Performance analysis and effect of pandemic condition on utility grid connected PV system

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ABSTRACT

In this research paper effect of pandemic and performance analysis of the utility grid connected PV system under net metering is evaluated for one years based on PV plant generation data. The performance of the system depends on annual average final yield, reference yield, and array yield and their values are 3.87 kWh kWp^{-1}. d^{-1}, 4.57 kWh kWp^{-1}. d^{-1}, and 4.297 kWh $kWp^{-1}d^{-1}$ the performance ratio and capacity utilization factor are 77.48% and 15.68%. Due to pandemic campus energy consumption is less so energy export to grid is more than the energy import from grid. As per the state energy policy minimum billing is done even the export units are more than the imported units which result in increase in return on investment (ROI) compared to post pandemic. The above statistics illustrate the quite strong performance of solar power plants built in the Indian state of the Andhra Pradesh, Guntur.

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1. INTRODUCTION

The RVR & JC College of Engineering, Guntur, Andhra Pradesh, India has installed a 500 kW land mounted PV system under net metering to meet the campus daily energy demands, improve environmental variables, e-mobility and energy efficiency. Ecological worries, self-reliance, and high per unit cost of fossil fuels are motivated for installation of renewable and sustainable energy system in campus. The solar power system installed on campus is designed to meet 80% of energy consumption from renewable sources. The plant was installed in Dec-2019 as the average solar irradiation in state of Andhra Pradesh state is 1266.52 W/sq.m. i.e., every 1 kWp solar rooftop plant will generate on an average over the year 5.0 kWh of electricity per day by considering 5.5 sunshine hours. Solar irradiance vs energy, analysis of yields, performance ratio, capacity utilization factor, energy import and export and direct consumption of campus, PV generation vs campus demand, and analysis of energy import and export during and after pandemic are evaluated.

Several studies on the effectiveness of photovoltaic systems around the world are discussed:

- Singh *et al*. [1] did performance analysis of a rooftop 5 kW_p grid connected PV system at Manipur, India having performance ratio (PR) of 74.4% and capacity utilization factor (CUF) of 14.4%.

- Narasimman *et al*. [2] has done modeling of 5 MW plant using different artificial neural network (ANN) for one year and concluded that compared with fixed tilt, optimized tilt increase PR and CUF by 48.5% and 9.3% with an increase in average power gain 5.4%.
- Mehdi *et al*. [3] done performance analysis on two different PV technologies polycrystalline (pc-Si) and cadmium telluride (CdTe) in Morocco, the PR is 1 for the pc-Si and around 0.9 for CdTe, energy yields for pc-Si and CdTe are of 7.51 kWh/kWp and 6.99 kWh/kWp respectively and CdTe is less affected for temperature variations.
- Owolabi *et al*. [4] analyzed mono crystalline type has better yield compared with poly crystalline type silicon panels for the PV system located in South Korea.
- Chamana *et al*. [5] using mixed-integer linear programming (MILP) model and controller hardware in-loop (CHIL) using resilience-oriented optimization algorithm, different micro grid types are implemented to serve critical loads at high priority like building level energy management under emergency conditions at military bases.
- Masrur *et al*. [6] analyzed techno-economic evaluations like net present value (NPC) levelized cost of energy (LOCE) for optimally tilted PV system located at Hatiya, Bangladesh, and concluded that the power exchange cost is lower than the value of the derating factor.
- Alsamamra and Shoqeir [7] using HOMER Pro software simulation of a 57.16 kW rooftop PV system with 144 panels and concluded that due to low working hours and less energy consumption the payback period is 4.38 years.
- Yadav and Bajpai [8] analyzed the performance analysis of a 5 kW rooftop solar plant in northern parts of India has an annual average reference yield of 5.23 kWh/kW/day, array yield of 4.51 kWh/kW/day and final yield of 3.99 kWh/kW/day.
- Pundir *et al*. [9] done comparative performance of 3.5 MW grid connected PV system located at IIT Roorke campus using mathematical model and actual values, the system performance ratio is 63.58%, capacity factor is 13.83% and efficiency is 8.76%. Pundir *et al*. [9] done comparative performance of 3.5 MW grid connected PV system located at IIT Roorke campus using mathematical model and actual values, the system performance ratio is 63.58%, capacity factor is 13.83% and efficiency is 8.76%.
- Adaramola and Vagnes [10] examined that it is feasible for installation of PV system by evaluating the performance of small scale grid connected PV system installed on Norwegian university with annual final yield of 2.55 kWh/kWp with annual performance ratio of 83.03%.
- Chokmaviroj *et al*. [11] analyzed a 500 kWp land mounted grid connected PV system using 1680 PV modules each 300 Wp (140 strings, 12 modules per string connected to 2-250 kW inverter) in Thailand connected to 22 KV distribution system for 8 month generated 383274 kWh, has performance ratio 70-90% with average final yield 2.91-3.98 kWh/day.
- Padmavathi and Daniel [12] analyzed the technical parameters for a 3 MW grid connected SPV system in India by considering the inverter and grid failure losses having average energy yield of 1372 kWh/kWp and 3.73 kWh/kWp as final yield.
- Lima *et al*. [13] analyzed the performance of 2.2 kWp PV system in Brazil from June 2013-2014 having 82.9% performance ratio and 19.2% capacity utilization factor.
- Yilmaz and Ozcalik [14] analyzed a 500 kWp solar plant mounted on the rooftop of a textile factory in Turkey with 2001 PV modules each 250Wp divided into 3 groups (73 strings - 23 modules in series, 6 strings - 18 modules in series, 8strings- 21 modules in series) produced 479700 kWh for the period of 8 months.
- Sharma and Goel [15] analyzed the performance of 11.2 kWp grid connected PV plant installed on the rooftop of ‘O’Anusandhan University Bhubaneswar, India having yearly average final yields of 3.67 kWh/d and average PV efficiency of 13.42% and reduction of 14.66 tons of CO_2.
- Bano and Rao [16] analyzed the performance analysis using excel model, PV system, and SAM software’s for 1 MW grid connected PV system under gross meter using and concluded that the performance ratios are closely related to 77%.
- Attari *et al*. [17] the performance of a polycrystalline 5 kWp Grid connected PV system installed at Morocco in 2015 having average final yield range 1.96-6.42 and performance ratio range 58-98%.
- In the year 2015 Elkholy *et al*., [18] experimentally evaluated the PV system parameters and power quality parameters for 8kW grid connected PV system installed in Egypt using power quality analyzer under different irradiance conditions.
- Nurdiana *et al*. [19] performance analysis of 10.6 kWp roof-top grid connected system in Indonesia designed with 40 PV modules @265Wp with battery system and 10.250 kW grid connected inverter accessed for 8 months has 82% performance ratio and 3.38 kWh/kWp as final yield.
- Srivastava *et al*. [20] using the software PV system and PV*SOL, a 100 kW integrated grid-connected PV system's performance is evaluated by considering the effects of shading.

- Dahbi *et al*. [21] Observed the performance of 6 MW land mounted grid connected PV system under harsh climate conditions Algeria for one year whose performance ratio is 74.6% and system efficiency is 11.39%.

In literature review, presented above most of the PV systems are connected to grid under gross metering, and low PV rated systems connected to loads under net metering cases energy import and export to grid are not discussed, and none of reviews evaluated energy import and export for grid PV system under net metering. The main objective of this paper is to analyse the performance and contribution of the PV system to the campus enery demand during and after pamdemic under net metering as per IEC 61724 standards [22]. Based on monitored data performance analysis for annual average energy yields, performance ratio, PV generated units utilised by the campus, monthly net energy-import and export, additional amount paid to distributed company (Discom) due to COVID-19 are calculated. The structure of the paper is divided in to four parts, part II describes the design of the PV system and part III describes the analysis of results and part IV describes the conclusions.

2. PV SYSTEM DESCRIPTION

Photovoltaic panels convert solar radiation into DC electrical energy the measurement of the amount of solar radiation incident on the PV panel is measured using pyranometer (EKO model: MS-40M sensitivity 12.34µv/W-m^{-2}) which convert the global solar irradiance it receives into an electrical signal, higher the irradiance the greater the output current results in higher power generation. The generated DC electrical energy from photovoltaic generators is converted into alternating current and fed into local distribution network with the help of an ABB string inverter using power electronic devices. To operate the inverter in safe thermal conditions the inverter automatically reduces the value of power fed into the grid under adverse environmental conditions or unsuitable input voltage values. When the PV generation is less than the campus power required the deficit energy is imported from grid vice versa. The inverter can limit the amount of active and reactive power fed into the grid based on volt-var and volt-watt modes. Figure 1 shows the schematic diagram of the PV System connected to the utility grid.

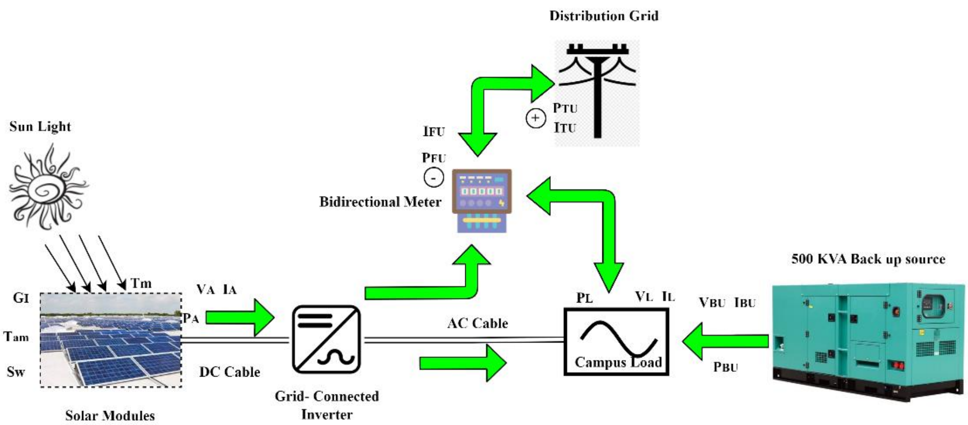

Figure 1. Schematic diagram of the captive based PV system

2.1. Configuration of PV system

Selection of suitable solar panels and sizing of suitable inverters are two important components for solar power generation. Selection of solar panels based on available power rating, power tolerance, solar cell efficiency, temperature coefficient, cost and efficiency. Other major and important component for smooth operation of plant is inverter. The selection of inverter is based on technical features like topology, rated out power, efficiency, over and under voltage protection, specific grid codes, protocol used for third party monitoring and control, and type of anti-islanding protection. Bidirectional Tri vector gross meter is installed to monitor the energy import and export between campus and PV system. The specifications of the PV module and inverter are shown in Table 1 and the configuration of PV modules to inverter is shown in Table 2. Advanced control system with fast and precise phase locked loop (PLL) is used to sense phase angle and amplitude of the grid, parameters at PCC for synchronization of power converter to grid. The inverter is capable of active power, reactive power support during grid disturbances for limited time as per IEEE1547, IEC61727, and VDE0126-1. Active island detection method [23] (active frequency drift with

RoCoF technique) is used to detect unintentional island of converter. The outputs of the inverters are connected to 3-Ø, 50 Hz 400 V/11 KV, 600 KVA Dyn11 vector group transformer having current ratings of 866.03/31.49A via AC cables.

2.2. Methodology used for collection of data

Energy real time status of the inverter power embedded with WLAN, Ethernet, and RS485 allows the inverter to communicate measured data as per IEC 61724 [24]–[33] from CT and PT coils using Aurora protocol, for changing the parameters remotely. The electrical parameters such as active power (kWh), reactive power (kVArh), apparent power (KVAh) and TOD, maximum demand, voltages of all phases, currents of all phases, power factors are recorded in DISCOM's Bi-directional tri vector energy meter [34]–[36], (Secure 300 premium) shown in Figure 2. The inverter embedded with WLAN, Ethernet, and RS485 allows the inverter to communicate measured data from CT and PT coils using Aurora protocol, for changing the parameters remotely.

Table 1. Specifications of module

Type of Module	Polycrystalline
Make	Vikram solar
Wattage and no of modules	330 wp, 1516 No's
No of strings and modules per string	76×20
Modules efficiency	17.2%
Latitude of the site	16.150° N
Longitude of the site	80.1925° E
AC rating	500 kW
Island detection method	Active frequency drift with RoCoF technique
Power Conditioning Unit	
Make and rating type of charge controller /MPPT	ABB India Ltd 50 KW with Triple MPPT 10×50 kW=500 kW
AC output	500 kW, 3-Phase
Input voltage to inverter	300-950 V DC
Make	Vikram solar

Table 2. Configurations of PV modules

Inverter	Modules per string	No. of Strings	Inverter	Modules per string	No. of Strings
Inverter-1	20No's	7 No's	Inverter-7	20 No's	7 No's
Inverter-2	20No's	7 No's	Inverter-8	20N o's	8 No's
Inverter-3	20No's	7 No's	Inverter-9	19 No's	4 No's
Inverter-4	20No's	8 No's		20 No's	4 No's
Inverter-5	20No's	8 No's	Inverter-10	20 No's	8 No's
Inverter-6	20No's	8 No's			

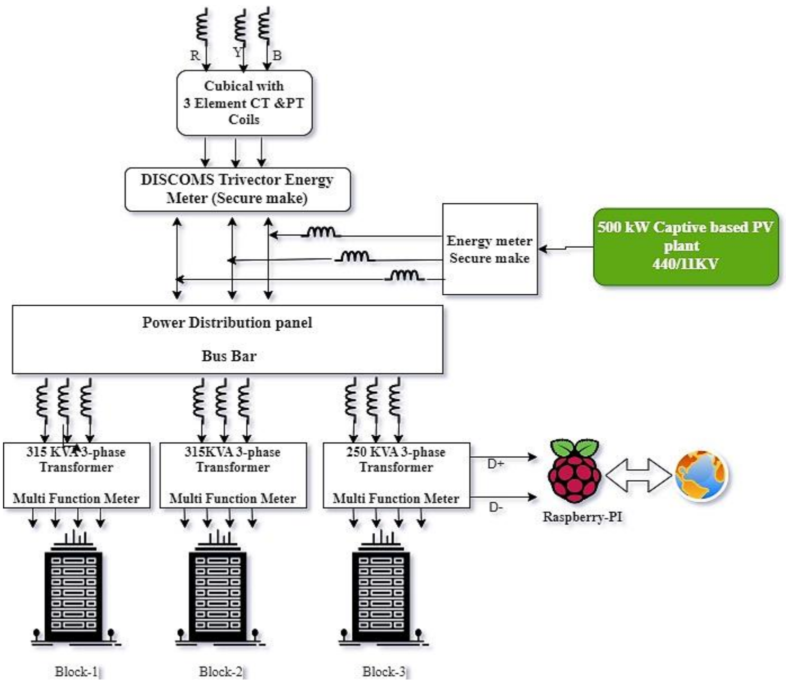

Figure 2. Real time parameters measured for performance evaluation

3. ANALYSIS AND RESULTS

In this section using the logged data evaluated the performance of PV system energy yields like reference yield, array yield, final yields, PR and CUF are calculated:

3.1. Array yield

It is defined as the ratio of a PV array's DC energy output to its rated power. It is calculated daily, monthly, or yearly. The formula for calculating the array yield is represented using (1).

$$Y_R = \frac{E_{DC}}{P_{PV\ rated}} \tag{1}$$

3.2. Reference yield (Y_R)

It is the ideal array yield without any losses based on the manufacturer's definition of the nominal power rating. At standard test conditions (STC), it is defined as the ratio of useful solar radiation that hits the panel to the actual reference irradiance. The formula for calculating the reference yield is represented (2).

$$Y_R = H_T/G_{STC}(kW * \text{kWp}^{-1}\,.\,\text{d}^{-1}) \tag{2}$$

3.3. Final yield (Y_F)

The final PV system yield is the portion of the daily net energy output of the entire PV plant which has supplied by the array per kW installed PV array. The formula for calculating the final yield is represented (3).

$$Y_F = E_{AC}/P_o(kWh\,.\,\text{kWp}^{-1}\,.\,\text{d}^{-1}) \tag{3}$$

During the evaluation period july 2020 to june 2021 daily average final yield, reference yield, and array yield variations range from 3.2-4.7 kWh $kWp^{-1}.d^{-1}$, 3.6-5.6 kWh $kWp^{-1}.d^{-1}$, and 3.8–5.88 kWh $kWp^{-1}.d^{-1}$. The variation of yeilds during the asessment period are shown in Figure 3.

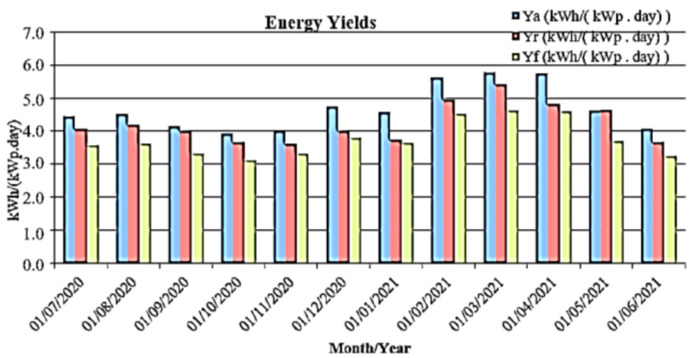

Figure 3. Yields of the system during the assessment period

3.4. Performance ratio (PR)

It compare performance of PV system located at different locations by considering all the environmental factors. Using the measured irradiance using pyranometer, area of the PV modules and efficiency of the PV module, performance ratio of a plant during July-2020-June-2021 are is the ratio of energy measured (kWh) to the irradiance (kWh/m^2)×active power of PV module (m^2)×PV Module efficiency. The formula for caliculating the performance ratio is represented in (4). The typical annual performance ratio of the plant is 77.11%. The highest % performance ratio value is 97% during month of January 2021 and lowest in November_2020 with 64.9%. The performance ratio and average performance during the assessment period are shown in Figure 4. The performance ratio during and after pandemic are 98.29% and 63.7%.

$$\%PR = \frac{Energy\ Measured}{Energy\ Modelled} \tag{4}$$

3.5. Capacity utilization factor (CUF)

It is the ratio of real solar energy produced over year (kWh) to the extreme possible output over year under perfect conditions considering solar radiation is available for 24 hours, 365 days represented in (5). local grid failure, service maintenance in campus, environmental factors such as changes in year-to-year irradiance values, panel de-rating are taken into consideration while calculating the CUF. The deviation in the CUF is due to the system losses. Greater the CUF lower will be the cost of power generation. The %CUF during and after pandemic is 15.6% and 14.6%. The CUF varies from 13.1% to 19.2% shown in Figure 5.

$$\%CUF = \frac{Energy\ Measured\ (kWh)}{Installed\ Capacity \times 8760} \quad (5)$$

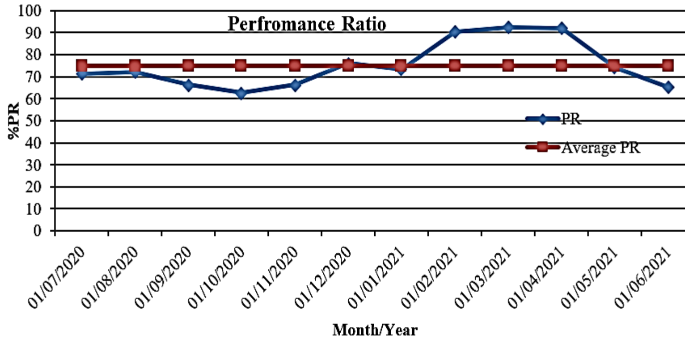

Figure 4. % PR of the plant during assessment period

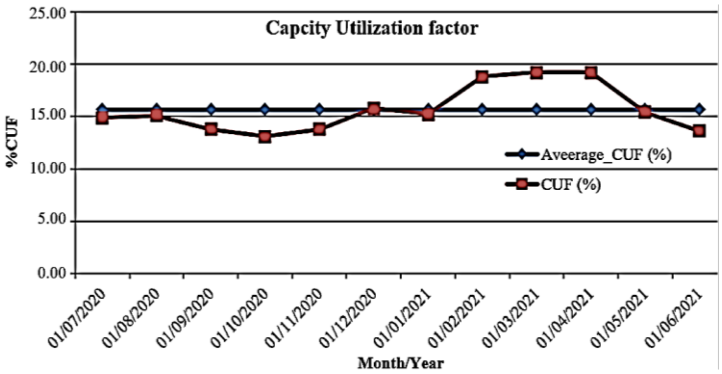

Figure 5. % CUF during the assessment period

3.6. Energy export and import before and after COVID

The analysis of energy import and export during and after coivd and PV generation data are recorded by using Trivector Bi-directional energy meter and Aurora software are shown in Table 3. During COVID PV generated units exported to grid are more than units imported from grid to meet the campus energy demand, as per the state solar policies of the power distribution companies (DISCOM) due to minimum billing additional amount @Rs:7.65 for 129810 kWh i.e., Rs:1033591 is paid to the Discoms's which increases the ROI, along with this grid support charges Rs: 150 per KVA are imposed. During COVID the ratio of campus energy demand to the PV exported units is 112%. After COVID units imported from grid to meet the campus energy demand are more than the PV generated units exported to grid and due to module derate factor decrease in enrgy yeild during and after COVID.

Table 3. Energy import and export before and after COVID

Duration	PV Generation (kWh/Year) (A)	PV generated units Exported to grid (kWh/Year) (B)	PV generated unit live consumption by campus (kWh/Year) (A-B)	Units Import from Grid (kWh/Year) (D)	Billing done by Discom (units/Year) (D-B)	Net-Export (or) Import kWh	Units with DISCOM
2020-2021 During COVID	684,956.2	324,846	360,110.2	319,546	129,810	5,300	135,110.0
2022-2023 After COVID	640,212	166,721	473,491	587,812	421,091	-421,091	0

4. CONCLUSION

In this paper, the performance and support of a 500 kWp grid connected system under net metering installed in campus has accurately evaluated without overestimating or underestimating its impacts on the electric network. The average solar irradiance during the accessed period is 4.29 kWh/m2/day; with average performance ratio of 77.62% with 15.84% capacity utilization factor with annual generation of 684 MWh/yearly. PV system installed in the campus has meat 80% of daily needs and the performance of the system shows good potential for producing electricity through PV system in Andhra Pradesh, India.

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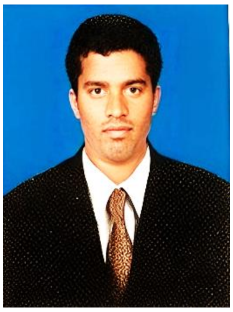

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