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Procedia Materials Science 6 (2014) 1942 – 1950
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www.elsevier.com/locate/procedia

3rd International Conference on Material Processing and Characterisation (ICMPC- 2014)

Some Analytical Studies on the Performance of Grid Connected Solar Photovoltaic System with Different Parameters

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Abstract

This paper presents some analytical studies on the performance of grid connected solar photovoltaic system with different parameters in Rajasthan. The various factors that are considered for performance evaluation are: solar irradiation, ambience, tilt angle, orientation and shading. Rajasthan is rich in solar energy with varying ambience. Thus, due to change in climatic condition the PV system performance varies from place to place to a considerable extent. This influences the energy yield as well as economics of such system. In this paper a performance evaluation have been carried out for a 5 MW_p crystalline silicon solar photovoltaic power plant in Rajasthan. As a part of the plant design, considerations have been taken in account on aesthetic, safety and cost aspects. The optimised annual energy yield of the 5 MW_p is in the order of 8 GWh at a tilt angle of 22^o, average ambient temperature of 26^{o}Cand relative humidity (RH) of 60%. The minimum yield observed was about 7 GWhat 28^o tilt angle, average ambient temperature of 20^{o}C and RH of 75%. These studies justified on the implementation of photovoltaic system in urban areas of developing countries where peak load demand is very high.

Selection and peer review under responsibility of the Gokaraju Rangaraju Institute of Engineering and Technology (GRIET)

Keywords: Performance Evaluation; Solar Irradiation;Ambience; Tilt Angle;Pitch and Energy Yield;

1. Introduction

Many projects on solar photovoltaic (SPV) systems installed throughout the world and most of them installed in the developed countries where climatic condition is generally cold and dry and humidity level is relatively low. Little data are available on the impact of climatic conditions on SPV systems in the hot and humid climatic countries like India.

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Selection and peer review under responsibility of the Gokaraju Rangaraju Institute of Engineering and Technology (GRIET)
doi:10.1016/j.mspro.2014.07.228

India is located in the equatorial sunny belt of the earth, thereby receiving abundant radiant energy from the Sun. In most parts of India, there are about 250 to 300 sunny days a year with an annual mean global horizontal solar radiation ranging from 4 – 7 kWh/m^2.day, depending upon location [Yang H and Lu L (2007), Jahn U (2000)]

Performance of photovoltaic systems under natural outdoor conditions in Rajasthan is analyzed in this study with particular emphasis on specific environmental parameters prevailing in hot desert locations (Jaisalmer, Jodhpur, Mount Abu, Kota and Jaipur); such as high ambient temperature, Aeolian dust, humidity and scarcity of rain. The performance of PV systems is also highly influenced by the modules' orientations and tilt angles. The PV modules must be oriented and tilted to gain the maximum solar radiation and to avoid unwanted shading. Sufficient pitch should also be given to take the benefits of shading losses. Most of the earlier studies dealt with the problem qualitatively and quantitatively for certain locations. However, little data are available for Indian perspective. The optimum orientation is usually suggested to be south facing in the northern hemisphere and the optimum tilt angle depends onlyon the local latitude, $\beta_{opt}= (\varnothing+15^0) \pm 15^0$(where $\varnothing$ is the latitude of the location) [Haeberlin H and Beutler C 1(995), Nasse W (2002)].There are limitations of the former quantitative studies by many researchers. The hourly clearness index was not taken into account and simplified sky models were usually used, while precise anisotropic sky models can give more accurate results. The main theme of the present work is to carry out detailed studies on the impact of climatic condition, tilt and azimuth angles and pitch of PV modules in hot and humid climatic condition and evaluate the design methodologies including the climatic factors (temperature, relative humidity and dust) in the design precept.

2. Basic System Description

Radial PV modules generate direct current (DC) electricity and it is necessary to convert into alternating current and adjust the voltage levels before powering equipment designed for normal main supply and before interfacing with grid [Jahn U Nasse, W (2000)]. Conversion would be achieved by using an electronic inverter and the associated control and protection devices. All these components of the systems are termed as power conditioning unit. After conversion from DC to AC, it would be exported to the grid. In case the plant needs DC electricity, the energy generated from the solar array would be stored in batteries and can be used as and when required. The SPV power plant described in this paper comprises of the following main components.

2.1. SVP Array

PV modules are the basic building blocks of solar photovoltaic systems. Modules consist of solar cells which convert solar radiations (sunlight) into DC electricity. The individual solar cells are connected together in a module in series and are hermetically sealed to survive in extreme temperature and weather conditions and ensure optimum performance. The PV module frame would be generally made up of anodized aluminium. The solar cells would be encapsulated between two layers of EVA (UV stabilized polymer) sheets and laminated between high transmission toughened glass super strate and tedler or polyester rear cover [Rindelhardt U (2001)]. The electrical output terminals from the series connected solar cells would be brought out to PVC module terminal box where they would be connected to the termination strips on the back side of the PV module.

PV module generates DC power in the range of 20 – 35 volts and 150 – 250 W_p depending upon the rating and solar radiation level. A number of modules would be formed into a group in which the modules are connected in series to obtain a voltage equal to the input voltage rating of the inverter. This will be referred as a string of modules. Several such strings are connected in parallel to form an array in line with plant requirement.

2.2. Mounting Structure

The mounting structure generally made up of galvanized iron (GI) sheet/pipe. Sometimes aluminum is also used. The design of the mounting structure would be such that the frame on which the module would be mounted would keep an inclination with the horizontal. Each structure would be capable of supporting cluster of modules. The structures would be designed to withstand maximum wind speeds at the site.

2.3. Power Conditioning Unit

2.3.1. Inverter

PV modules generate DC power, which is converted in to 50 Hz AC power at grid voltage for grid connectivity. PV modules would be arranged in suitable no of clusters and each cluster will have suitable number of inverters of minimum efficiency of 94% in maximum power point (MPP) voltage range to convert generated DC power of each module to 50 Hz AC power. Inverters would operate on maximum power point tracking (MPPT) mode to ensure maximum output from the PV modules/array[Jahn U Grochowski J Tegtmeyer D Rindelhardt U Teichmann G. (1994), Kiefer K Koerkel T Reinders A Roessler E Wiemken E (1995)]. The inverters shall have power measurement sensors, which will turn on the inverters when output power from solar modules exceeds threshold value. The system automatically starts in the morning and begins to export power to the grid, provided there is sufficient solar radiation and in the evening when output power from the modules falls below the threshold level then inverter would turn off. In the event of grid disturbances, the inverter will be disconnected from the grid and reconnected automatically when the grid stabilizes. When the exported power is lower than a threshold for a pre-determined time the inverter turn to sleep mode and disconnect from the grid[Decker B Jahn U (1997),A.J. Aristizabal and G. Gordillo (2008)]. Total harmonic distortion of the inverters shall be less than 3%.

Inverter shall be based on modular design i.e., each inverter shall be made by small modules of 50 kW, 75 kW, 100 kW, 250 kW ratings, so that outage of a module will not impede the functioning of the inverter. Inverters shall be installed in the air-conditioned room for better cooling and long life of the equipment.

2.3.2. Power Quality

To monitor and control the parameters of DC/AC power in the inverter, a power monitoring unit is required. This unit would monitor the grid power parameters and inverter power parameters and adjust them accordingly for proper synchronization. Inverter AC power quality should be continuously monitored and controlled to within the following limits:

(i) +10% to -18% voltage tolerance for normal operation once connected
(ii) ±3% voltage tolerance during synchronization
(iii) +1% to -5% frequency tolerance
(iv) <5% total harmonic distortion with no single harmonic >2%
(v) Minimum power factor of 0.90. Inverter design should not sustain damage if grid power factor dips below 0.90.

2.3.3. Power Quality

PV modules gives maximum power output at a single set of generated voltage and generated current. MPPT is micro processor based unit and for a given radiation level it will track the maximum power point of the module to get maximum power output from the modules.

2.4. Junction Box

2.4.1. Terminal Box

Terminal box is a part of a PV module, from which electrical output is taken. Each PV module generally associated with three to six by-pass diodes in the terminal box.

2.4.2. String Junction Box

One string junction box (SJB) generally coupled with each mounting structure for taking away final electrical output from the string (modules in series connection). A blocking diode is required in series with string of PV modules in this box. These junction boxes not only act as a junction point but also monitor each string output which would be fed to the central monitoring and analysis system.

2.4.3. Panel Junction Box

This is for paralleling various SJBs' output. Terminal blocks is provided in the panel junction box for paralleling positive and negative electrical output from different SJBs. Single compression cable glands of polycarbonate material would be used for all inlet and outlet to ensure IP 65 protection.

2.4.4. Main Combiner Box

Outputs from panel junction boxes would be connected in parallel in the main combiner box (MCB).

3. Basic System Description

3.1.1. Results on Energy Yield at Various Parameters

3.1.2. Effects of Solar Radiation

3.1.3. There are about 4426 – 5000 sunny hours in Rajasthan in a year with minimum of 322 – 400 hours in December to maximum of 414 – 500 hours in June. The state is rich in solar energy and the average annual solar insulation is about 230 – 239 W/m^2.Table 1 shows solar radiation data of the five selected sites for analysis

Table 1. Solar Data of the Selected Sites (W/m^2)

Month	Jaisalmer	Jodhpur	Mt. Abu	Kota	Jaipur
Jan	176	176	201	191	187
Feb	207	208	235	227	223
Mar	233	249	276	266	261
Apr	274	279	302	293	295
May	294	292	313	303	304
Jun	285	283	283	281	287
Jul	238	234	201	209	227
Aug	229	230	192	200	213
Sep	245	239	233	236	247
Oct	219	221	239	237	234
Nov	182	182	204	197	195
Dec	160	162	184	177	175
Annual	230	230	239	235	237

From the above table it is observed that all five sites receive more or less same solar radiation. The effects of solar radiation on energy yield are presented in Figure 1.

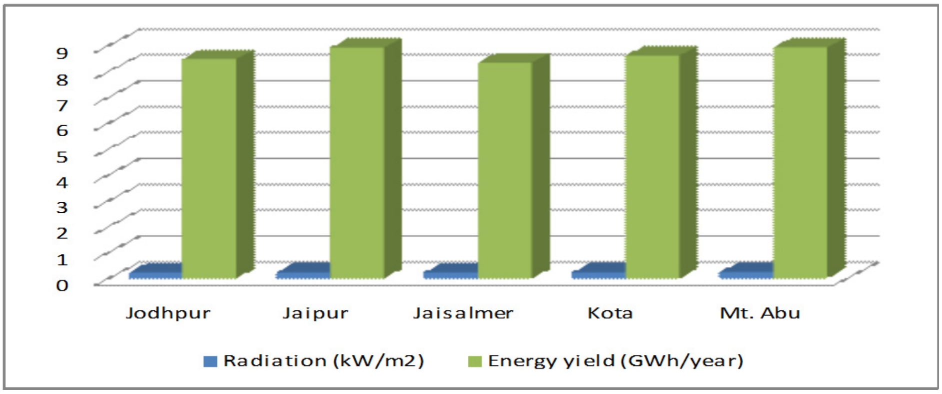

Fig. 1. The effects of solar radiation on energy.

From the bellow figure it is evident that the output is directly proportional to the radiation.

Site	Jodhpur	Jaipur	Jaisalmer	Kota	Mt. Abu
Radiation, kW/m^2	0.23	0.237	0.23	0.235	0.239
Temperature, ˚C	26.2	25.4	26.2	26.7	21.6
Energy yield, GWh/year	8.481	8.925	8.346	8.613	8.934

3.1.4. Effects of Local Weather Conditions

Typical arid to sub humid climate with little variation in summer and winter temperatures prevails at Rajasthan. May – July is the hottest summer period with the temperature rising up to the 50ºC mark, December – February is the winter period. The annual average ambient temperature is around 26ºC.Rajasthan gets all its rains from the south-west monsoons between June and September, for the rest of the year it remains dry. The average annual rainfall is 1135 mm. The annual average relative humidity is 42% with maximum RH of 70% and minimum of 25% during the month of August and March respectively. The effects on electricity output with temperature, soiling and RH are presented in Figure 2.

Table 2. Temperature Data of the Selected Sites.

Month	Jaisalmer	Jodhpur	Mt. Abu	Kota	Jaipur
Jan	15.4	15.1	12.3	16.9	15.5
Feb	18.0	17.9	14.9	19.4	18.3
Mar	23.6	23.8	20.5	25.6	23.8
Apr	29.3	29.4	25.7	31.7	29.1
May	33.6	33.8	29.0	35.7	33.0
Jun	34.8	35.0	28.3	34.1	33.6
Jul	33.0	32.6	25.4	29.9	30.1
Aug	31.3	31.1	23.8	28.3	28.3
Sep	30.3	30.5	24.4	29.6	28.6
Oct	27.1	27.3	23.0	28	26.1
Nov	21.7	21.1	18.1	22.6	20.8
Dec	16.7	16.3	13.6	18.6	17.0
Annual	26.2	26.2	21.6	26.7	25.4

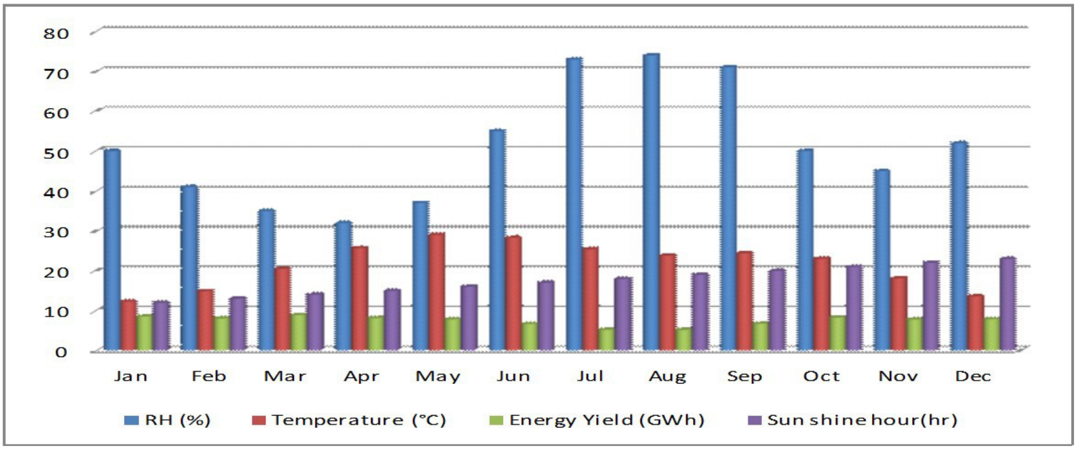

Fig. 2 Effects of local weather conditions.

In summer, temperature (From Table 2) and humidity is quite high, although duration of the sunshine is larger, due to high temperature, power output fall down to a certain level. Thus, it is evident from the above figure that ambiance has a direct impact on the energy yield. The weather data from the Metronome database of the year 1989 – 2000 are used for solar energy system simulation.

From Figure 2 it is also observed that the modules that has been exposed to quite dusty environment (5% soiling factor) has an energy reduction of about 10%, whereas, the modules that has been exposed to less dusty environment (1% soiling factor) has an energy reduction of about 2% if compared to a relatively clean module (0.5% soiling factor). Of course, cleaning the modules once in a week would not significantly raise the operation costs of the SPV system but it will increase the energy yield considerably.

3.1.5. Effects of Tilt Angle and Module's Orientation

The tilt and azimuth angles of a PV array affect the amount of incident solar radiation exposed on the array. Representations of these effects on the energy yield and the performance of the PV system are commonly based on the theoretical calculations. In the present study, the performance of crystalline PV modules has been investigated analytically at different tilt angles and orientations. The annual performance has been predicted using PVSyst simulation program and depicted in Figure 3 and Figure 4.

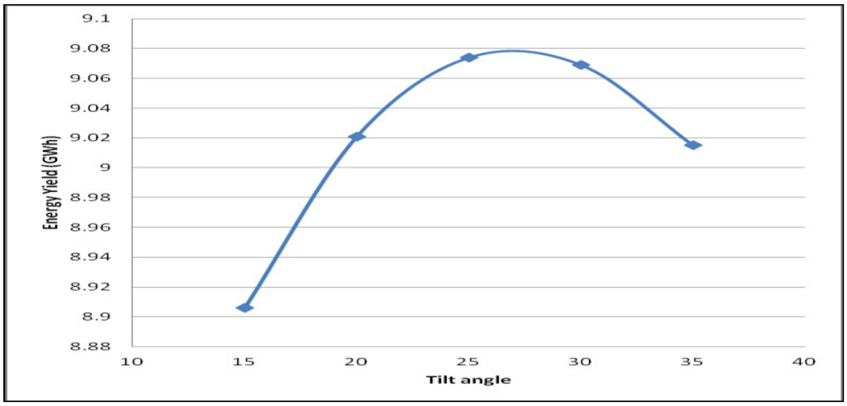

Fig. 3. Performance of PV system at different tilt angles

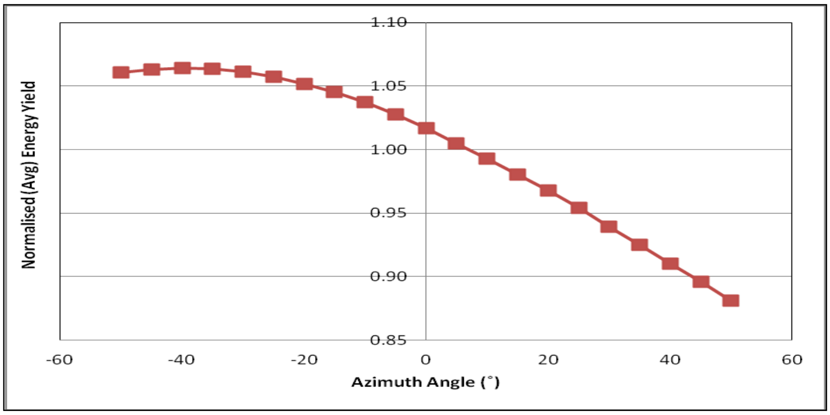

Fig. 4. Performance of PV system at different orientations.

Facing south with a tilt angle in the range of 27 – 29°. Besides, the annual maximum energy output of the PV modules mounted at different tilt angles and orientations is obtained as a fraction of its optimum value at the optimum tilt angle and orientation.

3.1.6. Effects of Shading

The quality of power supply from PV systems is very sensitive to shading effects of the modules. The energy yield of a partly shaded PV system is much lower than that of un-shaded one. Pitch has a direct impact on energy yield. Figure 5 shows effects of shading at different pitch.

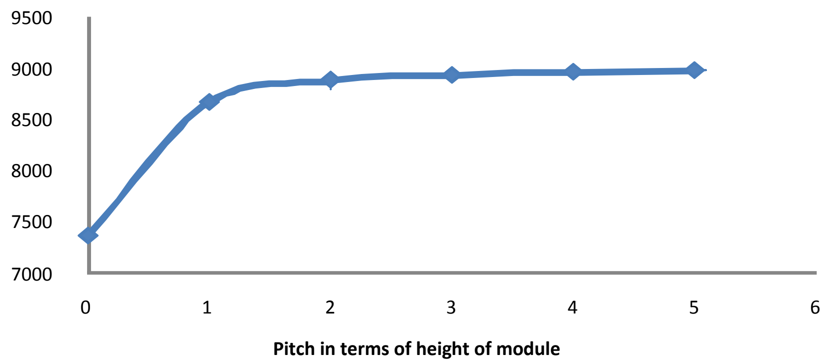

Fig. 5. Effects of Shading (Y axis represents energy output in MWh).

The results show that both the final yields and performance ratio of the PV systems with a pitch of 3 times of module height (at that reference site) are superior than that of the systems with pitch of 2.5 times of module height. In the first case, PV systems are about 2 times the final yields of the second case. The performance ratio of second case is about 5% lower compared to the first case.

3.1.7. Effect of Ventilation of Modules

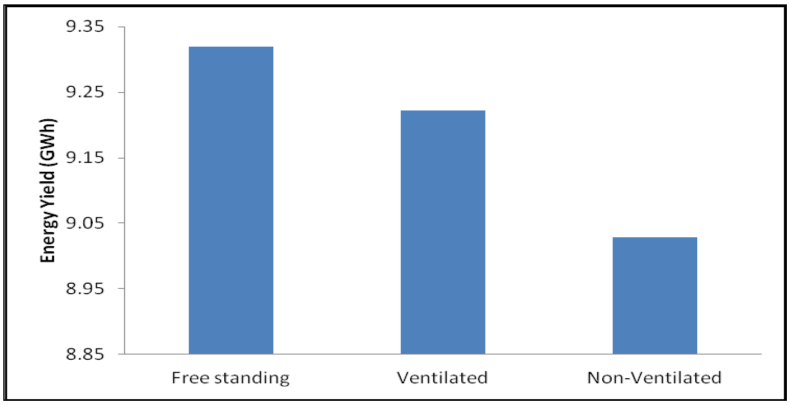

Fig. 6. Effects of ventilation.

From the above Figure 6 it is observed that free standing solar power plant gives higher energy output than non-ventilated even ventilated areas.

3.1.8. Effect of Module Efficiency

Higher the module efficiency more the energy output from the plant. By increasing 0.7% efficiency at standard state conditions, about 0.65% increase of energy yield is possible.

3.1.9. Effect of Albedo

Albedo largely depends on micro-siting of the PV systems; reflectivity of ground surface may vary significantly and could even change for different weather conditions. Usually the effect of Albedo plays a greater role for locations more distant from the equator, where module elevation angle is more elevated. In the tropics the PV module surface is facing towards the sky, thus reducing considerably possible Albedo. However, its effect in energy yield con not be neglected.

4. Typical cost

Technology (crystalline or thin film), module rating (Wp), required voltage level for grid connectivity, all determines the capital cost for a SPV power plant. The capital cost including transmission cost, typically varies between ` 7.5 and ` 10 crores /MWp as on FY 2012. It excludes the cost for land and land development and preoperative expenses. Expected cost of generation is about ` 7.5–10 per kWh, considering capacity utilization factor of about 19%.

The capital cost and cost of generation of the SPV power plants are high when compared with electricity generation by conventional way as well as generation using other renewable energy sources. The cost challenges the production volumes for major components and indigenous supply of some of the components.

5. Discussions and conclusions

The findings and observations during the study are summarized as follows:

The performance of the modules integrated into the south facing varies considerably depending upon the months and the season. The results showed that the performance of the modules is a function of ambient temperature, humidity and dust content of the ambience.

The accumulation of dust layer on the module surface has a direct impact in reducing the energy yield by about 2%. To overcome the problem, weekly cleaning of the module seems to be feasible compromise. Furthermore, a high ambient temperature of about 33oC during the daytime causes high operating temperatures of the modules (of about 45oC) which drastically reduces the performance ratio of about 5 to 15%.

The hourly clearness index is taken into account in the analysis. For PV systems in the Rajasthan (Mount Abu), their orientations affect their performance significantly and the slopes exceeding 30o should be avoided. For the PV systems, the annual optimum tilt angle for the south facing azimuth is 24o, which is slightly less than the local latitude.

The results indicated that sufficient pitch should be required in between the module's strings to minimize the shading losses and sufficient height above the ground enabling for natural ventilation and reduce the module surface temperature and achieve the maximum efficiency.

Based on these analysis power output from the SPV plant are typically in the range of 1600 kWh per kWp installed capacity in Rajasthan, Mount Abu in particular.

Acknowledgement

The authors would like to thank their colleagues for helpful discussions on this paper. They would also like to acknowledge the extended help from product suppliers and technology providers for supply of data, technological backup for this study.

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