Exergeoeconomic of 50 W Solar PV Module

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A B S T R A C T

The objective of the present study is to determine the exergeoecomic performance of solar PV panel. The study was conducted in April(2021) under climatic conditions of Udaipur (24°35'7" °N; 73°42'45" °E). The Exergy output, Exergy input and Energy input, Energy output was calculated. The Energy loss and Exergy loss was determined. It was found out that exergy loss was higher as compared to energy losses. Exergy input is always higher than energy input. Due to the change in ambient temperature and module temperature exergoeconomic performance is greatly affected. Due to the inclusion of factor related to temperature difference and wind velocity, exergy output is always less than the energy output.

Introduction

In this modern and technological era, there is always high energy demands, conventional sources are depleting at an alarming rate. Fossil fuels when burned leads to the emission of harmful gases such as carbon dioxide and carbon monoxide. These gases not only pollute the environment but also lead to global warming (1-2). The Intergovernmental Panel on climate change estimated a temperature rise of 2.5 degree Celsius by the next centuries. Solar energy is a form of renewable energy that is inexhaustible. Sudhakar *et al.,* (3,4)

reported that solar radiation intensity in Indian climatic conditions is varied in the range of 4–7 kW h/(m^2 day) annually. A solar PV system can convert solar radiation into electrical energy. Employing solar PV system enormously increase sustainability.

As per the Indian scenario, solar PV systems can meet the increasing energy demands, as India gets maximum hours of sunshine. Thus India holds immense potential in solar energy. The application of solar energy will also help in reducing pollution and the global warming effect.

Due to such great advantages of solar PV system engineers and scientists are constantly researching to increase its efficiency and performance. The conventionally used energy analysis does not give a clear insight intothe performance assessment of solar PV system.

Thus a new method of exergetic analysis was introduced. Exergy analysis is based on the second law of thermodynamics it thus helps in quantitatively detect and evaluate the thermodynamic irreversibility in a system.

Hence it helps in thermodynamic improvement of the system. Sahin *et al.,* (5) investigated the thermodynamic characteristics of the solar photovoltaic (PV) cells using exergy analysis. They developed and applied the new approach for the assessment of PV cells and found that the presented approach was realistic as it accounts for thermodynamic quantities such as enthalpy and entropy. Though this analysis helps in giving clear insight very few works of literature have been reported on the method.

The technique which combines scientific assessment with economic consideration to achieve optimum design is called exergoeconomics (6).

It helps in calculating of cost of inefficiencies by undertaking exergy losses and energy losses into consideration. Agrawal *et al.,* (7) conducted exergoeconomics analysis of a glazed photovoltaic thermal module air collector. The Exergoeconomic of the various thermal systemwas discussed by M. A Dincer *et al.,* (8).

The ratio of thermodynamic loss rate to capital cost is a significant parameter (9). Thus using this method experiment was conducted to estimate the exergy losses and economic parameters under the climatic condition of the Udaipur region.

Materials and Methods

System Description

An experimental investigation was carried out at College of technology Agriculture Engineering Udaipur (Rajasthan), India (24°35′7″ N; 73°42′45″ E and at an altitude of 582.5 m above mean sea level). The study was performed during April 2021 in real atmospheric conditions. The technical specifications of solar panel are presented in Table 1.

The values of the input parameter for further analysis of the PV system are shown in Table.2.

Exergoeconomic Analysis

Exergoecomic uses exergy and energy analysis with its economics. According to the study conducted by Rosen *et al.,* and Tiwari *et al.,* (10,11), on Exergy cost Energy mass analysis. First, all the exergy and energy analysis is performed. And energy loss rate and the exergy loss rate is calculated.

$$En_{in} - En_{out} = L_{en} \ldots (1)$$

$$Ex_{in} - Ex_{out} = L_{dest} \ldots (2)$$

Where Enis energy, Ex is exergy. Suffix in is for input and out is for output. Len is the energy loss rate and L_{dest} is the exergy destruction rate.

In this analysis, exergoeconomic parameter R is formed. This parameter is the ratio of the thermodynamic loss rate (L) to the net capital cost(K). The terminology 'Ren' is used to represent energetic terms whereas 'Rex' denoted exergitic parameters.

Thus, exergoeconomic parameter equation is given by.

$$R = \frac{L}{K} \quad …(3)$$

Similarly, for energetic and exergetic considerations the parameter equation is given by.

$$R_{en} = \frac{L_{en}}{K} \quad …(4)$$

$$R_{ex} = \frac{L_{dest}}{K} \quad ….(5)$$

Energy Loss Rate

In order to find the input and output energy of the PV module, the above parameters and values are calculated by instruments such as luxmeter for calculating solar radiation.

And wire wound rheostat of 50Ω, to calculate the current and voltage in load condition is used. The current-voltage data is read by the multimeters. The energy loss rate is a difference between energy input and energy output. Thus it's given by(12).

The energy input of the module is the product of solar radiation (Is) W/m² and effective area (A) m².

$$En_{in} = Is \times A \quad …(6)$$

The energy output is power generated by the PV module in load condition.

$$En_{out} = Vm \times Im \quad …(7)$$

Thus from equation (6) and (7)

$$L_{en} = IsA - VmIm \quad …(8)$$

Using the above equation exergeoeconomic parameter considering energetics of the system (Ren) is calculated.

Exergy Loss Rate

To find the exergy loss rate, exergy input and output is calculated by the equation given by (13) for electrical exergy and thermal exergy. Similarly, the exergy loss rate is a difference between exergy input and exergy output.

The Input exergy is calculated by the following equation

$$Ex_{in} = Is \times A \left(1 - \frac{Ta}{Ts}\right) \quad …(9)$$

Where Ts is taken as 5777K as per Holmberg's study (14).

The output exergy is the difference between electrical exergy and thermal exergy which can be calculated as per the equation given below.

$$Ex_{elec} = VmIm \quad …(10)$$

$$Ex_{therm} = \left(1 - \frac{Ta}{Tcell}\right) hcA \left(Tcell - Ta\right) \quad …(11)$$

$$hc = 5.7 + 3.8v \quad …(12)$$

Where v is wind velocity in m/sec. As per the above equation,the exergy destruction rate is calculated using Eq (9) and (12)

$$L_{des} = VmIm - \left(1 - \frac{T_a}{T_{cell}}\right) hcA \left(T_{cell} - T_a\right) \quad …(13)$$

The exergoeconomic parameter R_{ex} can be calculated considering the exergetic aspect of the system.

Results and Discussion

Exergy loss rate, Energy loss rate and exergoeconomic parameters

Exergoeconomic analysis has been performed in April. To obtain better changes four

consecutive days have been selected and result analysis has been illustrated in the following figures. According to the figure, there is a parallel variation between energy loss rate and exergy loss rate

Going further into details energy loss rate varies from 79.3W to 289W. And the exergy loss rate varies from 83.7W to 312W, with an average efficiency of the module 12.3%. The relative difference exergoeconomic parameters R_{en} varies from 0.0023 to 0.0053. Among the R_{ex} values of selected days 0.0026 W/Rs, was the minimum value and 0.006 W/Rs as the maximum value. Also depending

upon the L_{en} and L_{desr}, R values decrease during the afternoon and increase during the morning and evening period. The result obtained was similar as reported by Bayat *et al.,* (16).

As mentioned earlier solar irradiation have a linear relation with the $L_{en,}$ L_{dest}. Thus it can be seen in Fig(a) and Fig(b), the graph reaches peak at 1:00 pm. The values of R_{ex} and R_{en}were maximum during the morning and evening economically this means losses are more valuable during this time rather during the day. R_{ex} and R_{en} have also shown a lower linear behavior with the solar irradiation.

Table.1 Specification of PV system

Parameter	Values
Model No.	GOLDI050PM
Rated Power (Pmax)	50W
Open Circuit Voltage (Voc)	21.5V
Short Circuit Current(Isc)	3.14A
Voltage at Maximum Power(Vm)	17.7V
Current at Maximum Power(Im)	2.85A
Maximum System Voltage	1000V

Table.2 Input parameters used in research work

Input Parameters	Values
Ambient Temperature (Ta)	308 ± 5 K
Temperature of the Sun (Ts)	5777K
Cell Temperature (Tcell)	320 ± 10 K
Effective Area (A)	0.36 m^2
Fill Factor	0.85

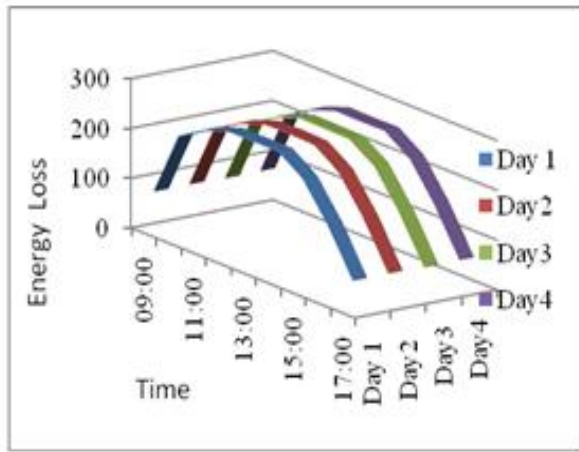**Fig.a** Energy Loss rate on selected days

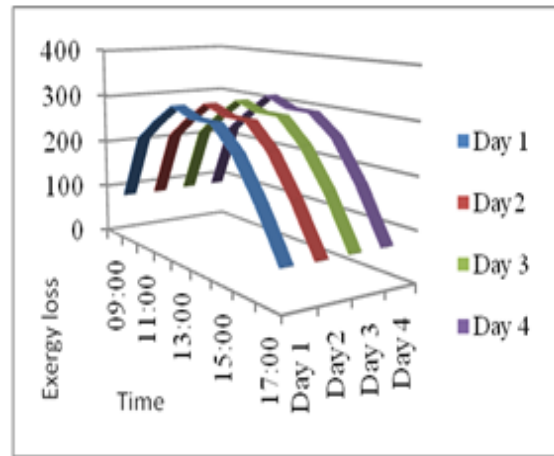**Fig.b** Exergy Loss rate on selected days

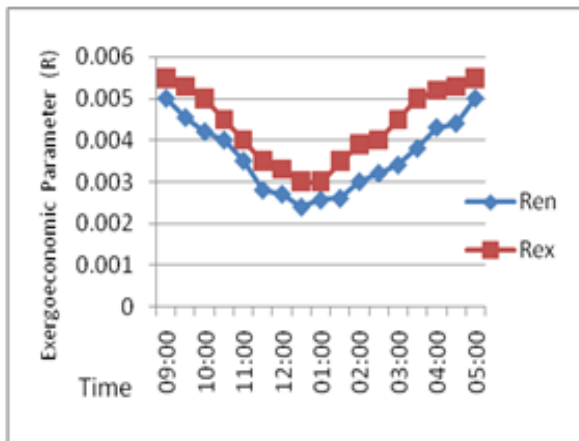
Fig.c Variation in R on 12 April
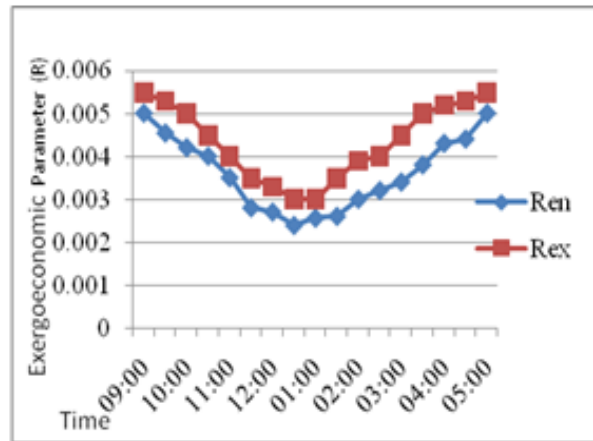
Fig.d Variation in R on 16 April

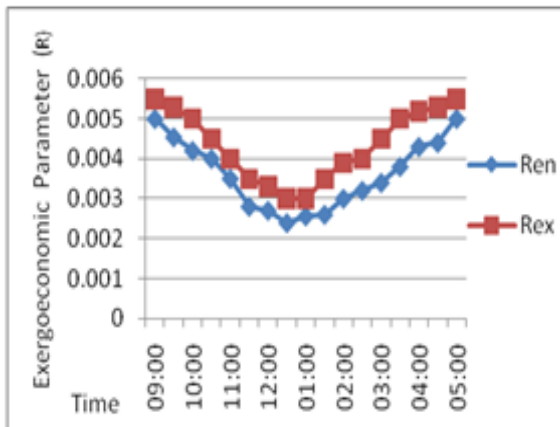**Fig.e** Variation in R on 20 April
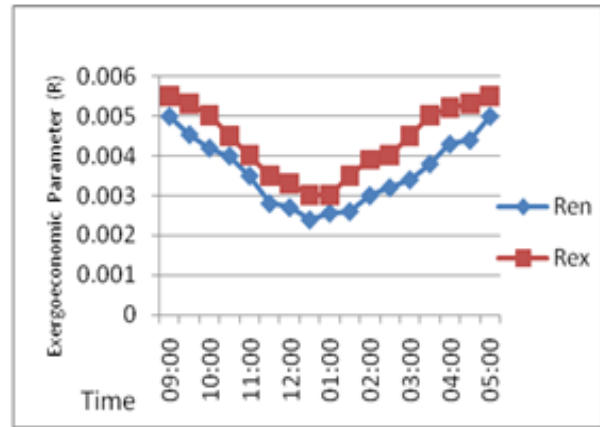
Fig.f Variation in R on 24 April

Figure a and b shows the variation in energy and exergy loss with time respectively. The change in exergoeconomic parameter(R) with time is shown in Figure c to f.

In this paper exergoeconomic parameters of energy and exergy efficiencies for 50 W solar modules were investigated in May. According to the investigation it was found out that R_{ex} is always greater than R_{en}. It was also observed that exergy losses are more than energy losses. As PV modules are electrical devices thus ambient temperature play an important role inthe overall performance of the system. It has been observed that ambient temperature has a negative effect on the system. Also, R_{ex} is a key parameter for device feasibility; the appropriate value of R_{ex} can be used as a design parameter for cost-effective and high-performance devices. Wind velocity impact on losses was found to be very less significant in the month April.

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