Automatic performance matrix generation as per IEC 61853 1 standard using only monitored outdoor MPPT data

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AUTOMATIC PERFORMANCE MATRIX GENERATION AS PER IEC 61853-1 STANDARD USING ONLY MONITORED OUTDOOR MPPT DATA

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ABSTRACT

The IEC 61853-1 standard published in January 2011 specifies a performance rating matrix at various temperatures and irradiance levels of a PV module. In the conventional method, this target matrix is generated using all the data points of several measured I-V curves and the translation procedures defined in IEC 60891 standard. In the proposed method, the target matrix is generated using only three commonly field measured parameters: module temperature, incident irradiance and MPPT (maximum power point). The MPPT could be either (or both) dc values of the array before inverter or ac values of the system after inverter. The proposed method can also be used as an online system level diagnostic tool to monitor the health of dc array (and/or ac system) over time (year over year) for performance degradation or soiling effect at any specific set of temperature-irradiance conditions. The primary objectives of the paper include: 1) Automatically generating P\textsubscript{max} matrix as per IEC 61853-1 in about 30 seconds using an interpolation and extrapolation of 6-minute MPPT data monitored and collected over 3 days on a fixed tilt module; 2) Checking the power linearity with irradiance and temperature of the test modules as per IEC 60904-10; 3) Calculating the RMSE (root mean square error) values; and 4) Validation of the program. The monitored three-column data points (temperature, irradiance and P\textsubscript{mppt}) are simply loaded on a pre-programmed Excel spreadsheet. With a click of a button provided in the spreadsheet, the IEC 61853-1 required P\textsubscript{mppt} matrix is displayed on the screen in about thirty seconds. In addition, along with the RMSE value, the program generates several plots including: 1) Irradiance versus P\textsubscript{mppt}, 2) Module temperature versus P\textsubscript{mppt}, and 3) Accuracy check with “Actual P\textsubscript{mppt} versus Calculated P\textsubscript{mppt}.

BACKGROUND

The temperature and irradiance matrix of performance parameters of a photovoltaic (PV) module can be used to predict energy production at various field operating conditions. The matrix of these parameters is usually obtained through a series of indoor or outdoor I-V measurements using temperature and irradiance controlled equipment [1, 2]. The I-V curves thus obtained are translated to the reporting/target temperature irradiance matrix conditions as required per IEC 61853-1 standard [1]. The translation of I-V curves is carried out using different methods defined in IEC 60891 [3] or by NREL [4]. This paper introduces a new and inexpensive way of generating the performance matrix using conventionally monitored MPPT (maximum power point) values at the array dc level or system ac level. The advantages of the new approach include:

- Predicting module(dc) / array(dc) / system(ac) output based on the routinely monitored outdoor data of irradiance, temperature and MPPT
- Avoiding the pre-cooling of PV module for temperature control while warming up under sun
- Eliminating the prolonged manual work of taking I-V curves outdoor, especially during hot summer days
- Eliminating the waiting period for a clear sunny day measurements
- Avoiding extensive and complex I-V curve translation methods
- Utilizing this spreadsheet as an online system level diagnostic tool to monitor the health of dc array (and/or ac system) over time (year over year) for performance degradation or soiling effect at any specific set of temperature-irradiance conditions.

METHODOLOGY

The experimental setup along with irradiance sensors is shown in Figure 1. The data may be obtained with one or more PV modules. In order to reduce the testing days, three identical modules may be used: Module with an insulated back to obtain data at high temperatures; Module without insulated back to obtain data at normal operating temperatures and irradiances; Module with a mesh screen to obtain data at low irradiances. In this paper, the results obtained based on a single module without insulated back or mesh screen is presented. Every MPPT value with its corresponding irradiance and module temperature is considered as a dataset. To obtain datasets at nearly every degree temperature raise, the data acquisition system is programmed to collect the datasets at a high frequency of 6-minute interval. These three-column (temperature, irradiance and MPPT) data sets are loaded into a pre-programmed Excel file.
Working of Excel file

The program developed in this work aims to generate an Excel table as per the power rating specification of IEC 61853-1 standard. To achieve this from the three-column raw data (temperature, irradiance and MPPT), the Excel file has to run through different procedures/programs. These procedures are designed to run in sequence with a click of a single button to minimize user effort. Or, each procedure can be individually executed using different buttons provided in the spreadsheets of Excel.

A screenshot of the Excel spreadsheet is shown in Figure 2. Different buttons for step by step processing can be seen in the figure.

Button 1 is used to round Irradiance and Tmod values to the nearest ones; Button 2 is used to arrange the whole data in increasing order of irradiance and deleting the data sets having less than 40W/m² irradiance; Button 3 is used to arrange this filtered data set in increasing order of module temperatures.

Now the whole data set can be viewed in groups of same module temperature. Each group has combinations of increasingly ordered irradiance and deleting the data sets having less than 40W/m² irradiance; Button 3 is used to arrange this filtered data set in increasing order of module temperatures.

Step 1: Considering all the data points with same module temperature as a set. A trend line equation is calculated using all the data points in a set. The data points deviating more than -13% are deleted.

Step 2: Trendline equation is calculated again for the same set and points and values deviating more than +16% are deleted.

Step 3: Assuming linear behavior of the module, the $P_{\text{max}}$ values are considered to be in increasing order with irradiance. $P_{\text{max}}$ values which do not follow the increasing order are deleted.

Step 4: Trendline equation is calculated again for the same set and points and values deviating less than +0.9% are deleted.

Finally, Button 6 is used to generate the performance matrix as defined in IEC 61853-1 or by the user at any temperature-irradiance sets of their choice.

When $P_{\text{max}}$ of the module is required for specific irradiance (X) and module temperature (Y), the program searches for group having the module temperatures in the range Y +/- 5°C. In the selected group, $P_{\text{max}}$ values are calculated for $Y^\circ\text{C}$ using temperature coefficient for. Now the group has different irradiance values with one temperature value (Y). The program searches for irradiance values X +/- 100 W/m² in the group. Three possible conditions may occur to find a range of irradiance values (+/-100W/m²) in the group.

1. X is less than lowest irradiance value in the group.
2. X is between any of the two irradiance values in the group.
3. The value of X is greater than the highest irradiance value in a group.

Condition 1 is addressed by interpolating the lowest irradiance values close to X.

For the second condition, a graph is created for irradiance values in the range of X+100 and X-100 versus $P_{\text{max}}$. Finally, the $P_{\text{max}}$ of the module at X irradiance and Y module temperature is calculated with the help of trend line equation.

For condition 3, The $P_{\text{max}}$ value is extrapolated from the irradiance values falling under range X-100 and X.

If the program did not encounter irradiance values under this range, the program searches for X irradiance at Y+1 module temperature. The program continuously goes into loop incrementing module temperature to achieve $P_{\text{max}}$ value under above 3 conditions. The program calculates $P_{\text{max}}$ of the module at X irradiance and Y+n module temperature. The $P_{\text{max}}$ is translated for Y module temperature using temperature coefficient of the module. This translated $P_{\text{max}}$ is for X irradiance and Y module temperature.

Button “AUTO” performs all the tasks of all the buttons identified above and generates the IEC 61853-1 power rating matrix. The power rating matrix can be user defined also. The irradiance and module temperature values in the power matrix can be changed according to the requirements of the user. When these values are changed, the matrix have to be updated by clicking “Button 6” present above the matrix.
Button “Verify” can be used if the user needs the output power of the module at specific irradiance and module temperature as shown in Figure 4.

![Figure 4: Output at specific irradiance and module temperature](image)

Validation: The program self evaluates its accuracy with a click of a button “Validate” provided in a different sheet. It calculates $P_{\text{max}}$ according to the program for all the raw data values and compares with the real data. It plots a graph between real $P_{\text{max}}$ values and generated $P_{\text{max}}$ values. It also generates a trend line equation whose slope and $R^2$ provide confidence in the accuracy of the generated $P_{\text{max}}$ values. The program also displays the RMSE (root mean square error) value.

**RESULTS AND DISCUSSIONS**

With a click of “AUTO” button provided in the spreadsheet, various tables and figures are generated. A sample of tables and figures based on 12-day datasets of a polycrystalline silicon module are presented below:

- IEC 61853-1 or user defined $P_{\text{mppt}}$ matrix [Table 1]
- $P_{\text{mppt}}$ versus Irradiance [Figure 5]
- $P_{\text{mppt}}$ versus Temperature [Figure 6]
- Actual $P_{\text{mppt}}$ versus Calculated $P_{\text{mppt}}$ [Figure 7]
- RMSE value

The generated matrix also differentiates the interpolated data (white cells) from the extrapolated data (yellow cells) as shown in Table 1.

**Table 1:** $P_{\text{max}}$ Matrix: Irradiance vs. Temperature

<table>
<thead>
<tr>
<th>TEMPERATURE (°C)</th>
<th>15</th>
<th>25</th>
<th>35</th>
<th>45</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>18.2</td>
<td>18.8</td>
<td>16.9</td>
<td>9.9</td>
<td>N/A</td>
</tr>
<tr>
<td>200</td>
<td>38.2</td>
<td>36.7</td>
<td>36.0</td>
<td>23.3</td>
<td>23.3</td>
</tr>
<tr>
<td>300</td>
<td>74.0</td>
<td>55.0</td>
<td>52.7</td>
<td>38.0</td>
<td>37.4</td>
</tr>
<tr>
<td>600</td>
<td>111.5</td>
<td>105.7</td>
<td>99.4</td>
<td>92.8</td>
<td>85.3</td>
</tr>
<tr>
<td>800</td>
<td>142.5</td>
<td>135.2</td>
<td>125.8</td>
<td>121.8</td>
<td>118.9</td>
</tr>
<tr>
<td>1000</td>
<td>167.4</td>
<td>160.1</td>
<td>152.8</td>
<td>148.8</td>
<td>144.1</td>
</tr>
</tbody>
</table>

![Figure 5: $P_{\text{max}}$ vs. Irradiance](image)

![Figure 6: $P_{\text{max}}$ vs. Temperature](image)

![Figure 7: Calculated $P_{\text{max}}$ vs Actual $P_{\text{max}}$](image)
For the program to generate an accurate matrix, sufficient number of data sets are required. One of the aims of this project is to reduce the number of days of data collection and generate the matrix using as few datasets as possible. To determine the required minimum number of days to collect the datasets, different approaches were followed as delineated below.

1) Single module approach
   A. 1-module 12-day approach:
      Data of a single module is collected from 7:00AM to 6:00PM for 12 continuous days every 6 minutes.
   B. 1-module 6-day approach:
      Data of a single module is collected from 7:00AM to 6:00PM for 6 continuous days every 6 minutes. Matrix generated using 6-day and 12-day datasets were compared. They were found to be practically identical at all irradiance conditions shown in Table 1 except for 100 W/m² at 35°C and 45°C which deviated by 6-9%.

When data is being collected from only one module, the program was not able to find sufficient or any data of extreme conditions of:
   a) Lower Irradiance, High Temperature
   b) High Irradiance, Low Temperature

To get data at such extreme conditions, 3-module approach was undertaken.

2) Three module approach

Based on the I-V curves obtained at 200, 600 and 1000 W/m², three identical modules have been selected for the 3-module approach. Among the three identical modules, first module was insulated on the backsheet, a transmittance calibrated mesh screen was mounted in front of the second module with a 3-inch air gap and the third module is left as without back insulator or front mesh screen. This study is currently underway and the results are not presented here.

CONCLUSIONS

Based on the results presented, it can be concluded that:

- The program checks for the $P_{\text{max}}$ linearity with irradiance and temperature
- The program checks for the data accuracy by comparing the calculated data with actual measured data
- The proposed approach has the potential generating various user-defined plots to use as a diagnostic tool for power plant degradation or soiling effect over time

REFERENCES


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Figure 2: Raw data in Excel

Figure 3: Final data arrangement in Excel