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Assessing the Energy Production Potential of a 2.6 Kw Solar PV System Using PV Syst

Vivek Kumar Shaw[1], K. Srinivasa Rao[2]
[1, 2]*Dept. of Electrical Engineering, BIET Hyderabad, India*

Abstract: This work focuses on designing a 2.6 Kw Solar PV system operating in Grid-Connected mode. A 3-Step method of efficiency evaluation is done in order to assess the energy production potential of the designed PV system. This method of assessment covers all the technical, economic and annual performance aspects of the designed PV system. Assessment is done and the results are demonstrated that forecast the energy production potential of this 2.6 Kw Solar PV system. The results will be verified using PV Syst software.
Keywords: PV Syst, Grid Connected Solar PV system, Electricity, Meteorological data.

I. INTRODUCTION

In today's world of technological developments, electricity plays a crucial role for a nation's development, for both developing and developed nations the challenge is being able to meet the growing demand for energy. According to a report from the Central Electricity Authority in 2018, it is observed that there is 8629 million units in energy supply but simultaneously 3314 megawatts in peak power demand. [1] To satisfy such demand, production needs to increase. Considering the limitations of conventional power sources, we go for alternative energy sources like solar and wind. This paper discusses on solar energy generation by designing a Grid Connected solar PV setup of 2.6 Kw power capacity in the location of Mangalpalli, Telangana. These systems are capable of feeding electricity directly into the connected grid, operating alongside conventional sources of energy. These produce clean electricity near where it's used, reducing losses and eliminating the need for batteries. [2] Their performance depends on local factors such as climate, PV Array orientation, and inverter efficiency.[3] Hence there is a need of a method to determine efficiency of such PV installations in a way where all technical, economic and annual performance aspects gets covered. For such designing and analyzing of PV systems, there are various tools available. These tools are implemented by engineers and scientists for optimization and analysis. Such tool is PV Syst, a PC software that was developed by the University of Geneva, it offers pre-feasibility analysis, simulation and forecasting for PV systems.[4] This research paper aims to design and simulate a 2.6 Kw solar PV system to implement 3-step method for efficiency evaluation in order to assess the energy production potential of this PV system.

II. METHODOLOGY

This paper proposes a 3-Step methodology where the complete evaluation of a PV system is divided into three important steps. They are-

A. Parameter Analysis

The Primary Block that extracts electricity out of solar irradiation is a solar cell. A solar cell produces output power according to its characteristics under different conditions. These characteristics examine Voltage, Current and Power parameters of solar cell under normal under constant and varying temperature. These characteristics help us in understanding the stability, compatibility with the power grid, efficiency and performance under different levels of irradiation. Overall, this analysis covers aspects related to solar cell and its efficiency in generating a stable efficient power.

B. Performance Analysis

Performance analysis is studying the performance of the PV system by considering power production, losses, efficiency, balance, irradiation in order to achieve valuable information about power production and estimate forecasting of aspects that enable us to gain understanding about the efficiency of the technical aspects of a PV system. All the technical aspects of this PV system like power production, performance, efficiency are covered under performance analysis.

C. Financial Analysis

Financial analysis is the study in which installation costs and operating costs of the PV setup are considered to gain calculated analysis on income variation, yearly net profit which are necessary for the planning and organizing of a solar PV system. This also gives a proper estimate on return on investment and cumulative cash flow to the user which aids in pre-feasibility of the system. Overall, this analysis covers all the monetary aspects behind establishing a solar PV system. Fig I illustrates proper understanding of this methodology below.

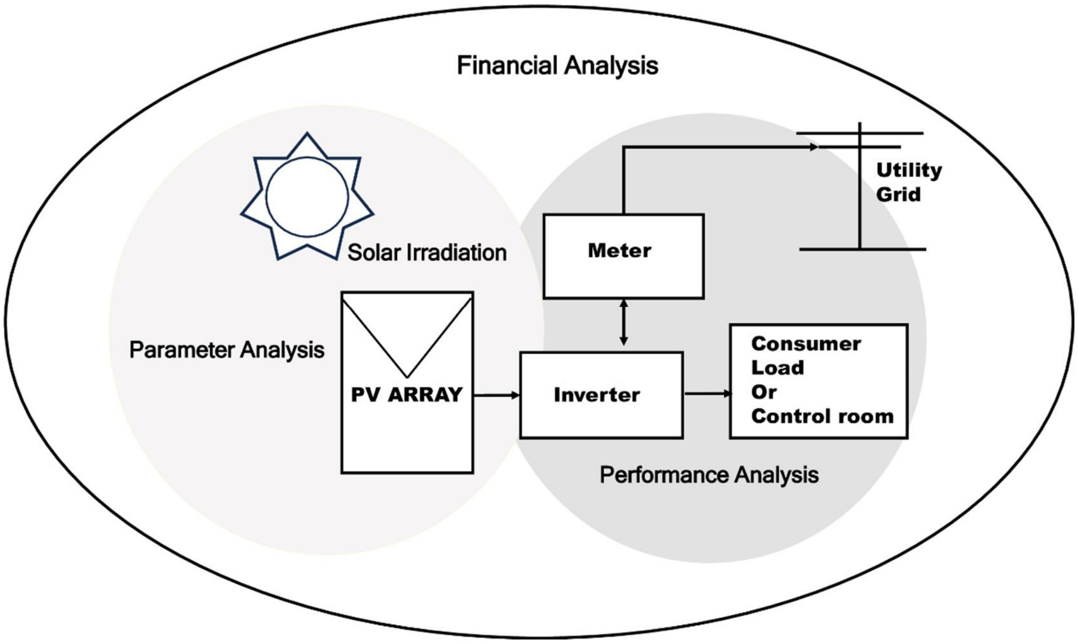

Fig 1 represents visual illustration of the 3-Step methodology of complete evaluation of the proposed 2.6 Kw Solar PV system

III. SITE AND TECHNICAL DETAILS

A. Site Location and Climatic Resources

The proposed site is in Bharat Institute of Engineering and Technology (BIET) campus which is in Mangalpalli village of Ibrahimpatnam mandal of Ranga Reddy district (Telangana), India. The site is located at Latitude of 17.21'N and Longitude of 78.59'E at an altitude of 526 meters.

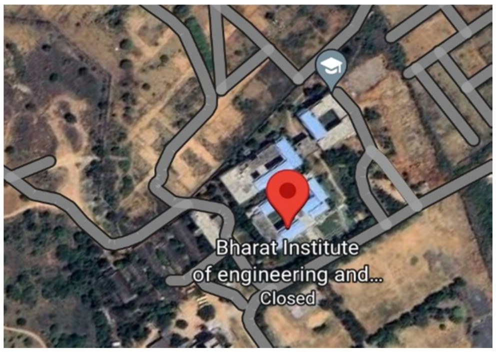

Fig 2 Satellite view of BIET campus

For estimation of Irradiation, temperature and Horizon data as per the geographical location, meteo database Metronorm 8.1 has been used.

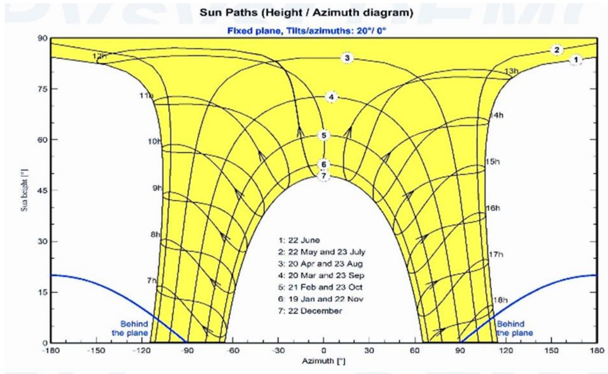

Fig 3 Trajectory of sun at BIET with Horizontal outline

B. *Solar PV technology*

Solar PV converts solar irradiation into usable electricity. PV modules used for this simulation are polycrystalline. Number of PV modules used for the simulation are 8 units in 4 series connected modules in 2 parallel strings. Total area covered by PV modules is 15.5 sq.mts as calculated after running the simulation in PV Syst software as shown in Fig 4 below.

C. *Inverter*

Inverter should be perfect for overall requirement of the PV system. It must be easy to operate and reliable with low maintenance cost and longer life. In our simulation, we are using 3 KW AC inverter as shown in Fig 4 below.

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Lubi Electronics	Manufacturer	Generic
Model	Poly 335 Wp 72 cells	Model	3 kWac inverter
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	335 Wp	Unit Nom. Power	3.00 kWac
Number of PV modules	8 units	Number of inverters	1 unit
Nominal (STC)	2680 Wp	Total power	3.0 kWac
Modules	2 Strings x 4 In series	Operating voltage	125-440 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	0.89
Pmpp	2439 Wp		
U mpp	139 V		
I mpp	17 A		
Total PV power		**Total inverter power**	
Nominal (STC)	2.68 kWp	Total power	3 kWac
Total	8 modules	Number of inverters	1 unit
Module area	15.5 m²	Pnom ratio	0.89
Cell area	14.0 m²		

Fig 4 PV Array and Inverter details

Table 1 Inverter specifications

Rating	3 Kw
Voltage rating	125 – 440 V
Nominal AC current	5.6 A
Output AC voltage	335 V
Efficiency	90-92%
No. of inverters	1

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D. System Orientation

The orientation of the panel is shown in Fig 5 below. The tilt angle is kept at 20' and Azimuth is kept 0'.

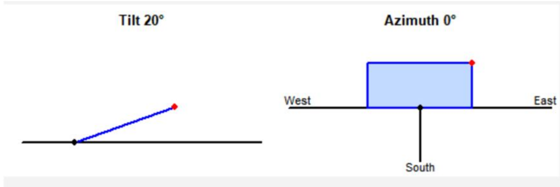

Fig 5 Orientation of Panel

IV. PARAMETER ANALYSIS

A. V- I Characteristics with Irradiance

When the irradiation is high i.e., 1000 watts/sq.mt then maximum power output is 311 watts whereas, when irradiation is lowest i.e., 200 watts/sq.mt then minimum power output of the panel is 59.9 watts as shown in Fig 6.

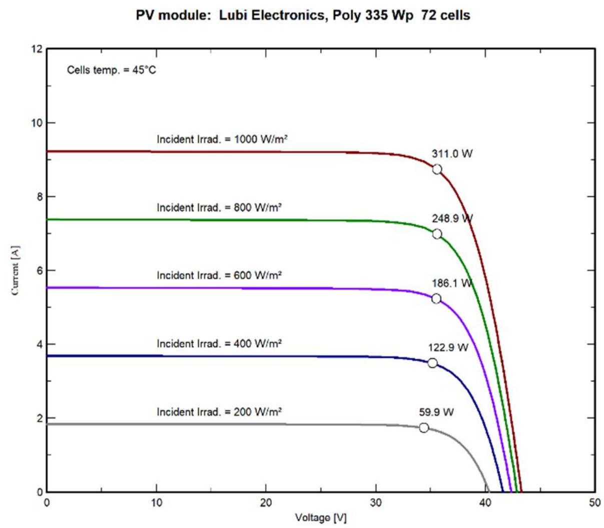

Fig 6 V-I Characteristics with Irradiation

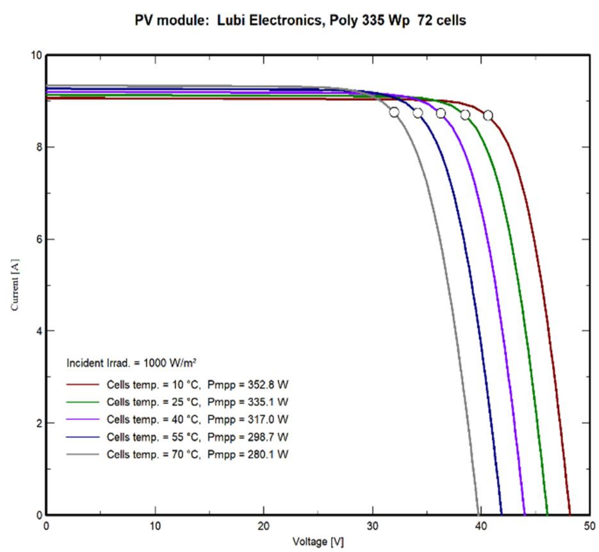

Fig 7 V-I Characteristics with varying temperature

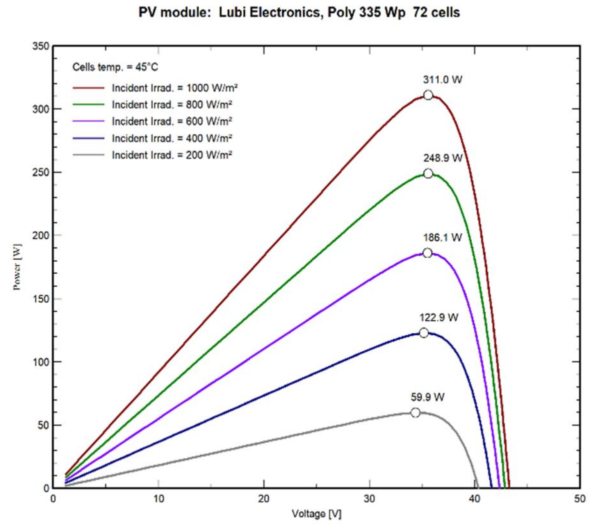

Fig 8 P- V Characteristics

B. V-I Characteristics with varying Temperature

In Fig 7 Graph shows when cell temperature is 10 degrees Celsius then maximum power output is 352.8 W. Similarly, for 25 degrees Celsius we get 335.1 W and for 40 degrees Celsius we get 317 W of maximum power.

C. P-V Characteristics with Irradiance

In Fig 8 Graph shows how power changes based on amount of sunlight received (irradiance). When irradiance is maximum i.e., 1000 watts/sq.mt we get maximum output power of 311 W whereas, when irradiance is minimum i.e., 200 watts/sq.mt we get minimum output power of 59.9 W.

D. P-V Characteristics with varying Temperature

In Fig 9 Graph shows when the temperature is lowest i.e., 10 degrees Celsius we get maximum output power of 352.8 W. It is clearly seen that as the temperature increases, maximum power is decreasing.

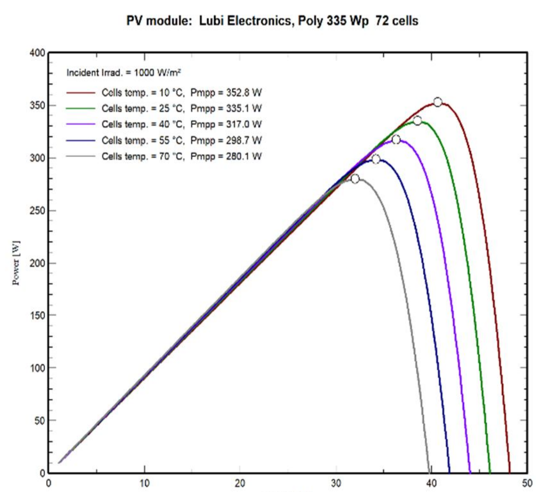

Fig 9 P-V Characteristics with varying temperature

After studying parameter analysis of the proposed 2.6 Kw PV system, we can say that the system is stable, compatible with the power grid and performs efficiently under different levels of irradiation and temperatures.

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V. PERFORMANCE ANALYSIS

A. Incident Irradiation Distribution

Fig 10 shows represents the incident irradiation distribution of global incident collection plane generated annually.

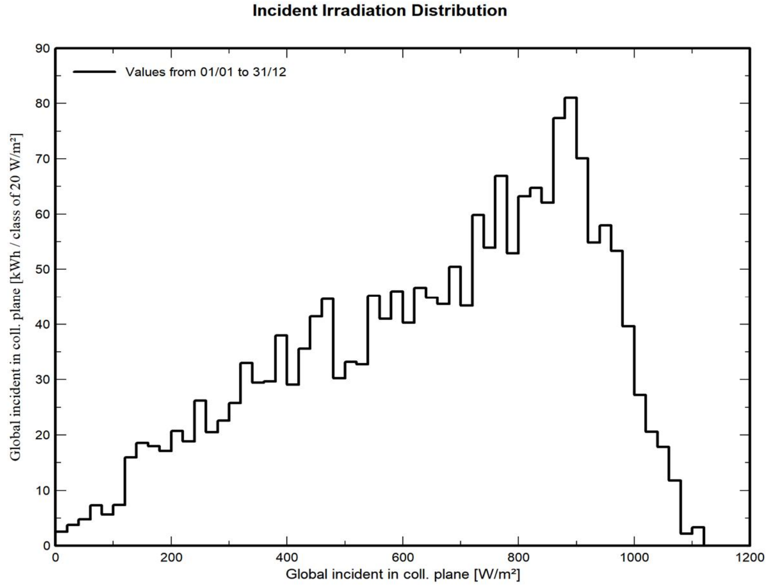

Fig 10 Incident Irradiation Distribution

B. Normalized Power Production

Fig 11 showcases the combined losses from PV array collection, system inefficiencies, and the resultant output from the inverter. This graphical representation clearly presents the monthly usable energy production as well as the losses incurred per kilowatt-hour (kWh). These normalized metrics, defined by the International Electrotechnical Commission (IEC), serve as standardized measures for assessing the performance of PV systems. Specifically, the collection losses or PV array capture losses are quantified as 0.99kWh/kWp/day. Additionally, the system loss amounts to 0.15kWh/kWp/day, while the solar energy generated stands at 4.21kWh/kWp/day.

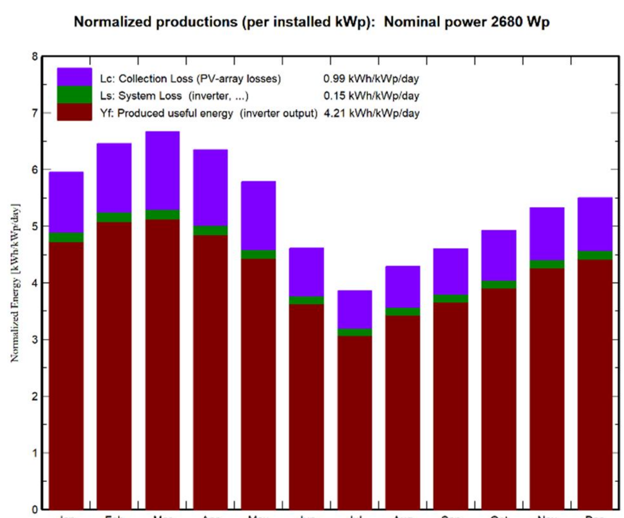

Fig 11 Normalized Power Productions

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C. Normalized Production and Loss Factors

Fig.12 represents the graph between normalized power production and loss factor which is yield on yearly basis. Here the energy supplied to the user is 78.7%, collection loss (PV array losses) is 18.5%, system losses is 2.9%.

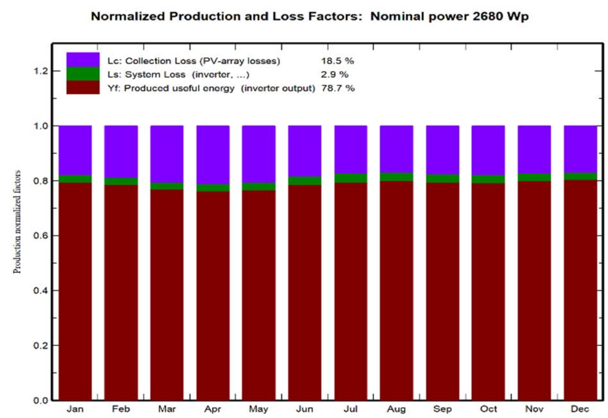

Fig 12 Normalized Production and Loss Factors

D. Efficiency vs Incident Global

Fig 13 graph that represents the efficiency at the maximum power point (Pmax) compared to the incident global irradiation. The graph indicates that the relative efficiency, when compared to the standard testing conditions (STC) with an incident irradiation of 1000 watts per square meter, is 17.27%.

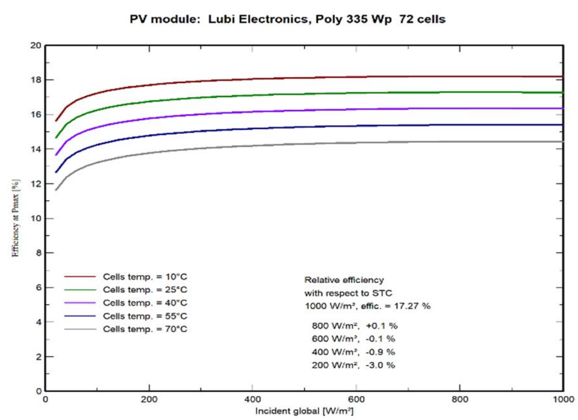

Fig 13 Efficiency vs Incident Global

E. Efficiency vs Cell Temperature

Fig 14 graph shows represents the efficiency at Pmax vs the cell temperature by varying the incident irradiation.

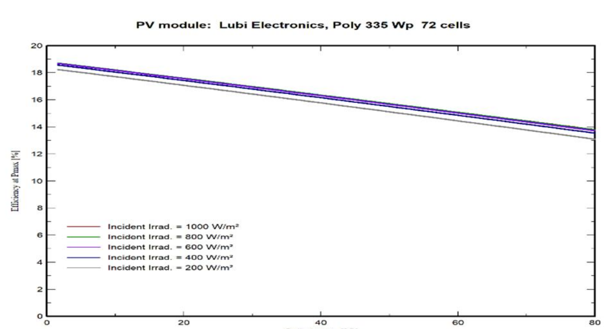

Fig 14 Efficiency vs Cell Temperature

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F. Balance and Main Results

Table 2 Main Simulation Results

Main Simulation Results
System Production = 4121 kWh/year Specific Production = 1538 kWh/kWp/year Performance Ratio = 78%

Specific Production-The produced energy/ Nominal power of the array ($P_{nominal}$ at STC)
This shows the potential of the system, Considering irradiance conditions like orientation, site, location, meteorological conditions. [4]
We can write,
Specific Production = Produced Energy / Nominal Power of the Array = 1538 kWh/kWp/year.
Table 3 shows the balance and main results of 2.6 kW Solar PV system. Yearly Global Horizontal irradiation is 1857.6 kWh/sq.mt. The yearly global incident energy on the collector plane is 1954.8 kWh/sq.mt.
Energy available at the output of the PV array is 4271.3 kWh. The energy injected into the grid is 4121.4 kWh. The average ambient temperature is 27.30 degrees.

Table 3 below shows Balance and Main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	150.3	47.45	23.32	184.4	180.2	406.8	393.2	0.795
February	156.5	55.61	26.25	180.9	176.7	394.0	381.1	0.786
March	194.3	70.02	29.71	206.6	201.7	440.7	426.1	0.769
April	193.1	75.36	31.94	190.6	185.6	403.5	389.8	0.763
May	193.4	89.57	33.53	179.3	173.7	381.7	368.4	0.767
June	152.2	82.77	29.24	138.5	133.7	303.2	291.8	0.786
July	129.4	83.45	27.40	119.8	115.5	266.1	255.4	0.795
August	138.2	88.03	26.38	133.1	128.9	296.8	285.5	0.800
September	136.0	74.19	26.29	138.1	134.1	305.7	294.4	0.795
October	140.5	70.09	26.33	152.8	149.0	337.0	324.9	0.794
November	136.1	56.73	24.17	160.0	156.4	355.1	343.0	0.800
December	137.7	51.24	22.98	170.6	166.8	380.6	367.8	0.804
Year	1857.6	844.51	27.30	1954.8	1902.3	4271.3	4121.4	0.787

G. Array Loss Diagram

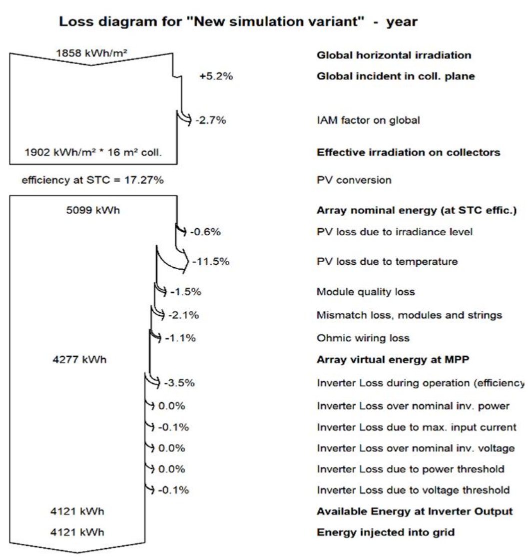

Fig 15 Array Loss Diagram

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The array loss diagram is generated through simulated studies, providing valuable insights into potential losses and constraints in PV plant installations. Fig 15 illustrates the array loss diagram, which highlights various system losses. The global irradiance on the horizontal plane measures 1858 kWh/Sq. m, while the effective irradiance on the collector is 1902 kWh/Sq. m. Consequently, there is a 0.6% energy loss due to the irradiance level. The photovoltaic module or array converts the simulated effective irradiance into electricity, resulting in a nominal energy of 5099 MWh at standard testing conditions (STC) with an array efficiency of 17.27%. The annual virtual energy from the maximum power point (MPP) of the array amounts to 4277 kWh. Among the array losses, temperature losses account for 9.6%, light-induced degradation accounts for 2%, module array mismatch accounts for 2.1%, and Ohmic wiring losses account for 1.1%. Annually, the inverter output of the plant yields 4156 kWh of available energy being injected into the grid as shown in fig.15 above.[6]

H. Performance Ratio

The performance ratio is used for performance analysis of the solar PV system. From Fig 16 it is observed that the performance ratio of most of the months is about 0.8 which is satisfactory.

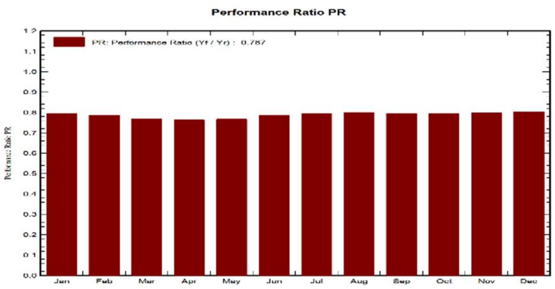

Fig 16 Performance Ratio

From analysing the performance, it is clear that the designed PV system is potent for producing power upto long term scale of time. The designed PV system is efficient and is well performing in all technical aspects of the simulation.

VI. FINANCIAL ANALYSIS

A. Cost of the system

Cost of the system

Installation costs

Item	Quantity units	Cost INR	Total INR
PV modules			
Poly 335 Wp 72 cells	8	11,400.00	91,200.00
Supports for modules	8	500.00	4,000.00
Inverters			
3 kWac inverter	1	18,400.00	18,400.00
Other components			
Accessories, fasteners	1	1,000.00	1,000.00
Wiring	1	1,000.00	1,000.00
Combiner box	1	2,000.00	2,000.00
Measurement system, pyranometer	1	9,000.00	9,000.00
Surge arrester	1	1,000.00	1,000.00
Studies and analysis			
Engineering	1	200.00	200.00
Permitting and other admin. Fees	1	100.00	100.00
Environmental studies	1	200.00	200.00
Economic analysis	1	200.00	200.00
Installation			
Global installation cost per module	8	500.00	4,000.00
Global installation cost per inverter	1	500.00	500.00
Transport	1	500.00	500.00
Settings	1	100.00	100.00
Grid connection	1	100.00	100.00
		Total	133,500.00
		Depreciable asset	114,600.00

Operating costs

Item	Total INR/year
Maintenance	
Provision for inverter replacement	3,680.00
Repairs	2,000.00
Total (OPEX)	5,680.00
Including inflation (1.00%)	6,253.40

System summary

Total installation cost	133,500.00 INR
Operating costs (incl. inflation 1.00%/year)	6,253.40 INR/year
Produced Energy	4121 kWh/year
Cost of produced energy (LCOE)	2.239 INR/kWh

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B. Financial Analysis

Financial analysis

Simulation period

Project lifetime 20 years Start year 2020

Income variation over time

Inflation	1.00 %/year
Production variation (aging)	5.00 %/year
Discount rate	0.00 %/year

Income dependent expenses

Income tax rate	0.00 %/year
Other income tax	0.00 %/year
Dividends	0.00 %/year

Depreciable assets

Asset	Depreciation method	Depreciation period (years)	Salvage value (INR)	Depreciable (INR)
PV modules				
Poly 335 Wp 72 cells	Straight-line	20	0.00	91,200.00
Supports for modules	Straight-line	20	0.00	4,000.00
Inverters				
3 kWac inverter	Straight-line	20	0.00	18,400.00
Accessories, fasteners	Straight-line	20	0.00	1,000.00
		Total	0.00	114,600.00

Financing

Own funds	80,100.00 INR
Subsidies	53,400.00 INR

Electricity sale

Feed-in tariff	Peak tariff	5.0000 INR/kWh	
	Off-peak tariff	3.0000 INR/kWh	20:00-07:00
Duration of tariff warranty		20 years	
Annual connection tax		5,000.00 INR/kWh	
Annual tariff variation		+1.0 %/year	
Feed-in tariff decrease after warranty		1.00 %	

Return on investment

Payback period	6.1 years
Net present value (NPV)	456,222.33 INR
Internal rate of return (IRR)	20.35 %
Return on investment (ROI)	569.6 %

Fig 17 Financial analysis shows Return of investment period of pay back to be 6.1 years.

C. Detailed Economic Results

Table 4 below shows Detailed Economic results

Detailed economic results (INR)

Year	Electricity sale	Own funds	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
0	0	80,100	0	0	0	0	0	-80,100	0.0%
1	15,587	0	5,680	5,730	4,177	0	9,907	-70,193	12.4%
2	16,833	0	5,737	5,730	5,366	0	11,096	-59,097	26.2%
3	18,153	0	5,794	5,730	6,629	0	12,359	-46,738	41.7%
4	19,554	0	5,852	5,730	7,972	0	13,702	-33,036	58.8%
5	21,040	0	5,911	5,730	9,399	0	15,129	-17,907	77.6%
6	22,615	0	5,970	5,730	10,915	0	16,645	-1,261	98.4%
7	24,286	0	6,029	5,730	12,526	0	18,256	16,995	121.2%
8	26,058	0	6,090	5,730	14,238	0	19,968	36,963	146.1%
9	27,937	0	6,151	5,730	16,056	0	21,786	58,749	173.3%
10	29,929	0	6,212	5,730	17,987	0	23,717	82,466	203.0%
11	32,043	0	6,274	5,730	20,038	0	25,768	108,235	235.1%
12	34,284	0	6,337	5,730	22,217	0	27,947	136,181	270.0%
13	36,660	0	6,400	5,730	24,530	0	30,260	166,441	307.8%
14	39,181	0	6,464	5,730	26,986	0	32,716	199,158	348.6%
15	41,854	0	6,529	5,730	29,595	0	35,325	234,482	392.7%
16	44,688	0	6,594	5,730	32,364	0	38,094	272,576	440.3%
17	47,694	0	6,660	5,730	35,304	0	41,034	313,611	491.5%
18	50,882	0	6,727	5,730	38,426	0	44,156	357,766	546.6%
19	54,263	0	6,794	5,730	41,739	0	47,469	405,236	605.9%
20	57,849	0	6,862	5,730	45,257	0	50,987	456,222	669.6%
Total	661,390	80,100	125,068	114,600	421,722	0	536,322	456,222	669.6%

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D. Yearly Net Profit

Yearly Net Profit shows that by 2039 year our Net profit will be increased upto 52,000 INR Rupees.

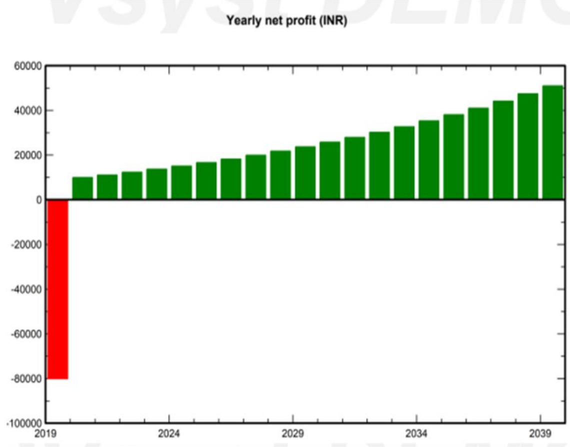

Fig 19 Yearly Net Profit

Above figure shows as per estimation by there will be considerable increase in the Yearly Net Profit (in INR) and by the year 2039 plant will gain upto 52,000 INR rupees of profit.[8]

E. Cumulative Cash Flow

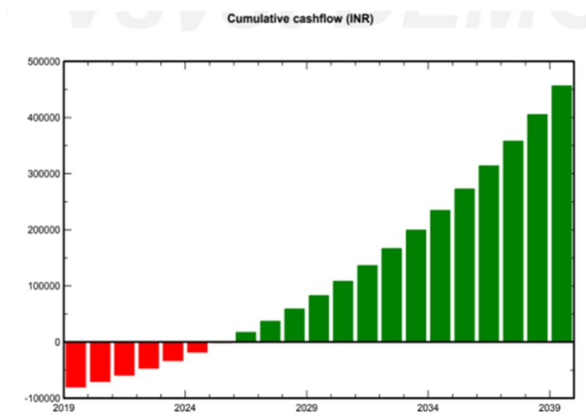

Fig 20 Cumulative cash flow

F. CO_2 Emission Balance

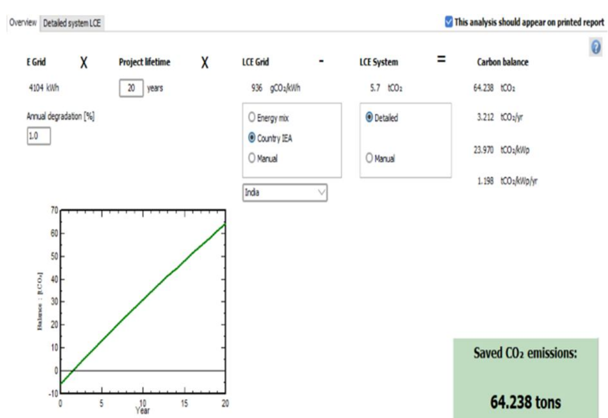

Fig 21 proves the designed system to be environment friendly and clean.

Hence, the above analysis clearly shows that we saved 64.238 tons of CO_2 emissions this proves the feasibility of this system. So, we can say that this PV system improves air quality, supports bio diversity and ecosystem.[6]
From Financial Analysis, we can say that this system efficiently produces energy of 4121 kWh/year spent installation cost of 133,500/-INR and operating cost of 6,253.40 INR/year. Considering Project lifetime to be 20 years with start year to be 2020. According to the forecasting results of this analysis, payback period is to be 6.1 years with Return of investment rate of 569.6%. This shows that financial analysis was successful for this PV system.

VII. CONCLUSION

In this paper, a 2.6 Kw Solar PV system integrated with Grid is designed and evaluated successfully using PV Syst software. It can be observed from all the analysis we have performed it proves this PV system to be stable, compatible with power grid, performs efficiently under different levels of irradiation and temperatures. Also, despite of minor losses the system is experiencing still persists to perform well and is potent in producing power for long term scale of time which makes this system financially secure and provides return on investment support and more profitability within 6.1 years of installation.

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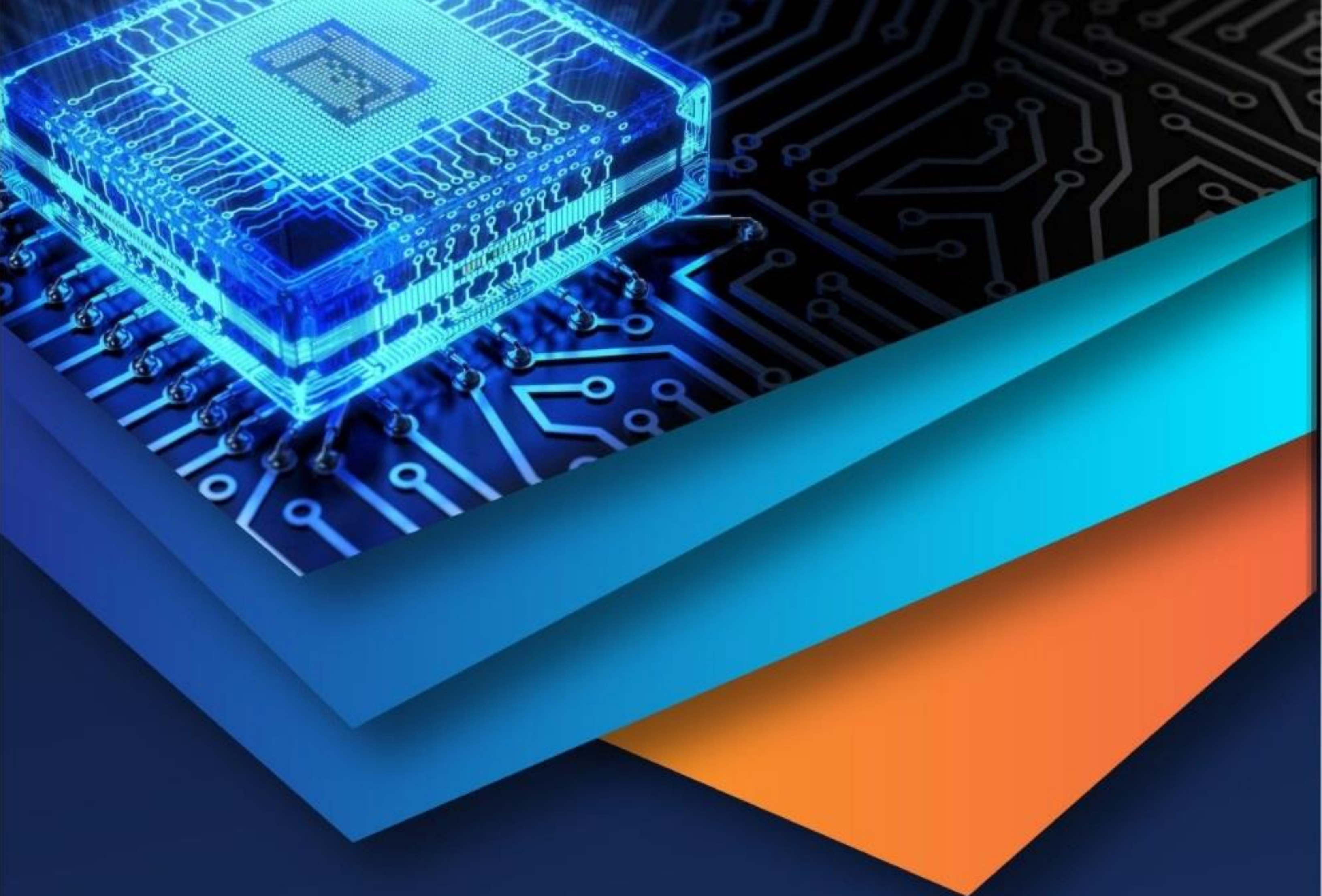

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