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Simulation and Performance Analysis of 100 KW_p Grid Connected Rooftop Solar Photovoltaic Plant Using PVSYST

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Abstract: ***The increasing energy demand in developing nations has triggered the requirement of energy security. This has made essential to utilize the potential of renewable energy resources. One of the best alternatives in renewable energy at large scale is grid connected solar photovoltaic systems. Performance evaluation of these grid connected solar PV plant is one of the most important aspect to assess the real-time behavior. Performance analysis could help in designing, operating and maintenance of new grid connected solar photovoltaic (PV) systems. In this study performance evaluation of 100 KWp rooftop solar photovoltaic grid connected power plant commissioned at Poornima University, Jaipur is carried out. In this paper, the solar photovoltaic plant design aspects and its annual performance is elaborated. The various power losses such as losses due to temperature, losses due to internal network, power electronics losses, grid connected losses etc. and performance ratio are also calculated. The performance results of the 100 KWp rooftop solar photovoltaic plant are also compared with the simulation values obtained from PVsyst V 6.39 software. The average final yield (Y_F) of the solar PV plant ranged from 1.60 to 5.60 h/d, and average performance ratio (PR) of 77.79% and capacity utilization factor (CUF) of 18.10% for September 2017 power generation are obtained.***

Keywords: Solar Energy, Solar PV Plant, Simulation, PVsyst V6.39, Solar Rooftop, Photovoltaics, Energy Efficiency.

1. Introduction

The 100 KWp roof top solar photovoltaic (PV) system installed at the Poornima University, Jaipur serves as model for the installation of rooftop solar PV systems in institutional sector in India, which could play a major role in energy self-sufficiency and security while solving the nation’s greenhouse gas emission problem. The main purposes of 100 KWp rooftop solar photovoltaic (PV) plant were:

1) To provide electricity to the University through renewable source
2) To support research and development by providing system performance data.

The solar photovoltaic systems are one of the most promising and cost-effective substitute for diesel generators in developing countries like India. In India most of the people lives in rural and remote areas where either the grid is not available or electricity is not available all the time. The authorities in Spain are supporting a rural electrification project of 65 sites with 50 kW_P Solar PV systems [1]. A 1 kW_p SPV system was implemented in Jordon to supply power to houses for 24 hours [2]. For climatic conditions of Dhaka Bhuiyan and Asgar had designed a Solar PV system for 4 hours of operation per day for a residential area [3].

In electricity generation, India is presently the sixth-largest country and accounts for approximately 4% of the world's total annual electricity generation. India is ranked sixth in annual electricity consumption. Fossil fuel based electricity generation systems are responsible global warming and therefore affecting the environment. Therefore, it is necessary to generate electricity by some renewable sources which are environment friendly in nature. According to data released by the Ministry of New and Renewable Energy (MNRE), total solar energy installations in India have reached 4.1GW [4]. A total of 358MW of grid-connected solar energy capacity has been installed in the first four months of this financial year 2015/16, with a target to deploy 1.4GW by the end of the fiscal year. In the off-grid solar PV installations, a total of 234MW has been installed [4]. Solar power technology remains the fourth-largest in terms of installed capacity among all renewable energy technologies in India.

2. Specification of plant

The rooftop solar photovoltaic (PV) plant at Poornima University, Jaipur is of 100 kWp capacity. From the site of MNRE, India it was found that Rajasthan has average solar irradiation of 1266.52 W/m2 and average sunshine hours is 5.5 hours. The plant will produce approximately 450 kWh per day and approximately 1,50,000 kWh per annum [5]. The per unit cost of electricity generated by 100 kWp grid connected rooftop solar photovoltaic system is Rs. 3.37/kWh. The total CO_2 emission mitigation from the 100 kWp grid connected rooftop solar photovoltaic system considering life of plant to be 30 years is found to be 7065000 Kg or 7787.82 ton. The carbon credit potential of 100 kWp grid connected rooftop solar photovoltaic system installed at Poornima University is found to be Rs. 13286020.92 [5].

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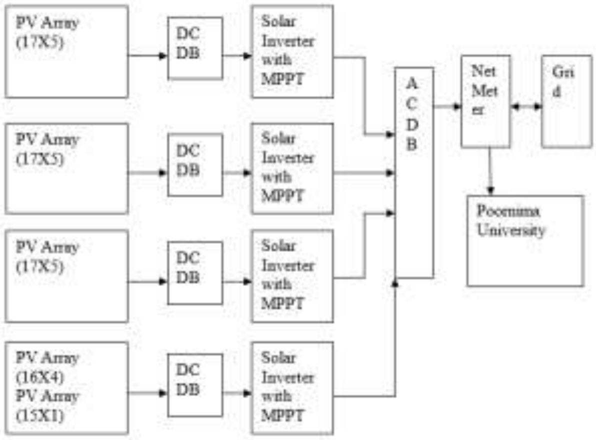

Figure 1: Block Diagram of 100 kW_P rooftop solar power plant at Poornima University

Figure 2: 100 kW_P rooftop solar power plant at Poornima University

Table 1: Specification of 100 kW_P rooftop solar power plant at Poornima University

Solar PV Module	
Model	ELDORA 300
Make	300 W
Open Circuit Voltage	45.1 V
Short Circuit Current	8.74 A
Maximum Current	8.05 A
Maximum Voltage	37.28 V
Efficiency	15.63 %
Fill Factor	76.13%
NOCT	45 ^{0} C
Number of Module	334
Solar Inverter	
Model	STP 25000TL-30
Number of Inverter	04
V (DC, maximum)	1000V
I (DC, maximum)	33A
V (DC, max. power point)	390-800 V
I (SC, PV)	43 A
Power	25 kVA
I (AC, maximum)	36.2 A

3. Performance Parameters

Array yield

Array yield is equal to the time for which the solar photovoltaic plant has to operate with nominal solar power Po to generate array energy E_A (Direct Current). Its units are kWh/d∗kWp.

$Y_A = E_a/P_O$

where, Array energy output per day $E_A = I_{dc}*V_{dc}*t$ (kWh),

I_{dc} = DC current (A)

V_{dc} = DC voltage (V)

P_0 = Nominal Power at STC.

Final Yield (Y_F)

It is the ratio of net energy output of the solar photovoltaic system to the rated power of the installed solar photovoltaic system [6-7]. Final yield provides the number of hours required by the solar photovoltaic system to operate at rated power to the yield the net energy. It is the normalized value of system energy output with respect to system size. Final yield estimates the solar photovoltaic system performance in terms of solar radiation resource.

$$Y_F = \frac{\text{System Energy Output}}{\text{System Rated Power(dc)}}$$

Reference Yield (Y_R)

It is the ratio of total in-plane solar insolation to the reference irradiance of solar photovoltaic system [6-7]. Reference radiation is considered as 1000W/m2 at STC. Reference yield normalizes the available solar radiation with reference radiation. It measures the solar energy input for required output. It generally depends on site geographical condition, weather conditions and orientation of solar photovoltaic array. Reference Yield for the solar photovoltaic plant is the actual energy plant would have been generated under STC 1000W/m2, 250C,1.5 Air mass and no wind.

$$Y_R = \frac{\text{Total In-Plane Solar Insolation}}{\text{Reference Irradiance}}$$

Performance Ratio (PR)

Performance ratio is a dimensionless quantity and is defined as the ratio of final yield to the reference yield [6-7]. Performance Ratio gives details about the day impact of overall system losses on the rated output. The losses include solar photovoltaic array losses, tilt angle losses, loss due to dust, loss due to shade, loss due to variation in module temperature. Performance ratio has effect on system down time and failure of components. It is used to analyze the performance of solar photovoltaic system annually and decrease in performance ratio is an indicator of the degradation of the system performance. Performance ratio will indicate how close the solar photovoltaic plant is able to approach the ideal performance in real time conditions. Mathematically it is expressed as,

$$\text{PR} = \frac{\text{Final Yield}(Y_F)}{\text{Reference Yield}(Y_R)}$$

Capacity Utilization Factor (CUF)

Capacity Utilization Factor (CUF) is defined as the ratio of actual energy output of the solar photovoltaic system to the energy output system would generate if it works at rated power for 24 Hrs/day/month/year. It is a dimensionless quantity and used to evaluate the performance of solar PV units [14].

CUF = Energy measured (kWh)/(365 ∗ 24 ∗ installed capacity of the plant).

To evaluate the various losses involved in solar photovoltaic system it is necessary to calculate array yield, capture losses and system losses. Capture losses includes thermal loss which depends on solar module temperature and other losses which depends on losses due to dust accumulation, variable irradiation etc. System losses include DC and AC cabling losses.

Inverter efficiency

The ratio of AC power generated by the inverter to the DC power generated by the PV array system is called inverter efficiency. The instantaneous inverter efficiency is given by, $\eta_{inv}=P_{AC}/P_{DC}$.

System efficiency

The instantaneous daily system efficiency is given as solar photovoltaic module efficiency multiplied by inverter efficiency.

$\eta_{sys,T} = \eta_{PV,T} * \eta_{inv,T}$.

Energy output or energy fed to utility grid

The energy generated by the solar photovoltaic system is the measure of energy across the inverter output terminals for every minute. It is defined as the total daily monitored value of AC power output and the monthly AC energy generated.

Array Yield (Y_A)

Array yield of the system is the ratio of annual/monthly/daily energy output to the installed capacity of PV system.

$$Y_A = \frac{E_A(KWhAC)}{P_r(KwDC)}$$

Capture Loss (L_e)

The difference between reference yield and array yield is called Capture losses.

$$L_c = Y_R - Y_A$$

System Loss (L_s)

The difference between array field and final yield is called System losses.

$$L_s = Y_A - Y_f$$

The performance of 100 KWp rooftop solar PV plant was carries out and the performance ratio (PR) was found to be in the range of 0.46 to 0.78 and the variation is shown in figure 3. The reference yield was found in the range of 4.5 to 6.9 h/d and the final yield was found in the range of 1.6 to 5.6 h/d for power generation by solar photovoltaic plant in September 2017 and shown in figure 4. The capacity utilization factor (CUF) of 100 KWp rooftop solar PV plant was found in the range of 0.08 to 0.25 and the variation is shown in figure 5. The results so obtained from experimental data are compared with simulated data using PVsyst software.

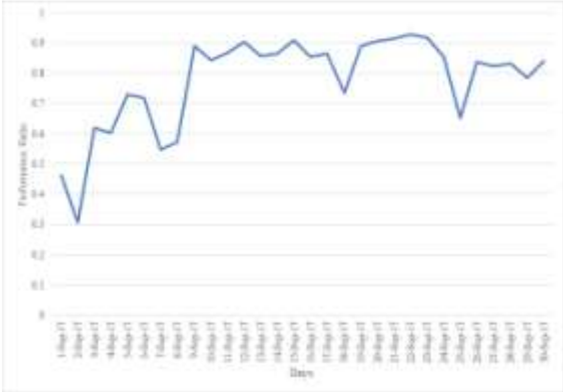

Figure 3: Variation of Performance Ratio for September 2017

Figure 4: Variation of reference yield (Y_R) and final yield (Y_F) for September 2017

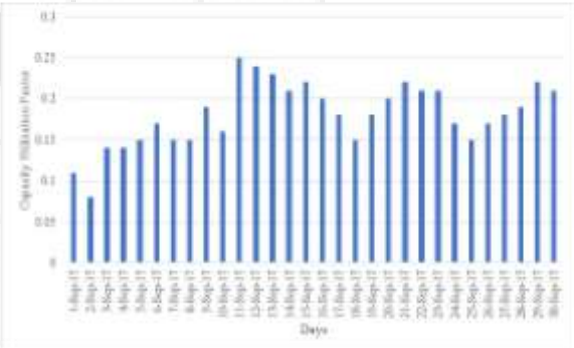

Figure 5: Variation of capacity utilization factor (CUF) for September 2017

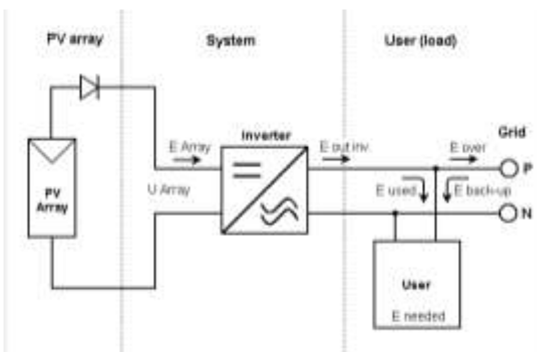

Figure 6: Block diagram of system

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Collector array

PV Array Characteristics
PV module Si-mono Model **XM60/156-300I35**
Manufacturer Sunera Solar
Total area Module area **521 m²** Cell area 456 m²
Inverter Model **Sunny Tripower 25000TL-30**
Manufacturer SMA
Characteristics Operating Voltage 390-80Unit Nom. Power 25.0 kWac

PV Array loss factors
Thermal Loss factor Uc (const) 20.0 W/m²K Uv (wind) 0.0 W/m²K / m/s
Wiring Ohmic Loss Global array res. 70 mOhm Loss Fraction 1.5 % at STC
Module Quality Loss Loss Fraction -0.5 %
Module Mismatch Losses Loss Fraction 1.0 % at MPP
Incidence effect, ASHRAE paramIAM =o1 - bo (1/cos bo Param. 0.05

Effect of each loss on the array characteristics
For given operating conditions (static loss values, not valid over a running period!)

External Operating Conditions
Irradiation 1000 W/m² Ambient Temper. 25 °C
Incidence Angle 27° Wind Velocity 1.0 m/sec
Beam/Global ratio 80 %

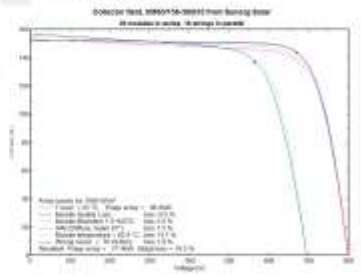

Figure 7: Simulation of 100KWp rooftop solar power plant using PVsyst

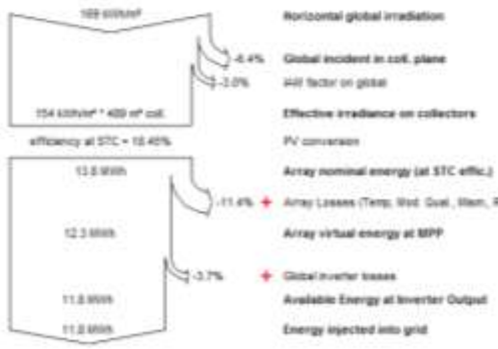

Figure 8: Sankey Diagram of estimated Losses of 50KWp PV plant

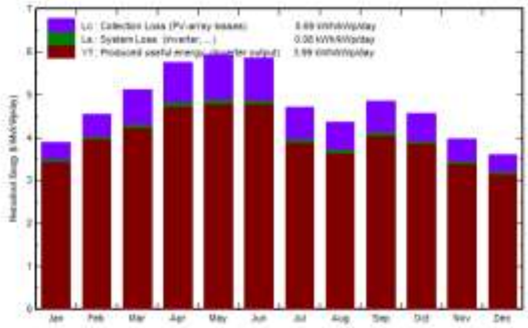

Figure 9: Normalized production per month

Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	124.0	15.10	120.3	115.1	9773	9580	16.63	16.30
February	131.9	18.00	127.5	122.9	10190	9988	16.35	16.03
March	169.3	24.40	158.4	153.6	12065	11822	15.59	15.27
April	183.3	29.10	172.7	168.0	13050	12786	15.47	15.15
May	197.8	31.50	184.4	179.2	13655	13378	15.16	14.85
June	187.2	30.80	175.6	170.8	13186	12920	15.37	15.06
July	158.1	28.40	145.8	141.5	11091	10867	15.57	15.26
August	146.0	27.40	135.0	130.8	10373	10164	15.73	15.41
September	153.6	27.30	145.5	141.3	11190	10966	15.74	15.43
October	148.5	25.70	141.6	137.1	10989	10773	15.88	15.57
November	124.8	21.30	119.2	114.3	9363	9176	16.08	15.76
December	115.9	16.80	111.6	106.3	8949	8771	16.41	16.08
Year	1840.4	24.68	1737.6	1680.8	133871	131190	15.77	15.45

Figure 10: 100KWp rooftop solar power plant output

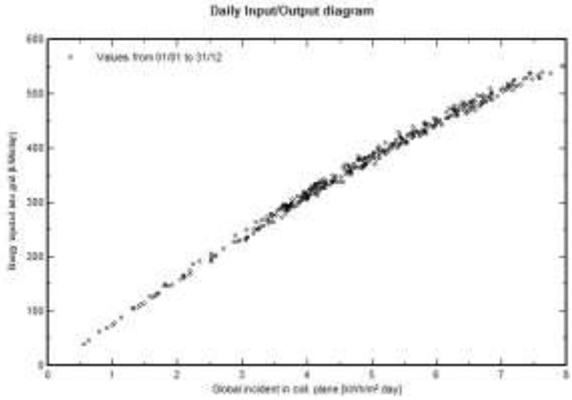

Figure 11: Daily input and output diagram

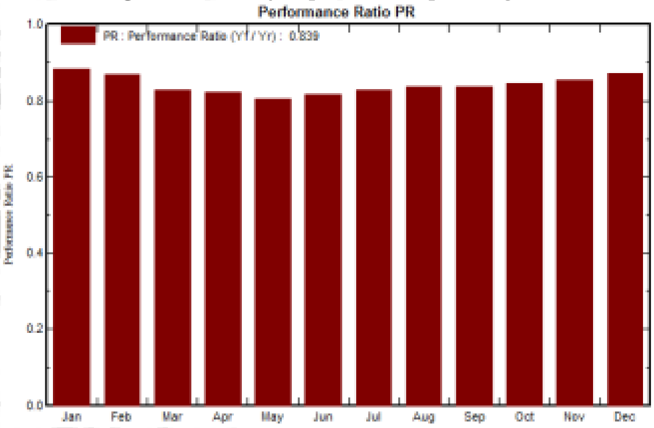

Figure 12: Performance ratio (PR) per month

4. Conclusion

Performance analysis of 100 KWp rooftop grid connected PV system installed at Poornima University, Jaipur had been investigated. Following observations were drawn:

1) Average daily energy output in September 2017 is 423.342 KWh.
2) Average daily performance ratio (PR) in September 2017 is 77.79%.
3) The average capacity utilization factor (CUF) in September 2017 is 18.10%.

The performance evaluation study throws light on different aspects related to plant operation and further expansion. Comparison of performance parameters like performance ratio (PR) and capacity utilization factor (CUF) for solar photovoltaic plants at different locations is summarized in table 2. If the performance ratio is maintained above 0.85, it results in optimal design without shading effect. Capacity utilization factor is an important measure to assess the output energy of solar photovoltaic system. It has impact on economics of the system.

Table 2: Comparison of performance parameters like performance ratio (PR) and capacity utilization factor (CUF)

S. No.	Plant Location	Performance Ratio	CUF
1	Tenneessee Plant TN, United states [8]	0.75-0.89	0.08-0.21
2	PV park, University of Cyprus [9]	0.74-0.85	
3	Faculty of Engineering, DEI, Agra, India [6]	0.47-0.91	0.06-0.13
4	Dublin, Ireland [10]	0.72-0.91	0.05-0.15
5	Tulin Village, Nepal [11]	0.29-0.40	
6	Solar Energy demonstration complex, Chosun University, Korea [12]	0.57-0.73	
7	Khatkar Kaln, India	0.74(average)	
8	Vishnu Solar Plant, India [13]	0.55-0.89	0.02-0.107
9	Ramagundam, India [14]	0.86 (average)	0.17 (average)
10	Poornima University, Jaipur, India	0.78 (average)	0.18 (average)

5. Acknowledgement

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