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Performance of 20w Solar Photovoltaic Module for Energy and Exergy Analysis

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ABSTRACT

The solar photovoltaic system generates both thermal energy and electrical energy by utilizing solar energy. In this paper an experimental attempt has made for calculating energy output as well as exergy output of solar PV panel installed at R.L.J.I.T. Bangalore. Energy and exergy analysis was performed by using first and second law of thermodynamics to evaluate energy and exergy. The framework involved in this process are ambient temperature, overall heat transfer, open-circuit voltage, short-circuit current, fill factor, solar radiations etc. It is predicted that temperature of pv solar module has most effect on the efficiencies. By the help of water or air the heat can be removed to improve both energy and exergy efficiencies.

KEY WORDS: *Solar PV module, electrical exergy, thermal exergy, electrical efficiency and exergy efficiency.*

I. INTRODUCTION

According to last few decades consideration we are developing renewable energy sources as a replacement of conventional energy sources [1-2]. India is hallowed with profuse solar radiation. India lies between 6° and 32° N latitudes. In a year 250-300 days are experienced with good sunlit weather. India has favourable climate conditions. Nowadays we are facing environmental challenges, especially global warming, resource depletion.

Except for water heating, solar energy technologies are not widely using. Solar cells converts 25% of irradiation into electrical energy. A solar cell is an electrical device which converts the light energy into electrical energy through the photovoltaic effect. When light reaches the p-n junction, through very thin p-type layer the light photons can easily enter into the junction. Energy analysis is based on efficiency of energy potential and quantity of energy use, thus energy potential ignores in energy analysis. The max work potential obtained from the energy is exergy [3]. By many engineers exergy analysis is recognized for the evaluation of economic performance and thermodynamic performance of the thermodynamic system [4]. Exergy analysis is based on usable energy and availability of energy [5]. By using exergy analysis finding the energy utilization efficiency of an energy conversation system. Exergy analysis deals with maximum exergy delivery. Input and output of energy and exergy is evaluated for the performance of energy and exergy analyses of solar PV module.

The analysis of solar water heating system and comparison of energy and exergy efficiencies are experimentally evaluated by Geng, Cenegal, and Turner [6]. For a sustainable future exergetic analysis and assessment of renewable energy sources was reviewed by Hepbasli [7].

The importance of this module is

1) To study the energy and exergy analysis of solar PV module and

2) To identify the exergy losses in the solar PV module.

2. METHODOLOGY

2.1 Energy efficiency of the solar PV module

By using 1st law of thermodynamics under a steady-state of an open system the exergy equation is given as

$Ex_{in} = Ex_{out}$(1)

$Ex_{in} - Ex_{out} = Ex_{loss}$(2)

Equation (2) is a energy balance general equation. When $Ex_{in}$is supply energy for a system then Ex_{out} is the maximum amount of exergy obtained from that system. The amount of exergy consumed is less than the exergy loss also less. The energy efficiency is defined as the ratio of output power to input energy of thesolar PV module. On basis of solar isolation and surface temperature the output power and energy efficiency varies for the solar PV module. From the following equation, energy conversion efficiency (Sahin, Dincer, and Rosen 2007; Joshi, Dincer, and Reddy 2009) [8-9] is calculated for a solar PV module:

$\eta_{energy} = \frac{Voc \text{ x } Isc \text{ x } FF}{A \text{ x } G}$. (3)

Current and voltage of solar PV module in simple form:

$I = I_1 - I_0 \text{ x } \exp^{(q \text{ x } (V - IRs))/(A \text{ x } K \text{ x } T)}$. (4)

Electric power output of solar PV module:

$P_{el} = I \text{ x } V$. (5)

Maximum power output of solar PV module:

$P_{max} = V_{oc} \text{ x } I_{sc} \text{ x } FF = V_{mp} \text{ x } I_{mp}$ (6)

The solar PV module is converted the solar energy into electrical energy and thermal energy, by neglecting convection, conduction and radiation. As more the top surface temperature increases, the solar PV efficiency decreases. By supplying water or air the solar PV module can be cooled to get more efficiency (Duffie and Beek-man 1991) [10].

2.2 Exergy efficiency of the solar PV module

Exergy analysis includes the quality of energy, which allows use of the energy potential [11]. For a solar PV module the overall exergy balance equation under a steady flow (Wong 2000) [12] is

Exergy In = Exergy Out + Exergy Loss + Irreversibility. (7)

The ratio of exergy output to the exergy input is known as exergy efficiency [14].

$\eta_{ex} = \frac{Ex \text{ output}}{Ex \text{ input}}$. (8)

Input exergy of a solar PV module:

It includes only solar radiation intensity exergy which effects on solar PV module [15-16] is given by

$E_x \text{ in} = AG\left[1 - \frac{4}{3}\left(\frac{Tab}{Tsun}\right) + \frac{1}{3}\left(\frac{Tab}{Tsun}\right)^4\right]$. (9)

Output exergy of a solar PV module:

It is calculated as [17] out let of PV modules include thermal exergy and electrical exergy

E_x out = E_x thermal + E_x electrical. (10)

Thermal exergy of a solar PV module:

E_x Thermal = Q [1-Ta/Tm]. (11)

$Q = UA (T_m - T_a)$. (12)

Overall heat loss coefficient of a solar PV module:

Overall heat loss coefficient of PV module [18] depends on the convection and radiation

$U = h_{conv} + h_{rad}$. (13)

Coefficient of connective heat transfer [19] of solar PV module:

$H_{conv} = 2.8 + 3V_w$. (14)

Coefficient radiation heat transfer [20]:

$H_{rad} = \varepsilon\sigma (T_{sky} + T_m) (T_{sky}^2 + T_m^2)$. (15)

Temperature of sky:

$T_{sky} = T_a - 6$. (16)

According to NOCT value temperature of the solar PV module:

$T_m = T_a + (NOCT - 20)\frac{G}{800}$. (17)

Electrical exergy of solar PV module [21]:

$Ex_{\text{ electrical}} = V_{oc} \text{ x } I_{sc} \text{ x } FF$. (18)

2.3 Experimental study

The experimental study was done in the south region of India. The location lies in 13° 17 ' 50.28 " N Latitude and 77° 32 ' 18.24 " E Longitude. The ambient temperature varying between 10°-40°C during a year in Bangalore. The solar PV module was experiencedunder some parameterssuch as V_{oc}, I_{sc}, V_w, T_a and solar irradiance etc. The module was tested under the time interval of 9:00am to 16:00 pm. By using anemometer the wind velocity was measured and ambient temperature was measured by using temperature indicator. Below tables 1-3 list the specifications of module and the parameters which are analysed.

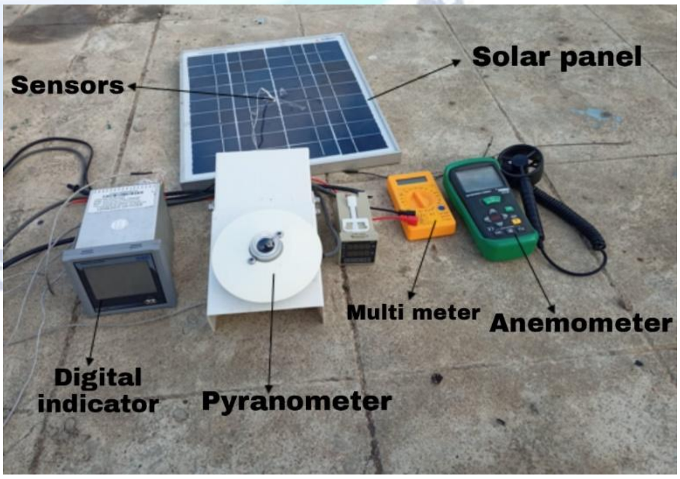

Figure 1: 20W solar PV module at R.L.J.I.T, Doddaballapura.

2.4 Input parameter and specification of the solar PV module

Table 1. Input parameters involved in this process.

Input parameters	Value
NOCT	41˚C
σ	5.67×10^{-8} W/m² K
Ɛ	0.9
Sun temperature	5780 K

Table 2. Specifications of the solar PV module.

Model	ECO 020
Maximum power	20W
Open-circuit voltage	21.6V
Short-circuit voltage	1.29A
Maximum voltage	600V
Dimensions	449X354X21
Weight	2.31Kg
Fill factor	1.19

3. RESULTS AND DISCUSSION

The experimental data was obtained in the month of January, the research was carried out at R.L.J.I.T, Doddaballapur, Bangalore, India. In the latitude of 13.2957˚N and longitude of 77.5364˚E. This experiment is carried on a clear day in January respectively. Exergy efficiency is calculated by using second law of thermodynamics. Based on experimental study exergy analysis is important in the study of the solar photovoltaic panel.

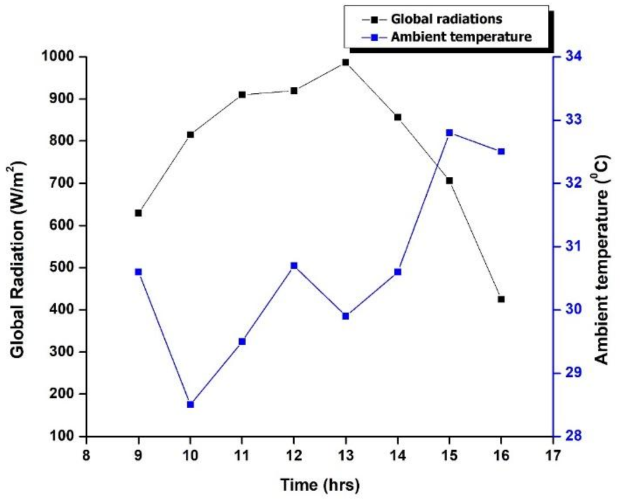

Figure 2: Variations of solar radiation, ambient temperature and time

The variation of solar radiation intensity during the test day is shown in above fig. The solar radiations are varied from 629 W/m² – 987 W/m². As the solar radiation increases the solar cell temperature increases which results to decrease in efficiency.

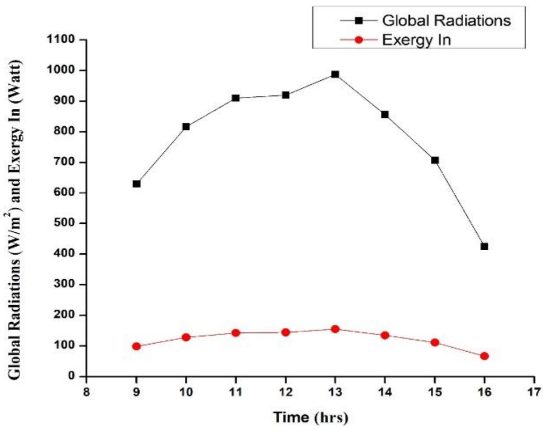

Figure 3: variations of solar radiations and exergy in The radiations of solar intensity and exergy in is shown in above fig. The exergy in varies from 80.18 and 188.19. The solar radiations are based on the ambient temperature

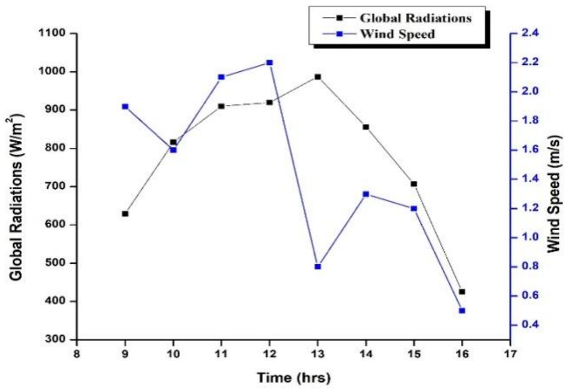

Figure: 4 variations of global radiations and wind velocity

The variations between global radiations and wind velocity is shown in above fig. The wind speed varies between 0.5m/s to 2.2m/s. And the global radiations varies between 425W/m² to 987W/m². Due to the variations in wind speed the heat transfer changes between surface of module and surroundings.

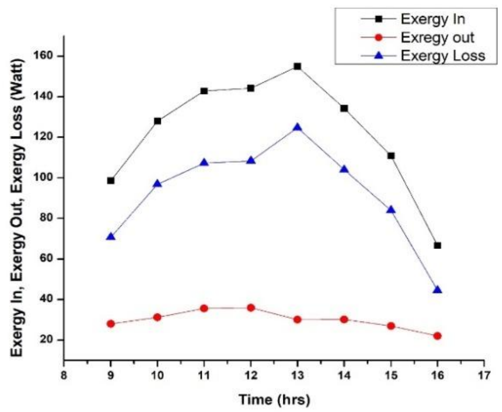

Figure: 5 variations between Exergy in, Exergy out, and Exergy loss.

Above fig shows the variations between exergy in, exergy out, and exergy loss. The exergy in varies from 66.65W to 144.33W, the exergy out varies from 22.101W to 35.97W, and the exergy loss varies from 44.54W to 108.35W.

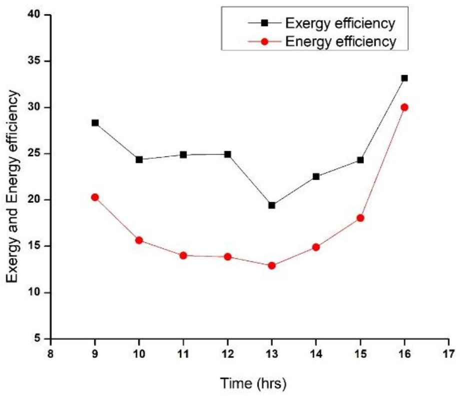

Figure 6: Energy and exergy efficiency of the PV module

The above fig shows the variation between exergy efficiency and energy efficiency. Exergy efficiency decreases on the basis of temperature. By cooling the PV module the exergy efficiency increases.

4. CONCLUSION

In this study, an exergy and energy analysis of 20W solar photovoltaic module was conducted at RLJIT, Doddaballapur, Bangalore rural, India. A research study had been conducted to investigate the performance of 20W solar photovoltaic module. The experimental results were obtained through accurate measurement of different parameter during a sunny day in January 2021. The data obtained is used to find the maximum exergy efficiency and losses of exergy and the optimum temperature also calculated. The following conclusions are taken from this experimental study.

1) The outcome result shows that the PV module have a minimum exergy efficiency (η_{ex}=42.2%) with respect to the solar PV module.
2) The ambient temperature increases as PV exergy decreases due to increasing in cell temperature and output electricity also increases.
3) The exergy efficiency increases due to solar radiation increases at beginning and then reduces after reaching the maximum point.
4) Research and development are focused in the direction of low cost semiconductor material and improving the efficiency of solar module and reducing the cost of solar PV electricity.

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NOMENCLATURE

I	Current (A)
I_{sc}	Short-circuit current (A)
I_{mp}	Current at maximum power point (A)
V	Voltage (V)
V_{oc}	Open-circuit voltage (V)
V_{mp}	Voltage at maximum power point
η_{energy}	Energy efficiency
I_l	Light generated current (A)
I_o	Saturation current density (A)
FF	Fill factor
q	Charge of electron (ev)
R_s	Series resistance (ohm)
A	Surface area of the module (m^2)
G	Global irradiance (W/m^2)
K	Boltzmann constant (J/K)
P_{el}	Electrical power (W)
P_{max}	maximum power (W)
Ex_{in}	input exergy (W)
Ex_{loss}	exergy loss (W)
Ex_{out}	output exergy (W)
$Ex_{thermal}$	thermal exergy (W)
$Ex_{electrical}$	electrical exergy (W)
T	temperature (K)
T_a	ambient temperature (K)
T_s	surface temperature of the sun (K)
T_m	module temperature (K)
T_{sky}	sky temperature (K)
Q	heat emitted to the surroundings (W)
U	overall heat loss coefficient (W/m^2K)
h_{conv}	convective heat transfer coefficient (W/m^2K)
h_{rad}	radiative heat transfer coefficient(W/m^2K)
V_w	wind velocity (m/s)
σ	Stefan Boltzmann's constant ($W/m^2\ K^4$)
Ɛ	emissivity of the module
NOCT	nominal operating cell temperature (°C)

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