Multivariate Analysis Using R for Various Climatic Effects on the Output Performances of CIGS and Multi-Crystalline Si Photovoltaic Systems Installed in Miyazaki, Japan

Multivariate Analysis Using R for Various Climatic Effects on the Output Performances of CIGS and Multi-Crystalline Si Photovoltaic Systems Installed in Miyazaki, Japan

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Abstract

Generally, the performance of a PV system depends not only on its basic technical characteristics but also on the environmental conditions in which they will be set up. Therefore, studying the effects of climatic parameters such as solar irradiance on the plane of array (G_{POA}), ambient temperature (T_a), relative humidity (RH) and wind speed (v_a) on the performance of PV is vital to be able to utilize efficiently solar energy.

The authors have studied the effects of various climatic parameters on the output performances of the two PV systems, 60 kW Copper Indium Gallium Selenide (CIGS) and 50 kW Multi-Crystalline Silicon (MC-Si), which were installed within the campus of University of Miyazaki, Japan. The main objectives of the research are to improve the prediction of the PV systems performance while knowing the climatic parameters of a particular area in which they stand, and also provide a useful dataset for the comparative studies.

The analyses were done by the multiple linear regression analysis (MLR) using the statistical software R. The performances of the two PV systems are in positive proportion to the G_{POA} and v_a, however, as per the values of the slopes of the regression equations, the MC-Si PV system is smaller than the CIGS PV system, attributed to their different module tilt angles and elevations of the PV sites. The performances are in negative proportion to the T_a, but the more sensitivity can be observed in the MC-Si PV system. The RH negatively affected on the MC-Si PV system, although its positive effects can be observed in the CIGS PV system.

Keywords: Photovoltaics, Performances, Climatic Parameters, Multiple Linear Regression, Statistical Software R

1. INTRODUCTION

Energy is an important factor for social and economic developments of a country, and nowadays, solar energy became one of the most attractive choices among renewable energy sources since it is the most promising energy source. The climbing energy costs and growing concern about climate change generate a rapid growth in the PV industries. PV production has been increasing by an average of 20% each year since 2002, making it a fast-growing energy technology. In 2017, the global cumulative PV installations have exceeded 402 GW[1)].

Generally, the performance of a PV system depends not only on its basic characteristics but also on the environmental conditions in which they stand. PV modules are rated under standard test conditions (STC, 1000 W/m^2 global irradiance with the air mass of 1.5 and 25 deg-C cell temperature). These conditions are different outdoors, and in order to efficiently and economically use the PV solar energy, there is a need to study the climatic parameters that can negatively impact on its output performance. Therefore, studying the effects of the climatic parameters such as solar irradiance on the plane of array (G_{POA}), ambient temperature (T_a), relative humidity (RH), wind speed (v_a) and precipitation (R_f) on the performance of PV is vital to predict their output performances.

Solar PV module's performance varies with the actual location and prevailing ambient conditions to which they are subjected. Different types of PV modules and PV systems studied with different climates in different regions have been taken into account by researchers[2) 3) 4) 5) 6)].

In the previous studies, the effects of T_a, and also other climatic parameters such as G_{POA}, RH and v_a on the performances of the same PV systems has been carried out by the linear regression analysis[7) 8) 9)]. This research presents how these climatic parameters affect on the DC output power (P_{DC}) of the two PV systems, 60 kW Copper Indium Gallium Selenide (CIGS) and 50 kW Multi-Crystalline Silicon (MC-Si), installed in Miyazaki, Japan, by the multivariate analysis using the statistical software R.

2. EXPERIMENTAL SET UP

There are various kinds of PV modules have been installed and monitored in University of Miyazaki, Japan[10)]. In this research work, the performance of the two PV systems under the variable ambient conditions of Miyazaki [31.8310° N, 131.4126° E] have been investigated for long-term. The two PV systems are with two different PV technologies, and in the both

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systems, the PV modules are connected in series and in parallel to a string inverter that converts the DC power of the PV modules into AC power and feeds it safely into the campus electrical grid. The PV systems are instrumented to record electrical performance at 1 minute intervals by the power conditioning system (PCS), but the climatic parameters are monitored and recorded at 10 seconds intervals by the weather station near the PV sites.

The CIGS PV system was installed on the roof of a seven-story building within the campus of University of Miyazaki in April, 2010, and the mounted modules are tilted according to latitude with a 10 degrees tilt to the horizontal plane and 180 degrees orientation towards true south. It consisted of 6 arrays with a total capacity of 60.52 kW. Arrays 1, 2, 4 and 6 each consist of 120 modules, but Array 3 has 104 modules and Array 5 has 128 modules.

The MC-Si PV System was installed on the roof of a three-story building within the same campus of University of Miyazaki in March, 2010, facing due south with a tilt angle of 20 degrees. It consisted of 5 arrays in parallel with a total capacity of 50.92 kW. Arrays 1, 2 and 3 consist of 60 modules each, but Arrays 4 and 5 each consist of 44 modules.

The installation sites are in a residential area of Miyazaki city, not in an industrial area, and there are no arterial roads near the PV sites. Originally, the energy conversion efficiency of the PCS used for the MC-Si PV system is significantly higher than that of the CIGS PV system. Consequently, it is noted that this difference should be taken into account when considering the difference of total energy conversion efficiency between the two PV systems.

3. EVALUATION METHOD

In this study, the relationships among climatic parameters of the PV site area, and how these parameters affect to the DC power output of the two PV systems were investigated by the multiple linear regression analysis (MLR) using the statistical software R. R is an extremely flexible statistics programming language and environment that is open source, and freely available for all mainstream operating systems. MLR is one of the statistical tools used for discovering relationships between variables, and it is used to find the linear model that best predicts the dependent variable from the independent variables.

We will focus on using four variables, G_{POA}, T_a, RH and v_a, as predictor variables. That is, we would like to model the P_{DC} of the two PV systems as a function of these affected climatic parameters. In the multivariable regression model, the dependent variable is described as a linear function of the independent variables X_i, as follows:

$$Y = a + b_1 X_1 + b_2 X_2 + \ldots.. + b_n X_n + \epsilon \qquad (1)$$

Where, Y = dependent variable
X_i = independent variables
a = constant (y-intersect)
b_i = regression coefficient of the variable X_i
ϵ = error

The model permits the computation of a regression coefficient b_i for each independent variable X_i. For the analysis, we use the function *lm* (*dependent variable ~ independent Var$_1$ + independent Var$_2$ + ... + independent Var$_n$*) in R.

In MLR, the coefficient of determination describes the overall relationship between the independent variables X_i (G_{POA}, T_a, RH, v_a) and the dependent variable Y (P_{DC}). It corresponds to the square of the multiple correlation coefficient, which is the correlation between Y and $b_1 X_1 + b_2 X_2 + \ldots + b_n X_n$. Each of the coefficients b_i reflects the effect of the corresponding individual independent variable X_i on Y, where the potential influences of the remaining independent variables on X_i have been taken into account, i.e., eliminated by an additional computation.

In this way, MLR permits the study of multiple independent variables at the same time, with adjustment of their regression coefficients for possible confounding effects between variables. The goal of statistical analysis is to find out which of these factors truly have an effect on the dependent variable, and the art of statistical evaluation lies in finding the variables that best explain the dependent variable.

4. ANALYSIS RESULTS AND DISCUSSIONS

4.1 Daily Analysis Results

For the daily analysis results, we used the data of the typical four days characterized as a clear day (August 2, 2015), a partial cloudy day (June 7, 2015), a cloudy day (June 20, 2015) and a rainy day (June 23, 2015). Table 1 summarizes the daily-averaged G_{POA}, T_a, RH, va and total R_f of the four different days. Figure 1 demonstrates that there is a negative correlation between RH and T_a, and it can be observed in Figure 2 that RH slightly decreases when the v_a increases, but the value of slope of the regression equation is negligibly small. The three dimensional plot in Figure 3 reveals that RH, v_a and T_a are closely related. It can be seen from this figure that the correlation among T_a, RH and v_a is nonlinear.

Tables 2 and 3 summarize the most important statistical values delivered by the MLR process applied to the data of the different four days analyzed. It is observed in Tables 2 and 3 that in the presence of multicollinearity, the standard errors of the parameter estimates are fairly low, resulting in stable estimates of the regression model. Moreover, the *Adjusted R-Squared* values are almost near to 1, and *p-values* for the models are significantly small in all of the cases. Therefore, we can say that reliable results can

Table 1. Daily-averaged climatic parameters on four different days.

Day	G_{POA} [kWh/m^2]		T_a [deg-C]	RH [%]	v_a [m/s]	R_f [mm]*
	CIGS	MC-Si				
Clear Day (02.08.2015)	7.29	7.30	28.6	74.0	1.32	0
Partial Cloudy Day (07.06.2015)	5.72	5.37	21.0	76.1	1.28	1.50
Cloudy Day (20.06.2015)	2.52	2.36	21.6	88.3	0.964	0
Rainy Day (23.06.2015)	1.86	1.75	20.9	93.4	0.771	27.0

* R_f [mm] means total precipitation.

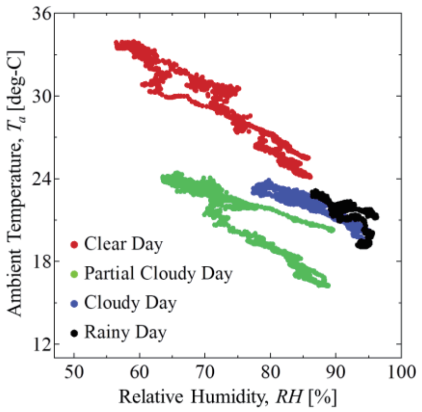

Fig. 1. Relationship between RH and T_a on four different days.

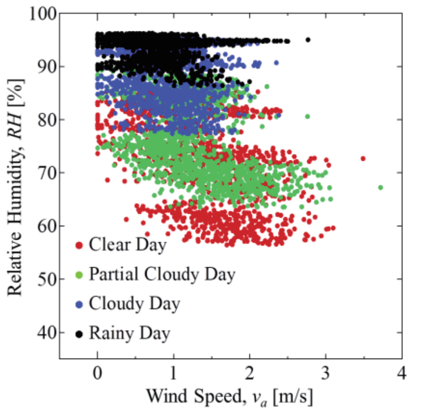

Fig. 2. Relationship between v_a and RH on four different days.

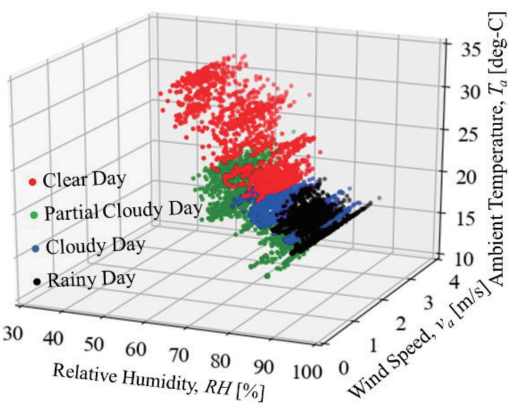

Fig. 3. Relationship among RH, v_a and T_a on four different days.

be obtained by using the MLR analysis, i.e., the regression model is fit enough to observe the effects of the climatic parameters.

The relevance of one variable on the explanation of the response variable is ensured by a *p-value* of the *t statistic* equal to zero or very close to it. These values are very low in Tables 2 and 3, and so, the climatic parameters (explanatory variables) have a significant effect on the P_{DC} (response variable). The *Adjusted R-Squared* value defines how much of the response variable can be represented by the explanatory variables. Then, in this case, the climatic parameters can explain 99.33% to 99.88% of the behavior of P_{DC}.

The different MLR equations have been developed for the four different days, and in the clear day, the regression equations,

$$P_{DC} = -18.1692 + 48.4135\, G_{POA} + 0.3461\, T_a + 0.1037\, RH + 0.2862\, v_a \tag{2}$$

for the CIGS PV system, and

$$P_{DC} = -30.5905 + 41.0158\, G_{POA} + 0.6142\, T_a + 0.1896\, RH - 0.6260\, v_a \tag{3}$$

for the MC-Si PV system, are observed. According to the significant codes, we can see that all of the climatic effects are very significant, and as for the values of the slopes of the regression equations, the CIGS PV system is higher than the MC-Si PV system in the effects of the G_{POA} attributed to their different module tilt angles, but lower in T_a and RH. The negative effect of v_a is occurred in the MC-Si PV system, although the CIGS PV system is positively affected by v_a.

In the partial cloudy day, the regression equations,

$$P_{DC} = 4.7883 + 51.9334\, G_{POA} - 0.0581\, T_a - 0.0518\, RH - 0.0693\, v_a \tag{4}$$

for the CIGS PV system, and

$$P_{DC} = -15.4131 + 42.4756\, G_{POA} - 0.2333\, T_a - 0.1304\, RH - 0.2574\, v_a \tag{5}$$

for the MC-Si PV system, are observed. The T_a, RH and v_a negatively affected on both PV systems, but according to the significant codes, we can see that the effect of v_a is not significant in the CIGS PV system. As for the values of the slopes of the regression equations, although the CIGS PV system is higher than the MC-Si PV system for the effects of G_{POA}, the

Table 2. Multiple linear regression analyses results based on raw data for the CIGS PV system.

Variable	*Estimates*	*Std. Error*	*t Value*	*Pr(>|t|)*	
Clear Day (02.08.2015)					
Intercept	-18.1692	1.4991	-12.1200	<2e-16	***
Solar Irradiance	48.4135	0.0800	605.1330	<2e-16	***
Ambient Temperature	0.3461	0.0308	11.2460	<2e-16	***
Relative Humidity	0.1037	0.0089	11.6300	<2e-16	***
Wind Speed	0.2862	0.0325	8.8050	<2e-16	***
Adjusted R-squared: 0.9988, *Residual standard error*: 0.6141, MODEL *p-value*: < 2.2e-16					
Partial Cloudy Day (07.06.2015)					
Intercept	4.7883	1.1481	4.1710	3.22e-05	***
Solar Irradiance	51.9334	0.1013	512.8180	< 2e-16	***
Ambient Temperature	-0.0581	0.0233	-2.4970	0.0127	*
Relative Humidity	-0.0518	0.0088	-5.8740	5.27e-09	***
Wind Speed	-0.0693	0.0505	-1.3730	0.1698	
Adjusted R-squared: 0.9971, *Residual standard error*: 0.8936, MODEL *p-value*: < 2.2e-16					
Cloudy Day (20.06.2015)					
Intercept	2.9478	1.5609	1.889	0.0592	.
Solar Irradiance	54.3701	0.1579	344.3500	< 2e-16	***
Ambient Temperature	-0.2092	0.0420	-4.9880	6.86e-07	***
Relative Humidity	0.0056	0.0078	0.7150	0.4749	
Wind Speed	0.2593	0.0241	10.7630	< 2e-16	***
Adjusted R-squared: 0.9966, *Residual standard error*: 0.3715, MODEL *p-value*: < 2.2e-16					
Rainy Day (23.06.2015)					
Intercept	-4.4732	0.8239	-5.4300	6.63e-08	***
Solar Irradiance	52.9844	0.1586	334.0260	< 2e-16	***
Ambient Temperature	-0.0017	0.0124	-0.1340	0.8931	
Relative Humidity	0.0396	0.0075	5.2470	1.78e-07	***
Wind Speed	0.0785	0.0294	2.6720	0.0076	**
Adjusted R-squared: 0.9937, *Residual standard error*: 0.4531, MODEL *p-value*: < 2.2e-16					
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

higher effects of other climatic parameters are observed in the MC-Si PV system.

In the cloudy day, the regression equations,

$$P_{DC} = 2.9478 + 54.3701\, G_{POA} - 0.2092\, T_a + 0.0056\, RH + 0.2593\, v_a \tag{6}$$

for the CIGS PV system, and

$$P_{DC} = -13.9202 + 47.5163\, G_{POA} + 0.3403\, T_a + 0.0718\, RH + 0.0444\, v_a \tag{7}$$

for the MC-Si PV system, are observed. The higher positive effects of G_{POA} and v_a are observed in the CIGS PV system, but the effect of RH is not significant in it as per the significant codes. Moreover, although T_a negatively affected on the CIGS PV system, its positive effect is observed in the MC-Si PV system.

Similarly, the regression equations,

$$P_{DC} = -4.4732 + 52.9844\, G_{POA} - 0.0017\, T_a + 0.0396\, RH + 0.0785\, v_a \tag{8}$$

for the CIGS PV system, and

$$P_{DC} = 0.6612 + 47.8361\, G_{POA} + 0.0023\, T_a - 0.0098\, RH - 0.0301\, v_a \tag{9}$$

for the MC-Si PV system, are observed in the rainy day. As per the values of the slopes of the regression equations, the higher positive effects of G_{POA} existed in the CIGS PV system. As per the significant codes, the effect of T_a is not significant in both of the PV systems, however, RH and v_a negatively affected on the MC-Si PV system. Therefore, as per these results, we can say that the MC-Si PV system is more sensitive to the effects of the climatic parameters than the CIGS PV system.

4.2 One Month Data Analysis Results

For this analysis, we used the data of August, 2015. The average T_a existed during August, 2015 ranging 26.9 deg-C, and this month is chosen since we would like to focus mainly on the effect of T_a to the

Table 3. Multiple linear regression analyses results based on raw data for the MC-Si PV system.

Variable	Estimates	Std. Error	t Value	Pr(>|t|)	
Clear Day (02.08.2015)					
Intercept	-30.5905	2.1872	-13.9900	<2e-16	***
Solar Irradiance	41.0158	0.1186	345.7900	<2e-16	***
Ambient Temperature	0.6142	0.0449	13.6700	<2e-16	***
Relative Humidity	0.1896	0.0130	14.5800	<2e-16	***
Wind Speed	-0.6260	0.0482	-13.0000	<2e-16	***
Adjusted R-squared: 0.9964, *Residual standard error*: 0.9116, MODEL *p-value*: < 2.2e-16					
Partial Cloudy Day (07.06.2015)					
Intercept	15.4131	1.3743	11.2150	< 2e-16	***
Solar Irradiance	42.4756	0.1277	332.6110	< 2e-16	***
Ambient Temperature	-0.2333	0.0279	-8.3660	< 2e-16	***
Relative Humidity	-0.1304	0.0106	-12.3470	< 2e-16	***
Wind Speed	-0.2574	0.0607	-4.2370	2.41e-05	***
Adjusted R-squared: 0.9933, *Residual standard error*: 1.0700, MODEL *p-value*: < 2.2e-16					
Cloudy Day (20.06.2015)					
Intercept	-13.9202	1.0876	-12.7990	< 2e-16	***
Solar Irradiance	47.5163	0.1166	407.3900	< 2e-16	***
Ambient Temperature	0.3403	0.0292	11.6460	< 2e-16	***
Relative Humidity	0.0718	0.0055	13.1530	< 2e-16	***
Wind Speed	0.0444	0.0169	2.6220	0.0088	**
Adjusted R-squared: 0.9977, *Residual standard error*: 0.2613, MODEL *p-value*: < 2.2e-16					
Rainy Day (23.06.2015)					
Intercept	0.6612	0.3904	1.6940	0.0905	.
Solar Irradiance	47.8361	0.0791	604.8070	< 2e-16	***
Ambient Temperature	0.0023	0.0058	0.3940	0.6936	
Relative Humidity	-0.0098	0.0036	-2.7150	0.0067	**
Wind Speed	-0.0301	0.0138	-2.1800	0.0294	*
Adjusted R-squared: 0.9982, *Residual standard error*: 0.2131, MODEL *p-value*: < 2.2e-16					
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

output power performance of the two PV systems. Firstly, the data of G_{POA} level of 500 W/m^2 and above are filtered from the data sets of the two PV systems. And then, the effects of the climatic parameters on the P_{DC} of the two PV systems are observed by the MLR analysis, and the results are compared between the two PV systems.

The regression equations,

$$P_{DC} = 6.5962 + 46.8913\ G_{POA} - 0.1818\ T_a + 0.0106\ RH + 0.1276\ v_a \tag{10}$$

for the CIGS PV system, and

$$P_{DC} = 18.2958 + 35.0366\ G_{POA} - 0.3308\ T_a - 0.0372\ RH - 0.2633\ v_a \tag{11}$$

for the MC-Si PV system, have been developed. It is observed that the *Adjusted R-Squared* values range 0.9709 for the CIGS PV system, and 0.9269 for the MC-Si PV system, i.e., in this case, the climatic parameters can explain 97.09% to 92.69% of the behavior of P_{DC}. Moreover, since the *p-values* for the models are significantly small in all of the cases, we can say that fairly reliable results can be obtained by the MLR analysis to observe the effects of the climatic parameters.

The positive effects of G_{POA} is clearly significant in both PV systems, and the values of the slopes of the regression equations range 46.8913 for the CIGS PV system, and 35.0366 for the MC-Si PV system, being a little different in values due to their different tilt angles.

The negative effects of T_a can be observed in both PV systems, and the values of the slopes of the regression equations range -0.1818 for the CIGS PV system and -0.3308 for the MC-Si PV system. As per the results, we can say that the MC-Si PV system is more sensitive to T_a than the CIGS PV system.

The P_{DC} of the CIGS PV system is positively affected by RH and v_a, but their negative effects can be observed in the MC-Si PV system. The values of the slopes of the regression equations range 0.0106 and 0.1276 for the CIGS PV system, and -0.0372 and

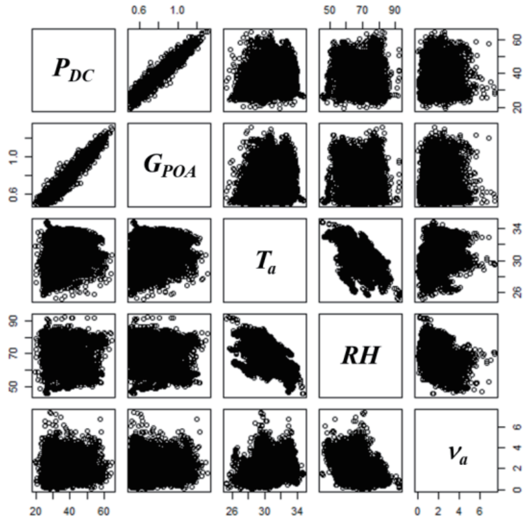

Fig. 4. Scatterplot matrix for the effects of climatic parameters on the P_{DC} of one month data for the CIGS PV system.

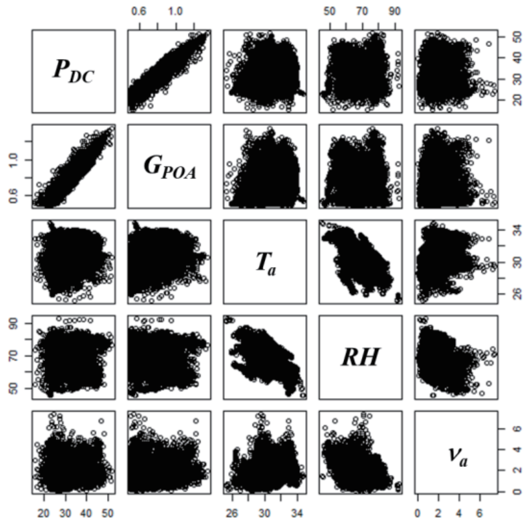

Fig. 5. Scatterplot matrix for the effects of climatic parameters on the P_{DC} of one month data for the MC-Si PV system.

-0.2633 for the MC-Si PV system. Therefore, we can say that the MC-Si PV system is more sensitive to RH and v_a than the CIGS PV system.

Contributing to the captioned analysis results, we can say that the MC-Si PV system is more sensitive to ambient conditions than the CIGS PV system.

4.3 Seasonal Analysis Results

For this analysis, we used the data of two seasons during 2015, summer (June, July and August) and winter (December, January and February). The same analysis method as shown in Sections 4.1and 4.2 is used to observe the effects of the climatic parameters on the P_{DC} of the two PV systems.

For the summer data analysis, the regression equations,

$$P_{DC} = 8.0353 + 47.5701\, G_{POA} - 0.2324\, T_a + 0.0031\, RH + 0.1742\, v_a \tag{12}$$

for the CIGS PV system, and

$$P_{DC} = 12.7525 + 35.5540\, G_{POA} - 0.2165\, T_a - 0.0158\, RH - 0.1427\, v_a \tag{13}$$

for the MC-Si PV system, have been developed. It is observed that the *Adjusted R-Squared* values range 0.9721 for the CIGS PV system, and 0.9327 for the MC-Si PV system. Moreover, since the *p-values* for the models are significantly small in all of the cases, we can say that the MLR analysis can be applied to observe the effects of the climatic parameters.

The positive effects of G_{POA} and the negative effects of T_a can be observed in both PV systems, being a little different in the values of the slopes of the regression equations between the two PV systems. Although the CIGS PV system is positively affected by RH and v_a, their negative effects can be observed in the MC-Si PV system. The values of the slopes of the regression equations range 0.0031 and 0.1742 for the CIGS PV system, and -0.0158 and -0.1427 for the MC-Si PV system. Therefore, we can say that the MC-Si PV system is more sensitive to RH and v_a than the CIGS PV system.

Similarly, for the winter data analysis, the regression equations,

$$P_{DC} = 0.1933 + 54.7314\, G_{POA} – 0.1190\, T_a + 0.0106\, RH + 0.1260\, v_a \tag{14}$$

for the CIGS PV system, and

$$P_{DC} = 4.0613 + 42.9232\, G_{POA} – 0.1742\, T_a + 0.0147\, RH + 0.1871\, v_a \tag{15}$$

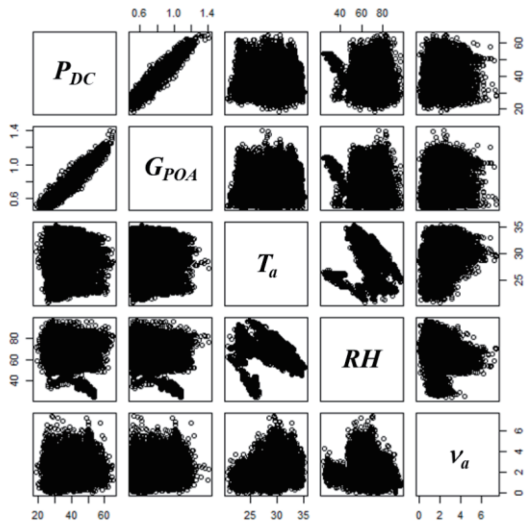

Fig. 6. Scatterplot matrix for the effects of climatic parameters on the P_{DC} of summer data for the CIGS PV system.

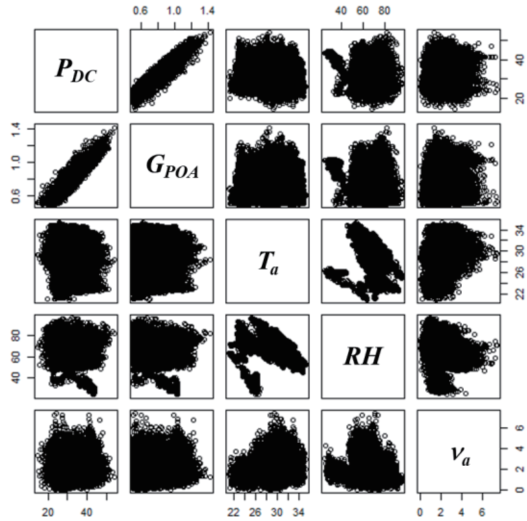

Fig. 7. Scatterplot matrix for the effects of climatic parameters on the P_{DC} of summer data for the MC-Si PV system.

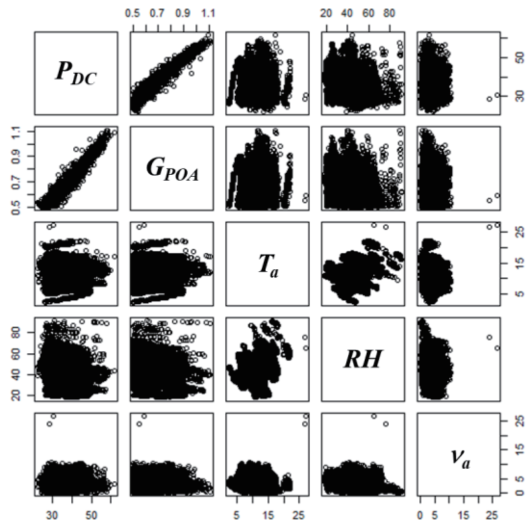

Fig. 8. Scatterplot matrix for the effects of climatic parameters on the P_{DC} of winter data for the CIGS PV system.

for the MC-Si PV system, have been developed. It is observed that the *Adjusted R-Squared* values range 0.9738 for the CIGS PV system, and 0.9599 for the MC-Si PV system. Moreover, since the *p-values* for the models are significantly small in all of the cases, the effects of the climatic parameters can be observed by the MLR analysis.

The positive effects of G_{POA}, RH and v_a can be observed in both PV systems, being a little different in the values of the slopes of the regression equations. However, the T_a negatively affected on the two PV systems, and sa per the values of the slopes of the regression equations, the MC-Si PV system is more sensitive to the ambient conditions than the CIGS PV system.

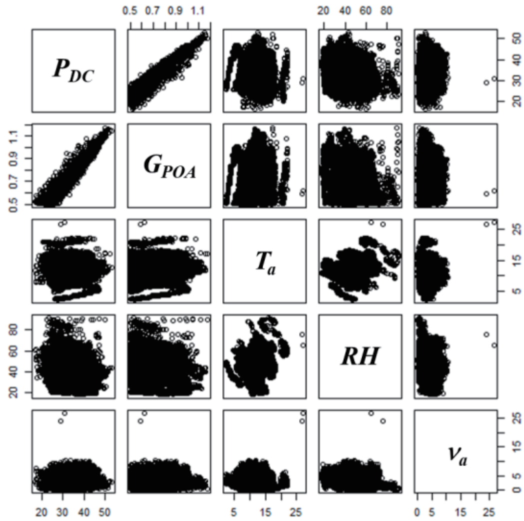

Fig. 9. Scatterplot matrix for the effects of climatic parameters on the P_{DC} of winter data for the MC-Si PV system.

4.4 One Year Data Analysis Results

For this analysis, we used the data of year 2015, and the objective is to confirm the analysis results. Similarly, the data of G_{POA} level of 500 W/m^2 and above are filtered from the data sets of the two PV systems. And then, the effects of the climatic parameters on the P_{DC} of the two PV systems are observed by the MLR analysis.

In this analysis, the regression equations,

$$P_{DC} = 4.8596 + 49.5948\, G_{POA} - 0.1691\, T_a + 0.0017\, RH + 0.1168\, v_a \tag{16}$$

for the CIGS PV system, and

$$P_{DC} = 8.9187 + 37.7813\, G_{POA} - 0.1922\, T_a - 0.0034\, RH + 0.0560\, v_a \tag{17}$$

for the MC-Si PV system, have been developed. It is observed that the *Adjusted R-Squared* values range 0.9751 for the CIGS PV system, and 0.9492 for the MC-Si PV system, i.e., in this case, the climatic parameters can explain 97.51% to 94.92% of the behavior of P_{DC}. Moreover, since the *p-values* for the models are significantly small in all of the cases, we can say that fairly reliable results can be obtained by the MLR analysis to observe the effects of the climatic parameters.

The positive effects of G_{POA} is clearly significant in both PV systems, and as for the values of the slopes of the regression equations, the CIGS PV system is larger than the MC-Si PV system, attributed to their different tilt angles.

The negative effects of T_a can be observed in both PV systems, and as per the values of the slopes of the regression equations, we can see that the more sensitivity to T_a existed in the MC-Si PV system.

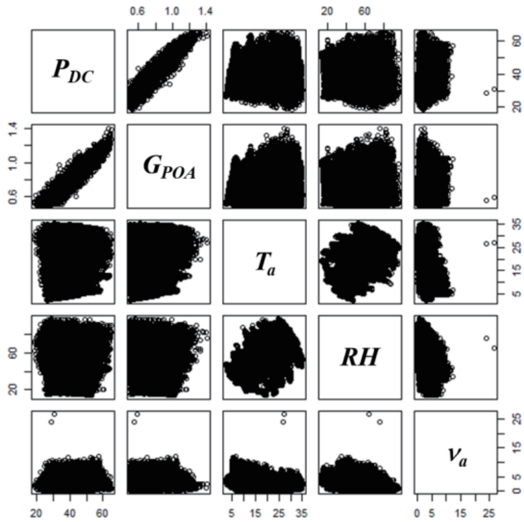

Fig. 10. Scatterplot matrix for the effects of climatic parameters on the P_{DC} of one year data for the CIGS PV system.

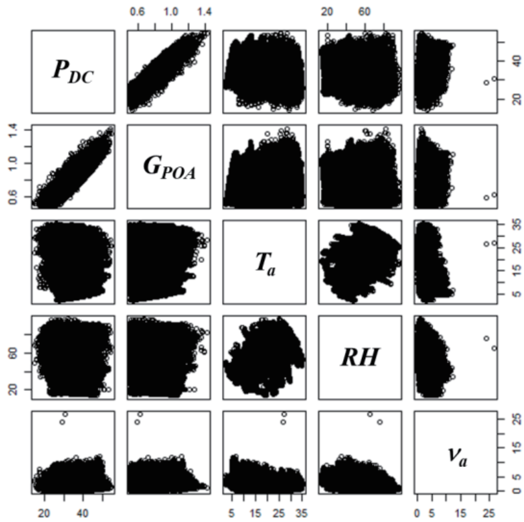

Fig. 11. Scatterplot matrix for the effects of climatic parameters on the P_{DC} of one year data for the MC-Si PV system.

Although the P_{DC} of the CIGS PV system is positively affected by RH, its negative effect can be observed in the MC-Si PV system. The values of the slopes of the regression equations range 0.0017 for the CIGS PV system, and -0.0034 for the MC-Si PV system. Therefore, we can say that the MC-Si PV system is more sensitive to RH than the CIGS PV system, although the effects are negligibly small.

The positive effects of v_a can be observed in both PV systems, and as for the values of the slopes of the regression equations, the MC-Si PV system is smaller than the CIGS PV system, and it may be related to the elevation of the PV sites.

4.5 Discussions

In this analysis, we used the various data ranges such as daily, one month, seasonal and one year, to be able to observe the effects of the climatic parameters on the P_{DC} of the two PV systems.

According to the results, the positive effects of the G_{POA} is very significant in all of the cases. However, in the daily analysis, both the positive and negative effects of other climatic parameters such as T_a, RH and v_a can be observed, depending on the day.

The negative effect of the T_a is very significant in all of the cases except the daily analysis results. As for the values of the slopes of the regression equations, the MC-Si PV system is greater than the CIGS PV system.

The positive effects of RH can be observed in the CIGS PV system, although its negative effects occurred in the MC-Si PV system, except for the summer data.

The positive effects of v_a can be observed in both PV systems, although its negative effects can be seen in the MC-Si PV system for one month data and summer data, i.e., it can be said that the negative effects of v_a occurred in the MC-Si PV system during the period of T_a higher.

As per the numerical results, we can confirm that the MC-Si is more sensitive to ambient conditions than the CIGS PV system.

5. CONCLUSION

In this research, the effects of the climatic parameters on the performance of the two PV systems, CIGS 60 kW and MC-Si 50 kW, are investigated by the MLR analysis using the statistical software R. The effects of the climatic parameters such as G_{POA}, T_a, RH and v_a on the P_{DC} of these two PV systems can be observed at the same time.

The major conclusions are summarized as follows:

1) The strong positve effects of G_{POA} can be observed in both PV systems, and the values of the slopes of the regression equations range 49.5948 for the CIGS PV system and 37.7813 for the MC-Si PV system.
2) The strong negative effects of T_a can be observed in both PV systems, and the values of the slopes of the regression equations range -0.1691 for the CIGS PV system and -0.1922 for the MC-Si PV system.
3) In spite of the positive effects of RH can be observed in the CIGS PV system, RH negatively affected on the MC-Si PV system. The values of the slopes of the regression equations are small, and range 0.0017 for the CIGS PV system and -0.0034 for the MC-Si PV system.
4) The positive effects of v_a can be seen in both the PV systems, and the values of the slopes of the regression equations range 0.1168 for the CIGS PV system and 0.0560 for the MC-Si PV system.

According to the values of the slopes of the regression equations, it can be said that the MC-Si PV system is more sensitive to ambient conditions than the CIGS PV system, in spite of a little difference exists in the module tilt angles and elevation of the PV sites between the two PV systems. These results can be useful to researchers and users dealing with prediction the output performance of the PV systems.

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