Performance Evaluation of On-Grid Rooftop Solar PV System in GMCH, Guwahati, Assam

Israfil Hussain, Utpal Chandra Baro, Rupa Chhetri, Vanita Agrawal, and Abdul Latif

Abstract In this paper, 500 KWp On-Grid Rooftop Solar PV plant installed and commissioned in 2018 at Guwahati Medical College Hospital (GMCH), Guwahati, Assam which is one of the largest in Assam is studied based on the information or the data in the report of Assam Energy Development Agency (AEDA) and its performance evaluation is carried out using PVsyst. Then we have compared the parameters with the one simulated by PVsyst for varying seasonal tilt i.e 20° in summer and 60° in Winter season and also for the fixed-tilt of 22°. Here the azimuth angle is taken 0° subject to the direction of the panel facing towards the south. The mean global horizontal radiation for the site is 4.72 KWh/m^2/day with the average annual temperature is 24.6 °C. This study includes the design and performance analysis of the plant and then compares it with the obtained simulation values. The study uses different techniques and methods of a PV system for performance analysis and optimizes the operational behavior of PV systems.

Keywords PV system · On-grid · Performance ratio · Annual energy yield

1 Introduction

In a tropical country like India, the possibility of solar power generation is huge. In most parts of the region, it receives around 300 days of sun annually with 7–8 h of sunshine every day. The average incident radiation in India is between 4 and 7 kWh/m^2/day [1]. The solar system received around 5000 Tera KWh of energy per year. The Ministry of Power (MoP), under Indian Government in November 2009 has launched a solar mission in the name of Jawaharlal Nehru with an aim for

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sustainable growth of solar power generation. The aim of the mission is to make the country strong in the fields of solar power by 2020 [2].

Government of India aims at installing 40 GW of Solar Rooftop grid-connected systems throughout the country by the year 2022. In fact, 250 MW Grid-tied Solar Rooftop projects have been provided in the state under the supervision of the Ministry of New and Renewable Energy (MNRE) and will be completed by the year 2022. Out of 250 MW, MNRE has sanctioned 14 MW grid-connected Solar Rooftop Program to Assam Energy Development Agency to implement the project in the state of Assam for the year 2017–2018 with 70% subsidy for Residential, Institutional (Non-Govt.) and Social Sectors Institutes. The "Smart City" initiatives by GOI have provided an unprecedented choice for the municipalities to use the modern technologies for better livelihood and better connectivity of the cities where we live. Before undertaking the program, the decision-maker predicts the solution to some of the key questions like "What we are planning to do?" and "What are the priorities for the city?"

The 'Solar City' development program initiated by the MNRE under India Government has aimed at developing the Guwahati city as the 'Solar City' in Assam by Assam Energy Development Agency (AEDA) through Guwahati Municipal Corporation in 2010. The 14 MWp Solar Rooftop Project has been sanctioned to Assam Energy Development Agency (AEDA).

Due to various land variations, the insertion of solar PV system on the geometrical area results in less efficiency. Hence, the rooftop area is emerging as a good option for energy generation. This rooftop grid-connected network will not only solve the failure of power but simultaneously it minimizes the environmental hazards generated by traditional fossil fuel based generation systems [3].

The plant performance work is described into two stages as follows:

1. Manual extraction of the parameters for electricity generation at a fixed-tilt.
2. Then, comparing the parameters with the one simulated by PVsyst in varying seasonal tilt and fixed-tilt. PVsyst is software that deals with the analysis of data, PV system sizing for grid-tied, independent, solar PV pumping as well as DC grid system.

2 Literature Review

Schaefer et al. [4] studied the performance, availability, and maintenance of 10 solar PV plants in U.S. Performance ratios, capacity factors are discussed here. The photovoltaic energy cost is mentioned which is followed by investment/maintenance costs, and capacity factor, and depends on the location, availability of plant, and the tracking system. Marion et al. [5] studied the performance indicators for grid-tied PV networks. The research focused on the importance of four performance indicators required for the total system performance assessment corresponding to the production of energy, solar reserve, and overall outcome of system losses which includes the absolute PV unit yield, base yield, performance factor, and PVUSA grading. Tudorache et al. [6] investigated the performance evaluation of sun-tracking PV panels of single-axis type. The efficiency of sun-tracking PV system is then equated with the fixed PV system. The device identifies the fittest PV unit position with reference to the sun via a DC motor which is governed by a smart drive unit that will receive input signals from LDR light sensors. Cristaldi et al. [7] studied the economical evaluation of PV system losses that occurs because of dust and pollution. This article presents a technique for the maintenance of a PV plant that includes the cleaning expenses of the panels, then compares them to the economic losses in order to increase the efficiency. Kumar et al. [8] illustrated the performance evaluation of a 20 kWp grid integrated solar photovoltaic which is installed in an industry, located in Tiruchirappalli, India that describes some important features of the plant and the performance as well as economic analysis has also been done perfectly. Finally, the results are obtained for energy generation per month, different factors (performance and capacity), economic as well as maintenance features, etc. Bharathkumar et al. [9] studied the performance assessment of grid-tied 5 MW Solar PV unit in the regions of Karnataka where, the grid-tied solar PV unit set up by the Karnataka Power Corporation Limited, is described, and the evaluation of performance is done correspondingly. Sundaram et al. [10] studied the performance assessment of 5 MWp grid-tied PV units in the Southern part of India wherein the real-time analysis of the plant parameters is done and is verified by RET screen plus software environment. Bahaidara et al. [11] reported the analyses of the performance of PV unit for the climatic scenario of Dhahran in Saudi Arabia. EES software is leveraged to compute the parameters like cell temperature, maximum power position current/voltage/efficiency, and power. The values were then equated with the simulated results extracted by placing the PV modules to its environmental condition. Khalid et al. [12] studied the importance of performance ratio in grid-tied PV units efficiency. It determines the efficiency and output power. It has highlighted some economic and environmental benefits of using PR by framing a scenario example from the project named 'SolMap project' in India. Vasisht et al. [13] studied the performance of solar PV installation in seasonal variations. This attempt emphasizes the performance analyses of PV units leveraging the Capacity Utilization Factor (CUF) and Performance Ratio (PR). Sharma et al. [3] studied the performance of a grid-tied PV unit (capacity: 11.2 kWp) in Eastern India. This paper presents the parameter results for the month in between September 2014 to August 2015 of the installed plant. PV panels/inverter efficiency, PV array yield, final yield, and PR of the unit are also described perfectly. Nirwan et al. [14] addressed the performance analysis of grid-tied solar PV unit employing PVsyst software. The performance evaluation has been done with PVsyst for 1 MW grid-tied power plant set up at PEC University of Technology. He studied the performance evaluation at the given tilt angle for which the plant is installed and compared it with the optimum tilt according to the site with and without the Horizon considerations.

Hussain et al. [15–20] studied the performance analysis of Autonomous Hybrid System using renewable energy sources. Hereby the author uses the Artificial Intelligence techniques for optimization of the parameters of the different controllers. Finally, the comparative performance of Artificial Intelligence controllers for the hybrid model is presented.

3 Depiction of Solar PV Grid Scheme

The installed rooftop grid-tied PV plant employs solar panels, dc to ac conversion system (inverters), a power conditioning unit, and grid-tied equipment. The system has no energy storage. When the grid-connected PV system generates surplus amount then it supplies the excess power to the utility grid (Fig. 1; Tables 1 and 2).

According to data available on the NASA website, the monthly average isolation falling on a horizontal surface at the location is 4.72 kWh/m^2/day and the average annual temperature is 24.6 °C.

3.1 Plant Layout of the Established PV System

The total capacity of the proposed GMCH rooftop PV plant is of 500 kWp with a total of 3567 m^2 rooftop area. The plant is characterized into three different blocks of the hospital building. Each building is characterized by different solar generation capacity in accordance with the rooftop area available, as shown below

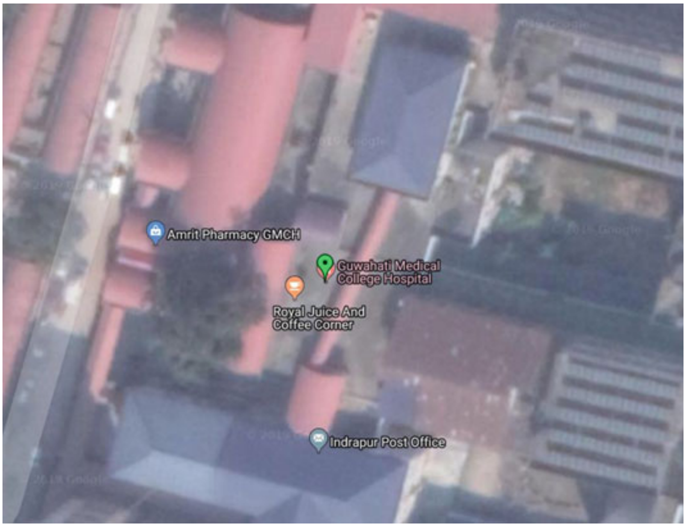

Fig. 1 Site location—GMCH, Guwahati

Table 1 Site information and Meteorological data

Site name	Rooftop of Guwahati Medical College Hospital
Coordinates	26° 10′ 34 N, 91° 45′ 46 E
Elevation	72 m above mean sea level
Altitude	43 m above ground level

Table 2 The table below showing the meteorological data of the located plant

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Hor. global	123.0	125.1	168.1	164.6	163.5	144.1	145.2	151.9	147.8	135.4	136.8	132.4
Hor. diffuse	42.4	53.2	73.0	85.9	93.8	86.6	80.5	82.5	69.7	70.3	34.5	23.3
Extraterrestrial	203.6	219.0	284.4	311.8	343.1	338.6	346.2	330.3	289.4	256.8	207.1	191.7
Clearness index	0.604	0.571	0.591	0.528	0.477	0.426	0.419	0.460	0.511	0.527	0.660	0.691
Amb. temp.	16.8	19.4	23.1	24.8	27.2	28.0	28.9	29.0	27.8	26.2	22.0	18.6
Wind velocity	0.3	0.6	0.9	1.3	0.9	0.7	0.7	0.7	0.7	0.6	0.5	0.3

1. Main building (rooftop)—370 kW (operating)
2. Main building (5th floor)—80 kW (operating)
3. Tin roof—50 kW (operating).

So, the total plant generation capacity as 500 kW (Fig. 2).

A total of 1516 solar panels and 10 string inverters that include two inverters of 60 kW, seven inverters of 50 kW, and one inverter of 30 kW. The efficiency of the inverter is 95%. These inverters convert the DC power to AC power and the extractable output is supplied to the 11 kV grids utility.

The solar modules used are of "SOVA SOLAR" of the type SS330P polycrystalline with open-circuit voltage (V_{oc}) given as 45.27 V and short circuit current (I_{sc}) given as 9.29 A (Table 3).

Fig. 2 Picture of 500 kWp grid-tied rooftop PV unit

Table 3 PV module and Inverter specification (Report of AEDA)

PV module parameters	Specification	Inverter parameters	Specification
Type of modules	Polly crystalline	Model BG50KTR	INVT
P_{max}	330 W	Maximum DC Input power	53,000 W
I_{mp}	8.89 A	Maximum DC Input voltage	1100 V
V_{mp}	36.78 V	MPPT range	200–900/750
I_{sc}	9.29 A	No. of MPPT/strings/MPPT	2/5
V_{oc}	45.27 V	Starting voltage	200/150 V
Cell temperature	25 °C	Rated output power	50,000 W
Array area	50,000 sqft	Max. AC output current	72 A
No. of modules	1516	Frequency of grid	50 Hz
Efficiency	15%	Max. efficiency	98.60%
Weight	21.20 Kgs		

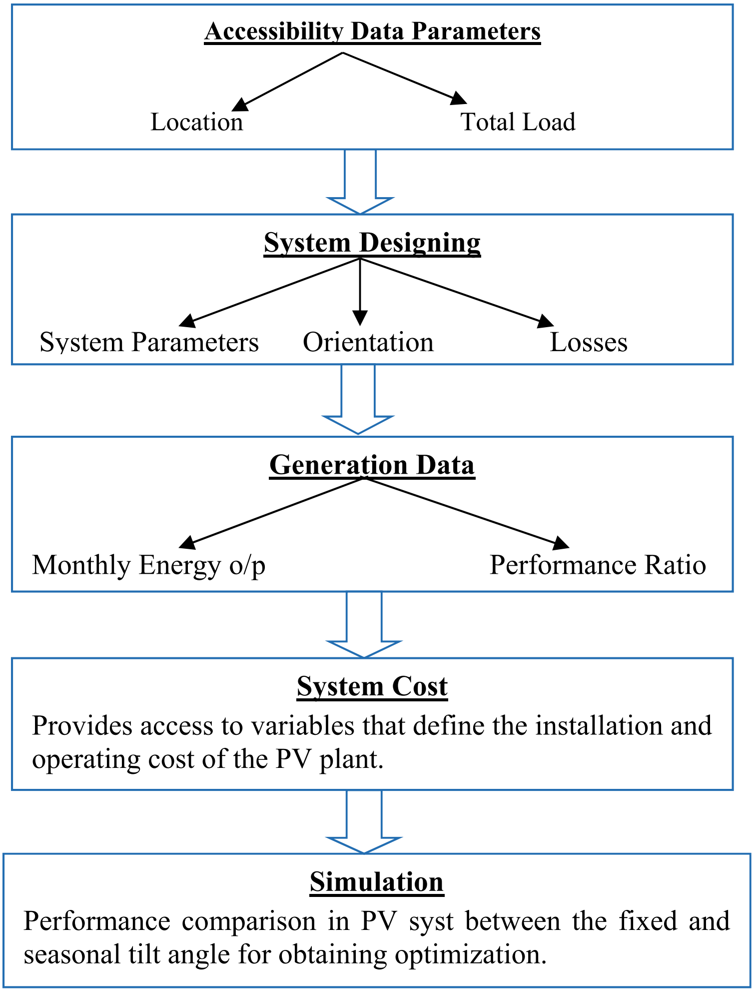

Fig. 3 Flowchart of the research work

3.2 Flowchart of the Work

See Fig. 3.

3.3 Plant Orientation

The tilt angle for the solar panels is inclined at 22°. The azimuth degree is 0° since the panels are facing towards the south. For optimization, the tilt angle is taken as 22°

for summer and 60° for winter with azimuth of 0° that means the panels are facing towards the south (Figs. 4 and 5).

Monthly energy generation of the installed plant for tilt angle 22° is shown below for the last four months Since the RMS is activated in July 2019.

Figure 6 is collected from TrackSo [21], an IoT based energy management platform to track the performance of the remote plants provide a full control without actually being present there. The fig. shows that in the month of October has the record for the highest solar energy yield, by considering 4 months from August 2019 to November 2019.

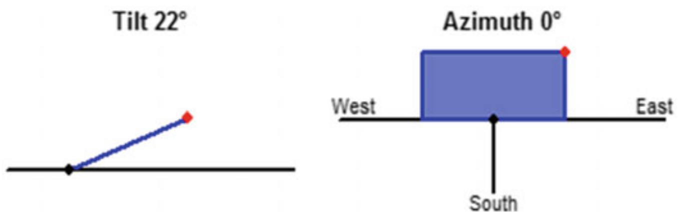

Fig. 4 Original tilt angle

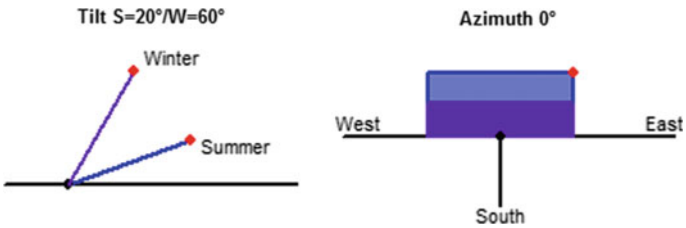

Fig. 5 Seasonal tilt angle

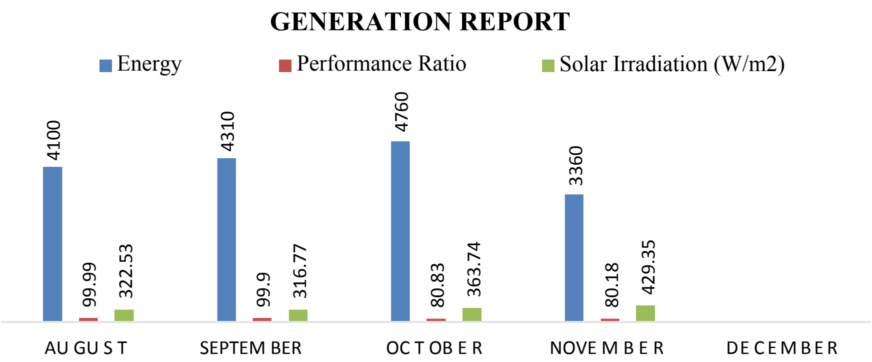

Fig. 6 Monthly energy generation and performance ratio

Table 4 Average energy yield for the specified months

Months	Monthly energy o/p	Avg. monthly extractable energy o/p (MWh)	Avg. annual extractable energy o/p (MWh)
August 2019	4.1	4.1	49.2
September 2019	4.3		
October 2019	4.7		
November 2019	3.3		
Total	16.4 (MWh)		

The average annual energy yield can be calculated by the product of the average monthly extractable energy output with the number of total months throughout the year. Thus, the annual energy yield is tabulated as in Table 4.

4 Performance Analysis

The solar PV plant performance depends on the various parameters that result in the true possibility of solar power generation variability. The calculation of the power, energy, and yield of the grid-tied PV power plants requires some important parameters. The required parameters given by [3] are shown below

1. **PV array yield**
   The PV array yield is referred to as the PV array extractable output, divided by its rated power. The output represented (in a day, month or year) is given by [3]

$$Y_{\mathrm{a}} = E_{\mathrm{DC.d}}/P_{\mathrm{pv\,rated}}$$

2. **PV final yield**
   The PV final yield is referred to as the output energy of the entire PV unit divided by the maximum (rated) power of the established PV array. Thus, the final yield is given by [3]

$$Y_{\mathrm{Fd}} = E_{\mathrm{AC.d}}/P_{\mathrm{pv\,rated}}$$

3. **PV segment efficiency**
   The efficiency of PV segment (module) is given as

$$\eta_{\mathrm{pv}} = (P_{\mathrm{DC}}/G_{\mathrm{t}} * A_{\mathrm{m}}) * 100$$

4. **DC-AC conversion (Inverter) Efficiency**
   The dc-ac conversion efficiency (η) is given as

$$\eta_{\mathrm{inv}} = P_{\mathrm{AC}}/P_{\mathrm{dc}}$$

5. **Efficiency of system**
   The overall system efficiency is given by

$$\eta_{\text{sys}} = \eta_{\text{pv}} * \eta_{\text{inv}}$$

6. **Performance Ratio (PR)**
   PR is referred to the energy supplied to the network or grid divided by the energy produced by the unit in DC power, for the maximum peak hours/day [12]. The expressed is given as-

$$\text{PR} = Y_{\text{F}}/Y_{\text{R}}$$

7. **CUF**
   It is a ratio of energy produced in a year by the PV unit to the aggregate of energy the PV unit will produce when operated under full rated power/day/year is known as the Capacity Utilization Factor (CUF). It is given as [13]

$$\text{CUF} = (E_{\text{ac.a}}/P_{\text{pv rated}} * 24 * 365) * 100$$

5 Simulated Results

The simulation is carried out for the comparison, using the PVsyst software by considering the total installed capacity, PV array area, field parameters, system sizing, etc.

Case 1 For fixed tilted plane field parameters include 22° angle with azimuth angle as 0° as the panels are south facing.

Case 2 For Seasonal Tilt the summer tilt is given as 20° and winter tilt as 60°. The azimuth is 0° as well.

As seen from Figs. 6 and 7, the optimized energy generated from the PV array with seasonal tilt is 4.54 kWh per kWp per day and the energy generated from fixed-tilt is 4.43 kWh per kWp per day. But the PR of fixed-tilt system shows quite a significant increase as compared to the performance ratio of the optimized tilt system (Fig. 8).

5.1 Loss Diagram Analysis

Figs. 9 and 10.

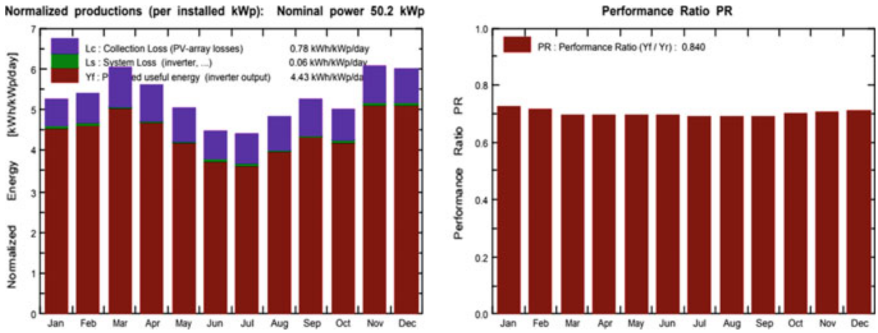

Fig. 7 Normalized production and performance ratio of original tilt

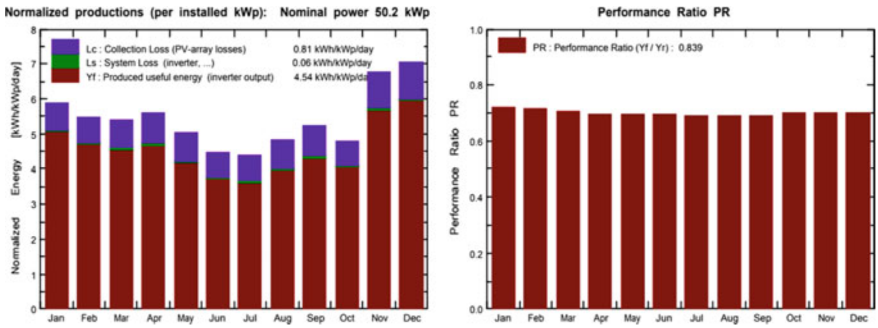

Fig. 8 Normalized production for seasonal tilt

6 Cost Analysis

As per the Electricity Regulatory commission for Assam the cost per watt of solar power is Rs. 53/Watt. The total cost of the plant is 2.65 crore with the MNRE capital subsidy of 70% of the project cost. The overall energy fed into the grid from the solar PV (SPV) plant is given as 81.1 MWh or 81,100 units per annum. The total time for the payback period is 7 years for the installed 22° tilt and south orientation with azimuth angle 0°.

7 Conclusion

The installed 500 kWp grid-tied PV unit at the rooftop of Guwahati Medical College Hospital, Assam was commissioned and monitored since August 2019 and its performance parameters are studied month wise. Then the PV system performance has been

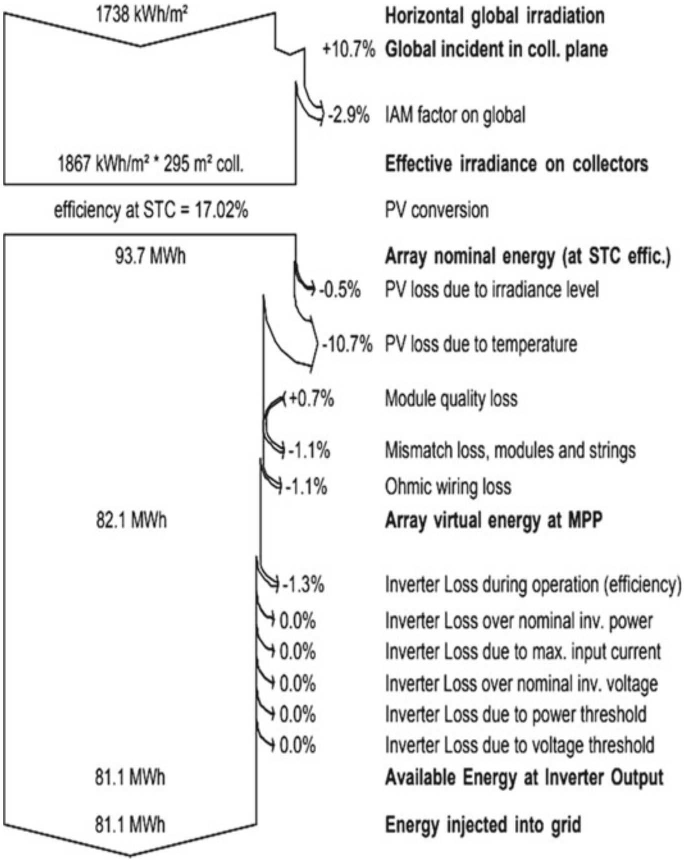

Fig. 9 Loss diagram for fixed-tilt angle

compared with the simulated values. Thus, the important features from this study are provided below-

1. The installed solar PV plant by using PVsyst shows that the 500 KWp power plant generates more energy for seasonal tilt angle equal to 22° for summer and 60° for summer.
2. The important factor to consider for designing the plant is that the energy produced is 1.92 ≈ 2% more in the case of a seasonal tilt than the original tilt angle.
3. The energy supplied to the grid is 2000 kWh more for seasonal tilt than that of the fixed tilted system.
4. Moreover, the mounted whole PV unit in GMCH has reduced about 25.22 ton of CO_2 from the atmosphere per year.

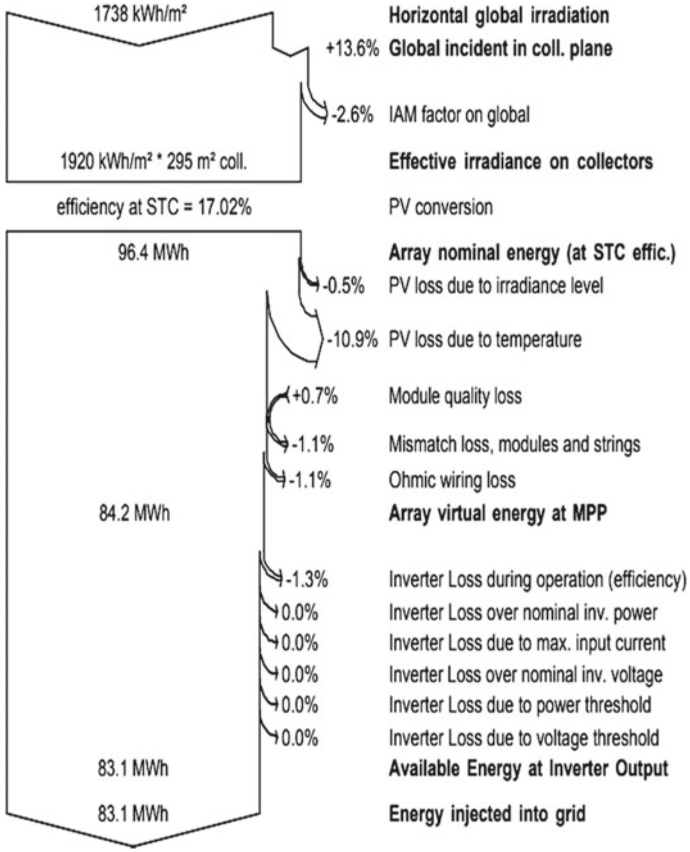

Fig. 10 Loss diagram for optimized tilt angle

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