Predicting Solar Potential: A Comprehensive Analysis of On-Grid Rooftop Solar PV System through HelioScope Design

Vivek Kumar Shaw

Dept. of Electrical Engineering, BIET Hyderabad, India

Abstract: This work focuses on designing an MWh generating On-grid Solar PV system installed in Mangalpally, Hyderabad. Regionally, this location receives 5.5 kWh/sq.mts/day of Solar Energy on an average. The main objective of this paper is to designing and simulation of a Solar PV system using a methodology that is capable of analysing the performance in an optimizable way irrespective of the capacity of the PV plant. Such software is HelioScope- a web-based software developed by Folsom Labs. This paper uses HelioScope methodology for simulation for assess and estimate of the Solar Energy Production. The results verify the Solar PV generation of the considered installation area.
Keywords: HelioScope, Folsom, PV, On-grid, Rooftop

I. INTRODUCTION

In today's world, " Solar " has become one of those necessary sources that are generally power for the growing demands and technology. This basic technology that produces electricity by harnessing sunlight has become a vital need and India has reached to the 5th global position for deploying solar power. Out of 370 Gigawatts of installed generated capacity, 35% is acquired from all the renewable sources of energy like solar, wind etc.., in which solar is giving 9.5% i.e., 35 GW of energy. [1] Solar, being such source has grown in many aspects enabling consumers themselves to generate power and feed into the Grid. Such PV systems are called as "On-grid" PV systems. [2] In order to install such PV system, we need to properly select the site and the other equipment that are required to establish an operational Grid-tied PV plant. [3] For that, we would require a software that is capable of taking into account of the geographical location, proper layout, connection diagram and the infrastructure of the installation. Here, we go for Helioscope software. Basically, it is a web-based software that was developed by Folsom Lab. [2] It enables us in designing our desirable On-grid PV system by considering the geographical data i.e., longitude and latitude of the area installation has to be simulated.

By correctly inserting the details of the place of installation, and proper selection of PV panels, inverters and transformers, we can demonstrate the results that forecast the power production of this PV plant. Results like output power, energy into the grid, no. of modules, panels grouping etc prove the specificity of the designed PV system. [3] In easy words, we can say that by using this software we can plan, design and estimate efficiency of an On-grid PV system leading us towards analysing the performance of the system. [4] Previously, they were many software that would evaluate the designing of a PV system. In today's industrial standard, energy estimation has become very important considering the factors like weather changes, shading losses, wiring, panel mismatches, aging etc. But, HelioScope has all the features that aid us in designing a PV system in more detailed manner because it has AutoCad functionality. So, it allows us to complete design in one package. [5]

The Rooftop area selected for Simulation is of Bharat Institute of Engineering and Technology, Mangalpally, Telangana. For proper evaluation proper selection of major components such as PV panels, Inverter and Transformer should be done. As a result after simulation we can obtain ILR (Inverter Load Ratio) that is given as:

$$\text{ILR} = \frac{Nameplate\ of\ DC}{Nameplate\ of\ AC} \qquad \dots(1)$$

The Performance Ratio is given as:

$$\text{PR} = \frac{Energy\ to\ Grid\ (Wh)}{POA\ Irradiance\frac{Wh}{m2} x \frac{DC\ Nameplate(W)}{STC(1000\frac{W}{m2})}} \qquad \dots(2)$$

The primary step to calculate the performance is to find the radiation incident on PV array plane (POA). Factors like Sun position, array orientation, shading, ground surface clearance affects POA radiation.

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Total Solar Resource Fraction (TSRF) analysis shows how much sunlight an area gets in a year. Its like measuring how productive an area is for PV installation. TSRF also checks how shading, the tilt of panels, and their direction affect how much sunlight we get. Under ideal conditions, we get 100% TSRF, which is not possible as we have trees or shading in practical cases. Solar Access, which is part of TSRF can be gives as:

$$TSRF = \frac{TOF}{Solar\ Access} \times 100\% \qquad ....(3)$$

$$Solar\ Access = \frac{haded\ Irradiance}{OA\ Irradiace} \qquad ....(4)$$

Efficiency of the overall system depends on the efficiency of the Solar PV panel. It can be given as the ratio between the output energy of the solar cell to the corresponding solar input in irradiance. We can say that efficiency depends on the spectrum and intensity of the solar light falling on the surface of the panel. That's why, the efficiency must be controlled in order to compare one device with the another.

Solar energy is given as fraction of incident power that is converted into electricity and is written as:

$$P_{max} = V_{OC} \cdot I_{SC} \cdot FF \qquad ....(5)$$

$$\eta = \frac{VOC \cdot ISC \cdot FF}{Pin} \qquad ....(6)$$

The input power of solar panels:

$$P_{in} = I_{Rad} \cdot A \qquad ....(7)$$

While the output of the panel is voltage and current, it can be gives as:

$$P_{out} = V_{PV} \times I_{PV} \qquad ....(8)$$

Average power value during test point is indicated by the equation

$$P_{average} = \frac{P1+P2+P3+\cdots Pn}{n} \qquad ....(9)$$

Row Spacing of the panels can be gives as:

RS = 1.5 x Perpendicular height of 1 row set of panels. ....(10)

HelioScope itself enables us to select the Row Spacing between the connected panels in the inputs section of the simulation. In a way, we can say that HelioScope is an effective software that aids in proper modelling, estimation, controlling of this On-grid Solar PV system.[5]

II. METHODOLOGY

Below Fig 1 shows the methodology flowchart. As HelioScope is a web-based software so we have to open it using a weblink as shown. In simple words, it can be said that this software generates a simulation layout based on the geographical input provided for the simulation.
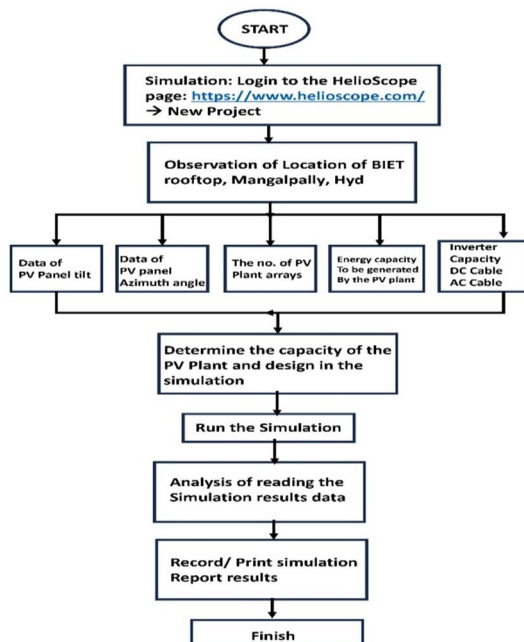

Fig 1 Methodology using HelioScope

At first, we provide details such as location address where we would like to install our Solar PV System in this case BIET is provided with its latitudes and longitudes respectively. Then, by specifying PV module and inverter model; we connect it into 3D layout using SketchUp , it is a free drawing program. On this 3D layout HelioScope performs shading analysis. [5]

Then, after wiring and adding small accessories such as DC and AC distribution boxes we connect AC output into Grid. HelioScope gives us details about panels, inverter and accessories. After running the simulation, final results show us annual and monthly production of irradiance and energy injected to Grid also, number of modules and inverters, Total Power Generation and Performance Ratio of this On-grid PV system. [5]

III. SITE AND SIMULATION DETAILS

A. Site Location

This Rooftop Solar PV System is simulated on BIET, which is situated in Mangalpally village of Ibrahimpatnam Mandal, Ranga Reddy district in Hyderabad, Telangana, India. Geographical parameters of this location are: (17.206668255030873, 78.60094815254752) (GMT 5.5) longitudes and latitudes respectively with an altitude of 18.288 meters.[8]
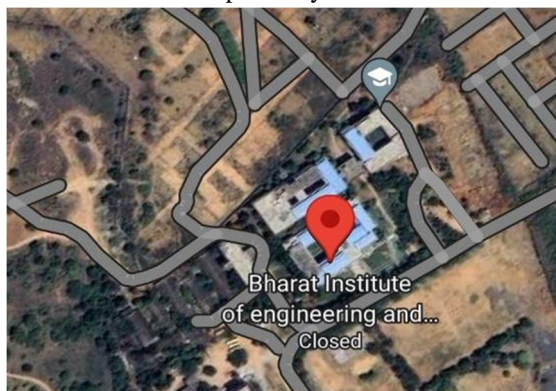
Fig 2 Satellite view of BIET Campus

The Location of BIET usually receives 5.5 kWh/sq.mts/day of Solar Energy on an average that is sufficient enough to design an On-grid Solar PV System.

B. PV Array details

Table 1 shows PV Array details that are used for simulation

Data	Parameter
Name	Soltech, 1 STH-335M
Height (m)	18.288mts
Racking	Fixed Tilt Racking
Azimuth (deg)	180 degrees
Tilt (deg)	20 degrees
Frame Size	3
Width	1
Orientation	Landscape
Row Spacing (m)	2.4384mts
Module Spacing (m)	0.3048mts
Frame Spacing	0
Span/ rise	1.6
GCR	0.50
Setback	1.2192mts
No. of Modules	321
Power Generated	107.5 KWp
Power capacity each module	335 KW
STC	335 W
Vmp	41.5 V
Imp	8.07 A
V_{OC}	49.9 V
I_{SC}	9 A

C. Inverter Details

Table 2 shows Inverter configuration details used for the simulation

Data	Parameter
Name	Delta Electronics, CL 100
Count	2 Nos
DC Nameplate	107.5 kWp
AC Nameplate	200 kWp
DC/AC Ratio	0.54
Maximum AC Power Rating	100 KW
Maximum Input Voltage	900 V
DC SIDE: Home Run	16mm^2 (Copper), 0.1%
Combiner Poles	10
Short Circuit Current	90 A
Stringing Range	12 – 19 modules
AC SIDE: Home Run	95 mm^2 (Copper), 1.1%
AC Panel inputs	1
PCC Home Run	12 AWG (Copper), 56.5%

D. Tranformer Details

Table 3 shows Transformer Details used for simulation

Type	Star-Delta
Inverter Voltage (V)	220 Y/ 127 V
Primary Side	220 Y/ 127 V
Frequency	50 Hz
Efficiency	80 – 90 % BIS Std.
No. of Transformer	1
Insulation Standard	IS: 1180 (Part-1)/2014

E. Input Data for Simulation

The Input Data shown in below table are used for the simulation using HelioScope software.[20]

Table 4 shows Input data for simulation

Data	Parameter
No. of Modules	321 Nos
Frame Size	3 Up and 1 Down
Orientation	Landscape (Horizontal)
Row Spacing	2.4384mts
Module Spacing	0.3048mts
Setback from edges	1.2192mts
Alignment	Central
Tilt angle of module	20 degrees
Keep out entrance	0
Inverter used	Delta Electronics, CL 100
Count of Inverter	2 Nos
Combiner boxes	10
Home runs string	12 AWG (Copper), 56.5%
Combiner string range	12 – 19 strings
Solar generation	107.5 KWp
Stringing	Along racking
Module	Soltech, 1 STH-335M

F. Simulation Design

The considered On-grid rooftop Solar PV system is designed and desktop assessment is done using HelioScope simulation software for BIET campus building. The design is done according to the roof and building as shown below where, whole infrastructure has been divided into 7 parts as named in accordance to their direction from the entrance as shown.[10]
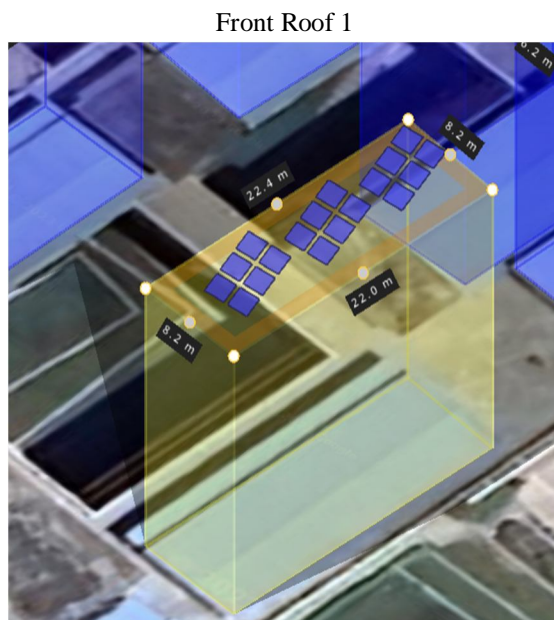
Front Roof 1

Fig 3 Front Roof 1: 18 modules, 6KW generation (named as it is front facing of the building-left to entrance)

It covers area of about 181.9 m^2 to generate power of 6KW.
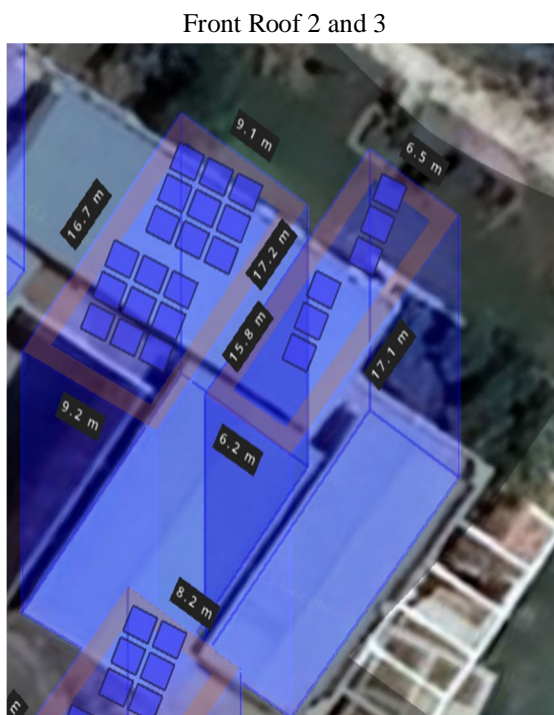
Front Roof 2 and 3

Fig 4 Front Roofs 2 and 3: 6 and 18 modules respectively, Generation of 2 KW and 6KW respectively (The near to front is 2 and back is 3)

Both covers area of about 257.3 m^2 to generate power of 8 KW combined.[15]
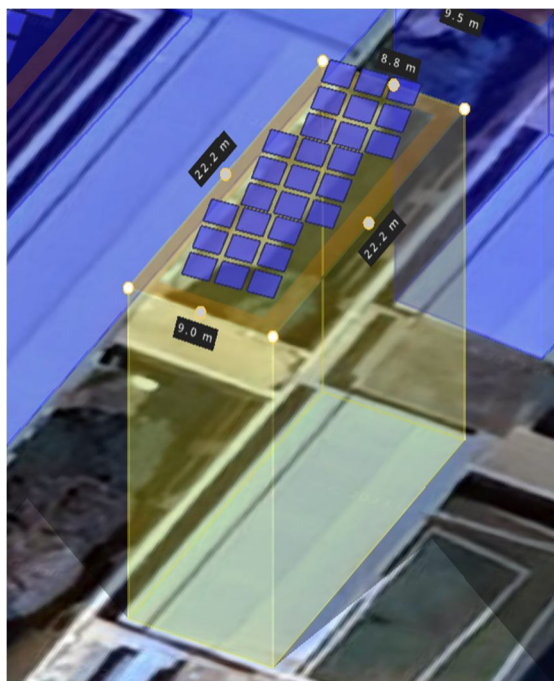
Mid-Roof 1

Fig 5 Mid-Roof 1: 27 modules, 9 KW generation (present in the middle area of the rooftop of whole building)

It covers area of about 196.9 m^2 to generate power of 9 KW.
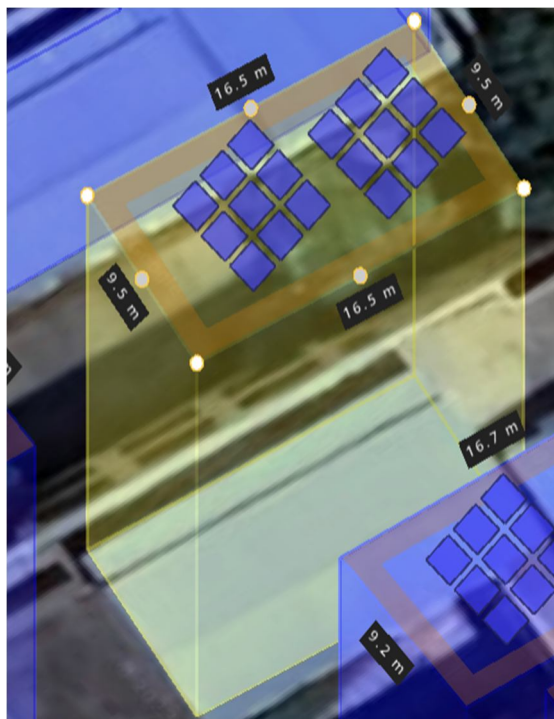
Mid-Roof 2

Fig 6 Mid-Roof 2: 18 modules, 6KW generation (present in the right side of middle are of the rooftop of the building)

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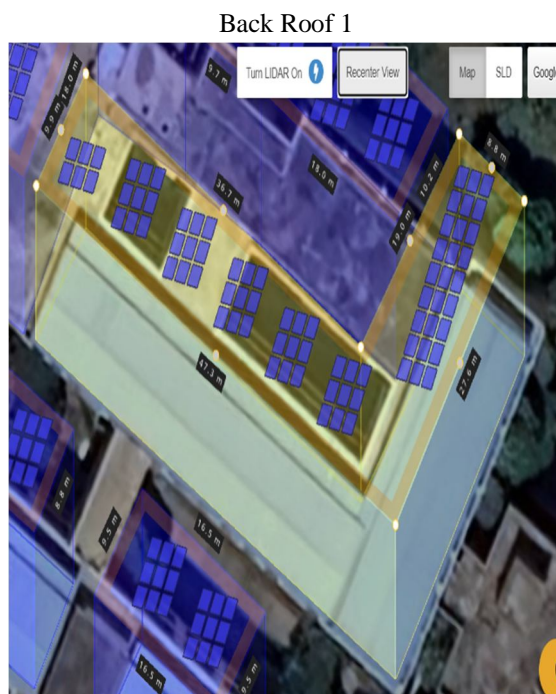It covers an area of about 157.0m^2 to generate power of 6KW.

Back Roof 1

Fig 7 Back Roof 1: 78 modules, 26 KW generation (present in the back side part of the campus building)

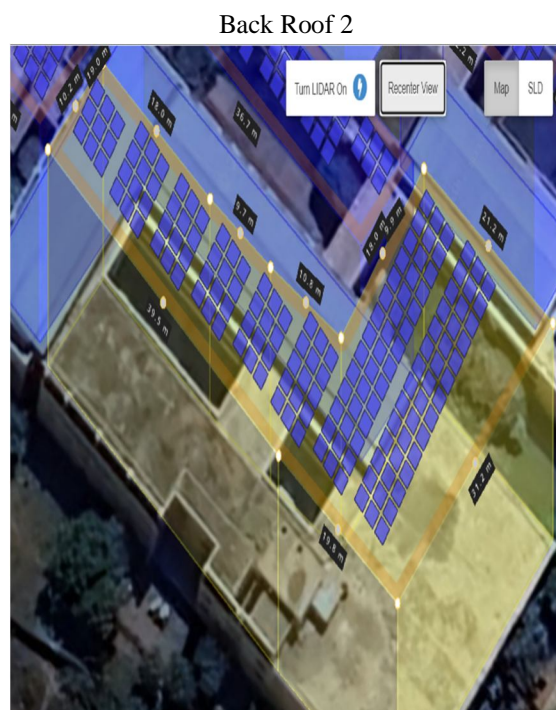It covers an area of about 616m^2 to generate power of 26 KW.

Back Roof 2

Fig 8 Back Roof 2: 156 modules, 52 KW generation (situated in the back end part of the campus building)

It covers an area of about 1,061.5 m^2 to generate power of 52 KW.

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Complete Simulation Diagram of the Campus combining all the Roof Parts

Fig 9 Complete Simulation diagram of the Rooftop Solar PV System using HelioScope .

Table 5 below shows various parts of rooftops with their no. of modules each and generation as per area covered in square metres/metre squares.

Roof	Modules	Generation (KW)	Area (Sq. mts)
Front Roof 1	18	6 KW	181.9
Front Roof 2	6	2 KW	108.5
Front Roof 3	18	6 KW	148.8
Mid-Roof 1	27	9 KW	196.9
Mid-Roof 2	18	6 KW	157.0
Back Roof 1	78	26 KW	616.0
Back Roof 2	156	52 KW	1,0615

Table 6 shows Wire Schedule of ths system

Tire	Wire	Length
AC Run	2 x 12 AWG	423 m
AC Branch	2 x 95 mm^2	216 m
Bus	3 x 16 mm^2	88 m
String	19 x 6 mm^2	1592 m

IV. SIMULATION RESULTS

After simulating the design we can observe that after running the design we are getting all the PV modules operating at safe condition that means our design is safe and efficient as shown in figure below. Colour Green indicates safe and efficient power production from the panels with less losses in the system.[7]
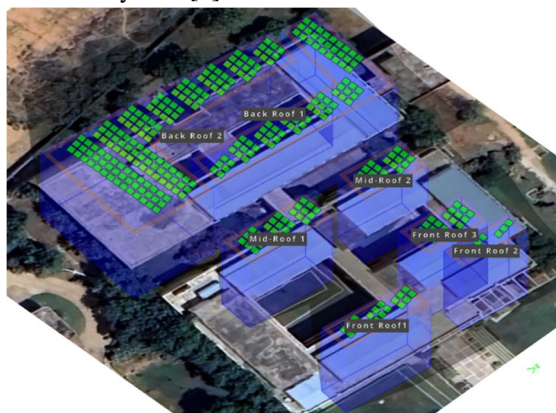

Fig 10 shows Top view from Southeastern angle

Table 7 shows Results obtained from the software simulation.

Data	Parameters
Total Generation Capacity	107.5 KW
Ground Clearance Ratio (GCR)	0.50
Annual Protection	139.6 MWh
Plant Performance Ratio	63.9 %

A. Monthly Production

We can observe that the Energy (KWh) distributed every month (from January to December), with a Total Energy injected into Grid i.e., 139,588.5 KWh.
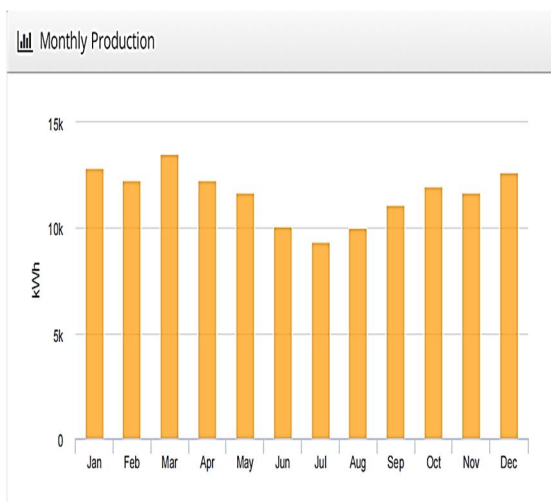

Fig 11 Monthly Production Graph

B. Annual Production

	Description	Output	% Delta
	⚡ Annual Production		
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,921.5	
	POA Irradiance	2,033.7	5.8%
	Shaded Irradiance	2,007.5	-1.3%
	Irradiance after Reflection	1,945.9	-3.1%
	Irradiance after Soiling	1,907.0	-2.0%
	Total Collector Irradiance	**1,906.9**	**0.0%**
Energy (kWh)	Nameplate	205,013.5	
	Output at Irradiance Levels	204,489.9	-0.3%
	Output at Cell Temperature Derate	181,507.1	-11.2%
	Output After Mismatch	176,401.0	-2.8%
	Optimal DC Output	175,438.2	-0.5%
	Constrained DC Output	175,432.7	0.0%
	Inverter Output	166,106.3	-5.3%
	Energy to Grid	**139,588.5**	**-16.0%**
Temperature Metrics			
	Avg. Operating Ambient Temp		29.1 °C
	Avg. Operating Cell Temp		40.0 °C
Simulation Metrics			
	Operating Hours		4617
	Solved Hours		4617

Fig 12 Annual Production

It can be seen that total collector radiation of 1,906.9 KWh/m^2 and an average ambient temperature of 29.1 deg. C and an average operating cell temperature of 40 deg. C are produced as the outputs of the simulation.[12]

C. Solar Access by Months

As we can see that the AC Power in kWh generated is following almost 99% of Solar access. Hence, Gradual AC generation is maintained between 11,730.6 to 12,642 kWh as shown.

Description	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Back Roof 2	98%	99%	99%	98%	98%	98%	98%	98%	98%	98%	98%	98%
Front Roof 1	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%
Mid-Roof 1	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%
Mid-Roof 2	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%
Front Roof 3	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%
Front Roof 2	100%	100%	100%	100%	100%	99%	99%	99%	100%	100%	100%	100%
Back Roof 1	99%	99%	99%	99%	99%	99%	99%	98%	99%	99%	99%	99%
Solar Access, weighted by kWp	98.9%	99.0%	98.9%	98.8%	98.7%	98.4%	98.4%	98.4%	98.6%	98.8%	98.7%	98.8%
AC Power (kWh)	12,845.7	12,323.8	13,510.6	12,324.2	11,730.6	10,080.3	9,330.7	10,022.2	11,094.0	11,964.3	11,720.1	12,642.0

Fig 13 Solar Access from January to December

D. Solar shadow effect losses

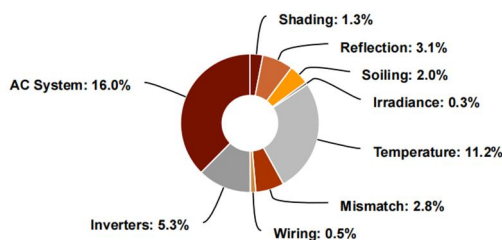In simulated On-grid Solar PV System, estimated losses are shown below.

Fig 14 Solar Shadow effect

Fig 14 represents various system losses for the designed PV system working under tilt angle of 20deg. With azimuth angle of 180 deg. C (South-West). We can observe that, the system losses like AC system inverters, wiring, mismatch, Irradiance, Temperature, Soiling, Reflection, Shading are considered to show Solar PV output.[18]

The energy production potential of the simulation on BIET rooftop for an year is 139.6 MWh with performance ratio of 63.8%. The panels undergo total overall loss of 42.5% based on above figure which is observed. The Potential for Solar irradiation in the Mangalpally area is 5.5 kWh/m^2/day which proves that the design is considerably efficient and potent enough to feed for long term.

V.   CONCLUSION

An On-grid Solar PV system was designed and results were demonstrated that show the operating temperature of solar PV array is the second biggest contributor for system losses with the value of 11.2% whereas, even at high altitude shadow losses are observed to be 1.3% due to shading. But, the first contributor is AC losses occurring due to clipping because PV array is producing more output which is more for two counts of inverters designed in the circuit so unable to handle and inverter is reducing the voltage of AC and reducing the power output. The AC losses observed can be overcome by using one more inverter count in the simulation, this will aid in balancing the DC/AC ratio and will likely reduce AC losses. These are not major as other losses, but still some minor effect is noticeable. Overall, even with some minor effect the designed On-grid PV plant is potent enough and efficient enough to feed into the grid for long term. This analysis has been done using HelioScope software and evaluation proves designed system efficient and reliable that generates 139,588 MWh annually.

APPENDIX

Final outcomes of the simulation of designed On-grid Solar PV System:

Data	Parameter
Total Collector Irradiance	1,906.9 kWh/m^2
Energy (kWh) fed into Grid	139,588.5 kWh
Annual Power Production	139.6 MWh
Performance Ratio	63.8%
Efficiency of Solar PV	56.37%
Losses	43.62%
ILR (Inverter Load Ratio)	0.5375

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