International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 6s
DOI: https://doi.org/10.17762/ijritcc.v11i6s.6967
***Article Received**: 30 March 2023 **Revised**: 24 May 2023 **Accepted**: 05 June 2023*

Solar Photovoltaic Parameter Extraction for Three Different Technologies Using Particle Swarm Optimization Method

Krupali Kanekar[1], Prakash Burade[2], Diraj Magare[3]
[1]Electrical Department, Sandip University, Nashik, India
Electronics and Telecommunication Engg, Ramrao Adik Institute of Technology, D. Y. Patil Deemed to be University, Navi Mumbai, India
krupali.kanekar@rait.ac.in
[2]Electrical Department, Sandip University, Nashik, India
prakash.burade@sandipuniversity.edu.in
[3]Electronics and Telecommunication Engg, Ramrao Adik Institute of Technology, D. Y. Patil Deemed to be University, Navi Mumbai, India
dhiraj.magare@rait.ac.in

Abstract— Industry and academia are becoming more interested in solar energy. The problem of providing an alternative to fossil fuels and limiting the environmental damage brought on by their emissions is what has brought about this increased focus. Solar photovoltaic is the subject of a growing number of studies. The goal of the current investigation is to investigate how various technological modules namely single junction amorphous silicon (a-Si), Hetero junction with Intrinsic Thin-layer (HIT) and multi crystalline silicon (mc-Si) are affected by seasonal spectrum variation respond to Indian climatic circumstances. Compared to many other nations, the entire Indian subcontinent has a relatively distinct climate with distinct seasonal patterns. The four seasons that are considered in this study are summer, winter, monsoon, and post monsoon. The impact of each season varies on the spectrum. Such a study will be helpful to measure the parameter connected to the spectrum and assess its impact on the effectiveness of the PV array. In order to conduct accurate performance investigations, the extraction of the right circuit model parameters is essential. The estimation of the solar PV parameter is done by using Particle swarm optimization (PSO) algorithm.

Keywords-photovoltaic, root mean square error; amorphous silicon; multi crystalline silicon; hetero junction with intrinsic thin layer; module temperature; particle swarm optimization; standard test condition.

I. INTRODUCTION

Our daily lives depend heavily on energy, and there is a growing need for alternative energy sources. Researchers have identified effective strategies to use renewable energy to close the supply-demand gap. A cheap and environmentally friendly energy source, renewable energy is widely accessible all over the world. The solar photovoltaic system has a very low operating cost [1]. Solar energy is a safe form of renewable energy, and because the sun's energy output is so great, it can reliably provide all of the world's energy needs. Over the past ten years and longer, research on solar PV cells has remained active due to the depletion of fossil fuels and the growing demand for renewable energy sources, which has drawn attention to new directions in the study of photovoltaic cells [2]. Modeling has persisted as one of the fundamental methods for studying any complicated system. Models have been used extremely successfully to comprehend and evaluate the operation and effectiveness of photovoltaic cells. Models assist in gaining a thorough understanding of the intricate connections between various external conditions and other innate characteristics that affect the performance of photovoltaic cells.

There are several different meta-heuristic optimization strategies, such as the flower pollination algorithm (FPA), genetic algorithm (GA), and particle swarm optimization (PSO) [3]. Presented work offers a fresh perspective on estimating new model coefficients for the site while maintaining the style of the literature reported module temperature models. For three different technology modules deployed at the Gurgaon site in India, amorphous-Si, hetero-junction with intrinsic thin-layer (HIT), and multi-crystalline-Si, the expected module temperature using predicted coefficients was compared with the experimental module temperature. It has been found that the estimation of module temperature using the new equations is precise and error-free when compared to experimental results. The parameters of solar cell models are extracted in this study using a metaheuristic technique based on the Teaching learning based optimization (TLBO) algorithm. Utilizing experimental data sets and objective function, analysis is carried out. It is suggested that the disparity between the estimated and

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measured values can be minimized through optimization with an objective function.

II. EMPIRICAL FRAMEWORK

Standard test conditions (STC) for PV modules at outdoor settings have never been completed satisfactorily in the real world. As a result, tests of the effectiveness of PV modules conducted outside and inside have differed significantly [11-13]. The utilization of a PV test bed, such as the one depicted in figure 1, is the most feasible method for verifying a PV technology for a site or extending for similar locations. An evaluation of the solar power plant's performance based on actual data that might be used to compare systems and spot operational problems. The data from weather stations and PV test beds are recorded using a structured format that is used to analyze the performance of different PV technology modules and predict the environmental effects.

Figure 1. Outdoor test set up of three different PV technology modules at NISE, Gurgaon, India [2]

These test locations were located at NISE, Gurgaon, in the northern region of India. The coordinates of this place are 28º37' N and 77º04' E, and it is 216 m above sea level. The four major elements of a PV test bed are an outdoor PV array, a weather station, a data logger with a PV array analyzer, and accompanying software for sensing, monitoring, retrieving, storing, networking for transmission, and analysis. PV test beds were conceived and designed using these elements.

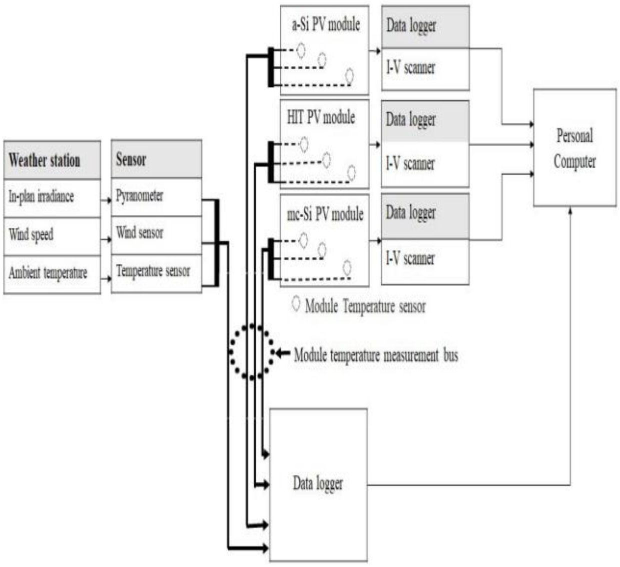

Figure 2. Schematic experimental setup of PV module measurement system [20]

Utilizing a pyranometer sensor, solar radiation is measured. a wind sensor of the propeller variety used to measure V_w at a height of around 3 meters. K-type thermocouples are used to measure atmospheric temperature. From 10:00 am to 3:00 pm, at intervals of 10 minutes, environmental data and each solar module temperature with current and voltage information were collected and stored in data logger as shown in figure 2.

TABLE I. PV MODULE PARAMETERS OF THREE TECHNOLOGY MODULES

PV module technology	Module Area, A' (m^2)	Module Power, P_{STC} (W)	Module Efficiency, η_{STC} (%)	Module NOCT, T_{NOCT} (°C)	Temperature coefficient of power, γ_m (%/°C)	Active module area, A (m^2)
a-Si	1.21	75	6.5	44	-0.30	1.15
HIT	1.25	210	20.0	48	-0.33	1.05
mc-Si	1.15	160	15.8	47	-0.49	1.01

Three PV modules of various technologies, each with a comparable area and a fixed tilt angle of 28º, were mounted in this. The module specifications are listed in Table I.

III. PROPOSED METAHEURISTIC ALGORITHM

A. Methodology

Irradiance is one of the environmental factors that significantly affect module power [15-17]. The module temperature is also significantly influenced by the ambient temperature and wind speed. The following equation provides a heuristic method for calculating the percentage of the power departure from STC while taking into account the inter-correlation and dependence of various ambient factors as well as the manufacturer specified technical parameters on the power. The power deviation is calculated by (ΔP):

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$$\Delta P = 100 * \left(\frac{P_{STC} - \left(\left\{a_1.A.G + a_2.A.G.ln\left(\frac{G}{G_{STC}}\right)\right\}\left\{1 + \gamma_m\left(\left[a_3.\left(1 - \frac{P_{STC}}{G_{STC}.A}\right).G + a_4 T_a + a_5 V_w + a_6\right] - T_{STC}\right)\right\}\right)}{P_{STC}}\right) \quad (1)$$

The letters G_{STC}, P_{STC}, and T_{STC}, respectively, denote the module's irradiance, power, and temperature under typical test conditions. One of the instantaneous environmental factors G, T_a, or V_w, represents each of the in plane irradiance, ambient temperature, and wind speed. The terms relating to module temperature are connected with coefficients a_3, a_4, a_5, and constant a_6, while the power generation components under the direct influence of irradiance are connected with coefficients a_1 and a_2. Regression analysis was used to determine the module temperature as a collection of linear terms with variable coefficients derived from the empirically reported module temperature. This strategy effectively accounts for the interaction of several factors. This equation of module temperature is created using the terms in Eq. (1), with coefficients and constants ranging from a_3 to a_6.

B. Particle Swarm optimization (PSO) Algorithm

The stochastic population-based metaheuristic known as particle swarm optimization was inspired by swarm intelligence [18-19]. In order to choose a location with enough food, it imitates the social behavior of other living things like flocking birds and schooling fish. In fact, without any centralized management, the swarm's exhibit coordinated behavior via local movements. PSO was initially successfully developed for continuous optimization issues [20-21]. A swarm in the fundamental model is made up of N particles that move about in a D-dimensional search space [23-28]. The vector x_i in the decision space represents each particle i which is a potential answer to the conundrum. A particle's position and velocity determine its direction of travel and step size shown in figure 3.

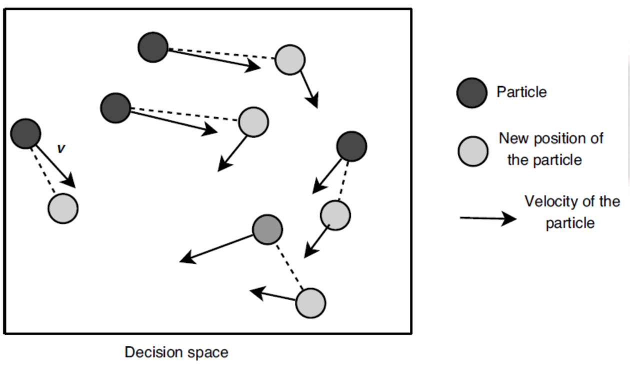

Figure 3. Particle swarms with their associated positions and velocities.

The collaboration of the particles is used for optimization. The performance of some particles will affect how their fellow particles behave. The best location each particle visits by itself (p_{besti}) is represented by $p_i = (p_{i1}, p_{i2},..., p_{iD})$, and the best position the entire swarm visits (g_{best}) (or l_{best}, the best position) are taken into consideration as it moves towards the global optimum.

C. Steps used in PSO are shown in below:

Step 1: Create the population and decide how many iterations there will be.

Step 2: Assess the needed design variables as well as the objective functions.

Step 3: Assign $P_{best[i]}$ = Initial solution with i = 1, 2,... N in step 3. (N: no of particles). Keep the objective value in hand.

Step 4: Choose the best particle out of every one and give it to G_{best}. Swapping is performed to obtain the step 3 objective function, step 2 and step 3 objective functions are compared, and the swapped data is stored.

Step 5: Create random beginning velocities for each particle in step 5.

Step 6: Update the velocities of the respective particles by adding them, as in Present[i] (new) = Present[i] old) + V[i].

Step 7: Updating speed in accordance with the formula V[i] = V[i] (present) + C_l * ($P_{best[i]}$ - present[i]) +C_2 * ($G_{best[i]}$ - present [i]).

Step 8: Review the revised particles to find new ones.

Step 9: If the number of optimization iterations is lower then move to step 6:

Step l0: Compare the value of the objective function with the previous solution; if they differ, move on to step 7, otherwise, exit the loop.

Step 11: After the required number of iterations, the algorithm must be stopped.

IV. RESULTS AND DISCUSSION

In this study, the relative seasonal effects of three different PV technology modules namely amorphous silicon, hetero-junction with intrinsic thin-layer semiconductors, and multi-crystalline silicon [29-30], installed at the National Institute of Solar Energy (NISE), Gurgaon, Haryana District, in northern India, under Indian environmental conditions, have been presented. The module temperature (T_m) parameter has also been taken into consideration. The estimation of the model's expected coefficients was completed satisfactorily in this study. At this Gurgaon site, the RMSE of the relative predicted coefficient was also estimated. The observed and expected findings are strongly correlated with measured values.

TABLE II. MODEL COEFFICIENTS AND CONSTANTS FOR A-SI TECHNOLOGY

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Coefficients	Monsoon	Post Monsoon	Winter	Summer
a1	0.0716	0.0681	0.0589	0.0653
a2	-0.0009	0.0205	0.0025	-0.0080
a3	0.0247	0.0339	0.0280	0.0247
a4	0.8236	1.5979	1.1488	1.1380
a5	-1.6113	-1.2325	-2.2413	-1.8062
a6	15.2796	-16.1362	3.2805	5.4206

TABLE III. TEMPERATURE AND POWER RMSE FOR A-SI TECHNOLOGY

	Monsoon	Post Monsoon	Winter	Summer
Temperature	2.2156	4.8441	3.2163	2.1457
Power	4.5658	3.6263	1.3953	4.7433

For performing the analysis with respect to various PV technologies, particle swarm optimization approach is proposed. A population based search technique based on the simulation of the social behavior of birds inside a flock is called the particle swarm optimization (PSO) algorithm. The key benefit of PSO is that there are fewer parameters to adjust. PSO uses particle interaction to get the optimal answer.

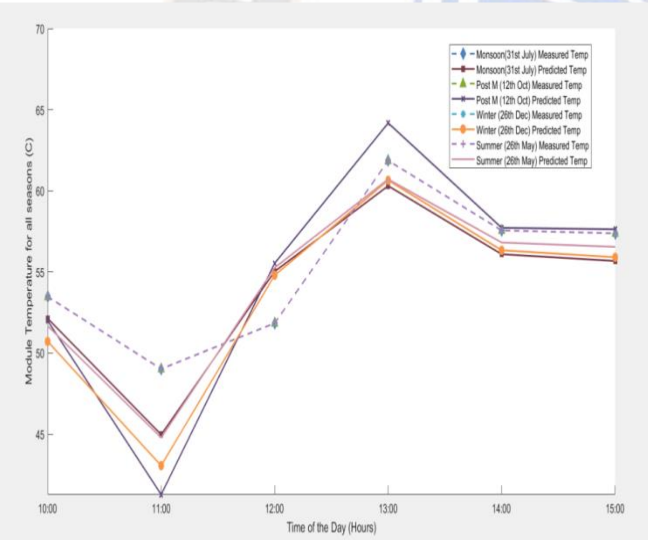

Figure 4. Season wise output temperature variation for a-Si technology

In Table II, model coefficients and constants for a-Si PV technology are calculated using PSO approach. The analysis is performed season wise namely monsoon, post monsoon, winter and summer. For monsoon seasons a_1 to a_6 values are 0.0716, -0.0009, 0.0247, 0.8236, -1.6113, and 15.2796 observed respectively. For post monsoon it's noted as 0.0681, 0.0205, 0.0339, 1.5979, -1.2325, and 16.1362. For winter observed coefficients are 0.0589, 0.0025, 0.0280, 1.1488, -2.2413, and 3.2805. Similarly it is noted for summer season as 0.0653, -0.0080, 0.0247, 1.1380, -1.8062 and 5.4206. From table III, it is observed that, root mean square error with respect to power is obtained minimum for winter season.

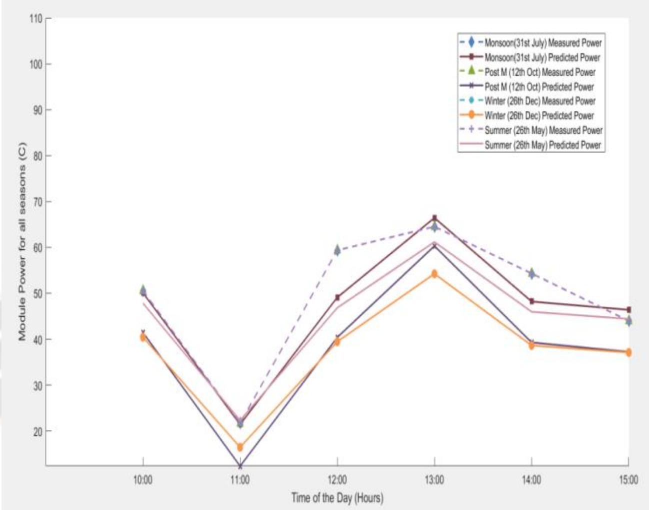

Figure 5. Season wise output power variation for a-Si technology

Season wise variations for a-Si technology are mentioned in figure 4 and figure 5. So we can conclude that a-Si technology is suitable for winter season because of small variation or less error value.

TABLE IV. MODEL COEFFICIENTS AND CONSTANTS FOR HIT PV TECHNOLOGY

Coefficients	Monsoon	Post Monsoon	Winter	Summer
a1	0.1260	0.1246	0.1277	0.1241
a2	-0.0145	-0.0110	-0.0042	-0.0113
a3	0.0359	0.0394	0.0417	0.0424
a4	1.2103	0.7934	1.0523	1.0238
a5	-1.5834	0.0822	-2.3557	-1.3448
a6	-0.9024	6.6479	2.1063	0.8015

TABLE V. TEMPERATURE AND POWER RMSE FOR HIT TECHNOLOGY

	Monsoon	Post Monsoon	Winter	Summer
Temperature	1.8719	2.8974	2.0625	1.6486
Power	2.3390	3.8731	2.6553	2.3313

Model coefficients a_1 to a_4 and constants a_5 and a_6 are mentioned in table IV. Temperature and power RMSE for HIT PV technology are calculated in table V using particle swarm optimization method. It is observed that RMSE value is less for summer that is for higher temperature. This is because; HIT technology is having low temperature coefficients i.e., can perform better at higher operating temperatures.

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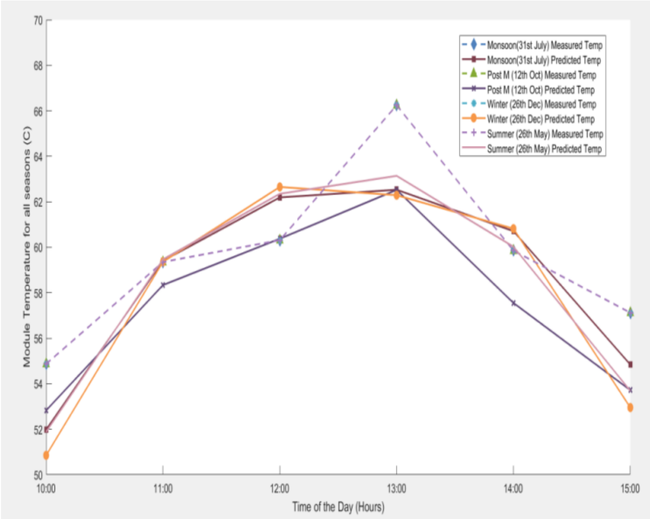

Figure 6. Season wise output temperature variation for HIT technology

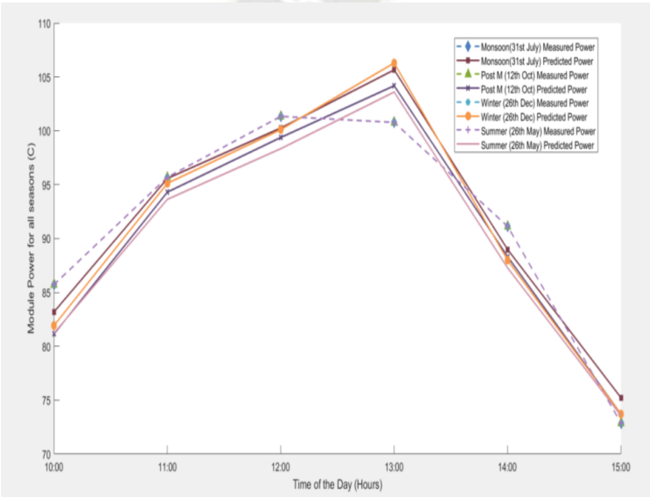

Figure 7. Season wise output power variation for HIT technology

Also a base layer of crystalline polysilicon sandwiched between two layers of amorphous polysilicon and two other technologies are combined to create heterojunction. More solar energy can be captured because to its construction. The cells are hence more efficient as a result as shown in figure 6 and figure 7.

TABLE VI. MODEL COEFFICIENTS AND CONSTANTS FOR MC-SI PV TECHNOLOGY

Coefficients	Monsoon	Post Monsoon	Winter	Summer
a1	0.2310	0.2285	0.2206	0.2277
a2	0.0013	0.0175	0.0144	0.0133
a3	0.0305	0.0371	0.0349	0.0334
a4	1.2999	1.1164	1.1701	1.1133
a5	-1.4282	-1.9691	-1.7282	-1.1044
a6	-3.9190	-2.3736	-2.4666	-1.7897

Table VI shows the model coefficients and constants for mc-Si PV technology. Root mean square value for temperature is observed with respect to seasons namely monsoon, post monsoon, winter and summer as 4.4314, 3.6745, 3.6479, and 3.7285 respectively. Similarly, with respect to power, RMSE values are noted as 2.8756, 4.1847, 5.2429 and 5.0324 for mc-Si technology as shown in the table VII.

TABLE VII. TEMPERATURE AND POWER RMSE FOR MC-SI TECHNOLOGY

	Monsoon	Post Monsoon	Winter	Summer
Temperature	4.4314	3.6745	3.6479	3.7285
Power	2.8756	4.1847	5.2429	5.0324

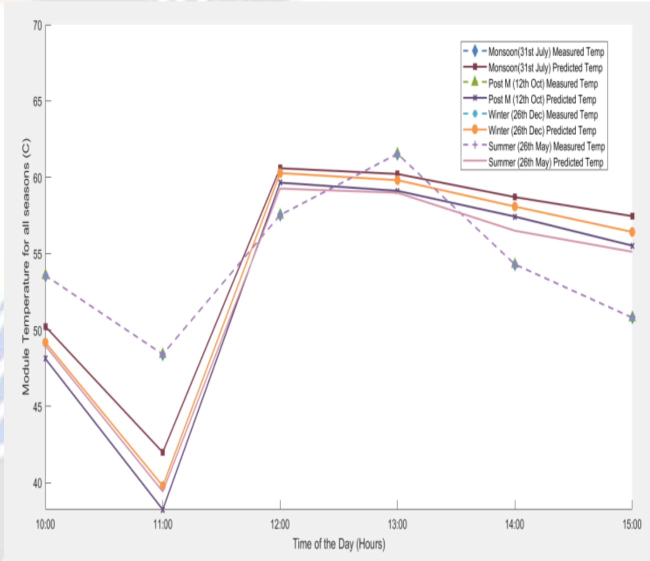

Figure 8.Season wise output temperature variation for mc-Si technology

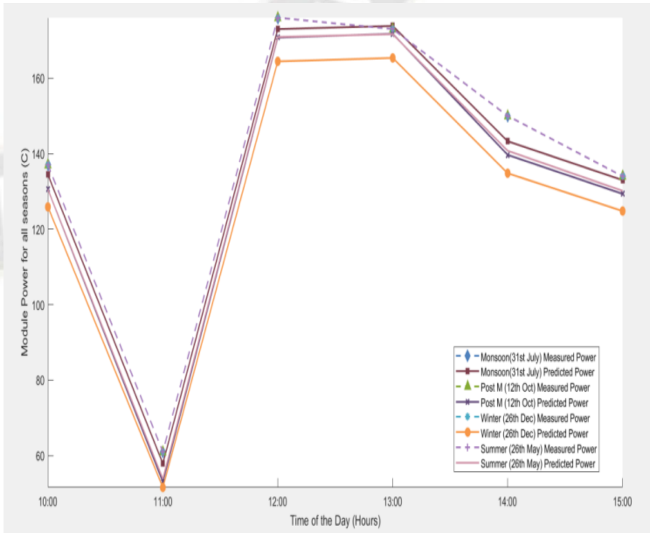

Figure 9.Season wise output temperature variation for mc-Si technology

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From the figure 8 and 9, it is observed that more variation is obtained with respect to temperature as well as power RMSE as compared to other technology.

TABLE VIII. COMPARATIVE ANALYSIS W.R.T. PROPOSED METHOD

PV Technology	Active module area, A (m^2)	Module power P_{STC} (W)	Temperature Coefficient of power (%/°c)	Temperature RMSE by Proposed (PSO) Method	Power RMSE by Regression method (%) (Magare, D.B et al., 2022)	Power RMSE (%) by Proposed (PSO) Method
a-Si	1.15	75	-0.3	3.11	3.72	**3.58**
HIT	1.05	210	-0.33	2.12	3.02	**2.80**
mc-Si	1.01	160	-0.49	3.87	4.68	**4.33**

The estimation of the model's expected coefficients was completed satisfactorily in this study. At this Gurgaon site, the RMSE of the relative predicted coefficient was also estimated using particle swarm optimization method. The PSO algorithm offers several key advantages over mathematical algorithms and other heuristic optimization techniques, including a simple concept, basic implementation, robustness to control factors, and computational economy. As shown in table VIII, temperature root mean square values obtained are 3.11, 2.12, and 3.87 for a-Si, HIT, and mc-Si respectively. By using regression method mentioned in the literature RMSE values with respect to power are obtained as 3.72 for a-Si, 3.02 for HIT and 4.68 for mc-Si PV technology. By using proposed method that is particle swarm optimization RMSE values get decreases and improve the performance. Observed RMSE values with respect to power are 3.58 for a-Si, 2.80 for HIT and 4.33 for mc-Si PV technology. It has been demonstrated that PSO can deliver superior results more rapidly and affordably than other methods.

V. CONCLUSION

The current paper compares the impact of seasonal spectral fluctuations on PV modules using the a-Si, HIT, and mc-Si technologies in an Indian setting. The measure-ment site is a part of the composite climate, which exhibits a significant seasonal change in environmental circumstances. Seasonal changes affect the solar spectrum that strikes the modules.

The results showed that, when compared to a-Si and mc-Si, the electrical efficiency and output power of the HIT PV module technology were performing well at the NISE site. This is due to its 2.80 power RMSE score and good efficiency. The study that has been given is crucial and applicable in evaluating the effectiveness of major solar power plants that have been erected all over the world.

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