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Performance Analysis of Solar PV System of Teaching Hospital, Kathmandu, Nepal

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Abstract

Grid connected and off-grid roof top solar PV systems have been installed at various places, either to export energy to grid or to reduce electrical bills in an industry, hospitals, etc. A 115 kWp solar PV plant with 115kVA On-grid inverters, 54kVA off-grid inverters and 3 identical battery banks of 48 kWh was installed at Teaching Hospital, Maharajgunj. The aim was to perform performance evaluation for a time of one year and to compare obtained results with simulated values from PVSYST. The actual data of generation has been extracted through sunny portal web monitoring box and weather data has been taken from NASA website as well as Department of Science and Humanities, Pulchowk Campus, Institute of Engineering, Lalitpur, Nepal.The main objective was to calculate the performance parameters of existing solar plant installed at B and C blocks of Teaching Hospital, providing power to Intensive Care Units and Operation Theatre loads and it has been found that the performance ratio was 17.41%, capacity utilization factor 3.52% and specific yield was 304.25 kWh per kWp per year and annual energy generation of 34.99 MWh.

Keywords

Performance Parameters – PVSYST– Specific Yield– Performance Ratio

1. Introduction

The recent trend towards energy diversity and use of alternative sources of energy such as solar PV has been in increasing with time. Solar PV, undoubtedly has been considered as one of the major alternative sources of energy. The on-grid and off-grid are two different types of solar system whereas tracking of panels towards the sunlight can be done to increase irradiance falling on panel surface and hence ultimately increase solar panel output in two ways- electrical and mechanical tracking. Electrical tracking, also known as MPPT tracking whereas mechanical tracking can be done on a daily basis or seasonal basis, however its increasing cost permits its use in some cases. Nepal receives a daily irradiation of 4.5-5 kWh/m^2/day whereas Germany receives only 2-3 kWh/m^2/day [1].A comparitive study of grid-tied system of Kathmandu and Berlin shows that 70% higher amount electrical energy can be fed into grid at Kathmandu as compared to Berlin under identical conditions [2]. In the modern era renewable energy generation technologies have broad societal impact and need to be assessed considering multiple perspectives including: social, technological, economic, environmental, and political (STEEP) [3]. The Performance Evaluation of a 2kW rooftop solar PV plant at Serbia [4] for the period from January 1, 2013 to January 1, 2014 found that the annual energy efficiency decreased with increase in ambient temperature and the annual PR was 93.6% and CUF was 12.88%.The performance of proposed 400kWp grid connected solar PV system at Dhalipur was studied by Kanchan Matiyali et al. [5] and performance ratio and several types of power losses were calculated. The value of performance ratio was calculated around 78.1%. During the feasibility study of PV solar plant at Algeria, Ali Malek et al. [6] found that the seasonal tilt gives 5% more energy as compared to fixed tilt. The case study and analysis of dust on efficiency of solar panel was observed at Kathmandu by Basanta et. al. [7] which discussed that the power output decrement due to dust deposition was found to be 3.16% in one day and reaching 10.41% in ten days and 15.74% in a month. Also, a cleaning device with brushes, slider and DC motor was proposed. The performance analysis of 10 MW grid connected solar PV system was done in India by B.Shiv Kumar and K. Sudhakar [8] and results were compared to those from PVSYST and the performance ratio was observed to be 86.12% whereas Capacity Utilization Factor 17.68% and average solar irradiation 4.97 kWh/m^2/day. Thus, this paper focuses on calculation of the actual performance parameters as per International Electrotechnical Commission standards and compare the actual values with simulated values from PVSYST as well as recommend some techniques to optimize genration of existing PV system.

2. Methods and Methodology

The research was done at a specific site and the system details are explained below.

2.1 Description of Solar System

2.1.1 Site Location

The Tribhuwan University Teaching Hospital is located at 27.73^{0}N, 85.73^{0}E at Maharajgunj, Kathmandu at an altitude of 1327m. The sun path diagrams has been calculated from the PVSYST software. The solar tilt angle is 30 degrees and azimuth angle is 180 degrees.

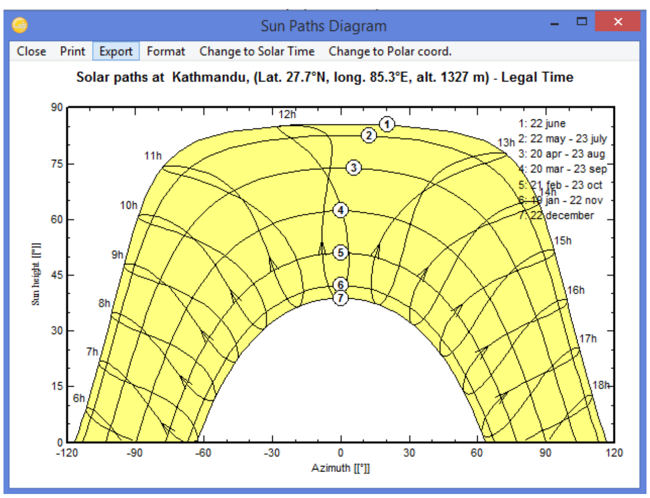

Figure 1: Sun Path Diagram of TUTH, Kathmandu(PVSYST)

2.1.2 PV Module

The solar panels used are Risen Polycrystalline modules, 72 cells, each rated 300Wp with V_{OC} of 45V and I_{MP} of 8.27 A and I_{SC} 9.27 A. There are altogether 10 combiner boxes, where the output of solar panels (DC) has been connected.

2.1.3 Inverters

The SMA inverters with multiple MPPT inputs have been used with MPPT working voltage range 390V to 800V. There are five On-Grid inverters, four inverters rated 25kVA and fifth inverter rated at 15kVA. They produce 3 phase AC output at 400V. Nine numbers of single phase off grid inverters were installed and used as three clusters of 3 phase inverters, each set comprising of 3 single phase inverters. Each cluster is connected with a battery bank of 1000 Ah@ 48V. One of these clusters are used as master cluster and rest two clusters are connected as slave clusters. The master clusters controls the slave clusters during operation. Again each cluster consists of individual master inverter which controls the remaining two inverters in the same cluster. The reverse power flow to the grid is controlled by off-grid inverter through reverse power flow relay.This relay is activated when off-grid inverter senses reverse power flow to grid and thus disconnects the grid source through an external contractor. The maximum power handling capacity of off-grid inverter used in this system is half of the capacity of on-grid inverters only.

2.1.4 Block Diagram

The solar panel input is connected to combiner boxes, whose output is fed to On-Grid inverters, producing 3 phase AC output at 400V. The multicluster box is a bus bar with common interconnection between On-grid and Off grid inverters, load and Grid/Diesel Generator Supply. The off-grid inverters charge the battery when solar energy is excess than load demand, whereas they provide supply to load from battery when load demand is higher than solar PV generation. The off-grid inverters also provide signal to external contractor when power flow occurs from PV system to the grid, thus restricting reverse power flow. The off-grid inverters disconnect the battery to load, if heavily discharged and disconnect from the solar PV, if fully charged. The 600A High Rupturing Capacity fuse is connected between battery and Off-grid inverter for deep discharge protection of the batteries. There are 3 identical battery banks, each having 24 batteries, each rated 2V@1000Ah. The literature review regarding combination of On-Grid inverter with Off-grid inverter with no energy flow to the grid shows that the output of inverters will be reduced to the lower value (54 kVA) only. Thus, the system is behaving like 54kWp system instead of 115.2 kWp system.

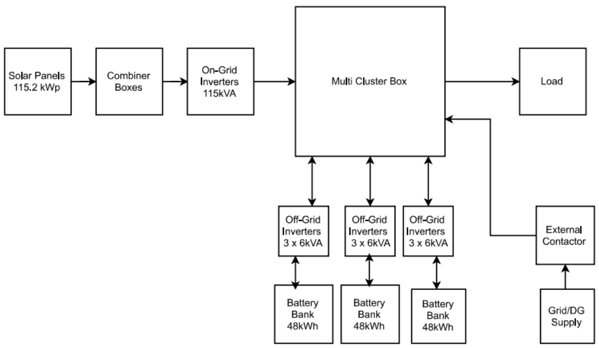

Figure 2: System Block Diagram (Courtesy: Teaching Hospital)

2.2 Methodology

The performance of PV system is divided into three stages:
i. Manually extract the data of the system (Generation in kWh) through Sunny Web Box.
ii. Calculate the performance parameters as per International Electrotechnical Commission (IEC) standards .
iii. Calculate the estimated performance parameters of system by simulation in PVSYST.

Parameters describing energy quantities for the PV system and its components have been established by the International Energy Agency (IEA) Photovoltaic Power Systems Program and are described in the IEC standard 61724 [9]. The performance parameters of the PV system are specific yield, performance ratio, and capacity utilization factor. The study period has been taken for 1 year from the date of installation (13 September 2016 A.D.) The total generation (kWh) has been recorded and extracted through Sunny Web-Box. The reference yield Y_R is the total in-plane irradiance H divided by the PV's reference irradiance G. It represents an equivalent number of hours at the reference irradiance. The target yield is the theoretical annual energy production (on the DC side of the module), only taking into account the energy of the incoming light and the module's nominal efficiency [10]. The system yield Y_F is the net energy output obtained divided by installed DC power capacity of the system. Its unit is kWh/kWp.

$$\text{Specific Yield} = \frac{\text{Actual Energy From the Plant (kWh)}}{\text{Total Plant Capacity (kWp)}} \tag{1}$$

The performance of a PV power plant is often denominated by a metric called the capacity utilization factor. It is the ratio of the actual output from a solar plant over the year to the maximum possible output from it for a year under ideal conditions [10]. Capacity utilization factor is usually expressed in percentage.

$$\text{CUF} = \frac{\text{Actual Energy From the Plant (kWh)}}{\text{Plant Capacity (kWp)} * 24 * 360} \tag{2}$$

The ratio of actual to theoretically possible energy output is known as performance ratio. The performance ratio is a measure of the quality of a PV plant that is independent of location and it therefore often described as a quality factor. The performance ratio (PR) is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant.

$$\text{PR} = \frac{\text{Actual Energy From the Plant (kWh)}}{\text{Calculated, nominal plant output in kWh}} \tag{3}$$

3. Results and Discussion

3.1 Observed Primary Parameters

The actual field parameters were obtained from the help of Sunny Web Box monitoring system and the irradiance data was obtained from Department of Physics, Pulchowk Campus, Lalitpur, Nepal. The load connected to the system was measured using energy meter and average value was found to be 28kWp.

3.1.1 Insolation

The variation of irradiance in the graph shows that it is maximum at May-June and least at Dec-Jan. It follows usual pattern for irradiance but it is slightly less in July and August.

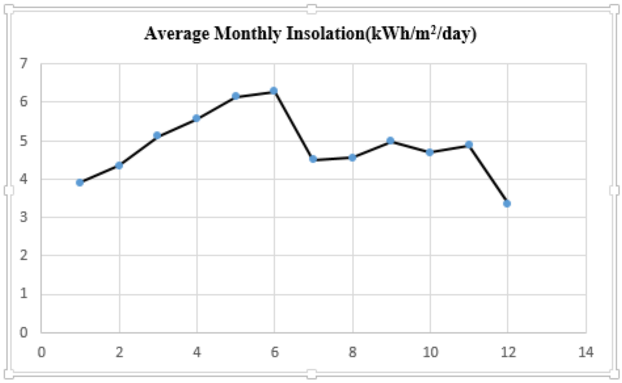

Figure 3: Monthly Irradiance Variation over the year

3.1.2 Monthly Generation, Specific Yield, Performance Ratio and Capacity Utilization Factor

The table shows the actual primary measured datas and performance parameters calculation on a monthly basis.

Table 1: Evaluated Performance Parameters

Month	Irr_G kWh/m^2	E_{GEN} kWh	Y_F kWh/kWp	PR(%)	CUF (%)
Jan	3.9	2142.02	18.63	15.43	2.58
Feb	4.35	1954.24	16.99	13.97	2.36
Mar	5.12	2584.16	22.47	14.16	3.12
Apr	5.57	4271.15	37.14	22.25	5.15
May	6.15	4795.02	41.7	21.89	5.78
June	6.29	4155.76	36.14	19.17	5.01
July	4.5	3073.66	26.73	19.18	3.71
Aug	4.55	824.52	7.17	5.09	0.99
Sept	4.99	3574.63	31.08	20.78	4.31
Oct	4.69	2086.24	18.14	12.48	2.52
Nov	3.88	2688.49	23.38	20.11	3.24
Dec	3.35	2838.50	24.68	23.8	3.42
Yearly	**4.78**	**34998.39**	**304.25**	**17.4**	**3.52**

From the above data, the monthly variation of Energy Generation, Specific Yield,Performance Ratio and Capacity Utilization Factor of the solar PV is observed. The annual specific yield is only 304.25 kWh/kWp whereas the Performance Ratio is only 17.41%.The generation during August was minimum as the PV system was dismantled for maintenance purposes. The maximum production was during June and July wehre as minimum production during August. The PR was maximum in September(31.08%) whereas least in August(7.17%). The CUF is 3.52%, calculated annually. The tabular data can be represented in graph as:

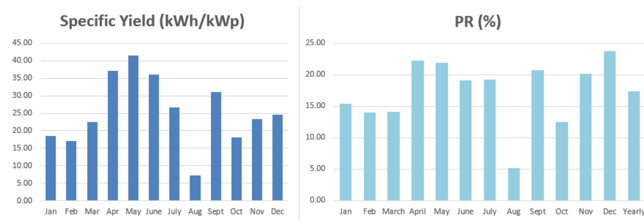

Figure 4: Specific Yield and PR Variation over the year

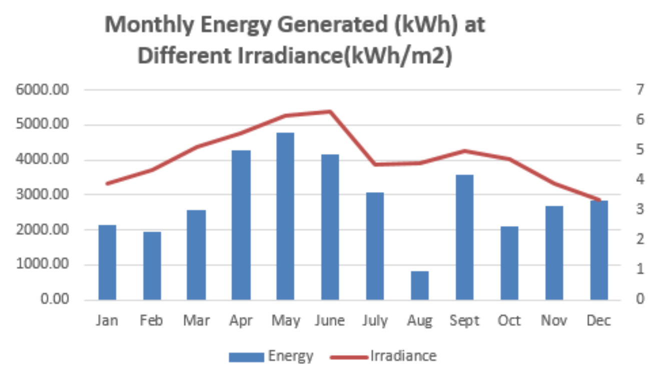

Figure 5: Monthly Energy Variation with Irradiance over the year

Thus, we can observe the variation of energy generated monthly, with irradiation. The both parameters, generated energy and irradiance are maximum during June-July.

3.2 Simulated values using PVSYST

PVSYST is a packaged software for performance evaluation of solar PV systems, widely popular for its simplicity, large database and user friendly interfacing. The simulation of PV system in PVSYST helps to provide estimated amount of energy that could be exported to it if the system was fully grid-connected with net metering. The exact model of panel and inverter using in existing system were available in PVSYST database.

Table 2: Simulation System Array

Array	Panels in Series	Parallel Strings	Total Panels	Capacity kWp
1	10	8	80	24
2	10	8	80	24
3	11	8	88	26.4
4	11	8	88	26.4
5	20	2	40	12
6	8	1	8	2.4
			Total	115.2

Thus, a system of 115.2 kWp was simulated.

The tabular data can be represented in graph as:

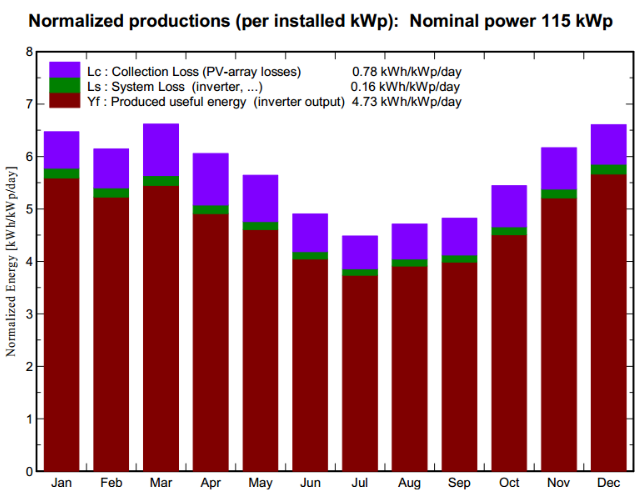

Figure 6: Specific Yield Variation over the year

b The monthly specific yield is least during July(117.1 kWh/kWp) and maximum during December(175.60 kWh/kWp). The monthly average specific yield is 114.02 kWh/kWp and total annual specifc yield is 1728 kWh/kWp. The parameters obtained from PVSYST simulation were:

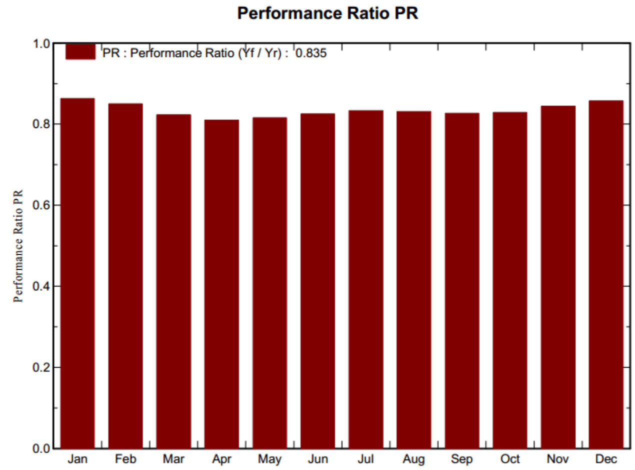

Figure 7: PR Variation over the year

The monthly PR is least during April (81.0%)and maximum during january(86.3%). The average PR is 83.5%.

New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	136.3	29.05	8.70	200.7	196.7	20.63	19.96	0.863
February	132.0	38.36	13.14	172.1	168.4	17.43	16.86	0.850
March	177.9	54.87	18.64	205.2	200.0	20.13	19.46	0.823
April	181.2	68.63	23.50	181.8	176.3	17.54	16.97	0.810
May	189.7	86.65	24.86	174.9	168.8	16.99	16.44	0.816
June	166.4	81.31	24.05	147.1	141.7	14.47	13.99	0.825
July	154.8	79.30	23.20	138.9	133.8	13.79	13.33	0.833
August	151.7	80.07	23.08	146.0	140.9	14.45	13.97	0.831
September	136.4	63.80	22.20	144.7	140.2	14.24	13.77	0.826
October	140.0	56.78	20.14	168.7	164.5	16.65	16.10	0.828
November	129.8	35.47	15.36	185.1	180.9	18.60	18.00	0.844
December	130.0	22.38	10.86	204.9	200.5	20.91	20.23	0.857
Year	1826.2	696.66	19.00	2070.1	2012.6	205.83	199.07	0.835

Legends:
GlobHor Horizontal global irradiation
DiffHor Horizontal diffuse irradiation
T Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Figure 8: Balance and Main Results

Similarly, the mean global horizontal irradiation and global diffuse irradiation are 1826.2 kWh/m^2 and 696.66 kWh/m^2. The annual mean temperature is 19 ^{o}C, with annual generation of 199 MWh.

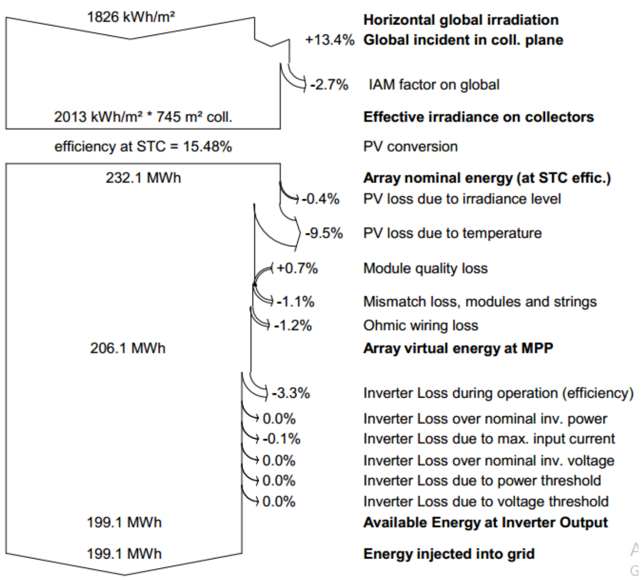

Figure 9: Energy Loss Diagrams

The energy loss diagrams show that total 232.1 MWh energy is generated but only 199.1 MWh injected to the grid with 33 MWh losses. The losses are due to irradiance loss, change in temperature, arrray mismatch losses, cable losses, inverter losses, transformer losses,etc.

3.3 Comparision between Actual and simulated parameters

The actual generation and other parameters are significantly less as compared to the PVSYST simulated parameters. The table presents the yearly analysis:

Table 3: Actual and Simulated parameters comparison

Annual Data	Actual	PVSYST	Difference	Units
$\mathbf{I_R}$	1744.1	2070.1	325.98	kWh/m^2
$\mathbf{E_{GEN}}$	34.99	199.1	164.11	MWh
$\mathbf{Y_F}$	304.25	1728	1423.75	kWh/kWp
CUF	3.52	20	16.48	%
PR	17.41	83.48	66.07	%

LEGENDS
Irr_G Irradiance in kWh/m^2
E_{GEN} Energy Generated in kWh
Y_F Specific Yield in kWh/kWp
PR Performance Ratio in %
CUF Capacity Utilization Factor in %

4. Conclusion

Thus, the observed data shows that the annual irradiance is 4.7 kWh/m^2/day, annual generation was 34.988 MWh, performance ratio 17.68%, capacity utilization factor 3.52% and specific yield 304.25 kWh per kWp per year. However, the PVSYST simulation results shows that the total estimated generation is 199.1 MWh/year, specific yield 1728 kWh/kWp/year and performance ratio of 83.48%. Similar studies at India by Omkar et. al. show that the Specific Yield 2102.196 kWh/kWp, PR 69.3% , and CUF 5.822% whereas another study by Shiva Kumar et. al. shows average annual irradiance 4.97kWh/m^2/day , PR 86.12%, and CUF 17.68%. This less generation is mainly due to following reasons:
i. The On-grid inverter and Off-grid inverter combination allows to use off-grid inverter only half of the size of on-grid inverter, thus reducing the total inverting capacity to smaller value. i.e. 54 kWp in this existing system.
ii. The off-grid inverter in this system prevents reverse power flow to grid by transferring signal to external contactor and disconnecting the grid, when panels generation exceed the load demand.
iii. Only 28 kWp load in average is connected to the system, and as energy is not injected to the grid, the system produces maximum power only to feed the load and charge the battery bank.

5. Recommendations

The system is currently working at Teaching Hospital, however its generation status can be increased by some techniques:
i. The power can be injected to grid so that excess energy will be generated. Otherwise, solar panels always generate energy only sufficient to load, despite panel size and nameplate capacity unless grid connection is available.

ii. Since power handling capacity of current inverter system is only 54kWp, remaining panels can be directly connected to grid by help of on-grid inverters.
iii. The average load consuming equipments can be increased so that generation is increased.

Acknowledgments

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