



Impact of Air Mass on PV modules Power Generation in Eastern Indian Climatic Zone

Debashis Majumdar¹, Sudipta Basu Pal^{2*} and Rajiv Ganguly¹

¹ Department of Electronics Engineering
University of Engineering & Management, Kolkata
India, Pin-700156
e-mails: debashism@gmail.com, rajivganguly72@gmail

^{2*} Department of Computer Science & Technology
University of Engineering & Management, Kolkata
India, Pin-700156
e-mail: sudipta_basu68@yahoo

Abstract. The PV technology has matured to the gigawatt (GW) level of power generation. Thus, many PV modules are connected in a series-parallel configuration to configure a GW level PV array. Now the vital question of the reliability of such a PV system depends mainly on the performance of the constituent modules (setting aside the reliability consideration arising from the BOS component). Therefore, different climatic parameters directly impact the power output of PV modules. In this research paper, the authors have tried to find out the impacts of climatological parameters like air mass (AM) on the power output as well as the overall performances of different technology PV modules. Mainly crystalline (mono-Si), amorphous silicon (a-Si), and poly-Si photovoltaic (PV) modules are examined thoroughly for different times of three seasons during the year in the eastern Indian climatic zone.

Now, for determining the reliability of any PV array or module, mainly the important parameters considered are regression analysis, Fill Factor variation with changing solar irradiation and temperature. After that, the performance ratio and Fill Factor parameters will be evaluated thoroughly under different climatic conditions. Finally, after the exhaustive evaluations of other reliable PV parameters like FF and PR under naturally outdoor

conditions, it is established that the poly-Si module shows the best performance in the Eastern Indian climatic zone with varying AM.

Keywords: PV Array, Solar Geometry, AIR MASS, FF, PR

1. Introduction

The photovoltaic array or module doesn't exact power under outdoor conditions as standard test conditions (STC) due to different meteorological reasons such as solar insolation, temperature, dust, humidity, and solar radiation changing throughout the year [1,2,3]. According to the researchers, the impacts of weather parameters on mono-Si and a-Si modules indicate that the dust effect is relatively more accurate under desert conditions than other factors such as relative humidity and temperature values [4]. Another group of scientists also developed a scientific model for the prediction of temperature effects on the PV module's energy yields [5]. Because the output power of the array is dependent on the solar spectrum, which fluctuates with changes

in Air Mass, the research subject of performance dependence of the PV array or module with regard to the air mass (AM) is also an important problem (AM). Different solar angles are used to determine the Air mass (AM) [6,7,8,9]. So, different types of solar angles mainly, azimuth angle, declination angle, elevation angle and Hour angle are elaborately explained in this research paper. All the experiments are conducted in two phases. Firstly, three different technologies of lower wattages of PV modules, are used for testing and performance analysis of each module is performed for hourly AM values. After that, based on the results of the first phase of the investigation, the second phase of the experiment was conducted and again performance analyses are made on selected higher wattages of PV modules.

2. Experimental Procedure

The performance evaluation of the PV modules is carried out by analyzing the different V-I characteristics at a different time of Day with hourly varying Air Mass. Figures of Merits such as Performance Ratio (PR)[10] and Fill Factor (FF) are estimated with respect to hourly variation of values AM [11]. Instead of using a resistive or capacitive load, the authors have uses a supercapacitor as the load against the open-circuit voltage of the PV modules while recording the V-I characteristics [12,13,14].

3. Estimation of Airmass

The path length of solar radiation as it goes through the earth's atmosphere, normalized to the shortest path length, is referred to as the Air Mass value (i.e. when the sun is directly overhead). The loss in light's strength as it passes through the atmosphere and is absorbed by air and dust is measured by Air Mass [15,16].AM is defined as,

$$AM = \frac{1}{\cos \theta}$$

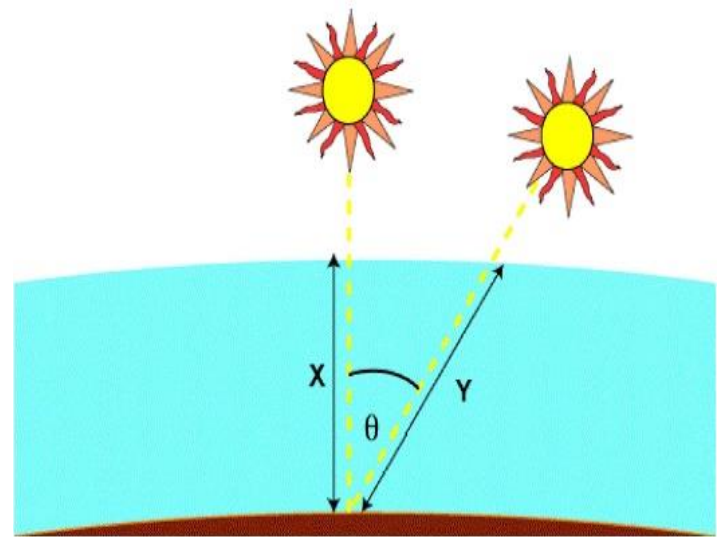


Fig-1: Shows Zenith angle θ between two sun positions.

Where θ is the Zenith angle of sun rays making at a given point on the earth's surface. This is shown clearly in figure-1. Air Mass varies from 0 to infinity. For $\theta=0^\circ$, Sun is vertical, and for $\theta=90^\circ$, Sun is horizontal w.r.t earth's surface. Table-1 shows air mass values using different solar angles at daytime instants from 10 AM to 4 PM.

Table1: Shows Air Mass (AM) for 15th Jan-2020

Day (d)	Standard Time	Latitude of the Location	Solar Time	Hour Angle	Declination Angle	Elevation Angle	Zenith Angle	Air Mass
15	10	22.5	10.23	-26.48	-21.2498993	39.15152	50.8484	1.5838
15	11	22.5	11.23	-11.48	-21.2498993	44.78532	45.2146	1.4195
15	12	22.5	12.23	3.5196	-21.2498993	46.05855	43.9414	1.3888
15	13	22.5	13.23	18.52	-21.2498993	42.61752	47.3824	1.4769
15	14	22.5	14.23	33.52	-21.2498993	35.34754	54.6524	1.7285
15	15	22.5	15.23	48.52	-21.2498993	25.5353	64.4647	2.3198
15	16	22.5	16.23	63.52	-21.2498993	14.16695	75.833	4.0858

4. Results

A. Estimation of PR concerning hourly varying Air mass

In this result section, Table-2 to Table-4 showing estimated values of performance ratio (PR) for the hourly variation of AM for three different technologies of modules for monsoon season at the

roof-top of University and Management, Kolkata, India. For the PR and GPOA evaluation the equations are used mainly,

$$PR = \left(\frac{mP_{MPP}}{P_{STC}} \right) \times \left(\frac{1000 \text{ W/m}^2}{G_{POA}} \right)$$

Where, mP_{MPP} = measured power in NON-STC condition

$G_{POA} = (Insolation \times \cos 22.5^\circ)$, Insolation incident on the plane of Array

Table2. Variation of PR against Air Mass for 10Wp poly-Si

Daytime	Insolation (W/m ²)	Air Mass	Pm	G _{POA}	PR
10.00 Am	630	1.583	5.3375	581.994	0.9171
11.00 Am	740	1.419	6.3066	683.612	0.9225
12.00 Pm	750	1.388	6.7217	692.85	0.9701
1.00 Pm	700	1.476	6.044	646.66	0.9346
2.00 Pm	625	1.728	5.54	577.375	0.9595
3.00 Pm	340	2.319	3.0177	314.092	0.9607
4.00 Pm	160	4.084	1.331	147.808	0.9004

Table3: PR against Air Mass for 10Wp c-Si

Daytime	Insolation (W/m ²)	Air Mass	Pm	G _{POA}	PR
10.00 Am	630	1.583	5.06	581.994	0.8688
11.00 Am	740	1.419	5.71	683.612	0.8358
12.00 Pm	750	1.388	5.72	692.85	0.8255
1.00 Pm	700	1.476	5.29	646.66	0.8177
2.00 Pm	625	1.728	4.97	577.375	0.8608
3.00 Pm	340	2.319	2.56	314.092	0.8163
4.00 Pm	160	4.084	1.27	147.808	0.8599

Table4: PR against Air Mass for 10Wp a-Si

Daytime	Insolation (W/m ²)	Air Mass	Pm	G _{POA}	PR
10.00 Am	630	1.583	4.63	581.994	0.7717
11.00 Am	740	1.419	5.47	683.612	0.7769
12.00 Pm	750	1.388	5.60	692.85	0.7844
1.00 Pm	700	1.476	5.31	646.66	0.7980
2.00 Pm	625	1.728	4.55	577.375	0.7654
3.00 Pm	340	2.319	2.56	314.092	0.7913
4.00 Pm	160	4.084	1.24	147.808	0.8144

Table-2, Table-3, and Table-4, PR for hourly varying AM for three different technology of modules is plotted and shown in Figure-2.

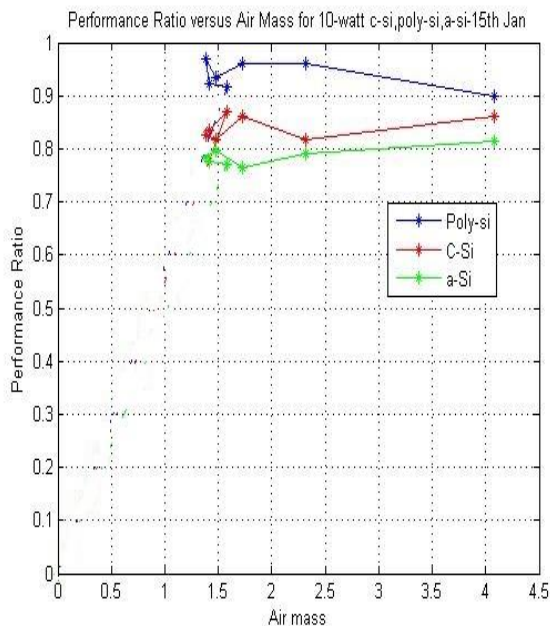


Figure2: PR variation with hourly varying AM

B. PR for AM for poly-Si PV modules with increased wattage

From figure 1, it is visible that the poly-Si PV module PR is consistently higher compared to a-Si and mono-Si PV modules. So, in this background, the authors evaluated the PR values for higher wattages

PV modules of poly-Si concerning hourly varying AM. PR testing for 74Wp and 100Wp modules is depicted in the below section.

Table 5. Performance ratio Vs. Air Mass chart for a 100Wp poly-Si module, 15th March-2020

Day-Time	Insolation (W/m ²)	Air Mass	Pm	G _{POA}	PR
10.00 Am	630	1.2397	53.32	572.756	0.9310
11.00 Am	710	1.1296	63.07	646.66	0.9753
12.00 Pm	880	1.1083	77.03	822.182	0.9369
1.00 Pm	820	1.1675	70.65	739.04	0.9560
2.00 Pm	690	1.3313	61.36	628.184	0.9768
3.00 Pm	620	1.6853	50.37	554.28	0.9087
4.00 Pm	220	2.5391	16.20	184.76	0.8768

The PR variation concerning the hourly interpretation of AM for 74Wp poly-Si during the rainy season is depicted in Table-6.

Table6. Performance ratio Vs. Air Mass chart for a 74 Wp poly-Si module, 20th July-2020

Day-Time	Insolation (W/m ²)	Air Mass	Pm	G _{POA}	PR
10.00 Am	730	1.0930	46.9412	665.136	0.9537
11.00 Am	830	1.0153	51.1291	739.04	0.9349
12.00 Pm	920	1.0029	59.5415	831.42	0.9677
1.00 Pm	790	1.0519	52.0596	720.564	0.9763
2.00 Pm	420	1.1781	27.8402	397.234	0.947
3.00 Pm	230	1.4316	13.1683	193.998	0.9172

C. FF variation with changing values of Air Mass

Fill Factor variation against hourly varying AM for three different types of PV modules is shown below in Table-7.

Table7: FF variation for Air Mass for 10Wp poly-Si,a-Si, mono-Si

Daytime	Air Mass (AM)	FF poly-Si	FF mono-Si	FF a-Si
10.00 Am	1.583	0.8043	0.70752	0.65544
11.00 Am	1.419	0.7378	0.6559	0.61672
12.00 Pm	1.388	0.7531	0.7029	0.6723
1.00 Pm	1.476	0.7620	0.6967	0.6588
2.00 Pm	1.728	0.7331	0.7024	0.6652
3.00 Pm	2.319	0.7144	0.6702	0.6394
4.00 Pm	4.084	0.7285	0.6499	0.6708

From Table-7 FF with respect to hourly varying AM is plotted and shown in figure-3.

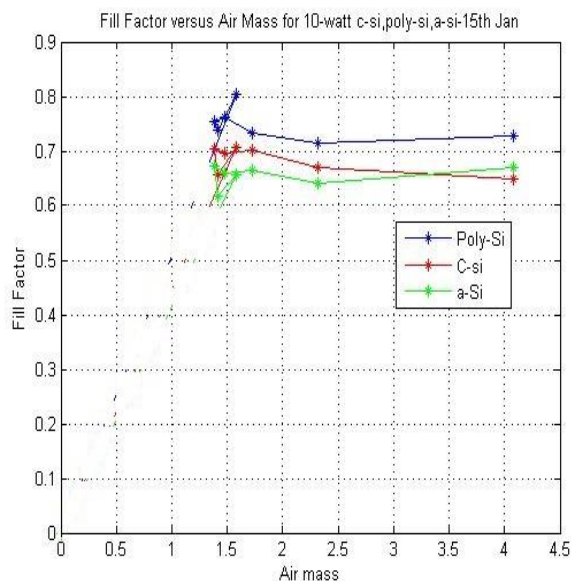


Figure 3. Shows FF vs. Air Mass for 10-watt c-Si, a-Si and poly-Si

5. Conclusion

Air Mass have a direct impact on the power output and overall performance of any PV array or module, and it has been established clearly in this research paper. All the above tables, especially Table 2 to Table 7, clearly show how the PR values and FF values vary with the AM for different technology PV modules. In this research, paper authors have also computed the AM, which is a well-known climatological parameter using different steps of operation.

Authors have critically examined the dependence of PV modules PR and FF on the hourly AM values in a particular season. An analysis made from the above tables that, Fill Factor values of poly-Si (72% to 80%) are higher compared to mono-Si (64% to 70%) and a-Si (61 to 67%). Also, PR values of poly-Si (0.90 to 0.97) is higher compared to mono-Si (0.81 to 0.86) and a-Si (0.76 to 0.81).

PR values for higher wattage, i.e., 100W and 74W, are estimated during different seasons and

find that PR is in the range of 0.90 to 0.96.

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