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Performance evaluation and validation of 5 MW_p grid connected solar photovoltaic plant in South India

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ABSTRACT

The main objective of this paper is to present the validated annual performance analysis with the monitored results from a 5 MW_p grid connected photovoltaic plant located in India at Sivagangai district in Tamilnadu. The total annual energy generated was 8495296.4 kW h which averages around 707941.4 kW h/month. In addition to the above, real time performance of the plant is validated through system software called RETscreen plus which employs regression analysis for validation. The measured annual average energy generated by the 5 MW_p system is 24116.61 kW h/day which is appropriately close to the predicted annual average which was found to be 24055.25 kW h/day by RETscreen. The predicted responses are further justified by the value of statistical indicators such as mean bias error, root mean square error and mean percentage error. The annual average daily array yield, corrected reference yield, final yield, module efficiency, inverter efficiency and system efficiency were found to be 5.46 h/day, 5.128 h/day 4.810 h/day, 6.08%, 88.20% and 5.08% respectively. The overall absolute average daily capture loss and system loss of the particular system under study is 0.384 h/day and 0.65 h/day respectively. A comparison is also made between the performance indices of solar photovoltaic system situated at other locations from the literature's published. Furthermore the effect of input factors over the output of the system is emphasized by regression coefficients obtained through regression analysis. In-depth analysis dealing with energy and exergy of the system are also included to strengthen the study.

1. Introduction

The trend for India's energy consumption out of conventional sources is found to increase with increased industrialization and civilization aspects of the society (see Fig. 1).

The total consumption of energy from conventional sources in India increased from 46,958 petajoules during 2011–2012 to 50,741 petajoules during 2012–2013, showing an increase of 8.06%. The per capita energy consumption increased from 3497.59 kW h in 2005–2006 to 6748.61 kW h in 2012–2013 with a cumulative annual growth rate of 8.56% and an annual increase of 8.76%. The estimated electricity consumption for various sectors such as domestic, commercial, agriculture, industry, traction and railways increased from 411,887e^6 kW h during 2005–2006 to 852,900e^6 kW h during 2012–2013, showing a cumulative annual growth rate of 9.53%. The percentage increase in electricity consumption for an annual period of 2012–2013 is 8.62% [1]. Thus the increasing demand and scarcity in conventional sources has triggered the scientist to pave way for the development of research in the field of renewable energy sources especially solar energy [2]. India is a tropical country located along the equatorial belt of the earth with latitude lying between 7° and 37° which makes it to receive enormous radiant power. There are about 300 clear sunny days in most parts of the country per year with an average global insolation of 4–7 kW h/m^2/day [3]. Due to the vast solar potential, the nation had eight initiatives launched under National action plan on climate change addressing the remedies for balancing the energy generation and demand. One of such initiative was Jawaharlal Nehru National Solar mission (JNNSM) set from January 2010 to deploy 20,000 MW of grid connected Solar power by 2020 [4]. India has installed solar photovoltaic (PV) projects of capacity amounting to 2208 MW out of which Tamilnadu contributes 31 MW.

The International Energy Agency (IEA), under photovoltaic power systems programme (PVPS) have framed a series of 13 tasks [5] for the outreach of operation, performance and monitoring solar photovoltaic plants under the platform of research and development. As India, not being a member of an International Energy agency, the studies and discussions on solar photovoltaic power

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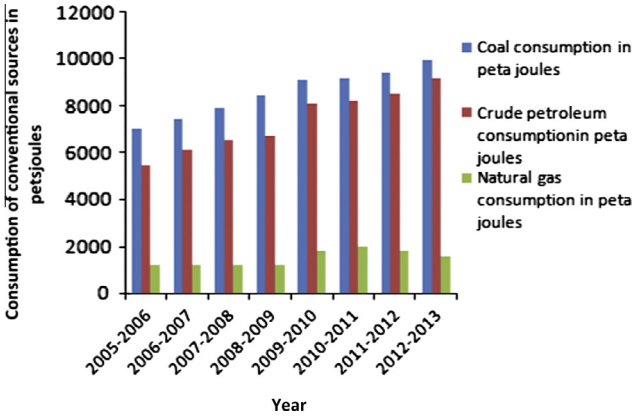

Fig. 1. Energy consumption from conventional sources in India.

plants as per IEC 61724 standard is not available [6] and hence it becomes imperative to document the performance of PV systems for knowing its efficient operation. Also successful integration of PV system includes knowledge on their operational performance under varying climatic condition [7]. Monitoring input parameters for performance study yields several advantages such as optimal sizing and survival of the plant. Monitoring global horizontal irradiance (GHI) and ambient temperature helps us to predict the energy output making the idea of installation over the locality stronger. Monitoring module temperature helps us to quantify the thermal losses of the PV array system which thereby affects the energy and the exergic efficiency deliberately affecting the generated output power. Moreover the study on performance of the plant helps in identifying the operational uncertainty (weather risk involving variation in weather and system risk which involves aspects of inverter conversion and control) which helps in improving the yield. Also annual average analysis extends itself in developing a theoretical model for predicting the daily average power generated from the system which forms the hot topic of current research. Additionally the storage of electricity is not required in a grid tied plat as the electrical energy generated is fed to the grid with ease of installation, operation and maintenance with less payback period. Hence grid connected photovoltaic (PV) plant is focussed in this analysis. Long term annual average analysis results in the incorporation of seasonal variation such as rainfall, frost, snow and intermittent problems occurring with balance of system which is absent in short term performance analysis occurring for less than a year.

The studies regarding the performance analysis of grid interactive photovoltaic plants in literatures deal with the evaluation of performance indicators. Some concrete literatures involving annual analysis are as follows. Drif [8] studied the performance characteristics of a 200 kW_p grid connected PV system during 2000–2003. In 2011 Ayompe [9], conducted a performance study on 1.7 kW_p roof top grid connected plant during the year 2008–2009. He has deduced the performance indicators and compared the same with the reported results. Furthermore, Padmavathi and Arul Daniel [6] analyzed the performance of 3 MW_p grid connected PV plant in Karnataka. Vikrant and Chandel [10], carried out a performance analysis of 190 kW_p plant and validated its performance using PVsyst. In 2014 Trillo-Montero [11] developed a software employing visual basic express for evaluating the system losses and the performance of two different plants of installed capacity 217.6 kW_p and 17.8 kW_p.

This study hence aims to analyze the performance of 5 MW_p grid connected photovoltaic system in Sivagangai, India. Besides performance evaluation it differs from other literatures as cited above, by employing a simulation software called renewable energy and energy efficient technologies, RETscreen for performance validation. RETscreen developed by the Government of Canada is used to validate the ongoing energy performance of energy systems. As the concentration on solar power projects brings out considerable support by the Government, a 5 MW_p solar plant was set up at Sivagangai by Moserbaer Corporation with the aid of Government of Tamilnadu in 2010 in order to export the power generated by the solar PV panels to the southern grid.

2. System, measurements and application

The inputs for the performance analysis is derived from the operational condition of the 5 MW_p solar photovoltaic plant situated at about 8 km from Sivagangai in Rettaipalyam village with latitudinal and longitudinal ranges of 9.47°–9.48°N and 78.26°E–78.27°E with an altitude of 102 m above the sea level. Sivagangai is located in the southeastern coast and is bounded by Madurai district on western side, Pudukkottai district on northern side and Ramanathapuram district on southern side. The annual average in-plane solar insolation for the 5 MW_p site at Sivagangai is around 5.4149 kW h/m^2/day which is measured by employing CMP11 pyranometer which has the sensitivity ranging from 7 to 14 μV/W/m^2. The balance of system and its single line schematic is shown in Fig. 2.

2.1. PV array

The modules installed were thin film modules manufactured by Moserbaer from an indigenous technology. A total of 61,020 PV modules of varying peak power capacity ranging from 76 W_p to 86 W_p were arranged amounting to peak power rating of 5 MW_p. The power generation is segmented into 5 sections each contributing 1 MW_p. Each MW_p was formed from 226 array junction boxes (AJB), 33 sub main junction box (SMJB) and 8 module junction box (MJB). This arrangement repeats consecutively to form 5 MW_p. There were 5 control rooms for monitoring the power delivered by the set of module junction boxes. The modules are predominantly south oriented, tiltled at an angle of 10°. The ambient and module temperature are monitored by Vaisala weather transmitter.

2.2. Power conditioning unit

There were 10 numbers of inverter each of 500 kW capacity ensuring the conversion of 5 MW_p DC to AC. Each power conditioning unit is supplied by 4 module junction boxes capable of generating power of 500 kW_p. Thus a set of 2 power conditioning units form a segment of 1 MW_p power generation. The energy generated by the inverter is measured by the energy guard sensor manufactured from Skytron and the data is transmitted through a RS485 data bus.

2.3. Power evacuation

The inverter output is fed to 1250 kVA, 270/11 KV, 50 Hz transformer for stepping up the voltage to 11 kV. There were 5 transformers of 1250 kVA which was capable of handling the generated power. The total power output from the five transformers are fed to a main transformer of 6.3 MVA, 11 kV/110 kV, 50 Hz which further steps up of voltage for the Tamilnadu Electricity Board (TNEB) grid export. The power exported to the grid is monitored by a metering cubicle supplied by the TNEB.

2.4. Data monitoring system

The solar photovoltaic plant runs for all working days except for exceptional technical faults interrupted the system. The data