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Performance evaluation of a rooftop solar photovoltaic power plant in Northern India

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ABSTRACT

The rapid growth of electricity demand due to the increase in population has put the burden on the power stations of India to enhance their generation. With the serious drop in prices of solar photovoltaic (SPV) generated electricity and rising tariffs on conventional electricity have drawn attention to generate electricity through the solar photovoltaic plant. Therefore, it is important to assess accurately and precisely the annual and monthly yield of SPV plant to help in designing and installation of new plants. Performance analysis of a 5 kWp roof-top photovoltaic plant has carried out, and the effect of temperature analyzed. The annual average daily reference yield, array yield, and final yield found 5.23 kWh/kWp/day, 4.51 kWh/kWp/day and 3.99 kWh/kWp/day respectively. The annual average daily array efficiency, inverter efficiency and system efficiency found to be 11.34%, 88.38%, and 10.02% respectively. The annual average daily performance ratio and capacity utilization factor measured 76.97% and 16.39%. The annual energy yield of the plant recorded 7175.4 kWh. Results show that energy loss is maximum during May when the temperature is highest. The performance of the plant compared with PV plants installed all over in India and found comparable.

Introduction

In the 21st century, energy security is the primary goal of India. It is impossible to achieve this goal with conventional energy resources. The scarcity of conventional energy sources and environmental problems associated with them has emphasized to use renewable energy sources to fulfill the energy needs. Renewable energy sources will play a vital role in the nation's target to be energy secured. The solar photovoltaic energy systems can play a significant role to meet the present energy demand and contribute to the sustainable development. In the Indian context, solar photovoltaic conversion technology is preferred over other renewable energy technologies due to availability and intensity of solar radiation. India receives 4–7 kWh/m^2 per day with an annual radiation ranging from 1200 to 2300 kWh per square meter. It has an average of 250–300 clear sunny days and 2300–3200 h of sunshine per year (Kapoor, Pandey, Jain, & Nandan, 2014). Therefore, SPV systems provide the opportunity for individual as well as industrialist to generate the electricity through solar energy.

The Government of India has taken several initiatives to the development of the solar sector in which JNNSM is the milestone. The Jawaharlal Nehru National Solar Mission (JNNSM) under the brand 'Solar India' was launched in 2010 with the aim of achieving grid parity by the year 2022. It proposed at the deployment of 20,000 MW of grid-connected and 2000 MW of off-grid solar power during the three phases (first phase up to 2012–13, second phase from 2013 to 2017 and the third phase from 2017 to 2022) of its operative period (JNNSM, 2008). The Central Government of India has increased the target of the JNNSM to 100 GW to be obtained through grid-connected projects, off-grid projects and solar parks of 2022 (PIB, 2015). Therefore, many stand-alone and grid-connected solar photovoltaic systems have been installed and being installed rapidly to meet the target all over India. It is necessary to assess all performance parameters of installed PV plant precisely for the choice of technology, project development and viability of a new project for a location.

The main problem of the PV system is to capture sunlight efficiently and convert it into electricity. When solar photovoltaic module operates into the real environment, its output characteristics vary compared to standard test conditions (1000 W/m^2 irradiance, 1.5 AM and 25 °C temperature). The output power of a SPV module is affected by local climatic parameters (temperature, wind, humidity, dust deposition, etc.) and geographical factors (latitude, longitude, etc.). Essentially, the performance of plant is affected by the temperature. The efficiency of SPV modules reduces with the increase of ambient temperature. The International Energy Agency PVPS-Task 2 group has analyzed the performance of 18 selected grid-connected PV systems of different mountings (free standing, roof-mounted and integrated PV facades) from the different geographic site in five countries. To see the temperature effect on the systems, the group has used annual datasets of hourly data 17 out of 18 systems. Datasets showed an annual temperature loss ranging from

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1.2 to 10.3%. The annual average daytime temperature for all the PV systems is between 2 and 21 °C. A well-cooled PV array can have a temperature rise of about 25 K at 1000 W/m^2 and a temperature loss of less than 4% (Nordmann & Clavadetscher, 2003).

Another study performed in Italy, the campus of the University of Salento to know the effect of climatic parameters on the performance on installed PV system in a particular geographical area. A 960 kWp photovoltaic system divided into two subfields with different tilt angle (3–15°) and different nominal powers (353.3 kWp and 606.6 kWp). The values of performance parameters like final yield, reference yield, PV system efficiency, performance ratio (PR) and cell temperature losses were analyzed. The study concluded that the PV system efficiency varies between the highest value of 17% in spring to the lowest value of 15% in summer, and the PR rises at the maximum point of 86.5% in March to the minimum point of 79% in June. The cell temperature losses were reported to a minimum of 3.5% in October to a maximum of 8% in June (Congedo, Paolo, Malvoni, & De Giorgi, 2013).

Vasisht, Srinivasan, and Ramasesha (2016) calculated the effect of temperature variation on the performance of a 20 kWp grid-connected SPV plant for different seasons throughout the year. In summer, as module temperature rises above 45 °C module efficiency reduces by 0.08% per degree rise in temperature. In monsoon, for module temperature rises 35 °C, module efficiency reduces by 0.04% per degree rise in temperature. In post-monsoon module's efficiency reduces by 0.06% per degree rise temperature when module temperature increases than 38 °C. However, in winters, module temperature is 55 °C but the minimum drop in efficiency recorded due to the cool breeze and low ambient temperatures.

In this present study, the performance of a 5 kWp rooftop grid-connected solar power plant is evaluated based on normalised parameters like reference yield, array yield, final yield, PV module efficiency, inverter efficiency, system efficiency, performance ratio and capacity factor using monitored data for the year 2015. Calculated results give a detailed information of system performance and provide a source for the techno-economic development of a new project. The effect of temperature on the performance of the plant is also observed in different seasons throughout the year. Here, the present study reveals the annual behavior of PV system with concerning operating temperature. The performance of plant is also compared to the other plants installed all over India.

The SPV system specification

The experimental analysis conducted in the Centre of Excellence in Renewable Energy Education and Research located at the New Campus of the University of Lucknow. It situated on 26.30 and 27.10 North latitude and 80.30 and 81.13 East longitude. Lucknow's weather can be broadly divided into four seasons winter (Dec–Feb), summer (Mar–June), monsoon (July–Sep) and post-monsoon seasons (Oct–Nov). To reduce the consumption of conventional electricity and fulfill the demand through clean electricity, state nodal agency UPNEDA (Uttar Pradesh New and Renewable Energy Development Agency) has installed a SPV plant to the University of Lucknow, which is a 5 kWp solar photovoltaic power plant on the building roof of the Centre of Excellence in Renewable Energy Education and Research (Fig. 1). The funding of the project has been from the Ministry of New and Renewable Energy, Government of India. All generated electricity fed into the centre's load. The plant has grid connection to fulfill the energy demand in the absence of solar radiation and supply electricity to the load during the excess requirement of electricity in some special occasions.

The solar photovoltaic power plant consists an array of 20 solar photovoltaic modules manufactured by Sova Power Limited-SS250P. PV array covers an area of 38.4 m^2 with 1.92 m^2 single module area. Each module comprises 72 polycrystalline silicon series connected solar cells with area 202.8 cm^2. The modules are oriented toward the south direction at the tilt angle of 26.5° (latitude of Lucknow) to receive the maximum solar radiation. Array consist four series connected modules form a string and these strings arranged in parallel, which attached to a junction box. The output of junction box connected to MPPT based inverter also called Power Conditioning Unit (PCU), which converts DC to AC to match load demand. It provides uninterrupted power to the load using solar and grid input in same order of priority. The PCU had 90.0% rated efficiency with 5 kVA maximum AC power. PCU consists latest Digital signal processor (DSP) based pure sine wave inverter, which provides continuous pure sine wave power to the load (Fig. 2).

Data logging

A weather data logging station installed near the plant, which records solar radiation, temperature, relative humidity, wind speed and direction, rainfall, atmospheric pressure, and soil moisture data

Fig. 1. Satellite view of location of 5 kWp rooftop SPV array.