Analysis and Evaluation of Performance Parameters of 120kW Solar PV Power Plant

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Abstract: The resources of fossil fuel are depleted on a faster rate, which demands search of alternative energy sources to fulfill present energy demand. In this context, Solar Power is one of the most inexhaustible, clean & environment friendly energy resource among all renewable energy resources.

Recently, Government of India took great initiative to explore and increase the potential of Solar Energy. With the public-private partnership many solar photovoltaic (PV) plants are setting up in India; especially in Rajasthan, where the Solar Power has huge potential compare to other part of the country.

Due to seasonal and periodic variations a single or standalone solar PV system cannot meet the continuous power demand; therefore grid connected power systems are installed which connects both solar and conventional systems.[2]

In this paper, the performance of a 120kWp PV plant is analyzed, which is installed in Suresh Gyan Vihar University, Jagatpura, located in south-east part of Jaipur, Rajasthan. With the objective to estimate the potential of grid connected system, annual energy generation of solar plant, examine various parameters which affect its performance.

Technical parameters of the plant are evaluated. Variations in output of SPV plant on daily and seasonal basis are also shown. Normalized performance parameters are compared with the SPV plants and found comparable. At last, cost estimation of grid connected solar photo voltaic plant to check its viability.

Keyword: Solar Photovoltaic (PV), Solar Radiation, Performance Analysis, Solar Fraction, Loss Diagram.

I. INTRODUCTION

India's per capita energy use has been increased severely from 16.3 kWh in 1947 to 1200 kWh in 2019. In India a large potential of energy is produced from fossil fuels such as gas, coal and oil. Presently these sources are depleting at a faster rate. Therefore, the dependency on the conventional sources has to be overcome by using non-conventional sources such as hydro and solar. The share of renewable power generation is very little as compared to fossil fuel.

Due to equatorial location, India is receiving a great amount of radiant energy from sun. 300 clear sunny days are appearing in many parts of the country. The amount of incident solar energy in India varies from 4 to 6.5kWh $m^{-2}day^{-1}$.[1]

India's solar potential is vast and still fully untapped. Thinking about the same, Ministry of New and Renewable Energy (MNRE), Government of India initiated Jawaharlal Nehru National Solar Mission (JNNSM) in December 2009, with the objective of penetrating the solar technology across the country and maintaining a suitable environment for it. If we tap total incident solar energy effectively, we can meet the huge power requirement of the country.

Presently solar PV sector is in fastest developing phase. Since, it gives clean energy at low cost. Silicon PV modules used today are crystalline silicon modules, which are long lasting and has 25% more efficiency than commercial modules and also requires low maintenance.[3]

At present grid interactive (GI) power plant are also installed in government and private institutions and commercial buildings. These plants are having more energy conversion efficiency because they did not required storage. The generated energy is directly fed to the grid. Grid Interactive Solar plants are easy to install, operate compare to stand alone solar plants.

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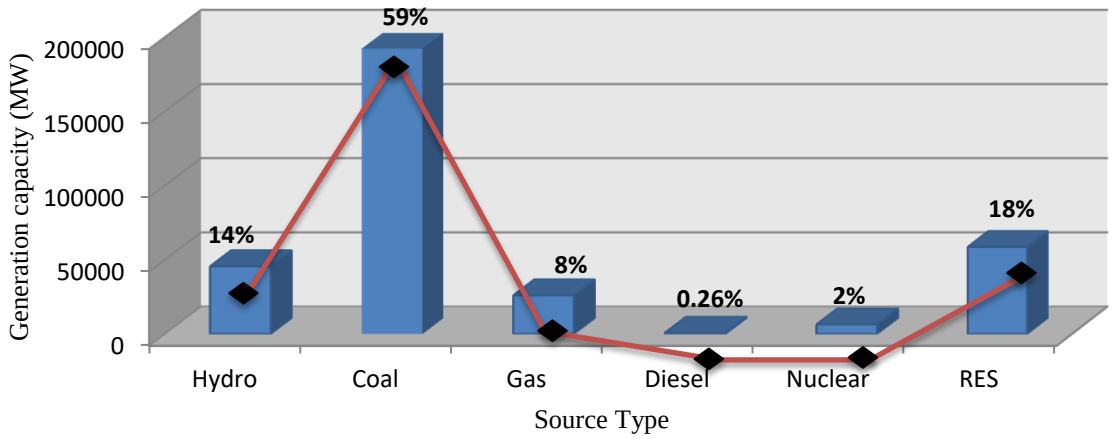

Fig. 1 Power installed capacity mix for Rajasthan in 2018

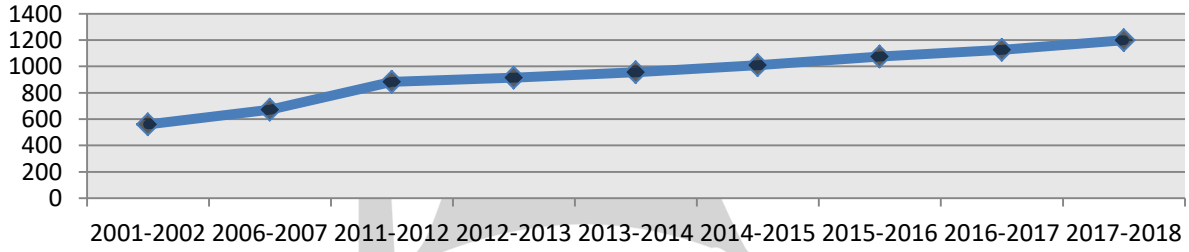

Fig.2 Per capita electricity consumption trend of Jaipur (in kWh)

Installed power capacity of Rajasthan is mainly dependent on conventional sources, but due to population growth at a faster rate, the demand is also increasing proportionally. To supply this demand we need to switch to non-conventional sources as soon as possible. In the present data respective share of energy resources are shown. As the maximum energy share is by the Coal, which is of 59% followed by Renewable energy sources with the share of 18% in the installed capacity mix of Rajasthan. By increasing the share of energy from renewable sources, we can help the overloaded conventional sources and increased demand of energy.[2]

Per capita energy requirement of Jaipur is increased from 520kWh in 2002 to 1200kWh in 2018.

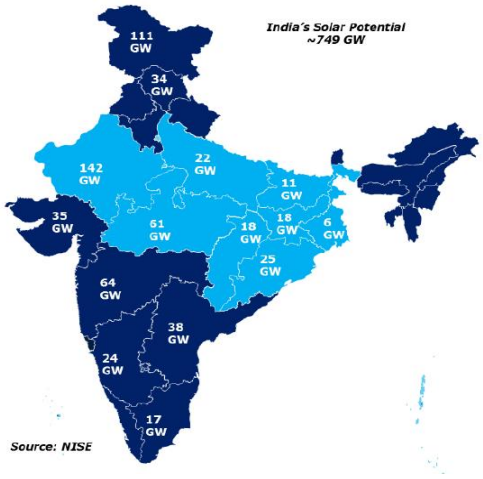

Fig. 3 India's total solar potential

Background

Suresh Gyan Vihar University (SGVU), Jaipur is a private university located at the outskirt of the city Jaipur, capital of Rajasthan, one of the largest states of India. Per capita energy requirement of Jaipur is 1200 kWh per head per year.

In order to reduce the overall dependency on grid, we installed a 120kW grid connected solar PV power plant on the roof top of the main library building. Since, the power cut is very frequent in summers due to high demand of power in the region. Before solar plant, this power cut is settled by the use of Diesel Generator set. But DG set requires fossil fuel and also it polluted air and sound. To reduce this fuel requirement and pollution, we installed a 120kW solar plant at SGVU, Jaipur with the help of Green First Power Ventures Pvt. Ltd. under "Capital Subsidy Scheme of RRECL/MNRE-2016-17".

Fig. 4 120KW Solar Power Plant in SGVU, Jaipur

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II. DESCRIPTION OF THE SPV POWER PLANT

A 120kW grid interactive Solar PV power plant has been installed on roof top of main library building SGVU, Jaipur in collaboration with Green First Power Ventures Pvt. Ltd. under GOI scheme named as "Capital Subsidy Scheme of RRECL/MNRE-2016-17". In addition, 120 kW more power has been added to generated by installing solar PV plant.

TABLE 1 Details of Site

Location	Jagatpura, Jaipur Rajasthan
Latitude	26.8090
Longitude	75.8613
Maximum	37˚C (Summer)
	22˚C (Winter)
Minimum	25.8˚C (Summer)
	5˚C (Winter)
Average Wind Speed	3.34 ms^{-1}
Average rainfall per annum	60-70 mm
Dimension of site	
Thickness of the roof	8'
Space for the control room	16 x 9 $ft.^2$

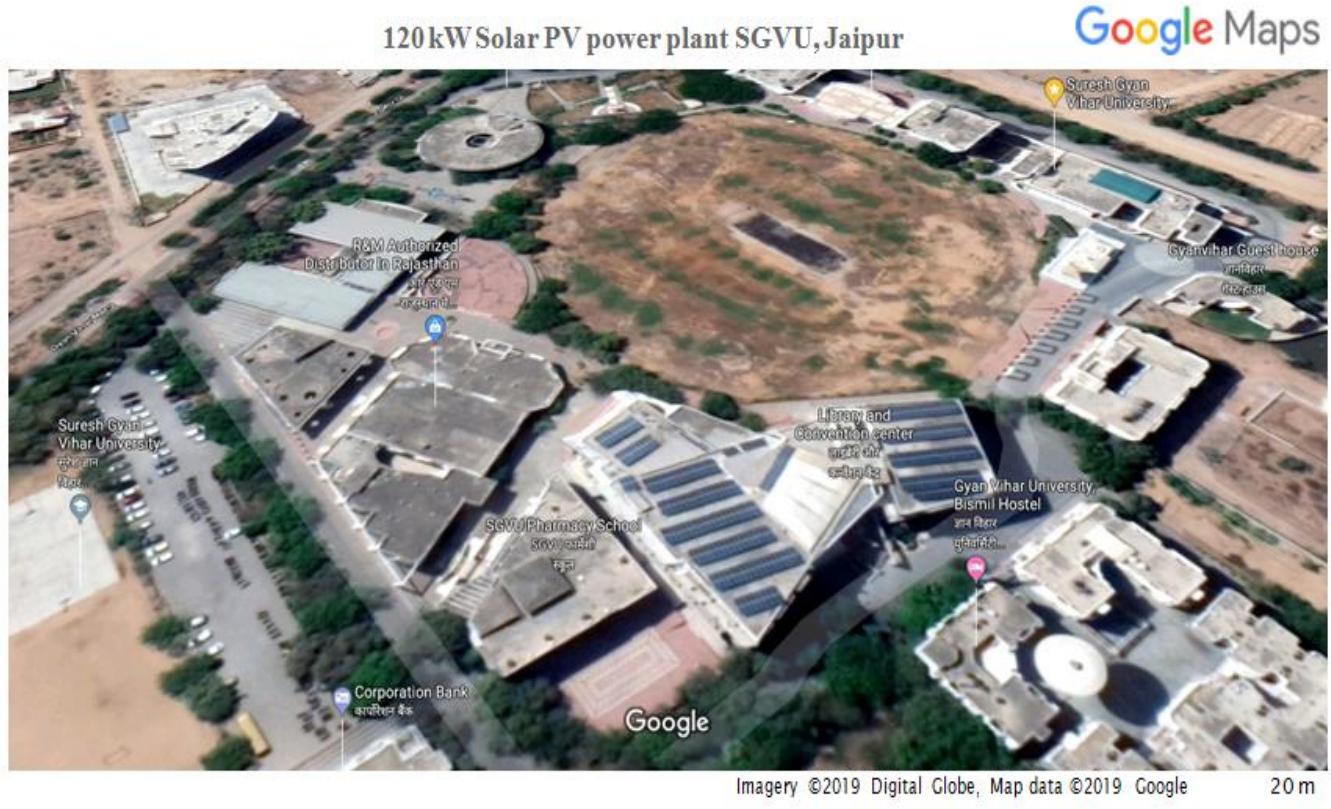
Load demand of the site under all seasonal changes is shown below in table. The average daily energy consumption for the site is varies between 800 to 820.52 kWh during a year.

TABLE 2 Details of Load

Load	Number	Power (Watt)	Use (hours)	Energy Demand (kWh day^{-1})
Spring (March-May)				
PC	485	150	5	363.75
Fan	1075	70	6	451.5
Tube Light	775	40	4	124
AC	18	1600	4	115.2
Projector	22	200	2	8.8
Total of daily energy demand				1063.25
Total demand for spring season				**95692.5**
Summer (June- August)				
PC	485	150	5	363.75
Fan	1075	70	6	451.5
Tube Light	775	40	4	124
AC	18	1600	4	115.2
Projector	22	200	2	8.8
Total of daily energy demand				1063.25
Total demand for summer season				**95692.5**
Autumn (September- November)				
PC	485	150	5	363.75
Fan	1075	70	2	150.5
Tube Light	775	40	4	124
AC	18	1600	2	57.6
Projector	22	200	2	8.8
Total of daily energy demand				704.65
Total demand for autumn season				**63418.5**
Winter (December- February)				
PC	485	150	5	363.75
Fan	1075	70	0	000
Tube Light	775	40	4	124
AC	18	1600	0	000
Projector	22	200	2	8.8
Total of daily energy demand				496.55
Total demand for winter season				**44689.5**
Total Annual Demand (Load)				**299493**

Plant Operation

120kW Solar PV power plant at roof top of main library building: Poly Crystalline Silicon modules, PV array, storage battery and PCU (power conditioning unit) are combined in it. PCU includes a regulator and an inverter (to convert DC into AC). Loads are directly connected to solar panels, battery



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Geographic Location of plant

Fig. 5 Geographic Location of 120kW Solar PV Power Plant at SGVU, Jaipur

and grid through PCU. During peak sunny days, load demand is supplied through solar energy [2]. If the demand is not fully satisfied by the solar energy then power is taken from grid to maintain the power balance and also supplied the energy to the grid under minimum load condition.[1]

Under "Capital Subsidy Scheme of RRECL/MNRE-2016-17", a 120kW solar plant is installed by Green First Power Ventures Pvt. Ltd. at SGVU, Jaipur.

TABLE 3: Electrical Load of SGVU. Jaipur

Building	kWh per year
Electrical & Electronics Block	34356
ISBM Building	6876
Round Building	275
Pharmacy Building	36547
Central Library	25124
Mechanical Block	15123
Main Building	172980
Street Lights	8212
Total Load (kWh)	**299493**

TABLE 4: Technical Specification of plant and PV module

Hours of operation	8 – 10 hours
Shading effect is discarded for this study	
System Voltage	400 V dc
Inverter Rating	400V, 25 KVA
Float Voltage	35.93 V per plate
Boost Voltage	44.64 V per plate
Operating Temperature	+5˚C to +37˚C
PV Module specifications	
Plane tilt angle	15^{o}
Array Power	120 kW_P
Type of material	Poly Crystalline Silicon
Make	ALPEX SOLAR
Model	ALP 300 W
Dimension of module	6 x 3 ft^2
Specification of each panel	300 W +/-3%, 44.67 V, 8.75 A
Number of panels	339
Number of series connected panel in each PV string	156, 27
Number of parallel connected panel in each PV string	2, 1

III. POTENTIAL OF SOLAR ENERGY ON SITE

Since, India is located in equatorial region geographically and compared to other states of India, Rajasthan has huge solar radiation potential. Jaipur's solar potential varies from 4.07 to 6.59kWh m^{-2} day^{-1} over the whole year.

TABLE 5: Month wise solar data for Jaipur

Month	ADNI	AGHI
Mar, 18	6.59	6.26
Apr, 18	6.01	7.02
May, 18	6.34	7.43
Jun, 18	4.74	6.61
Jul, 18	4.07	5.91
Aug, 18	3.68	5.37
Sep, 18	6.10	5.96
Oct, 18	6.19	5.55
Nov, 18	5.73	4.60
Dec, 18	5.44	3.98
Jan, 19	5.45	4.22
Feb, 19	6.40	5.23
Annual Average	**5.56**	**5.68**

ADNI: Average Direct Normal Irradiance (kWh m^{-2})

AGHI: Average Global Horizontal Irradiance (kWh m^{-2})

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TABLE 6: Sunshine duration

Month	Sunshine duration (in hours)	Sunny days (month wise)
Mar, 18	307	30
Apr, 18	321	22
May, 18	287.5	31
Jun, 18	360	20
Jul, 18	305.5	16
Aug, 18	279.5	10
Sep, 18	251.5	18
Oct, 18	265	31
Nov, 18	225	30
Dec, 18	228	29
Jan, 19	237.5	28
Feb, 19	256.5	22

IV. PERFORMANCE ANALYSIS METHODOLOGY (PERFORMANCE INDEX)

In this section we will discuss the methodology for analyzing the performance of a grid connected solar PV power plant. International Energy Agency (IEA) already developed some performance parameters for grid connected system. [1] Those are as follows:

- Total generated energy by the plant (E_{AC})
- Final yield (Y_F)
- Reference yield (Y_R)
- Performance Ratio (PR)
- Capacity factor (CF)
- Losses and energy flow of the system

All these parameters give information about system's performance regarding available solar resources, produced energy, losses and efficiency of the system.

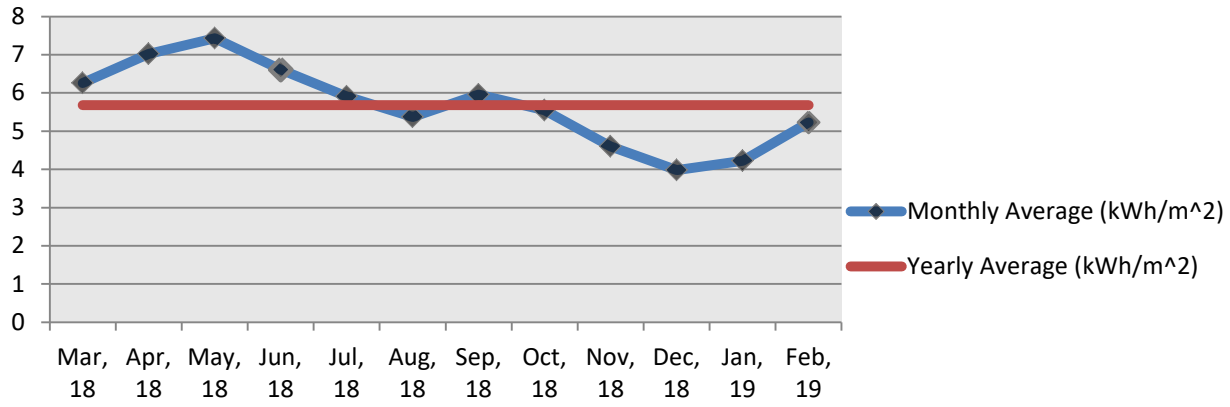

Fig. 6 Average Global Horizontal Irradiance (kWh m^{-2})

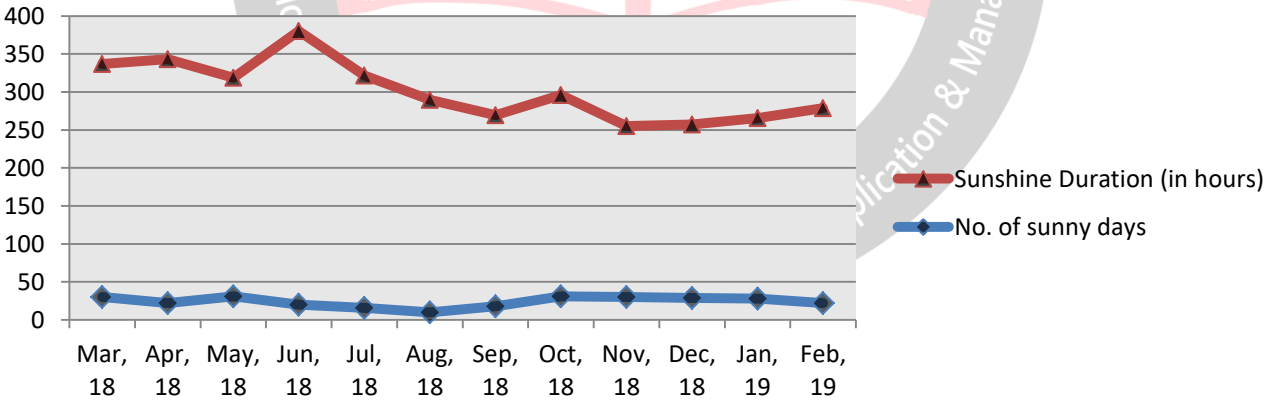

Fig. 7 Monthly Sunshine Duration (in hours)

Total generated energy (E_{AC})

To calculate total daily ($E_{AC,\ daily}$) and monthly ($E_{AC,\ monthly}$) energy (in kWh m^{-2}) by solar PV power plant, we use the following formulae: [2]

$$E_{AC,\ daily} = \sum_{t=1}^{24} E_{AC,\ instantaneous}$$

$$E_{AC,\ monthly} = \sum_{d=1}^{N} E_{AC,\ daily} \quad (1)$$

Here, N = Number of days in the month

$E_{AC,\ instantaneous}$ = Measured value at any instant

Final Yield (Y_F)

It is the ratio of total AC energy generated by the plant (E_{AC}) in a specified period to the rated output power (P_{PV}) of the installed system. [2]

$$Y_F = E_{AC} / P_{PV} \quad (2)$$

Reference Yield (Y_R)

It is the ratio of total solar insolation (H_t) to the reference irradiation (G). [2]

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$$Y_R = H_t\ (kWh/m^{-2}) / G\ (1\ kw/m^2) \quad (3)$$

TABLE 7: Month wise total energy generated by the 120kW plant

Month	Meter Reading Difference	MF	$E_{AC,\ monthly}$ (in kWh)
Mar, 18	315	40	12600
Apr, 18	320	40	12800
May, 18	336	40	13440
Jun, 18	360	40	14400
Jul, 18	398	40	15920
Aug, 18	321	40	12840
Sep, 18	325.8	40	13032
Oct, 18	311.3	40	12452
Nov, 18	383	40	15320
Dec, 18	313	40	12520
Jan, 19	320	40	12800
Feb, 19	307	40	12280
Annual Average	**334.175**	**40**	**13367**
Annual Total	**4010.1**	**40**	**160404**

Performance Ratio (PR)

It is the ratio of the final yield (Y_F) to the reference yield (Y). [2]

$$PR = Y_F / Y_R \quad (4)$$

It normalizes all the parameters and indicates the losses during the conversion of DC to AC. Performance ratio gives information of long term changes in performance of the system.

Capacity Factor (CF)

It is the ratio of actual AC energy output by the plant ($E_{AC,\ actual}$) to the rated output power (P_{PV}) of the installed system. [2]

$$CF = (E_{AC,\ actual} / P_{PV,\ rated}) \quad (5)$$

Losses and Energy flow of the system

There are certain losses occur during transforming the energy to the demand side and during conversion from DC to AC. After identifying the main sources of losses the loss diagram gives exact view of the quality of the system. [1]

There are different types of losses due to irradiance level, temperature, quality loss for module, loss due to array mismatch, loss due to ohomic wiring, full battery loss, loss due to battery efficiency etc.

TABLE 8: NORMALISED PERFORMANCE INDEX

Month	Final Yield (Y_F)	Reference yield (Y_R)	Performance Ratio (PR)	Capacity factor (CF)
Mar, 18	3.38	3.49	0.96	13.12
Apr, 18	3.16	4.31	0.73	13.33
May, 18	3.03	3.03	1.00	14.00
Jun, 18	3.33	5.67	0.58	15.00
Jul, 18	4.52	8.76	0.51	16.58
Aug, 18	4.01	7.85	0.51	13.37
Sep, 18	3.79	6.32	0.59	13.57
Oct, 18	3.76	3.76	1.00	12.97
Nov, 18	5.78	5.78	1.00	15.95
Dec, 18	5.28	5.64	0.93	13.04
Jan, 19	5.09	5.64	0.90	13.33
Feb, 19	4.36	5.55	0.78	12.79
Annual Average	**4.08**	**5.12**	**0.80**	**13.92**

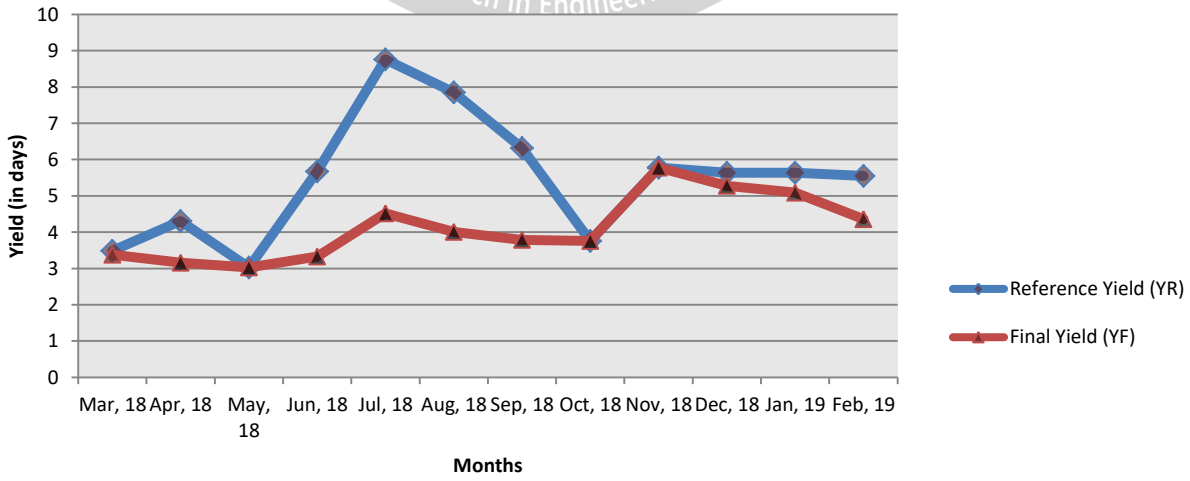

Fig. 8 Variation of monthly reference & final yield

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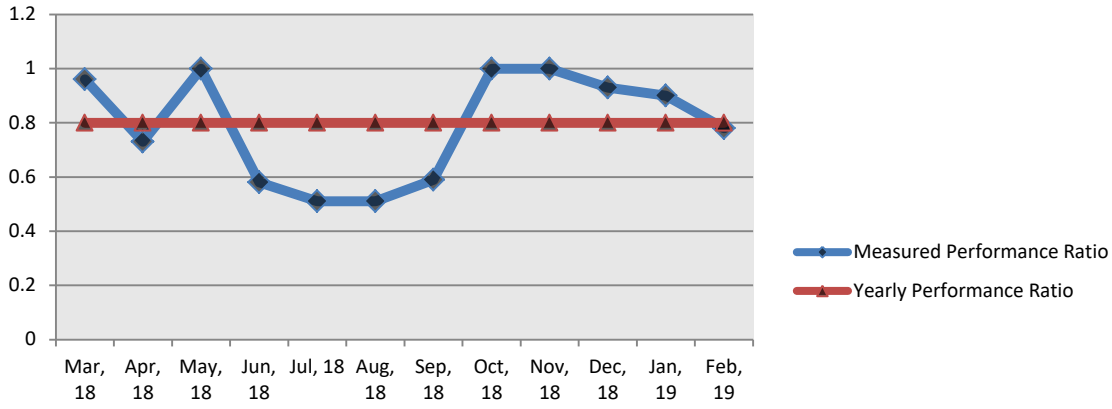

Fig. 9 Variation of monthly & yearly performance ratio

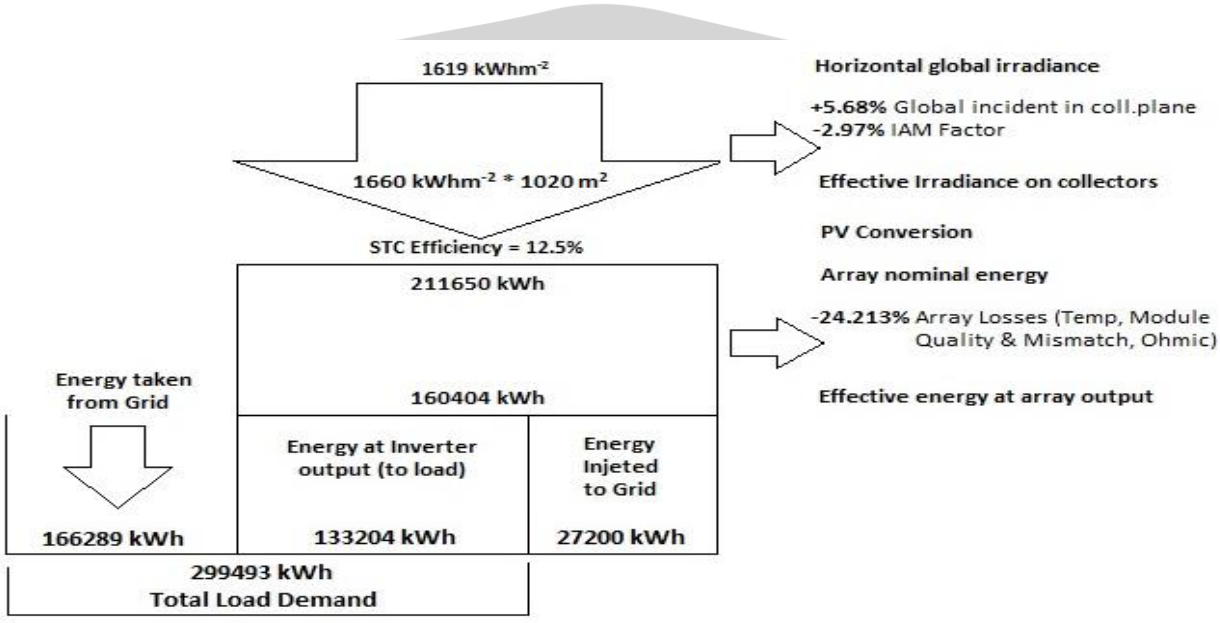

Fig. 10 Loss Diagram

Since, total energy available at plant site is 1619 kWh m^{-2} and the actual energy available at solar plate after considering IAM factor and 12.5% STC efficiency is 211650 kWh. Now due to different losses (24.213% in total) as shown in loss diagram, available energy form solar PV plant is 160404 kWh**.** From which 133204 kWh is directly given to loads during peak load demand and during light load conditions the 27200 kWh is supplied back to the grid (Grid Sub-Station, Jagatpura). Considering all losses, total energy available to load side is 133204 kWh. Since, energy demand for the site is 299493 kWh. Therefore, the remaining 166289 kWh is taken from the grid directly. [6]

So, plant is able to fulfill 44.47% of the demand and remaining 55.52% is supplied from grid.

V. RESULT AND DISCUSSION

The analysis result of measured performance parameters of SPV plant is shown. The variety of estimated month to month normal solar radiation on the tilted PV modules demonstrates that sun oriented radiation is least amid December (115.42 kWh/m2) and greatest in May (230.33 kWh/m2). [1]

The reference yield differs from 5.64 hours/day (December) to 3.03 hours/day (May). The deliberate month to month final yield differs from 5.28 hours/day (December) to 3.03 hours/day (May) (Fig. 8). The performance ratio goes somewhere in the range of 51 and 100% with a yearly normal estimation of 80% (Fig. 9). The month to month normal yearly capacity factor is observed to be 13.92% (Table 8), and efficiency of the plant as 75.78%. [2]

Solar PV power plant's performance is depends on accessible occurrence sun radiation on the plane of exhibit of the PV modules. In this manner, the modules are kept slanted as for the flat surface confronting south in order to amplify the sunlight based radiation.[2] The PV modules at SGVU, Jaipur are kept at tilt edge 41.8˚ during winter and 11.8˚ during summer.

In India the intensity of solar radiation is greatest amid the summer months (April to June) and least amid the winter months (November to February). Result shows that during summer due to less tilt angle solar radiations are not fully used.

All things considered the energy yield of the sunlight based power plant is most extreme amid September and October and less amid summer months. This demonstrates the ideal tilt edge is required to be decided for this plant in order to get extreme power consistently. As of now there is

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an arrangement for changing the tilt edge of the module which can be used once month to month.

VI. CONCLUSION

Clean and sustainable energy is the whopping demand of the present. Solar PV is one of the most suitable options as decarbonized energy source and also the alternative for future demand. Due to India's geographical location, it is very effective for injecting the surplus demand. [1]

In this paper various performance parameters are measured for 120kW solar power plant at Suresh Gyan Vihar University, Jaipur and the result shows that it can supply 44.47% of the total demand of the university. Remaining 55.52% is taken directly from the grid.

TABLE 9: ENERGY ACCOUNTING ABSTRACT OF THE PLANT

Performance Parameters	Exact data
Total average energy generated by the plant (E_{AC})	13367 kWh
Final yield (Y_F)	4.08
Reference yield (Y_R)	5.12
Performance Ratio (PR)	0.80
Capacity factor (CF)	13.92

At present two new solar PV power plants (40kW & 80kW) are also installed at SGVU, Jaipur.

These all installations will improve the healthy environment by reducing the pollution indirect way. As we know that Solar energy is used because for less availability of fossil fuels and it is emission free also. Suresh Gyan Vihar University will install more solar power to reduce emission level of environment and it will also help the government. SGVU wants to produce more energy so that all the 17 buildings of the campus can run on this energy and remaining energy is supplied back to the grid by taking the advantage of on grid.

VII. ACKNOWLEDGEMENTS

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