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Experimental Exergetic Performance Evaluation of Solar PV Module

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Abstract- Solar Photovoltaic system generates both electrical and thermal energy from solar radiation. In this work, an attempt has been made for evaluating thermal, electrical and exergy output of solar PV module (Tata BP 184459) at Energy Centre, MANIT Bhopal. Using the first law of thermodynamics, energy analysis was performed and Exergy analysis was carried out to determine exergy losses during the photovoltaic conversion process by applying the second law of thermodynamics. The operating and electrical parameters of a PV module includes module temperature, overall heat loss coefficient, open-circuit voltage, short-circuit current, fill factor, etc were experimentally determined for a typical hazy day (12 May 2014) at Bhopal. The experimental data are used for the calculation of the energy and exergy efficiencies of the PV module. Energy efficiency is seen to vary between 6% and 9% during the day. In contrast, exergy efficiency is lower for electricity generation using the considered PV module, ranging from 8% to 10%.

Index Terms- Energy, Exergy, PV module, thermal, performance evaluation.

I. INTRODUCTION

Renewable energies are going to be a main substitute for fossil fuels in the coming years for their clean and renewable nature. A solar photovoltaic (PV) module is one of the most significant and rapidly developing renewable-energy technologies, and its potential future uses are notable.

PV array performance parametrically depends on climatic, operating, and design parameters such as ambient temperature, solar radiation intensity, PV module temperature, overall heat loss coefficient, open-circuit voltage, short circuit current, maximum power point voltage, maximum power point current, and PV module area. It can be evaluated in terms of energy efficiency and exergy efficiency. Its evaluation based on the first and second laws of thermodynamics is known as energy efficiency and exergy efficiency, respectively [27].

The energy analysis has some deficiencies [1, 2]; fundamentally, the energy concept is not sensitive with respect to the assumed direction of the process; for example, energy analysis does not object if heat is considered to be transferred spontaneously in the direction of increasing temperature. It also does not distinguish the quality of energy; for example, 1W of heat equals 1W of work or electricity. Energy analyses on their own incorrectly interpret some processes [1, 2]; for example, environmental air, when isothermally compressed, maintains its energy (e.g., enthalpy) equal to zero, whereas the exergy of the compressed air is greater than zero. However, exergy data are more practical and realistic in comparison with the respective energy values. Thus, exergy analysis usually provides a more realistic view of process than energy analysis; sometimes, they are different [1, 2].

A little work has been carried out in field of PV module exergy analysis of it. Most important significant research work done in the field of energy and exergy by the several authors lost 35 years. Some of the described as below:

Joshi et al. (2009) also studied the performance characteristics of a photovoltaic (PV) and photovoltaic-thermal (PV/T) system in terms of energy efficiency and exergy efficiency, respectively. They proposed equations for the energy, electrical, and exegry efficiency of a PV system. Finally, they calculated the energy, electrical, and exegry efficiencies under given experimental data and gave useful results. [3]. Sarhaddi et al. (2008) investigated exergetic optimization of solar collector systems. In this paper, a detailed energy and exergy analysis will be carried out to evaluate the electrical performance, exergy destruction components, and exergy efficiency of PV array. [4]. 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. They investigated the effect of design and operating parameters and four weather conditions on the performance of above mentioned PV/T air collectors for five different cities of India and found that the latter one gives better results in terms of thermal energy, electrical energy and exergy gain [5]. Sahin et al.(2007). The energy efficiency of a PV array can be considered as the ratio of the electricity generated to the total, or global, solar irradiation. In this definition, only the electricity generated by a PV array is considered. The other components and properties of a PV array, such as ambient temperature, PV array temperature, chemical potential components and heat capacity of a PV array are not directly taken into account [6]. Jones and Underwood (2001) studied the temperature heat profile of a PV module in a non-steady state condition with respect to time. They conducted experiment for cloudy as well clear day condition. They observed that PV module temperature varies in the range of 300-325 K (27-52_C) for an ambient air temperature of 297.5 K (~24.5_C) [7]. Infield et al. (2004) analyzed a PV system that consisted of PV module and double glass wall (PV facades). They concluded that the temperature of PV module could be reduced by flowing air between PV module and double glass wall [8].

Several other researchers Atmaca (2013) [9]; Barnwal et al (2009) [10]; Nishi et.al (2013) [11]; Oner et al. (2009) [12] and

Tiwari et al. (2009) [13] conducted different significant works on energy and exergy of solar PV system.

In this work, a detailed energy and exergy analysis will be carried out to evaluate the electrical performances, exergy losses, and exergy efficiencies of 36W PV module (Tata BP 184459). PV module exergy analysis is parametrically dependent on its energy analysis. Hence, firstly PV module energy analysis will be carried out then the exergy loses and exergy efficiency of PV module will be computed.

II. METHODOLOGY

A. *Energy Analysis*

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell; it can be modeled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell. Two diode models are also available but only single diode model is considered here [14]-[18].

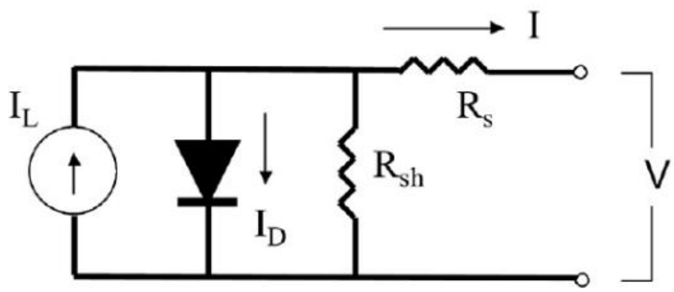

Figure 1: Single diode model of a solar cell.

I-V Equation of PV cell: General mathematical description of I-V output characteristics for a PV cell has been studied for over the past four decades [14]. The PV cell is usually represented by the single diode model. The single diode equivalent circuit of a solar cell is shown in Figure 3.3.The I-V characteristics equation of solar cell [19] is given as follows:

$$I = I_L - I_O \left\{ \exp\left[\frac{q(V+IR_s)}{AkTc}\right] - 1 \right\} - \frac{(V+IR_s)}{R_{sh}} \qquad (1)$$

I_L is a light generated current or photo current (representing the current source), I_O is the saturation current (representing the diode), R_s series resistance, A is diode ideality factor, k (= 1.38 $\times 10^{-23}$ W/m^{2}K) is Boltzmann's constant, q (=1.6$\times 10^{-19}$C) is the magnitude of charge on an electron and T_C is working cell temperature.

Photo current or light generated current, mainly depends on the solar insolation and cell working temperature, which is described as:

$$I_L = G[I_{SC} + K_i \ (T_C - T_{ref})] \qquad (2)$$

Where I_{sc} is the short circuit current at 25°C and 1KW/m^2, K_i is the short circuit current temperature coefficient, T_{ref} is the reference temperature and G is the solar insolation KW/m^2, on the other hand, the cells diode current or saturation current varies with the cell temperature which is described as:

$$I_O = I_{RS} \left(\frac{T_C}{T_{ref}}\right)^3 \exp\left[\frac{qEG\left(\frac{1}{T_{ref}} - \frac{1}{T_C}\right)}{KA}\right] \qquad (3)$$

Where I_{RS} is the cells reveres saturation current at reference temperature and a solar radiation, E_G is the band-gap energy of the semiconductor used in cell

Energy efficiency of a PV system can be defined as the ratio of the output energy of the system (i.e electrical energy) to the input energy (i.e solar energy) received on photovoltaic surface. The energy efficiency of a PV system is given by [3]

$$\text{Energy efficiency} \quad \eta_{en} = \frac{V_{oc} I_{sc}}{S} \qquad (4)$$

However, this definition of energy efficiency is restricted to theoretical cases. In equation 1, S is the solar absorbed flux and it is given by:

$$S = G.\, A_{mod} \qquad (5)$$

$$\text{And} \quad A_{mod} = L_1 L_2 \qquad (6)$$

Where, L_1 and L_2 are the length of solar module and width of solar module respectively.

For PV system in practical cases, energy efficiency measure the ability of converting solar energy in to electrical energy [3,6]. The electrical power output of a PV module is the product of its voltage and current of photovoltaic device. This conversion efficiency is not constant, even under constant solar irradiation. However, there is point of maximum power, where voltage is V_{mp} , which is less than open circuit voltage (V_{oc}) but closed to it, and current is I_{mp} , which is less than short circuit current (I_{sc}) but closed to it shown in Figure 2. In Figure 2, E_{GH} stands for the highest energy level of electron at maximum solar irradiation conditions. E_{GH} is equivalent to area under the I-V characteristics curve $\int_{V=0}^{Voc} I(V)dV$. In addition, E_L stands for the low energy content of electron, which is the practical case, as shown by the rectangular area in same figure. E_L is thus equivalent to I_{mp} V_{mp}. The maximum power point is restricted by a term called *fill factor* as follows:

$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}} \qquad (7)$$

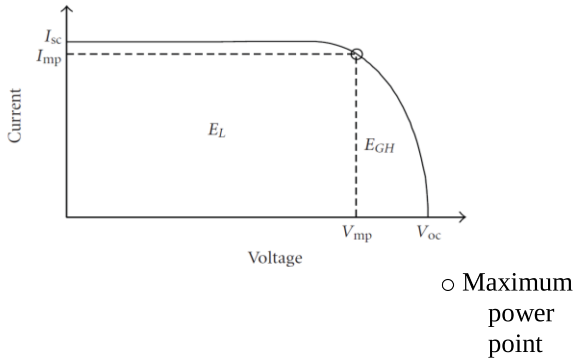

Figure 2. Representation of a general I - V characteristic curve and its parameters.

The energy efficiency of a PV system at maximum power is defined as the ratio of actual electrical output to input solar energy incident on PV surface area and it is given by [3,6]

$$\eta_{el} = \frac{V_{mp} I_{mp}}{S} \quad (8)$$

This efficiency is also called *solar power conversion efficiency*. The solar power conversion efficiency of PV module can be defined as in terms of fill factor FF as follows:

$$\eta_{pce} = \frac{FF \times V_{oc} I_{sc}}{S} \quad (9)$$

B. Exergy Analysis

Exergy analysis technique that uses the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the analysis, design and improvement of energy and other systems. Exergy is defined as the maximum amount of work that can be produced by a system or a flow of mass or energy as it comes to equilibrium with a reference environment [20]. The general form of exergy balance equation for a control volume is written as [20,21]

$$\dot{E}x_{in} - \dot{E}x_{out} = \dot{E}x_{dest} = \dot{E}x_{loss} \quad (10)$$

Where $\dot{E}x_{in}$, $\dot{E}x_{out}$ and $\dot{E}x_{dest}$ are inlet exergy, outlet exergy and exergy destruction or exergy loss in control volume, respectively.

Exergy efficiency of the PV module is defined as the ratio of total output exergy to total input exergy[20,21]. An exergy efficiency of the solar PV can be defined as the ratio of the exergy gained by the solar PV (exergy output) to the exergy of solar radiation (exergy input) [1].

$$\eta_{ex} = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} \quad (11)$$

Inlet exergy(Input exergy) for a PV system includes only solar radiation intensity exergy. According to the petela theorem it is given by [1,2]

$$\dot{E}x_{in} = GA_{mod} \left[1 - \frac{4}{3}\left(\frac{T_{amb}}{T_{sun}}\right) + \frac{1}{3}\left(\frac{T_{amb}}{T_{sun}}\right)^4\right] \quad (12)$$

Outlet exergy (output exergy) of the PV system can be calculated as [22]

$$\dot{E}x_{(pv)out} = \dot{E}x_{out} = \dot{E}x_{el.} - \dot{E}x_{th.} \quad (13)$$

Exergy of the thermal energy

$$\dot{E}x_{th.} = Q\left[1 - \frac{T_{amb}}{T_{mod}}\right] \quad (14)$$

Where $Q = UA_{mod}(T_{mod} - T_{amb})$ (15)

The overall heat loss coefficient of PV module includes conversion and radiation losses.

$$U = h_{canv.} + h_{rad} \quad (16)$$

Convective heat transfer coefficient [23]

$$h_{conv.} = 2.8 + 3V_w \quad (17)$$

Irradiative heat transfer coefficient between PV module and surrounding [7]

$$h_{rad.} = \varepsilon\sigma\,(T_{sky} + T_{mod})(T^2_{sky} + T^2_{mod}) \quad (18)$$

Effective temperature of sky [7]

$$T_{sky} = T_{amb} - 6 \quad (19)$$

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

$$T_{mod} = T_{amb} + (NOCT - T_{ambNOCT})\frac{G}{G_{NOCT}} \quad (20)$$

Electrical exergy in the output electrical power of the PV module [7]

$$\dot{E}x_{el.} = V_{oc} I_{sc} FF \quad (21)$$

The energy efficiency of a solar panel, the ratio of the power output to the energy originally delivered to the solar panel, conventionally is used to measure solar PV efficiency. Energy analysis, which is based primarily on the first Law of Thermodynamics, as compared to exergy analysis, which is based on the second Law. Energy analysis is concerned only with quantity of energy use and efficiency of energy processes. Energy analysis thus ignores reductions of energy potential, which could be used productively in other physical and/or chemical process. Energy analysis can provide sound management guidance in those applications in which usage effectiveness depends solely on energy quantities.

Exergy is maximum work potential which can be obtained from energy [24]. Exergy analysis is recognized by many engineers to be a powerful tool for the evaluation of the thermodynamic and economic performance of thermodynamic system in general [25]. Exergy analysis provides an alternative means of evaluating and comparing the solar PV. Exergy analysis is based on the separate quantification and accounting for usable energy, called exergy or availability, and usable energy, called irreversibility [26]. Exergy analysis is used to find

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out the energy utilization efficiency of an energy conversion system. Exergy analysis yields useful results because it deals with irreversibility minimization or maximum exergy delivery. The exergy analysis has been increasingly applied over the last several decades largely because of its advantages over energy analysis. To perform energy and exergy analyses of the solar PV, the quantities of input and output of energy and exergy must be evaluated.

III. EXPERIMENTAL ANALYSIS

A. Experimental set-up

The experimental set-up at roof top of energy center MANIT Bhopal shown in Figure 3. Experimental study was done in the Central region of India. The latitude and longitude of the location are 23°25 N and 77°42 E. The ambient temperature fluctuates in the range of 5 to 48 ºC during a year in Bhopal. The solar photovoltaic panel was tested and the parameters like Open circuit voltage (V_{oc} V), and Short circuit current (I_{sc}A), Wind speed (V_w m/s), solar intensity (G W/m^2), and ambient temperature (T_{amb}ºK), etc., needed for the evaluation of the systems were measured at interval of one hour between 9.00 and18.00. Specification of measuring instruments in experiment shown in Table 1. Also input parameters used for analysis and manufacturer data sheet for (Tata BP 184459) PV module shown in Table 2 and Table 3. Experimental measured parameters are listed in Table 4.

Figure 3. Experimental set-up on the roof top at the energy center Maulana Azad National institute of technology Bhopal, India on 12 May 2014.

Table 1: Specification of measuring instruments used in experiment

S.no	Name of the instruments	Make and model No	Ratings	Applications
1.	Solar Power Meter	TM-207 (Taiwan)	0 – 1999W/m^2	Solar radiation intensity
2.	Thermo Hygrometer	HT-3006A (china)	0-100% 0-100℃	Ambient temperature and humidity
3.	Solar Module Analyzer	MECO-9009 (India)	V_{OC} = 0-60V I_{SC} = 0-12A	PV module characteristics
4.	Infrared Thermometer (Infrared Gun)	Ray Tek (china)	0-500℃	PV module temperature
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 2: Input parameter used for analysis.

Input parameter	Values
Nominal operating cell temperature (NOCT)	41 ºC
Stefan Boltzmann constant (σ)	5.67×10^{-8} W/m^2-K
Emissivity of the panel (ε)	0.9
Sun temperature (T_{sun})	5780 K

Table 3: Specification of the PV module

Parameters	Values
Maximum power (P_m)	36W
Open circuit voltage (V_{oc})	18V
Short circuit current (I_{sc})	2A
Number of cells	36
Dimensions	950×425×35 mm
Weight	6 kg
Fill factor (FF)	0.85

Table 4: Experimental measured parameters for (Tata BP 184459) PV Solar module.

Time	Solar Intensity G (W/m^2)	Ambient Temperature T_{amb} (K)	Relative Humidity (%)	Module Temp T_{mod} (K)	Open circuit Voltage V_{oc} (V)	Short circuit current I_{sc} (A)
9.00	700	310.00	60.00	298	18.00	1.10
10.00	750	312.00	58.30	311	18.50	1.30
11.00	860	314.00	45.10	310	17.91	1.38
12.00	900	313.90	38.80	311	17.67	1.56
13.00	898	314.50	34.50	313	17.70	1.55
14.00	790	313.50	33.40	310	17.59	1.36
15.00	120	310.30	35.60	306	17.71	0.22
16.00	149	311.60	44.20	298	17.73	0.27
17.00	85	308.30	43.10	287	17.23	0.14
18.00	54	307.80	41.20	281	16.54	0.09

IV. RESULTS AND DISCUSSIONS

Actual data obtained for a typical hazy day in May for Bhopal was applied to investigate the effect of the ambient conditions on the performance of the module. The average measured annual ambient temperature was taken as 298K for May. The exergy efficiency of solar PV System has been computed on the basis of second law of thermodynamics, by taking exergy of sun radiation. An energy and exergy balance for the solar panel was carried out. Exergy analysis is more convenient than the energy analysis for predicting the efficiency of the solar panel. It is concluded that exergy is more effective and more efficient tool for the performance analysis of the solar panel.

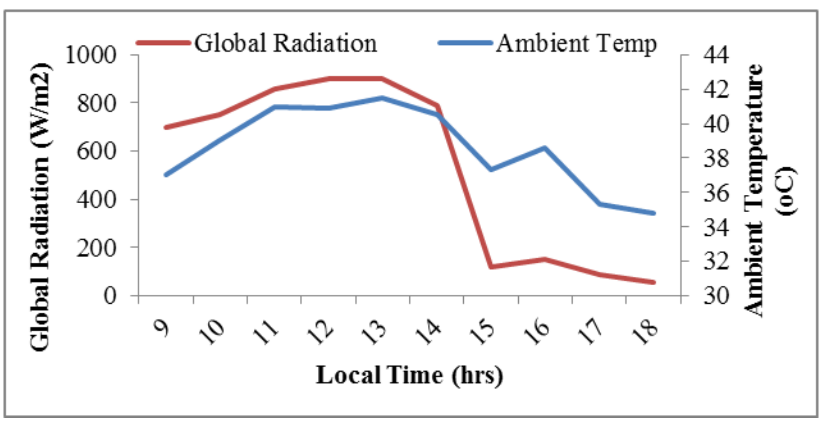

Fig 4. Variation of Solar radiation intensity and ambient temperature during 12 may, 2014 at Bhopal, India

The variation of solar radiation intensity and ambient temperature during the test day is shown in Fig.4. The wind speed was found to be almost constant 0.5m/s. This effects the convective heat transfer coefficient between the PV array surface and the ambient air. The min and max temperature was found to be 307.8 to 314.5 K. The maximum and minimum solar radiation intensity was found to vary between 900 & 54 W/m^2.

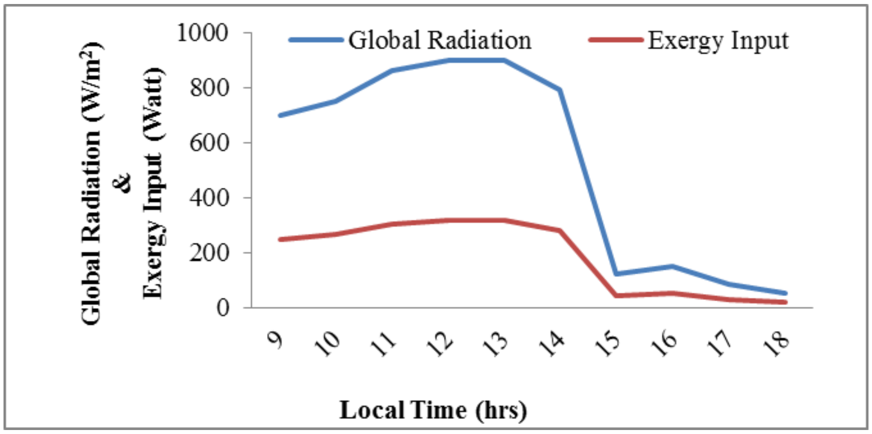

Fig.5. Global Irradiance and solar exergy input on 12 may, 2014 at Bhopal, India

Fig.5. shows the variation of solar irradiance and input exergy for a hazy day 12 May 2014. The shape of the input exergy fallows that of the global irradiance and greater the value of irradiance the greater the difference between the two. Solar exergy is very high due to the high temperature of the sun which can be used to do useful work.

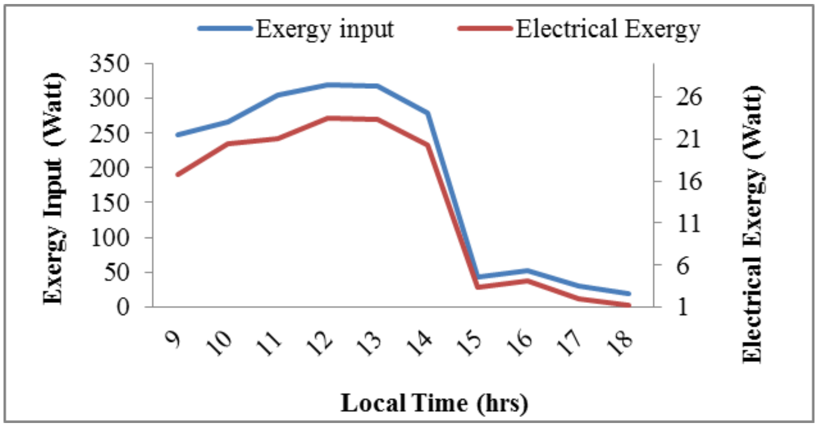

Figure 6. Solar Exergy Input and Electrical Exergy on 12 may, 2014 at Bhopal, India

Fig.6. shows the input exergy and electrical exergy of the PV module. It is clearly understood from the figure that electrical exergy from the PV module is much less than could be extracted, because of major loss of exergy as a result of irreversibility.

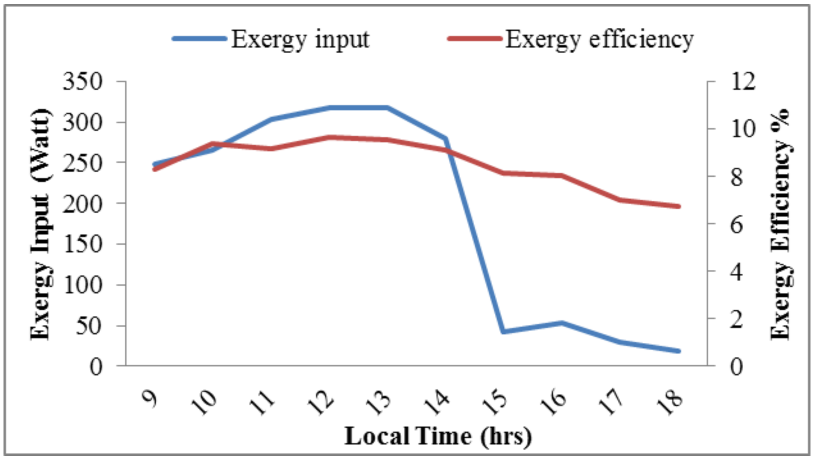

Figure 7. Solar Exergy Input and Exergy Efficiency on 12 may, 2014 at Bhopal, India

Fig.7. shows the variation of exergy efficiency and input exergy on the PV module. The photovoltaic exergy efficiency is very low and it was around 8% throughout the day, far from the ideal 100% reversible process. This low exergy is due to the irreversibility of the photovoltaic conversion process. There is also a significant waste of solar exergy incident on the module. The photovoltaic conversion process with conventionally available silicon modules, despite their advantage and wide spread availability, implies an enormous loss of exergy. The exergy efficiency of the photovoltaic module increases with increase in solar intensity.

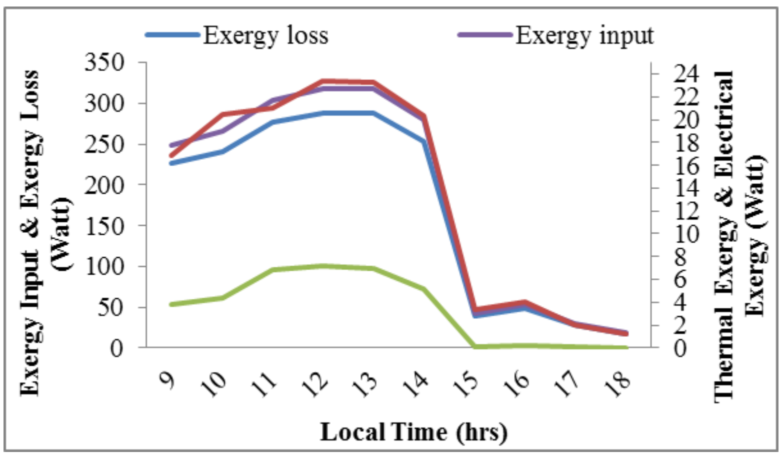

Figure 8. Exergy Loss, Electrical Exergy and Thermal Exergy on 12 May, 2014 at Bhopal, India

The relative loss of exergy exceeds 90% throughout the day as seen from Fig.8. This huge amount of useful exergy is being lost and this show that today's silicon module takes very little advantage of the high exergy content of the sunlight. The overall analysis gave average exergetic efficiencies of 5.2% and energetic efficiencies of 4.5%. The exergy efficiency of conventional silicon cell solar panel is small as the output energy is of low quality. Large exergy losses occur inside the solar panel. The exergy destruction factor for the PV is 92.3%.

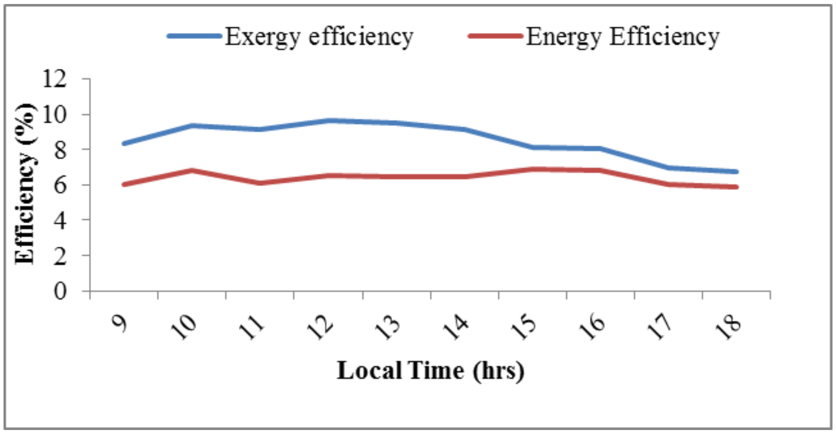

Fig.9. Energy and Exergy efficiency on 12 may, 2014 at Bhopal, India

Fig.9 shows the variations of energy efficiency, exergy efficiency with respect to module temperature. The variations of energy efficiency, exergy efficiency and electrical efficiency with respect to PV array temperature are plotted in Fig. 7. The energy efficiency of the PV module is maximum corresponding to the PV module temperature of 313 K. The exergy efficiency of the PV module is maximum corresponding to the PV module temperature of 337 K. In order to have maximum exergy efficiency, PV module temperature should be kept near the cell operating or in other words, PV module temperature should be controlled by surface cooling of the panel using water.

V. CONCLUSION

In this study, a comprehensive energy and exergy analysis of the Solar Photovoltaic module (Tata BP 184459) at Energy Centre, MANIT-Bhopal, India is conducted experimentally. The following are the conclusions drawn from the present study:

(1) The results showed the photovoltaic modules have a low exergy efficiency (η_{ex} = 8.5%). With respect to the photovoltaic system, the exergy analysis showed that today's silicon modules take very little advantage of the high exergy content of solar radiation.

(2) The values of energy and exergy efficiencies for the solar module are found to be 6.4% and 8.5%, respectively.

(3) The PV exergy efficiency decreases as the solar radiation and ambient temperature increases due to increasing cell temperature and irreversibility while the output electricity increases.

(4) Research directed toward improving the efficiency of the solar module could be useful. Development and low cost semiconductor material could significantly reduce the cost of electricity generation with solar energy.

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Nomenclatures:

A: Diode Ideality Factor
A_{mod}: Area of Module (m^2)
E_G : Band Gap Energy (eV)
E_{GH}: Highest energy level of electron at maximum solar irradiance (eV)
E_L: Low Energy Content of Electron (eV)
$\dot{E}_{X(pv)out}$: Solar Module Exergy Output Rate (W)
$\dot{E}_{Xdes}$: Exergy Destruction Rate (W)
$\dot{E}_{Xel}$: Electrical Exergy Rate (W)
$\dot{E}_{Xin}$: Inlet Exergy Rate (W)
$\dot{E}_{Xloss}$: Exergy Loss (W)
$\dot{E}_{Xout}$: Outlet Exergy Rate(W)
$\dot{E}x_{th}$: Thermal Exergy Rate (W)
FF: Fill Factor
G: Solar Insolation (W/m^2)
G_{NOCT}: Solar Radiation Intensity at NOCT (W/m^2)
h_{conv}: Convection Heat Transfer Coefficient (W/m^2k)
h_{rad}: Radiation Heat Transfer Coefficient (W/m^2)
I_L: Light Generated Current or Photo Current of PV Cell (A)
I_{mp}: Current at Maximum Power Point (A)
I_O: Saturation Current (A)
I_{RS}: Cell Reverse Saturation Current at Reference Temperature (A)
I_{sc}: Short Circuit Current (A)
k: Boltzmann's Constant (1.388 x 10^{-23})(W/m^2-k)
K_i: Short Circuit Temperature Coefficient (mA/°C)
L_1, L_2: Length and Width of Module (m)
NOCT: Normal operating cell temperature
Q: Heat Emitted to the surrounding (W)
q: Magnitude of Charge on the Electron (1.6 x 10^{-19}C)
R_S: Series Resistance (Ω)
R_{Sh}: Shunt Resistance (Ω)
S: Solar Absorbed Flux (W)
T_{amb}: Ambient Temperature (°K)
T_{aNOCT}: Ambient Temperature at NOCT (°K)
T_C: Working Cell Temperature (°K)
T_{mod}: Module Temperature (°K)
T_{ref}: Reference Temperature (°K)

T_{sky}: Sky Temperature (ºK)
T_{sun}: Sun Temperature (5780^0K)
U: Overall Heat Loss Coefficient ($W/m^2.K$)
V: Voltage of Single Solar Cell (V)
V_{mp}: Voltage at Maximum Power Point (V)
V_{oc}: Open Circuit Voltage (V)
V_w: Wind Speed (m/s)
α: The Current Temperature Coefficient (mA/ºC)
η_{el}: Electrical Efficiency (%)
η_{en}: Energy Efficiency (%)
η_{ex}: Exergy Efficiency (%)
η_{pce}: Solar Power Conversion Efficiency (%)
σ: Stefan Boltzmann's Constant (5.67×10^{-8})(W/m^2-K^4)

REFERENCES

[1] R. Petela, (2008) "An approach to the exergy analysis of photosynthesis," Solar Energy, Vol. 82, No. 4, pp. 311-328.

[2] R. Petela, (2003) "Exergy of undiluted thermal radiation," Solar Energy, Vol. 74, No. 6, pp. 469-488.

[3] Joshi, A.S., Dincer, I. and Reddy, B.V. (2009) 'Thermodynamic assessment of photovoltaic systems', Solar Energy, Vol. 83, no. 8, pp. 1139–1149.

[4] Sarhaddi, F., Farahat, S, Ajam, H and Sobhnamayan, F. (2008) 'Thermodynamic optimization of solar parabolic cookers and comparison with energy analysis', in Proceedings of the 5th International Chemical Engineering Congress (IChEC '08), Kish Island, Iran.

[5] Dubey, S., and A. Tiwari, (2009) 'Energy and exergy analysis of PV/T air collectors connected in series', Energy and Buildings, Vol.41, No.8, pp. 863-870.

[6] Sahin, A.D, Dincer, I. and Rosen, M.A (2007) 'Thermodynamic analysis of solar photovoltaic cell systems', Solar Energy Materials and Solar Cells, Vol. 91, no. 2-3, pp. 153–159,.

[7] Jones, A.D and Underwood, C.P (2002). 'A modelling method for building –integrated photovoltaic power supply.' Building services engineering research and technology, Vol.23, No.3,pp. 167-177.

[8] Infield, D., L. Mei and U. Eicker, (2004) 'Thermal performance estimation of ventilated PV facades', Solar Energy, Vol.76 No.1-3, pp 93-98.

[9] Atmaca , İ.(2013), 'Energy and exergy analysis of a solar-assisted heat pump space heating system for clear days', International journal of exergy, Vol.12, No.2, pp.226- 248.

[10] Barnwal, P. and Tiwari A.(2009), 'Thermodynamic performance analysis of a hybrid Photovoltaic-Thermal (PV/T) integrated greenhouse air heater and dryer.' International journal of exergy, Vol.6, No.1, pp.111 – 130.

[11] Nishi, Y. and Xie, Q.(2013), 'Exergy analysis on solar heat collection of three-dimensional compound parabolic concentrator'International journal of exergy, Vol.13, No.2, pp.260- 280.

[12] Oner,Y., Cetin,E., Yilanci, A. and Ozturk H. K. (2009), 'Design and performance evaluation of a photovoltaic sun-tracking system driven by a three-freedom spherical motor.' International journal of exergy, Vol.6, No.6, pp.853- 867.

[13] Tiwari, A., Sandhu, G.S., Barnwal, P. and Sodha M.S. (2009), 'Energy and exergy metrics analyses of Hybrid Photovoltaic-Thermal air collector.' International journal of exergy, Vol.6, No.5, pp.729-748.

[14] Steve Leone (2011). 'Report Projects Massive Solar Growth in India'. Renewable Energy World.

[15] "TERI Energy Data Directory and year book', (2000) The Energy Research Institute, New Delhi, pp.118.

[16] 'Study on Design and Development of Model SHP Based Self Sustained Projects' (2002), Alternate Hydro Energy Center, Indian Institute of Technology, Roorkee.

[17] Muneer, T., Asif, M., Munawwar, S. (2005). 'Sustainable production of solar electricity with particular reference to the Indian economy'. Renewable and Sustainable Energy Reviews Vol9 No.5. 444.

[18] "Status of Solar Energy in INDIA – 2010". Retrieved 2011-03-01.

[19] Pandiarajan, N. and Muthu.R (2011) 'Mathematical modelling of Photovoltaic module with Simulink', IEEE. pp. 258-263.

[20] Kotas, T.J., (1995) 'The exergy method of thermal plant analysis'. M alabar, FL: Krieger Publish Company.

[21] Wong, K.F.V., (2000). Thermodynamics for engineers. University of M iami, CRC Press LLC.

[22] Farahat, S., Sarhaddi, F. and Ajam, H. (2009) 'Exergetic optimization of flat plate solar collectors', Renewable Energy, Vol. 34, no. 4, pp. 1169-1174.

[23] Ajam, H., Farahat, S. and Sarhaddi, F. (2005) 'Exergetic optimization of solar air heaters and comparison with energy analysis', International Journal of Thermodynamics, Vol. 8, No. 4, pp. 183–190.

[24] Bejan, A., (1998) 'Advanced engineering thermodynamics' John W iley & Sons Ltd., Chichester, UK

[25] Rosen, M. A. and I. Dincer. (1999) 'Thermal storage and exergy analysis: the impact of stratification'. Transactions on the CSME, Vol. 23, pp.173-186.

[26] Larson, D. L. and L. A. B. Cortez. (1995). 'Exergy analysis: essential to effective energy management', Transactions of the ASAE Vol. 38, No.4, pp. 1173-1178.

[27] Sarhaddi, F, Farahat, S and Ajam, H. and Behzadmehr, A (2009) 'Exergetic optimization of solar photovoltaic array', Journal of thermodynamics, Vol. 1, pp. 1-11.

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