Performance Analysis of PV Module Using Pyramid Surface Texturing Approach

Rahul Kumar Bansal, Satyendra Singh, Alok Kumar Singh, and Md. Waseem Ahmad

Abstract Performance analysis of thin-film solar modules has been done using the pyramid texturing technique. To change the geometry of the surface of the solar cell through surface texturing technique, it increases the effective area of thin-film module. Significant improvement has been found by inserting a random pyramid structure. TCAD and PvSyst software is used to design and development of surface texturing and temperature-dependent loss minimization. Efficiency improvement of 3% has been achieved using this noble approach.

Keywords Efficiency improvement · Loss forecasting · PVsyst · Performance parameter · Thin-film solar PV module · TCAD · Surface texturing

1 Introduction

In 1954, first era of semiconductor silicon-based PV cells was imagined, with an efficiency of six percent, and used for space applications. Presently, the PV innovation is improving quickly since the late 1980s with a plan to improve efficiency and decrease cost. PV solar energy, solar board life is roughly 30 years [1]. Confirmed board outrageous warmth and cold, downpour, hail, storms is impervious to such hard conditions. Being a non-straight gadget, thusly its attributes change with the

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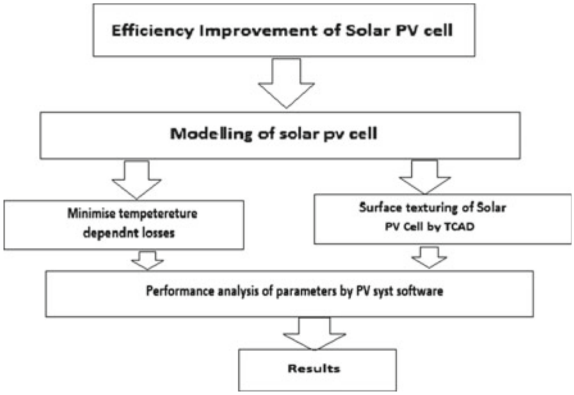
Fig. 1 Flowchart of work



change in solar light and temperature [2]. The procedure of the direct conversion of sunlight into power is called photovoltaic impact. Some semiconductor material like Si or Ge displays the property of photovoltaic impact which causes they retain the light photon and discharge electrons. A French physicist Edmund Becquerel in 1839 found that some material, when presented to light, delivered a little measure of electric flow. Later on, Albert Einstein depicted the photovoltaic impact and nature of light in 1905. Solar cells produce an electric field made by uncommonly treating a thin semiconductor wafer. When light strikes the solar cell's surface, electrons are ejected from the semiconductor material's particles. If the positive and negative sides of electrical channels switch, they structure electric circuit, and there will be a stream of electrons which result into electric flow [3, 4].

In the proposed work (as shown in Fig. 1),

- Mathematical modeling and design installation of solar photovoltaic arrangement with grid connection and losses have been analyzed for different manufacturing technologies. The performance characteristics of the thin-film module were clearly superior to those of the mono-Si and poly-Si modules for Jaipur. But these performance parameters have the drawback of the low spectral efficiency of thin-film modules.
- The second part of this research deals with the implementation of surface texturing to increase the active area of photovoltaic modules. Significant improvement was achieved by surface texturing of PV modules by inserting random pyramid structures [5, 6].

2 Intelligent Data Analytics for Performance Analysis of PV Module

2.1 Data Analytics for Performance Analysis of PV Module

There is much research work that has been done on the topic “intelligent data analytics for performance analysis of PV module.” In this chapter, the author represents a comparative analysis of research work with different field publications through some graphs.

1. Scholarly works overtime:

This graph represents the publication data from the year of 1970–2021 in this field in different research sections (Fig. 2).

2. Field of study covered by most active institutes:

This graph represents the comparative study covered by most active institutes in different research fields [7] (Fig. 3).

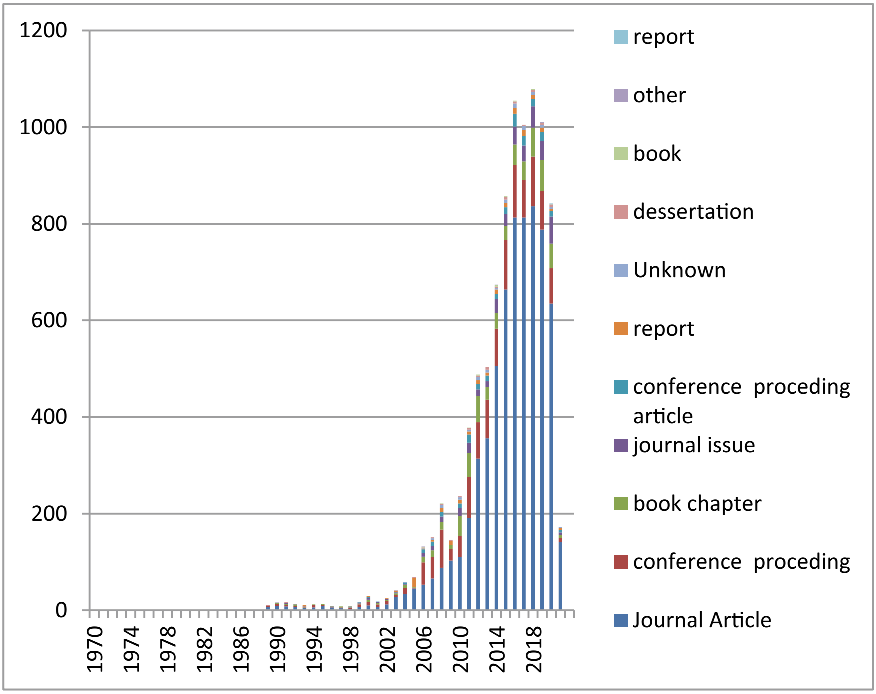


Fig. 2 Graph of scholarly works over time

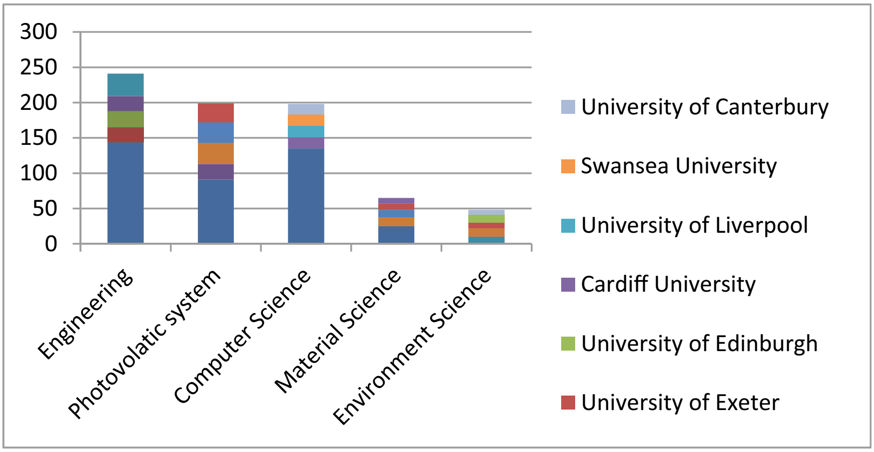


Fig. 3 Graph of the field of study covered by most active institutes

2.2 Data Analysis for Application of Pyramid Surface Texturing Approach

Much research work has been done on the topic "data analysis for application of pyramid surface texturing approach." In this chapter, the author represents a comparative analysis of research work with different field publications through some graphs.

1. Scholarly works overtime:

This graph represents the publication data from 1970 to 2021 in this field in the different research sections (Fig. 4).

2. Field of study covered by most active institutes:

This graph represents the comparative study covered by most active institutes in different fields of research [8] (Fig. 5).

3 Working Principle of Solar PV System

A solar PV cell is a device that directly converted sunlight into electricity. It operates on the basis of the photovoltaic effect [9]. Once the sun's shines reached at the surface of semiconductor material, which is doped with boron, phosphorus, etc. converts into electricity. A photovoltaic cell is a semiconductor diode. When a particle of sunlight strikes the surface of the solar cell, pair of electrons–holes are generated [10]. These

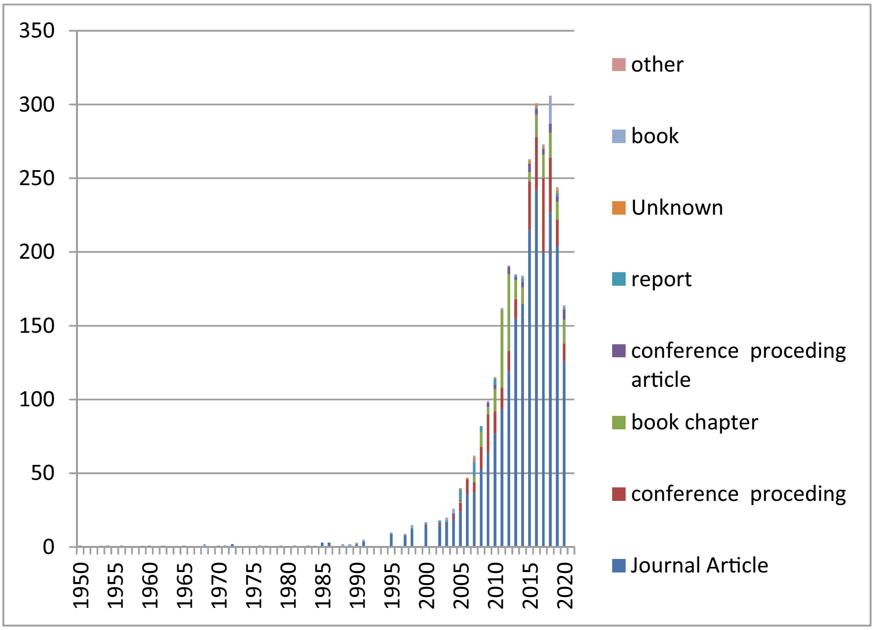


Fig. 4 Graph of scholarly works over time

electrons and holes are known as light-generated electrons and holes. These light-generated pairs can create electricity and start flowing current in the circuit. Figure 6 shows the working of solar photovoltaic cells [11].

4 Surface Texturing of Solar Cell

When the sun's rays are incident on the surface of the solar cell, it has been seen that a portion of energy reflected back and other portion is transmitted. Solar cell converts only transmitted portion of energy into electricity [12]. Generally, bare silicon reflects about 30% portion of incident rays and these reflected energies minimize the efficiency of solar PV cells. There are different techniques to increase the conversion rate of energy from sunlight into electricity. One of the techniques is to etch and text the front surfaces. This phenomenon is known as texturing the surface of the solar cell. This technique provides a chance to incident multiple times on the surface of solar cells that release more energy from sunlight [13, 14] (Fig. 7).

This technique increases the absorption rate of sunlight by increasing the effective area of thin-film solar PV cell [15]. This technique has also reduced the total cost of the same rating solar module. Since crystalline silicon is a semiconductor material that is not directly attached, the transmitted portion of sunlight is comparatively weak. To use lamination with single or multilayer exceeds the thickness of a few millimeter

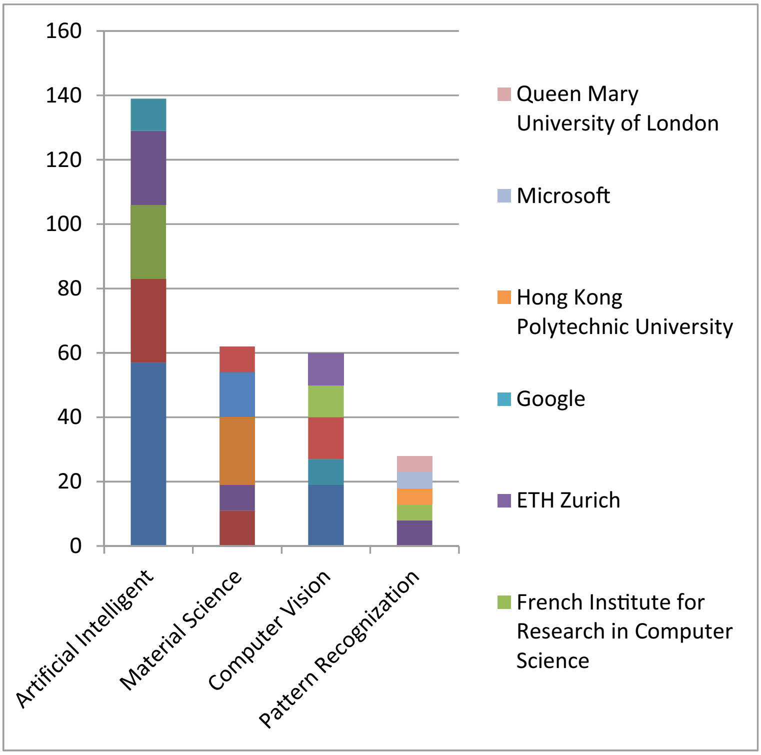
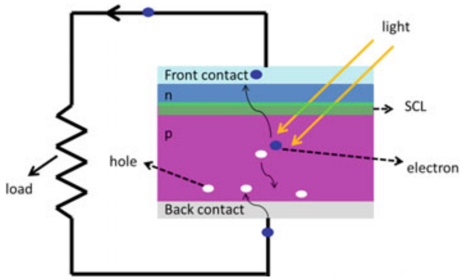


Fig. 5 Graph of the field of study covered by most active institutes

Fig. 6 PN junction solar cell



absorption rates of sunlight which increases the weight and cost of materials, and the quality recombines, resulting in resistance. The radiation efficiency is reduced. Textured surfaces can be made in a variety of ways. These methods are different for single-crystal silicon and polycrystalline silicon [16, 17] (Table 1).

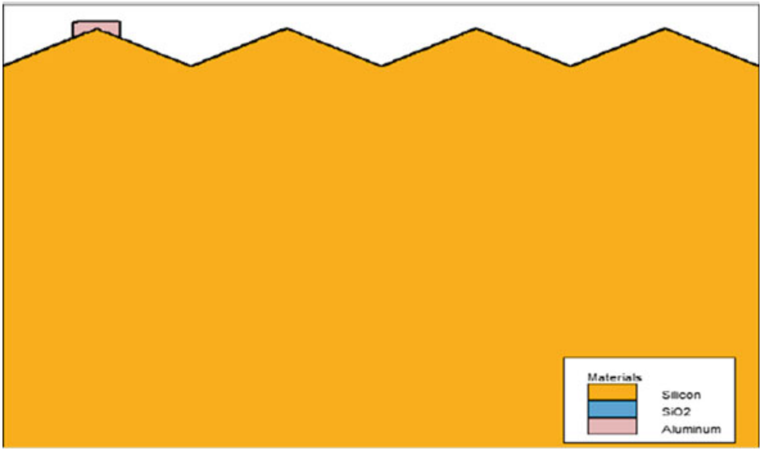


Fig. 7 Surface texturing on solar cell

Table 1 Data of surface texturing

Height of pyramid	5 μm
Thickness of Si	50 μm
Band gap (e-V)	1.12
Temperature	300 K

5 Simulation of Integrated PV System

Usually, PVsyst software is used for design and installation of solar PV arrangements for the 1 MWp system at Jaipur. Three different technologies have been selected for analyzing temperature-dependent losses. Comparative analysis system parameter and mathematical modeling of the system have been done using PVsyst and TCAD software. The results of the simulation process are more accurate as compared to other software [18, 19] (Fig. 8 and Table 2).

Using manufacturer datasheet and Meteonorm solar irradiation and geographical data, 1 MWp system was simulated for Jaipur. Comparative analysis of the active area of Jaipur is mentioned below. It can be noted that thin-film-based solar photovoltaic system required a comparatively larger area due to less spectral efficiency [20, 21] (Table 3).

Yield Simulation—Yield simulation is used to calculate hours per day of production for a power plant. Simulation of yield was done in PVsyst software for 1 MWp system to calculate a relative comparison of manufacturing technologies of solar PV system [22, 23] (Fig. 9).

Losses Simulation—Losses in solar photovoltaic systems have been classified into three clusters. Losses in photovoltaic systems are due to irradiance, losses due to

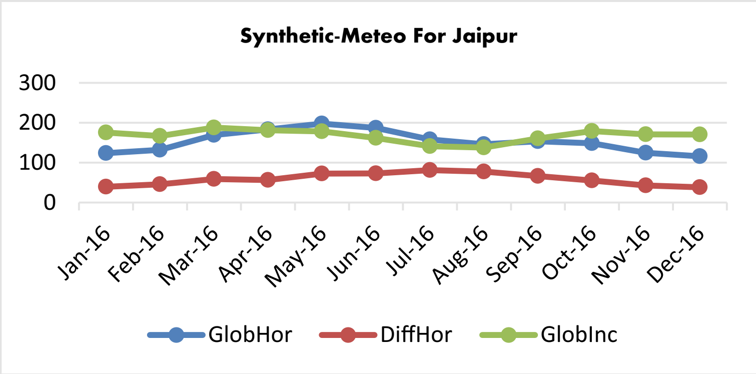


Fig. 8 Synthetic generated Meteo data for Jaipur

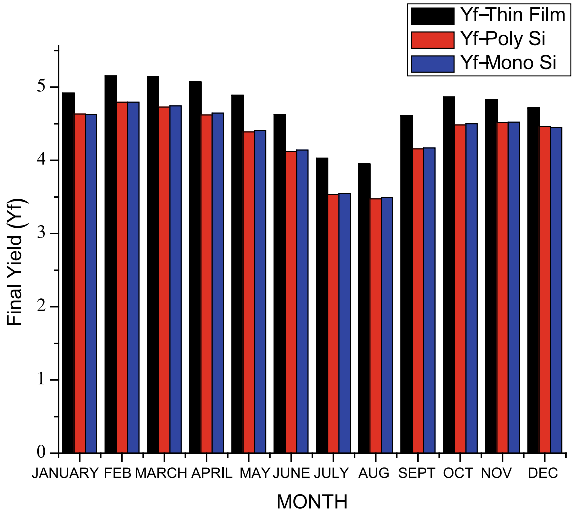
Table 2 Details of modules considered

Technology	Manufacturer	Model number
Poly-silicon	Tata Power	Tata-135
Thin film	Bosch Solar	BSM-EU1510
Mono-silicon	SunPower	BSM-EU 40123

Table 3 Comparative analysis of active area for Jaipur

Technology	Model number	Efficiency (%)	Active area of system (m^2)
Poly-silicon	Tata-135	14.6	6440
Mono-silicon	SunPower	17	5720
Thin film	BSM-EU1510	9.8	11,010

Fig. 9 Comparative analysis of yield for Jaipur



PV modules, inverter losses and losses due to soiling. Using PVsyst, temperature-dependent losses were calculated for different manufacturing technologies for the given system. It was evident that thin-film technologies perform better to counter losses due to the temperature and heating of solar panels (Fig. 10).

Performance Ratio—The final yield in hours/day divided by the reference yield is known as the performance ratio defined in hours/day of production from the solar photovoltaic system. The thin-film system's performance ratio was calculated using a PV system simulation and found to be comparatively better than poly-Si-based structures and mono-Si-based structures (Fig. 11).

Forecasting of Production—With PVsyst simulation tool, the annual production figures were computed for 1 MW system at Jaipur in terms of kWh/month. On

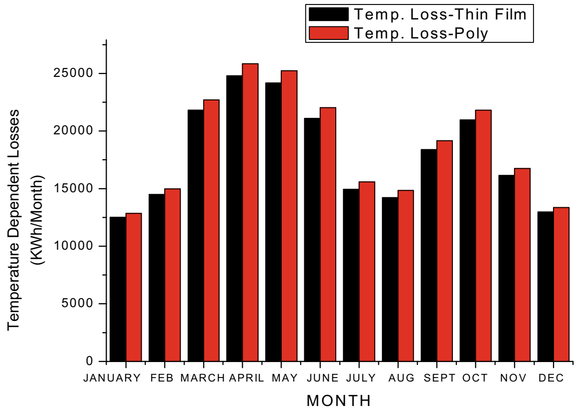


Fig. 10 Analysis of temperature-dependent losses

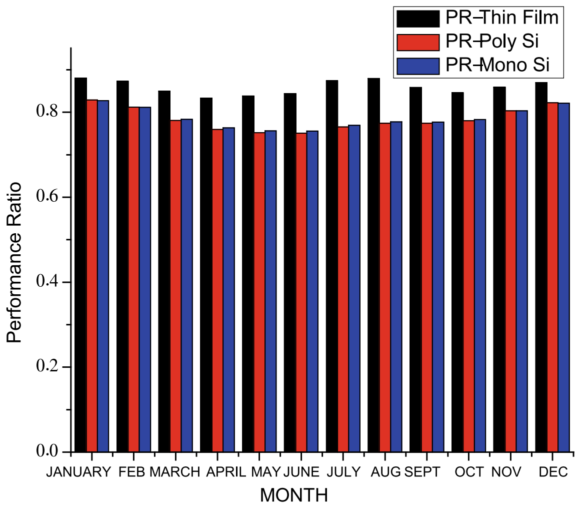
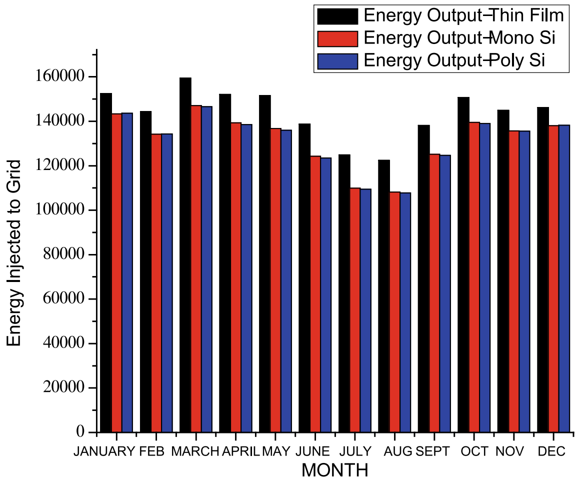


Fig. 11 Relative comparison of performance ratio

Fig. 12 Relative assessment of energy injected to grid



the basis of kWh/day, for each of the four production technologies, we also calculated the expected value of produced power from solar PV installations. Figure 12 shows the results.

6 Results

Integration of system in PVsyst explained that the overall operational parameters, i.e., yield, energy injected to the grid, temperature losses and performance ratio, was superior in the solar photovoltaic system based on thin films. Solar photovoltaic system based on thin films has low conversion efficiency, which costs more active area for the given system. The problem of countering the poor efficiency of solar photovoltaic systems based on thin film was addressed, and surface texturing of the top surface of thin-film-based solar cells was achieved in the TCAD tool. Pyramid texture simulation was carried out in the TCAD tool by designing solar cells in SILVACO ATLAS and ATHENA tools. The simulation showed that efficiency up to 11.7% was achieved after inserting pyramid texture in the top surface of the solar cell. The efficiency curve with respect to the number of pyramid textures is explained in Fig. 13.

The simulation showed that due to the addition of pyramid texture, the value of current increased four times in solar cells. Pyramid texture helped in increasing active area and collection of solar irradiation by multiple reflections in a solar cell with surface texturing of pyramid shape.

Figure 14 shows the increase in current in a solar cell with a pyramid texture. A significant increase in output current was observed in the simulated solar cell (Fig. 15).

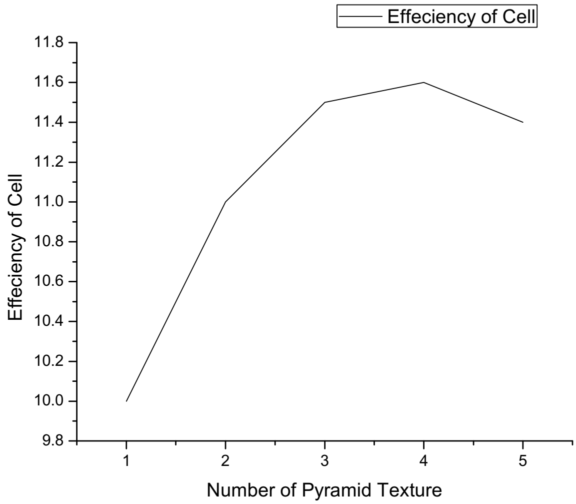


Fig. 13 Efficiency with respect to pyramid texture

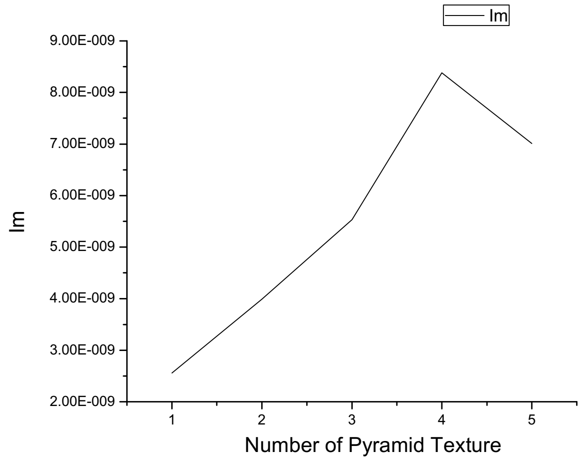


Fig. 14 Current with respect to pyramid texture

At constant voltage, current of pyramid textured solar cells increased significantly due to the increased active area of solar cells having pyramid texture. Simulation was carried out for a different number of the pyramids in order to calculate an optimum number of pyramids based on the area of the cell (Fig. 16).

Due to the increased efficiency, the relative area requirement for 1 MWp system for thin-film technology has shown a significant decrease. Figure 17 explains the close comparison between our conditions before and after surface texturing of modules. This decrease in the area was due to an increment achieved in the power output of panels. Figure 18 explains the relative comparison of power output by module before and after achieving surface texturing.

Fig. 15 Power with respect to pyramid texture

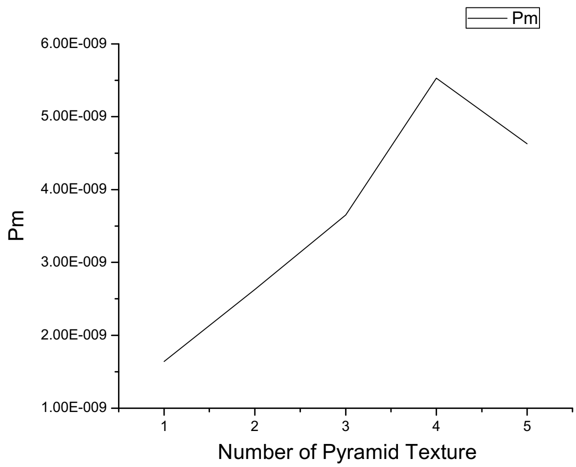


Fig. 16 Current density with respect to texture

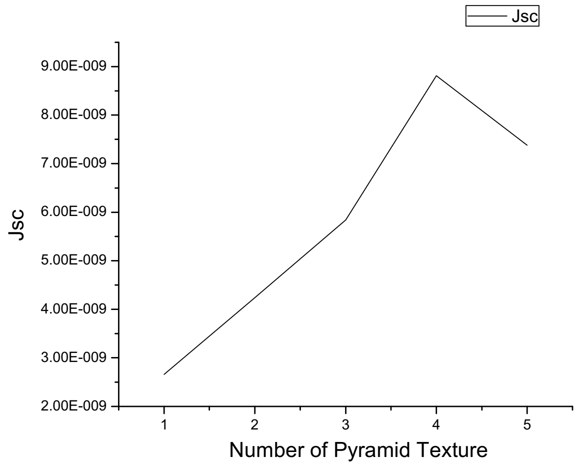
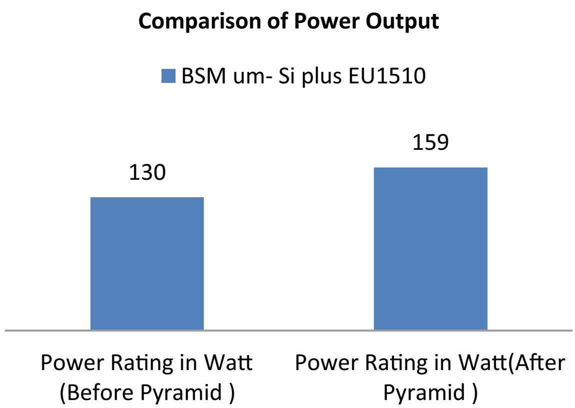


Fig. 17 Comparison of power output



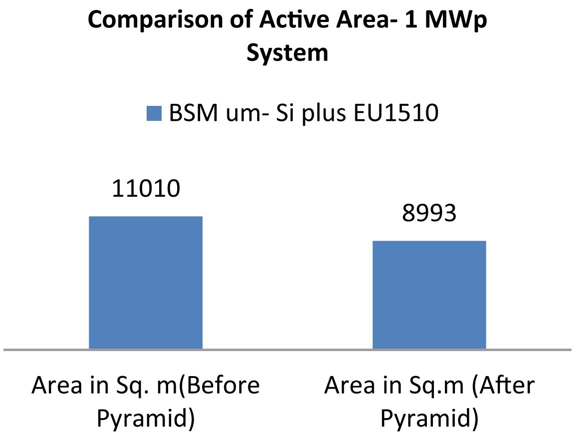


Fig. 18 Comparison of active area

7 Conclusion

In this chapter, the problem of temperature-dependent losses and low spectral efficiency of thin-film modules was addressed.

- The relative comparison of a performance parameter of 1 MWp grid-tied solar PV system was carried out on PVsyst software for different module manufacturing technologies for Jaipur, India.
- The analysis of results proved that thin-film technology performs best in terms of operating efficiency in high-temperature conditions. The value of energy injected into the grid was maximum for thin-film technology-based power plants.
- In the second part of the research, the problem of the low spectral efficiency of thin-film modules was addressed and for simulating the physical modeling of thin-film modules TCAD-based approach was used. Surface texturing on mesh structure of solar cell was achieved by SILVACO TCAD tool, and an increase in 3% efficiency was achieved.
- Analysis on PVsyst for improved module explained that there was significant increase in power and a significant reduction is required for the thin-film-based system after surface texturing.

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