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Research paper

Performance simulation of grid-connected rooftop solar PV system for small households: A case study of Ujjain, India

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ABSTRACT

Solar rooftop PV system is an attractive alternate electricity source for households. The potential of solar PV at a given site can be evaluated through software simulation tools. This study is done to assess the feasibility of grid-connected rooftop solar photovoltaic system for a household building in holy city Ujjain, India. The study focuses on the use of various simulation software, PV*SOL, PVGIS, SolarGIS and SISIFO to analyze the performance of a grid-connected rooftop solar photovoltaic system. The study assesses the energy generation, performance ratio and solar fraction for performance prediction of this solar power plant. PV*SOL demonstrates to be easy, fast, and reliable software tool for the simulation of a solar PV system.

1. Introduction

Solar energy is most readily available source of energy. Solar energy is Non-polluting and maintenance free (Shukla et al., 2016a). Solar PV system is more widely used technology all over the world. Solar energy is becoming more and more attractive especially with the constant fluctuation in supply of grid electricity (Zeyringer et al., 2015). Solar power plant is based on the conversion of sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power. Solar PV energy generation employs solar modules comprising a number of solar cells containing a photovoltaic material. There are several configurations of Photovoltaic systems in use, grid-connected PV systems (On-grid) and stand-alone Photovoltaic systems (Off-grid) (Menconi et al., 2016). The installation capacity for off-grid cannot be compared to the grid-connected, as the rapid development of grid-connected PV eliminates the off-grid. The integration of photovoltaic system into the building can enable self-production of electricity (Shukla et al., 2017). At the same time, the system can help the electricity-grid by injecting the extra photovoltaic electricity produced, especially during hot and sunny periods. Because, during these periods the electrical demand is the highest, due to the use of air conditioning (Lau et al., 2016). This will also help in reducing the climate and environmental impacts. However, for the feasibility of a PV system, there should be enough solar energy throughout the year. India is found to have a huge scope for solar generation.

There are several types of solar PV generating systems, where the differences between each technology reside in the yield, the price as well as the material used. The performance of a PV system depends strongly on meteorological conditions, such as solar radiation and temperature (Shukla et al., 2016c). To provide continuously energy during the year, a PV system must be correctly dimensioned. This requires a rigorous study in order to make the best choice, the most efficient and at the lowest cost (Missoum et al., 2016). In fact, the PV system is characterized with different performance parameters including: Energy yield, ambient temperature and performance ratio (Shukla et al., 2016b).

Various studies have been conducted in literature on PV system performance investigation. Khatib et al. (2013) carried out techniques for solar PV systems size optimization that suggest optimization of PV systems strongly depends on meteorological variables such as humidity, wind speed, solar radiation and ambient temperature. So it becomes important to have a detailed analysis at various locations for accurate results. Saeed et al. (2015) compared the experimental behavior of these two common PV module technologies (m-Si and p-Si). Different studies have been conducted

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Table 1
Site information.

Site name	Ujjain, Madhya Pradesh, 456010, India
Coordinates	23.17449 °N, 75.78517 °E
Annual global irradiation	1983.7 kWh/m^2
Annual air temperature at 2 m	25.1 °C

Table 2
System description.

Installed power	6.4 kW_p
Installation type	Roof Parallel
Type of modules	Mono Crystalline, Efficiency 14.9%
No. of Module (320 Wp)	20 (1-Soltec Inc, 1-STH 320)
Mounting system	Fixed mounting, free standing
Azimuth/inclination	180°(south)/23°
Load Profile	2-Person household with 2-children
Availability	95.0%
Albedo	20%

on the performance parameters of installed PV power plants in different geographical locations and different climatic conditions. Messinaa et al. (2014) studied two 2.4 kWp grid-connected PV systems installed at different locations i.e. Tepic and Temixco-Morelos and they concluded that the Temixco-Morelos solar PV system supplied nearly 90% of electrical energy need for the house and identified grid-connected PV system in the urban and suburban areas. Shiva kumar and Sudhakar (2015) assessed the performance of a 10 MW grid-connected solar PV power plant in India and they found annual performance ratio of 86.12%. Shukla et al. (2016d) analyzed the performance of a solar PV system and compared the performances of different PV technologies through energy models in simulations. Sharma and Goel (2017) evaluated performance analysis of an 11.2 kW prooftop grid-connected PVsystem in Eastern India and they found 78% performance ratio.

In this regard, modeling and feasibility of the system in the proposed location is to be studied and investigated first. These can be done on the various available software platforms and the reports generated can be used to compare and get the best-suited model among them in implementing the same at field level.

The present analysis is aimed:

- To assess and define the solar resource potential at the Ujjain site, Central India.
- To predict the performance of 6.4 kWp grid-connected rooftop solar power plant using PV*SOL, PVGIS, SOLARGIS, and SISIFO.
- To compare the annual energy yield, performance ratio and energy yield of the PV system from various software.

2. Location information and system description

2.1. Site details

The site selected for the study is based on hypothetical household building for Ujjain holy city in Madhya Pradesh, India. It is located in the central part of Madhya Pradesh at a latitude of 23.1793°N, longitude of 75.7849°E. The Ujjain city obtains its power from Madhya Pradesh electricity board public grid, which is shared with other residential and industrial consumers. The site selected for the study is a residential Building with small space available on rooftop area (roughly 70 m^2). The location and site-specific information are shown in Fig. 1 and Table 1. The site selected is a demo model to study the installation requirements at large scale. The city also comes under passing of tropic of cancer. Thus it receives enough solar energy annually. The annual ambient temperature is moderate 30 °C–35 °C.

2.2. System description

The system description is given in Table 2. A 6.4 kW_p rooftop system is chosen. The PV cell material chosen is mono-crystalline because of the higher efficiency. The system is of fixed stand type and can sufficiently power a household of a small family.

The grid connected PV system, consists of solar arrays to absorb and convert sunlight into electricity, a solar inverter to convert DC current to AC current, a mounting, cabling and other electrical accessories. Schematic of the grid connected PV system is shown in Fig. 2. The main component for grid-connected solar PV power systems comprise of:

- Solar PV modules, connected in series and parallel, depending on the solar PV array size, to generate DC power directly from the sun's intercepted solar power.
- Maximum power point tracker (MPPT), making sure the solar PV modules generated DC power at their best power output at any given time during sunshine hours (Manju and Sagar, 2017).
- Grid-connected DC/AC inverter, making sure the generated and converted AC power is safely fed into the utility grid whenever the grid is available (Laib et al., 2018).
- Grid connection safety equipment like DC/AC breakers fuses etc., according to the local utility's rules and regulations.

2.3. Solar PV simulation software

Table 3
Various system software used for performance analysis of rooftop solar PV systems.

S.No.	Software	Software specifications	Inputs required	Developers	Ref.
1	PV*SOL	Used for Planning and Simulation of a site-specific solar PV system.	Location Coordinates, meteorological data, system and auxiliary devices requirements	Developed by Valentin Software, online access	http://pvsol-online.valentin-software.com/#/
2	SolarGIS	A satellite map supported online simulation tool for site prospection and comparing energy yield from various PV technologies, planning and optimization of solar PV systems	Type of PV technologies, Local coordinates, AC/DC losses, load demand, cable sizing.	Developed by SolarGIS, Slovak Republic.	https://solargis.info/pvplanner/
3	PVGIS	An open source research tool for performance assessment of PV technology in geographical regions and as a support system for policymaking in Europeanunion	Total irradiance, Monthly values of atmospheric conditions, the mounting position	European Commission and National Renewable Energy Laboratory(U.S.)	https://photovoltaic-software.com/pvgis.php
4	SISIFO	An open webservice software for simulation of PV systems	Location of the system, the solar resource data, technical characteristic of the system and optionally system economics.	developed by IES-UPM in European project PVCROPS	https://www.sisifo.info/es/default

Fig. 1. Location and Satellite view of Ujjain Engineering College, Ujjain.

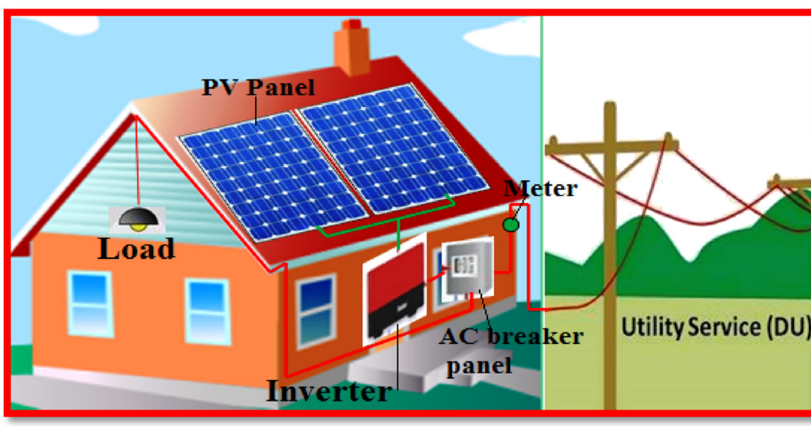

Fig. 2. Schematic of the grid connected PV system.

3. Methodology

*3.1. Simulation of grid-connected PV system using PV*SOL*

The PV*SOL software supports householders and system designers in deciding the PV system. The software evaluates the necessary data and calculates the solar yield. The orientation and inclination of the roof can be determined in this software. After choosing one of the three types of solar PV modules monocrystalline, polycrystalline or thin film, the required size of the module array or the peak power is entered. The overall area required for installation is taken 1.3–1.5 times of the area covered by PV modules for spacing between modules for regular maintenance and avoid shading effects. The software automatically determines the location of the solar PV system on a map. Alternatively, any location in the world can be entered manually. PV*SOL software uses the climate database in PV*SOL. The simulation itself is quite a complex process.

The main steps involved in the simulation are given below http://pvsol-online.valentin-software.com/#/.

Step 1. Start quick design via File > New project > "Start new project with quick design" > OK.

Step 2. Enter a project name.

Step 3. Click on Climate data to set a location.

Step 4. Click on PV module to select a PV module from the database.

Step 5. Enter the Azimuth and the Inclination of the PV modules.

Step 6. Enter either the desired system output or a set number of modules.

Step 7. Accordingly, click either on Inverter to select one from the database, or on Inverter Combinations, Inverter combinations — configuration selection.

Step 8. The calculated sizing: installed power, total number of modules, gross PV area and below the selected configuration.

Step 9. All other parameters are filled out with practical standard values alongside the entry Parameters in the quick design.

Step 10. Click on simulation.

Step 11. Following the simulation, you are given a summary of the project report. This onepage report can be printed out.

With the climate-data for the location and the characteristics determined for the solar PV system, the expected annual yield of the system is calculated using a detailed hourly simulation. The simulation uses the PV*SOL calculation model on the Valentin Software server in order to calculate the system quality and yield from the following results:

- Annual irradiation on the horizontal plane (kWh/m^2)

- Annual radiation on the inclined surface (kWh)
- PV yield (kWh)
- Performance ratio

3.2. Simulation of grid-connected PV system using SolarGIS

The SolarGIS software is a map-based online simulation software tool for designing and optimization of photovoltaic systems with local geographical data at high accuracy and spatial resolution to site specifications. To simulate a Solar PV system in SolarGIS software following are the steps followed https://solargis.info/pvplanner/.

Step 1. Start with https://solargis.info/pvplanner/ for online simulation.

Step 2. Go to "search "option that allows user to choose the desired location.

Step 3. Enter the coordinates of the site of interest within the location.

Step 4. Click "Continue" to enter into simulation page.

Step 5. Enter the details of installed capacity required of the PV System.

Step 6. Enter the types of modules materials, inverter Euro efficiency, DC/AC losses.

Step 7. Enter the availability of solar radiation, mounting scheme and inclination for the given site.

With the location, climate data and PV system details, SolarGIS gives results of PV electrical potential, losses at various stages, performance ratio, site horizon, sun path and local air temperature over the entire year.

A report is available in PDF and Excel format, which can be used for future planning and installation.

3.3. Simulation of grid-connected PV system using PVGIS

PVGIS is online simulation software that is used to calculate various parameters of a solar PV system. The software based on the data inputs evaluates the daily irradiation, energy production, annual yield and total system losses. The simulation is performed in the following manner https://photovoltaic-software.com/pvgis.php.

Step 1. Start "PVGIS" online simulation software.

Step 2. Enter radiation databases as "Climate SAF-PVGIS".

Step 3. Choose the PV technology to be used in the system.

Step 4. Enter system capacity requirement for installation.

Step 5. Enter the permissible total system losses.

Step 6. Choose the mounting scheme, the angle of azimuth and inclination and tracking options.

Step 7. Click on calculate to run the simulation.

Step 8. A report is generated; giving data of average daily/monthly electricity production, average daily/monthly sum of global irradiation per square meter received by the modules and combined PV system losses.

3.4. Simulation of grid-connected PV system using SISIFO

This is an online web-based facility for simulation of PV system. Following are the steps performed to simulate the PV system https://www.sisifo.info/es/default.

Step 1. Go online on https://www.sisifo.info/.

Step 2. Enter the site input with the project name, location, local latitude, local longitude and local altitude.

Step 3. Enter the metrological inputs meteo data type, meteo sky type.

Step 4. Choose the PV module details like cell material, power model, the coefficient of power with temperature, type of mounting.

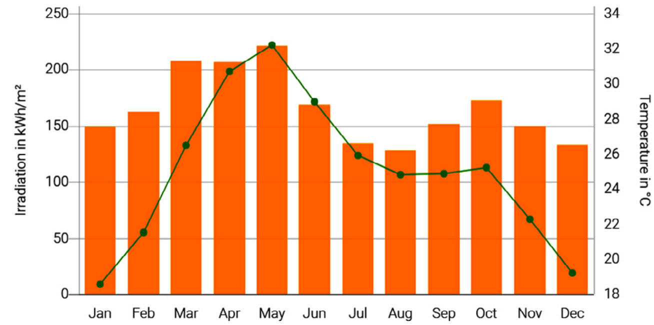

Fig. 3. Monthly variation of solar irradiation at Ujjain by PV*Sol.

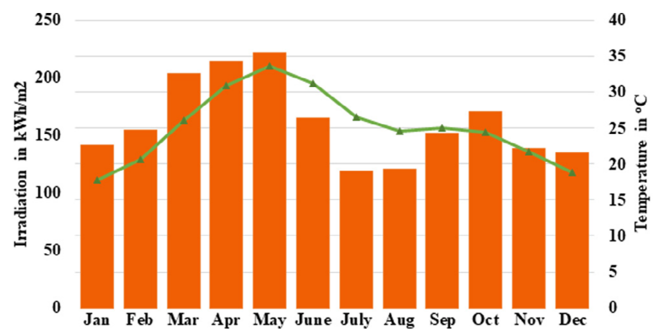

Fig. 4. Monthly Variation of Solar Fraction at Ujjain by SolarGIS.

Step 5. Enter system parameters like nominal system power, nominal PV power per inverter, nominal PV power per transformer, real power-nominal power ratio, Bypass diodes horizontal, Bypass diodes vertical.

Step 6. Choose from the static and tracking structures available for simulation.

Step 7. Enter physical parameters like separation ratio between trackers in E-W- direction, maximum rotating angle orientation, axis inclination, separation ratio between trackers in N–S direction, module inclination, and backtracking option.

4. Result and discussion

4.1. Solar resource potential

Solar irradiation is the most important input for a professional assessment of energy yield of PV system. The performance analysis depends on site-specific meteorological factors (solar irradiance characteristics, wind speed, and ambient temperature) and installation site factors (latitude, orientation, dust, pollution level and tree cover).The minimum and maximum ambient temperature greatly influence the power output of the solar photovoltaic system. Similarly, humidity should be given special consideration while determining the power output of the PV plant. High humidity in the atmosphere adversely affects the performance of the PV module as it condenses and forms a deposit on the module during nighttime. The solar PV system has more irradiation (218 kWh/m^2) and temperature (31 °C) in the month of May. The sites receive solar insolation of value 218 to 140 kWh/m^2 throughout the year. The data of irradiation and temperature obtained from PV*SOL is shown in Fig. 3.

The Monthly variation of solar irradiation by SolarGIS is shown in Fig. 4. Solar irradiation is maximum in the month of May (222 kWh/m^2), and the temperature is (33.7 °C).

The monthly solar radiation obtained from PVGIS is shown in Fig. 5. The maximum solar radiation is obtained in May month (235 kWh/m^2), and temperature is 33.7 °C.

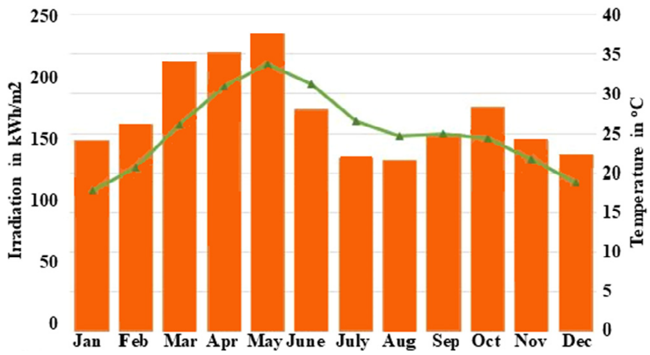

Fig. 5. Monthly variation of solar irradiation by PVGIS.

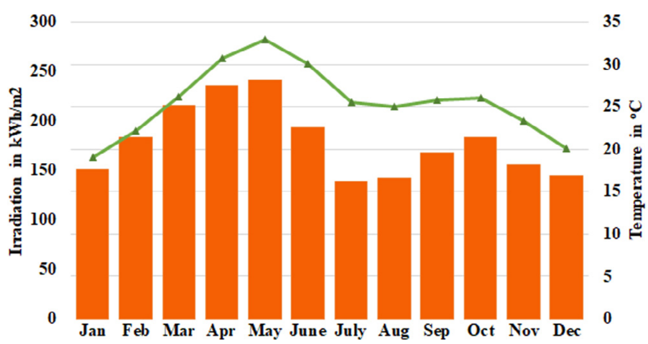

Fig. 6. Monthly variation of solar irradiation by SISIFO.

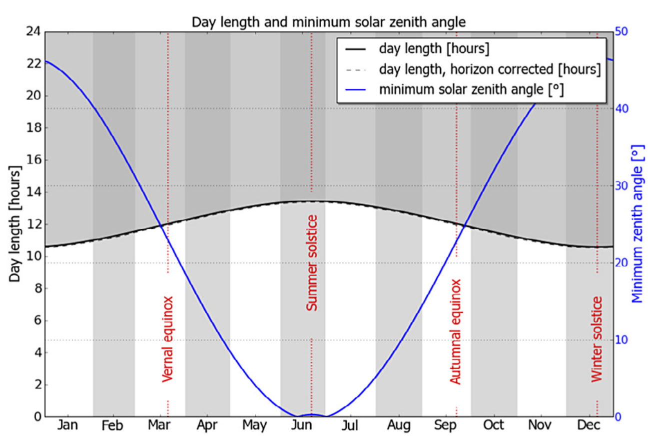

Fig. 7. Variation of day length and zenith angle.

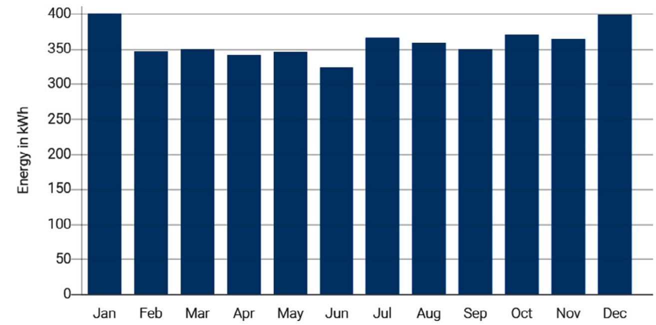

Fig. 8. Energy consumption for small household using PV*SOL.

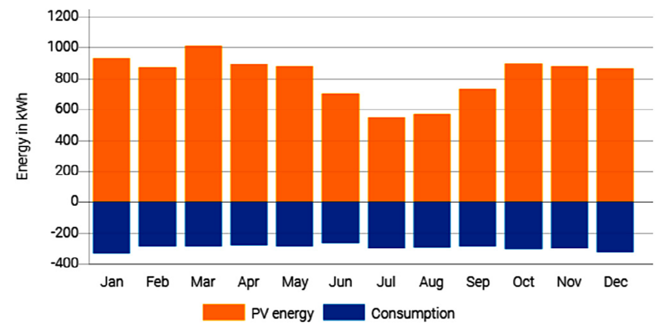

Fig. 9. Monthly variation of energy generation and energy consumption PV*SOL.

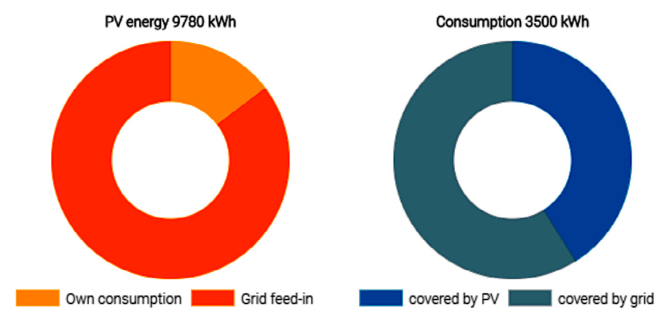

Fig. 10. Energy feed-in grid and energy consumption covered by PV and grid PV*SOL.

The solar radiation obtained from SISIFO is shown in Fig. 6. The maximum global irradiation is found in may month(241 kWh/m^2), and the maximum temperature is also obtained in the month of May(32.95 °C).

For the given location, The day length and minimum zenith angle are shown in Fig. 7. The day length depends on altitude of sun, geographical latitude of location, angle of declination of sun and hour angle.

4.2. Performance parameters

The maximum energy production is 1000 kWh in the month of March and minimum in the month of August, which is 500 kWh using PV*SOL software as shown in Fig. 8. The reason behind is clear solar radiation and low ambient temperature in March month and in August month energy production is low due to the cloudy or rainy season. Similarly, the maximum energy consumption 400 kWh in the month of January and December because of a heavy electrical load connected in the system like water geyser, room heater etc. Minimum energy consumption is in the month of July, which is 310 kWh due to normal environmental parameters (ambient temperature, humidity etc.) as shown in Fig. 9. All the electricity generated was assumed to be utilized for meeting the building energy requirements. It is observed that the energy generation fluctuates depending on the insolation. Based on the simulation results; the cumulative energy output delivered for household building grid was approximately 8342 kWh. Annual PV energy production found to be 9780 kWh.The specific energy production found to 1528.125 kWh/kWp.

The total energy consumption for the small household is estimated as 3500 kWh from the software. Out of which energy consumption supplied by solar PV is 1438 kWh, i.e., 41.09%, and remaining energy consumption covered by the grid is 2063 kWh, i.e., 58.91%. Total annual energy generated from solar PV is 9780 kWh. A 1438 kWh is taken from own fulfillment amounting around 14.7%. The remaining energy is fed into the grid 8342 kWh, i.e., 85.3%. This is huge power injection into the grid as shown in Fig. 10.

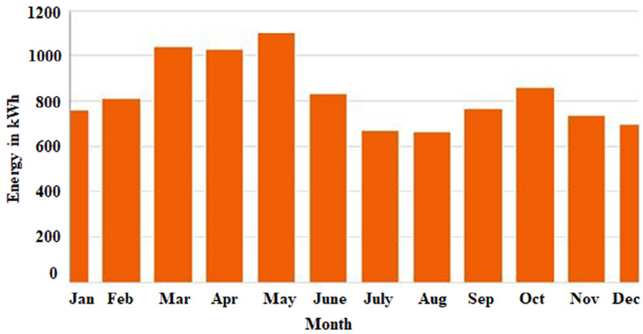

Fig. 11. Monthly variation of energy generation using SOLARGIS.

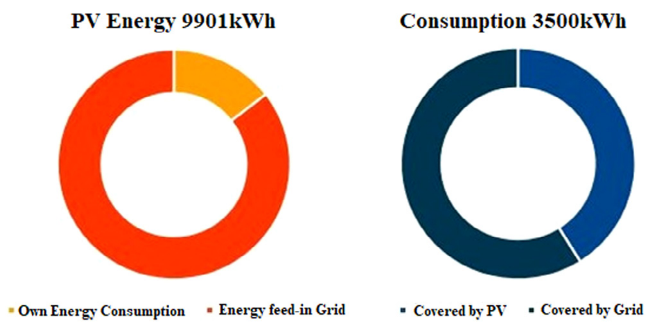

Fig. 12. Energy feed into the grid and energy consumption covered by PV and Grid.

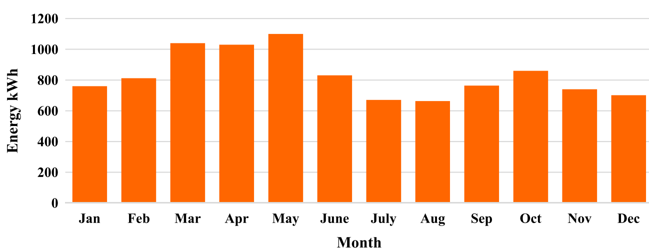

Fig. 13. Monthly variation of energy generation using PVGIS.

The maximum energy production is 1039 kWh in the month of March and minimum energy production in the month of August, which is 561 kWh as shown in Fig. 11. Based on the simulation results the cumulative energy production is found to be 9901 kWh. The specific energy found to be 1547 kWh/kWp. The other system data obtained from SOLARGIS is mentioned below.

The total calculated household energy consumption is 3500 kWh annually. The PV supplies 1438 kWh and the remaining 2063 kWh is covered from the grid. The PV shares 41.08%, and the grid supplies 58.91%.The Total PV generation is 9901 kWh. The load is supplied 1438 kWh, i.e. 14.52% and remaining energy 8463 kWh is supplied into the grid 85.47% as shown in Fig. 12.

The maximum energy production is 1100 kWh in the month of May and minimum energy production in the month of August, which is 663 kWh as shown in Fig. 13. This is in contradict to the obtained results from previous softwares. The temperature is very high in May month, and this reduces the PV output power. Based on the simulation results the cumulative energy production is found to be 9970 kWh. The specific energy found to be 1557.8 kWh/kWp.

The total calculated household energy consumption is 3500 kWh annually. The PV supplies 1438 kWh and the remaining 2063 kWh is covered from the grid. The PV shares 41.08%, and the grid supplies 58.91%.The Total PV generation is 9970 kWh as shown in Fig. 14. The load is supplied 1438 kWh, i.e. 14.42% and remaining energy 8532 kWh is supplied into the grid 85.57%

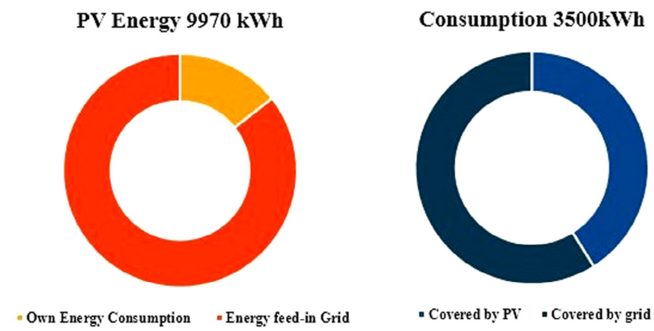

Fig. 14. Energy feed into the grid and energy consumption covered by PV and Grid.

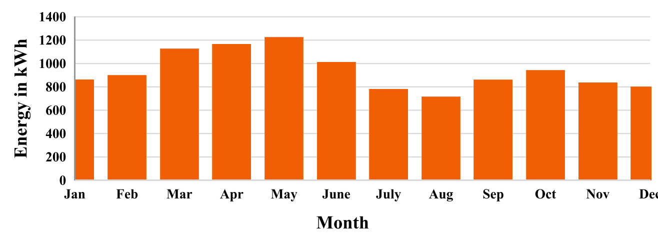

Fig. 15. Monthly variation of energy generation using SISIFO.

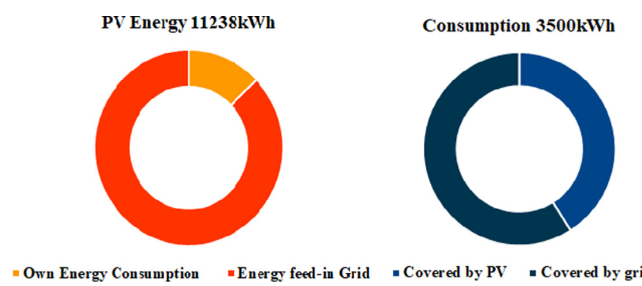

Fig. 16. Monthly variation of energy generation and energy consumption.

The maximum energy production is 1225 kWh in the month of May and minimum energy production in the month of August, which is 714 kWh as shown in Fig. 15. This is also in contradict to the obtained results from previous softwares. Based on the simulation results the cumulative energy production is found to be 11238 kWh. The specific energy found to be 1755.9 kWh/kWp.

The total energy consumption for the small household 3500 kWh from the software as shown in Fig. 16. The energy consumption supplied by solar PV is 1438 kWh, i.e. 41.09%, and remaining covered by the grid is 2063 kWh, i.e. 58.91%.The energy generated from solar PV is 11238 Wh. A 1438 kWh is taken delivered to load i.e. 12.79%. The remaining energy is fed into the grid 9800 kWh, i.e. 87.20%.

4.3. *Solar fraction*

It is defined as the portion of sun energy utilized or sun energy use to convert in the utility in any energy forms. The main factors that affect the solar fraction are climate condition, operation, storage and load of the system. In Ujjain, solar fraction varies between 33% to 43% means average utilization of solar energy throughout the year may be around 38%. Monthly variation of the solar fraction is shown in Fig. 17.

4.4. *Performance comparison*

The technical performance simulation data of the solar PV system is compared and reported in Table 4.

Table 4
Summary of Performance parameters.

Performance parameter	PVSOL	SolarGIS	PVGIS	SISIFO
Annual PV energy	9780 kWh	9901 kWh	9970 kWh	11238
Specific annual yield	1528.125 kWh/kWp	1547 kWh/kWp	1557.81 kWh/kWp	1755.93 kWh/kWp
Own energy consumption	1438 kWh	1438 kWh	1438 kWh	1438 kWh
Energy feed-in grid	8342 kWh	8463 kWh	8532 kWh	9800 kWh
Own power consumption	14.70%	14.52%	14.42%	12.79%
Total energy consumption	3500 kWh	3500 kWh	3500 kWh	3500 kWh
Covered by PV	1438 kWh	1438 kWh	1438 kWh	1438 kWh
Covered by grid	2063 kWh	2063 kWh	2063 kWh	2063 kWh
Performance ratio	75.01%	73.5%	76.4%	73.80

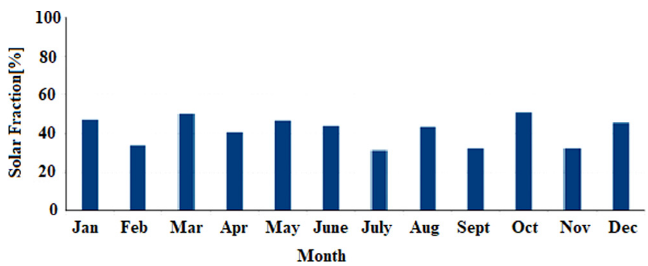

Fig. 17. Monthly variation of solar Fraction at Ujjain.

The softwares PV*SOL, SOLARGIS and PVGIS almost give the same solar PV energy output but SISIFO energy output deviates much compared to the other three. In terms of maximum energy output, PV*SOL shows in the month of March while SOLARGIS, PVGIS and SISIFO shows maximum energy output in May month. The solar PV output decreases as the temperature increases. Therefore, the output in May month should be less. The moderate temperature in March month is allows maximum energy extraction from solar PV which is observed in PV*SOL software only. The performance ratio obtained by PV*SOL and PVGIS are significantly higher than SOLARGIS and SISIFO.

5. Conclusion

A simulation study was carried out to determine the technical performance of a6.4 kW pgrid-connected rooftop solar PV-system for a household to supply electricity. Mono Crystalline Solar PV modules have been simulated to determine performance ratios, energy consumption, electricity feed-ingrid and Energy yield. The lack of monitored irradiance data and PV power output limit the validation of the results. The variation in the predicted value of energy generation, performance ratio, solar fraction and energy yield are due to the slight difference in model equations and the climate database among simulation software. Despite these limitations, this study provides some valuable insight into the roof top energy generation to meet the typical household's energy requirements. Also, it can be used as a reference to simulate grid-connected PV system using various simulation software's. This study suggests that in the Ujjain region, the PV power generation performance is good with the scope for increasing the capacity above 6.4 kWp depending on the availability of rooftop area. The simulated performance can be used to analyze and validate the actual measured solar PV performance data.

The major findings of the present study are as follows:

- The annual energy yield 1528.125 kWh/kWp determined for the system is a good indicator that grid-connected system installations in the central region of India are technically viable energy solution even for urban areas, government buildings , etc.
- Annual energy generated feed into the grid from solar PV is 85.30%, for which the utility pays the owner of a solar PV system
- The performance ratio of the Solar PV system is 75.01%, which is reasonably good for installation and commissioning.
- The annual energy requirement from the electrical grid is approximately reduced by 41.09% by using the proposed PV system.
- Among the simulation software studied, PV*SOL demonstrates to be an easy, fast, and reliable software tool for the simulation of solar PV system.
- The grid-connected rooftop PV system in Ujjain is technically viable, and the wider implementation of these systems will have substantial benefits in energy savings and CO_2emission reduction.
- The solar resource and potential rooftop assessment of this study were limited to the smallhousehold building while there is a chance to extend the study to the other areas.

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References

Khatib, Tamer, Mohamed, Azah, Sopian, K., 2013. A review of photovoltaic systems size optimization techniques. Renew. Sustain. Energy Rev. 22, 454–465.

Laib, I., Hamidat, A., Haddadi, M., Ramzan, N., Olabi, A.G., 2018. Study and simulation of the energy performances of a grid-connected PV system supplying a residential house in north of Algeria. Energy http://dx.doi.org/10.1016/j.energy.2018.03.157.

Lau, K.Y., Muhamad, N.A., Arief, Y.Z., Tan, C.W., Yatim, A.H.M., 2016. Grid connected photovoltaic systems for Malaysian residential sector: Effects of component costs, feed-in tariffs, and carbon taxes. Energy 102, 65–82.

Manju, S., Sagar, Netramani, 2017. Progressing towards the development of sustainable energy: A critical review on the current status, applications, developmental barriers and prospects of solar photovoltaic systems in India. Renew. Sustain. Energy Rev. 70, 298–313.

Menconi, M.E., dell'Anna, S., Scarlato, A., Grohmann, D., 2016. Energy sovereignty in Italian inner areas: Off-grid renewable solutions for isolated systems and rural buildings. Renew. Energy 93, 14–26.

Messinaa, Sarah, Paz Hernández Rosales, I., Saldaña Durán, Claudia E., Jesús Quiñones, J., Nair, P.K., 2014. Comparative study of system performance of two 2.4 kW grid-connected PV installations in Tepic-Nayarit and Temixco-Morelos in México. Energy Procedia 57, 161–167.

Missoum, M., Hamidat, A., Imessad, K., Bensalem, S., Khoudja, A., 2016. Impact of a grid connected PV system application in a bioclimatic house toward the zero energy status in the north of Algeria. Energy Build. 128, 370–383.

Saeed, E., Mehran, A., Masoud, I., 2015. Comparative performance investigation of mono- and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates. Appl. Energy 160, 255–265.

Sharma, R., Goel, S., 2017. Performance analysis of a 11.2kWproof top grid-connected PVsystem in Eastern India. Energy Rep. 3, 76–84.

Shiva kumar, B., Sudhakar, K., 2015. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. Energy Rep. 1, 184–192.

Shukla, A.K., Sudhakar, K., Baredar, P., 2016a. A comprehensive review on design of building integrated photovoltaic system. Energy Build. 128, 99–110.
Shukla, A.K., Sudhakar, K., Baredar, P., 2016b. Design, simulation and economic analysis of standalone roof top solar PV system in India. Sol. Energy 136, 437–449.
Shukla, A.K., Sudhakar, K., Baredar, P., 2016c. Exergetic assessment of BIPV module using parametric and photonic energy methods: A review. Energy Build. 119, 62–73.
Shukla, A.K., Sudhakar, K., Baredar, P., 2016d. Simulation and performance analysis of 110 kWp grid-connected photovoltaic system for residential building in India: A comparative analysis of various PV technology. Energy Rep. 2, 82–88.
Shukla, A.K., Sudhakar, K., Baredar, P., 2017. Recent advancement in BIPV product technologies: A review. Energy Build. 140, 188–195.
Zeyringer, M., Pachauri, S., Schmid, E., Schmidt, J., Worrell, E., Morawetz, U.B., 2015. Analyzing grid extension and stand-alone photovoltaic systems for the cost-effective electrification of Kenya. Energy Sustain. Dev. 25, 75–86.