Energy and Exergy Analysis of Crystalline Silicon Solar Photovoltaic Module for clear sky Day at Bhopal

Ankit Singh , O.P Shukla and Nishant saxena
Scholar of Thermal Engineering, Millennium Institute of Technology, Bhopal (M.P), 462044, India
Department of Thermal Engineering, Millennium Institute of Technology, Bhopal (M.P), 462044, India

ABSTRACT

With the growing population, demand for a renewable energy source has reached to peak level. It is necessary to have that source available easily and in sufficient quantity so that with the diminishing non renewable source basic need of energy can be fullfiled. This source can be the all time available source – SOLAR energy. Concern of most of the countries is just that to make the availability of this source better and cheaper. Researches are ongoing in this field.

This paper present the thermal analysis for 10 W polycrystalline solar photovoltaic module with regard to the first and second laws of thermodynamics by taking analytical and experimental test reading at the Energy centre, MANIT, Bhopal, India, on a hazy day of (11 June, 2016). We have to evaluate energy, exergy or availability, and power conversion efficiency of the module. This evaluation depends on parameters like solar intensity, wind speed module temperature and ambient temperature. exergetic efficiency of polycrystalline photovoltaic module varied from 11% to 8% throughout the day. It is clear that PV modules are very promising devices and there exists lot of scope to further improve their performances. All these evaluation and analysis will result to give recommendation that will befitted to improve the efficiency of PV module, along with making it cost effective and more compatible in today's market.

Keywords: Energy efficiency, Exergy efficiency, power conversion efficiency, PV module.

INTRODUCTION

With the growing demand of energy, development of a new or convenient energy source is very important in all over the world. It can be in the form of derived energy or or from some renewable source that have futuristic value. Energy is the basic need necessarily to be fulfilled in any developing country, as with the increasing demand and utilizing capacity the hike in prices of the fuel reaching beyond limits for one or other person in developing country.

Also in few coming decades the availability of those fossil reserves is near to get diminished. To switch these depleting sources with some new and effective source. Researchers are being carried out in this way. One of the most viable sources that is widely available and from which energy can be obtained in unlimited amount- SUN.

India is highly benefitted and has great scope for generating solar energy because of its geographical location on Earth. This is the reason of India being a tropical country as it receives solar radiation almost throughout the year, which accounts to about 3,000 hours of sunshine per year. This is equal to more than 5,000 trillion kWh. Almost all parts of India receive 4-7 kWh of solar radiation per sq meters. States like Andhra Pradesh, Bihar, Gujarat, Haryana, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, and West Bengal have great potential for trapping solar energy due to their location. As in our country majority of the population lives in rural areas where electricity is still a big problem, it will be of great benefit to promote solar energy to this region and thus increasing the scope for research. Also use of solar energy can reduce the use of firewood and dung cakes by rural household (1).

Basics of Photovoltaic solar module

Photovoltaic modules are used to convert solar radiation into electricity. Modules are made of semiconductors material. They convert incident solar radiation to heat energy by absorbing solar energy. Currently the most used type of semiconductor crystal is commonly made of silicone. Silicon crystal n-type and p-type layers are laminated and stacked on top of each other. Light rays striking on crystals, induces the “photovoltaic effect” and generates electricity. The form of electricity generated is called as direct current (DC) and it can be used immediately or stored in a battery. The power generated by photovoltaic panels is direct current. This doesn't need to install the inverter for the establishment of the alternating current from as inverters are used for sync with the mains power for conversion. It can be used normally (3).

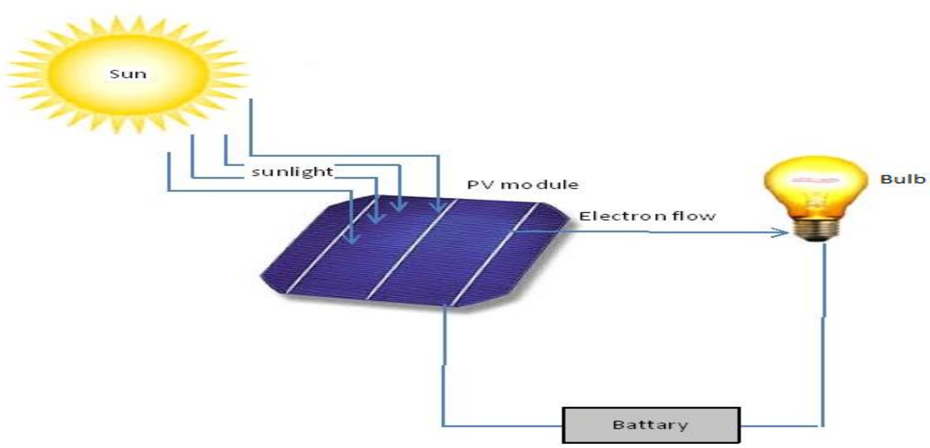

Figure.1. basic principal of photovoltaic module

Different types of performance parameters are dependent on the materials of PV modules and on the climatic conditions of place such as ambient temperature, solar radiation intensities, module temperature. Operating and design parameters are overall heat loss coefficient $(U)_{loss}$, open- circuit voltage$(V)_{oc}$, short-circuit current $(I)_{sc}$, maximum power point voltage $(V)_{mp}$, maximum power point current $(I)_{mp}$, etc. These parameters are evaluated to get gain and loss of thermal energy. This refers to the heat received or gain by solar radiation and heat rejected or loss by module and converted into work form, where work mean electricity and it can also be calculated in terms of energy efficiency and exergy efficiency(2). The efficiency of the panel is approximately in the range of 6-17%. They depend upon type of solar cell at standard temperature and pressure. Here reduction in photoelectric conversion efficiency of the module is 0.5% with an increases the temperature 1 degree Celsius (°C) of the module (4).

Basic concept of thermodynamic

Energy and exergy analysis are dependent on laws of thermodynamics. Energy analysis is based on the first law of the thermodynamic and exergy analysis is based on second law of thermodynamic. Energy analysis gives information about the quantity of energy or heat use .They doesn't give information about the loss of energy its means that rejection of heat to the system that loss of energy or rejection is based on second law of thermodynamic. Thermodynamic analysis has normally divided into closed and open system. Both heat and work are boundary phenomenon. Usually the heat rejected to the system and work transferred into the system, are considered negative (-ve) and heat transferred into the system and the work done by the system, are considered positive (+ve). Energy analysis for first law of thermodynamic for any process between two state 1 and 2 which are in equilibrium is given by the equation (7):

$$\int_1^2 \delta Q = \int_1^2 \delta W + \int_1^2 \delta E \quad (1)$$

After integration, we get

$$Q_{1,2} - W_{1,2} = E_{1,2} \quad (2)$$

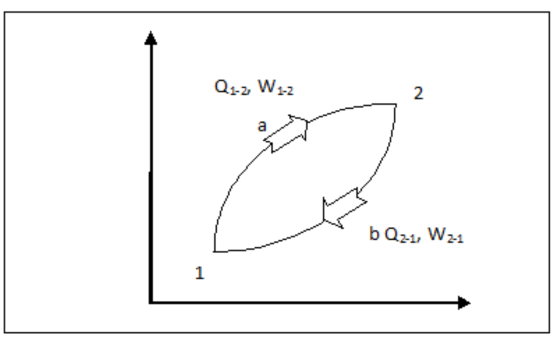

Figure 2 process for given system

Where $Q_{1,2}$ is heat transfer to any process 1 to 2, $W_{1,2}$ is work transfer for any process 1 to 2, and $E_{1,2}$ is the energy transfer for any process 1to 2. Hence heat and work are path fallowed by the particular process as they are path function. It is inexact differential, not a property and it is boundary phenomenon. (5)

The quantity $E_{1,2}$ is same for both path a & b but it is independent of path and it dependents only on end point (2 & 1) therefore $E_{1,2}$ must be a property and **this property is known as energy.**

The "exergy or availability of a system which gives the maximum amount of useful work obtained from the system when it comes into equilibrium with reference to the environment" (5).

Exergy or Availability:

• Yields the maximum work producing potential or the minimum work requirement of a process •Allows evaluation and quantitative comparison of options in a sustainability context (6)

Table 1-Summary of some previous research works:-

Dubey et al.(2009)	Evaluated the energetic and exergetic performance of a PV/T air collector with air duct above the absorber plate and the one with air duct below the absorber plate	it is found that the latter one gives batter results in terms of thermal energy, electrical energy and exergy gain
Swapnil Dubey et al.(2009)	Energy and exergy analysis of PV/T air collectors connected in series	The hourly variation of cell temperature and cell efficiency is shows that as the temperature increases cell efficiency decreases. Result shows that for the present design of PV module the cell efficiency decrease by 1.6% with increase in cell temperature by 24.4 8C.
S.Armstrong et al. (2010)	A thermal model for photovoltaic panels under varying atmospheric conditions and It is a interested to determined thermal response time of the PV panel.	It is measurements of the wind speed, global radiation, PV panel back surface temperature and ambient temperature are used to calculate the convective and radioactive heat loss from the panel. The predicted time constant values are compared to the measured time constant under the three different wind speeds.

K. Sudhakar et al. (2013)	analysis of Energy and exergy 36 W solar photovoltaic module	it is concluded that exergy is a more effective and more efficient tool for the performance analysis of the solar panel.
Mehid Hosseini et al.(2013)	They are analyzed Energy and exergy of fuel cell they are combined heat and power type systems means hybrid system for residential applications.	It was found energy and exergy efficiency of PV system. They are 17% and 18.3% respectively.
Latifa Sabri et.al. (2014)	In this study ,an experimental research concerning the Effect of Ambient Conditions on Thermal Properties of Photovoltaic Cells: Crystalline and Amorphous Silicon	The influence of cell temperature on the thermal characteristics such as the specific heat and thermal conductivity of the cell is show that specific heat increases exponentially by increasing the cell temperature, and also indicates the thermal conductivity decreases linearly for both crystalline and amorphous silicon.
M. Pathak et al.(2014)	Optimizing Limited Solar Roof Access by Exergy Analysis of Solar Thermal, Photovoltaic, and Hybrid Thermal Systems	Which are able to utilize all of the thermal and electrical energy generated, are superior in exergy performance to either PV+T or PV only systems.
Nouar Aoun et al.(2014)	Study of Experimental Energy and Exergy of mono-crystalline PV Panel	In this paper We find from the cloudy day that the energy efficiency varied between 22.3% and 17.2%, the exergy efficiency varies between 5.3% and 12% and power energy efficiency varies from 12.3% to 16.1%. However, from the clear days. The energy efficiency varied between 10.83% and 21.85%, the exergy efficiency varies between 7.98% and 14.54% and power energy efficiency varies from 8.1% to 16.38%. While, from the clear days (i.e. March 23) the energy efficiency varied between 9.28% and 22.1%, the exergy efficiency varies between 1.8% and 15.5% and power energy efficiency varies from 7.55% to 16.83%.
Adarsh kumar pandey et al.(2015)	they investigated the Energy and exergy performance evaluation of a typical solar photovoltaic module	Using different parameters of the module obtain the cell efficiency =19.9 and module efficiency = 17.4 of PV module efficiency

C. Schwingshackl et al (2015)	Wind effect on PV module temperature: Analysis of different techniques for an accurate estimation	This study we tested several existing models to evaluate the PV module temperature as a function of solar irradiance, ambient temperature and wind. We used data from a large PV power plant from the city of Bolzano (Italy) located at the bottom of an alpine valley. This PV power plant consists of different PV technologies and is equipped with several instruments to monitor solar radiation, wind speed and direction, ambient and PV cell temperatures
Cheikh El Banany ELHADJ SIDI et al.(2015)	Analysis of Outdoor performance of monocrystalline photovoltaic module and temperature effect on exergetic efficiency.	Results give an exergetic efficiency of the module varying from 14.87 to 17.93% per day for monocrystalline 30 Wp PV module. The results also show a variation of exergetic efficiency for the same irradiance and decrease in efficiency with increasing module operating temperature.
Arvind Tiwari, et al. (2016)	Performance evaluation of solar photovoltaic/thermal systems and also analyzed to Exergy analysis of integrated photovoltaic thermal solar water heater under Constant flow rate and constant collection temperature modes.	It is observed that the overall exergy efficiency indicating the optimum value of flow rate of 0.006 kg/s as reported earlier. However, thermal efficiency increases significantly with increase of flow rate up to 0.006 kg/s and then increase is marginal as expected. For comparison, the hourly variation of solar cell, back surface PV module, water temperature and solar cell efficiency has been evaluated.

METHODOLOGY-

A system description and the method of analysis in view of energy and exergy on bases for evaluation are presented in this Paper.

PV modules performances based on energy and exergy analysis

The module performance is based on a total efficiency of the system and total efficiency of the module is a function of electrical and thermal efficiencies. With the increasing the numbers of glazing in photovoltaic module reduction in thermal losses occur and increases thermal efficiency of the module. This is advantage of first law thermodynamics. When cover glass reflects back the solar radiation and reduces the amount reaching the solar cell which in turn reduces the generation of electrical energy. According to first law of thermodynamics value for electrical energy are higher as compared with thermal energy (8).

Energy analysis of PV module

Energy is dependent on the parameters of matter or energy flow only. It is independent of the environment parameters. Energy is governed by the first law of thermodynamics for all the process so that it is always conserved in a process, by the first law of thermodynamic energy neither be created nor destroy. It used to measurement the quantity only. For a reversible system it can be expressed as:

$$\sum Q_{enter} = \sum Q_{leaving} \tag{7}$$

Total solar incident radiation on the collector plate surface is given by (11):

$$\sum Q_{Solar} = AI_S \tag{8}$$

Where A is the area of collector & I_S is the solar intensity at particular location. The energy absorbed by the collector can be written an:

$$\sum Q_{absob} = \alpha\tau AI_S \tag{9}$$

Where α is the absorptance of glass and τ is the transmittance of outer surface of the collector.
Energy absorbed by the sun radiation is converted into Electrical energy that is:

$$E_{elect} = V_{oc} I_{sc} \tag{10}$$

Where,

I_{sc}= short- circuit current, V_{oc}= open-circuit voltage

The actual electrical energy output of the PV module is defined by:

$$E_{elect} = V_{oc} I_{sc} FF \tag{11}$$

Here (FF) is fill factor and it is define as it is ratio of the maximum electrical energy to the actual electrical energy. it is expressed as

$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}} \tag{12}$$

Maximum Energy efficiency of a PV system can be defined as the ration of the output energy by the system (electrical) to the input energy into the system (solar energy) reach on photovoltaic surface. Then the energy efficiency can be expressed as:

$$\eta_{energy} = \frac{E_{out}}{E_{in}} = \frac{E_{Electrical}}{E_{Solar}} = \frac{V_{oc} I_{sc}}{I_S A_{mod}} \tag{13}$$

Solar power

conversion efficiency of PV system is defined as actual electrical energy output to the actual input energy of the sun. **Solar power conversion efficiency** is expressed as (11):

$$\eta_{spce} = \frac{E_{out}}{E_{in}} = \frac{V_{oc} I_{sc} \times FF}{I_S A_{\text{mod}}} \qquad (14)$$

Exergy analysis of PV module

Exergy or Availability is defined as its difference between maximum possible work to the irreversibility of any given system.
Availability = Maximum possible work-Irreversibility
Steady-flow exergy equation is:

$$Ex = H - T_0S \qquad (15)$$

Where H is a Enthalpy, T_0 is the temperature of a heat reservoir (usually the environment) and S is entropy of the system (6).

For the steady-state flow process during a finite time interval, the overall exergy balance of the solar PV can be written as follows (10):

Exergy Input=Exergy Output +Exergy Loss +Irreversibility.

We can assume that first law of thermodynamics equation for open system under the steady state condition for PV module can be written as (9):

$$Ex_{enter} = Ex_{leaving} \qquad (16)$$

Entering and leaving energy of any control volume of the system is equal in steady state condition because of no accumulation of mass & energy into the control volume of the system.
But second low of thermodynamic is giving the information of loss of energy of the system is given by :

$$Ex_{enter} - Ex_{leaving} = Ex_{loss} \qquad (17)$$

This is a general equation for exergy balance here difference of both the entering and leaving exergy give the information of small amount of exergy loss (9).
So that exergy efficiency of the photovoltaic module is the ratio of total output exergy (exergy gained) given by the system to the input exergy (solar radiation) into the system that is a mathematically express as:

$$\eta_{ex} = \frac{Ex_{leaving}}{Ex_{entering}} = 1 - \frac{I_{c.v}}{Ex_{enetring}} \qquad (18)$$

Where $Ex_{enteingr}$, $Ex_{leaving}$ and $I_{c.v}$ are the entering exergy, leaving exergy and irreversibility in control volume, respectively (11).

The input exergy i.e. exergy of solar radiation is given by(14):

$$Ex_{solar} = \left(1 - \frac{T_{amb}}{T_{sun}}\right) I_S A_{\text{mod}} \qquad (19)$$

According to the Petala theorem, the entering exergy includes only solar radiation intensity exergy (13). Entering exergy equation is :

$$Ex_{enter} = I_S A_{\text{mod}} \left[1 - \left(\frac{4}{3}\left(\frac{T_{amb}}{T_{sun}}\right) + \frac{1}{3}\left(\frac{T_{amb}}{T_{sun}}\right)^4\right)\right] \qquad (20)$$

Where, T_{amb} is a ambient temperature and T_{sun} is the Sun's temperature both the temperature in Kelvin.

The irreversibility in control volume is a summation of external exergy losses and internal exergy losses (exergy destruction) in control volume (12, 13)

$$I_{c.v} = \Sigma\left(Ex_{los} + Ex_{des}\right) \qquad (21)$$

The external energy loss caused by heat leakage is given by Farahat et al. (2009) which is numerically equal to $\dot{E}x_{thermal}$ for PV system.

Thermal energy ($Ex_{Thermal}$) the system in form of heat loss (Q)

$$Ex_{thermal} = Ex_{loss} = \left(1 - \frac{T_a}{T_{\text{mod}}}\right) Q \qquad (22)$$

Where the convective heat loss (Q) is calculated as:

$$Q = UA_S\left(T_{cell} - T_a\right) \qquad (23)$$

U Overall convective heat transfer coefficient (W/m^{2}K) of the module is assumed that when variable is constant factor so that all values are fixed but adverse effect of the system it is not constant so it includes two losses they are convection and radiation.

Which has been assumed as a constant factor or variable with little effect, whereas, it is not constant than it includes convection and radiation losses:

$$U = h_{con} + h_{rad} \qquad (24)$$

h_{conv} = convective heat transfer coefficient
h_{rad} = radiative heat transfer coefficient

$$h_{cov} = 2.8 + 3u_{air} \tag{25}$$

Where, u_{air} is wind speed (m/s).

The radiative heat transfer coefficient between photovoltaic module and surrounding is express by give equation (16):

$$h_{rad} = \varepsilon\sigma\left(T_{sky} + T_{\mathrm{mod}}\right)\left(T_{sky}^2 + T_{\mathrm{mod}}^2\right) \tag{26}$$

The emissivity of a any surface is defined as the ratio of the emissive power of the surface to the emissive power of the hypothetical black surface at same temperature. It is denoted by ε.Its value varies for different substances ranging from 0 to 1. for a black body ε=1, for a white body surface ε=0 and gray bodies it lies between 0 to 1. It may vary with temperature or wavelength.
Thus

$$\varepsilon = \frac{E}{E_b}$$

Where, ε ,E, E_b , σ *and* T_{sky} are the emissivity, emissive power of any surface, emissive power of the hypothetical black surface, Stefan Boltzmann's constant, and the effective temperature of the sky is calculated by the following relation (19):

$$T_{sky} = T_{amb} - 6 \tag{27}$$

Temperature of the module can be calculated on the basis of the NOCT value (19).

$$T_{\mathrm{mod}} = T_{amb} + (NOCT - 20) \times \frac{I_S}{800} \tag{28}$$

The total heat collected from the solar radiation is calculated by equation:

$$Q_{rad} = \int_{tsr}^{tss} I dt \tag{29}$$

Where *tsr* and *tss* are time at sunrise and time at sunset, respectively. Solar radiation intensity I_s[W/m] is the data collected by experimental testing of given station (17).
The internal exergy losses (exergy destruction) caused by optical losses in PV module surface.

$$Ex_{des,opt} = I_S A_{\mathrm{mod}} \left[1 - (\tau\alpha)\right]\left(1 - \frac{T_{amb}}{T_{sun}}\right) \tag{30}$$

$$Ex_{opt,dest,\Delta T_{\mathrm{mod}}} = I_S A_{\mathrm{mod}} T_{amb}\left(\frac{1}{T_{\mathrm{mod}}} - \frac{1}{T_{sun}}\right)(\tau\alpha) \tag{31}$$

Where, τ,α is the

effective product of transmittance, absorptance (14).

The electrical exergy destruction of the module is calculated by give formula (20):

$$Ex_{elec,dest} = \left(I_{sc}V_{oc} - I_{mp}V_{mp}\right) \quad (32)$$

Therefore, exergy efficiency of PV module obtained:

$$\eta_{ex} = \left\{ \frac{V_m I_m - UA_{\text{mod}}\left[T_{\text{mod}} - T_{amb}\right]\left(1 - \frac{T_{amb}}{T_{\text{mod}}}\right)}{I_S A_{\text{mod}}\left[1 - \frac{4}{3}\frac{T_{amb}}{T_{sun}} - \frac{1}{3}\left(\frac{T_{amb}}{T_{sun}}\right)^4\right]} \right\} \quad (33)$$

Given expression for exergy efficiency (η_{ex}) of PV module .here exergy content by photovoltaic surface is fully utilized to generate maximum electrical energy.

Experimental method

One polycrystalline PV module (MODEL NO-1216) 10 Watt rating was selected to perform experimental work by taking a reading of polycrystalline PV module by using different measuring devices for hazy day, 20 Jun 2016 between 9 AM to 5 PM. by using given reading we are evaluating to energy and exergy analysis of given system. Operating, climatic and design parameters of module are standard test condition (STC) and specification of polycrystalline PV module is shown by given tables:

Table.2 Specification of all measuring instruments

Serial No.	Name of measuring instrument	Manufacturing and model no.	Rating	Application
1.	Solar power meter	TM-207 (Taiwan)	0 – 1999W/m^2	Solar radiation intensity
2.	solar module analyzer	MECO(9009) india	V_{oc}= 0-60V I_{sc} = 0-12A	PV module characteristics
3.	Infrared Gun (thermometer)	Raytek (china)	0-500 °C	Ambient temperature and humidity
4.	Thermo Hygrometer	HT-3006A(	0-100%	Ambient

		China)	0-100 °C	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 3 Climatic, operating and design parameters

Input parameters	***Values***
Nominal operating module temperature (T_{mod})	41°C
Ambient temperature (T_{amb})	35°C
Solar radiation (I_S)	1000W/m^2
Stefan Boltzmann constant (σ)	5.67×10^{-8} W/m^{2}k
Emissivity of the panel (ε)	0.9
Sun temperature (T_{sun})	5760K
Average wind velocity (u_{air})	0.5m/s

Table 4 Specifications of (polycrystalline model no-RE 1216) PV module

Parameters	***Specifications***
Maximum power (P_m)	10W
Open-circuit voltage (V_{OC})	21.5V
Short-circuit current (I_{SC})	650mA
Number of cell's in module	36
Specific size of the module (A_{mod})	34×28 c.m
Maximum power point voltage (V_{mp})	17.8V
Maximum power point current (I_{mp})	590 mA
Fill factor (FF)	0.78
Tolerance at peak power	+5%
Standard test condition (STC) Irradiation, spectrum and cell temperature	1000W/m^2, AM$_{1.5}$, 25°C

These following parameters was measured by various instrument used for testing and performance of polycrystalline PV module.

Time	Ambient Temperature (°C)	Wind speed (m/s)	Relative Humidity (%)	Solar Intensity (W/m²)	Module Temperature (°C)	Energy Efficiency					
						V_{OC}	V_M	I_{SC}	I_M	P_{max}	η
09:00AM	32	1.62	35.2	695	34	19.58	15.82	365	353	5.58	8.43
10:00AM	35	1.31	35.4	775	39	19.63	15.93	385	382	6.08	8.24
11:00AM	36.8	2.13	35.9	870	43	20.71	16.25	509	498	8.09	9.76
12:00AM	37.4	1.91	38	980	47	21.12	17.02	635	565	9.61	10.3
01:00PM	40	1.24	37	996	54	21.35	17.75	613	545	9.67	10.4
02:00PM	41	2.35	39	975	57	21.01	17.32	632	555	9.61	10.3
03:00PM	39.8	1.5	40	825	60	20.25	17.13	565	455	7.87	10
04:00PM	38	1.4	38.5	720	53	19.11	16.15	402	385	6.21	9.05
05:00PM	36.4	1.8	38.6	580	45	18.65	15.53	345	322	5.00	9

Table 5 EXPERIMENTAL DATA SHEET FOR CLEAR DAY

RESULTS AND DISCUSION

The effect of climatic, operating, and design parameters on the performance of polycrystalline PV module is observed, using selective instruments. This performance gives the information about the exergy efficiency of solar PV module, which has been measure on the basis of second law of thermodynamics, using the energy from solar radiation. Convective heat transfer coefficient (h_{conv}) between the PV module surface and the ambient air did not affect the experimental performance. The shape of the input exergy follows that of the global irradiation and greater the value of irradiance, greater the difference for polycrystalline modules.

In central India, monsoon clouds begin to appear in June, therefore starting week of the this month some days are clear sky and after two to three week monsoon clouds begin to appear so that few days are cloudy and few days are hazy. This test is performed on the bases of three different climatic condition for three different days of the month of June these different climate condition was Clear sky day, Hazy day & cloudy day at three different dates was i.e 11th, 20th, 25th of june. One by one we are evaluate the Energy and exergy performance of the photovoltaic module for different climatic condition at Bhopal India.

PURPOSE OF EXERGY ANALYSIS

- To determine exergy losses (true thermodynamic losses) in processes and systems
- minimization of losses / optimization of driving forces

To calculate the exergy of heat (at temperature *T*):

• make use of a reversible thermal power cycle (closed cycle)

• Heat is discharged only to the environment (at T_0)
• System brings matter into equilibrium with environment

By putting values from the data observed, to the equation (7) and (28)

$$\eta_{energy} = \frac{E_{out}}{E_{in}} = \frac{E_{Electrical}}{E_{Solar}} = \frac{V_{oc} I_{sc}}{I_S A_{mod}} \quad (7)$$

$$\eta_{ex} = \left\{ \frac{V_m I_m - UA_{mod}\left[T_{mod} - T_{amb}\right]\left(1 - \frac{T_{amb}}{T_{mod}}\right)}{I_S A_{mod}\left[1 - \frac{4}{3}\frac{T_{amb}}{T_{sun}} - \frac{1}{3}\left(\frac{T_{amb}}{T_{sun}}\right)^4\right]} \right\} \quad (28)$$

We calculate the energy and exergy efficiency of the PV module for different climatic condition

CONDITION FOR CLEAR SKY DAY

Actual experimental data obtained for a typical clear sky day at Energy Centre, Bhopal were applied to investigate the effect of the ambient conditions on the performance of PV module. This test is performed on a clear sky day 11th June 2016. The exergy efficiency of the PV module has been calculated on the basis of the second law of thermodynamics, by taking exergy of solar radiation. An energy and exergy balance for the PV module was carried out. Calculation is done by taking clear sky day climatic condition into account because parameters like wind speed, ambient temperature, humidity, module temperature, and solar intensity were varying with time throughout the day.

When calculation is done for clear day the maximum and minimum ambient temperature was found changing from 41°C to 32°C . The maximum and minimum wind speed and solar intensity was found 2.35 to 1.24 (m/s) and 996 to 580 W/m$^{2.}$ The given graphs showing the variations of solar intensity, input exergy, ambient temperature, electrical exergy, thermal exergy, power conversion efficiency and exergy efficiency for a polycrystalline PV module respectively.

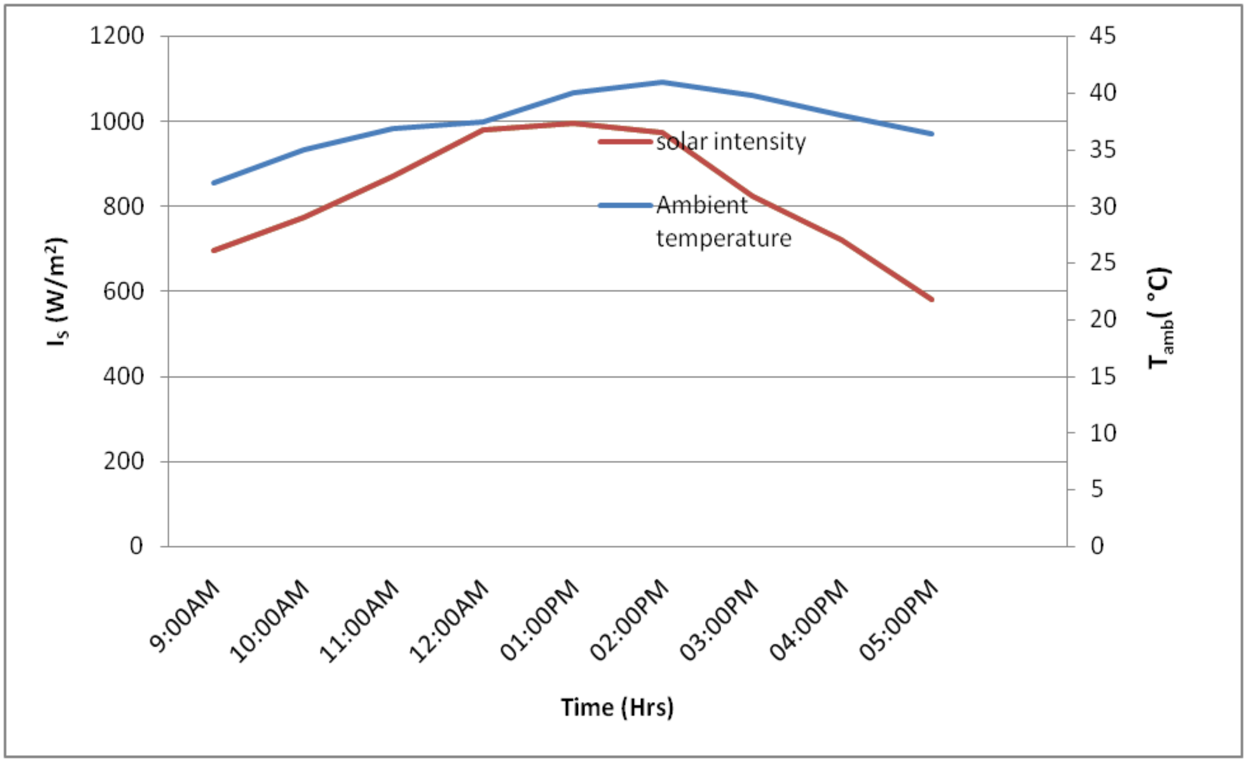

Figure.1 Variation of solar intensity and ambient temperature for clear days

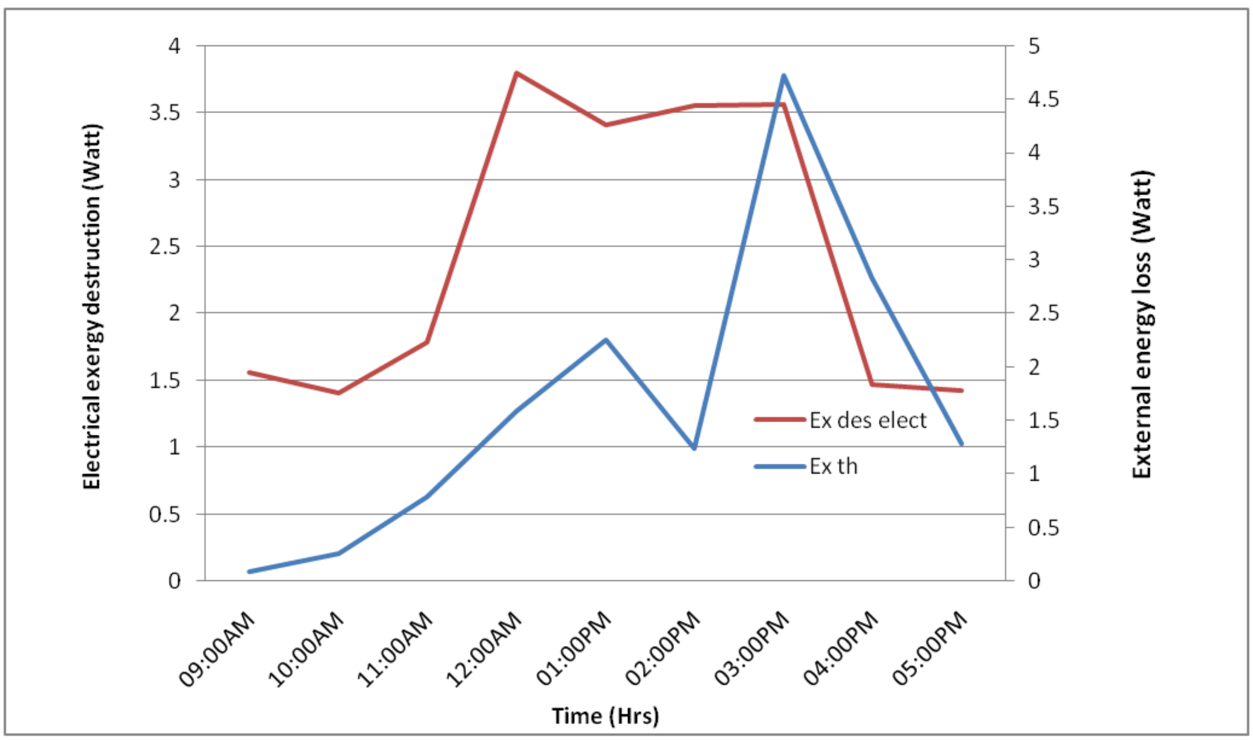

Figure.2 Variation External energy loss (Watt) and Electrical energy destruction in PV panel for clear day

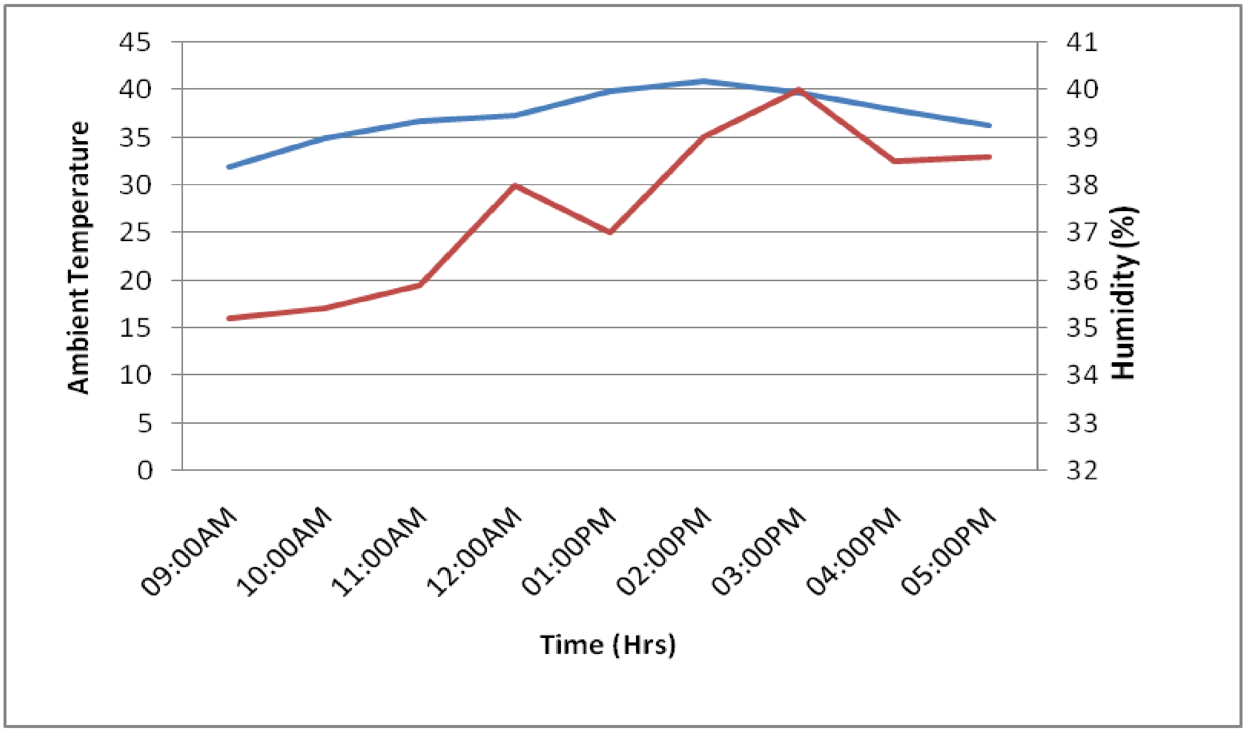

Figure.3 Variation of Ambient temperature and humidity (%) for clear day

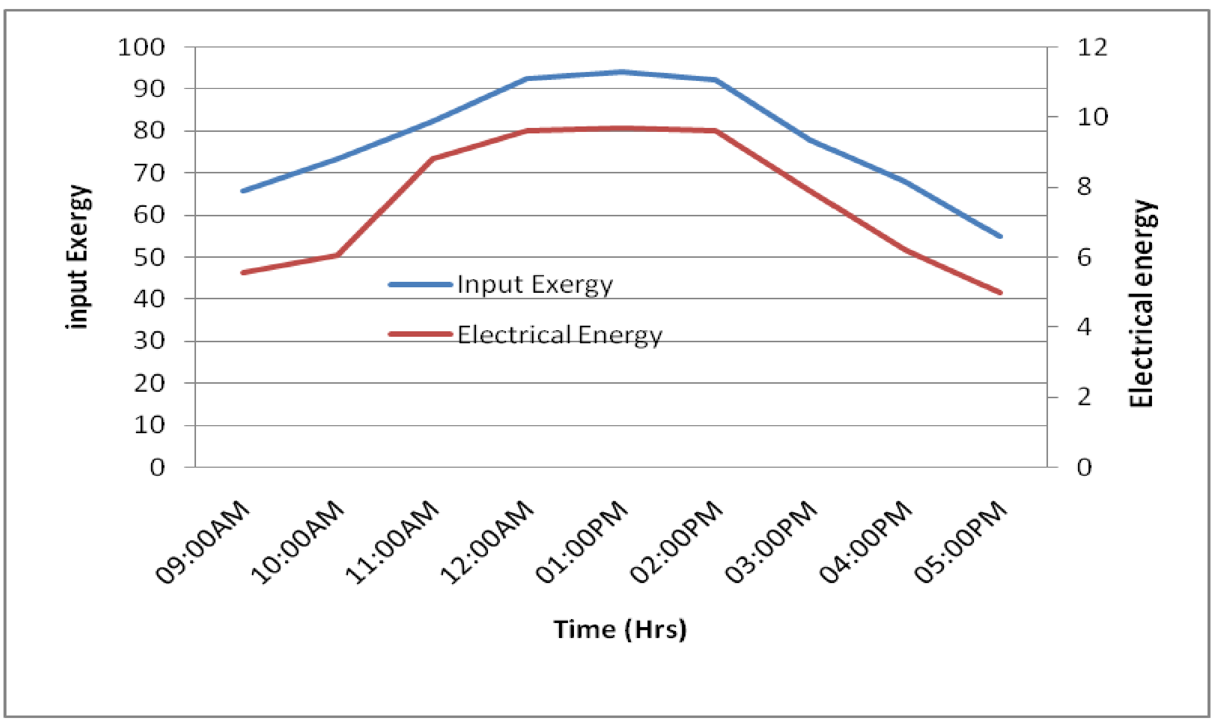

Figure.4 variation in input Exergy and Electrical (Watt) energy of PV module for clear day

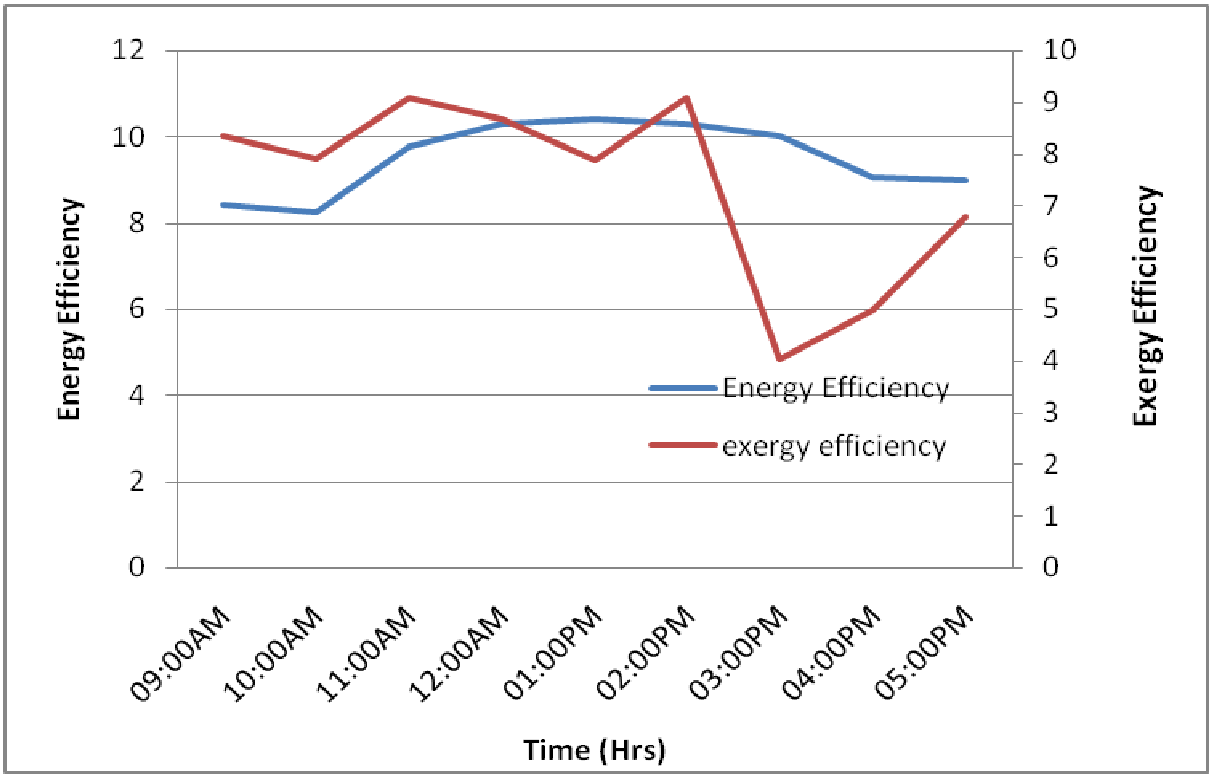

Figure.5 Variation of Energy efficiency and Exergy efficiency for clear days

Fig.5 shows the variation of exergy and energy efficiency of the 10Watt PV module. The energy efficiency is varies between 4% and 10% and exergy efficiency 8% to 11% throughout the day. that given results shows the overall performance of polycrystalline PV module like exergy losses(thermal exergy), input exergy, electrical exergy, exergy efficiency, and solar power conversion efficiency. Here highest and least module temperature observed was 60 °C to 34°C and maximum solar intensity was observed 996(W/m^2).average ambient temperature was 37°C.

CONCLUSION

This paper presents the experimental study of 10 Watt polycrystalline PV module for a CLEAR SKY day 11th JUNE 2016. PV module based on Energy and Exergy analysis of Crystalline Silicon Photovoltaic Solar Module for clear sky Day has been carried out. This experimental data was obtained by some basic measuring instrument giving accurate measurement during the end days of summer. The experimental data obtained through measurements during the experiment was analyzed to find the optimum temperature, which leads to the exergy efficiency analysis and to calculate maximum efficiency and maximum solar power conversion efficiency of the module. The exergy loss in photovoltaic conversion process of module has also been found out by this analysis.

The following conclusions are written by experimental and theoretical study:

- The result showed that polycrystalline photovoltaic module is dependent on solar intensity of the sun. When intensity of the sun is low efficiency of the module is also low when intensity is high-efficiency is also maximum to achieved by the module.
- For one day the average values of exergy efficiency (η_{ex}) and power conversion efficiency (η_{spce}) for polycrystalline module are found to be (η_{ex} = 5.314, η_{spce} = 6.18) respectively.
- Exergy analysis is more effective and more efficient tool for the performance analysis of the solar panel.
- When solar radiation and ambient temperature increases in summer days due to increasing the cell temperature and loss of energy (irreversibility) of the module. That condition output energy generation (Electricity) increases.
- Research done for the improvement of efficiency of solar module can prove to be highly beneficial. It can be made cost effective by developing low cost semiconductor materials and thus cost of electricity generation can be reduced.

RREFRENCES

1) Rumani saikia phukan, Solar Energy in India – Pros, Cons and the Future related article, July 30,2014.
2) Pandey, A. K., *et al*.: Energy and Exergy Performance Evaluation of a Typical Solar THERMAL SCIENCE: Year 2015, Vol. 19, Suppl. 2, pp. S625-S636.
3) M. R. Abdelkader, A. Al-Salaymeh, Z. Al-Hamamre, Firas Sharaf, A comparative Analysis of the Performance of Monocrystalline and Multiycrystalline PV Cells in Semi Arid Climate Conditions: the Case of Jordan, volume -4, number 5, November-2010 ISSN1995-6665 page 543-552.
4) P.Rawat, M.Debbarma, S.Mehrotra, K.Sudhakar, P. kumar sahu, Peformance Evaluation of solar photovoltaic/ Thermal hybrid water collector, impending power demand and innovative energy paths- ISBN: 978-93-83083-84-8.
5) G.N.Tiwari, Swapnil Dubey, Book "Fundamental of Photovoltaic Modules and its Applications", 2009, P001-P004.
6) http://www.nptel.ac.in/courses/112108148/pdf/Module_8.pdf
7) S.A.Kalogirou , Sotirios Karellas, V. Badescu, K.Braimakis, E nergy analysis on solar thermal system: A better understanding of their sustainability, Renewable Energy 85 (2016) 1328-1333.
8) T. T. Chow, G. Pei, K. F. Fong, Z. Lin, A. L. S. Chan, and J. Ji, "Energy and exergy analysis of photovoltaic-thermal collector with and without glass cover," Applied Energy, vol. 86, no. 3, pp. 310–316, 2009.
9) K. Sudhakar and Tulika Srivastava, Energy and exergy analysis of 36 W solar photovoltaic module, International Journal of Ambient Energy, 2013 http://dx.doi.org/10.1080/01430750.2013.770799.

10) Wong, K. F. V. 2000. Thermodynamics for Engineers. University of Miami, Boca Raton, Fla, USA: CRC Press LLC.
11) K.N. Shukla*, Saroj Rangnekar and K. Sudhakar, A comparative study of exergetic performance of amorphous and polycrystalline solar PV modules, int.J. Exergy 17 (4) (2015) 433-455, http://dx.doi.org/10.1504/IJEX.2015.071559.
12) Bejan, A. (1982) Entropy Generation through Heat and Fluid Flow, John Wiley and Sons,Chichester, UK.
13) Bejan, A. (1998) Advanced Engineering Thermodynamics, John Wiley and Sons, Chichester, UK.
14) S.Farahat, F.Sarahaddi,H.Ajam, Exergetic optimization of flate solar collectors, renew.energy 34(4) (2009) 1169-1174.
15) R.Petela, Exergy of undiluted thermal radiation, solar energy 74 (2003) 469-488
16) Akash kumar shukla, k.sudhakar, Prashant baredar, Exergetic assessment of BIPV module using parametric and photonic energy methods: A review, Energy and Buildings 119 (2016) 62–73.
17) Himsar Ambarita, Hideki Kawai, Experimental study on solar-powered adsorption refrigeration cycle with activated alumina and activatecarbon as adsorbent, Case Studies in Thermal Engineering 7 (2016) 36–46.
18) S. Armstrong, W.G. Hurley, A thermal model for photovoltaic panels under varying atmospheric conditions. Applied Thermal Engineering 30 (2010) 1488e1495.
19) Watmuff, J. H., W. W. S. Charters, and D. Proctor. 1977. Solar and wind induced external coefficients for solar collectors. Cooperation Mediterraneenne pour l'Energie Solaire,Revue Internationale d'Heliotechnique, 2nd Quarter. p. 56.2, 56.
20) A.S.Joshi, A. Tiwari, Energy and exergy efficiencies of a hybrid photovoltaic–thermal (PV/T) air collector, Renewable Energy 32(13):2223-2241 · October 2007