

Performance Assessment of 5 MW Grid Connected Photovoltaic Plant in Western Region of India

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Abstract—The main objective of this work is to present the performance assessment of ground based photovoltaic power plant and plant components. The Gujarat power corporation limited has been measuring and monitoring all the parameters of 5 MW Gujarat Power Corporation Limited (GPCL) solar power plant in Charanka solar park, Gujarat (latitude 23.88°N and longitude 71.17° E. Average solar insolation available in Gujarat city is 5.7- 6.0 kWh/m²/day. This is one of the highest insolation areas in the world. In this paper, Six months data from 1st March 2014 to 31st August 2014 are used for the analysis of daily and monthly variation in yield of PV power plant due to change of insolation (global horizontal irradiation), Tilted insolation (global tilted horizontal irradiation), temperature and sun-availability. In the performance analysis of PV power plant, data quality plays an important role. The estimation of the performance indices of the PV plant is important from this perspective. In this article, we perform the data quality check on global horizontal irradiation and tilted global horizontal irradiation to obtain the estimated performance ratio of concerned PV plant. For validation of data quality control, standard guidelines, equations and correlations are applied in this article. This helps in estimating the actual Performance ratio and Capacity Utilization Factor of the plant. The performance analysis based on the International Energy Agency (IEA) standard Indices such as final yield, performance ratio and capacity utilization factor of the plant is presented

Keywords- PV, Plant, Performance Analysis

I. INTRODUCTION

In 21st century the energy management and environmental Security are the biggest challenges for us. In this era the current issue is global energy problem can be attributed to insufficient fossil fuel supplies and excessive greenhouse gas emissions resulting from increasing fossil fuel consumption. Which we can see in the form of global warming. Energy demand and supply has become one of the most important problems facing humanity [1]. The day by day increasing demand for energy is show fossil fuel supplies [2] and record-high oil and gas prices due to global population growth. So the energy shortage has played an important role in the future for our society. Because of increasing fossil fuel consumption we all are facing problem of Global warming and energy crisis [3-5]. At this large scale, solar energy seems to be the most viable choice to

meet our clean energy demand. The sun continuously delivers to the earth 120,000 TW of energy,

which dramatically exceeds our current rate of energy needs (13TW) [6]. This implies that covering only 0.1% of the earth's surface with solar cells of 10% efficiency would satisfy our current energy needs [7]; however, the energy currently produced from sun light remains less than 0.1% of the global energy demand [8-9]. The solar energy can be broadly used in two areas: (a) PV systems which convert solar energy directly into electrical energy and; (b) thermal systems that convert solar energy into thermal energy. The solar energy is used in various application such as solar heating and cooling, Building integrated Photovoltaic (BiPV) systems and products, grid connected Renewable Energy (RE) systems Including biomass and PV systems, day lighting, solar thermal electricity generation, and solar refrigeration. Gartner has predicted an increase in PV industry revenue to increases within the next five year. [10] Generally PV system can be classified into three types:

- (a) Stand-alone system
- (b) Hybrid system and
- (c) Grid-connected system.

A grid-connected system comprises of the modules and an inverter. The inverter converts the direct current (DC) electricity generated by the PV array into alternating current (AC) electricity that is synchronized with the mains electricity .The electric power produced by PV system then can be consumed by the connected load and no power is taken from the main grid unless load connected to the system is less than capacity of PV systems [11]. Roof and facades of existing buildings represents a huge potential area for PV system installation, allowing the possibility to combine energy production with other functions of the building or non-building structure. BiPV systems seem to offer the most cost and energy effective application of grid connected PV systems [11, 12-14] Description of PV power plant.

II. PV POWER PLANT DESCRIPTION

Gujarat has extreme climatic conditions characterized by very hot and dry summers and cold and chilly winters. Hence the performance of the solar power plant varies not only with solar radiation but also temperatures in each

season. Fig. 1 show 5MW grid-connected Multi crystalline photovoltaic power plant. It is developed in approx. 2,024 hectares of government waste land and has the capacity to generate 7.75 million units of electricity in favorable conditions. The GPCL has used the state of the art technology considering the local conditions. The project is fully commissioned and operational. The plant is located at a Latitude 23054'20.24"N and Longitude 71011'54.29"E.



Fig. 1 5MW Aerial view of MW Gujarat power cooperation limited solar photovoltaic power plant

A. System Description

Solar PV array is made of high efficiency poly/multi crystalline -Si SPV Modules. The plant consist of 21,277 no. of 235Wp poly/multi crystalline-Si from "C-Sun" Solar. Details of solar photovoltaic panels are shown in Table 1. The basic function of power conditioning unit is to convert DC electricity generated by solar modules into AC electricity which is then fed into the grid. The plant comprises of 5 power conditioning units and 5 Inverters of 1000 MVA inverter from "Bonfiglioli" are shown in Fig. 2.

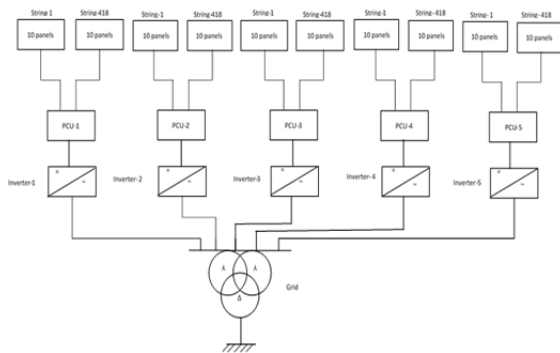


Fig. 2: Schematic block diagram of the considered PV plant (5 MW GPCL solar PV plant)

Table 1 C-Sun 235 Wp Solar panel specification

Particulars	Specifications
Power (W)	235
Tolerance	3%
Max. Power Voltage (V)	29.5
Max. Power Current (A)	7.97
Open Circuit Voltage (Voc)	38.8
Short Circuit Current (Isc)	8.59
Temperature Coefficient of Power (%/OC)	-0.408%/k
Maximum system voltage (Vdc)	1000
Length (mm)	1640
Width (mm)	990
Height (mm)	50

Weight (kgs)	19.8
Max. Power Current (A)	7.97
Open Circuit Voltage (Voc)	38.8

B. Online Data Monitoring System

In this solar power plant, data acquisition using ground based measurement of the solar resource parameters and meteorological data is used. Two pyranometers are used to measure global hour radiation (GHI) at the horizontal surface and at near tilted module for tilted GHI. Solar photovoltaic plant power generated is monitored at the both DC and AC side using data acquisition system controlled by sunny sensor web box. RS232/RS485 peripheral interface is used for data communication and stored in the computer system using with a data acquisition system (SCADA) and data can be retrieved via USB and storage device and read directly in to a system and this whole data is saved in .CSV file. The daily average and monthly power generation report from time to time is sent to Gujarat, state load dispatch center (SLDC). Converted DC power is directly fed in to 11 kV grid of Gujarat power cooperation limited via a 415V/11 kV transformer. The schematic diagram of the solar power plant is shown in Fig. 3.

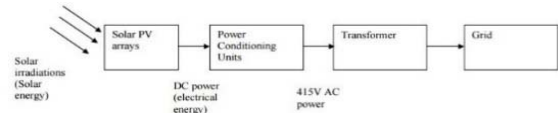


Fig. 3: Schematic diagram of 5 MW GPCL SPV power plant

Data acquisition system monitored 6 parameters: global horizontal irradiation, global tilted horizontal, maximum ambient temperature, module temperature, sun availability and plant generation respectively. Here solar radiation, ambient temperature, module temperature and sun availability are have the largest effect on plant output. In this study six months data (March-August 2014) is considered for data analysis on the basis of peak months in a year. Daily averaged GHI, tilted GHI and maximum ambient temperature with module temperature are considered in this data set.

III. PERFORMANCE ANALYSIS

The main objective of this section is to describe the standard performance indices of photovoltaic power plants. These performance indices are used for the analytical assessment of performance analysis of the PV power plants in the electricity grid. In the grid operational problems and reliable electric power services, these indices are playing an important role[15-19].

The International Energy Agency (IEA) developed these performance indices and described in IEC 61724 standard for the performance analysis of grid connected solar PV plants. The performance of Solar PV power plant depends on the deterministic and stochastic variables. These are the main reason for solar power generation variability. So while computing the power, energy, and yield related performance indices of grid-tied PV plants, some parameters are required. These parameters are given below in Table [2].

Table 2 Plant performance parameters

S. No.	Parameters	Notation
1.	Plant Energy Output	E_{ac}
2.	Array Yield	Y_a
3.	Final Yield	Y_f
4.	Performance Ratio	PR
5.	Capacity Utilization Factor	CUF

Plant Energy Output

Energy generated at AC side of the photovoltaic power plant is described by $E_{ac,d}$ for the daily energy generation and $E_{ac,m}$ for monthly energy output from the PV plant and is calculated by Eq.[1-2]:

$$E_{ac,d} = \sum_{t=1}^{t=24} E_{ac,t} \quad \dots (1)$$

$$E_{ac,m} = \sum_{d=1}^N E_{ac,d} \quad \dots (2)$$

Array yield

The array yield $Y_{a,d}$ is the ratio of array based DC energy output to the rated DC power of PV plant shown in Eq. (3)[15].

$$Y_{a,d} = \frac{E_{ac,d}}{P_{pv,rated}} \quad \dots (3)$$

And the array yield for the month is calculated by Eq. [4]

$$Y_{a,m} = \frac{1}{N} \sum_{d=1}^N Y_{a,d} \quad \dots (4)$$

Reference Yield

The reference yield Y_r is the ratio of total in plane irradiance to reference irradiance at PV module level. It can be described as generated energy under standard test conditions (STC) for a day [16].

Performance Ratio

The performance ratio shows the overall effect of losses on photovoltaic array's nominal power output. It also shows how accurate the plant can be under ideal operation conditions. Performance ratio also represents the total losses in the Photovoltaic system during converting DC to AC [15-16]:

$$PR = \frac{\text{Energy Measured (kWh)}}{\text{Energy Modeled (kWh)}} * 100\%$$

Capacity Utilization Factor

The capacity utilization factor (CUF) basically represents the energy produced by the SPV plant. If the plant produces the full installed power daily, its capacity factor should be unity. It is a ratio of the net yearly energy generated to the net amount of energy the PV plant would generate under installed capacity. The capacity utilization factor for a grid-tied Photovoltaic plant is given in Eq.(5)[16-19].

$$CUF = \frac{\text{Energy Measured (kWh)}}{\text{Installed Capacity (kW)} * 8760 \text{ hours}}$$

$$CUF = \frac{E_{ac,a}}{P_{pv,rated} * 8760} \quad \dots (5)$$

IV. RESULTS

In this section, 5 MW ground-based grid connected photovoltaic plant of Gujarat Power Corporation Limited is considered for the performance assessment. A detailed description of the plant and its component is described in previous section. Geographical location of the plant is $71.17^{\circ}E$ and $23.88^{\circ}N$ in western region of the India. Average solar irradiation available in Gujarat city is 5.7- 6.0 kWh/m²/day. This is one of the highest insolation areas in the world. In this work, Six months data from 1st March 2014 to 31st August 2014 are used for the analysis of daily and monthly variation in yield of PV power plant due to change of global horizontal irradiation (GHI), global tilted irradiation (GTI), temperature and sun-availability. In the performance analysis of PV power plant, plant availability, grid availability and generation availability play an important role in understanding the behavior of plant and grid during power generation. Figure 4 shows the daily variation in Plant availability and grid availability during these months.

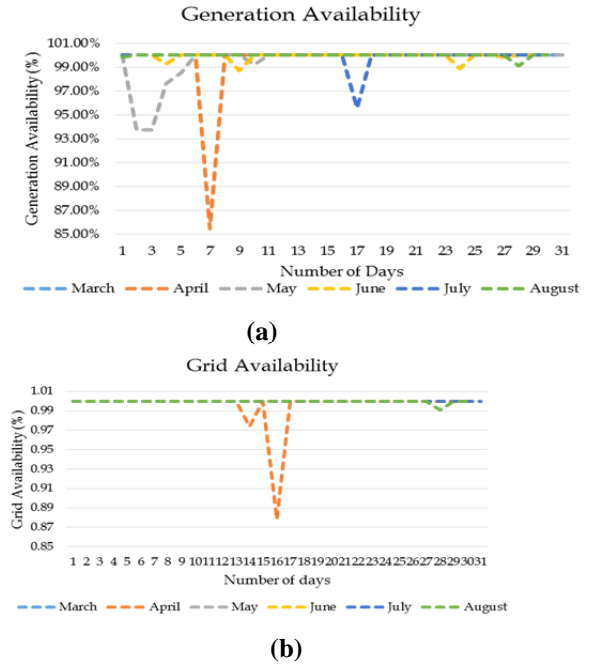
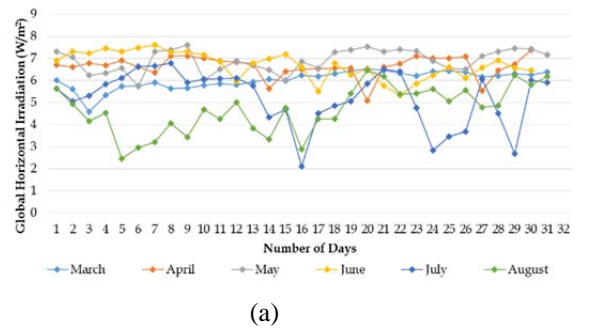
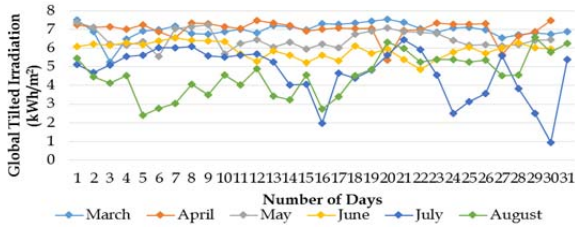


Fig. 4: Comparison of daily variation in (a) Plant availability (b) Grid availability in various months





(b)

Fig. 5: Comparison of daily variation in (a) Global horizontal irradiation (b) Global tilted irradiation

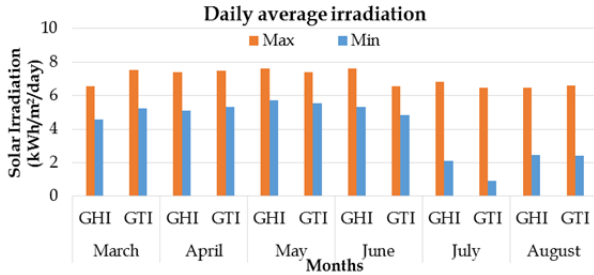


Fig. 6: Min-Max range of daily average GHI and GTI in various months

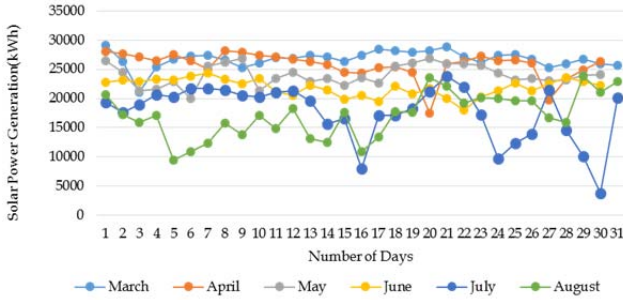
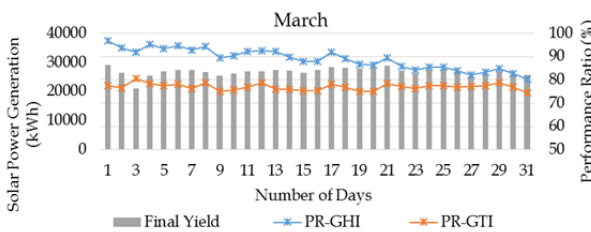
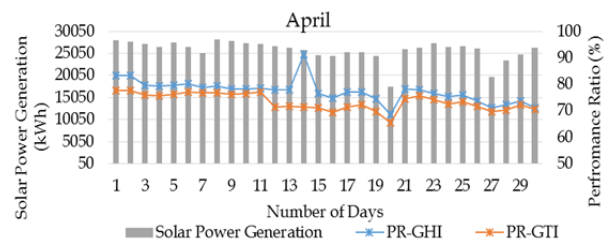


Fig. 7: Comparison of daily basis solar power generation in various months

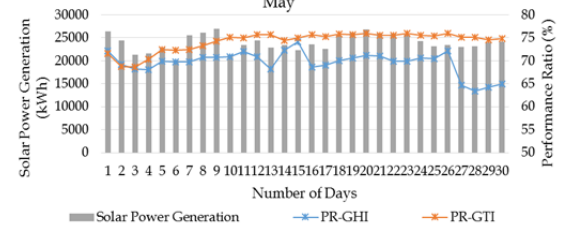
Figure 5 shows the daily variation in global horizontal irradiation and GTI. It is observed that, minimum 145.9 kWh/m² and maximum 214.53 kWh/m² total GHI is received in the month of August and May respectively. Whereas the total GTI minimum and maximum is received in August and March, which are 141.17 kWh/m² and 215.8 kWh/m² respectively. The minimum and maximum ranges of GHI and GTI are shown in Figure 6. Daily variation in generated solar power is demonstrated in Figure 7.



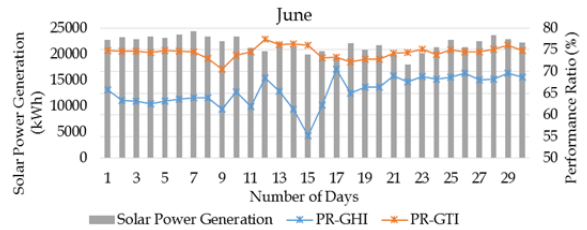
(a)



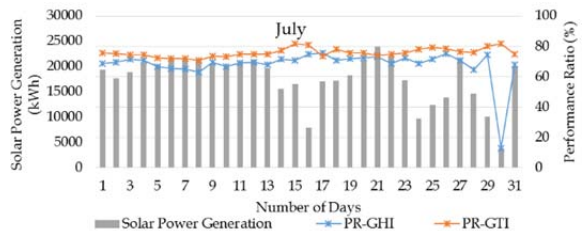
(b)



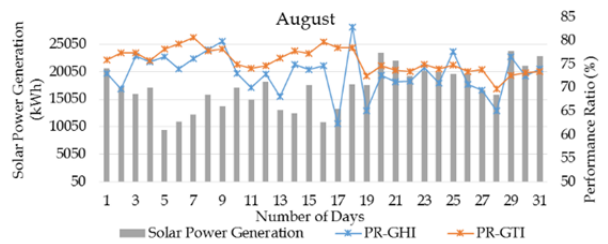
(c)



(d)



(e)



(f)

Fig. 8: Plant performance ratio using GHI and GTI with respect to solar power generation for the month of (a) March (b) April (c) May (d) June (e) July and (f) August

Daily variation in solar power generation and performance ratio is presented in Figure 8 for various months. With the help of Figure 8, we can understand the behavior of power generation due to the variation in irradiation. With the help of GHI and GTI data, we have calculated the performance ratio of the plant for various months. Table 3 show the minimum and maximum variation in GHI and GTI based performance ratio for various months.

Table 3: Min-max range of performance ratio using GHI and tilted GHI

	Performance Ratio			
	GHI		GTI	
	Min	Max	Min	Max
March	80.07813	96.84859	74.38316	80.48473
April	68.66405	91.22124	65.44944	77.76338
May	63.38167	74.10649	68.68065	75.97087
June	55.25	70.48913	65.54844	77.42264
July	12.62458	75.47788	70.59638	68.07817
August	62.3271	82.85047	69.68421	80.63607

Figure 9 presented the monthly averaged performance ratio of the plant using GHI and tilted GHI. The monthly average performance ratio is 89.15% (PR-GHI) and 77.37% (PR-GTI) and 77.37% (PR-GHI) and 73.41% (PR-GTI) for the month of March and April. Performance ratio for rest of the months is mentioned in Figure 9. The monthly averaged capacity utilization factor is also mentioned in Figure 10.

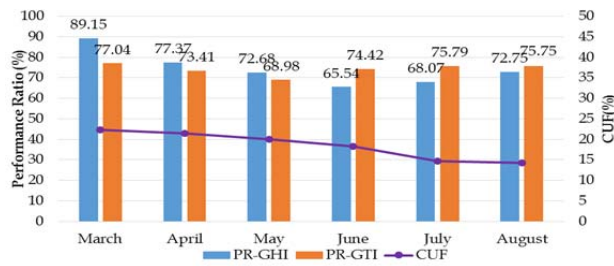


Fig. 9: Monthly average performance ratio using GHI and GTI and CUF for various months

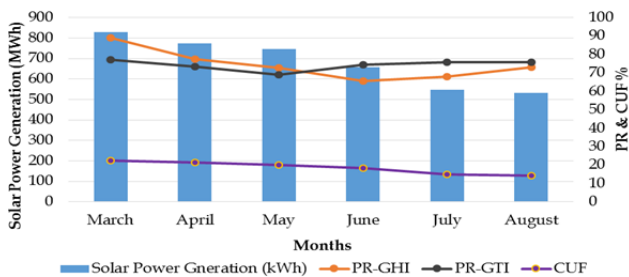


Fig.10: Monthly Variation in power generation and performance ratio for various months

Figure 10 presented the monthly variation in solar power generation, performance ratio and capacity utilization factor for various months. The highest capacity utilization factor (CUF) is calculated using Eq. 5, which is 24.25 % for March and lowest is 3.16% for July and average performance ratio and CUF for various months are 74.29% and 18.50%, respectively.

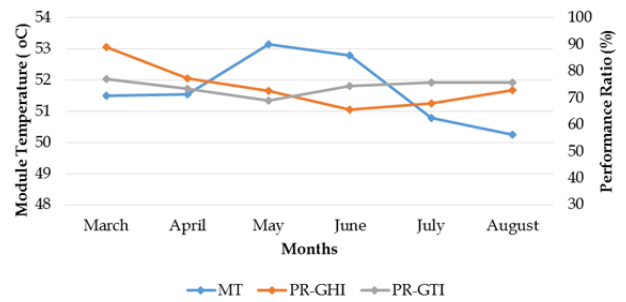


Fig. 11: Monthly Variation in power generation and performance ratio for various months

For a better understanding, the relationship between monthly average module temperature and performance ratio is presented in Figure 11. With the help of Figure 11, it is clear that performance ratio and module temperature have an inverse relationship with each other. So it is mentioned in the figure that as temperature increases performance ratio decreases and if the temperature decreases then performance ratio increases.

CONCLUSION

It is easily observed that performance ratio is inversely proportional to module temperature. Module temperature depends on the climatic parameters like solar irradiation, ambient temperature, and wind velocity, etc. So performance ratio varies with the seasonal changes. In conclusion, plant under standard condition provides maximum power generation with higher performance ratio. Therefore, performance ratio varies in different months and due to thermal losses. Performance ratio is higher in winter season compare to summer or rainy season. Indices used for PV plant performance analysis can be useful for comparative performance analysis of two different plants and at different locations.

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BIOGRAPHICAL INFORMATION

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