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Performance study on a grid connected 20 kW_p solar photovoltaic installation in an industry in Tiruchirappalli (India)

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ABSTRACT

This paper discusses the details and results obtained from a study carried out on a roof top 20 kWp solar photovoltaic (PV) power plant in a reputed manufacturing industry in India. Although there is plenty of sunshine, various financial supports and government policies, the growth of photovoltaic (PV) power plants in developing countries is still facing significant barriers due to unclear techno-economic aspects of the PV power plant. Therefore this paper highlights a few salient features of the installation, operational performance and economic calculations of a grid connected solar photovoltaic (PV) power plant. A few important aspects of solar power plant installation such as the feasibility of location in terms of geographical data, solar panel mounting design, interfacing aspects of PV system with grid are outlined. The results obtained from the study such as month wise energy generation, performance ratio, capacity factor, maintenance aspects, economic analysis, etc. of the system are discussed in detail. The study enables researchers and engineers in this area to understand roof top solar PV power plant and its economic viability. It is expected that this study will encourage and provide guidance to industries in this region to set-up similar PV power plants.

Introduction

The role of new and renewable energy has been assuming increasing significance in recent times with the growing concern for energy security throughout the world. Energy self-sufficiency was identified as the major driver for new and renewable energy in India. The Jawaharlal Nehru National Solar Mission was launched on the 11th of January, 2010 by the Prime Minister (JNSM, 2012) with the ambitious target of deploying 20,000 MW of grid connected solar power by 2022. It is aimed at reducing the cost of solar power generation in the country through (i) long term policy; (ii) large scale deployment goals; (iii) aggressive R&D; and (iv) domestic production of critical raw materials, components and products.

Bharat Heavy Electricals Limited (BHEL) Tiruchirappalli, India is one of the leading boiler manufacturers in the world and India's largest engineering and manufacturing enterprise providing total boiler island solutions for utility, industrial, captive power and heat recovery applications (Forbes Lists, 2012). The company also manufactures valves for power and industrial applications, soot blowers and seamless steel tubes. The manufacturing facilities are comparable with the best in the world with modern design, engineering, material preparation, fabrication, welding, heat treatment, handling, testing and shipping facilities.

BHEL has planned to set up solar photovoltaic (PV) power systems in its campus to generate clean electricity without emitting CO_2, SOX, NOX, etc. It is imperative to study the economic analysis of such plants before setting up any major PV power plants (Garcia Valverde et al., 2009; Ravindra et al., 2009). In order to evaluate the performance of PV power systems in BHEL, a trial project was carried out as per the guidelines of the Ministry of New and Renewable Energy (MNRE), India. A 20 kW_p grid connected PV power system has been installed at BHEL in Dec 2012. This is the first of its kind in Tiruchirappalli district. The main aim of the set-up is to study the economic feasibility and environmental impacts of the system for further implementation of the PV systems at BHEL campus. The following sections discuss the location information of the project, construction details of the PV power system, operation of the power conditioning unit, characteristics curve of solar PV module and performance and maintenance aspects of the PV power system.

Location information

The geographical information of the location is discussed in this section. BHEL is located in the plains of Tiruchirappalli district of Tamilnadu, India. The area is hot and dry for about eight months of the year. The geographical data and general conditions of the location are presented in Table 1 (Gaisma, 2012). The hottest months are from March to July, during which the days are extremely warm and dry.

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Table 1
Geographical data of Tiruchirappalli.

Description	Value
Latitude	+10° 44′ 32″
Longitude	+78° 47′ 30″
Elevation	88 m
Heating design temperature	20.35 °C
Cooling design temperature	32.91 °C
Earth temperature amplitude	12.26 °C
Frost days at site	Nil

From August to October, the climate is moderate with some thundershowers and from November to February the climate is cool and pleasant. The annual data of solar irradiance, temperature, and humidity of the location obtained from NASA Langley Research Center (NASA, 2012) is presented in Table 2. From this table, the average solar irradiation of the location is found to be 5.21 kWh/m2/day, which is a fair value for PV power generation comparing other sites with the largest PV power plants given in Appendix-2.

The clearness index of the site (Gaisma, 2012) is shown in Fig. 1. The clearness index is the fraction of insolation at the top of the atmosphere which reaches the surface of the earth. This value is near zero during over cloudy conditions and closer to 0.6 for fully bright sunny days. This figure shows that most months in the year, there is sufficient solar insolation in the proposed location. Fig. 2 shows the location's sunrise, sunset, dawn and dusk times for the whole year in Tiruchirappalli. It is evident from this figure that almost 12 h per day in the whole year, sunlight is available in the region. To be specific, consider 18th Dec 2012: dawn begins at 06:04 h; the sun rises at 06:27 h and sets at 17:57 h. Dusk ends and darkness begins at 18:20 h. The length of the day is 11 h and 30 min. The data in Tables 1 and 2 together with the information available from Figs. 1 and 2 indicate that Tiruchirappalli is a very suitable location for PV systems.

Details of the PV power system

This section explains the mounting of PV array, layout of the PV modules and single line diagram of the system.

Mounting of PV modules

The proposed location has latitude of 10.8° and hence the mounting structures for PV modules are to be erected accordingly. The modules were erected on the rooftop (Dominguez et al., 2011) of the office annex of integrated production shop in BHEL complex. The PV panels were mounted on G.I. structures forming four strings with 22 modules each. All the 88 modules were erected over a flat roof area of 150 m^2 and installed at an inclined angle of α degree facing north–south direction, where α is the latitude of the location. The floor is approximately 12 m high and the mounting structure is about 1.5 m high. The schematic of the panel mounting structure is shown in Fig. 3.

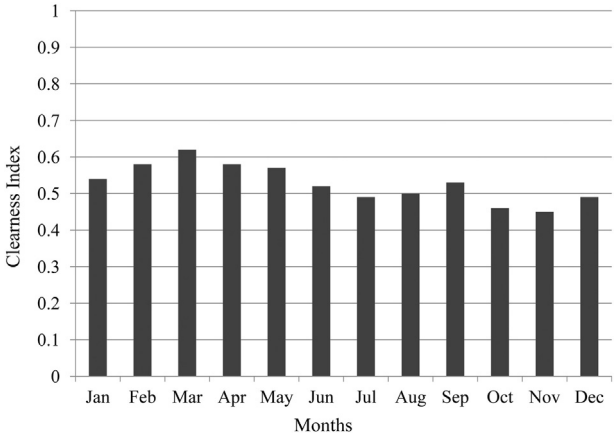

Fig. 1. Clearness index of the location.

Layout of the system

The general structural layout of the panels on the rooftop is shown in Fig. 4. About one meter clearance from the side walls was given and seven meter clearance was given from the southern boundary walls to avoid shadows of the adjacent building wall falling on the panels. A photograph of the installation is shown in Fig. 5.

Single line diagram

The 20 kW_p system is divided into four strings with an average PV output voltage of about 600 V in loaded condition. The outputs of the four strings are pooled in the array junction box (AJB) through DC breakers. A surge protector is incorporated in the system for transient protection. The output of the AJB is brought into the control room and to a DC distribution box (DCDB), where the power is trifurcated and fed to the power conditioning unit (PCU). The 20 kW Powerone Microsystems PCU, consisting of filters, maximum power point tracking (MPPT) system, inverter and control units, was used to convert the PV power to three phase-four wire, 415 V ± 5%, 50 Hz ± 3% AC power and to synchronize it with the grid. The output voltage and frequency of the inverter will follow the grid voltage and frequency during its normal operation. A single line diagram of the set-up is shown in Fig. 6.

Table 2
Surface meteorology of Tiruchirappalli.

Month	Atmospheric temperature °C	Relative humidity %	Daily solar radiation kWh/m^2/day	Wind speed m/s	Earth temperature °C
Jan	24.6	68.90	4.74	2.2	26.4
Feb	26.1	62.40	5.74	2.7	29.5
Mar	27.6	60.50	6.47	2.8	32.2
Apr	27.2	74.50	5.94	3	30.2
May	27.2	77.10	5.81	3.1	29
Jun	27.3	71.40	5.29	3.2	29.1
Jul	27.3	68.50	5.02	3.1	29.3
Aug	27.4	67.90	5.17	2.9	29.7
Sep	27.2	70.50	5.39	2.6	29.4
Oct	25.9	77.70	4.58	2.4	27.1
Nov	24.9	78.80	4.09	2	25.4
Dec	24.4	74.70	4.22	2.2	24.9
Average	26.4	71.10	5.21	2.7	28.5

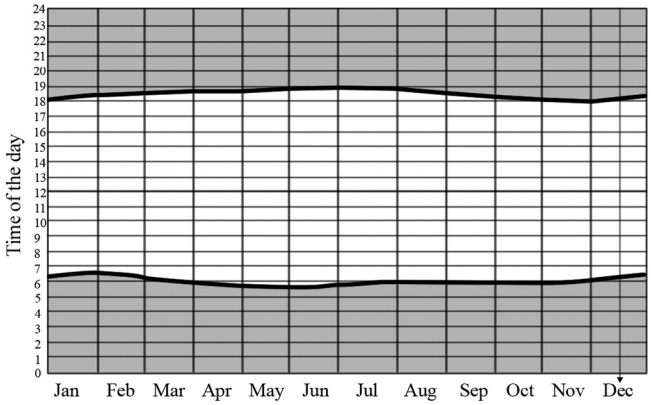

Fig. 2. Sun rise, sun set, dawn and dusk times.