Performance Estimation of 111kWp Grid Interactive Solar PV Power Plant at Integral University

Pankaj Kumar Kanoujiya, Piyush Charan, Tahsin Usmani, Zohaib Hasan Khan

Abstract: Solar Photovoltaic (SPV) is a novel technology to harvest solar energy as and when we talk about replacing the conventional grid electricity. The degree of development of a country is measured by the amount of energy used by humans. Energy demand is increasing due to population, urbanization and industrialization. As a result conventional electricity needs to be replaced with non conventional energy resources so as to save the environment from pollution due to increased number of unwanted gases and dust particles in the air. Harmful gases like CO_x and SO_2 in the environment are affecting the Air Quality Index (AQI) and making it difficult for humans to breathe. Solar Energy is a clean and green solution to improve the AQI of the earth. In this research we study and analyze the performance of a grid interactive SPV plant installed at Academic Block-II, Integral University. In this regard, we measure the performance ratio for 4 (four) months. The effect of shading on the PV panel is reviewed due to deposition of dust particles and bird feces.

Index Terms: **Solar Photovoltaic, Grid Interactive System, Performance Ratio, Capacity Utilization Factor**

I. INTRODUCTION

Solar photovoltaic systems are one of the sustainable power systems that use photovoltaic modules to convert solar radiation into electricity [1]. The generated power can be placed or used directly, again encouraging access to the grid lines or to at least one other generator or a more sustainable power source. Solar photovoltaic systems are a very robust and clean source of electricity for a variety of applications, such as home, industrial, agribusiness, and animals.

Fig.1. Solar Energy Harvesting through SPV Panels

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Solar PV systems prove to be a cleaner source of energy that is expected to meet the targets of globally accepted climate. In India, the Ministry of New and Renewable Energy (MNRE) and other Regulatory bodies (like the UPNEDA) of the state government have taken measures to adopt large-scale PV solutions which have reduced the economic barriers that often limit the use of PV systems. The government has formulated more stringent guidelines for a low-carbon future that has attracted companies to make significant changes in their business models. These regulatory bodies are also providing a subsidy of nearly 20-50% on all projects based on the Solar PV system. This has estimated the global renewable power capacity to nearly 2019GW by the end of 2017. India is among the top five power generating countries globally with a total power generation capacity of approximately 331GW. Solar photovoltaic power generation accounts for nearly 15% of India's renewable energy installed capacity. States such as Gujarat, Tamil Nadu and now Uttar Pradesh have developed their own solar power systems to meet their growing energy needs. As much as 34 solar parks of a cumulative capacity of 20,000MW have been sanctioned across various states in India. The Ministry of New Energy and Renewable Energy has recognized the potential of other states that can generate large amounts of electricity from solar energy. Uttar Pradesh, located in the northern part of the Indian Territory, has tremendous potential to harvest Solar Energy. India has increased its solar energy production capacity by 370% in 2014-17. Prime Minister Narendra Modi ji has inaugurated Uttar Pradesh's biggest solar power plant in Mirzapur. The state already has solar power plant in Allahabad and in Jalaun district. The UP state has a cumulative solar potential of approximately 22,830MW. Uttar Pradesh's electricity demand is increasing by about 10% annually. According to reports of Uttar Pradesh Investor Summit held in 2018, Lucknow, it is predicted that by 2021-22, the current capacity of the state to produce more than 10 GW of renewable energy will increase to around 28 GW. With the increasing number of installed solar projects including both off grid and grid interactive, the government has welcomed researchers to carry out research in the renewable sector [2]. Many educational institutions are solarising their campus and have attracted researchers so that research can be focused on tapping more solar energy by using solar concentrator technology or any other technique. Integral University is located 15 Kms away from the heart of the city of Lucknow. They have a grid interactive solar photovoltaic power plant of 1MW. In this paper, we are analyzing the performance ratio of 111kW grid interactive solar photovoltaic rooftop power plant and some suggestions in the conclusion are incorporated to increase the overall capacity of the system.

II. GRID INTERACTIVE ROOFTOP SOLAR PV SYSTEM

A. *Plant layout*

The basic block diagram of the 111 kW grid interactive solar plant is shown in Fig 2.

This solar plant is mainly consists of

(i) 417 Solar Panels
(ii) DC String Array and Combiner Box
(iii) Three Inverters (PCU)
(iv) AC Distribution Box
(v) Plant AC Energy Meter
(vi) Data Acquisition System

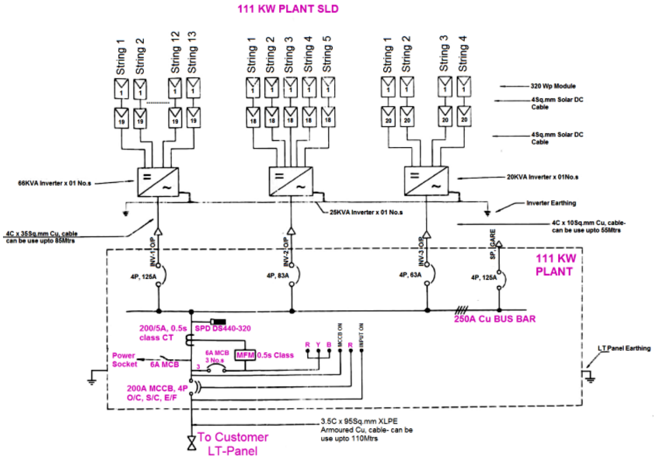

Fig.2. Plant Layout of 111kW of Grid interactive rooftop Solar PV System installed at Integral University, Lucknow

B. *Technical Specifications of the Plant*

Table1. Specifications of the Plant

Number of Modules	417
PV Technology	Polycrystalline 350 W_p
Module Manufacturer	Vikram Solar
Series Connected	19/18/20
Parallel Connected	13/5/4
Plant Rated Power	111 kWp
Area	698.5m^2
Tilt	15°
Number of Inverters	3
Manufacturer of Inverters	Schneider Electric, Germany
Rating of Inverters	66kVA×1, 25kVA×1, 20kVA×1
AC Combiner	1
Earth Pit	6
Cable	3.5c × 95sq.mm, 4c × 10sq.mm, 1c × 6sq.mm

C. PV Array

The total solar PV array installed capacity is 111kW. Individual PV module rating is of 350 watt. The PV array consists of framed multi-crystalline. A suitable number of solar PV modules are connected in series string and a suitable number of series strings are connected in parallel to formulate a series parallel array. Maximum DC output voltage of the array is nearly 1000 V. Conversion efficiency of the plant is approximately 16.49%. The front surface of the module consists of impact resistant low iron and high transmission toughened glass.

III. PERFORMANCE METRICS

A. *Performance Ratio*

The performance ratio is a measure of the quality of a photovoltaic power plant. It is position independent and is therefore often described as a quality factor [3]. The performance ratio (PR) is determined as a percentage and describes the relationship between the actual and theoretical energy output of the photovoltaic power plant. Thus, it shows the proportion of energy that can actually be used to output to the grid after deducting energy losses (eg, due to heat loss and drive losses) and energy consumption of the operation. The closer the PR value determined for a 100% PV plant is, the higher the efficiency of the corresponding PV plant will be. In real life, you can't reach 100% of the value, because the inevitable losses always occur in the operation of photovoltaic power plants (for example, heat loss due to heating of photovoltaic modules). However, high-performance photovoltaic power plants can achieve performance targets of up to 80%.

The life cycle performance ratio of the system can be estimated by using the following formulae.

(a) $Generation\ of\ one\ month\ energy = panel\ rating \times efficiency\ of\ cell\ \times days\ \times hour$ ……..(1)

(b) $Monthly\ Specific\ Yield\ \left(\frac{kWh}{kW}\right) = \frac{energy\ yield}{nominal\ solar\ power}$ … (2)

(c) $Performance\ ratio(pr) = [\{(Measured\ output\ in\ kW)/(Installed\ Plant\ capacity\ in\ kWp)\} \times \{(Measured\ radiation\ intensity\ in\ W/m^2)/(1000\ W/m^2)\}$ ……….(3)

(d) $capacity\ utilization\ factor\ (CUF) = \frac{energy\ measured(kWh)}{365\ \times 100kW \times 24}$ ……….(4)

Performance ratio informs you of the energy efficiency and reliability of your PV plant. Through the performance ratio, one can compare the energy output of the PV power plant with the energy output of other PV power plants, or monitor the state of the PV power plant for a long time. Determining the performance ratio at regular regular intervals does not provide an absolute comparison. Instead, it gives the operator the option to check performance and output: if the PV plant is supposed to run optimally during commissioning, and therefore the initial value of the performance ratio is 100%, then more PR values can be used over time. Identifying deviations means that appropriate countermeasures can be initiated quickly. Therefore, deviations in PR values below the normal range indicate that your PV plant may be malfunctioning at an early stage.

IV. PHOTOVOLTAIC SYSTEM PERFORMANCE ANALYSIS METHOD

For the performance analysis of Grid-connected solar photovoltaic power plant we have considered the analysis period from January 2019 to April 2019 of the 111kW power generation plant installed at Academic Block IV of Integral University, Lucknow.

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The entire process is divided into three segments, which are as follows:

1. Manually extract power generation parameters from SCADA system available at the web URL: https://dashboard.fourthpartner.co/
2. Evaluate the performance through estimation of annual energy yield, array yield, reference yield and system losses.
3. Calculation of the Performance ratio using formula (3) as mentioned above.

Performance parameters were developed by the International Energy Agency (IEA) (Ayompe et al., 2011) to analyze the performance of solar photovoltaic grid-connected systems. Many performance parameters are used to define overall system performance with respect to the overall impact of energy production, solar energy resources, and system losses. The various parameters are the performance ratio, the final PV system yield and the reference yield.

Table 2: Performance Ratio (PR) of 111kW Solar System for the month of January'19

Date	Irradiation (I_r) in kWh/m^2	Energy at inverters (E_i) in kWh	Energy at meters (E_m) in kWh	Reference Yield ($Y_r = I_r / G$; where $G=1kW/m^2$) in h	Final Yield ($Y_f = E_i / P_{max}$; where P_{max} =320 W or =0.32 kW) in h	Performance Ratio ($PR= Y_f / Y_r$)	PR in %
01 - Jan - 2019	0.9	499	485	0.9	1559.38	1732.64	17.33
02 - Jan - 2019	1.7	952.6	930	1.7	2976.88	1751.10	17.51
03 - Jan - 2019	1.9	1121.8	1088	1.9	3505.63	1845.07	18.45
04 - Jan - 2019	2.4	1372.7	1350	2.4	4289.69	1787.37	17.87
05 - Jan - 2019	1.9	1133.6	1090	1.9	3542.50	1864.47	18.64
06 - Jan - 2019	3.7	1762.3	1714	3.7	5507.19	1488.43	14.88
07 - Jan - 2019	2.8	1231.7	1205	2.8	3849.06	1374.67	13.75
08 - Jan - 2019	3.4	1865.2	1855	3.4	5828.75	1714.34	17.14
09 - Jan - 2019	1.2	686.8	692	1.2	2146.25	1788.54	17.89
10 - Jan - 2019	2	1162.1	1163	2	3631.56	1815.78	18.16
11 - Jan - 2019	1.9	1191.7	1095	1.9	3724.06	1960.03	19.60
12 - Jan - 2019	1.3	748.6	765	1.3	2339.38	1799.52	18.00
13 - Jan - 2019	2.8	1426.4	1397	2.8	4457.50	1591.96	15.92
14 - Jan - 2019	3.9	1366.7	1392	3.9	4270.94	1095.11	10.95
15 - Jan - 2019	3.8	1827.3	1802	3.8	5710.31	1502.71	15.03
16 - Jan - 2019	3.2	1731.6	1735	3.2	5411.25	1691.02	16.91
17 - Jan - 2019	2.3	1340.5	1335	2.3	4189.06	1821.33	18.21
18 - Jan - 2019	3.5	1927.2	1897	3.5	6022.50	1720.71	17.21
19 - Jan - 2019	3.7	2084.6	1993	3.7	6514.38	1760.64	17.61
20 - Jan - 2019	4.1	1966.2	1966	4.1	6144.38	1498.63	14.99
21 - Jan - 2019	3.4	1525.5	1571	3.4	4767.19	1402.11	14.02
22 - Jan - 2019	3.5	1862.5	1860	3.5	5820.31	1662.95	16.63
23 - Jan - 2019	3.5	1441.4	1427	3.5	4504.38	1286.96	12.87
24 - Jan - 2019	3.7	1763	1761	3.7	5509.38	1489.02	14.89
25 - Jan - 2019	3	1639.9	1663	3	5124.69	1708.23	17.08
26 - Jan - 2019	3.6	1637.6	1655	3.6	5117.50	1421.53	14.22
27 - Jan - 2019	3.2	1751.5	1774	3.2	5473.44	1710.45	17.10
28 - Jan - 2019	4.4	1939.1	1945	4.4	6059.69	1377.20	13.77
29 - Jan - 2019	4.2	1885.1	1873	4.2	5890.94	1402.60	14.03
30 - Jan - 2019	1.8	1036.3	1030	1.8	3238.44	1799.13	17.99
31 - Jan - 2019	1.8	1077.4	1016	1.8	3366.88	1870.49	18.70
Average	2.83	1437	1423	2.83	4649.56	1725.86	17.41

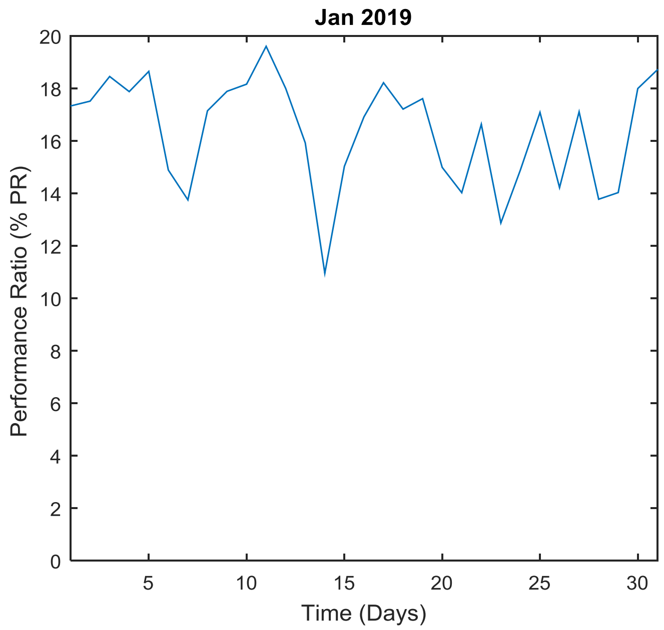

Fig. 3. Performance ratio with respect to Time (Days) for Jan 2019

Table 3: Performance Ratio (PR) of 111kW Solar System for the month of February'19

Date	Irradiation (I_r) in kWh/m^2	Energy at inverters (E_i) in kWh	Energy at meters (E_m) in kWh	Reference Yield ($Y_r = I_r / G$; where G=1kW/m^2) in h	Final Yield ($Y_f = E_i / P_{max}$; where P_{max} =320 W or =0.32 kW) in h	Performance Ratio (PR= Y_f / Y_r)	PR in %
01-Feb-2019	4	1582.4	1534	4	4945.00	1236.25	12.36
02-Feb-2019	4.5	1553.1	1606	4.5	4853.44	1078.54	10.79
03-Feb-2019	4.2	2381.6	2368	4.2	7442.50	1772.02	17.72
04-Feb-2019	4.7	2839.6	2802	4.7	8873.75	1888.03	18.88
05-Feb-2019	2.9	1644	1639	2.9	5137.50	1771.55	17.72
06-Feb-2019	3.1	1712.5	1689	3.1	5351.56	1726.31	17.26
07-Feb-2019	2.2	1257.6	1263	2.2	3930.00	1786.36	17.86
08-Feb-2019	4.6	2676	2594	4.6	8362.50	1817.93	18.18
09-Feb-2019	5.2	2878.8	2868	5.2	8996.25	1730.05	17.30
10-Feb-2019	4.6	2942.3	2910	4.6	9194.69	1998.85	19.99
11-Feb-2019	2.3	1274.3	1273	2.3	3982.19	1731.39	17.31
12-Feb-2019	2.1	1179.3	1158	2.1	3685.31	1754.91	17.55
13-Feb-2019	3.8	1832.5	1825	3.8	5726.56	1506.99	15.07
14-Feb-2019	5.6	2786.3	2761	5.6	8707.19	1554.85	15.55
15-Feb-2019	5.1	3032.2	3013	5.1	9475.63	1857.97	18.58
16-Feb-2019	4.7	2823.5	2794	4.7	8823.44	1877.33	18.77
17-Feb-2019	4.6	2627.9	2612	4.6	8212.19	1785.26	17.85
18-Feb-2019	4.7	2604.5	2591	4.7	8139.06	1731.72	17.32
19-Feb-2019	4.8	2952.5	2911	4.8	9226.56	1922.20	19.22
20-Feb-2019	5	2675.3	2664	5	8360.31	1672.06	16.72
21-Feb-2019	3.9	2531.7	2506	3.9	7911.56	2028.61	20.29
22-Feb-2019	4.5	2629.5	2618	4.5	8217.19	1826.04	18.26
23-Feb-2019	4	2384.7	2381	4	7452.19	1863.05	18.63
24-Feb-2019	4.1	2242.6	2244	4.1	7008.13	1709.30	17.09
25-Feb-2019	3.5	1876.8	1877	3.5	5865.00	1675.71	16.76
26-Feb-2019	5.3	2943.2	2928	5.3	9197.50	1735.38	17.35
27-Feb-2019	5.4	2838.7	2819	5.4	8870.94	1642.77	16.43
28-Feb-2019	4.9	2564.2	2554	4.9	8013.12	1635.33	16.35
Average	4.23	2331.38	2257.54	4.23	7305.56	1726.30	17.26

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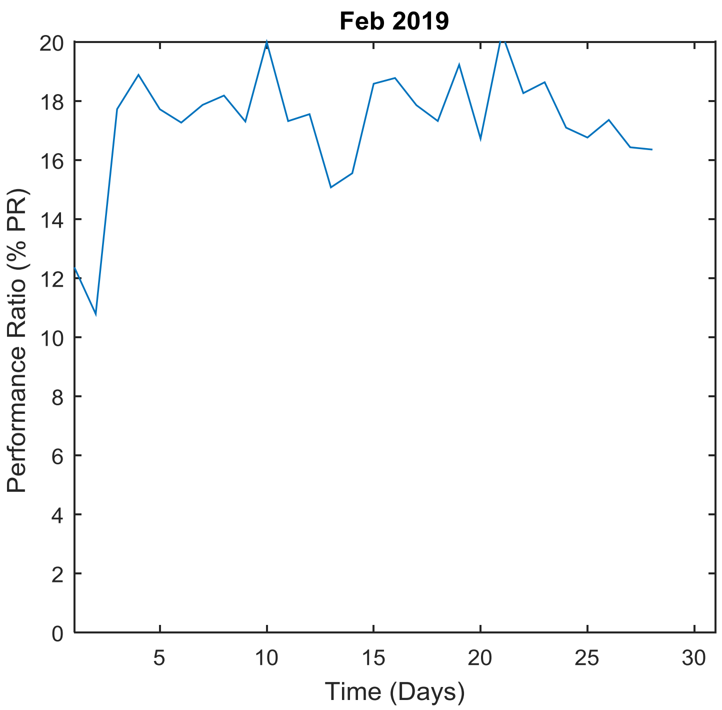

Fig.4. Performance ratio with respect to Time (Days) for Feb 2019

Table 4: Performance Ratio (PR) of 111kW Solar System for the month of March'19

Date	Irradiation (I_r) in kWh/m^2	Energy at inverters (E_i) in kWh	Energy at meters (E_m) in kWh	Reference Yield (Y_r = I_r / G; where G=1kW/m^2) in h	Final Yield (Y_f = E_i / P_{max}; where P_{max} =320 W or =0.32 kW) in h	Performance Ratio (PR= Y_f / Y_r)	PR in %
01-Mar-2019	5.2	2672.4	2666	5.2	8351.25	1606.01	16.06
02-Mar-2019	4.8	2489.6	2463	4.8	7780.00	1620.83	16.21
03-Mar-2019	5.5	2467.8	2443	5.5	7711.88	1402.16	14.02
04-Mar-2019	4.9	2538.3	2535	4.9	7932.19	1618.81	16.19
05-Mar-2019	4.9	2496.9	2465	4.9	7802.81	1592.41	15.92
06-Mar-2019	6.1	2841.1	2955	6.1	8878.44	1455.48	14.55
07-Mar-2019	6.3	3096.5	2902	6.3	9676.56	1535.96	15.36
08-Mar-2019	5.7	2740	2755	5.7	8562.50	1502.19	15.02
09-Mar-2019	6.2	3065.3	3044	6.2	9579.06	1545.01	15.45
10-Mar-2019	6.4	3224.3	3233	6.4	10075.94	1574.37	15.74
11-Mar-2019	6.3	2996.3	2938	6.3	9363.44	1486.26	14.86
12-Mar-2019	6.1	3153.4	3126	6.1	9854.38	1615.47	16.15
13-Mar-2019	5.5	3325.6	3229	5.5	10392.50	1889.55	18.90
14-Mar-2019	4.8	2736.6	2804	4.8	8551.88	1781.64	17.82
15-Mar-2019	4	2234	2153	4	6981.25	1745.31	17.45
16-Mar-2019	5.4	2975.3	2944	5.4	9297.81	1721.82	17.22
17-Mar-2019	6.1	3134.5	3107	6.1	9795.31	1605.79	16.06
18-Mar-2019	6.3	3058.3	3014	6.3	9557.19	1517.01	15.17
19-Mar-2019	5.5	3146.7	3135	5.5	9833.44	1787.90	17.88
20-Mar-2019	5.7	3124.8	3125	5.7	9765.00	1713.16	17.13
21-Mar-2019	4.7	1575.4	1553	4.7	4923.13	1047.47	10.47
22-Mar-2019	5.7	1856.5	3744	5.7	5801.56	1017.82	10.18
23-Mar-2019	6.3	3033.8	3097	6.3	9480.63	1504.86	15.05
24-Mar-2019	5.3	2568.9	2525	5.3	8027.81	1514.68	15.15
25-Mar-2019	6.8	1968.3	2000	6.8	6150.94	904.55	9.05
26-Mar-2019	6.4	3043.1	3221	6.4	9509.69	1485.89	14.86
27-Mar-2019	6.4	3246.5	3220	6.4	10145.31	1585.21	15.85

28-Mar-2019	6.4	3078.1	3184	6.4	9619.06	1502.98	15.03
29-Mar-2019	6.7	3276.5	3329	6.7	10239.06	1528.22	15.28
30-Mar-2019	5.8	2443.7	2396	5.8	7636.56	1316.65	13.17
31-Mar-2019	5.9	2857.4	2819	5.9	8929.38	1513.45	15.13
Average	5.75	2758.9	2842.71	5.75	8716.56	1520.54	15.20

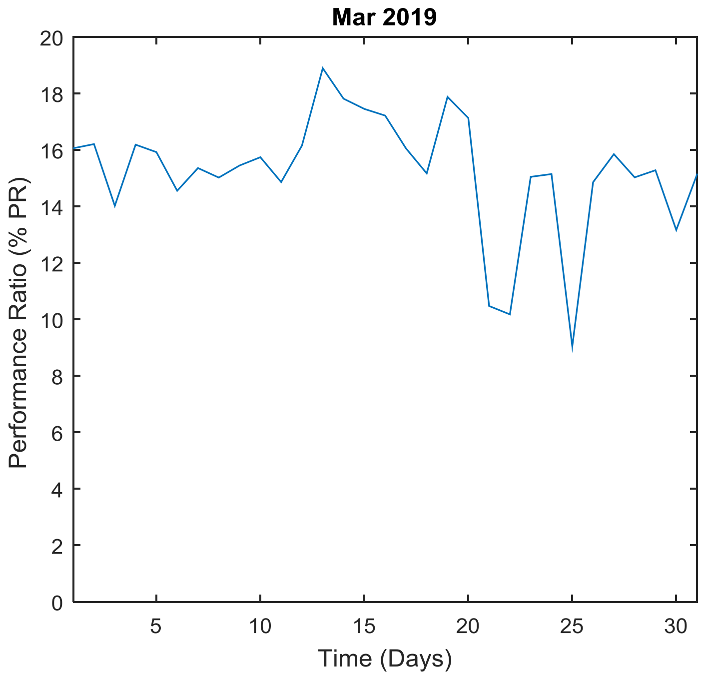

Fig.5. Performance ratio with respect to Time (Days) for March 2019

Table 5: Performance Ratio (PR) of 111kW Solar System for the month of April'19

Date	Irradiation (I_r) in kWh/m^2	Energy at inverters (E_i) in kWh	Energy at meters (E_m) in kWh	Reference Yield (Y_r = I_r / G; where G=1kW/m^2) in h	Final Yield ($Y_f = E_i / P_{max}$; where P_{max} =320 W or =0.32 kW) in h	Performance Ratio (PR= Y_f / Y_r)	PR in %
01-Apr-2019	5.5	2152.4	2535	5.5	6726.25	1222.95	12.23
02-Apr-2019	5.7	2934.6	2975	5.7	9170.63	1608.88	16.09
03-Apr-2019	5.5	2853.2	2813	5.5	8916.25	1621.14	16.21
04-Apr-2019	5.5	2825	2776	5.5	8828.13	1605.11	16.05
05-Apr-2019	5.8	2875.9	2847	5.8	8987.19	1549.52	15.50
06-Apr-2019	4.9	2465.7	2490	4.9	7705.31	1572.51	15.73
07-Apr-2019	6.1	3075.4	3039	6.1	9610.63	1575.51	15.76
08-Apr-2019	5.9	2547.7	2655	5.9	7961.56	1349.42	13.49
09-Apr-2019	4.6	2385.1	2361	4.6	7453.44	1620.31	16.20
10-Apr-2019	6.6	3463.8	3366	6.6	10824.38	1640.06	16.40
11-Apr-2019	4.5	2226.6	2257	4.5	6958.13	1546.25	15.46
12-Apr-2019	6	3085.2	3032	6	9641.25	1606.88	16.07
13-Apr-2019	6.8	3336.6	3287	6.8	10426.88	1533.36	15.33
14-Apr-2019	6.9	2874.3	2812	6.9	8982.19	1301.77	13.02
15-Apr-2019	6.6	2836.9	2807	6.6	8865.31	1343.23	13.43
16-Apr-2019	5.9	2686.2	2643	5.9	8394.38	1422.78	14.23
17-Apr-2019	5.6	2446.9	2432	5.6	7646.56	1365.46	13.65
18-Apr-2019	6.4	2774.7	2713	6.4	8670.94	1354.83	13.55
19-Apr-2019	6.5	2756.4	2852	6.5	8613.75	1325.19	13.25
20-Apr-2019	5.6	2536.2	2506	5.6	7925.62	1415.29	14.15
21-Apr-2019	6.1	2784.2	2746	6.1	8700.63	1426.33	14.26
22-Apr-2019	6.7	2667.6	2590	6.7	8336.25	1244.22	12.44
23-Apr-2019	7	2933.1	3068	7	9165.94	1309.42	13.09

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24-Apr-2019	6.7	2858.8	3086	6.7	8933.75	1333.40	13.33
25-Apr-2019	5.6	2858.3	2783	5.6	8932.19	1595.03	15.95
Average	5.96	2758.43	2778.84	5.96	8347.1	1406.31	14.06

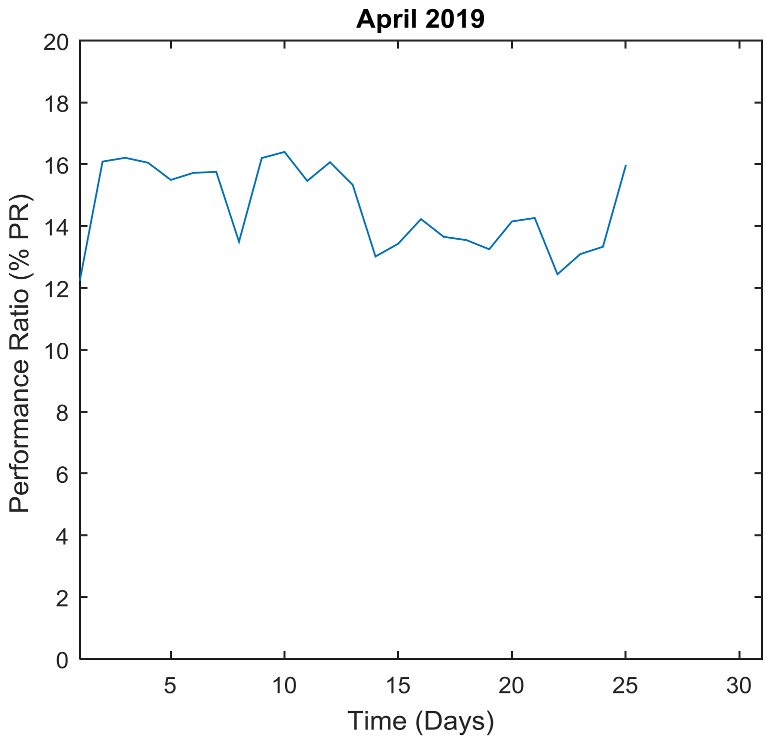

Fig.6. Performance ratio with respect to Time (Days) for April 2019

Figures (1to 6) shows the Performance Ration on daily basis of the 111kWp grid interactive solar photovoltaic rooftop power plant installed at Civil Building of Integral University, Lucknow. The graphical representation of the data collected from the online SCADA portal for the 111kW grid interactive solar photovoltaic rooftop power plant installed at Civil Building (Academic Block-II) of Integral University, Lucknow shows that the average Performance Ratio of the system for the period of study from January 2019 to April 2019 is approximately 16%. Empirical analysis of the system shows there is scope of improvement in the system and that the performance ratio of the solar PV plant installed at Civil Block of Integral University, Lucknow can be enhanced.

Use of Concentrating PV and Thermal (CPVT) system with the traditional solar array can enhance the current installed system to harvest more solar energy [4]. More Electrical Energy can be generated and can be supplied to the Grid by using CPVT systems. The additional solar energy generated by the CPVT system can be utilized to power wireless sensors deployed in areas where human approach fails [5]. Moreover, the cleaning of the panels on a regular basis is required so that the dust and bird feces may be removed and any chance of shadowing effect may also be reduced.

V. CONCLUSION

The performance ratio is purely based on defined variables, and may even exceed 100% under the influence of certain factors. This is because the performance characteristics of the PV module are used to calculate the performance ratio determined under standard test conditions (1,000 W/m^2 solar radiation and 25°C module temperature). Therefore, deviation conditions under actual operating conditions can affect the performance ratio. Certain factors which may impact the performance ratio of the grid interactive solar photovoltaic system are temperature of the PV module, solar irradiation and power dissipation, soiled PV module or covered with bird feces. Other factors that affect the performance ratio are conduction losses, efficiency factor of the PV modules, efficiency factor of the inverter and short measurement period. The intensive use of Concentrating PV and Thermal (CPVT) system along with regular cleaning of the PV panel are the two proposed solutions in this paper for the accurate evaluation of the performance ratio for the grid interactive SPV system.

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