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Simulation and performance analysis of 110 kW_p grid-connected photovoltaic system for residential building in India: A comparative analysis of various PV technology

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ABSTRACT

System simulation is necessary to investigate the feasibility of Solar PV system at a given location. This study is done to evaluate the feasibility of grid connected rooftop solar photovoltaic system for a residential Hostel building at MANIT, Bhopal, India (Latitude: 23° 16′ N, Longitude: 77° 36′ E). The study focuses on the use of Solargis PV Planner software as a tool to analyze the performance a 110 kW_p solar photovoltaic rooftop plant and also compares the performances of different PV technologies based on simulated energy yield and performance ratio. Solargis proves to easy, fast, accurate and reliable software tool for the simulation of solar PV system.

1. Introduction

Renewable energy sources are considered as alternative energy sources due to environmental pollution, global warming and depletion of ozone layer caused by green house effect. Earth receives about 3.8×10^{24} J of solar energy on an average which is 6000 times greater than the world consumption (Aliman et al., 2007). Solar energy is most readily available source of energy. Solar energy is Non-polluting and maintenance free. Solar energy is becoming more and more attractive especially with the constant fluctuation in supply of grid electricity. Solar power plant is based on the conversion of sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The voltage and current both are the function of light falling on solar PV. But too much insolation on the cell causes saturation and eventually the power output is reduced because of increase in mobility of electron and increase in temperature. The other problem is tracking of the sun according to the PV module i.e. orienting the panel in such a direction so that panel receives maximum irradiance. It is anticipated that photovoltaic (PV) systems will experience an enormous increase in the decades to come. However, a successful integration of solar energy technologies into the existing energy structure depends on detailed knowledge of the solar resource availability at a particular location. The electrical and thermal simulation of a roof-mounted BIPV system inclined at Ballymena, Northern Ireland and facing due south was performed by using TRNSYS (Mondol et al., 2005). The efficiency of the BIPV system as a shading device was examined at different months. The simulation program SOLCEL was developed to calculate the shading effect on the solar cells, PV module temperature, incident solar irradiance, BIPV output. The simulation of a BIPV system was performed to optimize its performance through parametric analysis (Yoo, 2011).

Masa-Bote and Caamaño-Martín (2014) developed a methodology to estimate BIPV electricity production under shadow. The developed methodology was validated by means of one-year experimental data obtained from two similar PV systems. The study included several weather conditions: clear, partially overcast and fully overcast sky. A performance analysis and modeling of a BIPV system in Romania was conducted by Fara et al. (2013). Forecasting tests were run by utilizing Autoregressive Integrated Moving Average models.

Kane and Verma (2013) investigated the performance enhancement of a BIPV module by using thermoelectric cooling. Thermoelectric module was attached at the back of the PV module. Mathematical modeling of individual systems was performed and then,

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Nomenclature

Abbreviation

PV: Photovoltaic
MANIT: Maulana Azad National Institute of Technology
STC: Standard Test Condition
AC: Alternating Current
PR: Performance Ratio

Symbols

c-Si: Crystalline silicon
a-Si: Amorphous silicon
CdTe: Cadmium telluride
CIS: Copper indium selenide
G_h: Horizontal Irradiance
Gh_m: Monthly sum of global irradiation
Gh_d: Daily sum of global irradiation
Dh_d: Daily sum of diffuse irradiation
T_{24}: Daily air temperature
E_{PV}: The annual PV electricity generated

the dynamic model of the BIPV system by considering the temperature of the PV module was developed. The results of the simulations revealed that the proposed cooling method improved PV efficiency with minimal power loss.

Mei et al. (2002) estimated the thermal parameters which describe the performance of ventilated photovoltaic façades integrated into buildings. The method allowed the heat transfer coefficients to be obtained from data measured on an operational ventilated photovoltaic façade.

The performance of PV systems is realized by comparison with a corresponding reference system. The simulations require input of the horizontal solar radiation and the ambient temperature data, both on a monthly basis, which have been obtained from PVGIS (0000).

Becker and Parker (2009) have stated that the words simulation and modeling used as synonyms, but they are not really the same thing; at least, not to those in the field bearing those words in its name. A simulation method was developed to study the temperature behavior of double façades (Von Grabe, 2002). The model accuracy was tested by using experimental data and the model accuracy was improved by modifying the flow resistance for several geometries. The performance simulation models of PV devices are also available in some existing software, such as PVsyst, PVWATTS, TRNSYS, PVFORM, INSEL, PHANTASM, P-Spice, PV-DesignPro, SolarPro, and PVcad (Ciulla et al., 2014; Lo Brano et al., 2012; Ma et al., 2014; Ishaque et al., 2011; Cameron et al., 2008; Al-Ibrahim, 1996).

Grid-connected rooftop solar PV power systems generate DC power direct from the sun's intercepted solar energy through solar PV modules. The solar PV modules are connected through a maximum power point tracker, to a grid-inverter, converting the generated DC power into AC Power, feeding the converted AC power into the public utility grid. If the grid-connected solar PV system is a roof-top system, it is often the case that the grid-connected solar PV system supplies first the power demands of the house the system is installed, selling the excess power to the local electricity provider (utility) at a defined feed-in tariff, paid by the utility company to the grid-connected solar PV system owner. Basic grid connected rooftop PV system shown in Fig. 1.

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.
- 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.
- Grid connection safety equipment like DC/AC breakers fuses etc., according to the local utility's rules and regulations.

Modeling of a yield simulation requires a large quantity of input data like solar irradiation, local weather conditions and other technical parameters of the planned PV systems (Huld et al., 2008). The level of accuracy needed for the energy yield prediction depends on the stage of project development. For example, a preliminary indication of the energy yield can be carried out using solar resource data and estimates of plant losses based on nominal values seen in existing projects (Huld et al., 2008). Photovoltaic software is widely used in the design of photovoltaic systems to calculate expected energy yield. Solargis PV Planner is one of the software that has the capability of Modeling Solar PV system (Kenny et al., 2006).

The present analysis is aimed:

- To describe and assess the solar resource potential at the given site.
- To perform simulation of 110 $\mathrm{kW_p}$ grid connected rooftop solar power plant using solargis PV Planner software.
- To determine annual energy yield and performance ratio of the PV system.
- To determine the best PV technologies for the building based on the simulation results.
- To provide a baseline information for energy and economic assessment of the PV generated electricity.

2. System description

The site selected for the study is based on institution campus located 10 km north of Bhopal, Madhya Pradesh India. The institution (MANIT, Bhopal) obtains its power from Madhya Pradesh electricity board public grid which is shared with other residential and industrial consumer. The site selected for the study is a residential Hostel Building with large space available on rooftop area (roughly 1065 m^2). The location and other site specific information are shown in Figs. 2, 3 and Table 2. The system description is given in Table 3 and total load consumption of Hostel building is listed in Table 1.

3. System modeling and performance evaluation

In PV Planner, photovoltaic power production is simulated using numerical models developed or implemented by Geo Model using aggregated data based on 15-min time series of solar radiation and air temperature data as inputs. The simulation itself is quite complex process. Fig. 4 shows the main steps involved in simulation.

Two parameters must be set before performing the PV simulation on the preselected site (Perez et al., 1992).

- Site Parameters: Provided by Solar GIS database (solar radiation parameters, air temperature parameters) and formulas implemented in Solar GIS system (sun path geometry).
- Technical Parameters: Provided by PV Planner user, otherwise default values are taken into consideration.