Study of Experimental Energy and Exergy of mono-crystalline PV Panel in Adrar Region, Algeria

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Abstract— This article presents the modeling and experimental validation of three different efficiencies i.e. energy, power conversion and exergy of mono-crystalline photovoltaic module. The experimental data sets are carried out in the Research Unit in Renewable Energies in the Saharan Medium, Adrar, Algeria (0.18 W, 27.82 N). The test was performed during three days from March 21 (cloudy day) to March 23-22 (two clear days), 2013. 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 (i.e. March 22) the energy efficiency varied between 10.83% and 21.85%, the exergy efficiency varies between 7.98% and 14.54% and power enegy 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 enegy efficiency varies from 7.55% to 16.83%.

Index Terms— Mono-crystalline, Cloudy day, Clear days, Energy, Power energy, Exergy, Efficiency.

1 INTRODUCTION

The energies source is an important factor affected directly the human life development. Due to the high cost of fossil fuels and the climate change problems, the photovoltaic cell/module technology is one of the promising green and renewable energy solutions. The Performance of a photovoltaic system strongly depends on the weather conditions such as ambient temperature, radiation and wind speed.

The exergy analysis is based on the second law of thermodynamics which is the maximum useful work that can be obtained from a system every time [1]. In literature there are many research which study the exergy phenomenon [2]- [3]- [4]- [5]. References [6]- [7]- [8]- [9] study the exergy analysis of PV/T water collectors, and Refs. [10]- [11]-[12] study the exergy analysis of PV/T air collectors. However; Refs. [13]-[14]-[15]-[16]- [17]- [18] study the effect of the exergy analysis of the photovoltaic modules.

This paper goal are presenting and comparing the energy efficiency, exergy and exergy efficiency at two different weather days. However, one is a cloudy day (21 march 2013), and the second is a clear days (March 22-23, 2013). The exergy efficiency methods of photovoltaic systems presented in this paper is purposed and studied by [14]. We used this method in the same month which was March and in the same year but in different climate.

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2 PHOTOVOLTAIC POWER CONVERSION EFFICIENCY, EXERGY AND EXERGY EFFICIENCY

The exergy analysis is the maximum quantity of work that can be created by a system. Moreover, it's considered the losses related to the system [19]. Equation 10 presented the exergy of photovoltaic module, where the first term represents the electrical exergy, and the second the thermal exergy terms of the photovoltaic panel. Moreover, the negative sign represent the heat loss [14].

$$Ex_{el} = V_p I_p - \left(1 - \frac{T_a}{T_c}\right) hca.A.(T_c - T_a) \quad (1)$$

The photovoltaic convective heat transfer coefficient for air flowing over the outside surface of the glass cover obtained by [20]:

$$hca = 5.7 + 3.8v \quad (2)$$

A and v are, the PV area surface and wind velocity respectively.

The exergy efficiency of a photovoltaic system is defined as the ratio the exergy of the PV system which is mainly the electrical power output of the system to the exergy rate from the solar irradiance. The exergy efficiency gives the quantitative and the qualitative of energy [19]. Therefore, exergy efficiency of the photovoltaic panels can be expressed [14]:

$$Ex_{pv} = \frac{V_p I_p - \left(1 - \frac{T_a}{T_c}\right) h.A.(T_c - T_a)}{\left(1 - \frac{T_a}{T_{sun}}\right) G_T A} \quad (3)$$

Where G_T is the solar radiation and T_{sun} is the sun temperature 6000 K [21].

The solar cell power conversion efficiency is the ratio of actual electrical output and input solar energy incident on the solar cell area [22]-[23].

$$\eta_{pc} = \frac{V_p I_p}{G_T A} \quad (4)$$

3 EXPERIMENTAL DATA SETS

The outdoor experimental testing data sets for a typical three days (21ed-23rd March 2013) in Adrar (0.18 W, 27.82 N), Algeria, are used to measure energy efficiency, exergy and exergy efficiency. These data sets included solar irradiation, open-circuit voltage, short-circuit current, maximum power point (I_P, V_P and P_P), cell temperature, ambient temperature, and wind speed. The PV panel was tilted at an angle equal to 36.8°, opposite the south.

The measurement outdoor data is performed as:

- The meteorological radiation is measured with a CM11 type Kipp & Zonen pyranometer.
- The cell temperature is measured by using Eq. 5 given as:

$$T_c = T_a + G_T \frac{NOCT-20}{0.8} \quad (5)$$

- The IV photovoltaic characteristics (I_{sc}, V_{oc}, I_p, V_p, IV curve and PV curve) were measured with a MP-160 I–V curve tracer.
- Finally the ambient temperature and the wind speed are measured by the station meteorological of NEAL installed in URER/MS Adrar (Research Unit in Renewable Energies in the Saharan Medium); the interval of measure is one minute.

The solar radiation, wind speed, ambient temperature and cell temperature used in this paper are shown in Figs. 1 and 2.

Figure 1 shows the cell and ambient temperatures during the three days. From the cloudy day i.e. March 21 the ambient temperature varies from a minimum of 19.13°C to a maximum of 29.21°C at 09:20 am and 14:10 pm respectively and the cell temperature varies from a minimum of 37°C to a maximum of 67.81°C at 09:20 am and 13:10 pm respectively. However, from the clear day i.e. March 23 the ambient temperature varies from a minimum of 16°C to a maximum of 32.73°C at 07:10 am and 16:20 pm respectively and the cell temperature varies from a minimum of 16.36°C to a maximum of 64.3°C at 07:10 am and 13:10 pm respectively.

Figure 2 shows the solar radiation from the clear day i.e. March 23 varies from 11.9 W/m² to 989 W/m² at 07:10 am and 13:10 pm respectively and varies from 446 W/m² to 1061.8 W/m² at 09:20 am and 13:10 pm respectively in the cloudy day. However, the wind speed varies from 0.39 m/s to 10.35 m/s at 10:30 am and 15:30 pm respectively in the clear day and from 1.71 m/s to 7.16 m/s at 12:50 am and 09:20 pm respectively in the cloudy day.

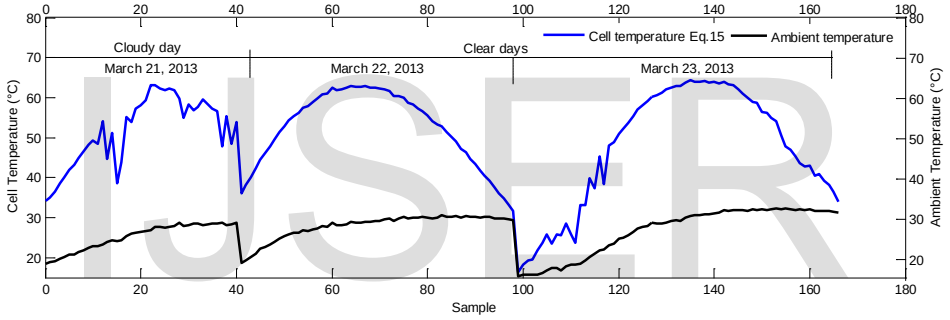

Fig. 1. Ambient temperature and cell temperature during the test days.

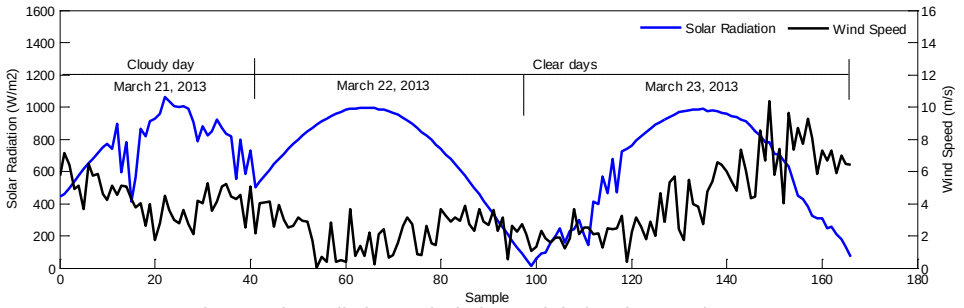

Fig. 2. Solar radiation and wind speed during the test days.

4 RESULTS AND DISCUSSION

Figures 3-5 shows the variation of energy efficiency, exergy efficiencies and power energy efficiency at the three days. Figure 3 present the plotted of the efficiencies during the cloudy day. The energy efficiency varies between 22.3% and 17.2%. The exergy efficiency varies between 5.3% and 12%. The power energy efficiency varies between 12.3% and 16.10%. Figure 4 presents the plotted of the efficiencies during the clear day of March 22. The energy efficiency varies between 10.83% and 21.85%. The exergy efficiency varies between 7.98% and 14.54%. The power energy efficiency varies between 8.10% and 16.38%.

While Fig.5 present the plotted of the efficiencies during the clear day of March 23. The energy efficiency varies between 9.28% and 22.1%. The exergy efficiency varies between 1.8% and 15.5%. The power energy efficiency varies between 7.55% and 16.83%.

A comparison of the exergy efficiency extracted from the cloudy day and that extracted from clear days are plotted at the same time in Fig.6. It is clear that the efficiencies decreased as a function of time during the day. The exergy efficiency decreases from 11.84% to 6.69% at 09:18 am to 15:50 pm from the testing day of March 21, from 14.54% to 7.98% at 09:20 am to 18:40 pm

from the testing day of March 22, and from 12.98% to 9.39% at 07:10 am to 18:20 pm from the testing day of March 23.

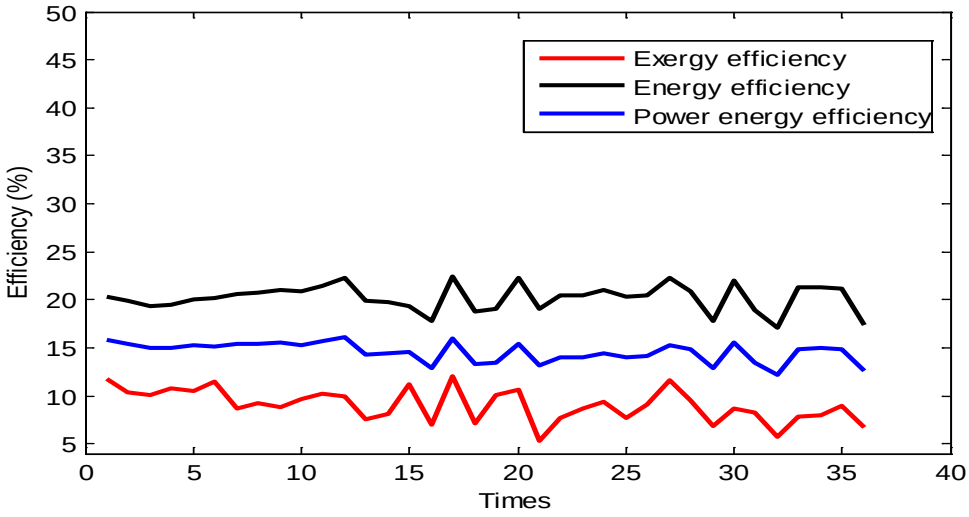

Fig. 3. Variation in efficiencies of energy, power energy and exergy in March 21, 2013.

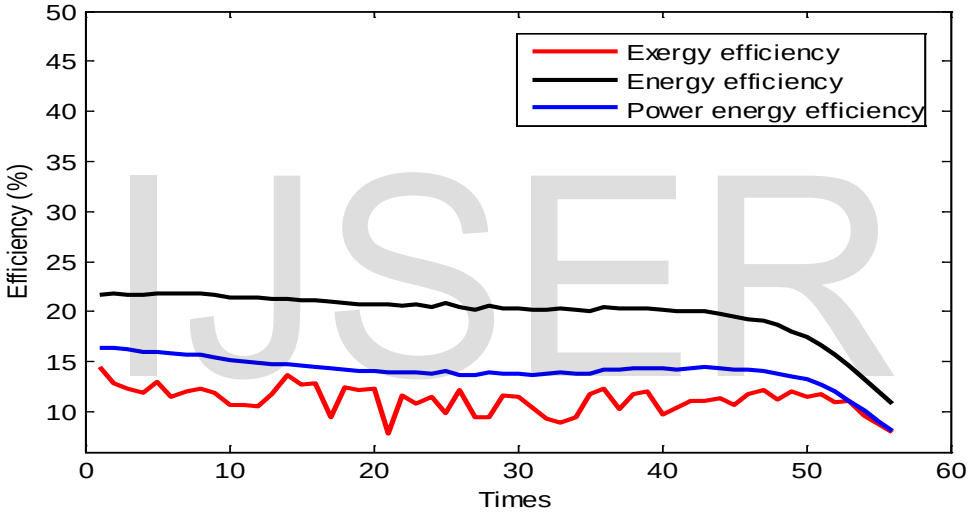

Fig. 4. Variation in efficiencies of energy, power energy and exergy in March 22, 2013.

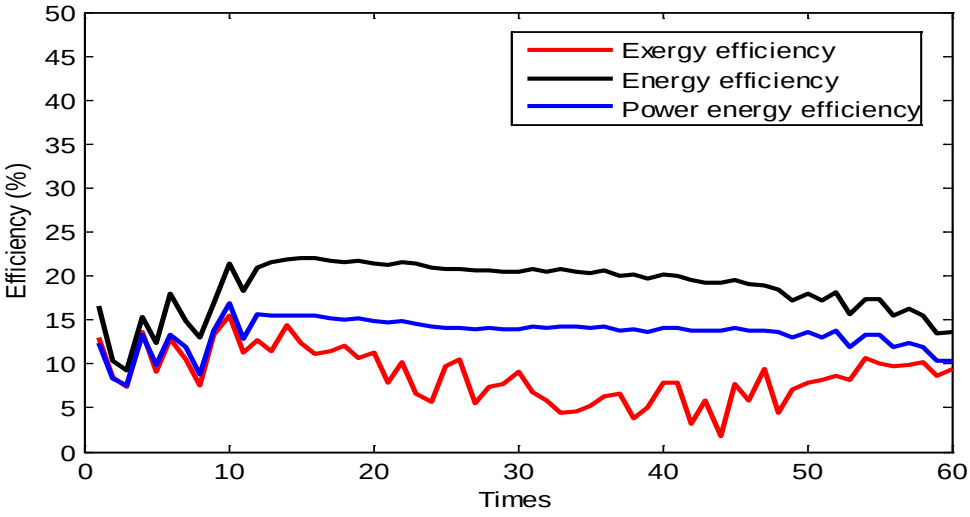

Fig. 5. Variation in efficiencies of energy, power energy and exergy in March 23, 2013.

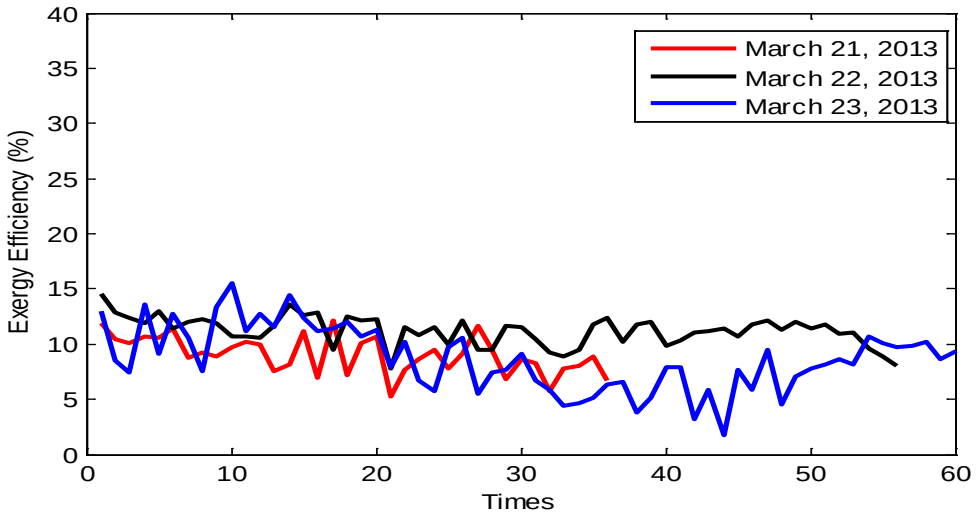

Fig. 6. Exergy efficiency during the three days.

We observed also in Fig. 6 that the three exergy efficiencies vary rapidly throughout the day. These variations are occurred to the rapid dependence rapidly of the wind speed, solar radiation and ambient temperature. With an increase of wind speed and ambient temperature there is a decrease in the exergy efficiency. However, the exergy efficiency increases with an increase in solar radiation.

Tables 1–2 present the experimental and measured test data on cloudy and clear days i.e. March 21 and 22, 2013 respectively. The data included measured energy efficiency, measured power energy efficiency, measured exergy efficiency, experimental wind speed, experimental ambient temperature and experimental solar radiation.

TABLE 1
MARCH 21, 2013 EXPERIMENTAL TEST.

Times	η_{ener} (%)	η_{pc} (%)	Ex_{pv} (%)	v (m/s)	T_a (°C)	G (W/m^2)
09:31	19.42	15.00	10.03	6.3910	19.6800	496.5
10:31	21.03	15.53	08.86	5.8600	22.3600	714.5
11:31	19.80	14.51	08.10	5.0390	24.7900	782.4
12:30	22.41	15.93	12.09	2.6390	26.4400	816.2
13:30	20.42	14.02	08.67	2.9670	28.2800	1006.5
14:30	17.79	12.84	06.81	4.0410	28.5000	882.7
15:30	21.17	14.82	08.93	4.4330	29.0100	816.0

TABLE 2
MARCH 22, 2013 EXPERIMENTAL TEST.

Times	η_{ener} (%)	η_{pc} (%)	Ex_{pv} (%)	v (m/s)	T_a (°C)	G (W/m^2)
09:30	21.77	16.34	12.84	4.0280	19.9000	539.5997
10:30	21.82	15.66	12.30	2.5250	24.5000	739.9437
11:30	21.26	14.70	13.61	0.0380	27.2700	892.3987
12:30	20.78	14.08	12.31	0.4080	29.2300	983.4125
13:30	20.43	13.74	12.16	0.2300	29.1400	994.4933
14:30	20.22	13.79	09.29	2.6320	30.1700	933.8290
15:30	20.37	14.32	11.79	1.5200	30.4900	795.1818
16:30	19.75	14.36	11.36	2.9290	30.7800	609.4993
17:30	17.99	13.56	12.05	2.6640	30.7800	375.9560
18:30	11.98	09.06	08.84	2.2520	30.3600	129.3956

5 CONCLUSION

In this paper, an investigate of the photovoltaic module performance was modeled and validated within the Research Unit in Renewable Energies in the Saharan Medium, Adrar, Algeria (0.18 W, 27.82 N) during three days March 21-23, 2013.

We have noticed that the three exergy efficiencies vary in an expeditious manner with the variation of climatic factors throughout the day. This change resulted from the negative impact of wind speed and ambient temperature on the efficiency. In other words, with increasing wind speed and ambient temperature we observe a decrease in the exergy efficiency. However, the increase in solar radiation leads to an increase in the exergy efficiency.

The results showed that:

- ✓ From the cloudy day the energy efficiency varies between 22.3% and 17.2%, the exergy efficiency varies between 5.3% and 12% and the power energy efficiency varies between 12.3% and 16.10%.
- ✓ From the clear day (i.e. March 23) the energy efficiency varies between 9.28% and 22.1%, the exergy efficiency varies between 1.8% and 15.5% and the power energy efficiency varies between 7.55% and 16.83%.

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