PERFORMANCE EVALUATION OF 100 KWP GRID CONNECTED SOLAR PHOTOVOLTAIC POWER PLANT IN INDIA

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Abstract: The growing energy demand in developing nations has triggered the issue of energy security. This has made essential to utilize the untapped potential of renewable resources. Grid connected PV systems have become the best alternatives in renewable energy at large scale. Performance analysis of these grid connected plants could help in designing, operating and maintenance of new grid connected systems. A 100 kWp photovoltaic grid connected power plant commissioned at J.B Institute of Engineering and Technology, Hyderabad, Telangana is one of the largest solar power plants with the site receiving a good average solar radiation of 4.97 kW h/m^2/day and annual average temperature of about 27.3 degrees centigrade. In this study the solar PV plant design aspects along with its annual performance is elaborated. The various types of power losses (temperature, internal network, power electronics, grid connected etc.) and performance ratio are also calculated. The performance results of the plant are also compared with the simulation values obtained from PV syst and PV-GIS software. The final yield (Y_F) of plant ranged from 1.96 to 5.07 h/d, and annual performance ratio (PR) of 86.12%. It has 17.68% CUF with annual energy generation of 142.14 MW h/Annum.

Keywords: Photovoltaic SCADA system PV syst software SolarGIS-pv planner Performance ratio.

1. INTRODUCTION

Increasing demand and scarcity in conventional sources have triggered the scientist to pave way for the development of research in the field of renewable energy sources especially solar energy (Goura, 2015).

India has tremendous scope of generating solar energy. The reason being the geographical location and it receives solar radiation almost throughout the year, which amounts to 3000 h of sunshine. This is equal to more than 5000 trillion kW h. Almost all parts of India receive 4–7 kW h of solar radiation per sq meters (Sudhakar et al., 2013). India has an ambitious plan to build large grid-connected solar power plants, with a cumulative installed capacity of 20,000 MW by 2020, under the National Solar Mission (Ministry of New and Renewable Energy, 2014).

Photovoltaic modules or panels are made of semiconductors that allow sunlight to be converted directly into electricity. These modules can provide you with a safe, reliable, maintenance-free and environmentally friendly source of power for a very long time. A successful implementation of solar PV system involves knowledge on their operational performance under varying climatic condition (Makrides et al., 2010).

A 5 MW SPV power plant was designed (Besarati et al., 2013) for 50 cities of Iran, using RET screen software and the highest capacity factor was found at Bushier and lower at Anzali, i.e. 26.1% and 16.5% respectively with a mean capacity factor of 22.27%.Elhodeiby et al. (2011) presented a performance analysis of 3.6 kW Rooftop grid connected solar photovoltaic system in Egypt. The system was monitored for one year and all the electricity generated was fed into the 220 V, 50 Hz low voltage grid to the consumer.

Studies (Pavlovic et al., 2013) were conducted in Serbia to find out possibilities of generating electrical energy through 1 MW PV power plants by taking different types of solar PV modules available and it was concluded that higher electricity is generated using CdTe solar modules.

The International Energy Agency (IEA), under photovoltaic power systems programme (PVPS) have framed a series of 13 tasks for the outreach of operation, performance and monitoring of 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 plants as per IEC 61 724 standard are not available (IEA, 2014). Hence, it is essential to document the performance of the large-scale grid-connected solar power plant installed in India.

The performance of 10 MWp grid connected solar photovoltaic power plant is carried out in this work with the following objectives.

(1) To study the seasonal variations in PV plant output from the monitored SCADA data system.
(2) To evaluate the technical performance through estimation of annual energy yield, array yield, reference yield and system losses.
(3) To compare the actual performance data with the simulated data of PVSYST and Solar GIS.

2. DESCRIPTION OF THE SOLAR PV-GRID SYSTEM

A grid-connected PV system consists of solar panels, inverters, a power conditioning unit and grid connection equipment. It has effective utilization of power that is generated from solar energy as there are no energy storage losses. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load to the utility grid. But, in stand- alone systems batteries are used to store energy or else energy has to be directly connected to load (see Fig. 1).

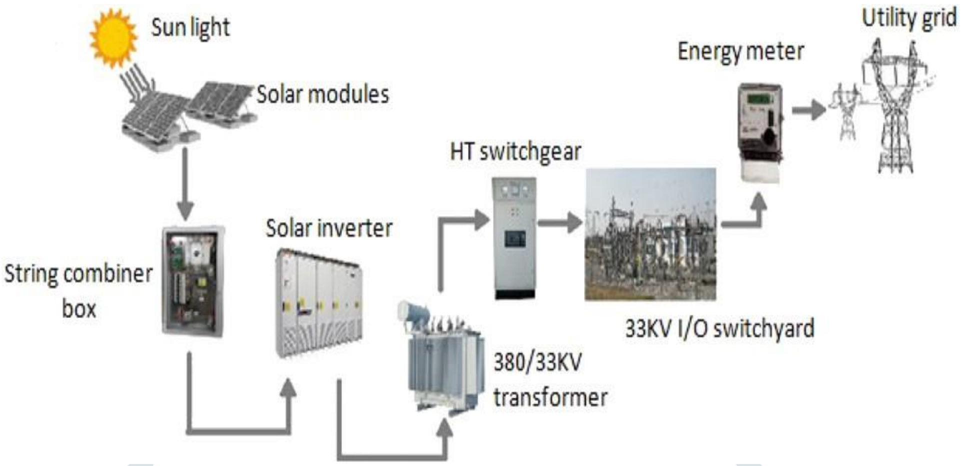


Fig. 1. Schematic diagram of JBIET 100 kWp solar plant.

Geographical location of the site

The JBIET 100 kWp solar power plant is located at a longitude of 78.27" E, latitude 17.24" N and at an altitude of 548 m. The Fourth Partner Energy Limited opted this site for their construction of its 100 kWp Solar Plant as it located at geographically good location where it can absorb more solar radiation for the entire year as power generated by solar plant completely depends upon its sun's insolation.

Plant layout

The total rating of the plant is 100 kWp occupied over 540 of land. This plant area is divided into three different blocks with each two equal blocks. Each individual block has the generating capacity of about 33 kW thus total of six blocks combined to form a 100 kWp generation capacity. Each block of solar panels consists of about 6 strings each and a total of 18 strings.

These large numbers of solar panels in single block are again divided into two blocks of strings. Each string consists of 24 solar panels connected in series and about 6 of these strings are connected in parallel to a single inverter through a main string combined box. Three phases double fed primary winding transformer is used. Converted AC power from the two inverters is fed to these two primaries of the transformer. Each string consists of 24 modules in that way 6 strings are connected to one string combined box (SCB). Total 3 SCB'S are connected to one main string combined box (MSCB'S). Each inverter is connected with one main string combined box. Total 3 inverters are connected to one transformer . The output of transformer is connected directly to 33 kV grid (see Fig. 2).

The plant is installed in such a way that it is cost effective, more reliable, and more energy output. During nights when there is no power generation due to lack of solar radiation, the power is taken back from grid for internal power requirement. The power is utilized for lighting, initial starting of the batteries, control room appliances.

Tilt angle

The tilt angle of the PV array is kept as equal to the latitude of the corresponding location to get maximum solar radiation (Labed and Lorenzo, 2004). moderate tilt angle of 18.75° is provided. The tilt angle is considered according to the geographical location of the plant.

Specification of solar panel

The solar panels mounted at JBIET 100 kWp solar power plant are of 250w_P rating and made up of polycrystalline. These panels have an efficiency of 14.06% and are of fixed type. Polycrystalline panel ratings are open circuit voltage (V_{OC}) of 36.42 V and short circuit current (I_{SC}) of 8.09 A. It has a maximum operating temperature of 43.2° centigrade. The solar panels are installed in such a way that structure to structure and leg center to center distance is at 4 m. The distance between panels (Panel to panel) is of 25 mm. Distance between grounds to lower edge of the module is 400 mm. To have a better yield panels are cleaned twice in a month.

Power conditioning units

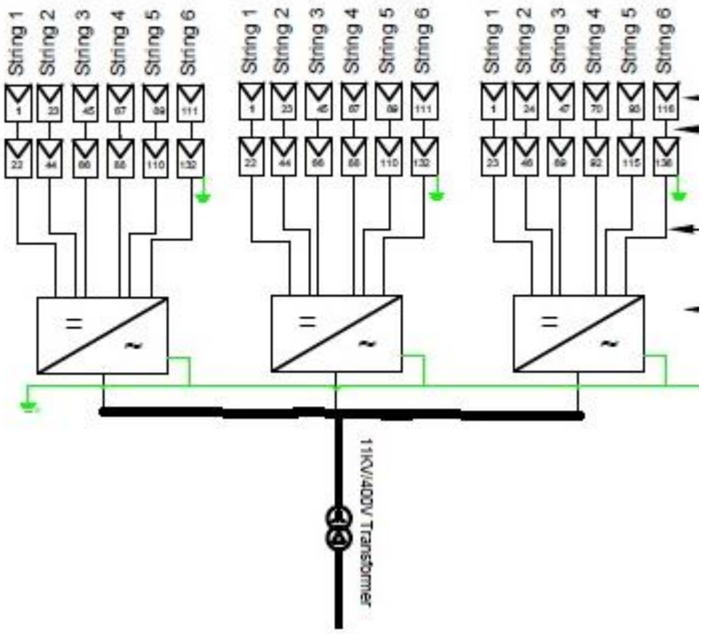
Inverter converts DC power into AC power. The inverter power rating is 33 kW. PV voltage of 874 V and supply DC current 845 A is fed as input to inverter. The output AC voltage and current from inverter are 350 V and 1040 A respectively. The output of the inverter is synchronized automatically with same voltage and frequency as that of grid.

3. METHODOLOGY FOR PERFORMANCE ANALYSIS OF THE PV SYSTEM

The performance of grid connected solar photovoltaic power plant work in this paper is divided in three stages.

(1) Manually extract the parameters of power generation through SCADA system.
(2) Compare the performance with the PVSYST software.
(3) Compare the performance with the Solar GIS.

The performance parameters are developed by International Energy Agency (IEA) (Ayompe et al., 2011) for analyzing the performance of solar PV grid interconnected system. Many performance parameters are used to define the overall system performance with respect to the energy production, solar resource and overall effect of system losses. The various parameters are the performance ratio, final PV system yield and reference yield.



Array yield

It is equal to the time which the PV plant has to operate with nominal solar generator power P_o to generate array DC energy Ea. Its units are kW h/$d*$kW p.

$$Y_A = E_A/P_O$$

where, Array energy output per day $E_A = I_{dc} * V_{dc} * t$ (kW h),

I_{dc} = DC current (A)
V_{dc} = DC voltage (V)
P_0 = Nominal Power at STC.

Reference yield

The reference yield is the total in-plane irradiance H divided by the PV's reference irradiance G. It represents the under ideal conditions obtainable energy. If G equals 1 kW/m^2, then Yr is the number of peak sun hours or the solar radiation in units of kW h/m^2. The Yr defines the solar radiation resource for the PV system. It is a function of the location, orientation of the PV array, and month-to month and year-to-year whether variability.

Its units are h/d.

$$Y_R = [\text{kW h/m}^2]/1 \text{ kW/m}^2.$$

$$Y_R = H_t/G_o$$

where,

H_t = Total Horizontal irradiance on array plane (Wh/m^2),
G_o = Global irradiance at STC (W/m^2).

Final yield

The final yield is defined as the annual, monthly or daily net AC energy output of the system divided by the peak power of the installed PV array at standard test conditions (STC) of 1000 W/m^2 solar irradiance and 25 °C cell temperature. Its units are kW h/d∗kW p.

$$Y_F = E_{PV,AC} / P_{maxG,STC}\,.$$

Performance ratio

The performance ratio is the final yield divided by the reference yield. Performance ratio can be defined as comparison of plant output compared to the output of the plant could have achieved by taking into account irradiation, panel temperature, availability of grid, size of the aperture area, nominal power output, temperature correction values.

$$PR = Y_F/Y_R.$$

Capacity utilization factor

It is defined as real output of the plant compared to theoretical maximum output of the plant.

CUF = Energy measured (kW h)/(365 ∗ 24 ∗ installed capacity of the plant).

Inverter efficiency

The inverter efficiency appropriately called as conversion efficiency is given by the ratio of AC power generated by the inverter to the DC power generated by the PV array system. The instantaneous inverter efficiency is given by,

$$\eta_{inv}=P_{AC} / P_{DC}\,.$$

System efficiency

The instantaneous daily system efficiency is given as PV module efficiency multiplied by inverter efficiency.

$$\eta_{sys,T} = \eta_{PV,T} * \eta_{inv,T}\,.$$

Energy output or energy fed to utility grid

The energy generated by the PV system is the measure of energy across the inverter output terminals for every minute. It is defined as the total daily monitored value of AC power output and the monthly AC energy generated.

Specific plant losses

Energy losses occur in various components in a grid connected SPV Power plant under real operating conditions. These losses are evaluated using the monitored data.

Arrays capture losses (L_C):

These are of two types.

- Thermal capture loss (L_{CT}): Losses caused by cell temperature higher than 25 °C are called thermal losses. Thermal capture loss (L_{CT}) is the difference between reference field and corrected reference field.

- Miscellaneous capture loss (L_{CM}): Losses that are caused by wiring, string diodes, low irradiance, partial shadowing, mismatching, maximum power tracking errors, limitation through dust, losses generated by energy conduction in the photovoltaic modules

$$L_{CT} = Y_R - Y_{CR}$$

$$L_{CM} = Y_{CR} - Y_A$$

$$L_C = Y_R - Y_A.$$

System losses (L_S)

These losses are caused by inverter, conduction and losses of passive circuit elements.

$$L_S = Y_A - Y_F.$$

Data monitoring

A common weather monitoring station located next to the plant records the wind speed, ambient temperature and solar radiation data. A dedicated server with the principle of supervisory control and data acquisition (SCADA) for assessment of the monitored data is also present. The server records the data of voltage, current, power factor, power output of inverters for each and every minute. It also records the solar irradiance, wind speed and ambient temperature data received from automatic weather station. The server collects the data from measuring sensors and at the outgoing side of the inverters through bus. It transfers the data files periodically and the server retrieves the data. Server along with the SCADA software is located in a control room

4. RESULTS AND DISCUSSION

Solar irradiance vs. peak power output

Solar irradiance absorbed by solar modules is converted to useful power. The power output varies with the solar insolationand an ambient temperature. A typical day result is shown in Fig. 3 to understand the effect of irradiance and Temperature on power output of the system.

As, the temperature increases the power output decreases up to some extent even if there is good amount of radiation. Also, with increase in temperature, the power generation decreases slightly even when there is constant solar irradiance. The trend can be clearly observed from the Figure

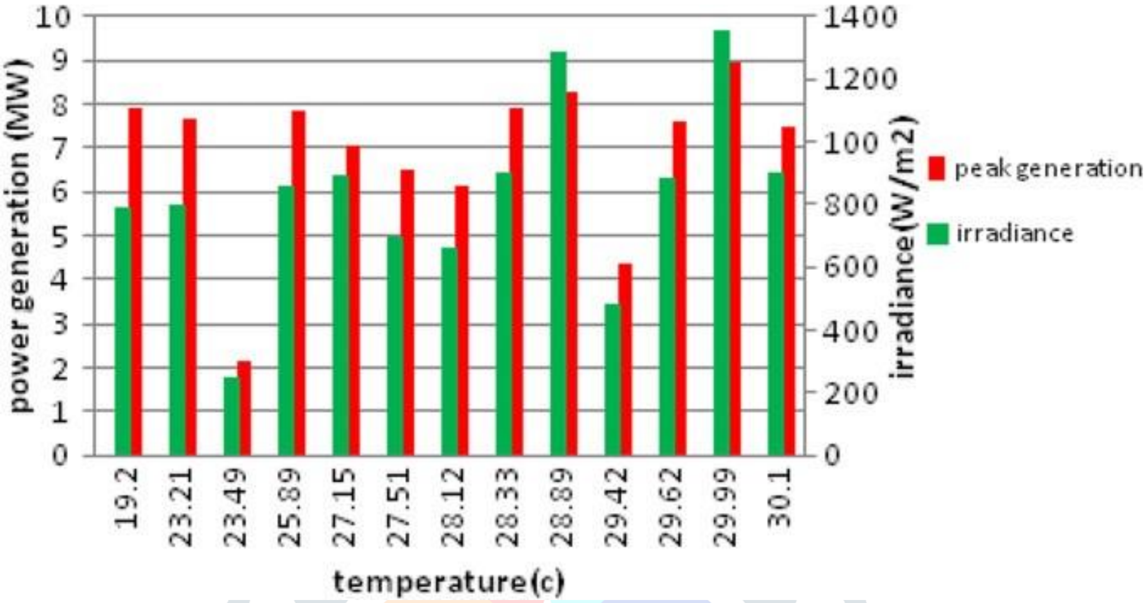
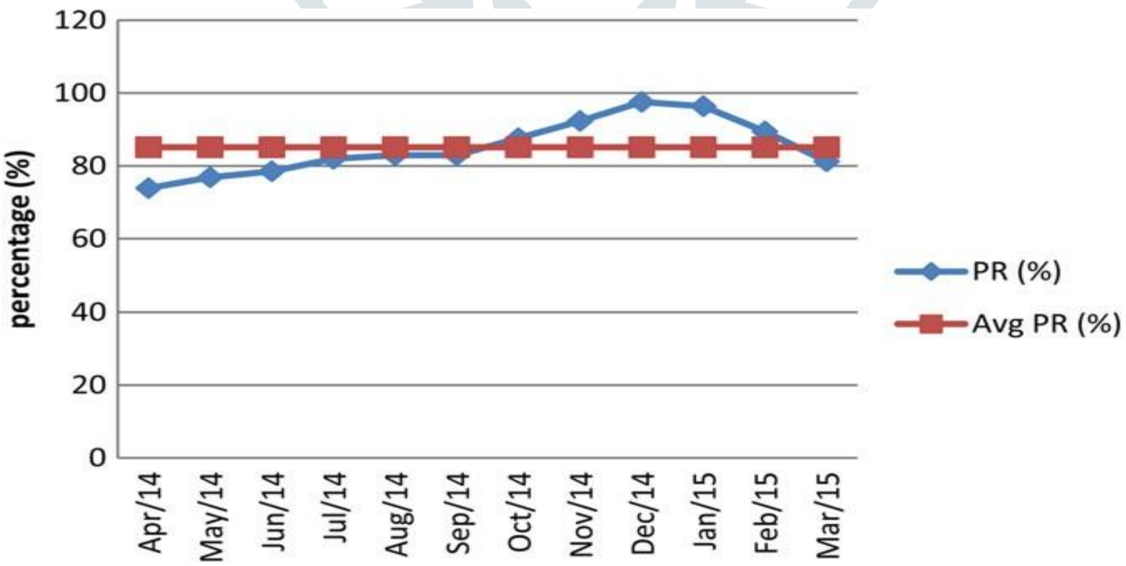


Fig. 3. Solar irradiance vs. peak power o/p.

Performance Ratio (PR)

The annual average value of PR ratio is nearly 85.12%. The highest value of PR is found to be 97.5% in the month of December and the lowest PR was 73.88% in the month of April. System malfunction can be deducted based on the PR values. Lower PR is attributed to the incorrect operation of the system and inverter malfunction (see Fig. 4).



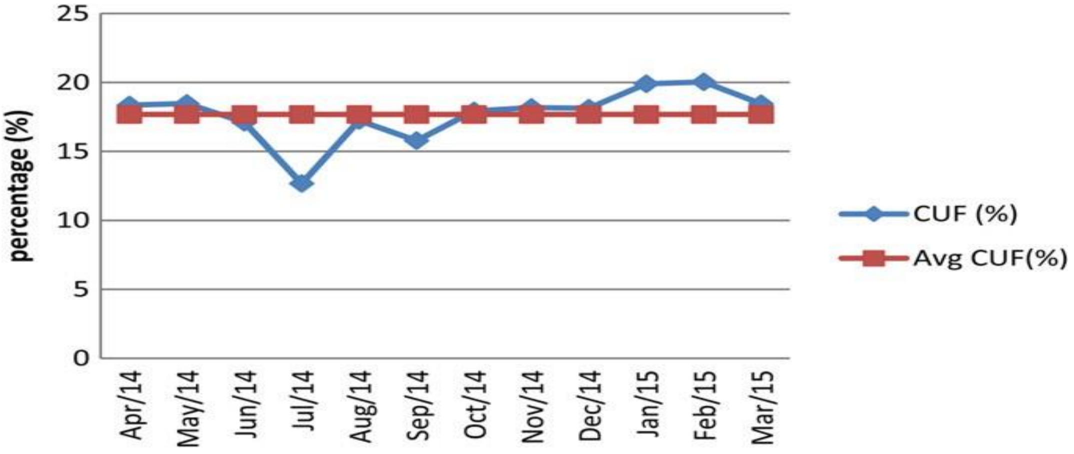


Fig. 5. Average capacity utilization factor in various month.

Energy generation

The data is collected manually by using SCADA software. The highest monthly sum of energy generation was 14.11MW h in the month of March and the lowest was 9.7 MW h in the month of July. This is all because of the seasonal tilt of the solar panels and the amount of solar radiation that is absorbed from the sun. The total annually generated output was 148.01MW h (see Table 1).

Table 1. Average Monthly Energy output

Month	Energy Generation	Annual Energy Generation
Jan	13672.62417	148016.6658
Feb	13569.40764	
Mar	14111.66368	
Apr	12632.80506	
May	13388.67134	
Jun	10997.25896	
Jul	9730.811	
Aug	10123.29974	
Sep	11585.46889	
Oct	13917.23966	
Nov	13428.45784	
Dec	10858.95777	

Simulation using PVSYST

The maximum energy is generated in the month of December (12.3 MW h) and minimum energy is in the month of July (9.2 MW h). The total amount of energy that is injected in to the grid for the entire year is 85 MW h.

Balances and main results

Annual global horizontal irradiation is 1939.9 kW h/m^2. Global incident energy that is incident on the collector plane annually is 2088.3 kW h/m^2. Total energy obtained from the output of the PV array is 16 532 kW h. Annual Efficient E_{out} array/rough area obtained is 10.43%. In the same way annual Efficient E_{out} system/rough area is 10.12% (see Table 2).

Performance ratio

The annual average performance ratio is 76.20%. From PV syst results the performance ratio obtained has no much difference with the actual performance ratio of the solar plant observed using SCADA system.

Normalized productions

The L_C value is recorded as 1.23 kW h/kW p/day and the L_S value is recorded as 0.13 kW h/kW p/day in the same way Y_F is given as 4.36 kW h/kW p/day (see Fig. 6).

Loss diagram

The global horizontal irradiance is 1940 kW h/m^2. The effective irradiation on the collector plane is 2030 kW h/m^2. Therefore, the loss in energy is 3.2%. The solar energy incident on the solar panels will convert into electrical energy. After the PV conversion, the nominal array energy is 20 489 MW h. The efficiency of the PV array is 13.30% at standard test condition (STC). Array virtual energy

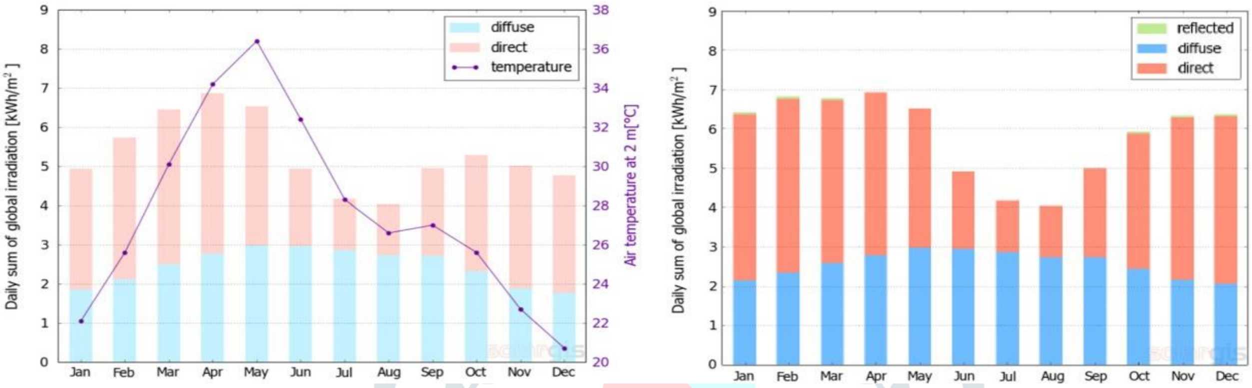


Fig. 6. Daily sum of global irradiation in horizontal and in-plane direction during various months.

5. CONCLUSION

A performance study of 100 kW peak grid connected solar photovoltaic power plant installed at JBIET was evaluated on annual basis. The following conclusions are drawn from the study.
A peak power output of 10.34 MW and 40.83 kW of minimum power output were observed during the year round operation. Maximum total energy generation of 14.11 MW h was observed in the month of March and lowest total energy generation of 9.7 MW h was observed in the month of July.

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