Conference Proceedings

EuroSun 2016
Palma de Mallorca (Spain), 11 – 14 October 2016

Effect of Ambient Conditions on Monthly Performances of Three Different PV Arrays

Talat Özden[1,2], Bülent G. Akınoğlu[3,4], Raşit Turan[2,3]

[1] Electrical and Electronics Engineering, Gümüşhane University, Gümüşhane (Turkey)

[2] The Center for Solar Energy Research and Applications (GÜNAM), METU, Ankara (Turkey)

[3] Department of Physics, METU, Ankara (Turkey)

[4] Earth System Science Program, METU, Ankara (Turkey)

Abstract

Solar PV cells may be mainly divided into two parts as crystalline and thin film. Mono-crystalline silicon (e.g. Mono-Si) and microcrystalline based amorphous silicon and other thin films (e.g. μc-Si/a-Si and CdTe thin films) are widely used PV cells in the arrays. The outdoor performances of these systems depend on some climatic parameters and conditions, and it is important to understand how the monthly efficiencies vary with these parameters. In the present study, the data obtained from three grid connected PV arrays of Mono-Si, a-Si/μc-Si and CdTe thin film that were operated for 41 months in Ankara-Turkey is analyzed. The results showed that Mono-Si array performance depends on the 5 parameters of outdoor climatic conditions while a-Si/μc-Si and CdTe thin film arrays performances are not significantly affected by the variation of the climatic parameters. The possible reasons are discussed in details.

Keywords: *Photovoltaic system, climatic parameters, efficiency*

1. Introduction and Methodology

Performances of solar PV systems are affected by meteorological parameters and ambient climatic conditions. Some examples from the literature are: (Bhattacharya et al., 2014; Sabri et al., 2007). In fact, all these references mainly discuss the temperature and wind speed variations of the PV system performances and with relatively for a period of short term data. Present study is the monthly performance variations of three PV systems installed in Ankara, Central Anatolia, with 5 monthly averages of climatic parameters, using a data set of 41 months. To the best of our knowledge, such an extended study for the monthly averages did not appear in the literature, both in terms of the length of the time period and number of climatic parameters analyzed. Such works are important in simulating feasible and optimum PV installations, toward the transition to clean energy policies for the decision makers, investors and end-users.

Fig. 1: Mono-Si, micro-crystalline based amorphous silicon and CdTe grid connected PV systems.

The specifications of the systems are as follows: The first one is Mono-Si array of 1.14 kWp and its total area is 7.584 m^2; the second one is μc-Si / a-Si array (thin film) with installed capacity of 1.26 kWp and its total area is 14.4 m^2 and the last one is CdTe thin film of 1.215 kWp and its total area is 12.96 m^2. There are

doi:10.18086/eurosun.2016.08.21 Available at http://proceedings.ises.org

three inverters connected to each PV array. The inverters are identical and the outputs are directly connected to the grid. The systems and the inverter specifications are presented in Table 1 and 2, respectively.

Tab.1: Mono-Si, CdTe and µc-Si / a-Si thin film PV systems properties.

Specifications	Mono-Si	CdTe	µc-Si / a-Si
Module brand	IBC	Abound	Kaneka
Module type	190 MS	AB1-67B	U-EA105
P_{MAX} [W]	190	67.5	105
V_{OC} [V]	45.2	46.6	71
I_{SC} [A]	5.56	2.2	2.4
V_{MPP} [V]	36.6	36.1	53.5
I_{MPP} [A]	5.19	1.9	1.96
Connection	6 series	6 series x 3 parallel	4 series x 3 parallel

Their performance and degradation analysis were carried out and presented before (Ozden et al., 2015 and 2016). As mentioned above in the present work, we analyzed the variation of the monthly performances of the arrays with respect to different climatic parameters. These parameters are monthly averages of ambient temperature (T_a, °C), relative humidity (RH, %), air mass at the noon of the average day (M) and solar irradiation on tilted arrays (H_t, kWh/m2). In this paper we present only the effects of two of these parameters: T_a and H_t.

Tab.2: Inverter properties.

Specifications	Energy Input Values [DC]	Energy Output Values [AC]
Inverter Brand	SMA	
Inverter type	SB 1200	
V_{MAX} [V] / V_{nom} [V]	400	105
V_{MPP} [V] / f_{nom} [Hz]	100-320	50/60
I_{MAX} [A] / I_{nom} [A]	12.6	5.2
--- / P_{nom} [V]	---	1200

Monthly efficiency (η) calculations are carried out using the hourly values I_t of solar irradiation on tilted panels and the hourly outputs of the systems by the equation:

$$\eta = \frac{\sum_j^N \left(\sum_i^{day} (hourly\ output)_i\right)_j}{\sum_j^N \left(\sum_i^{day} (hourly\quad I_t)_i\right)_j} \qquad \text{(eq. 1)}$$

where N is the number of days in the month and i and j are the indices that stand for the hour in a day and day in a month, respectively. The output and input in equation 1 are inserted in unit of kWh/m^2. In the previous analysis (Ozden et al., 2017, 2015) and in the present study, the calculation of hourly solar irradiation on tilted panels using anisotropic sky model HDKR, as named in (Duffie and Beckman, 2013), is used as it was demonstrated to be relatively better among one isotropic and another anisotropic model (Ozden et al., 2017, 2015).

Monthly performance ratio, R_P is defined as the ratio of the final monthly energy yield of the PV system, Y_f, to the monthly estimated reference yield, Y_r:

$$R_p = \frac{Y_f}{Y_r} \qquad \text{(eq. 2)}$$

In this equation, Y_f is calculated as the ratio of the monthly yield (Wh) of the PV array, E_{out}, to the installed array's rated output power P_{STC} (Wp), provided by the manufacturer. Y_r is calculated by dividing the total monthly tilted PV surface irradiation (Wh/m^2) E_t by the reference irradiance G_{STC} = 1000 W/m^2.

Variations of the monthly efficiency and performance ratio with the parameters H_t, T_a, M and RH are analyzed using IBM SPSS software package. The calculations of the monthly parameters H_t, T_a ve RH are simply carried out by averaging the hourly values in a full month. We used the noon air mass for a specific month calculated at the average day of the month (Duffie and Beckman, 2013).

Next section gives the graphical results and the discussion of these results. Section 3 is conclusion and future prospects.

2. Results and Discussions

2.1. Variation with temperature

Figure 2a and 2b depict the efficiency and performance ratio variation with respect to T_a. As it can be seen clearly, the temperature has negative effect on the monthly efficiency of the PV system with mono crystalline cells as expected. This is mainly due to the well-known band gap decrease with the increasing temperature which mainly affects the open circuit voltage and thus decreasing the efficiency.

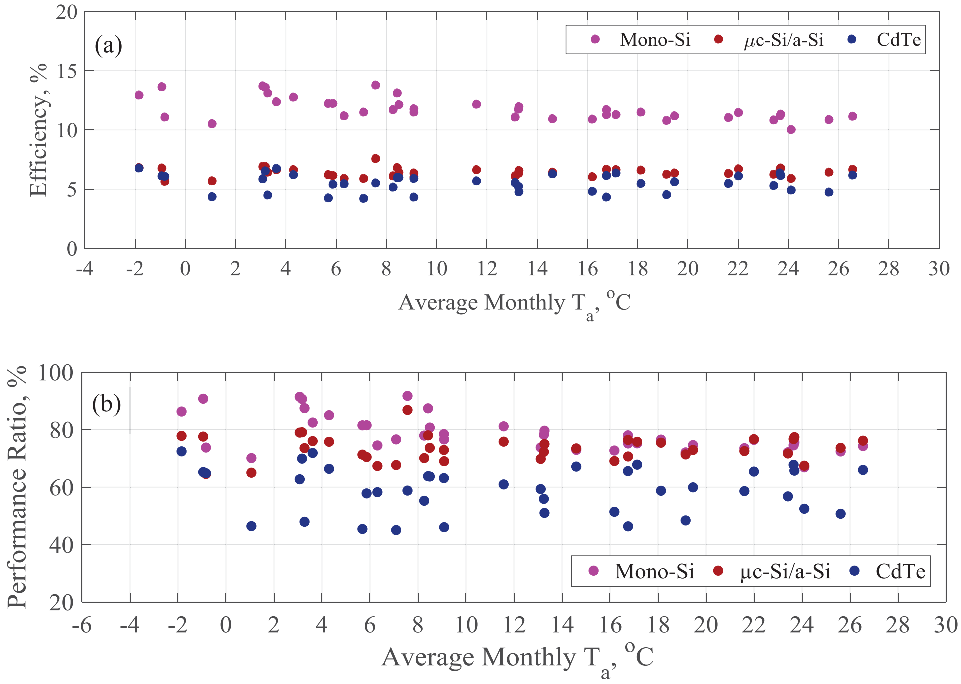

Fig. 2: Variation with temperature for Mono-Si, micro-crystalline based amorphous silicon and CdTe grid connected PV systems, (a) efficiency and (b) performance ratio.

For the systems with thin film solar cells however, the variation of the performances with the temperature is not that obvious as can be seen from Fig. 2. Although this is an unexpected result, we should note that the figure is obtained using the monthly performances and monthly average ambient temperature. Another reason may be the relatively narrower range of monthly average ambient temperatures in the outdoor testing conditions. We should note that in the laboratory, efficiency experiments with wider ranges of ambient temperatures (ambiance of the laboratory) would reveal the temperature variation clearly.

2.2. Variation with solar irradiation on tilted arrays

Similar to the variations with the temperature can be observed in the variation of the performances with the incident monthly average solar irradiation on tilted array as can be observed in Figure 3a and b. This can be attributed to the increase in the temperature of the ambient with the increase in solar irradiation. However, it seems that the thin film systems, especially in the variation of the performance ratio are also affected, as the monthly average incident solar irradiation is increased the performance ratio seems to decrease. To clarify, we calculated coefficient of Pearson correlation for all the variations and present in Tables 3 and 4. In the first columns of Table 4 one can observe that this variation is clearly revealed and the significance of correlation values given in Table 4 are also noteworthy. We discuss this result in the following sub-section.

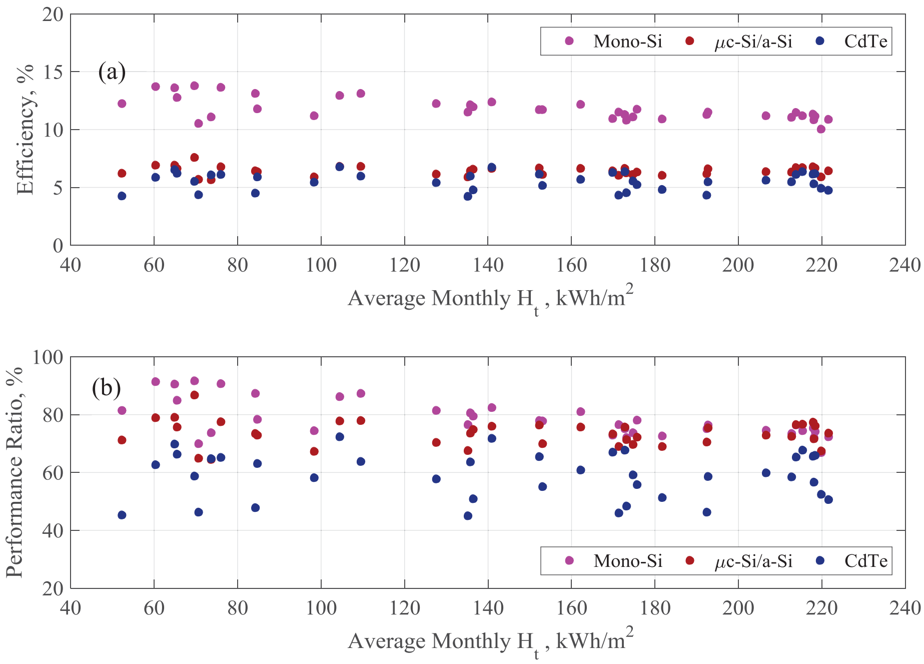

Fig. 3: Variation with solar irradiation on tilted arrays for Mono-Si, micro-crystalline based amorphous silicon and CdTe grid connected PV systems, (a) efficiency and (b) performance ratio.

2.3. Variation with air mass

Figures 4a and b present the variations with monthly average noon air mass. These variations follow very similar trends as in the variations with H_t. This conclusion can also be reached using Table 4 again. Of course, it is also a validation of the observed variation with H_t since it is clear that larger the air mass means the morning and evening hours so is smaller the solar irradiation and the ambient air temperature, and so increased performance. We should here note that these dependences of the thin film systems performances on H_t and M could not be clearly revealed in the efficiency variations (Figure 3a and 4a). Although this situation needs further test data and analysis to clarify, one might attribute it to the obvious difference between the laboratory test conditions and outdoor climate conditions.

Tab. 3: Coefficient of Pearson Correlation for grid connected PV systems (efficiency).

Module type	Pearson Correlation Coefficients				Significant of Correlations			
	H_t	T_a	RH	M	H_t	T_a	RH	M
Mono-Si	-0.682	-0.637	0.546	0.666	0.000	0.000	0.000	0.000
μc-Si / a-Si	-0,067	0.027	-0.060	0.112	0.683	0.868	0.718	0.498
CdTe	0.071	-0.054	-0.034	-0.062	0.669	0.746	0.839	0.708

Tab. 4: Coefficient of Pearson Correlation for grid connected PV systems (performance ratio).

Module type	Pearson Correlation Coefficients				Significant of Correlations			
	H_t	T_a	RH	M	H_t	T_a	RH	M
Mono-Si	-0.460	-0.468	0.324	0.446	0.003	0.002	0.037	0.003
μc-Si / a-Si	-0.271	-0.262	0.141	0.278	0.082	0.094	0.372	0.075
CdTe	-0.250	-0.282	0.141	0.277	0.110	0.071	0.375	0.075

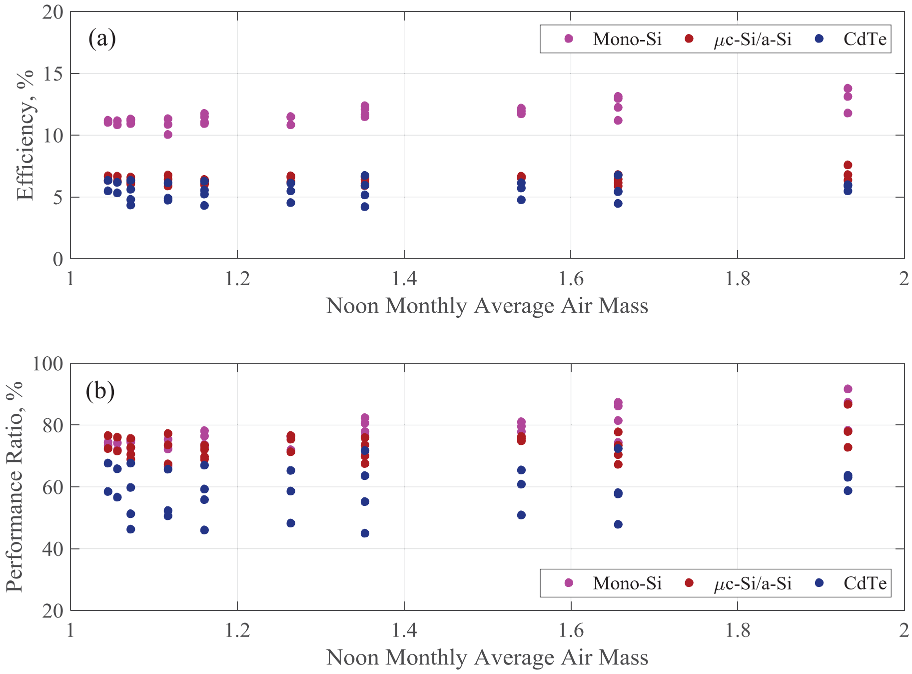

Fig. 4: Variation with air mass for Mono-Si, micro-crystalline based amorphous silicon and CdTe grid connected PV systems, (a) efficiency and (b) performance ratio.

2.4. Variation with relative humidity

Figures 5a and b are the variations of the monthly performance with the average monthly relative humidity. It is quite interesting that for the mono-Si system there exist considerable correlation between RH and system performance (Figure 5a and b, and see also Table 3 and 4). However, this can be attributed to the correlation between the monthly average ambient temperature and relative humidity as depicted in Figure 6.

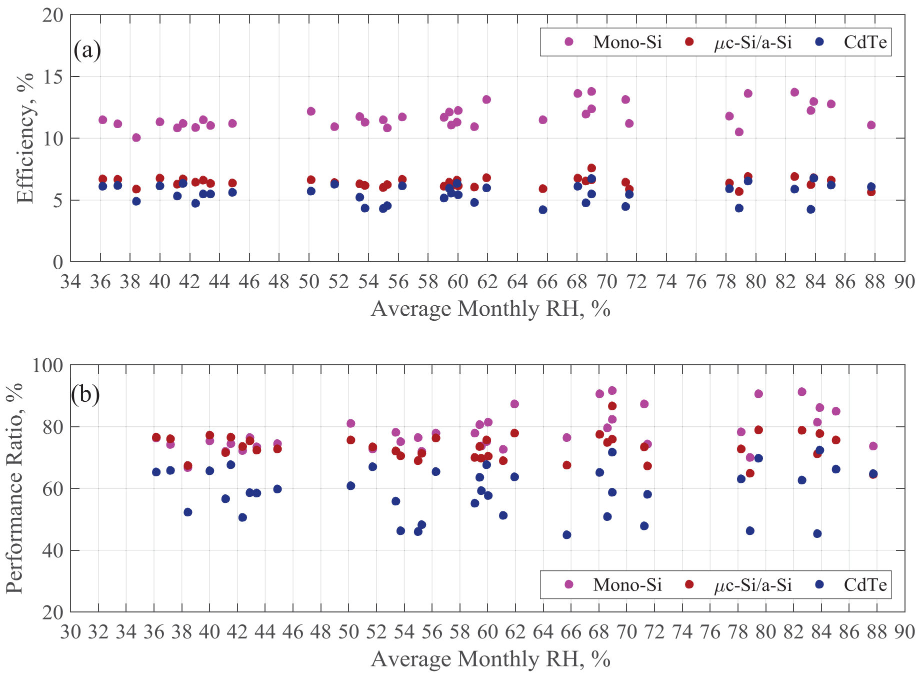

Fig. 5: Variation with relative humidity for Mono-Si, micro-crystalline based amorphous silicon and CdTe grid connected PV systems, (a) efficiency and (b) performance ratio.

The nature of this relation between T_a and RH is specific to the region of the installations and therefore, the correlation between performance and RH for mono-Si system should not be treated to be a physical effect of RH on the performance. That is, the correlation with RH for mono-Si is rather an artificial one which results due to increase in temperature with decreasing RH of the location. In any case, further data and analysis are needed to reach clearer conclusions. Similar to the T_a independence of the performance of the thin film systems, no considerable dependence on RH can be observed (Figure 5, and Table 3 and 4).

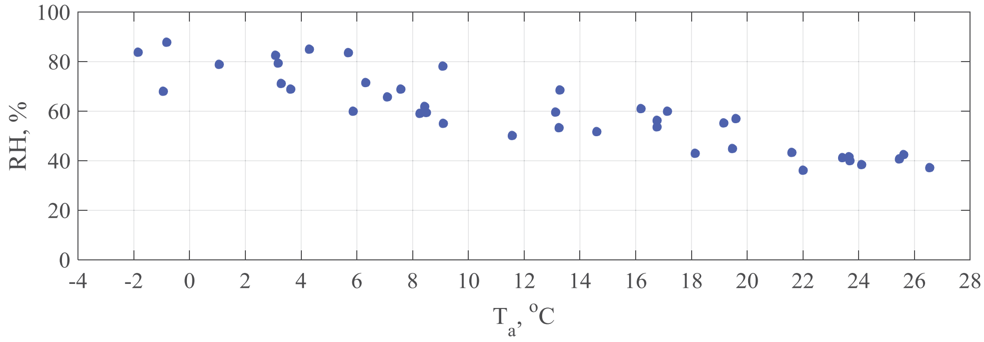

Fig. 6: RH with respect to T_a.

3. Conclusion

In this work, we analyzed the effects of all aforementioned monthly performance variation with climatic parameters and discuss the possible reasons of obtained correlations. As mentioned above, Mono-Si array performance depends on the outdoor climatic conditions while a-Si/μc-Si and CdTe thin film arrays performances are not significantly affected. Although one would expect decrease in efficiency with increasing temperature, we demonstrated that, a-Si/μc-Si and CdTe thin film array performances seems independent of T_a, while a decrease in the efficiency can be clearly observed for Mono-Si array. Similarly, H_t value affects the efficiency of Mono-Si while does not effect a-Si/μc-Si and CdTe thin film array efficiencies. In fact, Pearson's correlation coefficients for H_t independence are in accord with these findings for a-Si/μc-Si and CdTe thin film array monthly efficiencies. However for the performance ratio R_p, it seems that there is rather a significant correlation with H_t and we attributed this dependence to the obvious differences between the laboratory and outdoor climatic conditions. Air mass dependences of the performances are in accord with T_a and H_t dependences. There exists a dependence of the performances on the relative humidity RH however, this dependence should not be due to some unobvious physical effects but instead, it should be due to the interdependence of the T_a to RH specific to the region.

The results of the present work are important in planning and deciding the large scale PV installations to the regions with dry continental climate as in Central Anatolia. Further analysis of efficiency, performance and degradation of some larger number of different types of PV modules at the outdoor conditions of Ankara-Turkey are our future prospects.

4. Acknowledgments

The authors would like to thank B. Aksoy and MGM for the supply of meteorological data. The helps of Mr. C. Güvenç Oğulgönen, Mr. Harun Tanık and Mr. Ugur Yardım during installation, maintenance and data handling are acknowledged. One of the authors thanks to TUBITAK for the support from 2218 program.

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