EFFECT OF I-V TRANSLATIONS OF IRRADIANCE-TEMPERATURE ON THE ENERGY YIELD PREDICTION OF PV MODULE AND SPECTRAL CHANGES OVER IRRADIANCE AND TEMPERATURE

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Abstract

Energy rating is gaining importance in the photovoltaic (PV) community as it, unless power rating at standard conditions, allows an accurate estimation of the performance of PV modules in different climatic conditions. The device characterisation currently requires the measurement of a performance matrix using irradiance and temperature where values between measurements might be interpolated. Spectral changes are included by correcting using a quantum efficiency measurement. I-V translations of PV modules give better idea about the measurements of the PV modules as a function of irradiance and temperature. Two methods of I-V translations are applied in this study. Bilinear interpolation between the consecutive points of three selective data sets of irradiance and temperature in the power matrix reduces the prediction error below 2.5% compared to over 6% with linear interpolation between two extreme data set points in the power matrix.

Introduction

Photovoltaic modules are typically being sold on the basis of £/Wp, which is determined at Standard Testing Conditions (STC). However, the return of investments or user interest is better expressed in terms of £/kWh generation. This means that there is a mismatch between the initial investment and its returns. This mismatch in expectations can be overcome by given the user the opportunity to judge modules on expected energy yield. There are few energy yield prediction models available developed by different research groups across the Europe, but yet there is no standard available commercially. Development of a standard based on energy rating of PV module is underway proposed by IEC [1], which involves a standardised energy yield prediction for a standard operating environment using a standard method of calculation. Accuracy of energy yield prediction is the most important factor on the robustness of an energy rating method. Specific PV module measurement data and site specific environmental data are two common requirements as an input into the energy prediction modelling of any PV module.
Understanding of the behaviour of PV device performance over the range of irradiance, temperature and spectrum is very important in order to achieve an accurate energy yield prediction method. This can be assured by means of an uncertainty analysis of the modelling to estimate the power output of PV modules. Modelling uncertainty analysis allows better understanding of the behaviour of PV module output at their certain range, which allows deciding the appropriate modelling approach for energy yield prediction. Employing bilinear interpolation, linear interpolation between to consecutive points, can lead to better accuracy in prediction of the output of PV modules. This helps to decide the required number of measurement points for each parameter to characterise the module with better accuracy. Minimisation of number of measurement points in the performance matrix can minimise the cost of testing of PV modules. Uncertainty analysis of the energy rating methodology can significantly helps financial evaluation of PV systems.

A previous study [2] demonstrated the uncertainty of the modelling issues for IEC energy rating method using linear interpolation. In this study a comparison between linear and bilinear interpolation is employed for I-V translation to estimate the deviation between two approaches in the output of the PV module in terms of maximum power, which ultimately explain the appropriate method to use for better accuracy in the energy yield prediction. The methodologies for I-V translations used are based on the IEC 60891 standard [3].

Spectral effects on the efficiency of the c-Si PV device over the irradiance and temperature are also analysed. Effect of spectral contribution in the energy generation of PV modules in outdoor condition at different spectrum is under development.

I-V Translation Methodologies

Characterisation of PV module is one of the input required data into the energy yield prediction model are explained above along with environmental characterisation data. In order to achieve input module characterisation data, a c-Si PV module is characterised indoors under variable irradiance, temperature and spectrum using a in-house developed LED-based solar simulator [4]. Deviations of actual measured P_{max} and estimated Pmax of different approaches of I-V translations in compared. These modelling approaches ultimately declare the possibilities of the scale of modelling uncertainty in the energy yield prediction of PV modules. Marion et al [5], explains an indoor characterisation method to determine a PV module's temperature and irradiance correction factors in order to translate a reference curve to outdoor conditions of PV module temperature and irradiance for energy yield calculation based on translation equations of ASTM E 1036–96.

Anderson et al [6] demonstrated a new approached of I-V translation using dimensionless (relative) values of temperature coefficients for current and voltage. Procedure 2 of IEC 60891 (working draft) is employed for irradiance and temperature corrections based on single I-V measurement. In this paper IEC methods is been analysed and also a linear interpolation is applied using different datasets within the performance matrix as a function of irradiance and temperature for better accuracy over the wide range of irradiance and temperature generally a PV module can see in real operation.

I-V Translations

The measured current-voltage characteristics are translated to the other targeted irradiance and temperature conditions by using equations (1) and (2).

$$I_T = I_1 * (1 + \alpha_{rel} * (T_T - T_1)) * \frac{G_T}{G_1} \qquad (1)$$

$$V_T = V_1 + V_{oc1} * \left(\beta_{rel} * (T_T - T_1) + a * \ln\left({G_T}/{G_1} \right) \right) - k * I_T * (T_T - T_1) \qquad (2)$$

Where (I_1, V_1) are coordinates and V_{oc1} is the open circuit voltage at measured irradiance G_1 and temperature T_1. (I_T, V_T) are targeted coordinates at target irradiance G_T and target temperature T_T. α and β are the relative current and voltage temperature coefficients at G_1. 'a' is the irradiance correction factor for open circuit voltage with a typical value of 0.06 [3]. "k" is the curve correction factor of the test sample.

Temperature coefficients for current and voltage are estimated from measured I-V curves at AM1.5 spectrum and irradiance at 765 W/m^2 and temperature in the range of 15-55 ^{0}C. To calculate curve corrector factor (k), I-V characteristics at lowest temperature and at constant irradiance are used. All other I-V curves at different temperatures within the range of interest and at higher irradiances are translated to the I-V curve at temperature of 15^{0}C using equations (1) and (2) and also using the values of R_S and temperature coefficients as described in Figure 1.

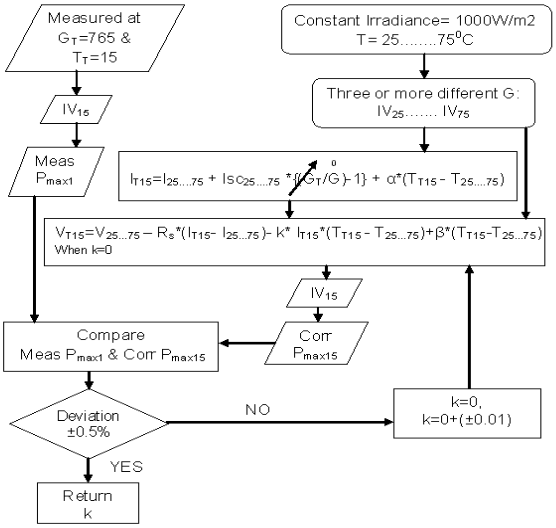


Figure 1: Flow diagram to estimate curve correction factor (k).

Maximum Power Interpolation

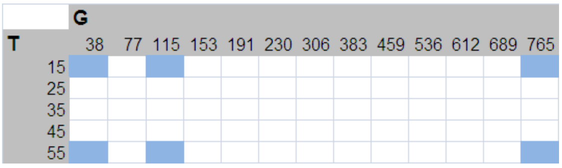
Linear interpolation is applied using equations (3) and (4) to estimate the intermediate maximum power (P_{max}) of the c-Si PV module of the power matrix as a function of irradiance and temperature at AM1.5 spectrum.

$$P_T = P_1 + a * (P_2 - P_1) \qquad (3)$$

$$a = \frac{(G_T - G_1)}{(G_2 - G_1)} \text{ OR } a = \frac{(T_T - T_1)}{(T_2 - T_1)} \qquad (4)$$

Where P_T is the maximum power of the I-V curve at targeted irradiance and temperature (G_T,T_T). P_1 and P_2 are the measured maximum power of the I-V curves at irradiance and temperature at (G_1,T_1) and (G_2,T_2) respectively.

P_{max} is corrected to its intermediate values from the four measured various irradiances and temperatures.



T \ G	38	77	115	153	191	230	306	383	459	536	612	689	765
15	🟦		🟦										🟦
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Figure 2: Different sets of data points in the power matrix as a function of irradiance and temperature.

Bilinear interpolation is basically a linear interpolation between different sets of four measured points in the range of interest as shown in Figure 2 where blue squares are the measured points in the matrix. and the deviation of estimated P_{max} and measured P_{max} are analysed.

Results and Discussion

Using equation (1) and (2) with the measured current-voltage (I-V) characteristics at 765 W/m^2 irradiance and 25^{0}C temperature, all other I-V curves are translated at different irradiance and temperature within wide range irradiance and temperature conditions as illustrated in Figure 3. Relative values of the temperature coefficients are used for current and voltage. Estimated and the measured maximum power points of each curve are then compared. Deviations between the estimated P_{max} and the actual measured P_{max} are shown in the Figure 3.

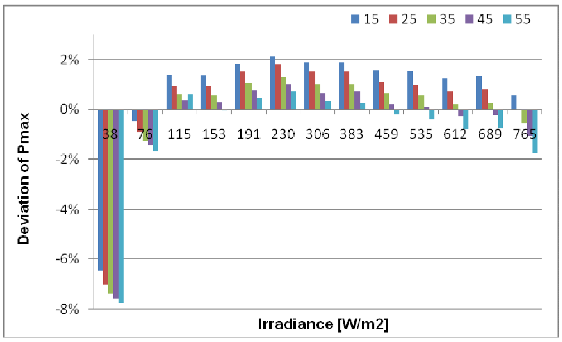

Figure 3: Deviation of measured and translated P_{max} based on procedure 2 of IEC 60891 standard.

For better accuracy at lower intensity levels Tsuno et al [7], demonstrated a linear interpolation/extrapolation between the four measured I-V curves within the range of irradiance and temperature conditions. Similar approach based on equation (3) and (4) in the power matrix is carried out in this study. Linear interpolations between extreme four points in the matrix are used. With this method the deviation between estimated and measured P_{max} are reduced to a certain extent compare to the previous method, as shown in Figure 4.

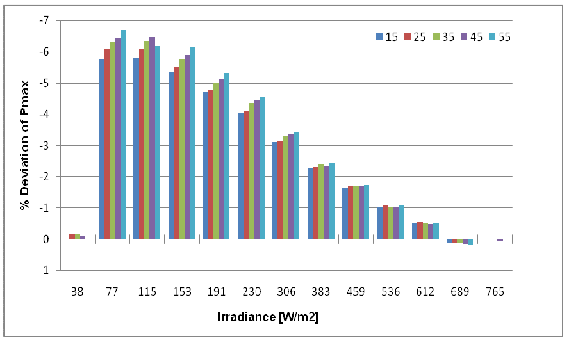

Figure 4: Deviation of measured and interpolated P_{max} with four extreme points of irradiance and temperature in the power matrix.

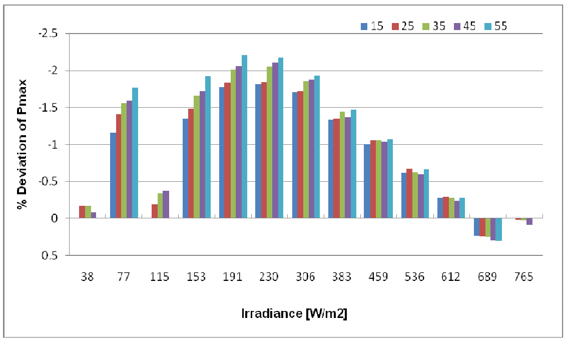

Figure 5: Deviation of measured and interpolated P_{max} with two different sets of four points of irradiance and temperature in the power matrix.

But the deviation of P_{max} over 6% (Figure 5) by the linear interpolation method can also significantly increase the energy yield prediction uncertainty. To minimise the modelling uncertainty in order to achieve accurate energy yield prediction method, a bilinear interpolation within the range of irradiance and temperature is introduced by selecting different set of data points and using linear interpolation between the consecutive points. By selecting two set of data points (blue squares blocks in Figure 2), deviation of P_{max} can minimised below 2.5% as shown in Figure 5 compared to over 6% deviation in P_{max} in Figure 4. This deviation implies that power output of c-Si is not linear in the lower irradiance level but it’s linear over the temperature.

Performance matrix of efficiency as a function of spectrum at different Air Mass (AM) and irradiance are analysed. Efficiency matrix at variable AM are normalised at AM 1.5 spectrum. Figure 6 shows that the normalised efficiency increases with air mass for c-Si module.

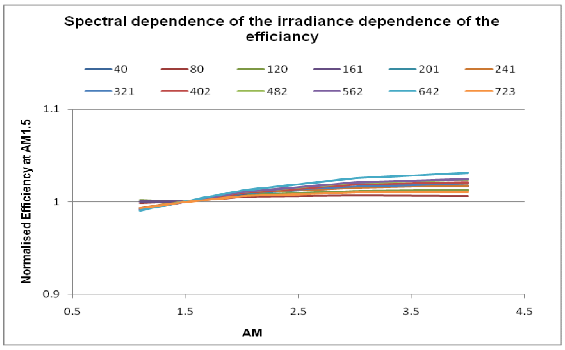

Figure 6: Spectral dependence of P_{max} over the irradiance.

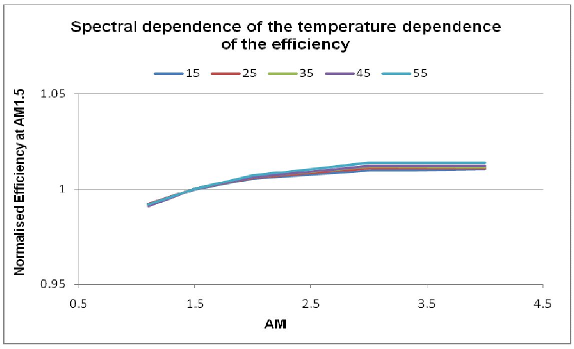

Figure 7: Spectral dependence of efficiency over the temperature.

Another trend also visible in Figure 6 and Figure 7 that the efficiency is increasing over the irradiance at the same spectrum but change in efficiency over the temperature at the same spectrum is not significant.

Conclusions and Future Works

Two different approaches of I-V corrections are studied in this paper. Procedure 1 of the standard IEC 60891 can introduce larger uncertainty in the energy yield prediction of a PV device in the UK where maximum energy yield occurs at lower irradiance level. Power output is linear at higher irradiance levels compared to lower irradiance. A better fitting can be achieved by applying bilinear interpolation of two different set of data points in the power matrix within the range of interest of irradiance and temperature compared to a linear interpolation between the extreme four points in the matrix. Uncertainty of the energy yield prediction model can further be minimised by increasing the number of measured data set points with bilinear interpolation between two consecutive points.

Optimisation of the required number of measurements and identification of the correlation between irradiance, temperature and spectrum based on Average Photon Energy (APE) at each spectrum is the current state of the work for this study in order to achieve higher accuracy in the energy rating of a PV module.

Acknowledgements

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