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Grid connected mega-watt range solar power plant in India: experimental measurement & performance analysis

J. Raja[1], Nishant Jain[2], C. Christober Asir Rajan[3]
[1.2]National Power Training Institute Ministry of Power and Govt. of India Faridabad, India
[3]Pondicherry Engineering College (A Government of Puducherry Institution), Puducherry, India

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ABSTRACT

Electric power generation through solar power plant is significantly growing in India to meet its future energy demand. This paper emphasis on the performance assessment of grid connected mega-watt solar power plant which is of 23MW and 5MW are located in different geographical location in India. Performance assessment is the finest way to determine the potential of energy generation in solar power plant and it also helps in evaluating the design, operation and maintenance of existing and future solar power plant. The parameters namely calculation of annual energy generated, reference yield, final yield, system losses, cell temperature losses, performance ratio and capacity utilization factor are considered in examining solar power plant performance. In this study experimental measurement of two solar power plant one is located in Gujarat (23MW) and another in Andhra Pradesh (5MW) are compared with the results of estimated model from METEONORM 7.1 and PVSYST V6.67 software tools. Experimental measurement at solar power plant location covers the following measurement for analysis like actual weather condition, daily/hourly irradiance, actual energy yield and compares with capacity utilization factor, performance ratio and temperature corrected performance ratio parameters. The results demonstrated in this paper show the gap between the actual performance of solar power plant and the estimated model from software tool. Performance of solar power plant is satisfactory in comparison with other literature reviews. The actual annual energy generated for 23MW solar power plant was 37991MWh, 18.83% capacity utilization factor, 73.87% performance ratio and 75.33% temperature corrected performance ratio. Similarly, the actual annual energy generated for 5MW solar power plant was 9047.7MWh, 18.41% capacity utilization factor, 80.31% performance ratio and 79.90% temperature corrected performance ratio.

Corresponding Author:

C. Christober Asir Rajan,
Pondicherry Engineering College,
A Government of Puducherry Institution, Puducherry, India.
Email: asir_70@pec.edc

1. INTRODUCTION

Significance of this paper is, every solar power plant (SPP) operated in the field is not ideal. Its output performance always varies in real time conditions. They always experiences a lot of variable field parameter like temperature, humidity, faults which affects the performance of the plants. The performance of plant is an indicator of health of the plant and is directly related to output of the plant. So, it is necessary to analysis the performance and find out the path to improve so that it may fulfill the increasing demand and its purpose. The comprehensive performance analysis of plants with the measure parameters such as generation, capacity utilization factor (CUF), performance ratio (PR) will helps to find out the way to improve the system in quality energy generation and it involves the analysis of different factors that hampers the performance of the plants.

The increasing energy demand in emerging nations like India has triggered the issue of energy security. This has made essential to utilize the available potential of renewable resources. Solar PV Grid connected systems have turned out to be the best alternatives in renewable energy at large scale. Also Government of India is moving towards renewable electricity sources, and targeted to grow massively by 2022. The objective of the Solar Mission is to create conditions, through rapid scale-up of capacity and technological innovation to drive down costs towards grid parity. The Mission anticipates achieving grid parity by 2022 and parity with coal-based thermal power by 2030 [1, 2], but recognizes that this cost trajectory will depend upon the scale of global deployment and technology development and transfer. By 2022, India is targeting the installation of 175GW of renewable energy capacity, an ambitious target that will require a four-fold growth in the sector. The country has installed capacity over 50GW of renewable capacity as of December 2016, 57% of which is wind. The 2022 target includes 60GW of large and medium-scale grid connected solar power projects, 60GW of wind, 40GW of solar rooftop projects, 10GW of bio-power and 5GW of small hydro. So far Indian government has achieved 13.9 GW at the 2017 in Solar PV power plants.

Performance analysis of these grid connected plants could help in designing, operating and maintenance of new grid connected systems. Sudhakar et al. [3-5] discussed the 10MW grid connected SPP which was commissioned at Ramagundam is one of the largest SPP with the site receiving a good average solar radiation of 4.97kWh/m2/day and annual average temperature of about 27.3 degrees centigrade. The plant is designed to operate with a seasonal tilt. This paper discussed the design aspects, PR, CUF with annual energy generation of 15,798.192 MW h/Annum.

PV is a semiconductor device which allows sunlight and converts directly in to electricity. These modules can provide you with a safe, reliable, maintenance-free and environmentally friendly source of power for a very long time. Makrides et al., 2010 [6] discussed the successful implementation of solar PV system involves knowledge on their operational performance under varying climatic condition. Ref. [7] Padmavati et al., discussed the performance analysis of a 3MP grid connected SPP located in Karnataka State, India as per IEC standard 61724, using monitoring data. Normalized technical performance parameters of the plant are evaluated for the year 2011. Inverter failure losses and grid failure losses are estimated for two years of plant operation.

As part of a performance analysis activity under Task 2 of the IEA-PVPS programme, long term performance and reliability issues of 21 selected PV systems from five different member countries under constant climatic conditions were reported. There is need to document the actual performance of the system in the field to understand the impact of different inventions and asses the cost effectiveness of renewable energy system (Banerjee et al., [8]). The IEA-PVPS Task 2 group has developed a database to accommodate technical and operational data of different types of systems operating under different climatic conditions (Jahn et al., [9]). Shady S. Refaat et. al., [10] investigates and reports on the dynamic stability of the power system with a large-scale photovoltaic system (L-S PV). Two different scenarios with centralized PV power plants are considered in the medium voltage level without voltage regulation capabilities. Suman Khichar et al. [11] proposed voltage and frequency control for islanding detection scheme has been projected for the operation of the islanded and grid-connected mode is demonstrated through MATLAB Simulink. Yafaoui et al. [12] investigated the new and Improved active frequency drift anti-islanding detection method for grid connected photovoltaic systems. Hasan Abouobaida, *et al.* [13] proposed the Modelling and control design for Energy Management of grid connected Hybrid PV-wind system. Adnan Hussein Ali, *et al*. [14] proposed the Performance Investigation of Grid Connected Photovoltaic System Modelling Based on MATLAB Simulation. Sangita R Nandurkar et al. [15] introduced and Modeling Simulation & Design of Photovoltaic Array with MPPT Control Techniques, International Journal of Applied Power Engineering. Olatona G.Iet al. [16] proposed Analysis of Solar Radiation Availability for Deployment of Solar Photovoltaic (PV) Technology in a Tropical City.

The objectives of the proposed works are: i) Comparative study of estimated simulated model against actual available SCADA data of a solar PV Plant on the basis of annual energy yield, Irradiation, Climatic condition. ii) Formulation of technical parameter for the comparison of Estimated data with the Actual Data i.e. Capacity Utilization Factor (CUF), Performance Ratio (PR), Temperature Corrected Performance Ratio (TPR), iii) Designing of Simulation Model using PVSYST of same Plant considering the actual measured site data, iv) Comparing the actual running plant with its simulated model and comment on its performance and v) To provides the best alternative way to boost the performance.

The organization of the paper documented in the following headings: i) Section 2 discussed the technical configuration of 23MW and 5MW SPP with single line diagram of 23MW, geographical location of site, PV panel specification, power conditioning unit and power evacuation components with numbers used in both the plant. Section 3 deals with proposed methodology of performance assessment of the plant, which is on the basis of 3 Nos. of models i) Based on estimated simulation model on the basis of Meteonorm data, ii) Based on actual SCADA data of the running SPP, iii) Real time simulation model: model is created using PSYST, simulated the system by taking actual site/SCADA data. Section 4 discussed the comparative analysis of proposed methodology of performance assessment of the plant on a particular year, this paper year 2014 data has taken for 23MW and 2016 data has taken for 5MW. Finally, section 5 concludes this paper, and suggested to improve the system performance in three ways i) maintaining 100% plant and grid availability, ii) Check the growth of vegetation, de-fertilize area to avoid unpredicted shading in the array and iii) cleaning of PV module in regular intervals.

2. TECHNICAL CONFIGURATION OF 23MW AND 5MW SOLAR PV POWER PLANT

This section lists the technical configuration of 5MW and 23MW of two different capacities of solar PV plant in different states in India. The assessment for the project is done using PVSYST V6.67 with the solar resources data form Meteonorm-7 weather database and the actual data & conditions taken from SCADA. The detailed configurations are listed in Table.1.

Table 1. Technical Specification of 23MW & 5MW Solar PV Plant Installed in Different Locations in India

Particulars	Project 1-Installed in Gujarat	Project 2-Installed in Andhra Pradesh
Plant capacity	23MW	5MW
Name of the State	Gujarat	Andhra Pradesh
Annual global solar irradiance	1966.4 kWh/m^2	1907 kWh/m^2
Meteorological data Source	Meteonorm 7.1	Meteonorm 7.1
Land availability (acres)	130.00	33.75
Type of system	Fixed Tilt: 25^0	Fixed Tilt: 15^0
Type of PV module	Poly-crystalline	Poly- crystalline
DC plant capacity	23.06 MW$_p$	5.599 MW$_p$
Solar PV modules	a) Jinkosolar 230W$_p$ JKM 230PP-48 b) Hareon 250W$_p$ HR-25018/Bb c) JASolar 240W$_p$ JAP6(BK) 60-240/3BB d) JASolar 245W$_p$ JAP6(BK) 60-245/3BB	Renesola 310W$_p$ (JC310M-24/ Ab)
Total number of PV modules	19464+54504+5112+15288= 94368	18060
Project module area required	147376 m²	35043 m^2
Inverter model	Bonfiglioli vectron RPS 1220 multi MPPT (20 Nos.)	SMA sunny central 900CP XT (5 Nos.)
Inverter rating capacity	1100kWac, 500-875 V, 50Hz	900kWac, 596-950V, 50Hz
Name of the customer of power	State distribution company	State distribution company

2.1 Geographical location of site

The 23 MW Solar PV Plant is located at latitude of 23.05^o N and longitude of 71.83^o E and at an altitude of 19m. The 5 MW Solar PV Plant is located at latitude of 14.02^o N and longitude of 78.15^o E and at an altitude of 561m. The sites are opted due to consistent and better site radiation throughout the year and the plant single line diagram is shown in Figure 1

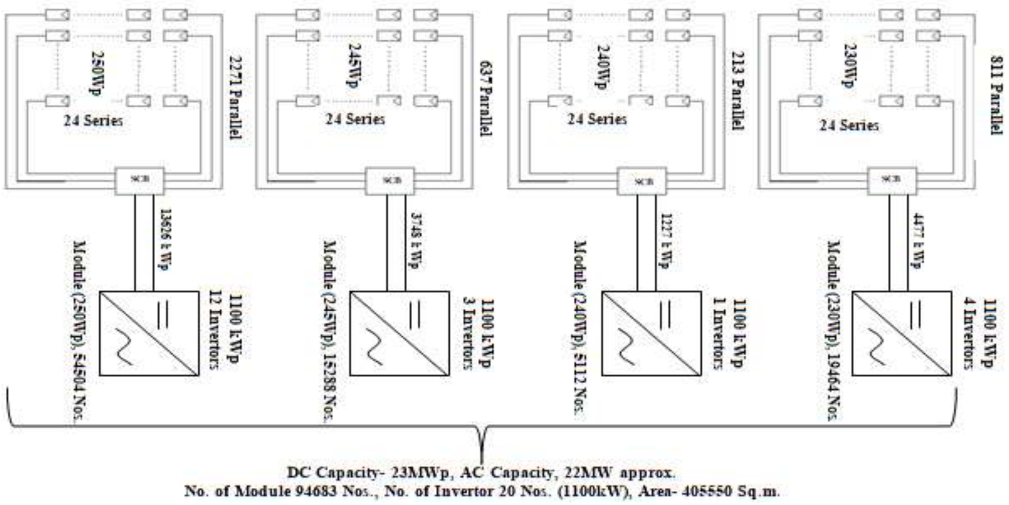

Figure 1. Single line diagram of 23MW SPP

2.2 Specification of solar panel

a. There are 4 different capacities of 94368 Nos. of polycrystalline modules are used to attain a DC capacity of 23.06MW with 24 Nos. of modules in each string are connected and each module specifications are listed below:
   1) Product name Jinkosolar with each panel capacity of 230Wp and 19464 Nos. of panels are used with V_{oc}=36.8V, Isc=8.35A, V_{mp}= 29.6V, I_{mp}=7.78A and efficiency 14.05%.
   2) Product name Hareon with each panel capacity of 250Wp and 54504 Nos. of panels are used with V_{oc}=37.41V, I_{sc}=8.79A, V_{mp}= 29.98V, I_{mp}=8.34A and efficiency 15.4%.
   3) Product name JASolar with each panel capacity of 240Wp and 5112 Nos. of panels are used with V_{oc}=37.3V, I_{sc}=8.65A V_{mp}= 29.38V, I_{mp}=8.17A and efficiency 14.68%.
   4) Product name JASolar with each panel capacity of 245Wp and 15288 Nos. of panels are used with V_{oc}=37.45V, I_{sc}=8.78A, V_{mp}= 29.63V, I_{mp}=8.27A and efficiency 14.98%.

b. 18060 Nos. of polycrystalline modules with same capacity panels are used to attain a DC capacity of 5.559MW, with 21 Nos. of modules in each string are connected and module specification is listed below, whereas the inverter AC capacity of the project is 4.5MW at 50^0 C ambient with unity PF:
   1) Product name Renesola with each panel capacity of 310Wp with V_{oc}=45V, I_{sc}=8.8A, V_{mp}= 37V, I_{mp}=8.38A. and efficiency 15.98%.

2.3 Power conditioning unit:

1) 20Nos. of string inverters are used in 23MW plant to attain AC output of 22MW with each inverter rating of 1100kWac AC output, 500V to 875VMPPT range with frequency 50Hz.
2) 5Nos. of string inverters are used in 5MW plant to attain AC output of 4.5MW with each inverter rating of 900kWac AC output, 596V to 950V MPPT range with frequency 50Hz.

2.4 Power evacuation

1) Output of 4Nos. of string inverter is combined through string combiner box (SJB), SJB output is connected to each inverter transformer. A total of 5Nos. of inverter transformer are used with a capacity of 6MVA, 415V/11KV each to evacuate the AC power output to 11kV Switchboard and further with the help of 02 Nos. of 18MVA, 11/66kV power is evacuated to 66kV substation through suitable overhead transmission line for 23MW SPP.
2) 5MW SPP consists of 3Nos. of inverter transformers with 02Nos. of 2250 kVA, 3Φ, 3 winding transformer and 1No. of 1250kVA 3Φ, 2 winding transformer is used for power evacuation at 33kV.

3. METHODOLOGY OF PERFORMANCE ASSESSMENT

The Methodology of performance assessment is carried on the basis of 3 Nos. of models

a. Estimated simulation model: it is the Simulation Model of Solar PV Plant at the stage of Designing on the basis of Meteonorm data.
b. Actual Model: it is the actual SCADA data of the running Solar PV Plant.
c. Real time simulation model: model is created using PSYST, simulated the system by taking actual site/SCADA data.
d. Comparison of all the 3 models on the basis of formulated parameters.

3.1 Estimated simulation model: it is the simulation model of solar PV plant at the stage of designing on the basis of meteonorm data

This Model is formulated during the stage of designing of Solar PV Plant. As per site location and the capacity of power plant a simulation model is developed on the basis of METEONORM Data and assuming the approximate losses, on that basis the energy yield for the entire year is predicted.

a. 23MW SPP

The performance ratio (PR) of a solar PV project represents the ratio of the effectively produced (used) energy, by respect to the energy which would be produced by a "perfect" system continuously operating at STC under same irradiance (incident global in the plane). The PR includes the array losses (shadings, PV conversion, mismatch, wiring, etc.) and the system losses (inverter efficiency in grid-connected, or storage/battery/unused losses in stand-alone, etc.).

For 23 MW solar PV power plant it is seen that maximum expected PR occurs for the month of January i.e. 80.20% whereas Minimum expected PR occurs for the month of April i.e. 75.20% is shown in Table 2. The overall expected PR for the whole year is comes to be 77.90%.

Table 2. Monthly Estimated Energy Yield of 23 MW Solar PV Power Plant

Month	GHI (kWh/m^2)	GTI (kWh/m^2)	Ambient Temp.(^oC)	Energy Generated (MWh)	DC CUF %	PR %
January	147.8	197.7	20.6	3621.64	21.11%	80.20%
February	157.0	192.9	22.7	3484.00	22.48%	78.30%
March	203.5	223.2	27.9	3914.88	22.82%	76.00%
April	214.0	210.7	31.8	3614.33	21.77%	75.20%
May	225.5	204.9	34.0	3477.50	20.27%	75.50%
June	183.0	164.0	32.4	2821.99	17.00%	77.70%
July	139.1	128.8	29.7	2257.20	13.16%	79.80%
August	136.2	130.7	28.4	2309.66	13.46%	80.00%
September	162.2	167.0	29.0	2946.18	17.74%	78.50%
October	171.2	197.2	28.9	3461.26	20.17%	77.00%
November	144.4	186.1	24.7	3340.28	20.12%	78.60%
December	137.1	189.1	21.7	3446.41	20.09%	79.90%
Total	2021.0	2192.3	27.7	38695.34	19.18%	77.90%

b. 5MW SPP

For 5MW solar PV power plant it is seen that the maximum expected PR occurs for the month of October i.e. 78.90% and minimum expected PR occur for the month of August i.e.75.50% is shown in Table 3. The overall expected PR for a whole year is 77.94%.

The estimated system losses are all the losses in the system, which cause the power actually delivered to the electricity grid to be lower than the power produced by the PV modules which is shown in Table 4. There are several causes for this loss, such as losses in cables, power inverters, dirt (sometimes snow) on the modules, ambient temperature, varying insolation levels and so on. While designing a PV system, we have to take into consideration all possible losses.

Table 3. Monthly Estimated Energy Yield of 5MW Solar PV Power Plant

Month	GHI (kWh/m^2)	GTI (kWh/m^2)	Ambient Temp.(^oC)	Energy Generated (KWh)	DC CUF %	PR %
January	170.3	199.3	24.3	877000	21.06%	78.60%
February	163.8	181.6	26.8	790000	21.00%	77.70%
March	199.4	208.3	29.7	896000	21.51%	76.80%
April	186.9	183.8	30.9	789000	19.58%	76.70%
May	182.5	172.3	30.7	746000	17.92%	77.40%
June	152.1	141.6	27.7	623000	15.47%	78.60%
July	146.8	138.0	27.2	610000	14.64%	78.90%
August	139.2	134.4	26.6	568000	13.64%	75.50%
September	151.3	153.4	26.0	677000	16.80%	78.80%
October	144.3	153.1	24.1	676000	16.24%	78.90%
November	143.6	162.3	23.3	706000	17.51%	77.70%
December	149.6	174.4	27.0	778000	18.68%	79.70%
Total	1929.8	2002.5	27.0	8736000	17.84%	77.94%

Table 4. Various Energy Losses Derived from PVSYST Simulation

Losses	Value (23 MW)	Value (5 MW)
IAM Factor	2.70%	3.80%
Near Shading Loss	1.00%	1.90%
Soiling	2.10%	1.50%
Module Degradation	0.50%	0.30%
Low Irradiance	0.40%	0.40%
Module Temperature	13.90%	9.10%
LID	1.00%	1.00%
Module Mismatch	1.70%	1.00%
DC ohmic	1.10%	1.20%
AC ohmic	0.80%	0.10%
Plant Unavailability	-	0.50%
External Transformer	1.90%	-

3.2 Actual model: it is the actual SCADA data of the running solar PV plant

Annual energy yield is the total energy generated by a solar PV plant once it comes in full flexed operation for a whole year. The monthly energy generated and the net exported energy is recorded in database on hourly basis with the help of SCADA software and the CUF & performance ratio is calculated.

supervisory control and data acquisition (SCADA) is a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management. However, in this case SCADA is interfaced with the Energy Meter via a set of communication protocol and records the generated energy from the Solar PV array and net energy transferred to the grid on hourly basis and maintains the database. The derived for calculations as shown in (1-6)

$$\text{Insolation}\left(\frac{\text{kWh}}{\text{m}^2}\right)=\frac{(\text{Irradiance}(\text{W}/\text{m}^2)\ \text{X Total No. of Sunshine Hours})}{1000} \quad (1)$$

$$\text{Capacity Utilisation Factor (CUF)} = \frac{\text{Net Energy Exported (kWh)}}{\text{Plant Capacity (kW) X 24}} \quad (2)$$

$$\text{Performance Ration (PR)} = \frac{\text{Net Energy Exported (kWh)}}{\text{Insolation}(\text{kWh}/\text{m}^2)\ \text{X Plant Capacity (kW)}} \quad (3)$$

$$\text{Module Temperature (MT)} = \text{Ambient Temperature}+\frac{(\text{NOCT-20})}{800\ (\text{W}/\text{m}^2)}\ \text{X S} \quad (4)$$

$$\text{Temperature Correction Factor (TCF)} = \frac{1}{1+(\beta(\text{NOCT}-\text{ModuleTemerature}))} \quad (5)$$

$$\text{Temparature Corrected Performance Ratio (TPR)} = \text{PR X TCF} \quad (6)$$

The Performance Analysis of 23 MW Solar PV as per SCADA Data for Year 2014 is shown in Table 5.

Table 5. Performance Analysis of 23 MW Solar PV as per SCADA Data for Year 2014

Month	GTI (kWh/m^2)	Net Energy (MWh)	Grid Availability	Ambient Temp. (^oC)	Mod. Temp (^oC)	PR %	TPR %	CUF %
Jan	184.80	3305.27	99.03%	23.11	37.80	77.56%	79.27%	19.27%
Feb	184.20	3298.56	98.62%	27.84	45.56	77.66%	77.53%	21.29%
Mar	224.40	4029.90	99.92%	35.62	52.67	77.88%	76.13%	23.49%
Apr	212.80	3801.48	100.00%	40.23	56.82	77.47%	74.82%	22.90%
May	208.10	3674.43	98.42%	43.37	60.04	76.57%	73.27%	21.42%
Jun	174.30	3151.76	97.53%	43.03	60.39	78.41%	74.95%	18.98%
Jul	132.20	2405.34	98.81%	42.01	58.91	78.90%	75.74%	14.02%
Aug	137.80	2583.17	98.80%	36.84	54.16	81.29%	79.12%	15.06%
Sep	142.00	2583.01	100.00%	37.32	54.35	78.88%	76.73%	15.56%
Oct	190.90	2708.66	98.67%	34.38	52.42	61.53%	60.19%	15.79%
Nov	177.80	3112.32	99.77%	29.23	46.43	75.91%	75.59%	18.75%
Dec	180.10	3337.11	98.89%	27.21	43.78	80.35%	80.65%	19.45%
Total	2149.40	37991.00	99.04%	35.02	51.94	76.87%	75.33%	18.83%

The comparative study reveals that the net actual energy yield for the year 2014 was lesser than the estimated.

a. 23MW Solar PV plant located in Gujarat is having a performance ratio of 76.87% which is lower than the estimation i.e.77.90%.
b. It is noticed that while considering the module temperature the performance of the plant reduces due to effect of temperature; the Performance ratio comes to 75.33%
c. The Expected energy yield for year 2014 is 38695.34MWh and the estimated annual irradiance is 2192.30kWh/m^2, whereas the actual energy generated for the year 2016 is 37991.00MWh with annual irradiance of 2149.40kWh/m^2.

In spite of fact, for the same period of time actual annual solar radiation on the plane of array (POA) is also lower then estimated.

a) 5MW Solar PV plant installed at Andhra Pradesh is having a performance ratio of 80.31% which is higher than the estimation i.e. 77.94%.
b) The Expected energy yield for year 2016 at the plant end is 8736000 kWh and the estimated annual irradiance is 1929.8kWh/m^2, whereas the actual energy generated at the plants end for the year 2016 is 9047700.00kWh with annual irradiance of 1991.48kWh/m^2.

It is noticed that while considering the module temperature the performance of the plant reduces due to effect of temperature; the Performance ratio comes to 79.90%. Table 6 shows that the net actual energy yield for the year 2016 was higher than the estimated in spite of fact, for the same period of time actual annual solar radiation on the plane of array (POA) is also higher then estimated.

Table 6. Performance Analysis of 5MW Solar PV as Per SCADA Data for Year 2016

Month	GTI (kWh/m^2)	Net Power (kWh)	% Grid Availability	Ambient Temp. (^{o}C)	Mod. Temp (^{o}C)	PR %	TPR %	CUF %
Jan	170.98	697500.00	100.00	25.33	40.32	72.73	71.67	16.84
Feb	194.33	814000.00	98.87%	29.51	47.86	75.57	76.21	21.03
Mar	210.09	878300.00	98.92%	25.33	43.58	75.54	75.18	21.22
Apr	197.22	873500.00	99.91%	36.39	53.61	79.17	81.11	21.82
May	171.94	761000.00	98.72%	31.99	46.44	79.88	80.16	18.38
Jun	138.72	640900.00	99.53%	28.70	40.77	82.93	81.86	15.97
Jul	140.00	649700.00	97.81%	27.33	40.77	78.13	77.07	15.66
Aug	162.42	746300.00	99.80%	28.68	42.44	82.60	81.94	18.01
Sep	130.72	612800.00	100.00%	27.44	39.32	84.26	82.82	15.29
Oct	154.61	853400.00	99.67%	28.77	44.91	82.10	82.06	20.63
Nov	160.15	780600.00	99.37%	27.21	42.39	87.55	86.85	19.25
Dec	160.32	739700.00	97.77%	24.83	39.71	83.27	81.90	16.81
Total	1991.48	9047700.00	99.20	28.46	43.51	80.31	79.90	18.41

3.3 Actual simulated data: on the basis of the actual site/SCADA data a simulation model is created using PV syst.

While comparing the actual data with the estimated data of the both the solar PV Power plant there is the change in climatic condition or pattern such as ambient temperature, daily solar radiation due to which the energy yield changes and the parameter related to it also changes i.e. Capacity Utilization Factor (CUF), Performance Ratio. On the Basics of actual Global Horizontal Irradiance (GHI) over the Plane of array (POA) for a certain year is measured along with the ambient temperature, wind speed, Global diffuse irradiance. These actual attributes are feed in the PVSYST software for the simulation to analysis the performance of plant. The Annual energy yield as per simulation model on actual parameters for both the Solar PV power Plant are as follow. Annual Energy Yield of a 23MW Solar PV power plant at Gujarat comes out to be 38576 MWh/Year. Monthly basics energy generated as per PVSYST is tabulated in Table 7.

Table 7. New Simulation Variant- Balances and Main Results

Month	GlobHor kWh/m^2	DiffHor kWh/m^2	T Amb ^{o}C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E-Grid MWh	PR
January	136.7	32.83	19.91	186.3	178.1	3573	3473	0.808
February	149.2	36.82	22.75	185.1	177.3	3460	3364	0.787
March	202.0	52.00	27.87	225.2	215.5	4059	3949	0.760
April	212.8	69.99	31.24	213.2	203.0	3793	3692	0.750
May	224.7	83.89	32.95	207.5	196.8	3701	3605	0.753
June	193.5	97.77	31.40	173.9	164.2	3188	3106	0.774
July	144.1	94.54	29.15	132.6	125.1	2498	2433	0.795
August	143.3	92.26	28.06	137.9	130.3	2609	2540	0.798
September	134.9	83.78	28.71	138.6	131.4	2591	2524	0.789
October	160.4	59.51	28.46	188.7	180.0	3460	3369	0.774
November	135.1	41.04	24.48	176.0	168.4	3296	3207	0.789
December	129.7	34.18	21.31	179.1	171.4	3409	3315	0.802
Year	1966.4	778.61	27.21	2144.1	2041.4	39636	38576	0.780

GlobHor: horizontal global irradiation
DiffHor: horizontal diffused irradiation
T Amb: ambient temperature
GlobInc: global incident in collector plane
GlobEff: effective global coor. For IAM and shading
EArray: effective energy at the output of the array
E-Grid: energy injected into grid, PR-Performance ratio.

It is observed that simulation results of 23MW Solar PV plant installed at Gujarat is having a performance ratio of 78.00% which is higher than the running plant Performance Ratio i.e. 76.87%. The Expected energy yield for year 2014 after simulation is to be 38577MWh and the annual irradiance is 2144.00 kWh/m^2, whereas the actual energy generated for the year is 37991.00MWh with annual irradiance of 2149.40kWh/m^2. Annual energy yield of a 5 MW solar PV power plant Andhra Pradesh comes out to be 8920 MWh/Year. Monthly basics energy generated as per PVSYST is tabulated in Table 8.

Table 8. New Simulation Variant - Balances and Main Results

Month	GlobHor kWh/m^2	DiffHor kWh/m^2	T Amb ^{o}C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E-Grid MWh	PR
January	145.3	48.80	25.33	168.3	158.5	775.3	762.7	0.809
February	174.9	50.20	29.51	194.5	184.3	875.5	861.4	0.791
March	199.6	61.10	25.33	208.3	197.1	959.0	943.2	0.809
April	199.2	78.60	36.39	196.2	184.6	860.4	846.6	0.771
May	182.3	90.30	31.99	171.3	159.5	771.0	758.7	0.791
June	148.4	88.90	28.70	138.3	127.9	635.1	624.7	0.807
July	148.4	92.50	27.33	139.8	129.3	647.0	636.1	0.813
August	168.9	78.90	28.68	163.4	152.8	755.0	742.6	0.812
September	128.1	70.60	27.44	129.9	121.1	600.9	590.9	0.813
October	145.3	72.30	28.77	154.9	145.3	713.2	701.3	0.809
November	140.9	56.50	27.21	158.9	149.8	735.7	723.3	0.813
December	137.9	56.90	24.82	159.5	150.0	741.7	729.4	0.817
Year	1919.2	845.59	28.43	1983.2	1860.2	9069.8	8920.9	0.803

GlobHor: horizontal global irradiation
DiffHor: horizontal diffused irradiation
T Amb: ambient temperature
GlobInc: global incident in collector plane
GlobEff: effective global coor. For IAM and shading
EArray: effective energy at the output of the array
E-Grid: energy injected into grid
PR: performance ratio.

It is observed that simulation results of 5MW Solar PV plant installed at Andhra Pradesh is having a performance ratio of 80.35% which is higher than the running plant Performance Ratio i.e. 79.90%.

The Expected energy yield for year 2016 after simulation is to be 8921MWh and the annual irradiance is 1983.8kWh/m^2, whereas the actual energy generated at the plants end for the year 2016 is 9047.7MWh with annual irradiance of 1991.48kWh/m^2. The Simulated Annual Losses for Both Solar PV Power Plant is tabulated in Table 9.

Table 9. Simulated Annual Losses for Both Solar PV Power Plant

Losses	5MW	23MW
Global Incident in collector	3.30%	9.00%
IAM Factor	2.90%	2.70%
Near Shading Loss	1.90%	1.00%
Soiling	1.50%	2.10%
Module Degradation	0.50%	0.50%
Low Irradiance	0.40%	0.40%
Module Temperature	9.70%	13.90%
LID	1.00%	0.10%
Module Mismatch	1.10%	1.70%
Shading: Electrical loss	0.10%	-
DC ohmic	1.20%	1.10%
AC ohmic	0.10%	0.80%
Plant Unavailability	0.00%	0.00%
Inverter loss during operation	1.60%	1.90%
External Transformer	-	0.80%

4. COMPARATIVE ANALYSIS

Analysis & performance of the already installed plant on the basics of energy output, yields (reference yield, array yield and final yield), array and system energy losses, system efficiencies (array efficiency, system efficiency and inverter efficiency), performance ratio and capacity factor. The comparison of Plant on the above basis of parameter for the estimated Model, Actual plant data and the actual Plant Simulated model is plotted for the results as follow:

4.1 23MW comparative analysis:

Figure 2 shows the performance comparative analysis of solar power plants is best defined by the Capacity Utilization Factor (CUF), from the above Chart it is observed that the actual plant running CUF is 18.83%, whereas the estimated CUF is 19.18%, and the actual Simulated CUF is 19.09%. The Estimated &

Simulated CUF is for 100% Plant availability, whereas the practically due to x% of plant unavailability i.e. for (100-x) % availability and Grid availability of 99.04% the CUF comes to be 18.83%. Which can be compensated or overcome in case if plant availability is improved.

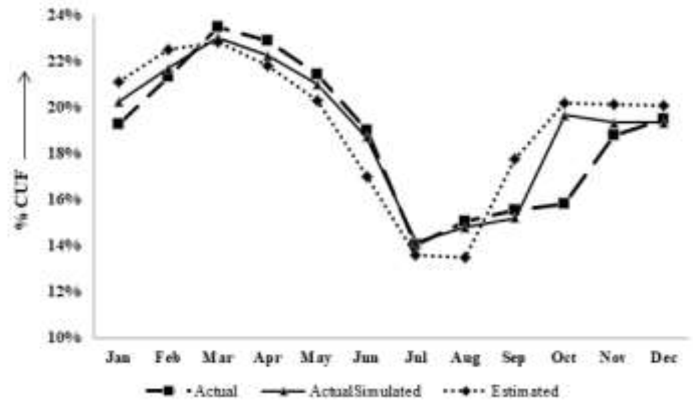

Figure. 2**.** Comparative analysis of actual, actual simulated and estimated % CUF for year 2014

The estimated irradiation on the POA 2192.3kWh/m^2 and the estimated energy generation at the plant end is 38695.34MWh. This gives an estimated PR of 79%. The normalize Annual actual POA for the period of January to December, 2014 was 2149.40kWh/m^2 while the Net Actual Annual Energy Generation at the plant ends during the same period was 37991.00MWh. This computes to an actual Achieved PR of 76.87%. On the other hand, Actual Simulated Plant on the measured values has estimated POA for the period of January to December, 2014 is 2041.40kWh/m^2 while the Net Actual Annual Energy Generation at the plant ends during the same period is 38576.70MWh. This gives to an actual needed PR of 78.00%. The Difference in Estimated PR & Actual Simulated PR is 1.26% which is because of change in daily solar irradiation, IAM losses, PV loss due to temperature. It is seen that for the period of January to December, 2014 the plant is underperforming by 1.44% practically (i.e. difference between Actual Simulated and Actual PR) and underperforming by the means of 2.69% theoretically (i.e. difference between Estimated and Actual PR) all three analysis shown in Figure 3. The band gap of 1.44% can be overcome by the proper operation & maintenance, as:

a) Proper Routine checkup & by maintaining 100% plant Availability.
b) Check the growth of vegetation, De-fertilize area that could eventually create Shade on the array.
c) Proper Calibration of measuring & indicating instruments.
d) Cleaning of PV module as per manufacturer instruction to reduce soiling losses.

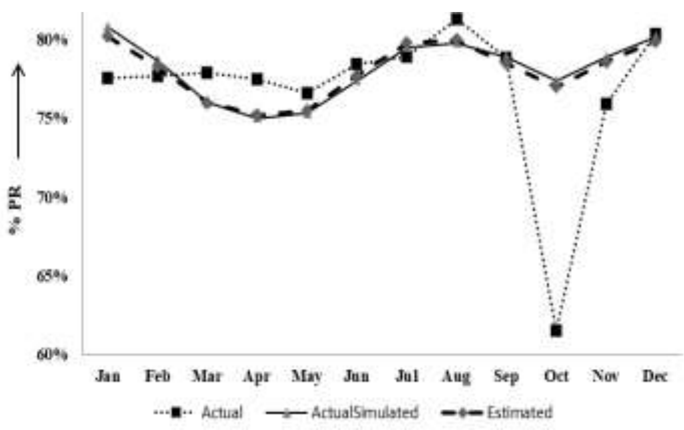

Figure 3. Comparative analysis of actual, actual simulated and estimated % PR for year 2014

4.2 5 MW comparative analysis:

Figure 4 shows the performance of solar power plants is best defined by the Capacity Utilization Factor (CUF), from the above Chart it is observed that the actual plant running CUF is 18.42%, whereas the estimated CUF is 17.84%, and the actual Simulated CUF is 18.22%. A system is made of components and its needs proper maintenance for its uninterrupted functioning. Factor like plant availability plays a very crucial role to maximize the output of plant. The Estimated & Simulated CUF is for 100% Plant availability, whereas the practically due to x% of plant unavailability i.e. for (100-x) % availability & 99.20% of Grid availability the CUF comes to be 18.41%. Which can be further compensated if plant availability is improved.

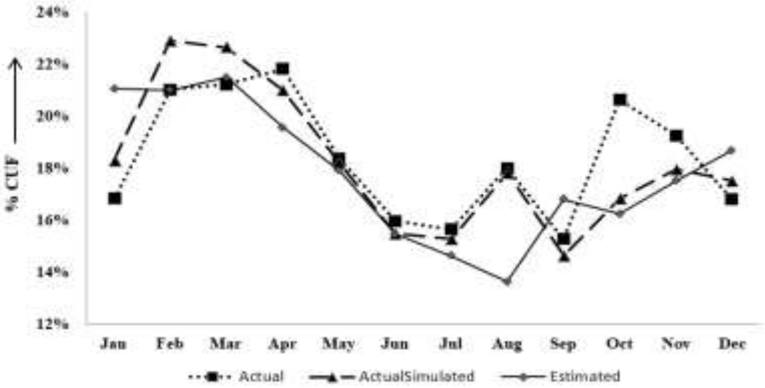

Figure.4. Comparative analysis of actual, actual simulated and estimated %CUF for year 2016

Performance of a PV plant independent of actual plant configuration and irradiation can be assessed through the use of Performance Ratio. The Performance ratio is a measure of quality of a PV Plant independent of the effect of location and it has therefore often described as quality factor**.**

The estimated irradiation on the POA 2002.5kWh/m^2 and the estimated energy generation at the plant end is 8736MWh. This gives an estimated PR of 78%. The normalize Annual actual POA for the period of January to December, 2016 was 1991.48kWh/m^2 while the Net Actual Annual Energy Generation at the plant ends during the same period was 9047.70MWh. This computes to an actual Achieved PR of 79.90%.
On the other hand, Actual Simulated Plant on the measured values has estimated POA for the period of January to December, 2016 is 1983.20kWh/m^2 while the Net Actual Annual Energy Generation at the plant ends during the same period is 8920.90MWh. This gives to an actual needed PR of 80.35%.

The estimated PR is less than Actual PR by 2.5% it means the plant is over performing for the year 2016 on the basis of change in climatic pattern and Daily Irradiance on the plane of Array all three analysis shown in Figure 5.

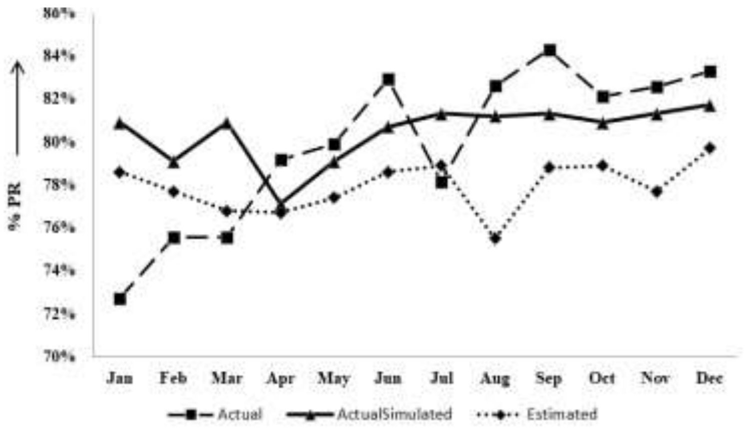

Figure 5. Comparative analysis of actual, actual simulated and estimated % PR for year 2016

It is seen that for the period of January to December, 2016 the plant is underperforming by 0.6% practically (i.e. difference between Actual Simulated and Actual PR). And over performing by the means of 2.5% theoretically (i.e. difference between Estimated and Actual PR). This Band Gap of 0.6% can be overcome by the proper operation & Maintenance i.e.

a) Maintaining 100% plant Availability & Grid Availability.
b) Check the growth of vegetation, De-fertilize area that could eventually create Shade on the array.
c) Cleaning of PV module as per manufacturer instruction to reduce soiling losses.

5. CONCLUSION:

A detailed investigation on performance analysis of already installed 23MW and 5MW of SPP in India is done based on the monitored data and estimation. The estimated simulation model for 23MW SPP on the basis of METEONORM 7.1 data predicts the estimated irradiation over the POA was 2192.3kWh/m^2, plant estimated energy generation at the year-end is 38695.34MWh. This gives an estimated PR of 79% and CUF of 19.18%. Whereas for 5MW SPP the estimated irradiation over the POA was 2002.5kWh/m^2, plant estimated energy generation at the year-end is 8736MWh. This gives an estimated PR of 78% and a CUF of 17.84%. From the real time data for 23MW SPP, the normalize annual actual POA for the period of January to December, 2014 was 2149.40kWh/m^2 while the Net Actual Annual Energy Generation at the plant ends during the same period was 37991.00MWh. This computes to an actual Achieved PR of 76.87% with a CUF of 18.83%.Whereas for 5MW SPP the Annual actual POA for the period of January to December, 2016 was 1991.48kWh/m^2 while the Net Actual Annual Energy Generation at the plant ends during the same period was 9047.70MWh. This computes to an actual Achieved PR of 79.90% with a CUF of 18.42%. On the basis of real time Simulation Model for 23MW SPP the irradiation over the POA for the period of January to December, 2014 is 2041.40kWh/m^2 while the Net Actual Annual Energy Generation at the plant ends during the same period is 38576.70MWh. This gives to an actual needed PR of 78.00%. Whereas for 5MW SPP the irradiation over POA for the period of January to December, 2016 is 1983.20kWh/m^2 while the Net Actual Annual Energy Generation at the plant ends during the same period is 8920.90MWh. This gives to an actual needed PR of 80.35%. The difference in performance Ratio is 1.44% for 23 MW SPP and 0.6% for 5 MW SPP Plant. These band gaps can be overcome and optimize with proper operation and maintenance techniques

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