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A STUDY OF MODELING, PARAMETER EXTRACTION, AND OPTIMAL POWER TRACKING IN PHOTOVOLTAIC SYSTEMS

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ABSTRACT

The process of optimization takes into consideration a variety of elements, including the orientation of the panels, the tilt angle, and the management of energy storage. The ultimate objective of this study is to improve the overall performance of solar power systems by delivering a resilient framework that is able to adjust to changes in the surrounding environment, guaranteeing that the maximum amount of energy is harvested, and contributing to the sustainability of renewable energy sources. This study has the potential to significantly improve the efficiency and dependability of solar energy systems, which will ultimately lead to the widespread adoption of these systems and a reduction in reliance on traditional energy sources. For the purpose of precisely simulating the behavior of solar panels under a wide range of climatic circumstances, the system that has been presented incorporates sophisticated modeling approaches.

KEYWORDS: Parameter Extraction, Optimal Power Tracking, Photovoltaic Systems, renewable energy sources, sophisticated modeling approaches.

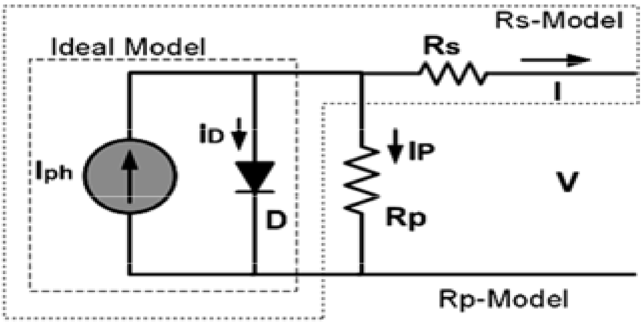
INTRODUCTION

The literature highlighted the availability of several photovoltaic (PV) models, the inconsistency of the models, the need for validation by a third party, and the necessity of often changing the parameters of the models in order to achieve greater accuracy. The vast majority of photovoltaic module models are constructed using comparable circuit diagrams, beginning with an ideal diode model that includes a current source that is connected in parallel with a diode. Additional components, such as series resistors, shunt resistors, and diodes, were included into other models in order to take into account a variety of losses and increase the accuracy of the simulation.

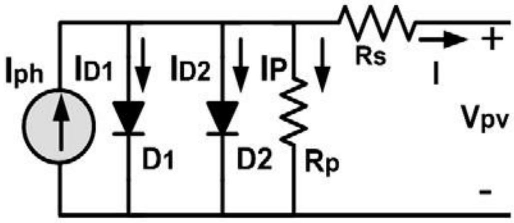
Models that are based on empirical evidence, such as the one created by Sandia National Laboratories, are primarily implemented for the purpose of designing (sizing) a photovoltaic array for a specific application. PV parameters, which are not supplied by manufacturers and must be calculated using the proper approach, have a significant impact on the accuracy of PV models as they are not provided by the manufacturers. This chapter suggested an improved Rp-model and simulated annealing (SA) technique for the application of unknown PV parameter extraction. Additionally, this chapter took into consideration all of the issues that are associated with modeling and parameter extraction.

EQUIVALENT CIRCUIT MODELS OF PV MODULES

Single-diode and double-diode models are the two categories that are used to categorize equivalent circuit models. There are three types of single diode models: an ideal diode, Rs- models, and Rp- models. The availability of significantly better comparable circuit models is another topic that is covered in chapter 1. This chapter has provided an overview of the fundamental concepts and mathematical relationships that are associated with comparable circuit models. Circuit diagrams that are identical to those of PV models are shown in Figure 1.



a). Single diode model



b) Double-diode model

Figure 1 Equivalent circuit of PV modules

IMPACT OF ENVIRONMENTAL FACTORS

A number of environmental parameters, including irradiance, operating temperature, wind speed, humidity, and others, may have an impact on the performance of photovoltaic modular systems. Increasing the temperature at which the module is functioning results in a drop in output voltage as well as a modest rise in module current. As a consequence of this impact, both the available power and the efficiency are reduced. The variation in irradiance has a direct relationship to the current in the short circuit, and it has a logarithmic relationship to the voltage in the circuit. Equations (1)–(2) are able to provide a concise summary of the influence that operating temperature and irradiance have on many parameters, including open-circuit voltage, short-circuit current, PV-current, diode saturation current, and series/shunt resistances, respectively.

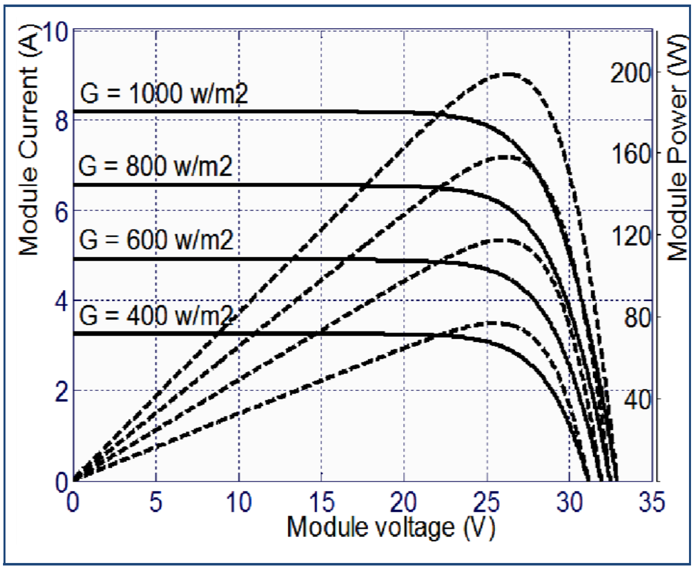
$$V_{oc} = V_{oc,STC} + \beta_{voc}(T - T_{STC}) + vT\ \ln\left(\frac{G}{G_{STC}}\right) \tag{1}$$

$$\begin{cases} I_{sc} = I_{sc,STC}\dfrac{G}{G_{STC}} + \alpha_{Isc}(T - T_{STC}) \\ I_{ph} = \dfrac{G}{G_{STC}}[I_{ph,STC} + \alpha_{Isc}(T - T_{STC})] \end{cases} \tag{2}$$

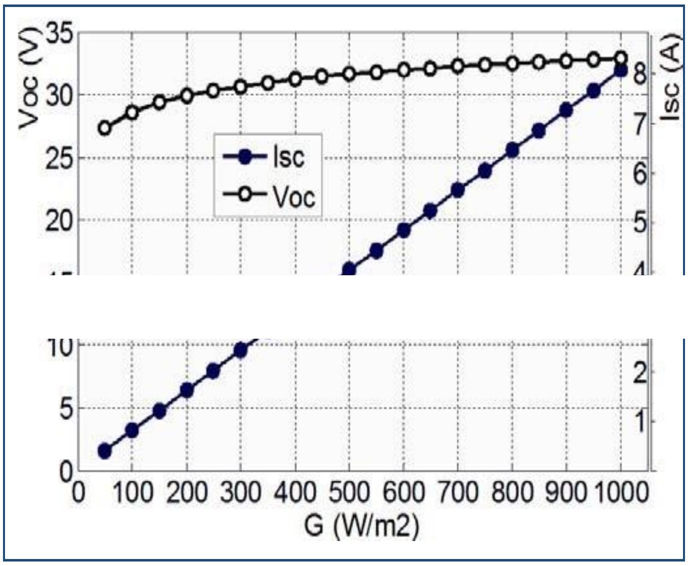
$$\begin{cases} I_O = I_{O,STC}\left\{\dfrac{T}{T_{STC}}\right\}^3 \exp\left\{\dfrac{E_g q}{ak}\left[\dfrac{1}{T_{STC}} - \dfrac{1}{T}\right]\right\} & \textit{diode saturation current} \\ I_O = \dfrac{\{I_{sc,STC} + \alpha_{Isc}\Delta T\}}{\exp\{[V_{oc,STC} + \beta_{voc}]/vT\} - 1} & \textit{improved diode saturation current} \end{cases} \tag{3}$$

$$\begin{cases} vT = vT_{STC}\left(\dfrac{T_{STC}}{T}\right) \\ R_s = R_{s,STC} \\ R_p = R_{p,STC}\left(\dfrac{G_{STC}}{G}\right) \end{cases} \quad (4)$$

The characteristic curves given in Figures 2 and 3 show the impact of variations in irradiance and operating temperature on the outputs of a typical PV module



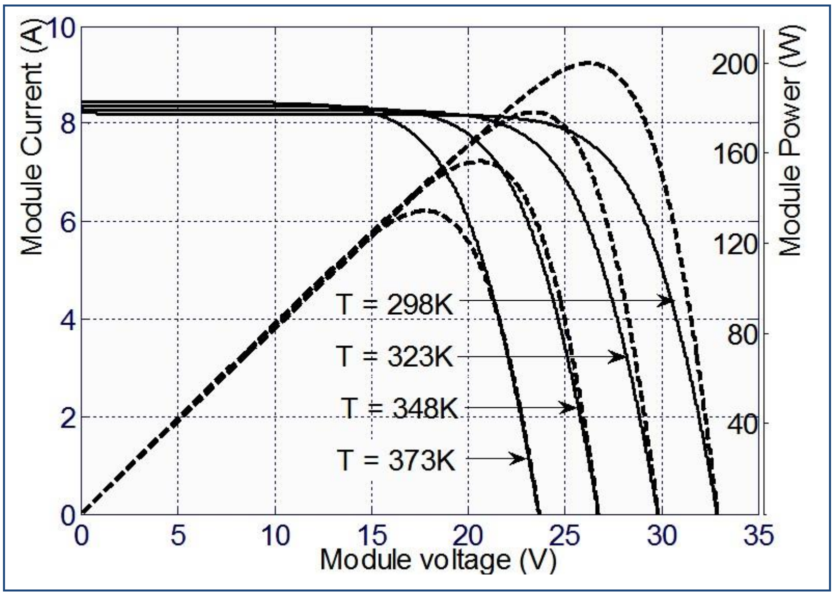
(a) I-V characteristic curve



KC200GT.

(b) Impact of irradiance on Voc and Isc

Figure 2 Impact of irradiance variation on PV parameters



I-V characteristic curve

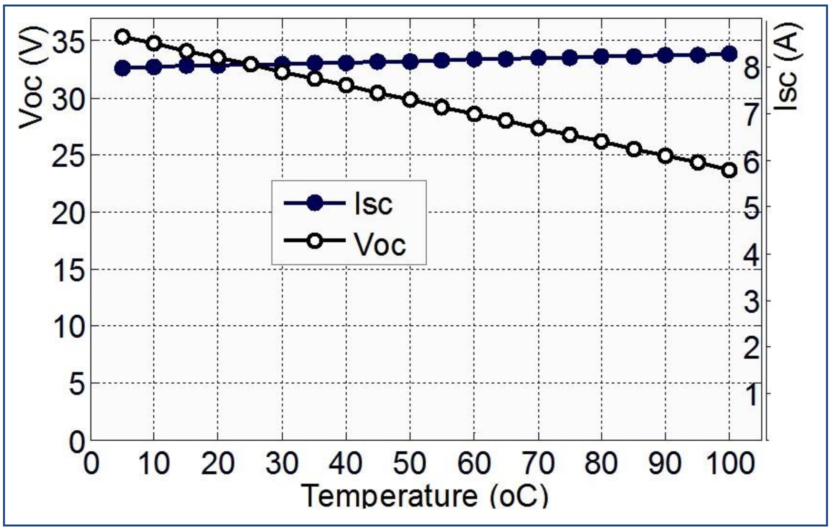


Figure 3 Impact of operating temperature variation on PV parameters

MODEL VERIFICATION

The validation of the photovoltaic module model may be accomplished by comparing the experimental data obtained from the manufacturer's data sheet with the findings that were computed using the suggested model. In the course of this investigation, the verification of the model was accomplished by contrasting the experimental data that was collected from the data sheet of the PV modules that corresponded to the suggested (SE-Rp) and Rp- models with the results of the simulations. For the purpose of this investigation, the experimental data is obtained by directly obtaining it from the data sheet provided by the manufacturer of the appropriate PV module.

The Rp-model is commonly used because it is a compromise in terms of accuracy and simplicity in comparison to other equivalent circuit models. However, it has the disadvantage of deviating from the actual value in the vicinity of the open circuit voltage for low irradiance values and the maximum power point region for high operating temperatures. This was summarized in Section 3.2 of the chapter.

The model that was provided took into account the benefits of the Rp model as well as the enhanced downsides of deviations from real values. Additionally, verification was performed for six PV modules that were manufactured using three typical PV production methods.

Consequently, I-V characteristic plots of experimental data extracted from manufacturers' datasheets, proposed models, and Rp-models have been carried out. Additionally, in order to provide a clear presentation of the improvements that have been made to the proposed model, absolute errors plots of module current have been carried out in comparison to experimental data at low irradiance levels and high operating temperatures, as indicated on the characteristic curves.

In the next sections, you will find the results of I-V characteristic plots for varied irradiance and operating temperature, as well as absolute error plots for the corresponding PV module at low irradiance and high operating temperature values, and maximum power point matching.

PV PARAMETERS ESTIMATION USING SIMULATED ANNEALING ALGORITHM

As of this moment, a number of different strategies for estimating PV parameters have been presented. These techniques may be roughly categorized as analytical, iterative, and evolutionary techniques. Through the use of evolutionary methodologies, it is possible to overcome the limitations that are associated with analytical and iterative approaches for the application in question. The next sub-sections will give the problem formulation, methodology, and estimated PV parameter that were obtained via the use of the Simulated Annealing approach.

- **Simulated Annealing (SA) Algorithm**

The annealing problem in metallurgy served as the inspiration for the simulated annealing algorithm, which is a physical process that includes heating and cooling a material in order to create the desired physical structure. This method is predicated on the concept of gradually cooling molten metal in order to arrive at the least function value for a problem involving minimization.

A simulation of the cooling phenomena of molten metal may be created by adding a parameter such as temperature (T) and manipulating it using Boltzmann's probability distribution.

- **PV Parameters Estimation using Simulated Annealing Algorithm**

The goal of the simulated annealing (SA) approach for determining unknown PV parameters is to minimize the objective function to a reduced tolerance value (preferably, one that is near to zero). In order to quantify the difference between the findings that were computed and those that were measured, the objective function being used is the root-mean square error (RMSE).

- **Results and Performance Evaluations**

For three different kinds of plots, verification was carried out by using simulation results and experimental data extracted from the manufacturers' data sheet. These plots included: (i) I-V characteristic curve plots for variable irradiance (G = 400 W/m2, 600 W/m2, 800 W/m2, and 1000 W/m2) and operating temperatures indicated on the I-V curve; (ii) absolute error plots of module current compared with experimental data; and (iii) maximum power matching capability using estimated parameters. The circled dots represent the result of comparing the plots to the experimental data. If you take a closer look at the graphs that are located close to the open circuit voltage, you will see that there are deviations from the experimental data at low intensity values. A series of absolute error estimations for the module current at low irradiance have been carried out in order to make the discrepancies more transparent. When compared to the use of Newton Raphson, the absolute error that is recorded for parameters retrieved via the use of simulated annealing is rather minimal.

MAXIMUM POWER EXTRACTION OF PHOTOVOLTAIC POWER SYSTEM

The solar photovoltaic power system is a competitive source of electricity that is expanding at a quick pace. This is due to the fact that it does not need any fuel, requires little maintenance, generates an abundant supply of solar energy, and does not produce any pollution. On the other hand, the non-linear characteristic feature, the dependency on climatic conditions, and the need for a significant initial investment mean that the available electricity must be extracted and used in the most efficient manner possible. In real-time applications, a photovoltaic (PV) system may be composed of various series/parallel configurations of PV modules. This is done in order to reach the needed magnitude of current/voltage. Furthermore, because of the non-uniform distribution of irradiance, the P-V characteristic curve may have many local and global maxima. MPPT algorithms are required for this in order to run the PV system at or near the global peak point location. The maximum power point (MPPT) algorithm's primary objective is to relocate the operating point to the maximum power point.

CONCLUSION

As a result of its clean, noiseless, plentiful supply of solar energy, and minimal maintenance requirements, photovoltaic power systems are expanding at a quicker pace than other types of power systems. There are, however, obstacles that need approaches for optimal extraction and exploitation of available electricity. These challenges include the non-linear feature, a large dependency on climatic conditions, poor efficiency, and expensive initial investment — all of which are challenges. You have been provided with a concise review of the fundamental ideas and algorithms that underlie standard MPPT approaches. In terms of efficiency, accuracy, tracking speed, and implementation complexity, MPPT methods come in a variety of forms. Many of the MPPT approaches that are now accessible are considered to be classical techniques. These techniques include perturb and observe, incremental conductance, hill-climbing, fractional short circuit, and open circuit voltage methods. These techniques are extensively used because they are easy to apply. On the other hand, these methods have several limitations, such as steady-state oscillation, incorrect tracking direction for quick changes in climatic circumstances, and the inability to monitor the global maximum power point when partial shadow is present.

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