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Design and Performance Analysis of Grid-Connected Solar Photovoltaic System with Performance Forecasting Approach (PFA)

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Abstract Solar Energy utilization is picking up speed globally due to its intermittent characteristics and eco-friendly inexhaustible nature. Electricity from the solar energy has always been a matter of great concern for engineers who always face hurdles due to its reliability aspects and techno-economic concerns. Solar Photovoltaic (PV) technology has emerged rapidly in recent past in standalone as well as grid-connected mode of operation. This paper discusses the performance forecasting analysis of grid-connected 12.5kW$_P$ Solar PV Power plant based on Mayo hospital metro station, Nagpur data. The paper includes design of PV system based on panel orientation, ratings of accessories, detailed losses, energy management parameters carried out in PVSyst 7.0 software. The analysis of the PV system was carried out based on Daily output (KWh) diagram, Performance ratio, power output distribution into the grid, Irradiance-Effective array temperature and others graphical results. The significance of this forecasting studies is to estimate the suitability of PV System at a location based on the availability of irradiance level and the forecasted results can give guidelines to the design engineers on design and performance aspects of the system like net power production, performance ratio, etc. where the decision making on real-time installation of the system can be taken based on the techno-economic evaluations. Feasibility evaluation to evaluate the system based on CO_2 emission count for solar installation is also done. This paper serves as a guideline for the design engineers and researchers working on solar PV power performance forecasting studies and provides and an approach to exploratory analyze the results and derive the perspectives which can enable decision making on real-time design and implementation of ON grid PV systems.

Keywords Solar photovoltaic (PV) · Solar irradiance · Performance forecasting analysis · Performance ratio · Techno-economic feasibility · System output power distribution

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Introduction

India has an ample amount of solar energy by nature itself. Almost all parts of the nation acquire 5.5 KWh on an average of energy per square meter in a day. The incident energy amounts to 5000 trillion KWh/year [1, 2]. The National Solar Mission in India aims to install 20GW of Solar Energy projects by 2022. India has already made it mandatory to install rooftop solar system in all government establishments, Schools, Hospitals, Colleges and University premises. India, in association with France, initiated the formulation of International Solar Alliance (ISA) in 2015 which transformed into a treaty-based organization headquartered in India. The total solar rooftop capacity in India is 1796.36 MW [4]. The current research presented at PV Specialist conference meet at Illinois, Chicago-2019, claimed to achieve the efficiency of 23.45% of solar cell [3]. However, these panels are yet to be manufactured in India. The solar panels used in India are having conversion efficiencies only up to 20%. The basic advantage of grid-connected systems is to avoid battery usage [5]. The usage of charge controllers and battery autonomy is not preferred in grid-connected solar PV systems as the operation is on net metering basis where higher amount of energy efficiencies can be achieved.

But the challenge exists to design optimized location centric PV system with optimum reliability.

At the preliminary level of solar PV system design, a lot of efforts are taken by researchers and design engineers to analyze through design, the performance of Solar PV system in off grid, on grid or for pumping applications through PV Syst software [6, 7].

The assessment of Solar irradiance potential is considered to be the most significant step and PV syst can help provide previous years dataset of metro stations depending on the location which can provide an insight of Solar power generation potential at the given location [8].

Normally, the selection of optimum tilt angle and solar panel orientation is a major design step and as a thumb rule, tilt angle is selected equal to angle of latitude of the location [9, 15].

When it comes to System design, selecting an appropriate configuration of solar PV System comprising of solar array, inverters, etc., is important. The level of solar irradiance at the location and number of sunshine hours available shall be taken as reference along with the area available to set up a project. For off grid applications in rural area [10], Solar PV powered water pumps for agricultural purposes are viable cost-effective alternative due to unavailability of grid power. These systems also require rigorous design process and performance anticipation and analysis which can also be carried out in PV Syst 7.0 software.

There have been many software products used by the researchers to carry out detailed design, analysis optimization based on cost and reliability of PV and hybrid systems like HOMER, HOGA, MATLAB and PSCAD.

The user friendliness of the software is the most important parameter in the design and analysis process for the convenience of design engineers and researchers.

The PV syst 7.0 is having unique advantage that upon confirmation of correct sets of inputs, it provides accurate results with an opportunity to analyze from different perspectives and as per the user requirement. The analysis of the 190 KWp PV system was carried out based on Daily output (KWh) diagram, Performance ratio, power output distribution into the grid, Irradiance-Effective array temperature and other graphical results [11].

The comparative analysis grid tied PV systems for different geographic locations in Nepal along with loss diagrams obtained from PV Syst software was done [12].

The very objective of design and performance analysis using software applications is to achieve optimized system performance in terms of reliability and cost economy, reliability improvement in transmission and distribution system with reference to cost economy was demonstrated [13, 14].

This paper is mainly focused on the design of 12.5 KWp grid tied system with reference to solar irradiance level and solar radiation geometry. The various design input parameters were configured like PV panel rating, inverter rating, etc. and have been defined and input–output characteristics of PV panels have been studied and analyzed comprehensively. The losses taking place in the system, Energy management and estimation with probabilistic approach is also estimated. The various performance indicators of system based on Daily output (KWh) diagram, Performance ratio, power output distribution into the grid, Irradiance-Effective array temperature with environmental considerations were comprehensively studied and analyzed.

The proposed work is largely intended toward performance forecasting of proposed Solar PV installation. In the era of Artificial intelligence and machine learning, the forecasting of different parameters is gaining extreme importance. In case of solar power systems, there is huge initial investment involved where the optimized design and forecasting of the performance is extremely important as the reliability of the whole system is at the stake due to variable solar irradiance level. In simpler words, the overall gain which is supposed to be received by end customer by investing large capital amount needs to be well justified to the customer in longer duration and hence systematic representation of design and forecasted elements to the end customer can only bring faith about the technology in society. There could be many solar energy consultants who are designing the systems and forecasting the performance using different approaches but everyone's perspective on design, analysis and forecasting could be different. Hence, to ensure widespread utilization of solar powered systems in society, this research article can help academicians as well as professionals with a systematic design and forecasting approach which can help them to convince the end customers or students about the solar power systems utilization and benefits.

There are many research articles [25–32] who had shared their research works pertaining to design, analysis and control strategy of grid-connected solar PV systems but the novelty of this research work presented in the paper is location centric system design and forecasting which can become a reference article for the engineers and professionals who are interested in detailed design, analyze and forecasting of PV system performance based on area available for system design and latitude and longitude of the location under study.

The literature [33–38] mainly deals with the design and performance assessment of rooftop grid-connected PV systems in Jaipur City, China, Morocco, Northern India, Northeastern Brazil which provides insight into design process and performance analysis approach of grid tied solar PV systems.

Site Survey Details

The location under study in the project is Nagpur in the state of Maharashtra India. The dataset referred was Nagpur Mayo hospital metro station with latitude 21 degree 9 min and longitude 79 degree 7 min 12 s located in Northern and Eastern hemisphere, respectively, with the altitude of 308 m above mean sea level. Figure 1 represents solar radiation data variation at the aforementioned location under study for the duration of 12 months.

From the Global horizontal irradiation, diffuse radiations in KWh/m^2/day data, the peak was observed in March, April, May and June. However, the temperatures are also beyond the permissible limits of 25℃ which sets limitation over optimum performance of solar panels. The lower values of Global horizontal irradiation, diffuse radiations in KWh/m2/day was observed from November to February due to winter season and lack of clearness in sky. It may be noted that the % year to year variability in the dataset is 4.5%. The orientation of the panels is always selected approximately equal to the angle of latitude which is selected as 22 degrees in this case as angle of latitude is 21.15 degrees (Fig. 2).

Site Nagpur(Mayo Hosp.) (India)

Data source Meteonorm 7.3 (1981-2010)

	Global horizontal irradiation kWh/m²/day	Horizontal diffuse irradiation kWh/m²/day	Temperature °C
January	4.45	1.56	20.8
February	5.28	1.89	23.8
March	6.06	2.28	28.4
April	6.56	2.64	31.9
May	6.62	2.87	35.2
June	5.21	3.07	30.9
July	4.00	2.87	27.8
August	3.94	2.83	27.1
September	4.77	2.43	27.3
October	5.04	2.29	26.5
November	4.54	1.81	23.0
December	4.26	1.47	20.5
Year	**5.06**	**2.34**	**26.9**

Fig. 1 Global horizontal irradiation, diffuse radiations in KWh/m^2/day with temperature in ℃, for the duration of 12 months

System Inputs to the Software

System Representation

As seen from the diagram represented in Fig. 3, Solar PV array fed the DC Energy based on insolation level to the single-phase inverter.

The energy delivered to the inverter is represented as $\mathbf{E}_{\mathbf{array}}$

The AC energy delivered by the inverter is $\mathbf{E}_{\mathbf{out\ inv}}$

Ideally $\mathbf{E}_{\mathbf{array}} = \mathbf{E}_{\mathbf{out\ inv}}$, but in presence of switching and conduction losses in inverter these two energies are never equal and hence $\mathbf{E}_{\mathbf{out\ inv}}$ is always less than $\mathbf{E}_{\mathbf{array}}$

So, the $\mathbf{E}_{\mathbf{out\ inv}}$ is the total energy available for usage which can be either be delivered to load or to the single-phase AC grid.

$\mathbf{E}_{\mathbf{used}}$ is the energy delivered to the load as per demand or connected load

$E_{over} = E_{out\ inv} - E_{used}$

$\mathbf{E}_{\mathbf{over}}$ is the actual energy delivered to the single-phase grid. The energy extracted for grid for single phase load is decided by $E_{\mathbf{needed}}$

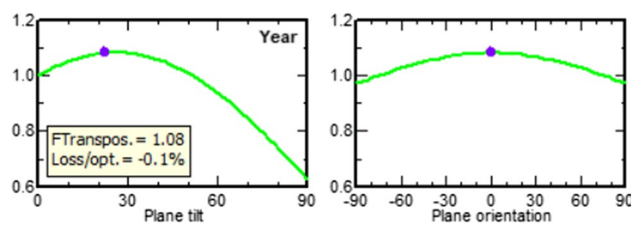

Fig. 2 Solar panel orientation with tilt angle for the duration of 12 months

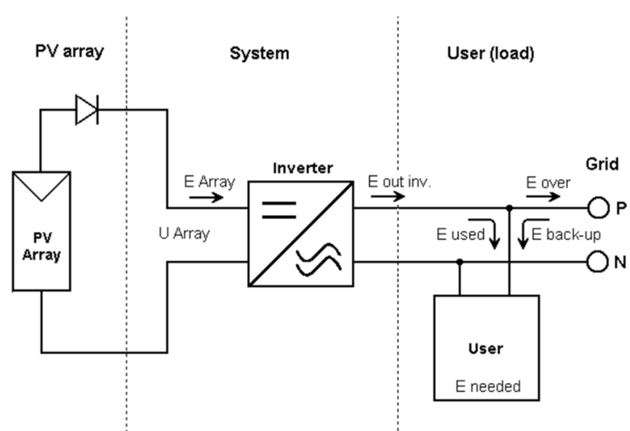

Fig. 3 Simplified sketch of Grid tied single phase 230 V PV system with energy exchange mechanism

If $\mathbf{E_{needed}}$ is greater than $\mathbf{E_{out\ inv}}$ then, the energy $\mathbf{E_{backup}}$ is derived from the grid. In case, $\mathbf{E_{needed}}$ is less than $\mathbf{E_{out\ inv}}$,$\mathbf{E_{over}}$ is supplied to the grid.

This complete energy exchange mechanism is known as **"Net metering"** in case of grid-connected solar photovoltaic systems

In case of off grid systems array and energy produced by it, i.e., Earray is directly supplied to the load through inverter interface where battery backup is needed during non-sunshine hours.

In grid-connected Solar PV system, the battery backup is not required due to availability of grid supply is case of overload, low solar irradiance condition

Hence, considering the geographic advantage larger solar irradiance in most parts of central India, the solar PV penetration into the grid can play a significant role in providing power to the grid and can reduce burden on conventional resources of energy and supplement effectively to other renewable sources of energy to mitigate power crisis.

This will also enable maintaining energy ecosystem and reduce carbon emission thus helping maintain an eco-friendly environment contributing largely to green energy initiatives. This will also facilitate conservation of fossil fuels and helps improve their sustainability usage for power generation and other related applications.

Solar PV Grid System Definition and Characteristics [37, 38]

The parameters of grid system definition are as follows:

Table 1 represents the grid system parameters defined for the system under consideration. The basis for the selection for Solar PV System in off grid or ON grid mode is the area available for installation of system considered to be a major governing parameter. As per the area available, planned power is calculated which is the maximum possible power that can be generated based on the system installation. Nominal PV Power is the actual power generation possible based on the insolation level data of location. Maximum DC Power is the Maximum possible power obtained at Maximum Power point, i.e., Vmpp and Impp. This is the maximum possible power output of solar panel incorporating MPPT algorithms.

Figure 4 represents the Power-Irradiance characteristics ranging from 0–1000 W/m2. It is observed that power generated is the function of irradiance in W/m2 where power generation increases as irradiance increases. The *P*nom Array/Inverter ratio is 0.83. The power generation reduces above the insolation level of 1000 W/m2 as a point of saturation is achieved.

The characteristics represented by green color in Fig. 5 represents the ideal characteristics of Single PV module at maximum power point of $P_{mpp} = 250$ W. Black characteristics represent the current and voltage operating limit for single PV module which is 15A and 60 V, respectively. The blue line represents actual characteristics representing Current, Voltage in turn Power based on actual irradiance level coinciding maximum power point at $P_{mpp} = 250$ W which is inverse exponential in nature.

Figure 6 represents Output Power versus Voltage characteristics of Single PV Module where the output power linearly increases with panel voltage, i.e., 26 V up to Maximum power point $P_{mpp} = 250$ W and then decreases as soon as voltage further increases beyond its rated value of 26 V which is also the open circuit voltage. The actual characteristics are represented by black and blue line representing current and voltage limits and MPP output which coincides with green characteristics at $P_{mpp} = 250$ W.

System Losses

As shown in Fig. 7, Array losses for 1000 W/m2 for 12.5KW of Nominal Power at 25°C are represented. The characteristics represent the deviation of ideal current & Voltage from current and voltage considering system losses. The total losses are observed to be 10.9% of Pmpp array which is 12.5KW. After considering system losses, the actual power of Pmpp array is 11. 1KW. The major parameter contributing

Table 1 Parameters of grid system defined largely on the basis of area available

S. N	Equipment	Governing parameter	Rated capacity/Number
1	–	Planned Power	12.5 Kwp
2	–	Operating frequency	50 Hz
3	–	Available area for modules	91m^2
4	Single Solar PV module	Power, Voltage & Current	250Wp,26 V,9A
5	–	No. of Solar PV modules	50
6	Inverter	Operating Power, Voltage & frequency	15Kw,750 V,50 Hz
7	–	Nominal PV power	12.8 Kwp
8	–	Maximum PV power	12.1KWdc
9	–	Nominal AC Power	15.0KWAC

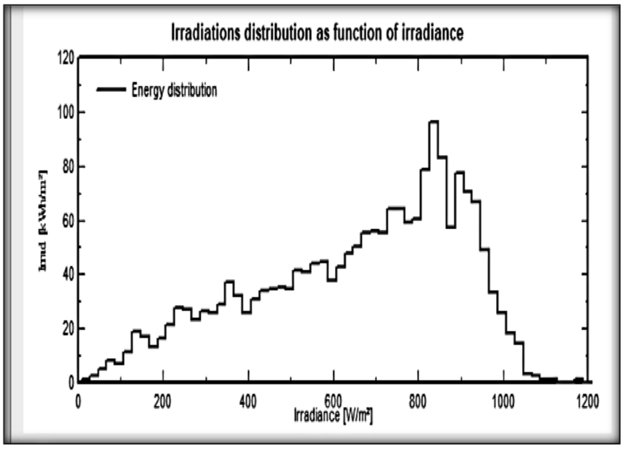

Fig. 4 Array voltage sizing, Power sizing characteristics and Irradiations distribution as a function of irradiance ignoring the loss parameter

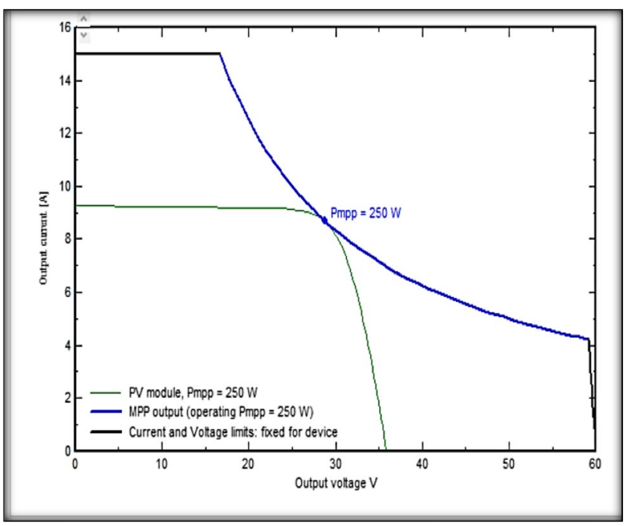

Fig. 5 Output Current versus Voltage characteristics of Single PV Module

losses is Module Temperature, i.e., 9.4%. Hence, it is extremely important to maintain module temperature below 25℃ through different cooling mechanisms like water sprinklers, etc. Loss minimization is a major factor governing efficiency of solar PV module.

Horizon Line Drawing-Legal Time

Figure 8 represents Horizon line diagram at Legal time representing sun trajectory based on sun height and azimuth angle. Tilt angle for the Solar PV system has been fixed as

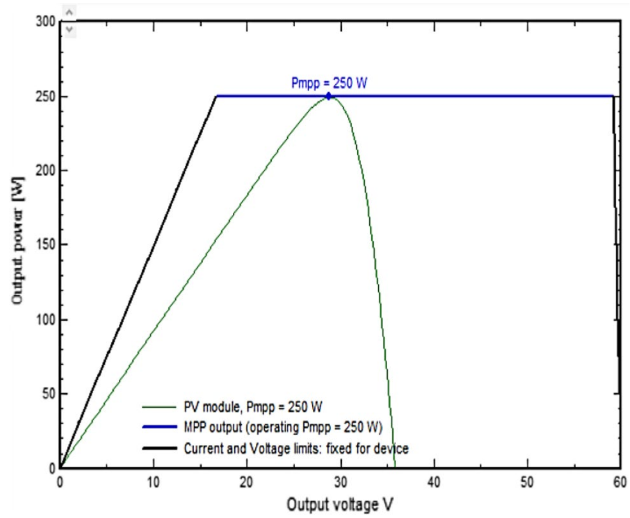

Fig. 6 Output Power versus Voltage characteristics of Single PV Module

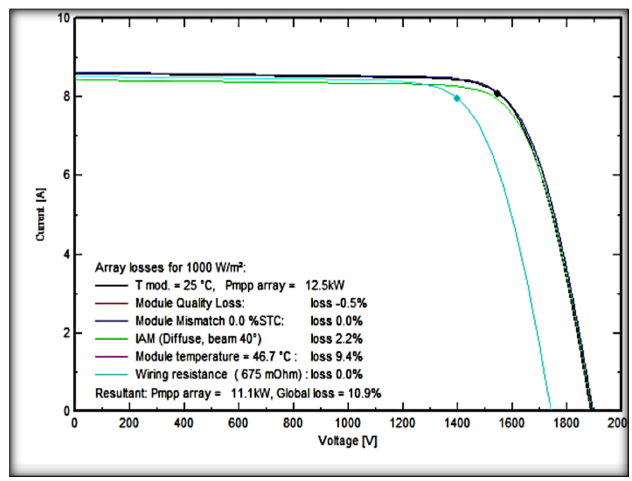

Fig. 7 Array losses for 1000 W/m2 for 12.5KW of Nominal Power at 25℃

22 degrees which is selected equal to angle of latitude for the location under study.

This diagram mainly represents the movement of the sun from East to West governed by solar angle. The trajectory represents the sun's position from 700 to 1800 h as a function of Azimuth angle.

The blue line represents the panel oriented at an angle of tilt angle of 22 degrees. The zone behind the plane is the time period when the solar radiations are not available. The azimuth angle is observed to be from − 120 to − 60 degrees to + 60 to + 120 degrees as represented in diagram.

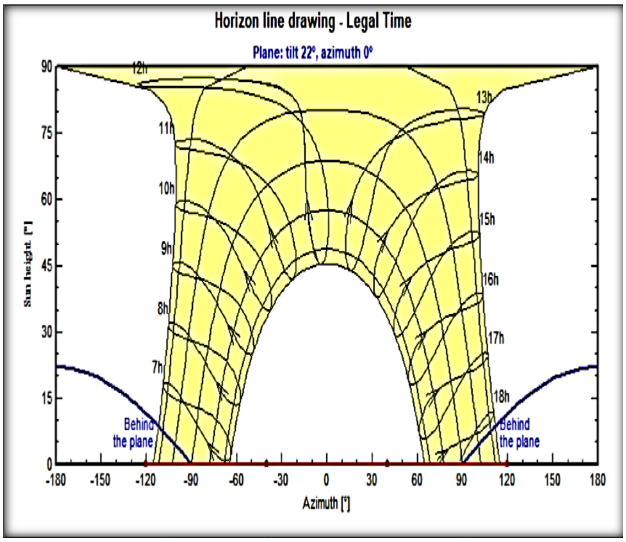

Fig. 8 Horizon line diagram-Legal time representing sun trajectory based on sun height and azimuth angle

Energy Management

Grid Energy management is the approach which manages energy exchange mechanism from source to grid and vice versa to optimally manage demand and supply of the energy.

This approach supposes that over several years of operation, the distribution of the annual yields will follow a statistical law, which is assumed to be the Gaussian (or "normal") distribution.

P50-P95 represent different yield levels, for which the probability that the production of a particular year is over this value is 50, 90, 95%, respectively. The problem is now to establish the 2 parameters of this Gaussian distribution, i.e., the Mean value and the Variance (named sigma or RMS). The main contribution to those parameters will be the uncertainty and variability of the metro data. But other uncertainties in the simulation process and parameters should be taken into account [17, 18].

The probability distribution is always represented by Gaussian curve and represented in Fig. 9 as P-50, P-90, P-95 probability distribution based on Energy management of Electrical energy supplied to grid by Solar PV System.

The Y-axis represents the percentage probability of supplied particular amount of energy in KWh to the grid in a particular year. The X-axis represents total yearly system production in KWh supplied to AC microgrid.

P-50, P-90, P-95 probability approach suggests the percentage probability of feeding particular amount of energy in KWh to the grid in a particular year. As per system calculations, P-95 probability function suggests that 15965KWh energy penetration into the grid at the percentage probability of 10%, P-90 probability function suggests that 16078KWh energy penetration into the grid at the percentage probability of 18% and P-50 probability function suggests that 16473KWh energy penetration into the grid at the percentage probability of 40% which is most optimal and maximal combination considering energy penetration and its corresponding probability.

It is highly desirable to penetrate the energy into grid at unity power factor and hence Solar PV system would require reactive power support while penetrating energy into the grid.

Grid-connected Solar PV Design Process

Solar PV system design is a comprehensive process which involves various steps which includes site selection based on solar insolation data analysis, Power generation forecasting analysis, Solar panel orientation and calculation of tilt angle, possible power generation based on area available, appropriate selection of Solar PV panels based on power, voltage and current requirement, Inverter rating and configuration, Techno economic evaluation, etc.

The design process may be described with the help of algorithmic representation as follows:

1. Site selection based on availability of solar irradiance data to estimate potentiality of solar PV generation.
2. Estimation of maximum energy that can be produced based on available area and deciding the orientation of Solar PV panels along with the finalization of tilt angle which is normally selected equal to angle of latitude of the location under consideration.
3. Deciding the solar PV modules rating and their configuration based on the possible power that can be generated for the location under consideration.

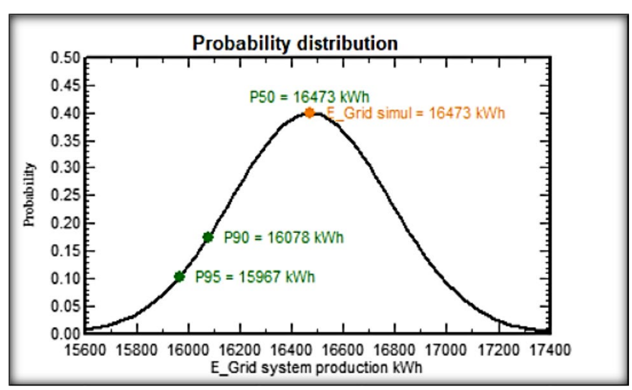

Fig. 9 P-50, P-90, P-95 probability distribution based on Energy management of Electrical energy supplied to grid

4. Estimate the requirement of battery storage which is ruled out if the Solar PV system is grid-connected and operating on net metering basis.
5. The generalized Grid-connected Solar PV system architecture is as follows [15, 16, 19]:
6. Basic components of grid-connected PV systems without batteries contains Solar photovoltaic modules, Array mounting racks, Grounding equipment, Combiner box, Surge protection (often part of the combiner box), Inverter, Meters–system meter and kilowatt-hour meter, Array and inverters disconnects [20, 21].
7. The selection of inverter and DC-DC Converter if MPPT and boosting the voltage level is desirable is also key factor in design process as the ratings of DC-DC converters and inverters are to be matched with grid parameters and solar PV Array parameters [22, 23].
8. The converters are normally so selected that they overrate the PV system energy production by 1.25–1.5 times so that the losses taking place in the converters can be compromised [24].
9. It may be noted while designing the grid-connected system that anti islanding protection should be placed along with reactive power support to maintain power factor close to unity and ensure maximum active power penetration ensuring that grid overload will not occur.
10. The most significant step in the system design is economic evaluation of the entire project which involves Installation cost which includes cost of PV modules, inverters, Studies and analysis honorarium to Solar Energy consultant, Transports, accessories, wiring settings and grid interconnection.
11. The maintenance cost includes salaries to the technicians and Engineers, reparation, cleaning including the cost of land for purchase or rent.
12. The subsidy of 30% on cost of installation may also be considered which estimating the total benchmark cost, if the system is to be designed for Indian context.

Simulation and Result analysis [33, 34]

Based on the inputs provided to the PVSyst 7.0 as described earlier

The results obtained are enlisted below:

(i) Daily system output energy
(ii) System output power distribution
(iii) System output power tail distribution
(iv) Performance ratio
(v) Array temperature versus effective irradiance

Daily System Output Energy

Figure 10 represents Daily system Energy production for the duration of 12 months considered on monthly average values.

The solar PV system is designed for the nominal power of **12.5 KWp** and injecting the energy ranging from **58KWhr/day (Minimum) to 80 KWh/day (Maximum)** into the grid. The peak energy penetration into the grid is achieved in the month of September while February, March and August seem to be the months where energy penetration into the grid is not taken place possibly due to lower values of solar irradiance for the location under consideration.

Total Energy penetrated to grid in KWh/day = Nominal power actually produced*No. of hours the said power is produced.

System Output Power Distribution

Fig. 11 represents the System Output Power versus Energy production for the duration of 12 months considered on monthly average values. The system is designed for the Nominal power output of 12.5KW and 30.9V and 8.1A. As seen from the diagram, energy and power are varying almost linearly over a certain period up to 8.3KW, 400KWhr/Bin. After 450 KWh/Bin, the power injected increases typically up to 12–13 KW, the energy in KWhr/Bin injected into the grid reduced. Power and energy relationship experiences the inverse relationship after a certain period as the designated amount of power might have been produced for a lesser duration of time.

System Output Power Tail Distribution

Fig. 12 represents System Output Power versus Energy production for the duration of 12 months considered on

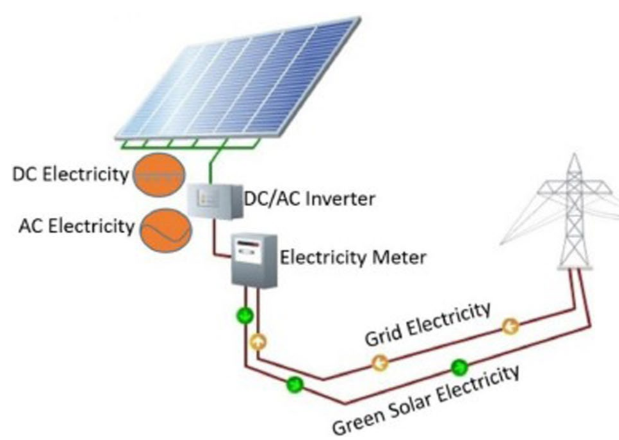

Fig. 10 Grid Connected PV system architecture

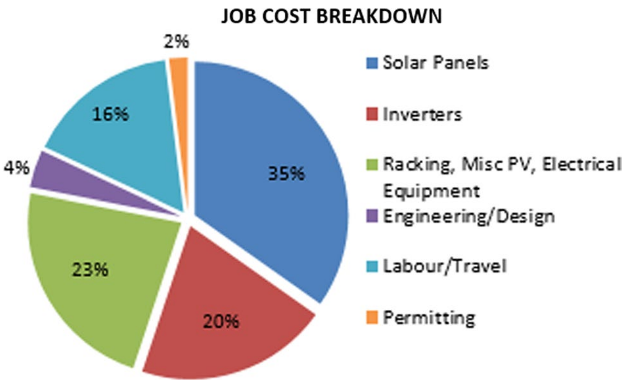

Fig. 11 Job cost breakdown of grid interconnected Solar PV system including installation, operation and maintenance cost

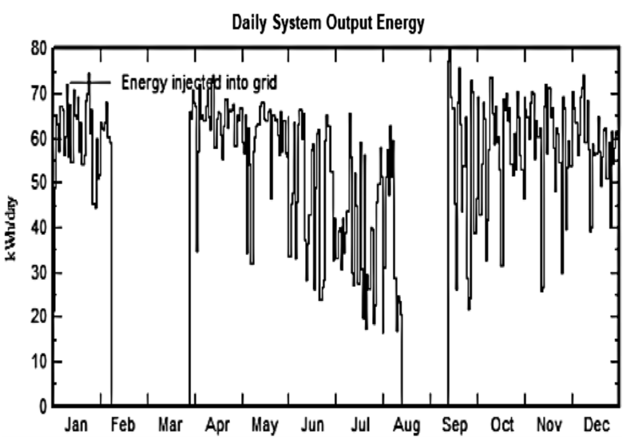

Fig. 12 Daily system Energy production for the duration of 12 months considered on monthly average values

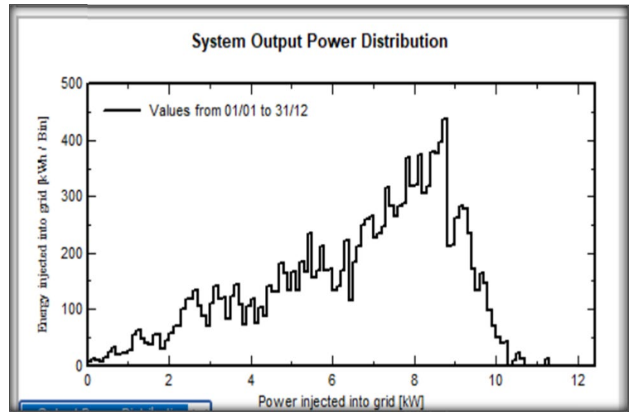

Fig. 13 System Output Power versus Energy production for the duration of 12 months considered on monthly average values

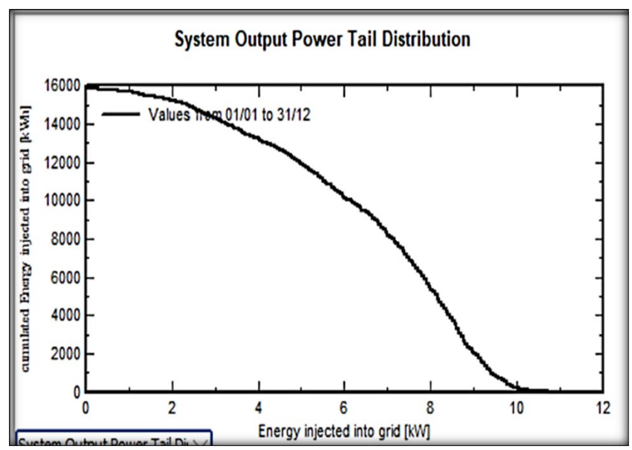

Fig. 14 System Output Power versus Energy production for the duration of 12 months considered on total power and energy injected on yearly basis

total power and energy injected on yearly basis. The system production is 15852 KWh/hr, i.e., the energy injected into the grid for power of 11KW. The performance ratio is observed to be 0.639 which means that out of total energy incident on solar panel, 63.9% of energy is actually converted into useful electricity by the solar panel. Power and energy injected into the grid experience the inverse relationship as the designated amount of power might have been produced for lesser duration of time. (Fig. 13).

Performance Ratio

The performance ratio may be defined as the ratio of solar energy incident on the solar panel in KWhr to the energy actually converted into useful electricity by the solar panel. For around 8 months in the year, the performance ratio is about 0.82 which means that out of total energy incident on solar panel, 82% of energy is actually converted into useful electricity by the solar panel. The performance ratio for February, March, August is comparatively very low, i.e., 0.2, 0.1 and 0.3, respectively. The average performance ratio is observed to 0.639.

Array Temperature vs Effective Irradiance

Figure 14 represents Average Array Temperature versus effective irradiance displayed over a period of 12 months. The array temperature seems to be varying from 15 to 40℃ over an irradiance range of 0–1000 W/m2. As per standards, to achieve maximum efficiency of solar panels, the panel temperature is to be kept nearer to 25℃. The solar irradiance and average solar panel temperature observe a linear relationship, i.e., with the increase in solar irradiance, average solar panel temperature increases. So at the higher irradiance values, there has to be a mechanism to maintain Solar module temperature nearer to 25℃.

Consolidated Results

As represented in Table2, broadly the DC energy feed by the array on average basis for the year is 20.673MWh and energy feed to the grid is 15. 852MWh. The losses taking places in the system are 4.821MWh which are in inverter, cables, etc.

The performance ratio is calculated as

$$\text{Performance ratio} = \frac{20.673}{15.852} = 0.639 = 63.9\%$$

It means that 63.9% of total energy generated by solar PV arrays is available to be supplied to the grid.

Carbon Emissions and Loss Diagram Analysis

Carbon Emissions [36]

The Carbon Balance tool allows to estimate the saving in CO_2 emissions expected for the PV installation. The criteria for estimation are Life Cycle Emissions (LCE), which represent the emissions of CO_2 associated with a given component or energy amount. These values include the total life cycle of a component or energy amount, including production, operation, maintenance, disposal, etc. The reasoning behind the Carbon Balance Tool is that the electricity produced by the PV installation will replace the same amount of electricity in the existing grid. If the carbon footprint of the PV installation per KWh is smaller than the one for the grid electricity production, there will be a net saving of Carbon Dioxide emissions. Thus, the total carbon balance for a PV installation is the difference between produced and saved CO_2 emissions [18]

From the calculations,

Generated emissions = 25.15 tCO_2.

Replaced Emissions = 462.9 tCO_2.

From the above details, total carbon credits generated by the PV system producing 16.48MWh/yr. are 25.15 tCO_2 and carbon credits saved as replaced emissions are 462.9 tCO_2 which leads to Carbon credits of 376.5 tCO_2, i.e., saving of 376.5 TCO_2 savings (Fig. 15).

Loss Diagram Analysis [35]

As seen from Fig. 16, Efficiency of the solar panels is observed to be 15.6% as Standard Test Conditions (STC) with the nominal energy production of 24211KWhr. Following losses are considered on nominal energy production

From Table 3, the negative loss parameters are the parameters which do not affect the performance of system, whereas the positive loss parameters like spectral correction, Module quality loss, etc., affects the actual energy production in the system considered over nominal energy production of 24211KWhr. Figures 17 and 18. Out of the available energy of 20210KWhr at inverter output, 15852KWhr, is the actual supplied to the grid

Table 2 Consolidated results indicating Global radiations, Diffused radiations, Global effective radiations, Global incident radiations in KWhr/m2, ambient temperature and energy produced by PV array and supplied to grid along with performance ratio for the duration of 12 months

Month	Global Horizontal radiations KWh/m2	Diff.Horizontal radiations KWh/m^2	Ambient Temperature (Degree Celsius)	Global Incident radiations KWh/m^2	Global effective radiations KWh/m^2	Energy by array MWh	Electricity to grid MWh	Performance ratio
January	137.9	48.47	20.77	175.8	171.9	1.890	1.848	0.841
February	147.8	52.92	23.78	176.1	172.3	1.852	0.438	0.199
March	187.8	70.59	28.38	204.8	200.4	2.093	0.269	0.105
April	196.7	79.35	31.94	196.0	191.3	1.963	1.919	0.783
May	205.3	89.02	35.17	191.5	186.1	1.894	1.851	0.773
June	156.4	92.25	30.86	143.5	138.8	1.474	1.439	0.803
July	123.9	89.11	27.78	115.4	111.6	1.214	1.184	0.821
August	122.2	87.58	27.09	117.4	113.7	1.242	0.477	0.325
September	143.2	73.02	27.33	147.8	144.1	1.546	1.038	0.562
October	156.1	70.99	26.50	176.7	172.9	1.855	1.814	0.821
November	136.1	54.17	22.96	167.6	163.9	1.787	1.748	0.835
December	132.1	45.72	20.51	172.9	169.0	1.866	1.825	0.845
Sum/Average	**1845.5**	**853.7**	**26.93**	**1985.4**	**1936.0**	**20.673**	**15.852**	**0.639**

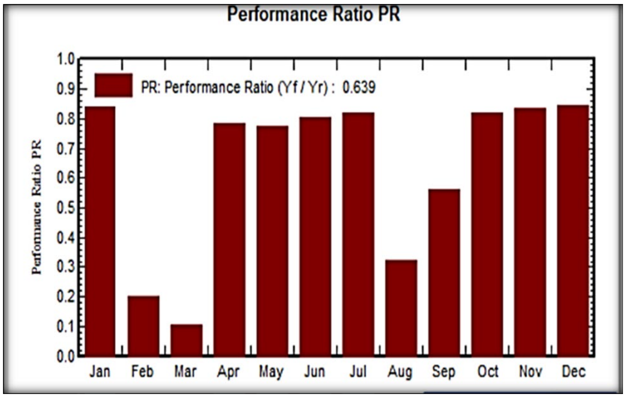

Fig. 15 Performance ratio for the duration of 12 months considered on total power and energy injected on yearly basis

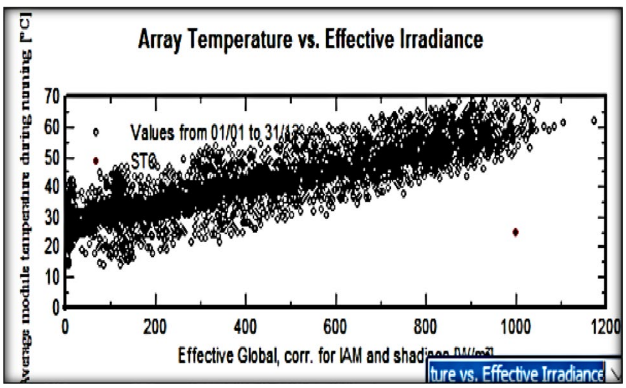

Fig. 16 Average Array Temperature versus effective irradiance displayed over a period of 12 months

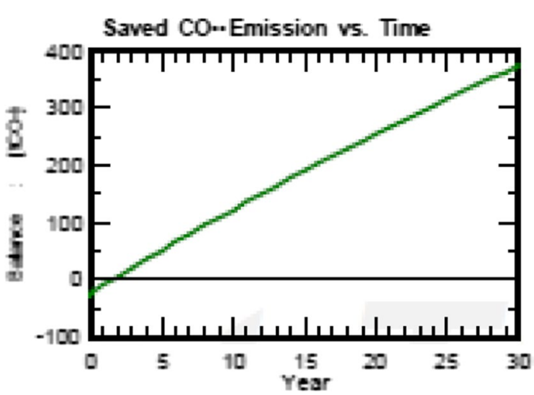

Fig. 17 Saved Carbon emissions over a project lifetime of 30 Years

considering that remaining energy is lost in to all positive loss parameters

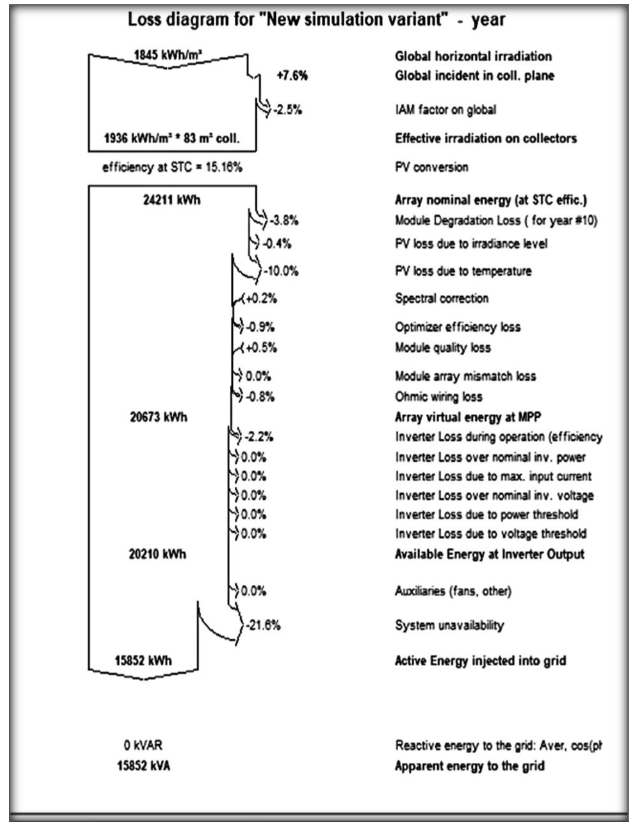

Fig. 18 Loss diagram indicating various losses taking place at different stages of Solar Photovoltaic system along with% system unavailability

Table 3 Percentage loss representation on the basis of different loss parameters

S. N	Loss parameter	% Loss
1	Module degradation loss	−3.8
2	PV Loss due to irradiance level	−0.4
3	PV loss due to temperature	−10
4	Spectral correction	+0.2
5	Optimizer efficiency loss	−0.9
6	Module quality loss	+0.5
7	Inverter loss during operation	−2.2

Conclusion

On the basis of research work carried out, it may be concluded that the grid-connected solar PV system designed for the nominal power output of 12.5Kw effectively can produce DC energy by the array on average basis for the year of 20.673MWh. Out of which 15.852MWh of energy is actually fed to the grid because of loss parameters mentioned in 6(ii). The performance ratio is observed to be 0.639 which means that out of total energy incident on solar panel, 63.9% of energy is actually converted into useful electricity by the solar panel. Hence, this paper provides guideline for the design engineers and researchers on solar PV power forecasting studies and provides an approach to exploratory analysis of the results and derives the perspectives which can enable decision making on real-time implementation of system. Hence, to ensure widespread utilization of solar powered systems in society, this research article can help academicians as well as professionals with a systematic design and forecasting approach which can help them to convince the end customers or students about the solar power systems utilization and benefits.

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Conflict of interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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