International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Thermal Examination of Polycrystalline Photo Voltaic Modules Under Various Spectral Intensities and Conditions

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ABSTRACT

With the development of radiation-absorbing materials and additional advancements in developing technology, this renewable energy source could meet energy demands in the years to come. Researchers are currently attempting to maximize its potential. Over the past 15 years, the demand for solar energy has increased daily and by roughly 30% annually on a global scale. In contrast, the annual growth rate of the hydrocarbon demand is between 0 and 2%. Numerous factors contribute to this rapid rate of increase in solar energy, including the rising cost of petroleum products and the concurrent decline in the cost of solar power generation, as well as global concern over the negative effects of fossil fuel use.

By taking analytical and experimental test readings at Bhopal and making observations under various ambient conditions, the thesis presents thermal analysis for 10 W polycrystalline solar photovoltaic modules with respect to the first and second laws of thermodynamics. The module's energy, availability, and power conversion efficiency were evaluated. Numerous factors, like spectral wavelength variation, sun intensity, wind speed module temperature, and ambient temperature, affect this judgement. Temperature and the wavelength of spectrum irradiation are both inversely related and alter in response to changes in the earth's climate. Using different spectral wavelengths, the energy efficiency of PV modules on clear, hazy, and cloudy days is found to be (ηen = 10.61, ηen = 6.44, and ηen = 2.17). The energy efficiency of polycrystalline photovoltaic modules varied from (ηex = 10.01, ηex = 7.42, ηex = 5.32, and ηex = 1.47) to 0.37% for various ambient conditions, and the power conversion efficiency ($\eta spce$) varied from 8.55, $\eta spce$ = 6.33, and $\eta spce$ = 3.33.

It is evident from the study that PV modules are extremely promising power generation devices that can deliver a longer energy supply at a lower cost. All of these analyses and evaluations will lead to recommendations that will help increase the efficiency of PV modules while also making them more affordable and suitable for today's market. PV module installation facilities should be available in every Indian location so that a vast amount of spectral energy can be efficiently converted into electrical energy to meet our daily needs for electricity.

Key Words: - PV module, Spectral Wavelength Variation, Renewable energy, Energy efficiency, Exergy efficiency, Climatic Condition, Polycrystalline Silicon cell.

1. INTRODUCTION

1.1. Basic of the Renewable Energy Sources

India's strong GDP growth rate has led to a massive need for energy, yet supply cannot keep up with demand. The Indian government has created new laws to promote renewable energy in general and solar energy in particular as a result of the current state of power generation. Actually, one of the few nations in the world with a ministry specifically focused on new and renewable energy is India. Today, we must learn about renewable energy sources, which are widely accessible and reasonably priced. It is employed to lower the price of producing energy. Therefore, the primary alternative to fossil fuels in the future will be renewable energy sources.

Given that 70% of India's electricity is produced by fossil fuels, it may be concluded that the country is heavily reliant on them. The Jawaharlal Nehru National Solar Mission (JNNSM) was started by the Indian government to promote solar energy in order to promote ecologically sustainable growth. The Prime Minister and his Cabinet approved a five-fold boost in funding this session to help India meet its solar power capacity objective of one million megawatts by 2030, under the direction of the Jawaharlal Nehru National Solar Mission (JNNSM). With the help of several developed nations, India will achieve this ambitious target and rank among the world's top producers of solar energy.

1.2. Basic Principal of Solar Module

Sunlight is converted into electrical power using photovoltaic panels. Semiconductor materials are used to make modules. By absorbing solar energy, they are transformed from incident solar radiation into thermal energy. Silicone semiconductor crystals are currently the most often used variety. The ntype and p-type layers of silicon crystal are laminated and stacked on top of one another. Electricity is produced via the "photovoltaic effect," which is caused by light striking crystals. Direct current (DC) is used to produce power, which can be used right away or stored in a battery.

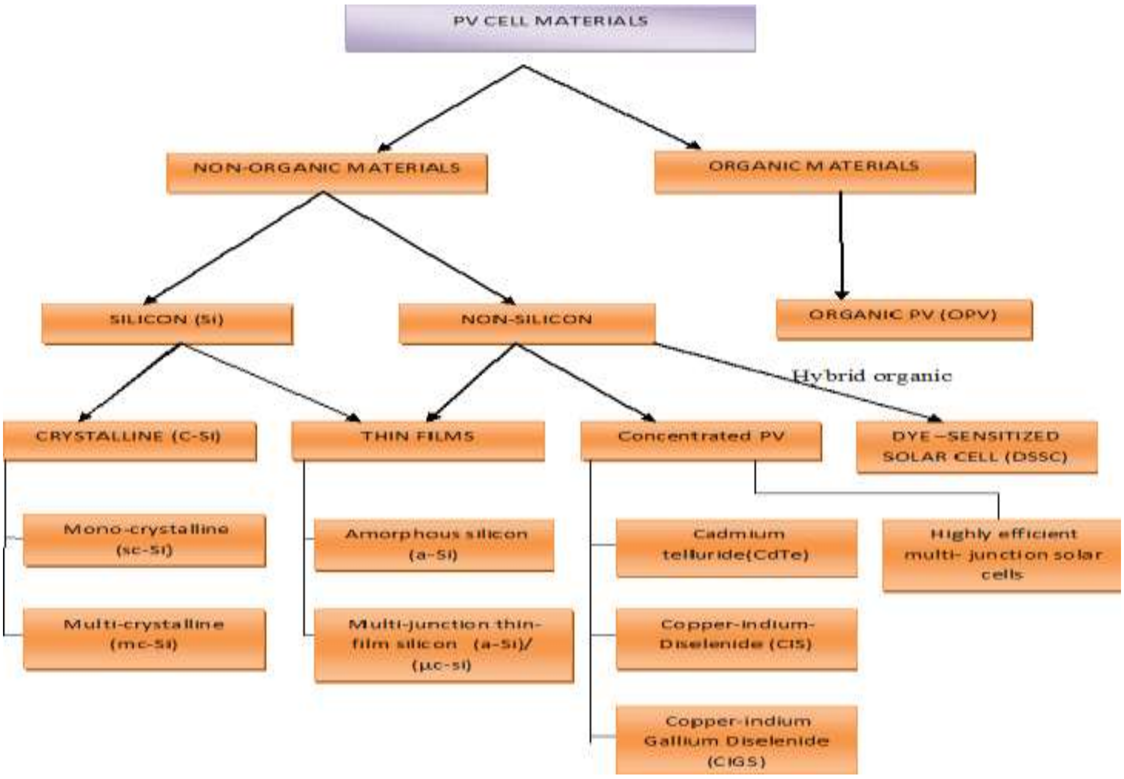

Fig.1.1 Classification of PV cell materials

2. LITERATURE REVIEW

2.1. Literature is Based on Energy and Exergy Analysis

In this chapter, a thorough review of the literature has been conducted on a number of research topics, including hybrid culture of solar power generation of solar photovoltaic (SPV) systems and thermal analysis (Energy and Exergy) at various climatic conditions, particularly at spectral solar irrediation variation. The literature includes the following: -

Nuruddeen Abdullahi et. al. [1] Researchers have produced a substantial impact and program in this effort to comprehend the modelling principles and performance of PV modules under a variety of situations, including wind, dust, and snow, which frequently and may cause PV module degradation.

Jannik Heusinger et. al. [2] With routinely available meterological input, this new energy balance model accurately simulates the full diurnal dynamics of PV module thermal behaviour. The model is thoroughly tested against sensible heat flux measurements, electrical output, and observed module surface temperature (daily and nighttime).

M. R. Abdelkader [3] This study assesses how well various solar modules function in Jordan's semi-arid climate. At various points during the year, an experiment is carried out to examine the performance of two photovoltaic modules. This article measures the following parameters: sun intensity, ambient temperature, and the PV modules' output open circuit voltage and short circuit current.

T.T.Chow [4] A review of hybrid solar technology that combines photovoltaic and thermal technologies. They provide details on fundamental ideas, early research, technology advancements in the 1990s, and PV system performance evaluation.

Alcantara S.P., Del et.al. [5] One technology that directly converts solar radiation into electrical and thermal energy is the solar photovoltaic (SPV) system. There are two direct ways to use solar energy that reaches the earth's surface: first, by using solar photovoltaic modules to turn it directly into electrical energy (electricity); second, by using solar collectors to heat the medium for low-temperature heating applications.

R. Gottschalag et.al. [6] In order to understand the impact of spectrum change in a marine climate on the performance of single and double junction amorphous silicon solar cells, the authors of this work have presented an accurate prediction of system performance together with an experimental examination.

Ricardo Ruther et. al. [7] This study compared the monitoring and outer door operation of amorphous silicon with the conventional and well-understood operation of crystalline silicon.

Giuseppina Ciulla et.al. [8] This work optimises the energy production process by implementing a hybrid system that combines the generation of thermal and electric energy. The PV module's temperature is the essential operating parameter to take into account.

D.G.Infield et.al. [9] This study examined the extent of incident solar spectrum variation and its possible impact on thin-film solar cell performance in a maritime environment. Amorphus silicon is found to be the most vulnerable to changes in the spectral distribution, with the useful frication of the light varying between +6% and -9% of the annual average, with the maximum occurring in the summer.

K. Sudhakar et al. [10] energy and exergy analysis 36-watt photovoltaic solar module It has been determined that exergy is a more effective and efficient instrument for analysing the solar panel's performance.

Pankaj Yadav et.al. [11] To concentrate solar radiation on a monocrystalline silicon-based photovoltaic module, a piecework linear parabolic trough collector is designed in this work. Electrical energy and exergy analysis of the flow concentration PV system operating under real-world test conditions is done using a theoretical model.

Sahin et al. [12] Using energy analysis, the thermodynamic properties of solar photovoltaic (PV) cells are examined. They created and implemented the novel method for evaluating PV cells, and they discovered that it was practical since it takes thermodynamic parameters like entropy and enthalpy into consideration.

Joshi et al. [13] energy and exergy study to determine the performance parameters of photovoltaic (PV) and photovoltaic-thermal (PV/T) systems in New Delhi, India. They discovered that the energy efficiency of PV/T ranges from 33 to 45%, while the equivalent energy efficiency ranges from 11 to 16%.

K.N.Shukla et.al. [14] Based on measurable variables like solar intensity, ambient temperature, wind speed, and module temperature, the energy, exergy, and power conversion efficiencies of both modules have been assessed.

Akash kumar shukla et.al. [15] A thorough examination of the energy and exergy analysis of building integrated photovoltaic modules to assess electrical performance, exergy destruction, and exergy efficiency with photonic method has been covered in this paper, which reviews the exergetic assessment of BIPV modules using parametric and photonic energy methods.

Tiwari et al. [16] Applications for thermal modelling of photovoltaic (PV) modules. Various PV module applications based on electrical and thermal output have been discussed in the review article.

Soteris A. Kalogirou et.al. [17] The solar thermal system's energy analysis is presented in this review study. Additionally, it provides information on the many kinds of solar collectors and how solar thermal systems are used.

S. Armstrong et al. [18] The determination of the PV panel's thermal reaction time is of interest, as is a thermal model for the panels under various atmospheric circumstances. Convective and radioactive heat loss from the PV panel is calculated using data of wind speed, global radiation, back surface temperature, and ambient temperature.

Arvind Tiwari, et. al. [19] Integrated photovoltaic thermal solar water heater energy analysis under constant flow rate and constant collection temperature modes, as well as performance evaluation of solar photovoltaic/thermal systems.

Latifa Sabri et. al. [20] This study examines experimentally how ambient conditions affect the thermal characteristics of photovoltaic cells made of crystalline and amorphous silicon.

Dubey et. al. [21] In terms of thermal energy, electrical energy, and exergy gain, the PV/T air collector with the air duct above the absorber plate performs better than the one with the air duct below the absorber plate, according to an evaluation of their energetic and exergy-related performance.

Swapnil Dubey et. al. [22] Analysis of PV/T air collectors connected in series in terms of energy and exergy. The hourly change between cell temperature and efficiency demonstrates that cell efficiency falls with increasing temperature. According to the results, the cell efficiency of the current PV module design decreases by 1.6% when the cell temperature rises by 24.48C.

Adarsh kumar pandey et. al. [23] They examined the energy and exergy performance assessment of a standard solar photovoltaic module, obtaining cell efficiency of 19.9 and module efficiency of 17.4 of PV module efficiency using various module parameters.

C. Schwingshackl et. al. [24] Wind effect on PV module temperature: Various methods for a precise estimate were examined and tested on a number of current models to assess the PV module temperature in relation to wind, ambient temperature, and solar irradiation.

M. Pathak et. al. [25] Optimising Limited Solar Roof Access through Exergy Analysis of Solar Thermal, Photovoltaic, and Hybrid Thermal Systems These systems outperform PV+T or PV only systems in terms of exergy performance since they can use all of the thermal and electrical energy produced.

Mehid Hosseini et. al. [26] They are examined. Fuel cell energy and exergy are integrated heat and power systems, which makes them hybrid systems suitable for home use. The PV system's energy and exergy efficiency was discovered.

Nouar Aoun et. al. [27] Investigation of Monocrystalline PV Panel Experimental Energy and Exergy According to this article, on cloudy days, energy efficiency ranged from 22.3% to 17.2%, exergy efficiency from 5.3% to 12%, and power energy efficiency from 12.3% to 16.1%.

Cheikh El Banany ELHADJ SIDI et. al. [28] Examination of monocrystalline solar module performance outdoors and the impact of temperature on energy efficiency.

3. OBJECTIVES

In order to gain a better understanding of the relative importance of incident irradiation spectrum variation and associated thermal behaviour of polycrystalline PV modules at various geographic locations, the overall goal of this work is to design a thermodynamics approach.

The objectives of this work are to:-

i. To ascertain the PV module's energy analysis for various climatic spectral conditions in Bhopal.

ii. To ascertain the PV module's energy analysis under various climatic spectral conditions in Bhopal.

4. EXPERIMENTATION

4.1 Experimental Methodology

This thesis examines how well 10W solar modules operate in Bhopal, India, under various weather situations, including clear skies, hazy days, and cloudy days. At Energy Centre, MANIT Bhopal, India, experimental test readings are conducted for various environmental conditions on various days. Using energy analysis, the PV module's performance efficiency is determined. Compared to energy analysis, energy analysis is more practical for forecasting solar panel efficiency. Because variables including wind speed, ambient temperature, and solar intensity changed over the course of the day, calculations were made while accounting for climatic circumstances.

The experimental configuration is displayed in Fig. 5.1. Table 3 displays the operational, design, and climate factors. Tables show the thermal, electrical, and metrological parameters that are measured for each hour of the PV module.

Fig. 4.1 Measuring Instruments

Serial No.	Name of measuring instrument	Manufacturing and model no.	Rating	Application
1.	Solar power meter	TM-207 (Taiwan)	0 – 1999W/m2	Solar radiation intensity
2.	solar module analyzer	MECO (9009) (india)	Voc= 0-60V Isc = 0-12A	PV module characteristics
3.	Infrared Gun (thermometer)	Raytek (china)	0-500 °C	Ambient temperature and humidity
4.	Thermo Hygrometer	HT-3006A (China)	0-100% 0-100 °C	Ambient temperature and humidity
5.	Multimeter	Rish muth 155 (india)	R, 0-100 Ω V, 0-1000V I, 0-300mA,0-10A	PV module output current and voltage

Table No. 4.1 Specification of Measuring Instruments

Parameters	Specifications
Maximum power (Pm)	10W
Open-circuit voltage (Voc)	21.5V
Short-circuit current (Isc)	650Ma
Number of cell's in module	36
Specific size of the module (Amod)	34×28 cm
Maximum power point voltage (Vmp)	17.8V
Maximum power point current (Imp)	590 Ma
Fill factor (FF)	0.78
Tolerance at peak power	+5%
Standard test condition (STC) Irradiation, spectrum and cell temperature	1000W/m2, AM1.5, 25°C

Table No.4.2 Specifications of (polycrystalline model no-RE 1216) PV module

4.2 Experimental data sheet for clear, hazy and cloudy day

Table No.4.3 Average of Three days 'Experimental Data For Clear Day

Time	Thermal Wavelength (m-K)	Ambient Temperature (°C)	Wind Speed (m/s)	Relative Humidity (%)	Solar Intensity (W/m2)	Module Temperature (°C)	Energy efficiency					
							Voc	Vm	Isc	Im	Pmax	η
09:00AM	1.008×10^-5	14.2	1.52	34.4	665	15.2	15.48	15.72	0.35	0.35	5.50	8.61
10:00AM	1.004×10^-5	15.6	1.28	36.3	725	16.8	15.53	15.9	0.36	0.36	5.72	8.21
11:00AM	1.015×10^-5	21.2	2.03	35.03	830	25.3	15.81	16.15	0.51	0.50	8.07	10.12
12:00AM	9.707×10^-6	25.5	1.83	36.22	940	30.2	16.55	17.12	0.54	0.55	9.416	10.13
01:00PM	1.015×10^-5	21.2	1.34	36.55	986	26	16.85	17.65	0.55	0.59	10.41	10.9
02:00PM	1.012×10^-5	22.1	2.33	38.95	995	24	16.95	17.42	0.52	0.58	10.10	10.57
03:00PM	1.019×10^-5	20	1.02	40.22	865	24.6	16.33	17.13	0.50	0.52	8.90	10.71
04:00PM	9.944×10^-6	18.4	1.65	39.05	740	22	16.26	16.28	0.34	0.39	6.34	8.92
05:00PM	1.006×10^-5	15	1.77	38.25	680	19	15.38	15.98	0.30	0.38	6.07	9.29

Table No.4.4 Average of three days ‘experimental data for hazy day

Time	Thermal Wavelength (m-K)	Ambient Temperature (°C)	Wind Speed (m/s)	Relative Humidity (%)	Solar Intensity (W/m2)	Module Temperature (°C)	Energy efficiency					
							Voc	Vm	Isc	Im	Pmax	H
09:00AM	9.595×10^-6	32	1.53	55	626.66	33	13.82	15.14	0.10	0.12	1.81	2.63
10:00AM	9.500×10^-6	35	1.44	51.13	690	37	13.9	15.29	0.12	0.15	2.32	3.53
11:00AM	9.439×10^-6	37	2.1	45.8	638.33	39	13.98	14.74	0.18	0.19	2.79	3.76
12:00AM	9.317×10^-6	38	1.42	39.66	581.33	40	14.74	15.17	0.24	0.24	3.73	6.44
01:00PM	9.287×10^-6	39	0.42	36.33	756.66	45	13.86	15.30	0.22	0.29	4.62	4.62
02:00PM	9.258×10^-6	40	1.80	33.4	542	46	13.98	15.07	0.15	0.16	2.40	4.16
03:00PM	9.408×10^-6	38	0.82	40.73	514.33	45	13.86	15.42	0.16	0.19	2.92	5.87
04:00PM	9.439×10^-6	37	1.90	37.86	95	38	11.68	12.96	0.07	0.08	1.04	5.46
05:00PM	9.469×10^-6	36	1.18	40.1	49.33	37	11.95	11.53	0.01	0.01	0.23	1.72

Table No.4.5 Three Average Days Of Experimental Data Sheet For Cloudy Days

Time	Thermal Wavelength (m-K)	Ambient Temperature (°C)	Wind Speed (m/s)	Relative Humidity (%)	Solar Intensity (W/m2)	Module Temperature (°C)	Energy efficiency					
							Voc	Vm	Isc	Im	Pmax	H
09:00AM	9.724×10^-6	25	1.86	39.66	45.66	28	8.91	9.46	0.061	0.06	0.592	0.39
10:00AM	9.659×10^-6	27	1.93	38	68	30	9.37	9.96	0.083	0.08	0.819	0.55
11:00AM	9.595×10^-6	29	2.3	37.33	93.33	31	9.67	10.27	0.35	0.09	0.975	0.91
12:00AM	9.500×10^-6	32	2.1	38.66	163	35	9.77	10.48	0.107	0.1	1.21	1.40
01:00PM	9.439×10^-6	34	1.83	40.5	218.33	38	10.37	10.98	0.117	0.103	1.32	1.25
02:00PM	9.377×10^-6	36	1.93	41.66	265	40	10.90	11.62	0.122	0.111	1.23	2.17
03:00PM	9.500×10^-6	32	1.63	31.96	163.66	38	10.38	11.02	0.358	0.092	1.022	1.34
04:00PM	9.595×10^-6	29	1.9	29.86	66.66	33	9.24	10	0.079	0.070	0.702	0.72
05:00PM	9.659×10^-6	27	0.83	26.63	31	31	9.06	9.28	0.038	0.027	0.253	0.37

5. RESULTS AND DISCUSION

Using specific equipment, the impact of operating, design, and climatic factors on the performance of polycrystalline PV modules is examined. Using the energy from solar radiation, this performance provides information on the solar PV module's energy efficiency, which has been measured using the second law of thermodynamics. The experimental performance was unaffected by the convective heat transfer coefficient (hconv) between the PV module surface and the surrounding air. The input energy's shape is determined by the global irradiation, and for polycrystalline modules, the larger the irradiance, the larger the difference.

The following figures below, which show the average thermal radiation of three days of data taken into consideration for different climatic seasons in Bhopal, can be used to analyse and compare the variation of power and efficiency found during an experiment of polycrystalline PV module operating performance on different climatic conditions such as clear, hazy, and cloudy season of Bhopal region India at different times.

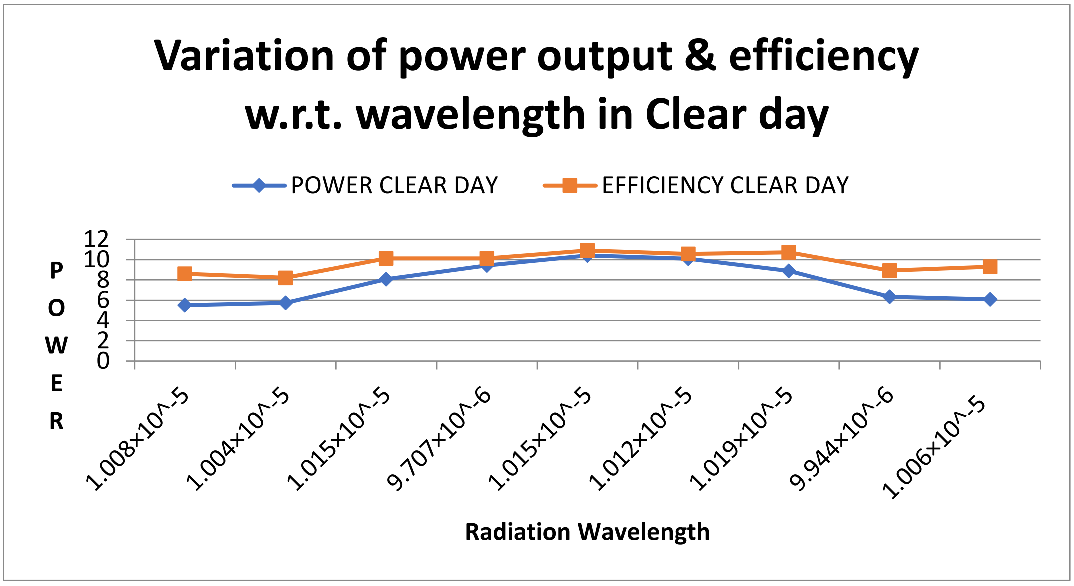

Fig.5.1 Variation of Power and efficiency w.r.t average radiation wavelength of three days in Clear Day.

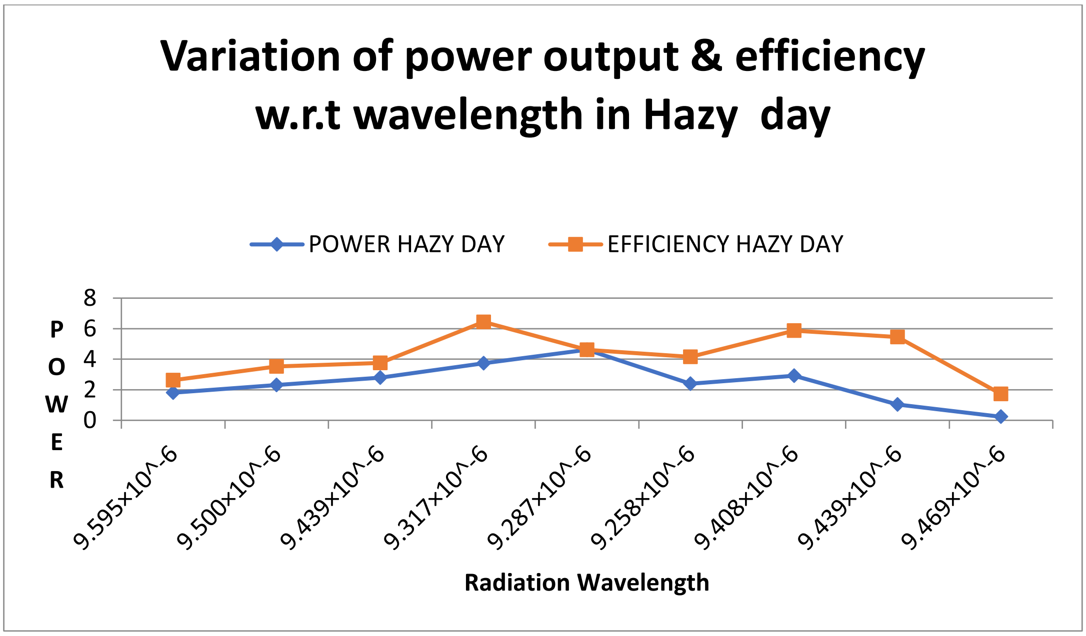

Fig.5.2 Variation of Power and efficiency w.r.t average radiation wavelength of three days in Hazy Day.

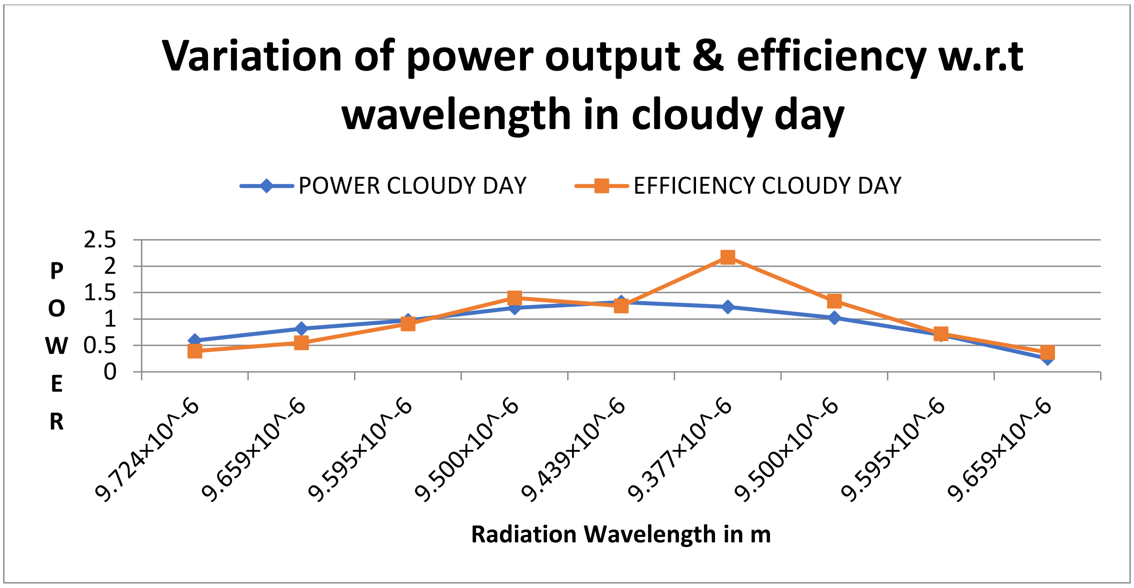

Fig.5.3 Variation of Power and efficiency w.r.t average radiation wavelength of three days in Cloudy Day.

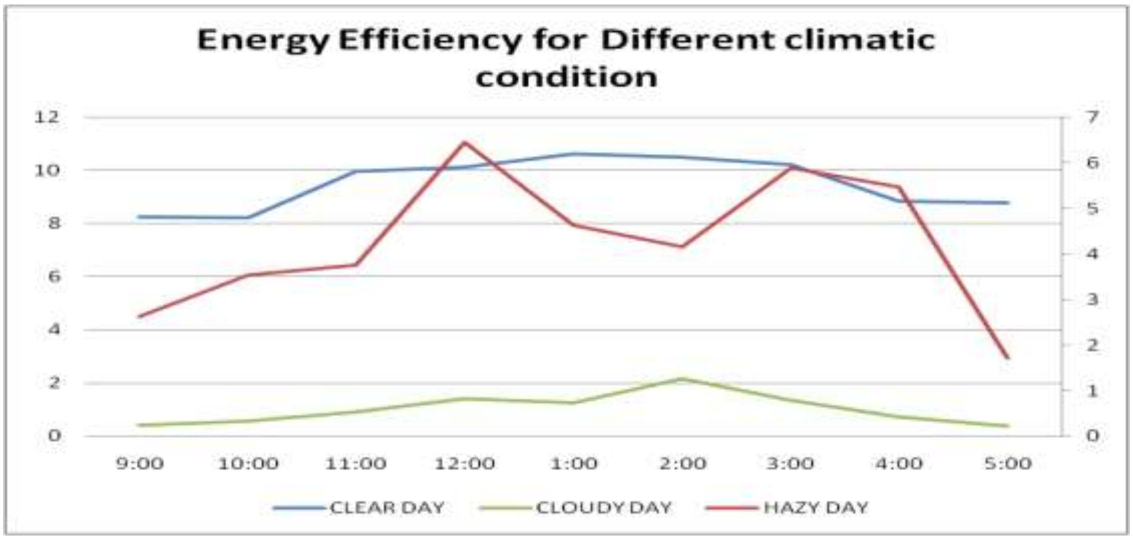

Fig.5.4 Shows comparison of energy efficiencies for different climatic condition of 10 watt polycrystalline module.

6. Discussion

For estimating the solar module's efficiency, energy analysis is less practical than energy analysis. This experiment determined the energy (ηen) and exergy (ηex) efficiency of a 10-watt polycrystalline photovoltaic module under various environmental conditions. On clear days, energy efficiency ranges from 10.61 to 8.21%, on hazy days, it ranges from 6.44 to 1.72%, and on cloudy days, it ranges from 2.17 to 0.37%. Energy efficiency ranges from 10.01 to 7.53% on clear days, 5.98 to 1.03% on hazy days, and 1.96 to 0.22% on gloomy days. From the perspective of the experimental investigation, the module performs better on clear days than on hazy ones, but on cloudy days, it performs far worse than on either day. Because the studies are conducted in real outdoor environments, there is a modest decrease in energy and energy efficiency. This analysis takes into consideration variables including wind speed, ambient temperature, and humidity.

7. CONCLUSION

By analysing the emitted spectrum, this paper presents an experimental analysis of a 10 Watt polycrystalline PV module under various environmental conditions. PV module based on Crystalline Silicon Photovoltaic Solar Module thermal analysis (Energy and Exergy) for various ambient conditions has been conducted at various irradiation wavelengths. During the last few days of summer, this experimental data was acquired using a simple measuring device that provided precise measurements. The optimal temperature in relation to the irradiation wavelength was determined by analysing the experimental data collected throughout the experiment. This led to an examination of the energy efficiency and the computation of the module's maximum efficiency and maximum solar power conversion efficiency.

This investigation has also determined the energy loss in the module's photovoltaic conversion process. The following are the findings of an experiment conducted to examine the thermal performance analysis of polycrystalline PV modules in the Bhopal climate region of India.

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