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Simulation and Performance Analysis of a Grid Connected Photovoltaic System in Cold Climate Region of India.

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Abstract

System Simulation of various solar photovoltaic (SPV) systems is required to investigate the suitability at a given location. This study analyzes the performance of various grid-connected SPV systems in cold region using PVsyst simulation software tool. The locations Leh, Srinagar and, Jammu located in the Himalayas are chosen for the study as the temperatures in these three regions varied between -15ºC to 32ºC throughout the year. A comparison has been made between four different PV (photovoltaic) technologies: mono-Si, poly-Si, CdTe and CIS to assess the appropriate PV technology in cold climatic environment. Leh is coldest and located at the highest altitude, has highest PR>90% for all four simulated PV systems. Srinagar with moderate temperature and high global inclined insolation has highest CUF> 21% and highest energy generation from all four simulated PV systems than their counterpart. Jammu is hottest with slightly lower global inclined insolation to Leh has shown low PR value, CUF value and, energy generation amongst all. The performance comparison shows CdTe performed better in cold climate region even though the market presence and module conversion efficiency of mono-Si and poly-Si are higher.

Keywords: Grid-connected SPV system, Cold climate, PVsyst, PR, CUF

INTRODUCTION

Solar module output is rated at standard and the comfortable temperature of 25ºC. One main challenge is to forecast the generation of such a module under extreme temperatures like as in too hot climate or in too cold climate. Various studies have been conducted to determine the performance of different PV technologies at elevated temperatures[1-6]. The temperature coefficient of each PV technology has been established by numerous researchers and manufacturers in their study and data sheet. Each PV technology has negative temperature coefficient (Table 2) which indicates that the power output decreases per every degree rise in temperature. Very few papers are published on the performance of PV technologies at lower temperatures, less than 25ºC[7]. Furthermore, PV plant performance in cold climate regions has not been well addressed in the existing literature. The Southern Andes and Himalayas are the coldest geographical locations on earth that have high energy potential of more than 1800KWh/KW PV due to the combination of large irradiation values and low temperatures[8]. The locations Leh, Srinagar and Jammu located in the Himalayan Mountains are chosen for the study as the temperatures in these three regions varied between -15ºC to 32ºC throughout the year. The crystalline silicon module technology: both mono-crystalline silicon (mono-Si) and poly-crystalline silicon (poly-Si) still dominates PV installations in the world owing to their high conversion efficiencies and low cost. And remaining is shared by thin-film technologies: cadmium telluride (CdTe) and copper indium selenium (CIS), also has better efficiencies[9]. This study presents the results obtained from simulated performance monitoring of these four different grid-connected $10kW_p$ SPV systems installed in chosen cold climatic regions of India. In order to investigate the performance of the SPV system, meteorological data such as temperature, humidity, rainfall and snowfall of all the three regions are taken into consideration. Data were analyzed to evaluate the suitability of these SPV systems for installation in the cold climatic region. The performance parameters calculated include performance ratio (PR) and capacity utilisation factor (CUF)

Location and meteorological data

The state of Jammu and Kashmir located in the Himalayan Mountains, falls under cold climate zone of India. The state comprises of three distinct climatic regions: cold arid desert areas of Ladakh, temperate Kashmir Valley, and the humid sub-tropical region of Jammu[10]. Three main locations Leh, Srinagar and, Jammu are chosen from these regions for the analysis. To investigate the behavior of the SPV power plant in the cold region, it is essential to study the meteorological data. Table 1 shows meteorological data of the three regions.

MATERIALS AND METHODS

a. Description of PV system

The SPV power plant in this study has used four different PV technologies for the analyses. They are of mono-Si, poly-Si, CdTe and CIS PV technologies. The PV module specifications of the four PV systems are shown in Table 2.

b. Simulation tool

For analyzing the performance of the $10kW_p$ grid-connected SPV power plant in three regions, following online software is applied:

- PVsyst V6.67 project design[11]

Grid-connected SPV system project for the three locations is created separately in the project design menu by specifying the geographical location, the orientation of the modules, the capacity of the power plant and type of modules. After all the required data is specified, the simulation was carried out. The process is followed for all four different PV technologies

- Meteonorm 7.1 provides ambient temperature and global insolation on the horizontal & inclined plane of these three locations.
- WeatherSpark [12] weather modeling system software presents humidity, rainfall, and snowfall of these three locations.

Table 1. Meteorological Data[12]

Location	Altitude	Ambient Temperature	Humidity	Climate	Snowfall months	Rainfall
Leh	5257 m	-15°C to 11°C	nil	coldest	Nov to Apr	very low
Srinagar	1590 m	2°C to 25°C	negligible	temperate	Dec to Mar	high
Jammu	373 m	10°C to 32°C	high: Jun to Sep	hottest	nil	very high

Table 2. PV system specification[13-16]

PV system type	Power module (W_p)	System size (kW_p)	Module efficiency (%)	Temperature Coefficient of P_{MPP} (%/°C)	Area (m^2)
Mono-Si	280	10	18	-0.39	58.9
Poly-Si	310	10	15.63	-0.4048	62.1
CdTe	120	10	17.0	-0.28	60.5
CIS	175	10	13.8	-0.31	68.8

c. *Performance parameters*

International Energy Agency (IEA) developed performance parameters for analyzing the performance of a grid-connected SPV system.

i. Performance ratio[17]

Performance ratio is defined as the energy output E_{AC} divided by the nameplate DC power E_{DC} obtained in standard test condition. The PR of a SPV system is inversely proportional to the ambient temperature.

$$PR = \frac{E_{AC,kwh}}{(E_{DC,STC} \ X \ \text{Irradiation})}$$

ii. Capacity Utilisation factor[18]

It is defined as the real output of the plant compared to the theoretical maximum output of the plant. The average CUF of SPV plants in India is in the range of 15-19% (MNRE, 2013)[19]. The CUF is proportional to energy generation from a SPV power plant which in turn depends on global solar insolation.

CUF = Energy measured (kWh) / (356 X 24 X installed capacity of the plant)

RESULTS AND DISCUSSION

This section analyzes and presents the results of $10kW_p$ grid-connected SPV system, obtained from PVsyst V6.67 project design.

a. *Energy injected to grid*

Fig 1(a), 1(b) and 1(c) shows monthly energy output fed to the grid by these four simulated SPV systems in Leh, Srinagar and, Jammu. The energy fed to the grid by all four SPV systems is high during the month of July in Leh, October in Srinagar and Jammu due to high global inclined insolation. The energy output of CdTe and mono-Si PV system is almost similar and high in Leh. The high temperature coefficient of poly-Si PV system has made it perform lower in both the regions. However, the overall energy fed to the grid from Srinagar is comparatively higher due to high global inclined insolation, moderate temperature and insignificant humidity.

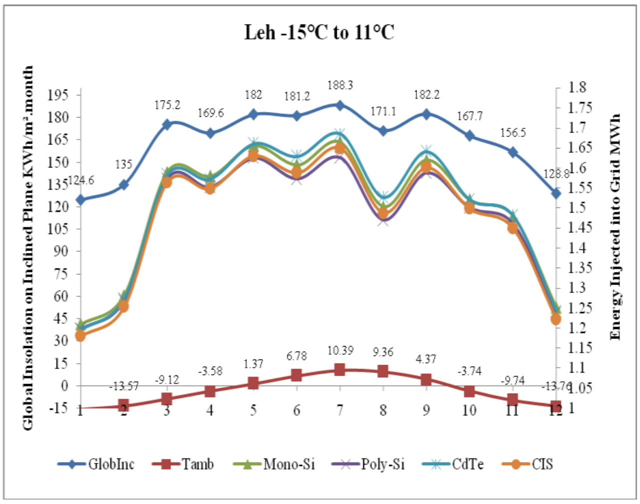

Figure 1(a). Monthly energy fed to the grid of the four simulated PV systems in Leh

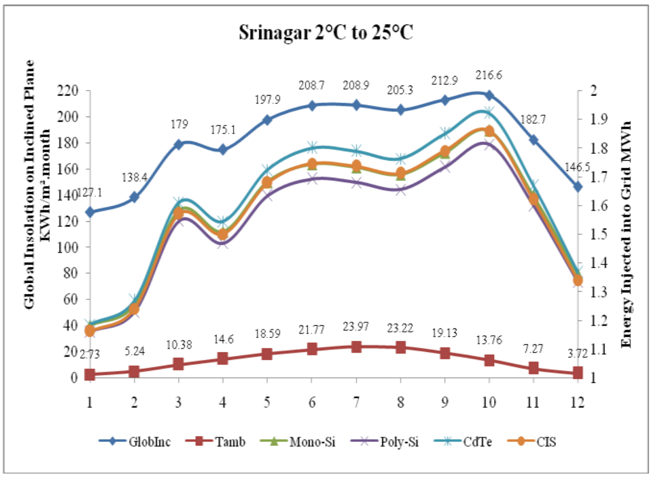

Figure 1(b). Monthly energy fed to the grid of the four simulated PV systems in Srinagar

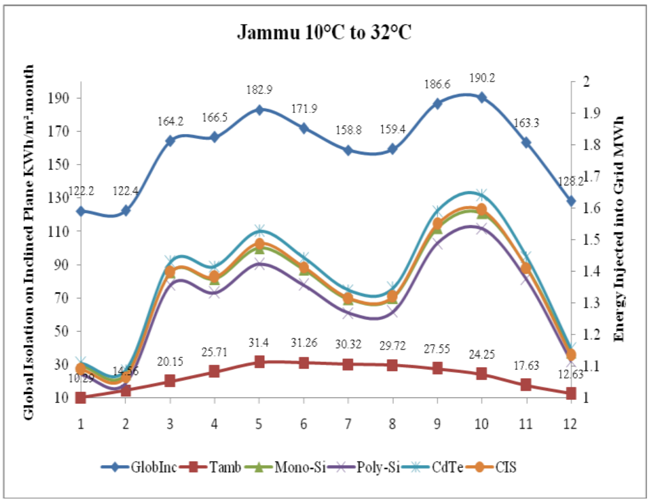

Figure 1(c). Monthly energy fed to the grid of the four simulated PV systems in Jammu

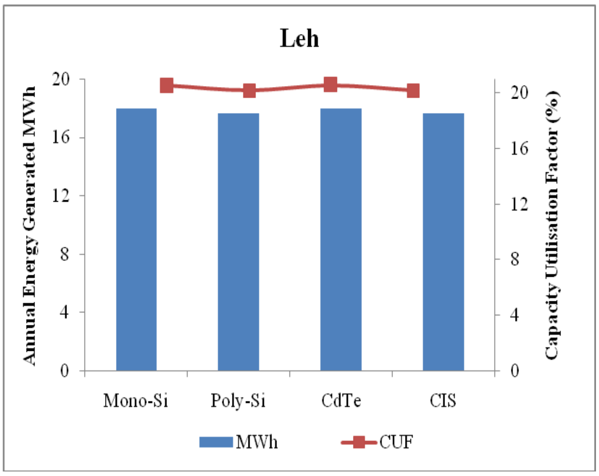

Figure 2(a). Annual energy generation and CUF of the four systems in Leh

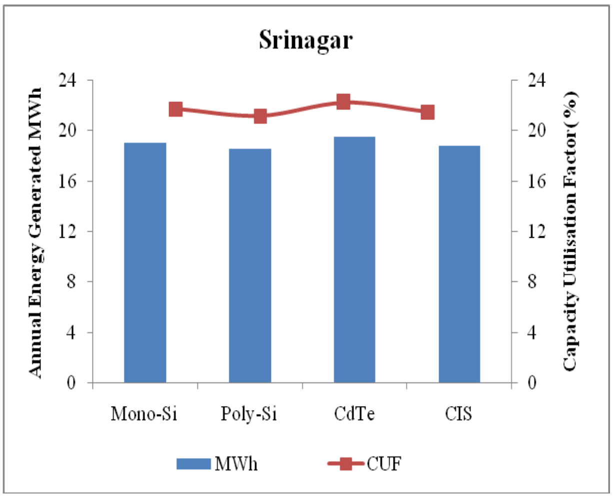

Figure 2(b). Annual energy generation and CUF of the four systems in Leh

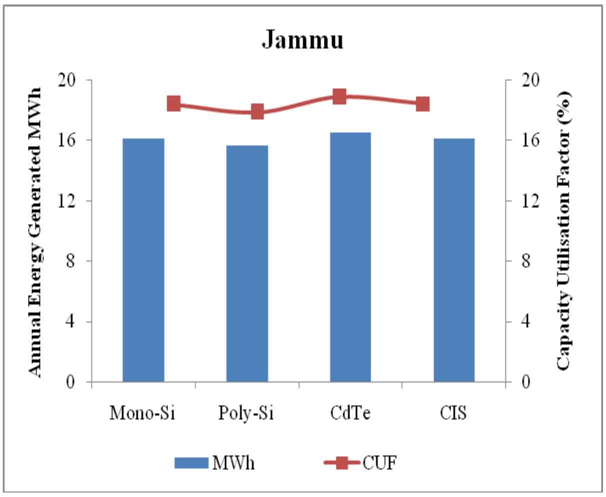

Figure 2(c). Annual energy generation and CUF of the four systems in Jammu

b. Capacity Utilisation Factor

The annual energy generation and CUF of the four SPV systems over a year in all three regions are presented in Fig 2(a), 2(b) and 2(c). The results show that annual value of CUF varied between 17 – 22% and higher in Srinagar. CdTe SPV power plant of Srinagar has higher CUF>21% than other systems in all three regions due to high global inclined insolation at that location. The higher the capacity factor, the superior the SPV system.

c. Performance Ratio

Fig 3(a), 3(b) and 3(c) shows the performance ratio of the four SPV systems plotted against the ambient temperature. All SPV systems in Leh have higher PR>90% due to the extremely low temperature at higher altitude. It is noticeable that the PR of CdTe and CIS PV system in all the three regions is high due to lower temperature coefficient.

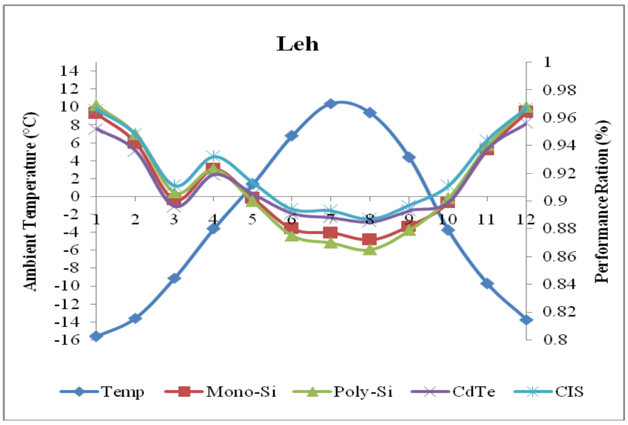

Figure 3(a). Monthly performance ratio of the four systems in Leh

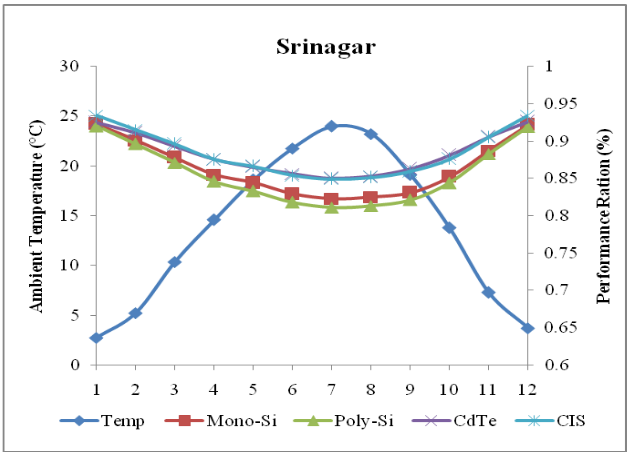

Figure 3(b). Monthly performance ratio of the four systems in Srinagar

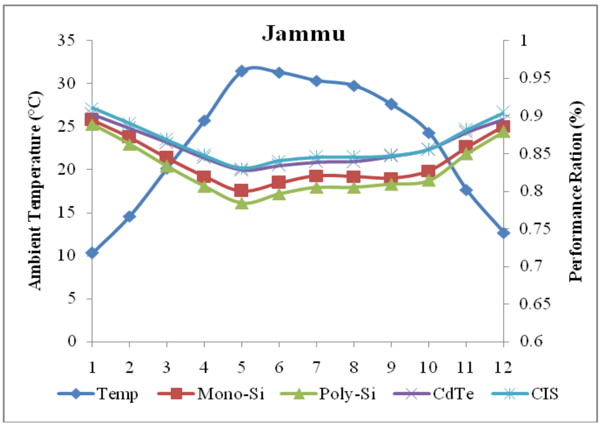

Figure 3(c). Monthly performance ratio of the four systems in Jammu

CONCLUSION

Simulated performance of a 10kW$_p$ grid- connected SPV system with various PV technologies in cold climate region is carried out in this study using PVsyst simulation software tool. From this study the following conclusions are drawn:

- The annual energy injected to the grid by CdTe SPV system is higher in all three regions. However, highest in Srinagar due to the better global inclined insolation, moderate temperature and insignificant humidity.
- The CdTe SPV system of Srinagar has higher annual CUF=22.26% than other systems of all three regions owing to high energy generation due to better global inclined insolation at that location.
- The PR value of CdTe and CIS is high among all because of their lower temperature coefficient. The PR of the poly-Si SPV system is lowest of all owing to its higher temperature coefficient. However, PR>90%, for all four technologies in Leh region due to the extremely low temperature at higher altitude.

The performance comparison shows CdTe performed better in cold climate region even though the market presence and module conversion efficiency of mono-Si and poly-Si are higher.

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