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iJET International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 5 No. 5, May, 2015

Computational Disparities between Critical Parameters of a Photovoltaic Array via Two Analytical Models

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ABSTRACT

This paper presents the computational disparities between the leading parameters of a photovoltaic array $(V_{oc}, I_{sc,} V_{mp}, I_{mp}, P_{mp}, FF\ and\ \eta)$ installed at the Faculty of Engineering and Engineering Technology of Abubakar Tafawa Balewa University, Bauchi, Nigeria. There is no doubt that Photovoltaic modeling has evolved over the years with attention focused more on analytical approach anchored on the readily available manufacturer's data for the PV module. The alternative approach of relying on field measurement to underpin the development of mathematical model for a PV array of interest has been largely unexplored. In this paper and for the sake of comparative evaluation, two mathematical models termed – Field Measurement Based PV Simplified Analytical Model (FMB-PV-SAM) and Manufacturer Datasheet Based PV Simplified Analytical Model (MDB-PV-SAM) have been individually used to determine the value of each leading parameter and the disparities between them graphically plotted as function of temperature. The results show that at low PV cell temperatures typically below 40^{0}C, the datasheet based model (MDB-PV-SAM) makes a very good approximation of the field measurement based model (FMB-PV-SAM) for computing all the leading PV array parameters except maximum power. However, the disparities at temperatures above 40^{0}C are particularly wide, thus indicating that the datasheet based model cannot replace the field measurement based model without significant loss of accuracy. Interestingly, smaller disparities are obtained with respect to maximum power of the array at temperatures above 50^{0}C higher rather than at lower temperatures.

Key Words: *Computational Disparities, PV Array, Simplified Analytical Models, Field Measurement, Manufacturer Datasheet*

1. INTRODUCTION

A photovoltaic (PV) system directly converts solar irradiance into electrical energy. The basic generating unit of a PV system is the solar cell, which generates only a small amount of power. However, solar cells may be grouped to form modules and arrays depending on the powers needs of the user. Under field conditions, the actual output of a PV system depends mostly on the array orientation, solar irradiance and cell temperature. Predicting, the output of a PV system while considering the effects of all these factors is crucial to design engineers. From the characteristic current-voltage curve of a given PV array, the following physical parameters are defined:

- Short circuit current of the array (I_{sc}^{A})
- Open circuit voltage of the array (V_{oc}^{A})
- Maximum power point power (P_{mp}^{A})

The determination of these variables is essential for the development of appropriate array models which generally require iterative numerical solutions due to the nonlinear and implicit relationships that exist between them [1].

Many mathematical models have been developed to estimate PV array shorts circuit current, open circuit voltage, maximum power point power and efficiency. An attempt has been made previously to determine these variables as function of temperature and irradiance [2]. Currents and voltages for PV points were determined from an explicit model by using manufacturer's data [3]. An analytical model based on manufacturer's data was presented in [4].

Thus, most of the previous models on PV array characterization were dependent upon input parameter values derived from the manufacturer's datasheet. Unfortunately however, it has been established that the results of such characterizations are not accurate [5].

In this paper, the two developed models - Field Measurement Based PV Simplified Analytical Model (FMB-PV-SAM) and Manufacturer Datasheet Based PV Simplified Analytical Model (MDB-PV-SAM) will be used to evaluate performance of a PV array by determining (I_{sc}^{A}), (V_{oc}^{A}) and (P_{mp}^{A}) parameter values and graphically plotting the differences between the values obtained via the two models. Results obtained from direct measurement based modeling will be used as benchmark for comparison with results of the other two models. .

2. METHODOLOGY

The functional representation of the overall proposed modelling techniques is presented in Fig. 1. The performance of the PV array will be evaluated through the following modelling techniques as detailed in the figure:

- Existing PV model simulation based on datasheet specifications on Excel platform.
- The proposed Simplified Analytical Models (SAM).
- Direct measurement based modelling.

It is clear from this figure that the major difference between the two simplified analytical models has to do with the choice of the model driving data base. Indeed, the same computational procedure applies to both models. The implementation of the algorithmic procedure to simulate the simplified analytical models is central to ascertaining the model accuracy in predicting the performance of the PV array test rig. The MATLAB software platform has been adopted for the purpose of some key simulation activities of this research work. In addition to MATLAB, the ORIGIN software and Excel have also been extensively used to achieve optimum curve fitting of the various PV field measurement data particularly the disparity plots and various sensitivity studies.

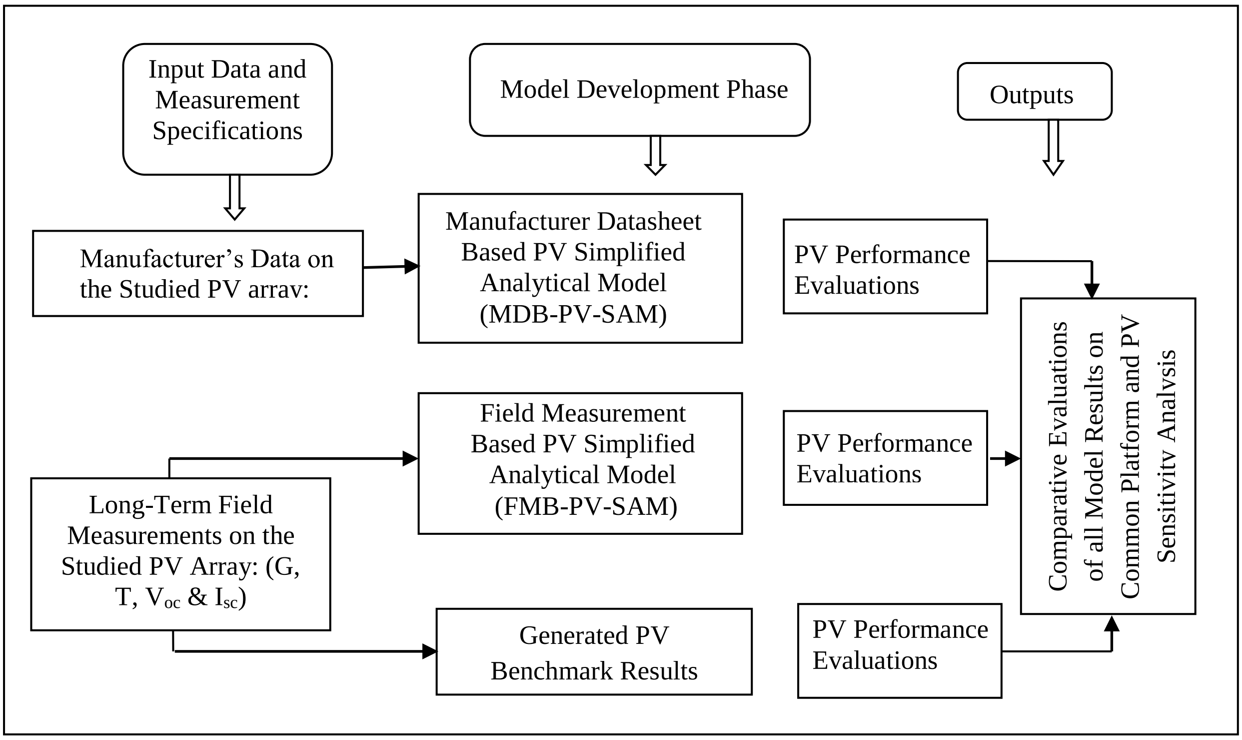


Figure 1: Functional Block Representation of the Overall Proposed Modeling Techniques

3. COMPUTATIOAL DISPARITY RESULTS

The computational disparity results obtained via the two mathematical models termed FMB-PV-SAM and MDB-PV-SAM are comprehensively discussed in the next subsections.

a. Computational Disparity Results for PV Array Performance Parameters

Fig. 2 depicts relative computational disparities between Fill Factors (FF^A), Maximum powers (P^A_{mp}) and open circuit voltages (V^A_{oc}) for the PV array predicted via the two analytical models for the harmattan season as function of temperature. Similarly Fig. 3 depicts the relative computational disparities between conversion efficiencies (η^A), maximum power voltages (V^A_{mp}), short circuit currents (I^A_{sc}) and maximum power currents (I^A_{mp}). The comparative evaluations of the various sensitivities for different climatic variants and average values for PV array are represented in the 3-D display of Fig. 4. These sensitivity coefficients already reported in detail in [6], essentially apply to the polycrystalline silicon PV array investigated. It is interesting to point out that the temperature sensitivity coefficients so determined compare favorably with those presented in [7] for a PV module of the same technological architecture but tested under different climate. As expected, it is seen from this plot that I_{sc} exhibits very insignificant temperature sensitivity coefficient amongst the parameters of the PV array. Fig. 5 constitutes 3-D Variation of Maximum Power with Respect to PV Temperature and Solar Irradiance for Harmattan Season for the PV array. The foregoing emerged from the field measurement based simplified analytical model (FMB-PV-SAM) and empirical relationships developed for the harmattan season as presented in [8].

Undoubtedly, the harmattan period is of particular interest because the power delivery capability of the PV array is significantly reduced and could be as low as 55 % of the manufacturer specified rating at STC. In order to counteract the negative impact of harmattan inclement weather condition, it will be necessary to call for a design philosophy constrained by climatic limitations for optimal sizing of photovoltaic system so as to meet the desired supply reliability requirements at all times.

3.2 Discussion of Computational Disparity Results for PV Array Performance Parameters

The results of the disparity plots of FF, V_{oc}, P_{mp}, η, I_{sc}, V_{mp} and I_{mp} as function of temperature for the PV array as obtained via FMB-PV-SAM and MDB-PV-SAM have been presented in the previous section as indicated in Figs. 2 and 3. It is worthy of note that although the datasheet based model (MDB-PV-SAM) is more popular among scientists in the literature, the field measurement based model (FMB-PV-SAM) is more direct, accurate and therefore taken as benchmark in this work. Discussions of the results obtained are now presented in sequel in what follows.

3.2.1 Discussion of Disparity Results for Fill Factor (FF)

The lower part of Fig. 2 indicates the disparity plots of Fill Factors as obtained via the two analytical models. A smaller and fairly constant average disparity of $2.51020774\text{x}10^{-2}$ is obtained between cell temperatures of 25^0C and 45^0C. Thereafter, the disparity rises steadily to a new average value of $5.1411145\text{x}10^{-2}$ between the cell temperatures of 50^0C and 70^0C. From this result, it is obvious that the two analytical models tend to give smaller disparities in Fill Factor values at temperatures below 45^0C while the disparities are almost doubled at temperatures above 50^0C. Thus, when the field measurement based analytical model (FMB-PV-SAM) is taken as benchmark, the datasheet based analytical model is accurate only at temperatures low cell temperatures typically below 45^0C.

3.2.2 Discussion of Disparity Results for Maximum Power (P_{mp})

The middle plot in Fig. 2 indicates the disparity between maximum powers as obtained via the two analytical models. As seen from the plot, a maximum disparity of 6.298615611 Watts in PV array power is obtained at a temperature 25^0C, which then steadily decreases to a minimum value of -1.620518893 Watts at a temperature of 40^0C. The negative sign indicates that datasheet based model (MDB-PV-SAM) is likely to be more accurate than the Field Measurement based model (FMB-PV-SAM) at this temperature. The disparity rises steadily to a constant average value of $6.20243532\text{x}10^{-2}$ Watts between the temperatures of 50^0C and 70^0C. Thus indicating that datasheet based model can be a very good approximation of the field measurement based model only at high rather than at low cell temperatures.

3.2.3 Discussion of Disparity Results for Open Circuit Voltage (V_{oc})

The upper plot of Fig. 2 indicates the disparity in open circuit voltages for the PV array as obtained via the two analytical models. The disparities are relative high for most of the temperature ranges, except between the temperature range of 35^0C and 40^0C where a relatively small average disparity of 0.025 V is obtained. The datasheet based model also appears to be more accurate model for V_{oc} estimation at 60^0C. From this plot, it can be concluded that the datasheet based model is a very good approximation of the field measurement based model for PV array V_{oc} estimation between the cell temperatures of 35^0C and 40^0C.

3.2.4 Discussion of Disparity Results for Conversion Efficiencies (η)

The first plot from the bottom of Fig. 3 indicates the disparities in the conversion efficiencies for the PV array as determined via the two analytical models. A smaller disparity of 0.46% is obtained at a temperature of 25^0C. A relatively high average disparity of 0.56% is maintained between 30^0C and 55^0C, but steadily declines to 0.5025% at temperatures above 60^0C. Thus the datasheet based model has a very good approximation of the field measurement based model at 25C. A relatively good approximation is also expected at temperatures above 60^0C.

3.2.5 Discussion of Disparity Results for Maximum Power Voltage (V_{mp})

The second plot from the bottom of Fig. 3 indicates the disparities of maximum power voltages for the PV array as obtained via the two analytical models. The disparity linearly increases with temperature from a minimum value of 0.267856 V at 25^0C. Thus the datasheet based model has a very good approximation of the field measurement based model at the very low cell temperature of 25^0C.

3.2.6 Discussion of Disparity Results for Short Circuit Current (I_{sc})

The forth plot from the bottom of Fig. 3 indicates the disparities in short circuit voltages for the PV array as computed via the two analytical models. The result obtained is similar to that obtained for the maximum power voltages in which there is a linear rise in disparity as a function of temperature. Specifically, the lowest disparity of $3.0579\text{x}10^{-5}$ A in I_{sc} is obtained at a temperature of 25^0C, thus enabling the best approximation between the two models at this temperature.

3.2.7 Discussion of Disparity Results for Maximum Power Current (I_{mp})

The top most plot of Fig. 3 indicates the disparities for maximum power currents for the PV array as determined via the two analytical models. The result obtained also indicates a linearly rising disparity from a small minimum value of 2.03375 A at 25^{0}C. Thus affirming the fact that the datasheet based model also gives the best approximation of the field measurement based model at this low temperature.

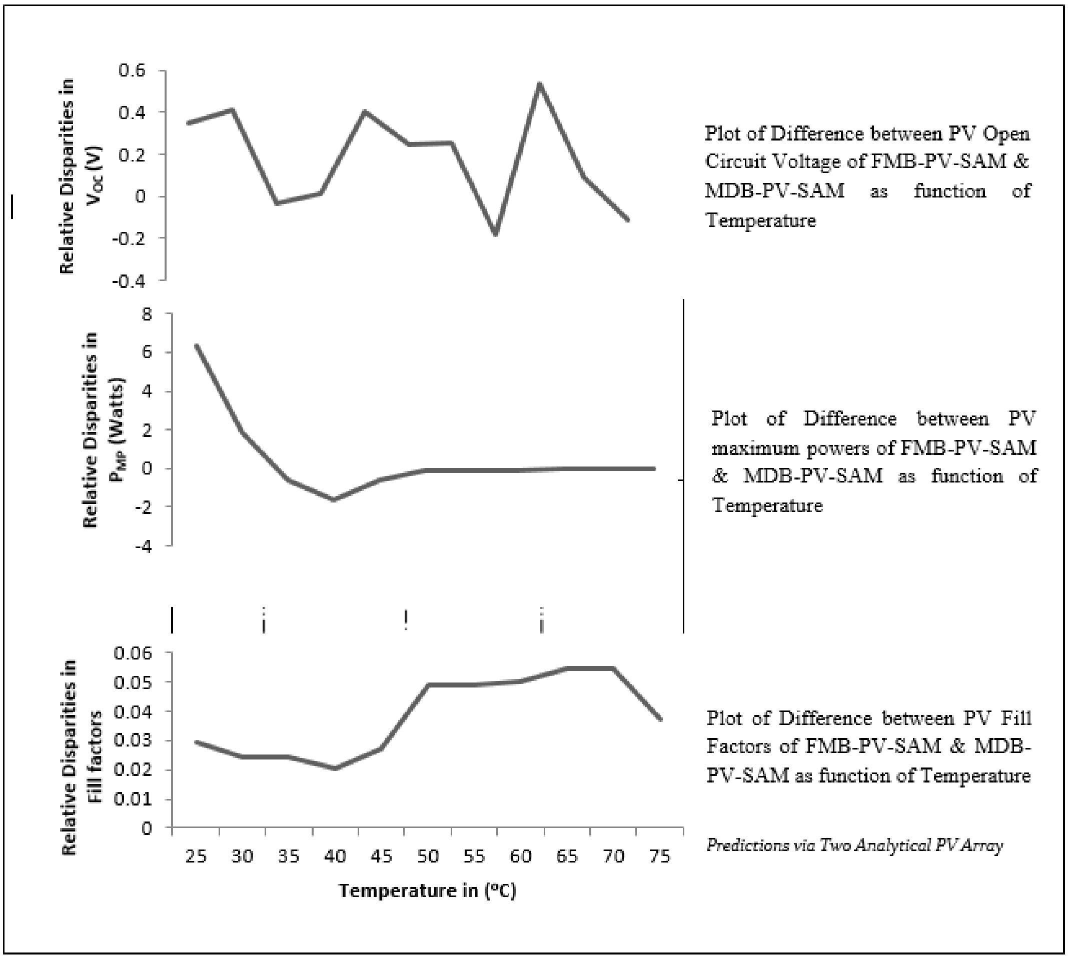
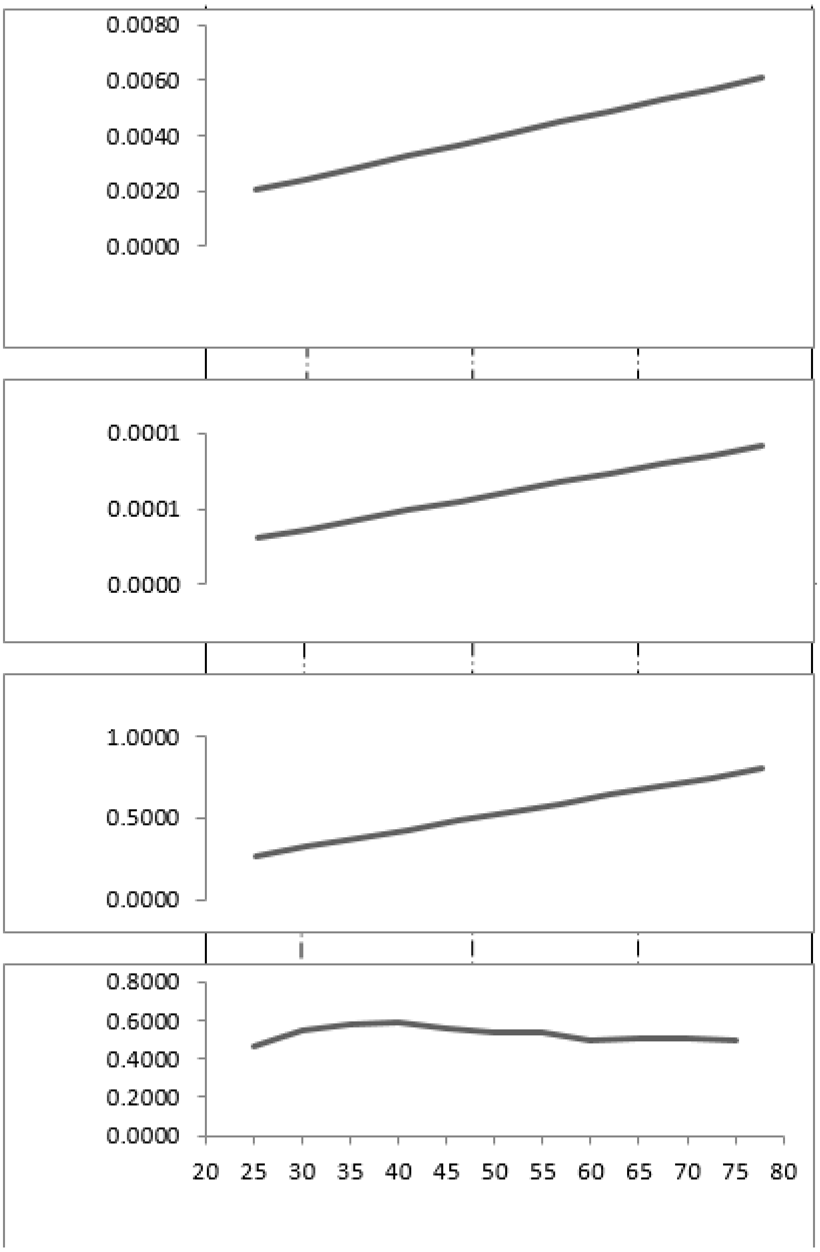


Fig. 2: Computational Disparities between Fill Factors, P_{mp}, and V_{oc} Performance Predictions via Two Analytical PV Array Models



Plot of Difference between PV Array Maximum Power Current of FMB-PV-SAM & MDB-PV-SAM as function of Temperature

Plot of Difference between PV Array Short Circuit Current of FMB-PV-SAM & MDB-PV-SAM as function of Temperature

Plot of Difference between PV Array Maximum Power Voltage of FMB-PV-SAM & MDB-PV-SAM as function of Temperature

Plot of Difference between PV Array Conversion Efficiency of FMB-PV-SAM & MDB-PV-SAM as function of Temperature

Figure 3: Computational Disparities between Conversion Efficiencies, V_{mp}, I_{sc} and I_{mp} Performance Predictions via Two Analytical PV Array Models

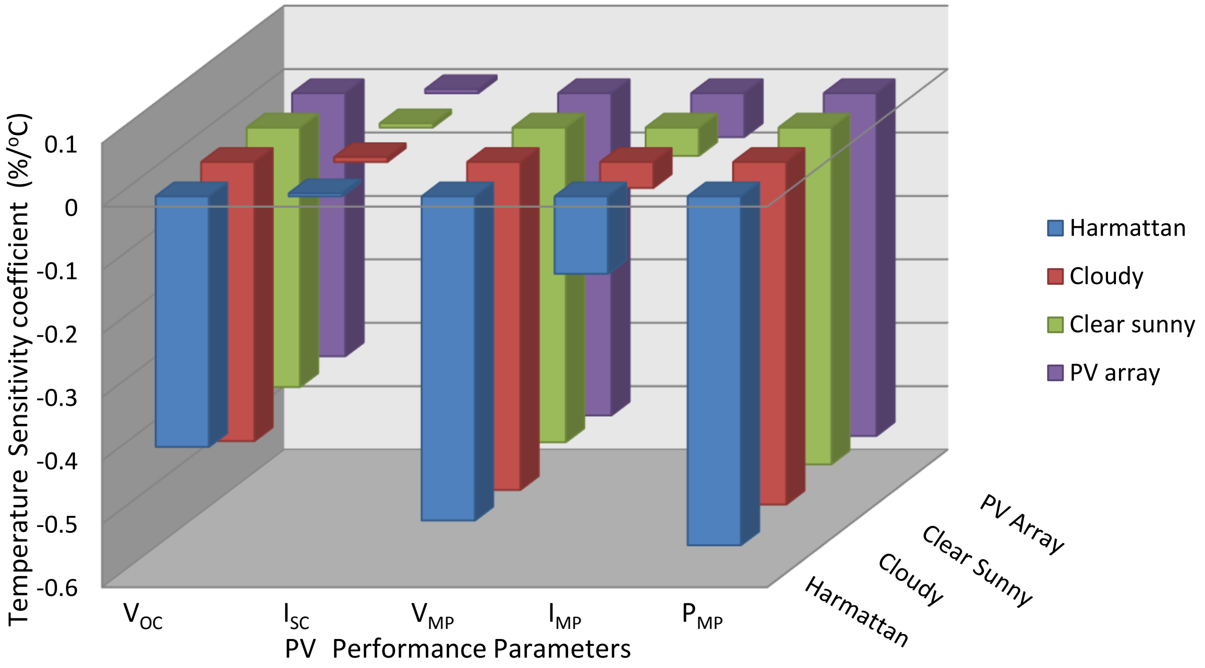


Fig. 4: Comparative Evaluations of Temperature Sensitivity Coefficients of PV Performance Parameters

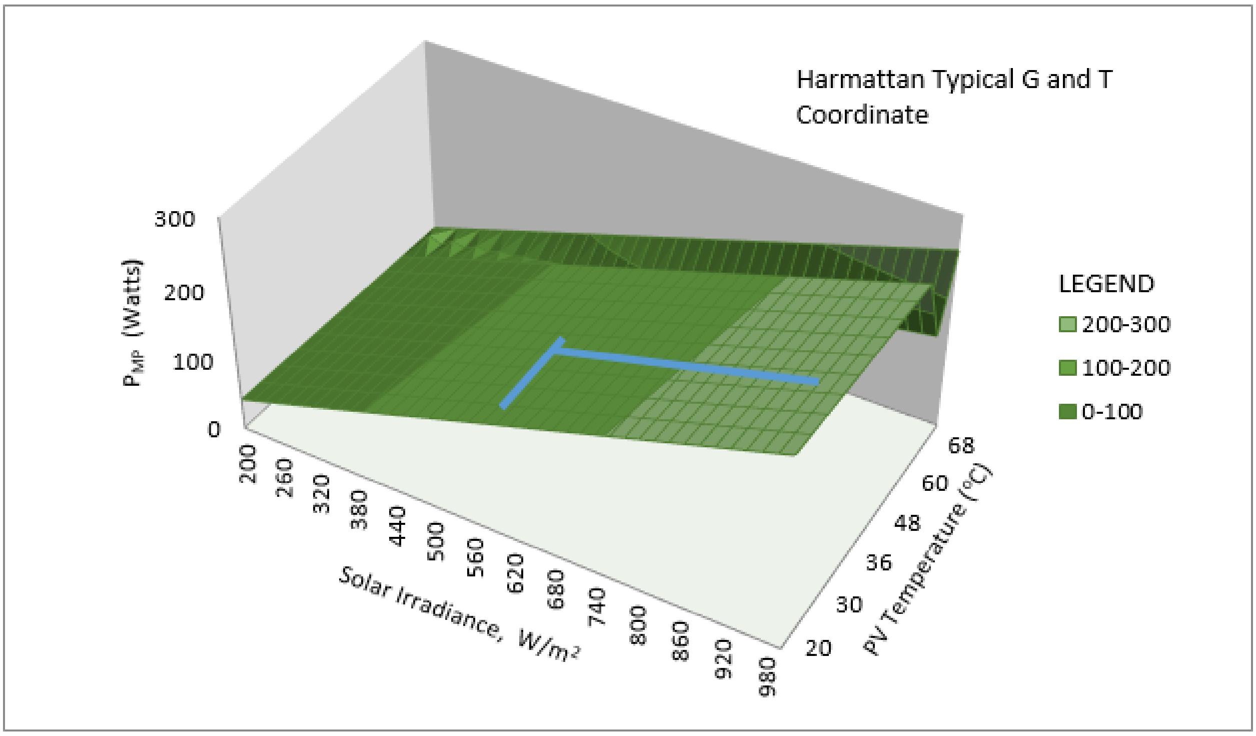


Figure 5: 3-D Variation of Maximum Power with Respect to Temperature and Solar Irradiance for Harmattan Season

4. CONCLUSION

Two PV array simplified analytical models – FMB-PV-SAM and MDB-PV-SAM have been used to create comparative disparity framework with respect to PV performance evaluations. Each of the models is independently used to evaluate the value of PV array performance parameters. The differences were then systematically plotted as function of temperature while taking FMB-PV-SAM as the bench mark. The results obtained indicate that MDB-PV-SAM model may be used as a very good approximation to FMB-PV-SAM at low cell temperatures particularly at 25^0C. However, the disparities at temperatures above 40^0C are particularly wide, thus indicating that the datasheet based model cannot replace the field measurement based model without significant loss of accuracy. Interestingly, smaller disparities are obtained with respect to maximum power of the array at higher rather than lower temperatures. This happens particularly during clear sunny seasons when the negative effects of high temperature are offset by the availability of high solar irradiance.

The combined effects of temperature and solar irradiance on maximum power of the PV array as well as the comparative evaluations of the temperature sensitivity coefficients of all the PV performance parameters have been graphically illustrated using 3-D plots.

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