment such as an inverter which converts DC to AC current, A solar array which is supported by a racking system, wiring, and other accessories.

The names "solar array" and "PV system" are usually wrong used, in spite of this solar array does not include the whole system. Furthermore, the solar module is also generally used as the synonym of the solar panels.

The low voltage of a single solar cell (such as 0.5V), numbers of cells in series are wired for the producing of "laminate". Making of the solar panels or modules, its sub-parts are laminated and then gathered to make them weatherproof. The numbers of modules together make the PV array. In 2012, the efficiency of solar panels for the customers was up to 17%, although the commercial was up to 27%. It has been estimated that a cell is built which has efficiency reach up to 45%, the scientist assuming that its efficiency could reach 50% or can become more feasible [2].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

DESIGN AND METHODOLOGY

Geographical location of the site

Delhi Technological University (DTU), Delhi, India. It is an engineering college under the MHRD, Government of India. It is one of the largest engineering college's in terms of a number of enrolled students and in terms of the vast area. The total area of campus is 164 acres. The entire campus consists of an administrative and academic building, workshop, Library and community center, Residential accommodation for students and staff general amenities such as health center, bank facility, an auditorium with the capacity of approximately 600 persons and sports complex. DTU is situated geographically at Latitude – 28°44'59.81" North and Longitude – 77°7'1.30" East [3].

Layout of Project Area

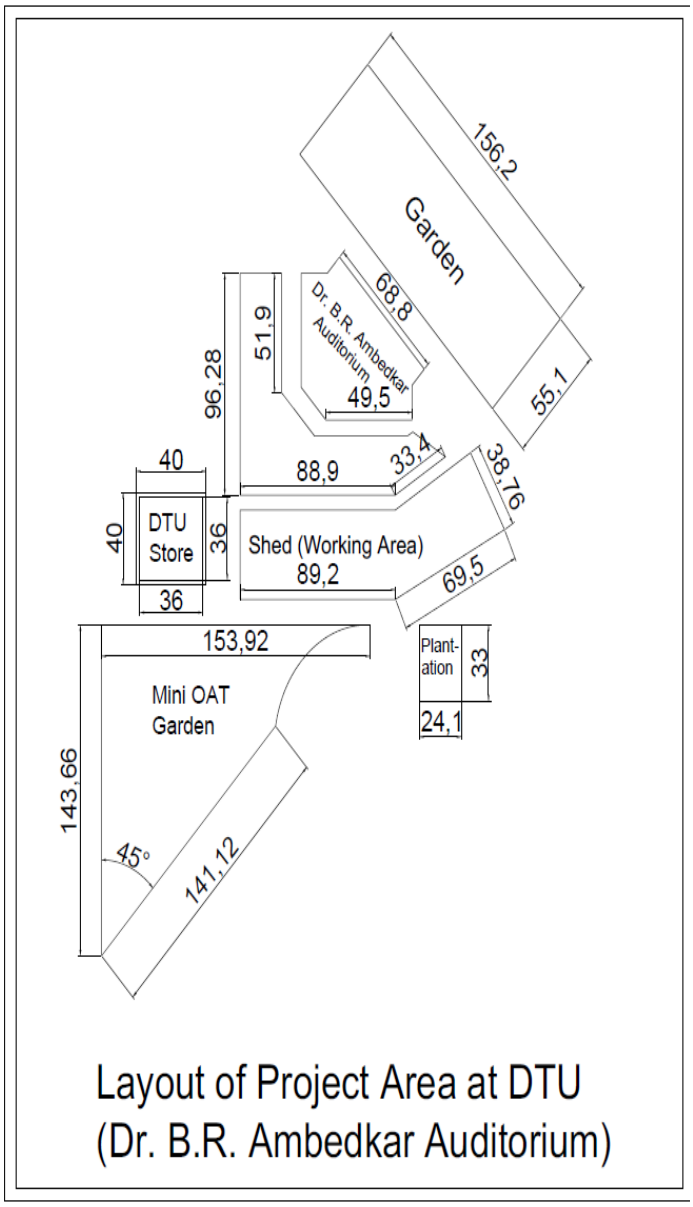

Figure 1: *Layout of Project Area at DTU (Dr. B.R. Ambedkar Auditorium)*

Introduction to Google SketchUp Designing Software

SketchUp is an intuitive 3D modeling application that lets you design and edit 2D and 3D models. Sketchup is the modeling software which is used for various purpose in the field of design like the solar PV system design, interior design (for residential and Industrial), video game design, and architectural, etc. SketchUp has also found a lot of success and popularity amongst solar PV design engineers, assisting them in creating 3D model mockups to assess shading and analyze site data, while seamless using it along with other design software.

How Google SketchUp is different from other 3D designing tools

- Sketchup software is a 3D software that makes the design a very easy manner.
- Learning of this software is easy and can adjust your design according to your comfortability and you will make your design quickly.
- Sketchup has various useful tools that help you to design better in any field like solar system design, architecture, civil, mechanical, etc.
- In this software, there is a tool that names as "Google Earth" which is used for importing the real site from the google map.

STEP BY STEP DESIGN PROCESSES OF PV SOLAR PANEL ON ROOFTOP

1) Adding location using Google Maps:

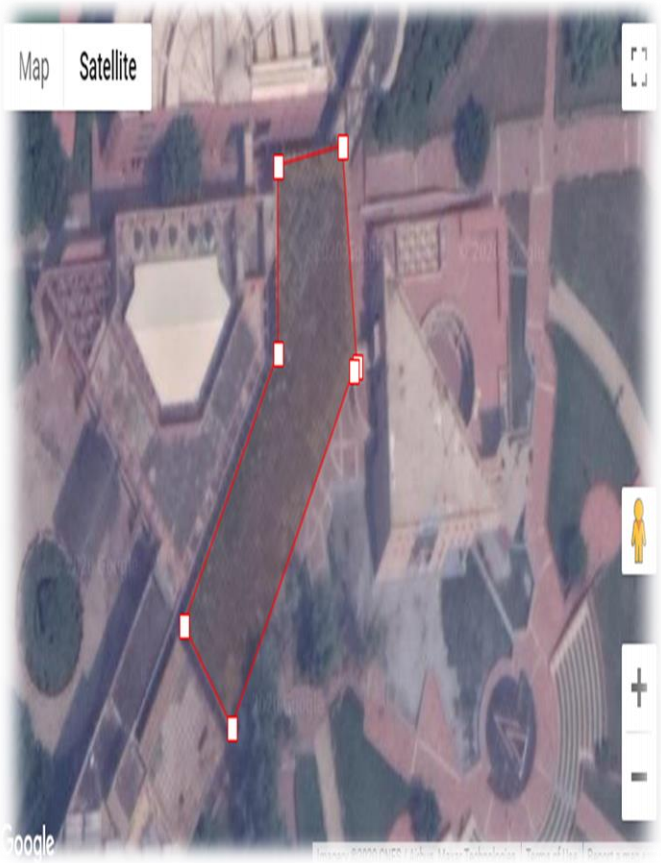

Figure 2: *Dr. B. R. Ambedkar Auditorium (DTU)*
Source: *Google Map (*28°44'59.81" N & 77°7'1.30" E)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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2) How to build a 3D version of any selected site:

Step 1: Getting started: Open SketchUp.

Step 2: Acquire Imagery and location: In this step, firstly use the google earth tool to import the area from the google map where work is to be done. While you can show terrain relief by clicking File>>Geolocation>>show terrain. After importing the image, you can set or place the image according to your design area, and then it can be maximized or minimized resolution of the image as suitable for your design.

Step 3: Navigation: When you are in 3D mode then you can use the scroll button of the mouse to rotate your drawing or image in around. Using the trackwheel you can zoom in and zoom out, and you can also do it by using Orbit. Pan tool is used for the moving of the image or design.

Step 4: Add blank ground layer: If you want to build the design by the image then you can make that part as transparent and then create your drawing using the line tool over the image.

Step 5: And flat features: You can create what you want by using the line tool or import from the "3D warehouse", this feature is also available in the SketchUp software.

Step 6: Add small 3D objects: In 3D warehouse, there are various already created 3D models available like solar panels, trees, cars, lights, humans, buildings, and etc. Which helps to create your drawing very easily.

Step 7: Create buildings and large structures:
If you want to create buildings, use the tool to draw the building model along with google map and using the push/pull tool and extruded.

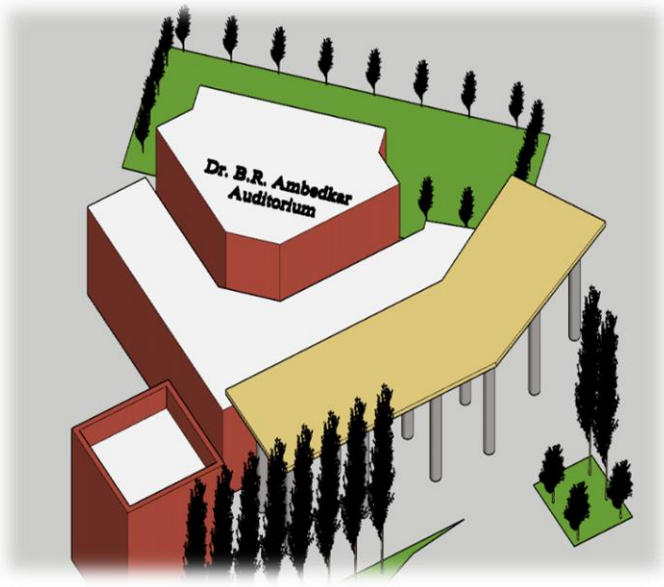

Figure 3: *Dr. B. R. Ambedkar Auditorium (DTU)*

Step 8: Solar Panel Design:

- Just draw a basic rectangle.
- You need to give depth to the module using push/pull tool.
- Now select the module and make it group.
- Using rotate tool to give an angle to the module which is according to the location.
- On the other hand, we take the solar panel from the 3D warehouse browsers.
- We are considering double structured module as per market trend.
- We are making multiple modules in a horizonal row using copy tool and taking distance between one module to another module is 24mm that is known as Solar Array.
- We arranging the solar arrays set on the top of the whole roof while considering the pitch. Which is the distance between first solar array's starting point to another solar array's starting.

Step 9: Solar Panel Installation Made Easy:

i. *Direction of the solar panel face:* For the better strength of the solar system, it is compulsory that the mounting structure should be properly fastened to the rooftop of the residential houses and buildings. This structure (mounting structure) is built up of aluminum material. The right position or direction of the solar panel decides the better efficiency of the solar panel. South is the perfect direction for facing solar panels to absorb huge solar radiation. East and west are good directions. The panel should not be placed in the North direction because India is situated in the Northern Hemisphere so south is the perfect direction for placing solar panels instead of north direction.

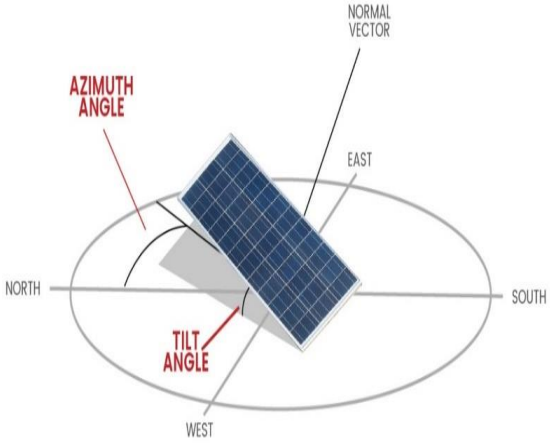

Figure 4: *Tilt Angle*
Source: *KUGA Electrical*

Both monocrystalline and polycrystalline can be attached to the mounting structure of the rooftop solar system. As the function of the mounting structure holds the solar panel.

ii. *Installation of solar panel angle:* The "Tilt Angle" in the solar system is taken between the horizontal ground and the solar panels and it has considered by the latitude of geographical location worldwide. It is basically taken that the tilt angle is equal to the latitude of that location which will generate maximum electricity by the solar system. The solar tracker can be used for optimizing the high

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

efficiency of the system. The latitude angle is 24º – 30º.

a) *Sun Path:* The "sun's path" is the major factor to understand the concept of solar radiation for the designing of the solar electric system. The following term is related to the solar system:

- Shadow Length
- System Performance
- Tilt Angle

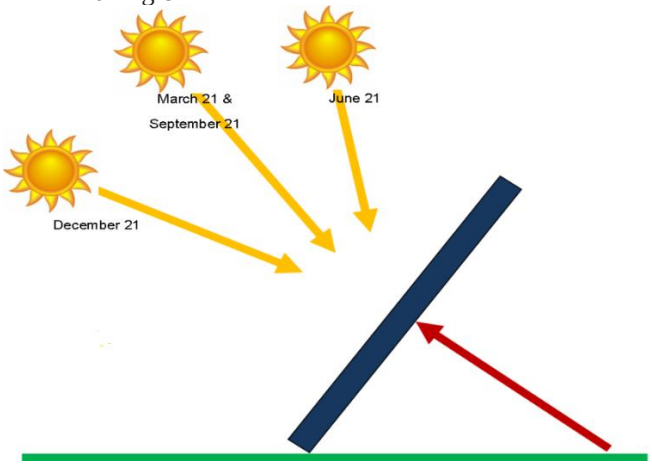

Figure 5: *Sun Path*
Source: *PVeducation*

The path of the sun is generally in the form of an arch in the sky. At the noon, the sun is at the highest peak at their arch. When the latitude at higher the sun will be lower in the sky and then latitude at lower the sun will be higher in the sky.

b) *Solar Azimuth:* Solar Azimuth is the measurement of the tilt angle that shows the direction of tilted solar panels. It measured by taking the reference of North. North is considered as 0 or 360 degrees and the south is 180 degrees.

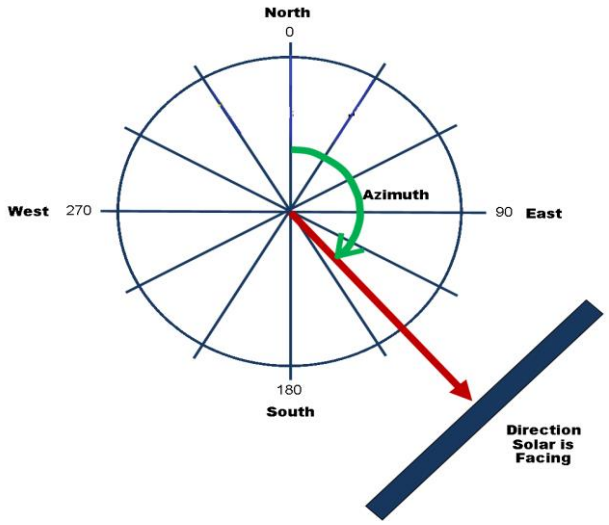

Figure 6: *Azimuth*
Source: *PVeducation*

c) *Roof Pitch and Roof Angle (Degrees):* When designing the solar system must be noted about the tilt angle. During optimizing the solar system performance must be used the tilt angle in degree. When installing the solar system on the roof or ground, it has to keep in mind that the first-row solar panel's shadow should not on the second-row solar panel. If you are thinking about the installation of the solar PV system on your homes or offices that would be neglect the roof pitch in degree.

Step 10: Final installation of Rooftop Solar PV system:

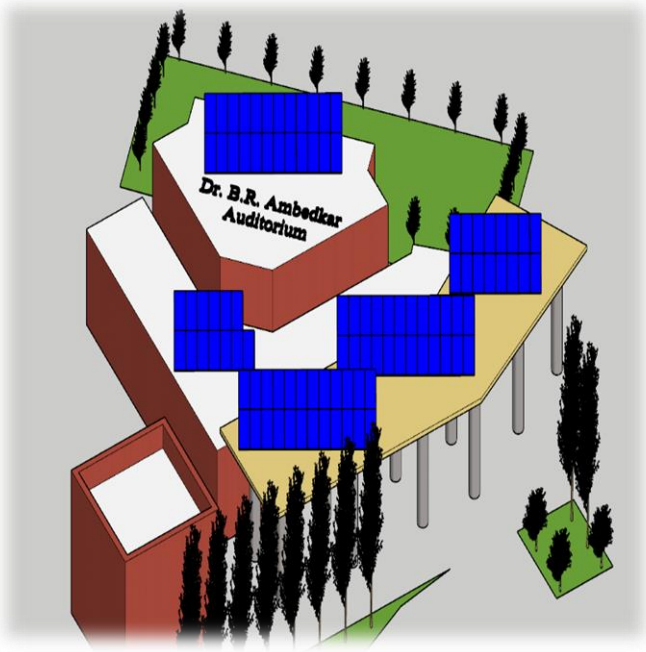

Figure 7: *Dr. B. R. Ambedkar Auditorium (DTU)*

CALCULATION

Following assumption are made for design:

- At max. the total energy requirement of the system is 100kW for 10 hours for 10 days in a month or which implies 120 days in a year.

- **Consumption** = 100kW x 10h x 30 day

  = 30,000 kWh / month

As per the consideration, taken the 10 days in a month or 1/3 of the month,

$$\textbf{Actual Consumption} = \frac{100\text{kW X } 10\text{h X } 30\text{ day}}{3}$$

$$= \frac{30{,}000}{3}$$

$$= \textbf{10,000 kWh}$$

- Output power rating per panel = 330 W
  Energy produced by per panel
  = 330W x 10h x 30 day
  = 99,000 W / month or

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

= **99kW / month**

- **Number of solar panels required**

$$= \frac{\text{actual consumption}}{\text{energy produced by per panel}}$$

$$= \frac{10{,}000\ \text{kW}}{99\ \text{kW}}$$

= 101.01 panel

= **101 panels** (round figure)

- When using 100 hours per month and panels are producing 300 hours per month,

- **PV system size** = total no. of panels x output power rating per panel
  = 101 panel x 330 W
  = 33,330 W or
  = **33.33 kW**

- **Cost of the system:**

1. Cost of Vikram solar panel price starts from Rs.26 per watt for 330 watt is Rs. 8,580. [5]

   Then,
   Total cost of panel = no. of solar panels x cost of each panel
   = 101 panel x 8,580
   = **Rs. 8,66,580**

2. Cost of luminous solar nxi 25 kW on grid solar inverter is **Rs. 1,40,000**. [6]

3. Cost of Solar DC Wire, 4 square mm, 15 Meters Pair is **Rs. 1,800**. [6]

4. Cost of solar edge power optimizer P700 is Rs. 5000 each optimizer [7]

   Total cost of solar power optimizer
   = no. of solar panels x cost of each optimizer
   = 101 panel x 5,000
   = **Rs. 5,05,000**

5. Miscellaneous cost is **Rs. 50,000**.

6. Other material costs are:

7.

Part Name	Quantity	Unit Cost	Total Cost
Rails & Splices			
Iron Ridge XR100 Rail, 14 Feet Black Finish	54	3,440.57	1,85,790.78
XR10 Bonded Splice (incl. Self-tapping Screws)	38	568.69	21,610.22
Clamps & Grounding			
Universal Model Clamp, Black	267	290.24	77,494.08
Stopper Sleeve, 38MM, Black	44	44.90	1,975.6
Grounding Lug, Low Profile	14	572.43	8,014.02
Attachments			
All Tile Hook (Incl. 2 lags)	214	616.97	1,32,031.58
Square-Bolt Bonding Hardware	214	97.23	20,807.22
Accessories			
Kit, End Cap XR10 (10 sets per bag)	2	1,141.12	2,282.24
Microinverter Bonding Hardware, T-Boit	105	123.47	12,964.35
TOTAL			**4,62,970**

Table 1: *Bill of materials*

Total cost of system = total cost of panel + cost of solar inverter + cost of Solar DC Wire + Total cost of solar power optimizer + miscellaneous cost + cost of other materials

= 8,66,580 + 1,40,000 + 1,800 + 5,05,000 + 4,62,970 + 50,000

= **Rs. 20,26,350**

- **Cost of Production (COP)** = PV system size x working hours
  = 33.33 kW x 10h
  = **333.3 kWh** (per day)

- Energy charge of a unit is Rs. 6.5 (according to TPDDL)

COP per day = 333.3 x 6.5
= Rs. 2,166.45

COP per month = 2166.45 x 30
= Rs. 64,993.5

COP per year = 2166.45 x 365
= **Rs. 7,90,754.25**

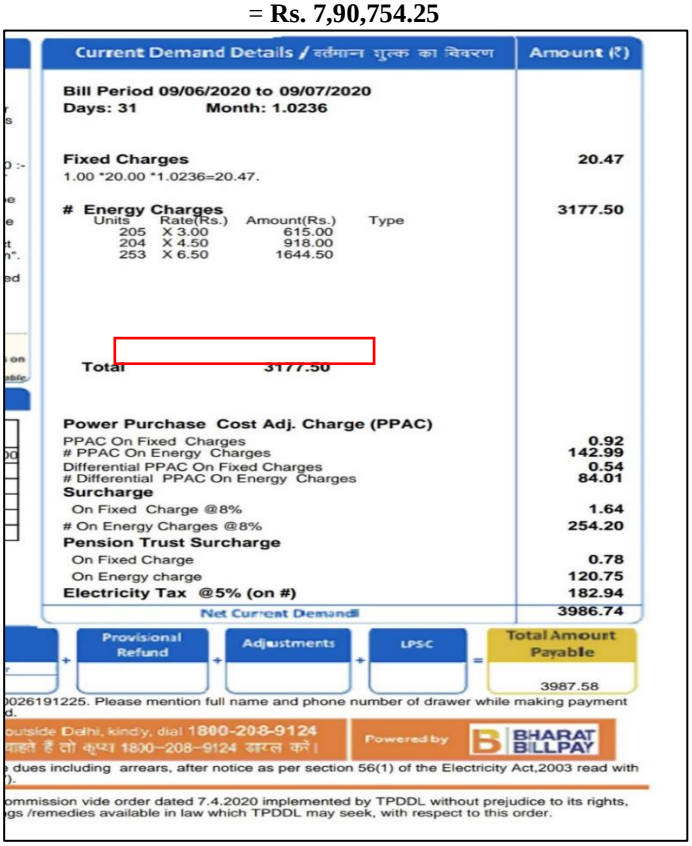

Figure 8: *reference of TPDDL energy charge per unit*
Source: *TPDDL Electricity Bill*

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

- **Payback Period** = $\frac{\text{Total cost of system}}{\text{Cost of Production}}$

$= \frac{20,26,350}{7,90,754.25}$

= **2.56 year or 30 month**

- **System uses per year**

= 100 kW x 10h x 10 days x 12 month

= **1,20,000 kWh per year**

- **System production per year**

= PV system size x working hours x year

= 33.33 kW x 10h x 365 day

= 1,21,654.5 kWh per year

If system size changes, then cost of the panels, no. of optimizer, no. of panels, other materials cost and cost of system will also change.

- **Production of 25 years**:
System production for one year

= 1,21,654.5 kWh per year

System production for 0-5 year = 5 x 1,21,654.5
= **6,08,272.5 kWh**

Years	Duration	Percen-tage	Production (in kWh)
0 – 5	1st Five-year production	100 %	6,08,272.5
6 – 10	2nd Five-year production	92 %	5,59,610.7
11 – 15	3rd Five-year production	85%	5,17,031.625
16 – 20	4th Five-year production	80%	4,86,618
21 – 25	5th Five-year production	80%	4,86,618
TOTAL			**26,58,150.83**

Table 2: *Total Production of 25 year*

- **Total cost of production (COP)**

= Total production of 25 year x Energy charges

= 26,58,150.83 x 6.5

= **Rs. 1,72,77,980.36**

- **Cost of the system production per unit for lifetime**

$= \frac{\text{Total production of 25 year}}{\text{Total cost of system}}$

$= \frac{26,58,150.83}{20,26,350}$

= **Rs. 1.31 (per unit for 25 years)**

- **Return on Investment (ROI)**

= Total cost of production (COP) - Total cost of system

= 1,72,77,980.36 - 20,26,350

= **Rs. 1,52,51,630.36 (for 25 years)**

- **ROI for a year**

$= \frac{\text{Return on Investment}}{25 \text{ year}}$

$= \frac{1,52,51,630.36}{25}$

= **Rs. 6,10,065.22**

BENEFITS TO THE SOC IETY

- Solar technology is used to take advantage of solar radiation to transform into power (electricity) for residential, houses, buildings, and cities. The solar system helps the nation to utilize renewable resources which is available in huge amounts on earth.
- The rooftop solar PV system is a perfect idea for India because of Indian weather, where the proper availability of the sunlight (solar radiation). India is located in a perfect geographical location where sunlight present in huge amounts. There are atleast approximately 300 cloudless days every year. that's why using the rooftop solar PV system is best here.[14]
- This research paper will help the society to understand about what is solar panel, benefits of PV systems, the installation cost of a rooftop solar PV system and also how to maximize profits and how to minimize losses.
- Reliable – In the rooftop solar system contains all parts as fixed, and that is profitable for 25 years. [16]
- Minimal maintenance – The maintenance cost of the solar system is minimum for the consumer. [16]
- Flexible configurations – The solar array can set up on a variety of roofs, like parking areas and also there where the weight of panels bearing by structures. They can generate power (electricity) in various ranges such as from low power (1kW) to a huge amount (1MW or more). [16]

ECONOMIC ANALYSIS

For householders, business holders and society rooftop solar PV increases cost effective. It helps to decrease the cost of technology, innovative financing, and the growing network of solar installers for residential systems.

It found that between 2010 to 2018 installation of PV projects has dropped about 80 percent. It is an analysis by the International Renewable Energy Agency (IRENA). India is a growing economy and in power consumption is only used for increase. Because of this we use an alternate form of energy. It is a way to balance and manage the growth of economic and sustainable development. Starting in 2010, the government has decided to take a step to increase continuous growth in the project. India has become the cheapest producer in a very short time period because of these changes to help the growth of the solar industry economy has reached.

International Journal of Engineering Research & Technology (IJERT)
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In 2010 capacity of solar installed was 10 MW but in 2016 capacity of solar installed is 6000 MW. March 2019 Installation of total solar capacity stands at 30 GW. Growing five times in 3 year. Our target is 100 GW. recently solar only reached 30% of 2022. renewable energy is giving a 38% contribution. The Government of India is encouraging the developer of the solar PV system to hike up day by day. through this system, would get a positive response in the field of solar PV system. Nowadays, Indian consumers are enjoying the installation of a solar power system which gives the result in a profitable manner till 25 years.

Rooftop Solar PV system Capacity and Growth Over the Years:

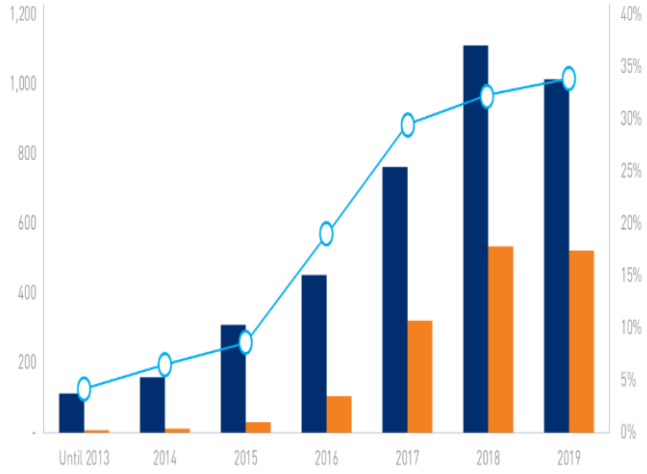

Figure 9: *Growth Over the Year*
Source: *Bridge To India*

The power generation cost by the solar PV system is very low as compared to fossil fuel. It will also save fossil fuel and become economically friendly. On the positive side, has been important Investing and 'learning' is essential to create a positive continuous framework and advance workforce for small scale deployments, also compare the market on New technology. Government of India was giving the subsidy for the installation of rooftop solar PV system which was up to 30%. Now the government has increased it (in case of special category states it is up to 70%). Various factors have contributed to this slow growth including:[18]

- Delivery of subsidy on time.
- Minimum electricity charges for the residential.
- There should be the availability of finance.
- There is problem that occurs in the process and there is also delay in time for taking permission of net metering.
- The consumers do not have sufficient knowledge.
- Policy unpredictability.
- There is fear of money loss in investment that is why there is minimum support.

Progress of Target achieving of 175 GW:

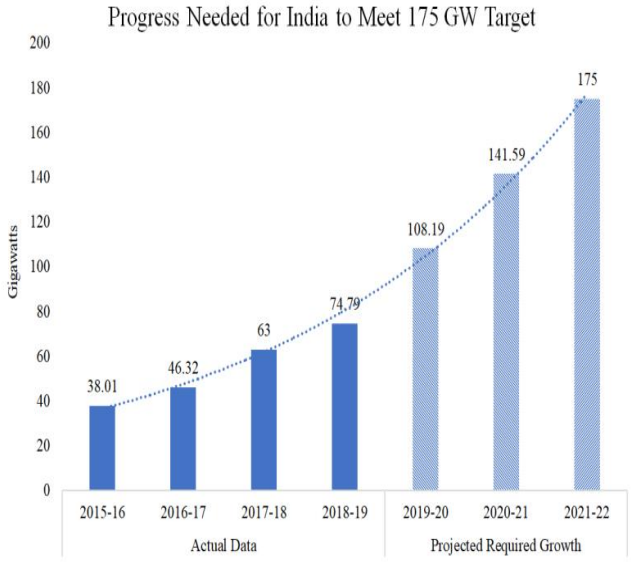

Figure 10: *Progress Needed for India to Meet 175 GW Target*
Source: *cogitASIA, February 27, 2019*

RESULTS AND DISCUSSION

The world is familiar with non-renewable energy resources. The solar photovoltaic systems have been becoming more popular on account of its economic benefits. This can also be used with an inter-grid system with a continuous power supply. It is highly profitable than other resources like renewable or non-renewable. So, it is an alternative source that is the promise and relevant to fulfill the meet high energy demands. Researches on the rooftop solar photovoltaic systems and solar energies are promising to have a future worldwide.

This research paper helps the society to understand the concept of solar panels, benefits of solar panels and the installation cost of a rooftop solar PV system as well as optimize maximum profits and minimize losses. we have considered there is 100 kW system in which actual consumption is 10,000 kWh which is Energy produced is 99kw per month by a single panel. After calculating, we got the number of panels required is 101 panel and the total cost of system installation is Rs. 20,26,350 (including the cost of solar, inverter, wire, no. of the optimizer, miscellaneous and other material costs).

Through calculation analysis, after 2.5 years or 30 months, the cumulative net present worth will become positive. This ensures that after 2.5 years or 30 months, the solar photovoltaic system will start to work in a positive profitable manner and reduce the financial burden. According to the getting results of the overall research, the solar panel lifespan as 25 years. The solar panels setup would be highly profitable as compare to pay in a year. After thinking about all the issues, it is clear that the money invested will be beneficial.

After all calculations, the conclusion comes out that the setup cost of the PV system is high but as of succeeding years it seems less and become profitable. The solar panel has limited life cycle through which the efficiency of system

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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production will decrease every five years which output of total system production is Rs. 26,58,150.83.

As per the comparison between the total cost of production and the total cost of the system, the recovery of investment will be got in positive manner, on the basis of which the cost of energy charge per unit is Rs. 1.31 for the 25 years.

It will be definitely environment friendly and beneficial in economics by setting up the rooftop solar system. Recovery of investment on the rooftop PV system will be within 2.5 years or 30 months, whereas the solar system has a lifespan of 25 years. According to our analysis, the results come in that the solar panels are not efficient after 25 years, because of its total life cycle of 25 years.

It has a high capacity of power generation which is generated annually by the PV system, Its payback period minimum under 2.5 years or 30 months for this system. In a year, the huge amount of sunlight available in Delhi. Whereas in Delhi city, the big problem with the land. So, power generation by the rooftop solar PV system is a good idea for the Delhi state. Global warming is a big issue in the world, DTU will also help to reduce global warming by the installation of a solar PV system. So, DTU is also contributing to achieving the target 175 GW which is set by the Government of India by 2022.

PVWatts Calculator

RESULTS

122,137 kWh/Year*

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Value ($)
January	2.68	6,268	N/A
February	3.70	7,770	N/A
March	5.13	11,677	N/A
April	6.17	13,218	N/A
May	6.37	14,027	N/A
June	5.97	12,794	N/A
July	5.11	11,666	N/A
August	4.98	11,513	N/A
September	4.89	10,868	N/A
October	4.05	9,266	N/A
November	3.14	7,016	N/A
December	2.60	6,053	N/A
Annual	4.57	122,136	0

Location and Station Identification	
Requested Location	110085
Weather Data Source	Lat, Lon: 28.75, 77.15 3.2 mi
Latitude	28.75° N
Longitude	77.15° E

PV System Specifications (Residential)	
DC System Size	100 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	20°
Array Azimuth	315°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

Economics	
Average Retail Electricity Rate	No utility data available

Performance Metrics	
Capacity Factor	13.9%

Figure 11: *System calculated by PV Watts calculator*
Source: *PVwatts Calculator*

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

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