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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