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Design and Simulation of Grid Connected Solar Si-Poly Photovoltaic Plant using PVsyst for Pune, India Location

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Abstract

During the past decades, increasing energy demand across the world has fueled the energy production significantly, which has led to the environmental impacts such as global warming and depletion of the ozone layer; it has also endangered the species. Hence, the whole world started shifting towards the green energy generation, eliminating all the negative impacts on the environment. The solar power is the most efficient source of energy among the other renewable energy sources. In this work, we analyze the simulated performance of a 250 kWp grid-connected Si-poly photovoltaic plant. This work is conducted in order to evaluate the performance and feasibility of a solar PV plant for Pune, India Location. Each Module has a rating of 310 Wp, connected in 65 strings with 12 panels per string. 42 string inverters are utilized. The simulation is carried out in the PVsyst 7.2 and the Meteonorm8.0 data is used. The simulation is carried out to in order to get maximum energy production; this experiment is performed in 2 phases, one with a fixed angle throughout the year and another by adjusting the tilt angle for every month. The multiple trials are conducted in order to get the best angle for the maximum production of electricity, and we compared the parameters such as the incident radiation, performance ratio, energy into the grid and energy output at array and losses. The optimum angles are chosen based on the input energy at the grid.

Keywords: *Power, Renewable energy, Tilt angle, Energy generation.*

1. Introduction

Electricity is an integral part of our lifestyle. Today, most electricity is produced by the existing thermal and hydroelectric power plants. The renewable energy technologies such as the solar power and wind power are recommended for the production of electricity due to the growing concern about the greenhouse gas emissions and other environmental issues. The requirement to reduce the greenhouse gas emissions provides an opportunity for most countries to develop new energy policies. These policies were created in order to promote renewable energy sources in the power sector.

2. Design Considerations of Solar PV Plant

1. The availability of solar radiation.
2. The meteorological data means climatic data like sunshine hours, wind power, cloudy-rainy days, and natural disasters.
3. The installation location should have required land for the desired plant capacity, and there should not be any building/structures that can make shading or cover the solar panels and the sunshine.
4. The current requirements and future potential demands of electricity.
5. Structure, transportation, cost, construction conditions.
6. Easy to operate and maintain.

3. Geographical Location of Site

The location of the plant in Pune at a latitude of 18.52^o North, longitude of 73.86^o East, altitude of 551 m.

4. Plant Layout

The designed plant layout has an energy generation capacity of 250 KWp. The components required for SPP are the solar PV module, inverter, mounting structures and cables, meters switches, fuses and so on. Since it is a grid connected SPP, the batteries are not used.

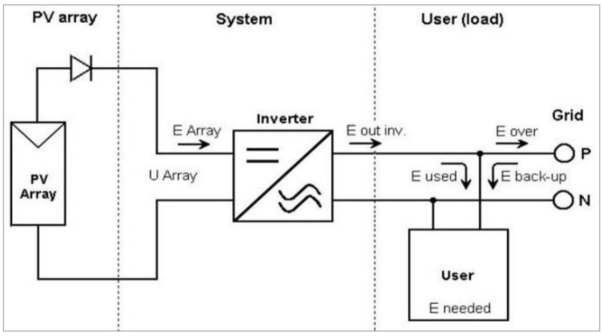

Figure 1. Plant layout.

The total number of PV panels required for the system is given by:

$$N_M = \frac{P_{Array}}{P_{Module}} \quad (1)$$

The desired voltage and current are obtained by connecting PV modules in series and parallel, and it is given by:

$$N_S = \frac{V_{DC}}{V_{Max}} \quad (2)$$

$$N_P = \frac{V_{DC}}{N_S} \quad (3)$$

From the above equations (1 to 3), it can be found that the number of PV panels connected per string are 12, and the number of strings are 65; hence the number of PV panels require 780 units.

4.1. PV Module

The PV modules convert the solar radiation into electric energy by means of the photovoltaic effect. The details of the solar panels used are given in following table:

Table 1. PV module specifications

PV module	Tata power solar system
Technology	Si-Poly
P_{nom} STC	310 Wp
V_{OC}	45.5 V
I_{SC}	8.99 A
Number of cells	1×72
Module size	0.992×1.955 m^2

4.1.1 Inclination and Orientation of PV panels

Optimizing the PV panels is for getting the maximum solar irradiation. Hence, the inclination angle of the PV array should be about equal to the latitude of the site [1]. The panels face towards the south [2]. In order to find out the angle for maximum production of energy, see the Results section.

4.2. Inverter

The inverters are used to convert the DC current into the AC current. The inverter size for the PV system must be high enough to handle the peak load power supply [3].

$$I_S = P_{REQ} \times C_F \quad (4)$$

There are two types of inverters:

1. String invertor
2. Central invertors

The string inverters are low-capacity inverters such as 50 KW or 60 KW. However, they are more effective because they are small and easy to install and maintain. The central inverters are high-capacity inverters such as 1 MW or 5 MW. In this work, 42 string inverters were used.

Table 2. Inverter Specifications

Inverter	Bosch
Minimum voltage	170 V
Maximum voltage	550 V
P_{nom} AC	4.6 kW_{AC}
I_{nom} AC	20 A
Efficiency (η)	96.5%
Size	530×180×620 mm

4.3. Transformer

A transformer is a device that transfers the electric power applied in a primary winding to a secondary winding by electromagnetic induction. The transformer operation is done at a constant frequency but with different voltages and currents. There are 2 types of transformers, i.e. step-up and step-down transformers. In this work, the step-up transformer was used to transmit the power.

4.5. Mounting Structures

The PV modules are mounted on base with determined title angle and orientation of modules using the mounting structures. The mounting structures are of two types, i.e. fixed structures and tracking axis systems. The fixed structures are not designed to track the solar radiation. The tracking axis systems are of two types, i.e. 1-axis tracking systems and 2-axis tracking systems; the difference between both systems is the number of degrees of freedom. The tracking axis system mountings are not expensive, but they require energy for motion. The 2-axis tracking systems are better than 1-axis at tracking, but they add up maintenance. The fixed mountings are studied in this work.

5. Performance Parameters of Solar PV Plant

5.1. Array Yield

It is also called the matrix efficiency defined by daily output energy in DC, related to the nominal power (kWh/KWp/day). In other word, the array yield is the ratio of daily, monthly, or yearly energy output in DC from PV array to the rated PV array power [4].

$$Y_A = \frac{E_{DC}}{P_O} \quad (5)$$

5.2. Reference System Yield

The reference system yield is the ideal array yield according to Pnom without any loss, as defined by the manufacturer. It can be understood that as each incident kWh should ideally produce the array nominal power (P_{nom}) during one hour at STC, the reference radiation is considered to be 1000 W/m^2 in STC. It normalizes the available radiation to the reference radiation and Y_R is numerically equal to the incident energy in the array plane, expressed in (kWh/m²/day). It usually depends on the geographic conditions of the plant site, weather, and orientation of the solar PV panels [5].

$$Y_R = \frac{H_t\ (\mathrm{kWh/m^2})}{I_A\ (\mathrm{kW/m^2})} \quad (6)$$

5.3. Final System Yield

The final system yield is the amount of output energy to the grid on annual or monthly or daily basis. It is defined as the ratio of the AC energy output of the solar PV system (inverter output) to the peak power, i.e. per installed kWp of the PV array at STC. The final yield provides the number of hours required by the solar photovoltaic system to function at the rated power to yield the net energy. It is the normalized value of the system energy output with reference to the system size. The final yield esteems the solar PV system performance in terms of the solar radiation resource [6]

$$Y_F = \frac{E_{AC}}{P_P} \quad (7)$$

5.4. Performance Ratio

It is defined as the ratio of the final yield to the reference yield. The performance ratio provides information about the daily effect of the system-wide losses on the rated output. The loss includes loss of solar panel, loss of inclination angle, loss due to dust, loss due to shade, and loss due to fluctuations in the module temperature. It is used to analyse the performance of the solar power systems annually. The performance ratio degradation is an indicator of the system degradation. The performance ratio shows how close a solar power plant can get to the ideal performance under the real-time conditions. It is the global system efficiency with respect to the installed nominal power and the incident energy [7].

$$PR = \frac{Y_F}{Y_R} \quad (8)$$

5.5. CUF

The capacity utilization factor (CUF) is the ratio of the actual energy generated by the solar PV plant annually to the equivalent energy output at its rated capacity over the same period [5].

$$CUF = \frac{E_{AC}}{P_P} \times 8760 \quad (9)$$

5.6. PV Module Efficiency

The PV module efficiency is mathematically given by [7]:

$$\eta_{PV} = \frac{E_{DC}}{G_i \times A_{PV}} \times 100\% \quad (10)$$

5.7. Inverter Efficiency

The ratio of AC power generated by the inverter to the DC power generated by the PV array system is called the inverter efficiency. The instantaneous inverter efficiency is given by [9]:

$$\eta_{inv} = \frac{P_{AC}}{P_{DC}} \times 100\% \quad (11)$$

5.8. PV System efficiency

The overall PV system conversion efficiency is defined as the energy output from a PV array divided by the total in-plane solar insolation, and is given as [9]:

$$\eta_s = \frac{E_{AC}}{G_i \times A_{PV}} \times 100\% \quad (12)$$

The loss parameters also affect the performance of the solar PV plant. The losses can occur in almost any component used in the design of a solar PV plant. In order to evaluate the various losses associated with a solar PV plant, it is necessary to calculate the capture loss, system loss, and array yield. The capture losses include heat losses. This depends on the temperature of the PV module and the loss due to variable irradiation, dust accumulation, etc. The system losses include the losses in the DC and AC cables.

5.9. Array Capture Loss (L_A)

It is the difference between the reference yield and the array yield. This loss mainly occurs in photovoltaic arrays, and is caused by various factors such as the increased temperature of photovoltaic cells, partial shading, dust accumulation in photovoltaic arrays, maximum power point errors, and mismatches. It is also known as the collection loss [8].

$$L_A = Y_R - Y_A \qquad (13)$$

5.10. System Loss (L_S)

It is the difference between the array yield and the final system yield. It includes the inverter loss in the grid-connected systems or the battery inefficiencies in stand-alone [8].

$$L_S = Y_A - Y_F \qquad (14)$$

6. Result and Discussion

Meteonorm 8.0 data input was used in this experiment. The azimuth angle was kept zero throughout the work. The Albedo of earth was assumed to be 0.2. The work was carried out in two cases, as follows:

Case 1: Changing tilt angle of panel every month

In order to find the optimum tilt angle for every month, multiple trials were performed. Table 3 shows the tilt angle, PR ratio, incident radiation and energy input at grid for every month.

It was found that the maximum incident radiation did not ensure the maximum energy generation since the thermal losses had a significant impact on it. Thus, the optimum angle deciding factor was the input energy at the grid.

Table 3. Balances and main results for case 1.

Month	Tilt angle degree	Gi kWh/m^2	D_H kWh/m^2	G_H kWh/m^2	G_E kWh/m^2	T_{Amb} °C	E_{ARRAY} MWh	E_{GRID} MWh	PR ratio
January	47	195.8	50.77	145.8	192.5	20.04	37.22	35.98	0.760
February	45	184.7	51.78	154.3	181.0	22.75	34.73	33.57	0.752
March	23	210.3	62.29	195.9	205.7	26.53	38.54	37.24	0.733
April	5	205.4	70.61	204.0	200.5	29.35	37.98	36.71	0.739
May	0	216.7	79.42	216.9	211.9	29.88	40.45	39.11	0.746
June	0	156.4	92.54	156.5	152.0	26.42	30.96	29.90	0.791
July	0	130.7	82.05	130.8	126.9	25.06	26.17	25.24	0.799
August	0	131.0	84.70	131.1	126.8	24.17	26.36	25.44	0.803
September	15	150.4	69.33	145.7	146.4	24.46	29.07	28.05	0.771
October	31	177.4	69.16	157.4	173.6	24.46	33.95	32.79	0.765
November	44	185.1	52.30	143.7	182.0	22.37	34.95	33.78	0.755
December	49	192.6	49.19	139.2	189.6	20.26	36.61	35.39	0.760

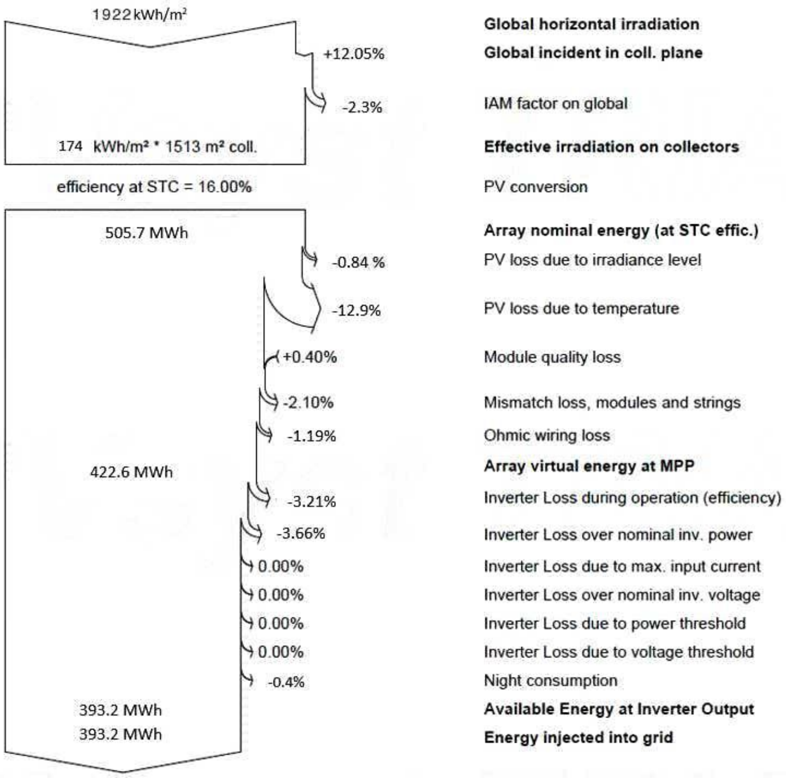

Figure 2. Loss diagram for case 1.

The average monthly incident radiation was 178.04 kWh/m^2, and the maximum energy produced was 377502 kWh annually. The average performance ratio throughout the year was 0.7645. The total annual loss was found to be 14.55 %, as shown in Figure 2. Figure 3 shows the capture losses and system losses for varying the angle every month. It can clearly be seen in Figure 3, that the capture losses vary with the monthly climate, where the system losses are approximately the same.

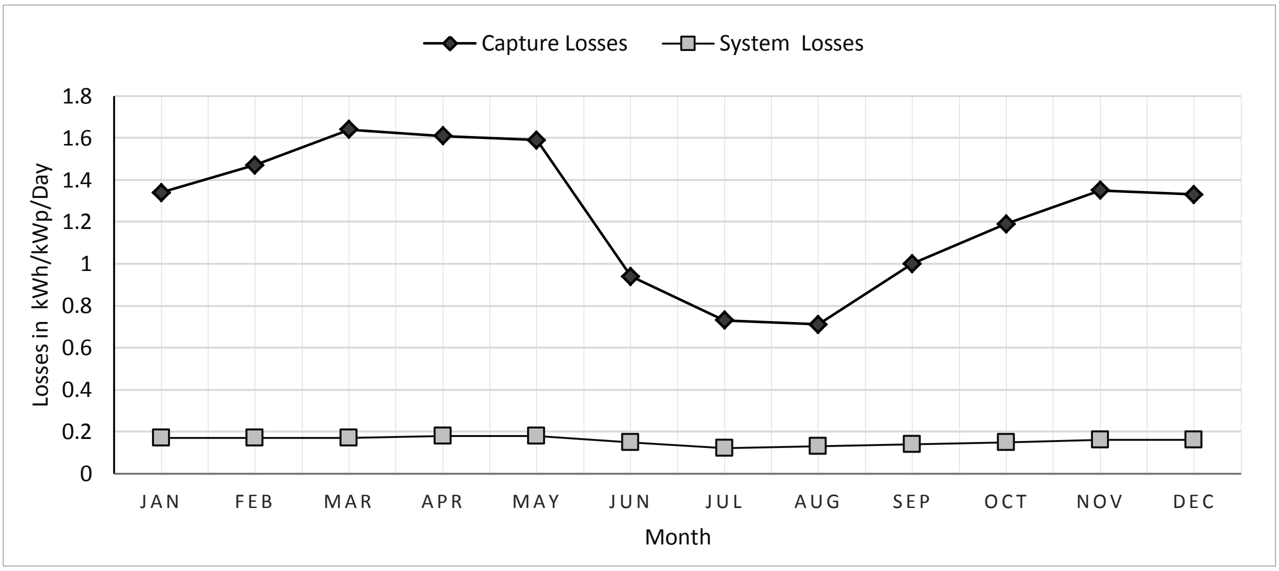

Figure 3. Comparison of capture and system losses for case 1.

Case 2: Kept fixed tilt angle throughout the year

Many times, it becomes difficult to change the tilt angle of solar panel mountings monthly. Hence, after multiple trials, the 20^o tilt angle was found to be optimum for the maximum energy generation. The average monthly incident radiation was 169.46 kWh/m^2, and the maximum energy produced was 377502 kWh Annually. The average performance ratio throughout the year was 2033.5.

The total annual loss was found to be 19.61%, as shown in Figure 3. The Capture losses and system losses for the fixed angle 20° throughout the year are shown in figure 5.

Figure 6 shows the daily input-output for a fixed tilt angle throughout the year. The energy into the grid is not linear to the incident radiation after some point. Hence, the E_{Grid} parameter was used to choose the optimum tilt angle for a month as well as a year, and hence, the optimum tilt angle for the year was 20°, and for months, it could be found in Table 3. As demonstrated in [10], the best angle was decided based on Gi. However, according to the above results, it did not show any significance as the maximum incident radiation did not ensure the maximum energy generation since the thermal losses had significant impact on it.

Table 4. Balances and main results for case 2.

Month	Gi kWh/m^2	D_H kWh/m^2	G_H kWh/m^2	G_E kWh/m^2	T_{Amb} °C	E_{ARRAY} MWh	E_{GRID} MWh	PR ratio
January	179.4	50.77	145.8	175.3	20.04	34.92	33.75	0.778
February	179.1	51.78	154.3	175.3	22.75	33.85	32.72	0.755
March	210.0	62.29	195.9	205.4	26.53	38.51	37.21	0.733
April	201.8	70.61	204.0	196.6	29.35	37.29	36.04	0.739
May	201.0	79.42	216.9	195.3	29.88	38.88	36.61	0.753
June	143.3	92.54	156.5	138.6	26.42	28.61	27.63	0.797
July	121.3	82.05	130.8	117.3	25.06	24.48	23.60	0.804
August	125.8	84.70	131.1	121.7	24.17	25.37	24.48	0.805
September	150.2	69.33	145.7	146.2	24.46	29.01	28.00	0.771
October	174.9	69.16	157.4	170.8	25.04	33.62	32.48	0.768
November	172.9	52.30	143.7	169.0	22.37	33.31	32.19	0.770
December	173.8	49.19	139.2	169.8	20.26	33.92	32.80	0.781

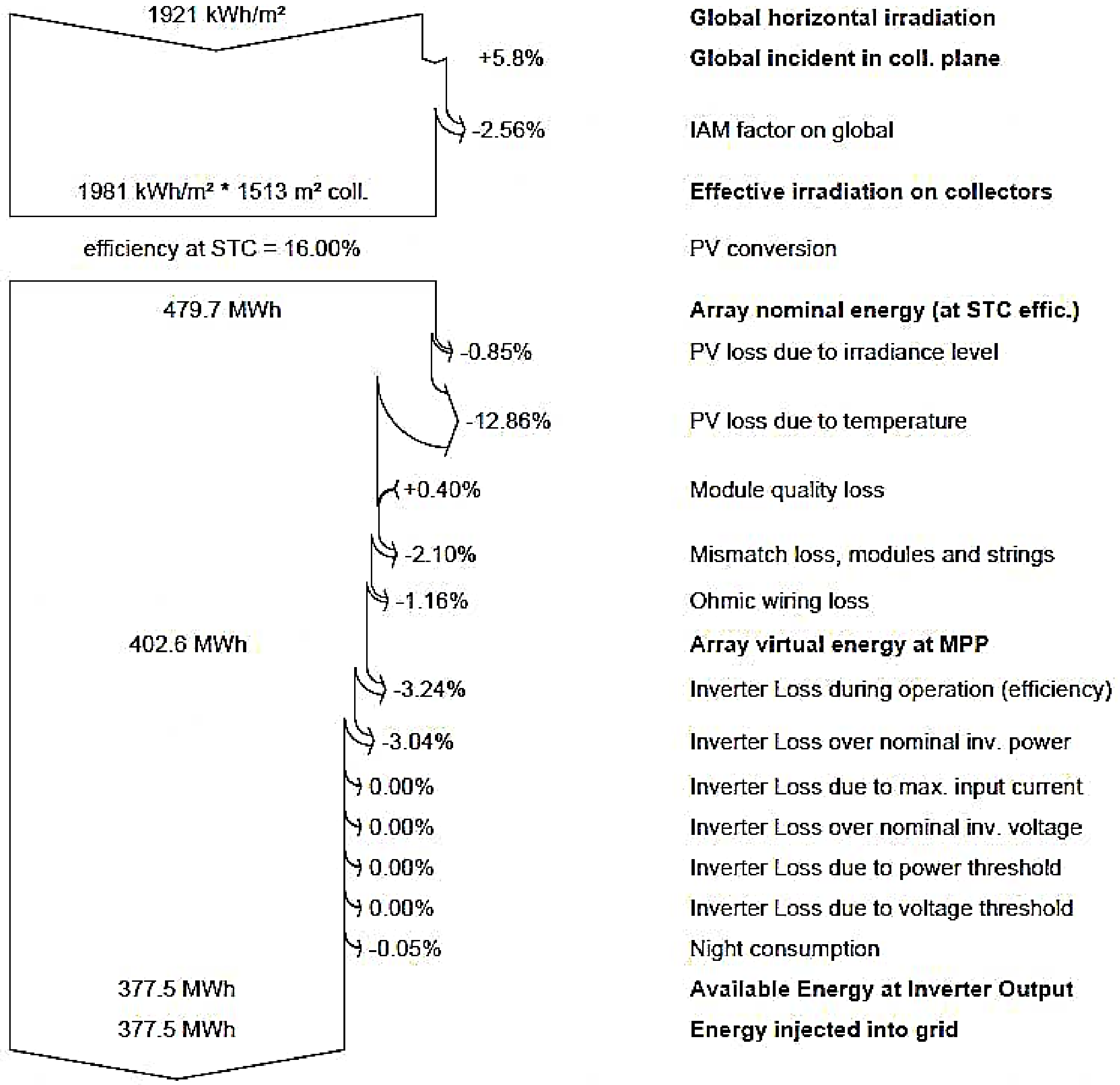

Figure 4. Detail losses diagram for case 2.

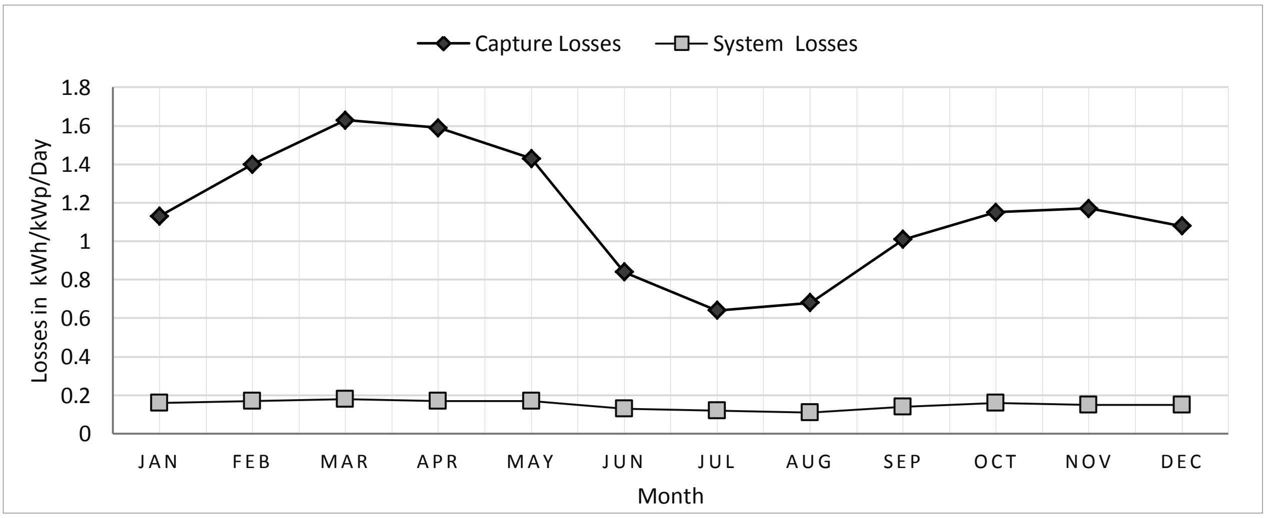

Figure 5. Comparison of capture and system losses for case 2.

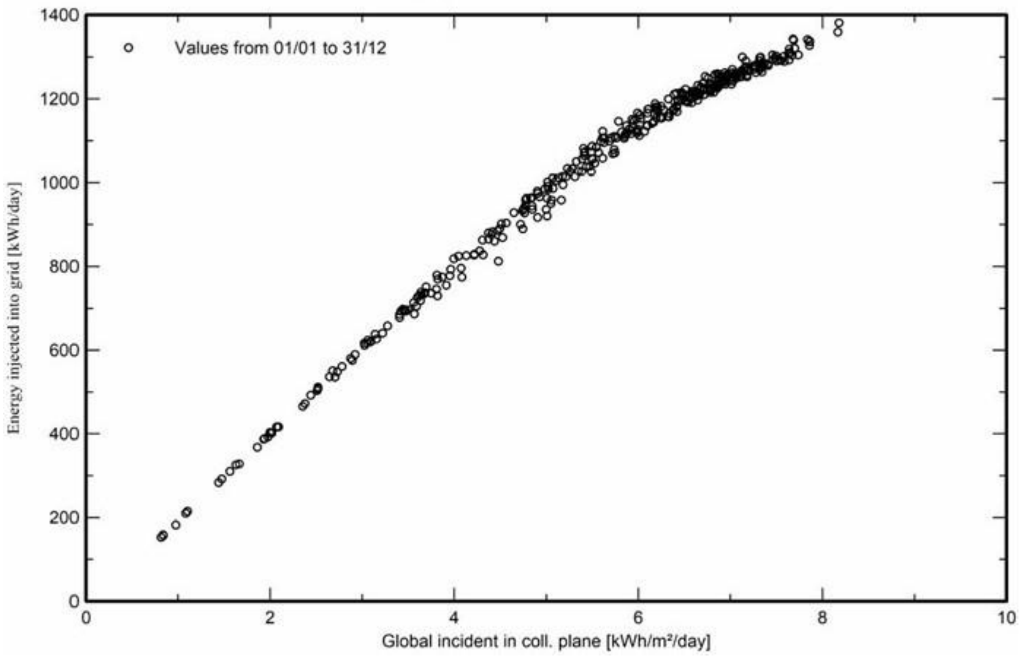

Figure 6. Daily input/output diagram for fixed angle.

7. Conclusion

In this work, a 250 kWp grid connected solar PV plant at Pune (India) was designed and simulated in the PVsyst software in order to evaluate the performance.

1. The Maximum energy injected into the grid in a year by changing angle every month was 377502 kWh. The angles were 47, 45, 23, 5, 0, 0, 0, 0, 15, 31, 44, and 49, respectively, for the optimum energy generation. The maximum energy injected into the grid in the month of March was 37.24 MWh, and the least energy in the month of July was 25.24 MWh.
2. The maximum energy injected into the grid in a year with a fixed angle at 20^o was 377502 kWh. The maximum energy injected into the grid was in the month of March, i.e. 37.21 MWh, and the least energy was in the month of July, i.e. 26.60 MWh.
3. Changing the angle per month improved the energy generation by 15744 kWh than a fixed angle was all-round the year, and improved the energy generation by 4.17% annually, and also the total losses were down by 5.06 % annually.

8. Nomenclature

A	Ampere
AC	Alternating current
A_{PV}	Area of PV panel
C_F	Correction factor for safety
CUF	Capacity utilization factor
DC	Direct current
D_H	Horizontal diffuse irradiation
E_{ARRAY}	Energy at array output
E_{DC}	DC output of PV array
E_{Grid}	Energy injected into grid
G_E	Effective global, corr. For IAM and shading
G_H	Horizontal global irradiation
Gi	Global incident in collector plane
H_t	Total in-plane solar insolation
I_A	Array reference irradiance
Inom	Nominal current
I_S	Size of inverter
I_{SC}	Short circuit current
MPP	Maximum power point
P_{AC}	AC power (kW)
P_{DC}	DC power (kW)
P_{nom}	Ratio of DC:AC
P_O	Nominal power of the PV array at STC
P_P	Peak power of the PV array at STC in kWp
PR	Performance ratio in percentage
P_{REQ}	Power required
PV	Photovoltaic
Si-Poly	Silicon poly-crystalline
SPP	Solar power plant
STC	Standard testing condition
T_{Amb}	Ambient temperature in °C
L_A	Capture losses kWh/kWp/day
L_S	System losses in kWh/kWp/day

V_{OC}	Open circuit voltage
V_{max}	Maximum MPP voltage
V_{min}	Minimum MPP voltage
Y_A	Array yield
Y_F	Final system yield
Y_R	Reference yield
η	Efficiency

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