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Design of Solar PV for K.K. Wagh Boy's Hostel

Swapnil Sunil Talele[1], Satya Prakash Parida[2], Gaurav S. Suryavanshi[3]
[1, 2, 3]Department of Mechanical Engineering, K.K.W.I.E.E.R Savitribai Phule Pune University, Nashik, India

Abstract: It is necessary to simulate and investigate the proper feasibility of Solar PV system at a given location. This study is done to evaluate the feasibility of grid connected rooftop solar photovoltaic system for a K.K. Wagh Institute of Engineering Education and Research, Nashik, India. This paper focuses on the aspects of the design involved in the setup of the system, not only just the design, but also the component such as installation, site evaluation of a given rooftop to the final cost analysis. This paper will give the average understanding of how a rooftop photovoltaic system is been processed.
Keywords: Solar PV System, grid, design, installation, site evaluation, cost analysis.

I. INTRODUCTION

Solar Energy is one of the most popular harnessed forms of renewable energy in the globe. Considering its availability in major section of the globe, outrunning other sources such as availability of wind, water resources as well as natural heat producing elements. Sun is the source of inexhaustible energy; emit energy in the form of (light, heat, and electromagnetic radiation). Radiation consists from sun as a result of nuclear fusion reactions which occur deep in the heart of sun. Sun produces heat and light that received to ground to maintain sustainability of life and it loses mass of 4 million tons each second. This mass turns to energy in its three forms. Solar Power System based on photovoltaic arrays that store the excessive energy from Renewable Energy Sources (RES) in the form of electric energy for many applications. The key decision factors for the power management strategies (PMSs) are the level of the power provided by the RES and the state of charge (SOC).

Solar energy as such is a form of energy that can be utilized in the form of either a natural heat source; like the usage in concentrated solar power systems, and the other form being conversion of the light of the sun into electricity, better known as photovoltaics [1]. This paper focuses on the latter, as it is more suitable in a commercial building setup where it would be beneficial to tap in renewable sources, mostly to save the electricity bill, while doing it greener. The solar photovoltaics has a major advantage compared to other forms of renewable power [2], i.e., once it is setup and installed, it produces no pollution during its operation and on top of it releases no harmful green gas emissions.

The best suited system for the Indian scenario would be the rooftop photovoltaic power generation system connected via the local grid, which would be primary focus of this paper. In this paper, there will be a detailed discussion about the process involved in a typical rooftop solar installation in an Indian scenario, involving the steps such as installation site evaluation, preliminary design, required load calculation, precise design, installation and cost estimation.

The major con of this technology in India is the scarcity of available land. The estimated land required for every 40 to 60 MW generation is approximately 1 km^2 [3]. Hence the emergence of solar rooftop systems, which not only generates the required electricity for a building, but also efficiently utilizes the barren area that is of a little productivity [4]. Including both ground and roof-mounted plants, the country's installed solar power capacity was 64.381 GWAC as of 28 February 2023 [5]. Solar electricity generation from April 2022 to March 2023 increased to 101.27 TWh from 73.48 TWh in the same period a year ago [6].

II. PV SYSTEM DESIGN

The sun's radiation is converted into the form of the light by the photovoltaic system into usable electricity. It comprises of the Balance of system components and the solar array.

Any combination of the solar panels, inverters and the hardware needed to flow the energy through the panels are essential for the solar panel systems. The utilization of the string inverters, microinverters or the power optimizers to convert the energy are depended upon the type of the system, but the basic setup of the Solar PV system is almost the same.

On the solar panels, the Solar PV technology is generally employed. The PV cells are connected to each other and are mounted on the frame called as a module. Thus, when these modules come together and wired, they form an array. These arrays can be scaled up and down to produce the amount of the power needed. Solar power plant consists of solar cells, and the devices such as solar inverters, power optimizers, isolators, lightning arrestors earthling plate, distribution boxes, connectors, cables, etc.

A. Solar System Working

1) *Solar Panels:* Absorbs energy from sun and turns it into DC current
2) *Inverter:* Converts DC current into AC current and controls electricity and production
3) *Electric Panel:* Distributes electricity to your home.
4) *Utility Meter:* Excess solar electricity will flow back to the grid through the meter
5) *Utility Grid:* Provides electricity when exceeded the amount produced by solar panels To design the PV System for rooftop, the step-by-step procedure are categorized as follows:

III. SITE DETAILS AND EVALUATION

The primary step for site evaluation is to roughly estimate the required amount of electricity for the whole building as it would give us the carpet area of the rooftop, to allow the designer to calculate rough number of the solar panels required on the building. Then the shadow is determined from the structures such as water tanks or such aesthetics provided for the building to prevent it from falling on the solar panels to maintain the efficiency in the power generation.

Then comes the proper placement of the solar inverter and distribution boxes, so that the DC run is not too long. Hence, an optimum design should be such that the DC cables carrying the output from the panels should not travel long towards a distribution box, but to be short in length and provide a scope for the minimal losses. It also involves the location of meter room for the local grid to provide the suitable spot to attach a net meter and also allows the designer to compute the AC run from the inverter. Normally a grid meter is placed at the ground level of a building structure, hence the site evaluation must incorporate the structure height also, in order to determine the length of cables required to travel from the rooftop to the meter room.

The following are the details of the K.K. Wagh Boys Hostel, Amrutdham, Nashik, India:

1) Longitude: 73.8198°
2) Latitude: 20.0122°
3) Altitude: 600m
4) Time Zone: 5.5

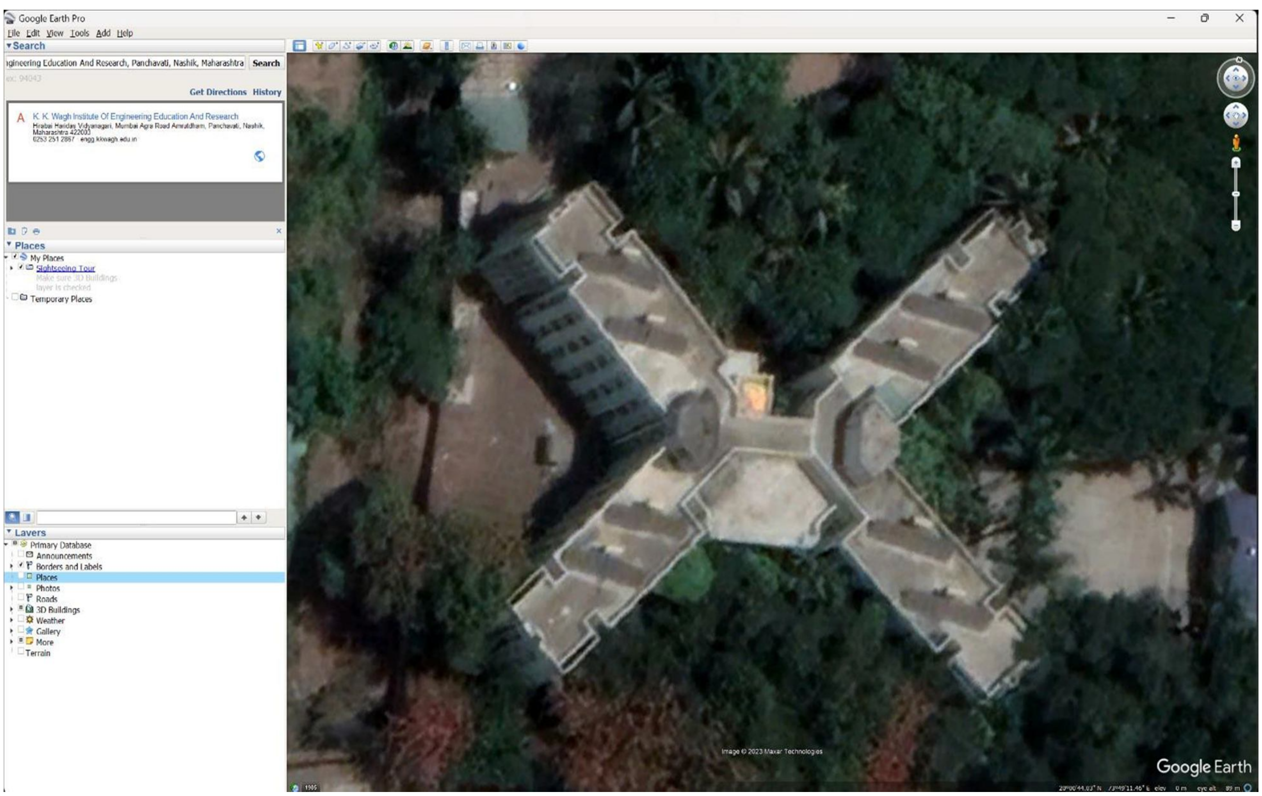

Fig. Site Location

IV. PRELIMINARY DESIGN

After the evaluation of the site, a structure is made by the designer to virtually simulate the building and provide a rough placement of the predetermined solar panel, keeping in consideration the shadows and other such constraints. The types of constraints are such as solar irradiance and also some solar angular values obtained for the coordinate of the rooftop. Then the approximate number of solar panels which are to be mounted on the rooftop is estimated; which is designed to draw the maximum power to be extracted from the panels that would be mounted. This is the pre-sizing step of a project. Its aim is to quickly define the general features of a planned PV system. In this mode the system yield evaluations are performed very quickly in monthly values, using only a very few general system characteristics, without specifying specific system components. A rough cost estimate of the system is also available.

V. DESIGN OF SOLAR PV

Using detailed hourly simulation, performance analysis and PV-System Design are performed thoroughly. Meteorological hourly data and geographical situation are held essentially, they are organized in the framework of the project. Through different simulation runs which are known as variants, optimizations and parameter analysis can be performed.

A. *Project, System and result Summary*

Project summary

Geographical Site		Situation		Project settings	
undefined		Latitude	°S	Albedo	0.20
		Longitude	°W		
		Altitude	m		
		Time zone	UTC		

Meteo data

System summary

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation		Near Shadings	User's needs
Fixed plane		No Shadings	Fixed constant load
Tilt/Azimuth	27 / 0 °		7.50 kW
			Global
			65.7 MWh/Year

System information

PV Array		Inverters	
Nb. of modules	56 units	Nb. of units	1 unit
Pnom total	30.2 kWp	Pnom total	30.0 kWac
		Pnom ratio	1.008

Results summary

Produced Energy	49381 kWh/year	Specific production	1633 kWh/kWp/year	Perf. Ratio PR	82.68 %
Used Energy	65700 kWh/year			Solar Fraction SF	37.82 %

Fig. Summaries

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B. Mateo Values and Sun Path Diagram

Geographical Site
Nashik KKW
India

Situation

Latitude	20.01 °N
Longitude	73.82 °E
Altitude	600 m
Time zone	UTC+5.5

Monthly Meteo Values

Source Meteonorm 8.1 (1996-2015), Sat=100%

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	146.5	157.2	199.4	208.0	211.2	144.0	98.1	108.7	134.0	152.5	143.8	134.7	1838.1	kWh/m²
Horizontal diffuse	42.4	44.1	58.2	68.1	75.4	81.4	73.6	75.1	72.4	68.4	50.3	46.7	756.1	kWh/m²
Extraterrestrial	232.9	240.5	299.9	316.2	338.3	329.5	338.5	330.4	299.8	277.5	233.9	222.2	3459.7	kWh/m²
Clearness Index	0.629	0.654	0.665	0.658	0.624	0.437	0.290	0.329	0.447	0.550	0.615	0.606	0.531	ratio
Ambient Temper.	21.0	24.1	28.2	31.5	32.5	27.9	25.9	25.1	25.4	25.7	23.1	21.1	26.0	°C
Wind Velocity	0.8	1.0	1.2	1.5	2.6	2.8	2.7	2.5	1.6	0.9	0.8	0.8	1.6	m/s

Sun paths

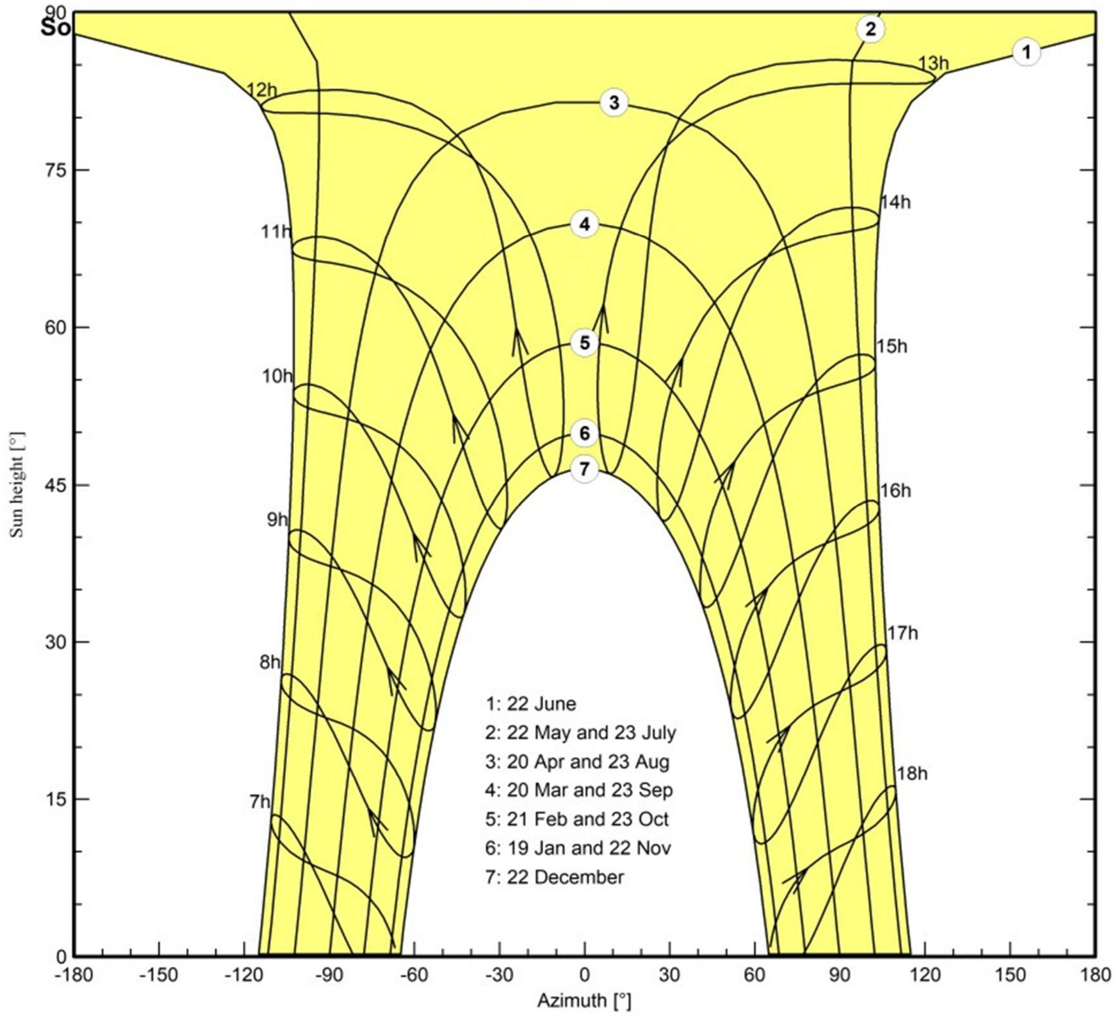

Fig. Mateo Values and Sun Path Diagram

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C. Orientation and Variant

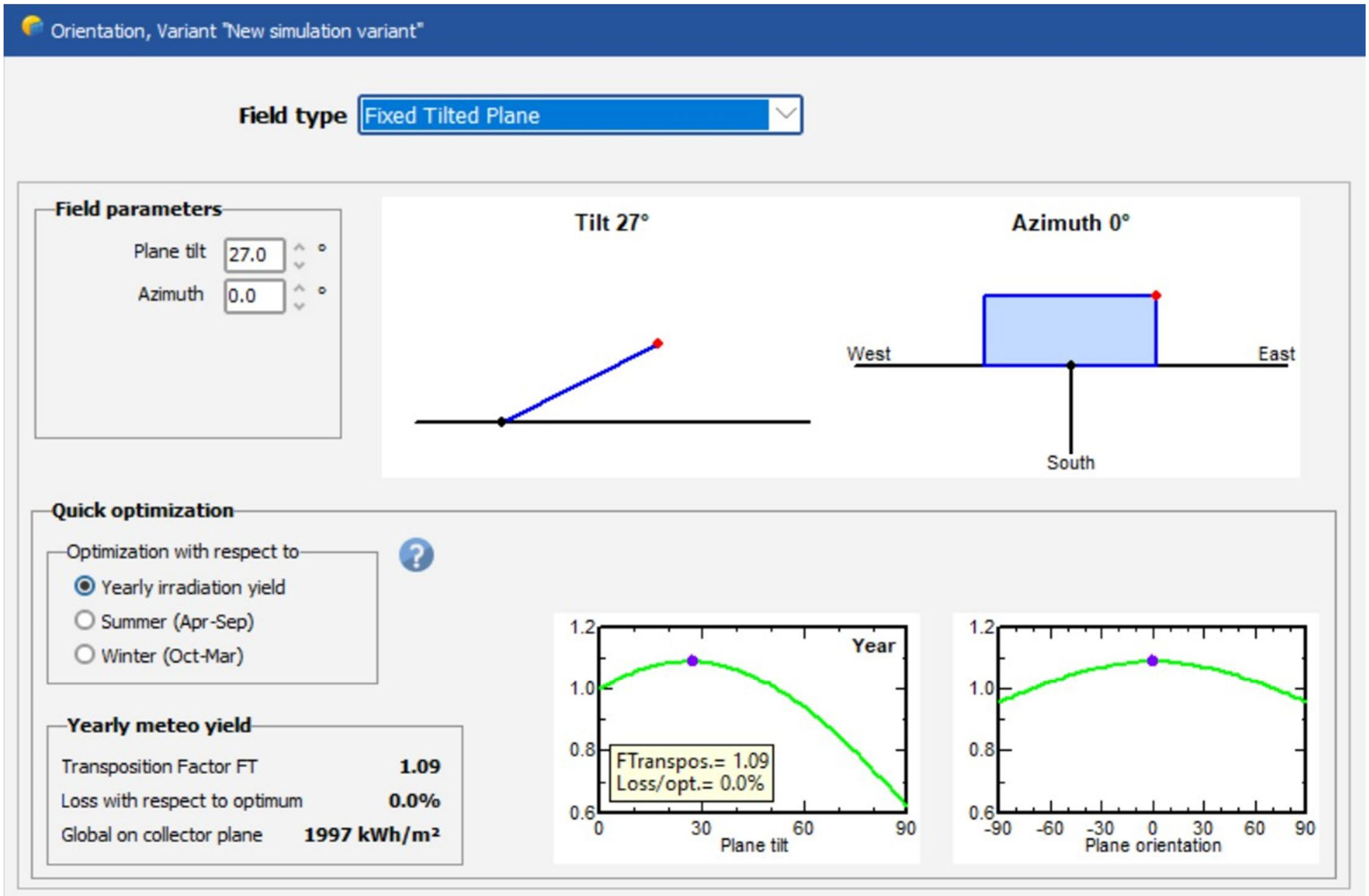


Fig. Orientation and variant

D. PV Array Characteristics

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	AE 540MD-144	Model	SUN2000-30KTL-M3-400V
(Custom parameters definition)		(Custom parameters definition)	
Unit Nom. Power	540 Wp	Unit Nom. Power	30.0 kWac
Number of PV modules	56 units	Number of inverters	4 * MPPT 25% 1 unit
Nominal (STC)	30.2 kWp	Total power	30.0 kWac
Modules	4 Strings x 14 In series	Operating voltage	200-1000 V
At operating cond. (50°C)		Max. power (=>55°C)	33.0 kWac
Pmpp	27.88 kWp	Pnom ratio (DC:AC)	1.01
U mpp	534 V	No power sharing between MPPTs	
I mpp	52 A		
Total PV power		**Total inverter power**	
Nominal (STC)	30 kWp	Total power	30 kWac
Total	56 modules	Number of inverters	1 unit
Module area	145 m²	Pnom ratio	1.01

Fig. PV Array Characteristics

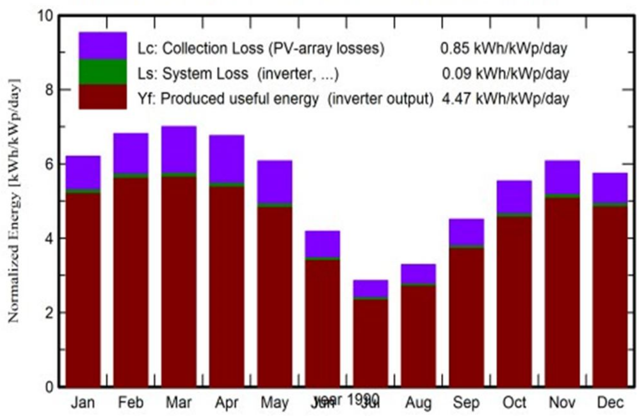
E. Main Results

Main results

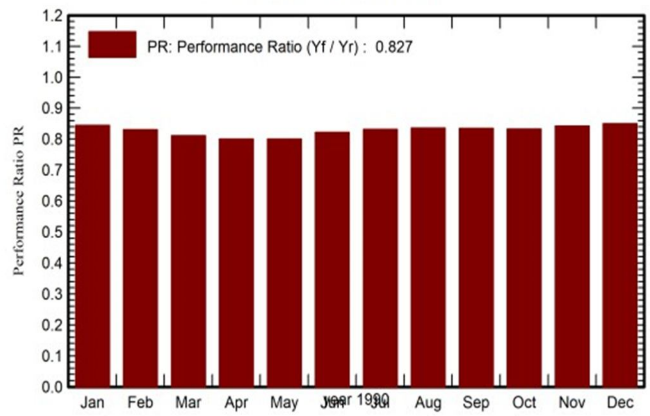
System Production

Produced Energy	49381 kWh/year	Specific production	1633 kWh/kWp/year
Used Energy	65700 kWh/year	Perf. Ratio PR	82.68 %
		Solar Fraction SF	37.82 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_User kWh	E_Solar kWh	E_Grid kWh	EFrGrid kWh
Jan. 90	146.5	42.41	21.01	192.4	184.0	5005	5580	2171	2742	3409
Feb. 90	157.2	44.15	24.09	190.8	182.6	4881	5040	2057	2735	2983
Mar. 90	199.4	58.17	28.15	217.2	206.9	5427	5580	2349	2976	3231
Apr. 90	208.0	68.12	31.45	202.8	192.6	5006	5400	2290	2620	3110
May 90	211.2	75.36	32.49	188.5	178.2	4654	5580	2315	2248	3265
June 90	144.0	81.35	27.93	125.7	118.3	3190	5400	1955	1168	3445
July 90	98.1	73.64	25.87	88.6	83.4	2283	5580	1660	567	3920
Aug. 90	108.7	75.15	25.09	101.9	96.1	2632	5580	1762	811	3818
Sep. 90	134.0	72.40	25.35	135.2	128.2	3479	5400	1923	1487	3477
Oct. 90	152.5	68.44	25.73	171.7	163.5	4404	5580	2165	2157	3415
Nov. 90	143.8	50.31	23.14	182.2	174.2	4731	5400	2127	2517	3273
Dec. 90	134.7	46.69	21.14	178.1	170.7	4662	5580	2071	2505	3509
Year	1838.2	756.19	25.96	1975.1	1878.9	50355	65700	24846	24535	40854

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Solar	Energy from the sun
GlobInc	Global incident in coll. plane	E_Grid	Energy injected into grid
GlobEff	Effective Global, corr. for IAM and shadings	EFrGrid	Energy from the grid

Fig. Main Results

F. Daily System Output Energy & Array Power Distribution

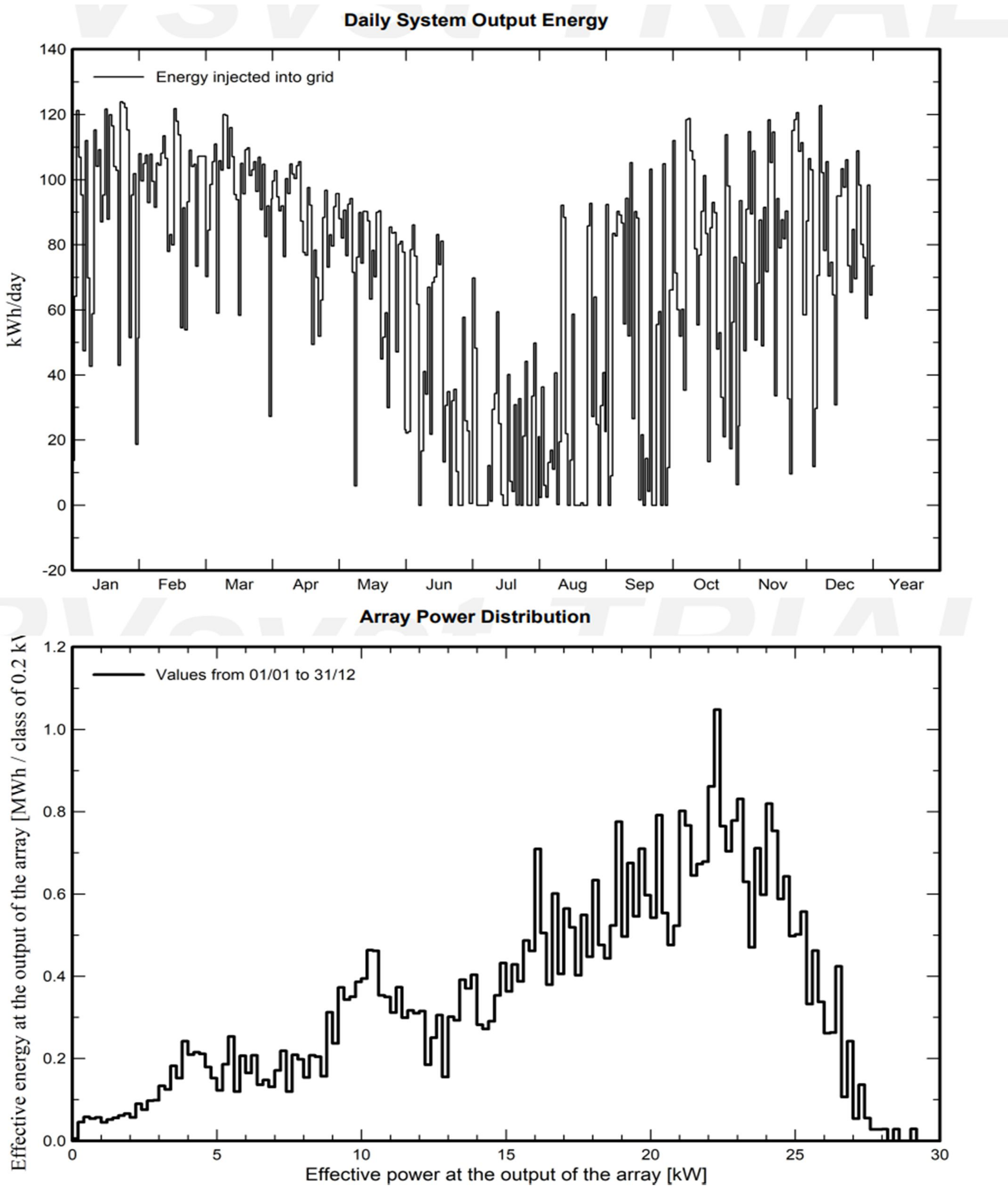
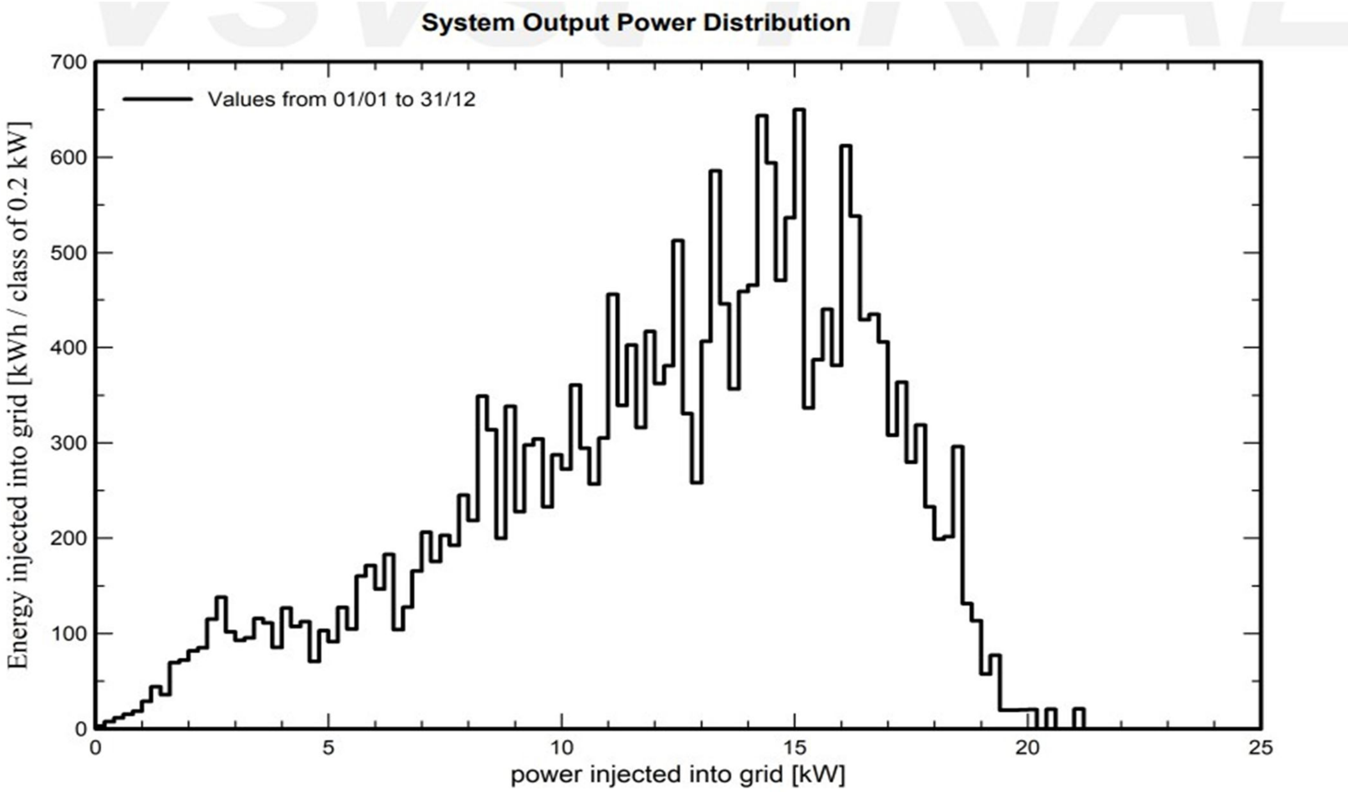


Fig. Daily System Output Energy & Array Power Distribution

G. System Output Power Distribution & Cumulative Distribution



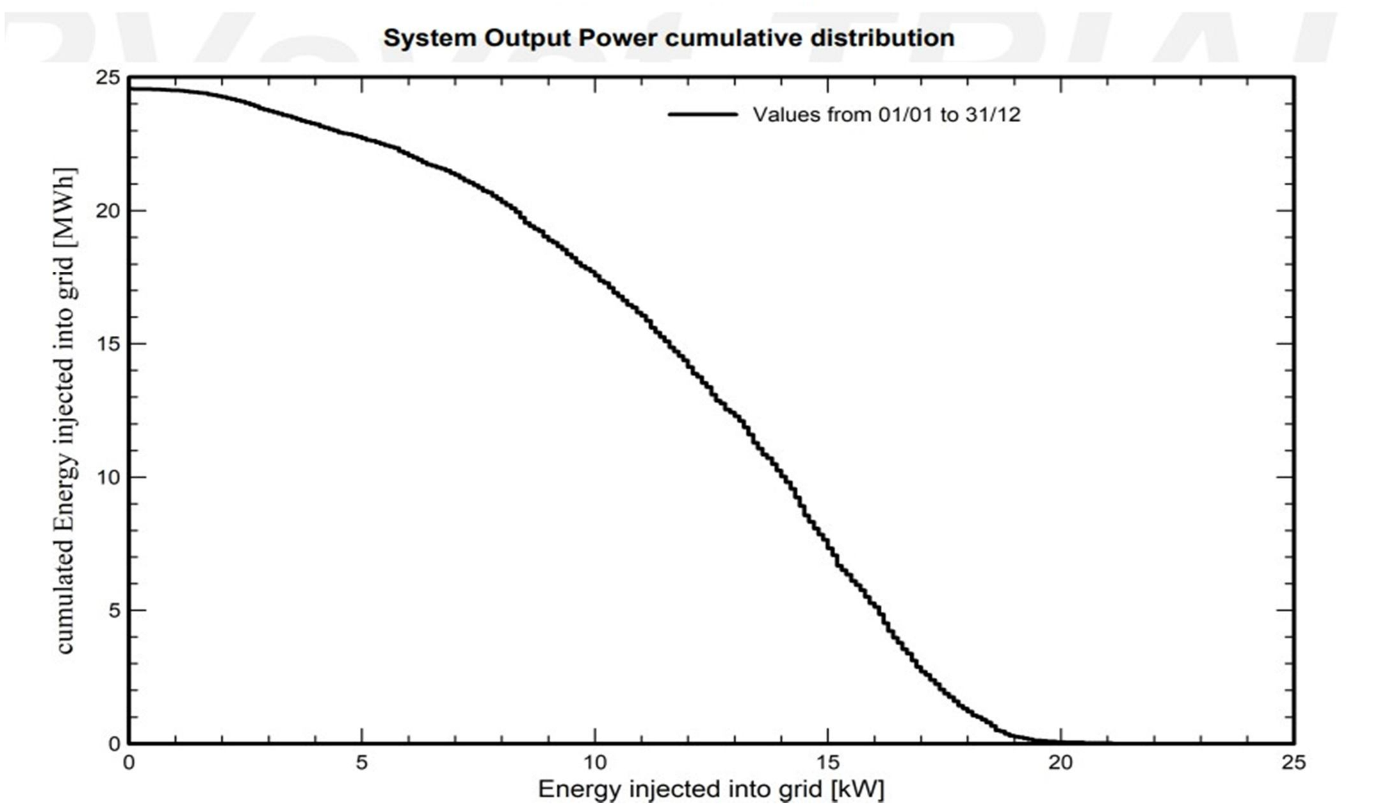


Fig. System Output Power Distribution & Cumulative Distribution

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H. Losses Diagram

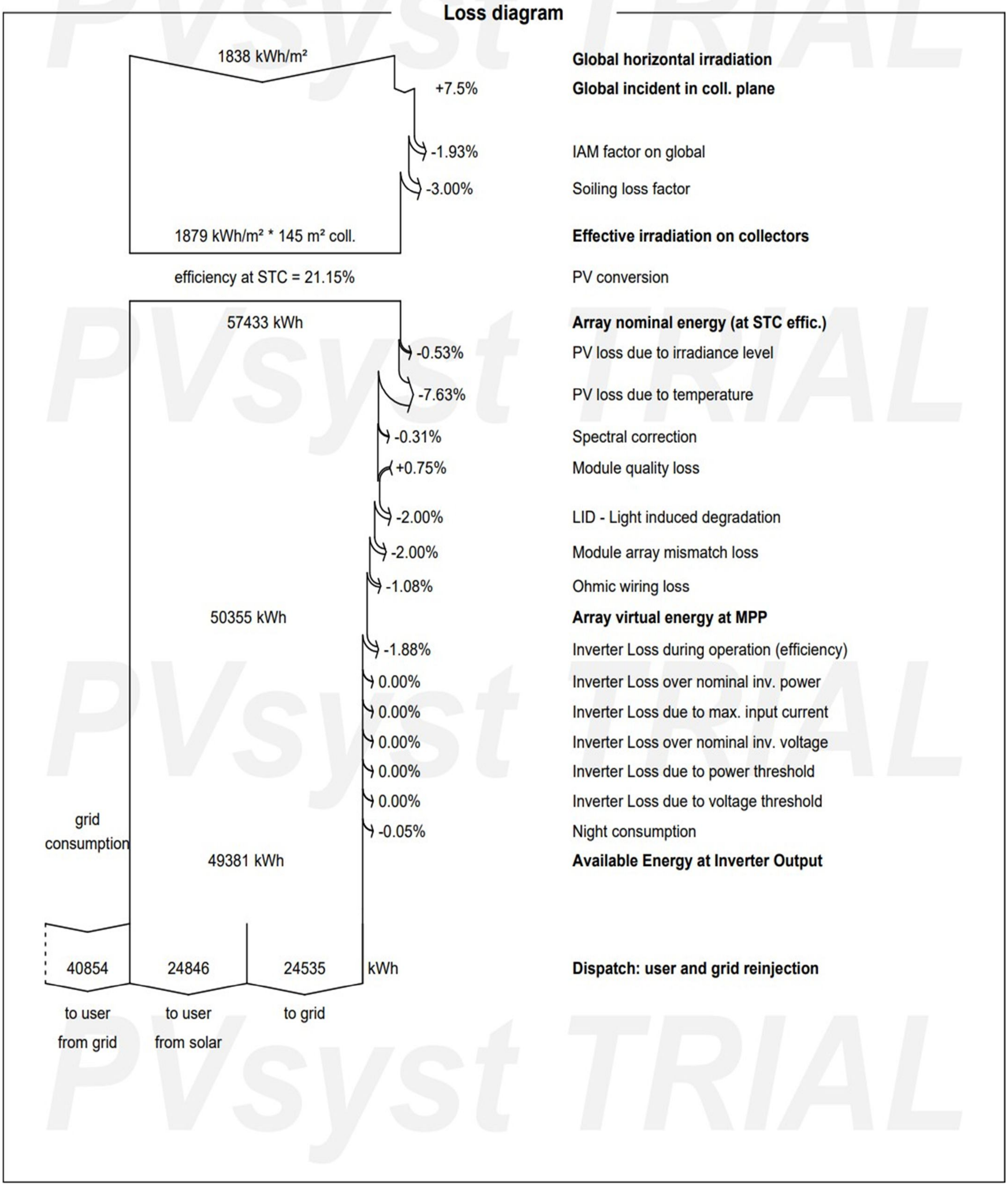

Fig. Losses Diagram

I. System Losses

Array losses

Array Soiling Losses
Loss Fraction 3.0 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 169 mΩ
Loss Fraction 1.5 % at STC

LID - Light Induced Degradation
Loss Fraction 2.0 %

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

IAM loss factor
Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Spectral correction
FirstSolar model
Precipitable water estimated from relative humidity

Coefficient Set	C0	C1	C2	C3	C4	C5
Monocrystalline Si	0.85914	-0.02088	-0.0058853	0.12029	0.026814	-0.001781

J. Single Line Diagram

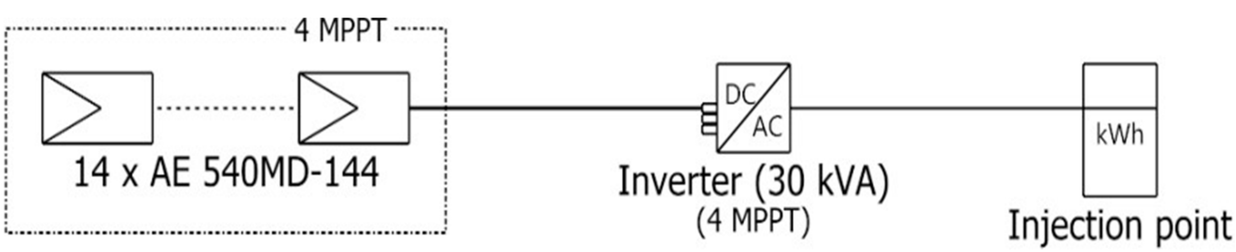

Fig. System Losses

The above report provides all sort of requirements including type and number of photovoltaic cells, inverters, number of modules to be connected in series and parallel, geographical area needed etc.

A bi-meter is installed at the interface between Solar plant and grid, which will track inflow and outflow of energy from Solar plant to grid and vice-versa. In case when Solar generation is more than consumption, surplus power will flow into grid and when load is higher than generation, then power will be sourced from grid. Any surplus power at the end of the month may be carry forwarded to the next billing cycle. Surplus power if any at the end of the financial year will be compensated at Average Power Purchase Cost.

VI. COMMERCIAL COST

Description	Amount
System Cost	15,81,722
GST (13.8%)	2,18,278
Total Project Cost	18,00,000

Table 1. Commercial Cost

VII. BOM (BILL OF MATERIAL)

Particulars	Technical Specifications	Make	Qty	UoM
Solar Modules	Mono Half Cut Cells	Waaree/ Satvik	56	No
Inverter	30 KW Three Phase	Growatt/ KSolare/ Sofar	1	No
AC Cable	25Sq MM Alu. Armard Cable	Polycab		Mtr
ACDB	1 in 1 out RYB Ph. Indicator with Thermal MCB + SPD	AC MCB : Siemens/Schneider/ABB SPD : Feelo/Elpro/Phonex/Finder	1	No
DCDB	3 in 3 out Fuse + TB + MCB - 800V - 3 + SPD - 3 {2-MPPT Inverter}	DC MCB: BE/Feeo/Eaton/ Chint SPD : Feelo / Elpro/Phonex/ Finder	1	No
MC 4 Connector	CE Mark IP67 Protection	ISI Standard	1	No
DC Cable	4 Sq mm Solar DC cable	Polycab	4Sq MM	Mtr
Lightning Arrestor	Copper, Franklin Rod with Base	As Market Standard	1	No
Earthling Plate	50x1 Mtr Pipe with BFC	ISI Standard	3	No
Earthling Cable	4 Sq MM	Polycab		Mtr
Meter		HPL		No
Structure	Standard Structure	As Market Standard		
Installation		As Market Standard		

Table 2. BOM

VIII. RETURN ON INVESTMENT/ SIMPLE PAYBACK PERIOD

Total Project Cost i.e., Investment = ₹18,00,000 Total units consumed per day = 180
Total units consumed per year = 65700 As per MSEB, 1 unit = ₹12
∴Annual Savings = 65700 units x ₹12 = 7,88,400

$$\therefore ROI = \frac{\text{Investment}}{\text{Annual Savings}}$$

$$= \frac{18,00,000}{7,88,400} = 2.9 \text{ years}$$

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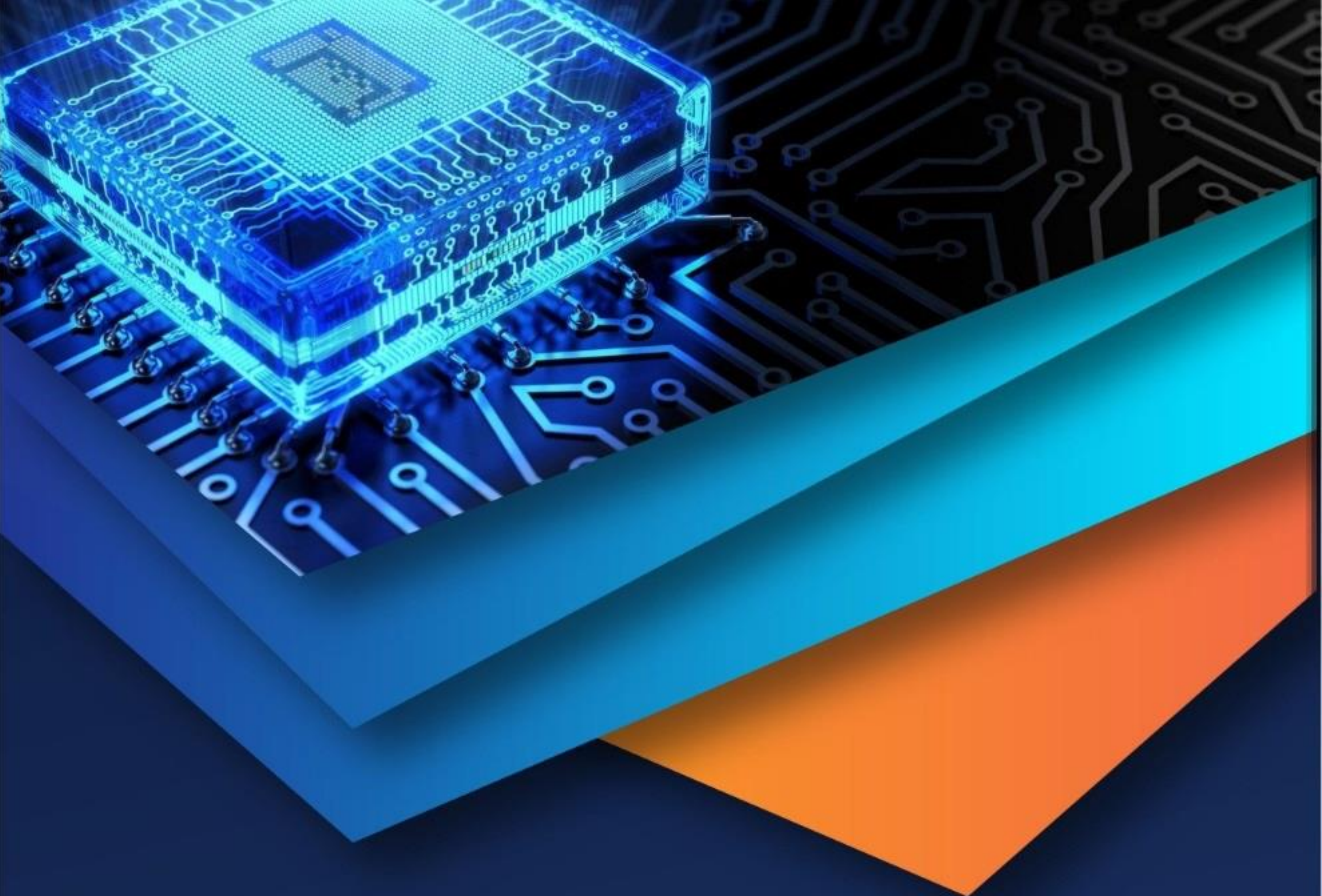

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