

Photovoltaic array simulation technique for non-uniform insolation conditions

J. Mroczka, M. Ostrowski

Chair of Electronic and Photonic Metrology
 Wroclaw University of Technology
 B. Prusa 53/55, 50-317 Wroclaw, Poland
 Phone/fax number: +48 71 320 62 32

Email: janusz.mroczka@pwr.wroc.pl, mariusz.ostrowski@pwr.wroc.pl

Abstract. The development of algorithms of maximum power point tracking for photovoltaic panels requires an accurate model. The developed software enables simulation of a photovoltaic panel in any light and temperature conditions, including the change of temperature and illumination at the same time. The software allows to load the pattern of shade as the actual shading image, move it on the surface of the panel and calculate sunlight power with which the model of panel should be working in order to obtain energy and temperature appropriate for a given intensity of lighting depending on the ambient temperature, insolation and time. In addition, the simulation of maximum power point tracking's algorithms is possible in the conditions resembling the actual shade. The results confirm the correctness of the software used for the simulation of photovoltaic panels at the partial shading conditions.

Key words

photovoltaic array, solar system, simulation, partial shading conditions, maximum power point

1. Introduction

The development of photovoltaic technology requires working out accurate models of photovoltaic panels, but also the simulation environment to identify the operating conditions of PV modules simulating the actual conditions of lighting and temperature. The solutions, developed until now, assume a change of radiation intensity and unchanging temperature during the simulation. In real terms the working of PV panel depends on ambient temperature, insolation, humidity and many others. As the temperature rises, the maximum power point and open circuit voltage change (figure 1). Therefore, it is an important simulation parameter.

The relationship between ambient temperature and solar module illumination describe equation number 1:

$$T = T_o + (T_{STC} - 20) \frac{G}{G_{STC}}, \quad (1)$$

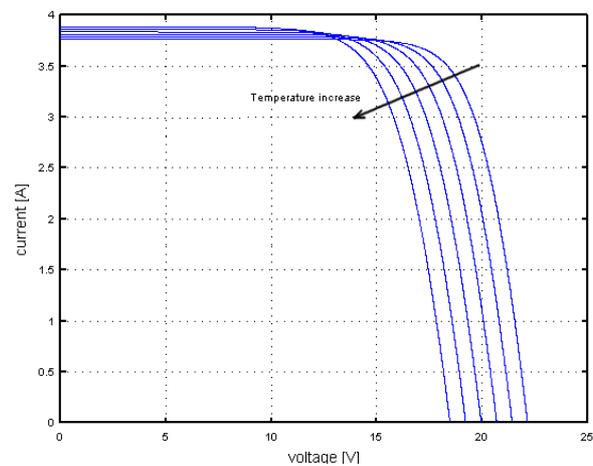


Fig. 1: Temperature characteristics of photovoltaic array

Where: T is the temperature of the solar panel, T_o is ambient temperature, T_{STC} is temperature in standard test conditions, G is illumination in W/m^2 , G_{STC} is illumination in standard test conditions.

In previous studies, the temperature is adjusted in steps or as in the case of [3] it is assumed to be constant for the whole panel. This simulator enable a linear adjustment of temperature and sunlight, making the simulation result closer to the actual current-voltage characteristics for a given illumination.

2. Software description

Software is based on the Qt library and octave application programming interface. Within the solution proposed by the authors [3] software allows to load any image file presenting the actual shade. There are calculated the intensity of illumination and temperature resulting from covering the panel with a shade at a given moment. The simulator uses any model of photovoltaic module in Octave/Matlab™ describing the current-voltage characteristics depending on temperature and insolation. The main window of the application is shown in Figure 2.

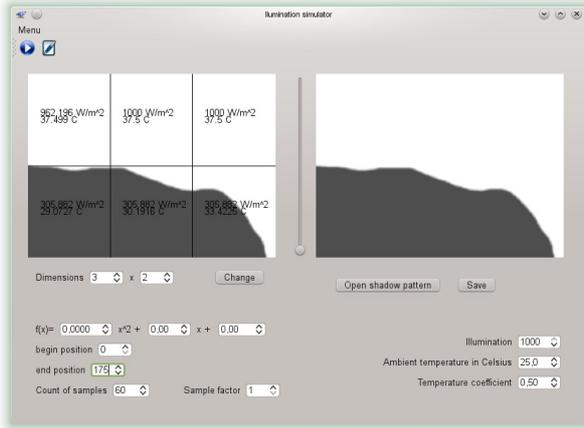


Fig 2: The software main window for shadow pattern show in figure 7

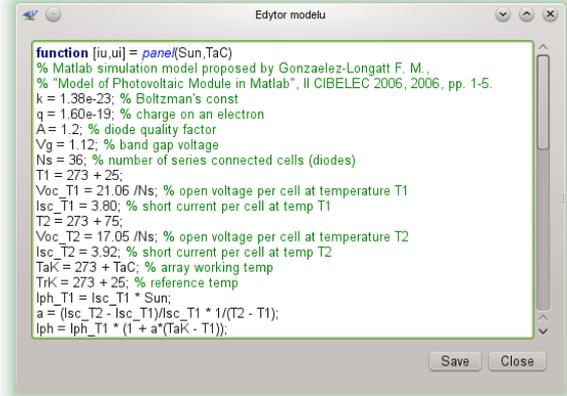


Fig 4: Photovoltaic module model editor

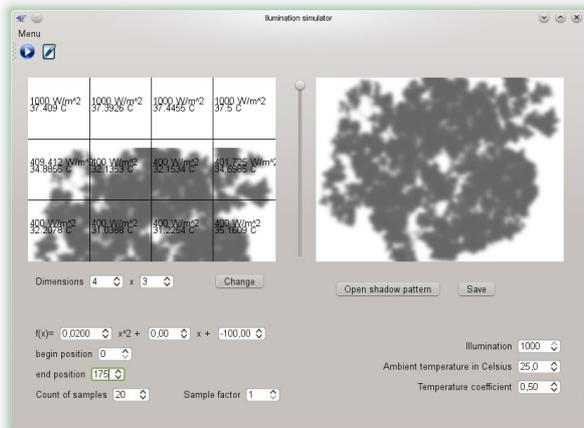


Fig 3: The software main window for shadow pattern show in figure 8



Fig 5: Photovoltaic panel simulator

After the image of the shading has been loaded, it can be seen on the right of the simulator window. We have the option of entering the values of illumination in uniform light condition, ambient temperature and the temperature coefficient, which depends on the environmental parameters, such as humidity, wind and etc. The left part of the main window enables you to set the simulation parameters such as an arrangement of the modules on the surface of the photovoltaic panel, a curve describing the movement pattern of the shading across the surface of the panel, initial and final position of the pattern of shading, number of samples and multiplier.

In Figures 2 and 3 the Main window with the two patterns of shading and modules layouts are shown; shadow caused by a cloud on a panel consisting of six modules arranged into two rows, and shadow caused by a tree on a panel consisting of 12 modules arranged into three rows, respectively.

The model of the photovoltaic panel is specified by an Octave/Matlab™ script. User can change the model at any time during the simulation by launching the editor what is presented in Figure 4. The simulator enable working on any model of photovoltaic module written in an Octave / Matlab™, that describes the dependency between current and voltage of the photovoltaic module

depending on insolation and temperature. This is undoubtedly an advantage of the simulating environment because it does not depend on a used model.

The user can write the value of illumination, ambient temperature, time of simulation, coefficients of the shade transfer function and temperature coefficient, which represents the change in temperature over time. After starting the simulation, the program calculates the illumination and temperature on the basis of input image, parameters written by user and time. The temperature is calculated on the basis of the mean value of solar radiation incident upon individual modules of the PV panel and equation 1,

$$T(n) = a \left[T_o + (T_{STC} - 20) \frac{G_{MEAN}(n)}{G_{STC}} \right] + (1 - a) T(n-1) \quad (2)$$

where G_{MEAN} is mean value of solar radiation incident upon individual modules and a is a thermal coefficient.

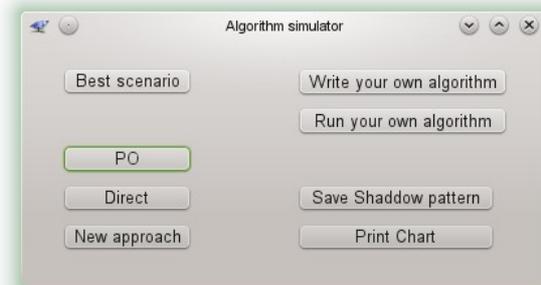


Fig 6: Search algorithms simulator

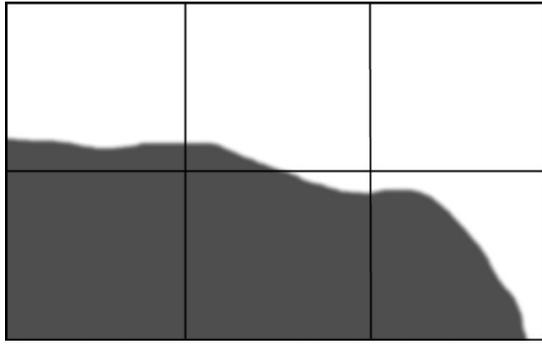


Fig 7: The shading pattern of cloud used in simulation

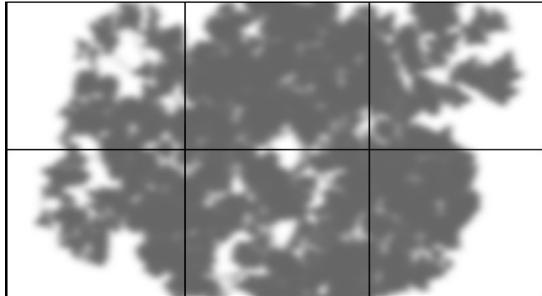


Fig 8: The shading pattern of tree used in simulation

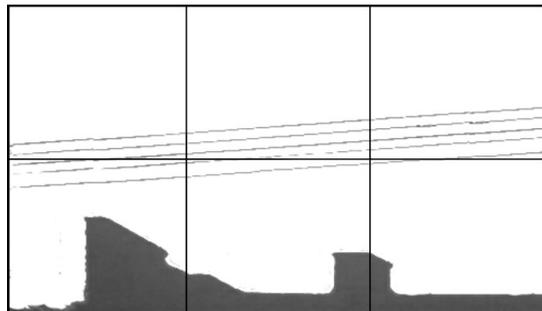


Fig 9: The shading pattern of building used in simulation

The value of illumination of a solar module is calculated on the basis of the percentage of the shading surface of the module and the shading value calculated on the basis of a drawing. Moreover, for each second software generates samples of voltage and current.

Figure 5 shows the simulator's window. During the simulation a progress bar is displayed, it shows the progress of the entire simulation.

As a result of the simulation a file that contains changing in time current-voltage characteristics of the photovoltaic panel is generated, which can be later used in maximum power search algorithm simulation.

Additionally, software can also simulate any maximum power search algorithm on the basis of the obtained samples.

Figure 6 shows the window of algorithm simulator. Currently, it allows the simulation of P&O algorithm, the DIRECT algorithm and algorithm based on open circuit voltage of the panel. An additional advantage of the software is the ability to create your own search algorithm and test it in real shading condition. The algorithm should be written in java script language using the functionality provided by the simulator. The results of the simulation are presented in the next section.

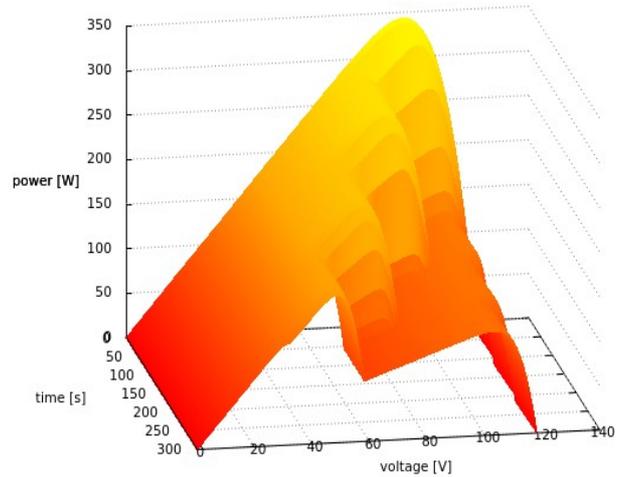


Fig 10: Power curve caused by shading in figure 7

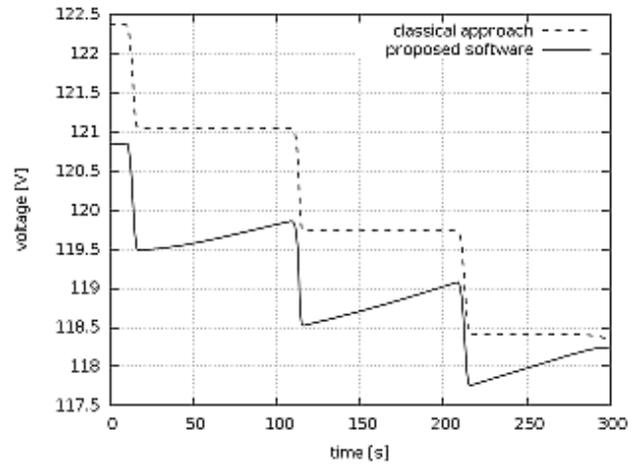


Fig 11: Comparison of the voltage at the classical approach and the proposed technique

3. Simulation results

The simulation was performed for the panel composed of six MSX60 Solarex photovoltaic modules connected in series with the bypass diodes for each of the solar panel. Model of the solar panel created on the basis of single diode model shown in [2]. The duration of the simulation was set to 300 samples with multiplication 1 that is equivalent 300s. The full illumination and temperature is set to 1000W/m² and 25°C, respectively. The shading patterns are shown in figures 7,8 and 9.

Figure 7 shows a pattern of shading caused by cloud. The loaded image moving along the x-axis of photovoltaic panel from uniform illumination of the light due to shaded by leaved pattern. The result characteristic $P=f(V, t)$ is shown in Figure 10.

As expected, we can see the the appearance of few local maximas. Analysing the chart we can see that the open circuit voltage and position of maximas depend of the sun, but also during changes of the temperature. Figure 11 shows a comparison of changes in open circuit voltage for simulation of the classical approach and the proposed technique. Sudden voltage changes is caused by changes

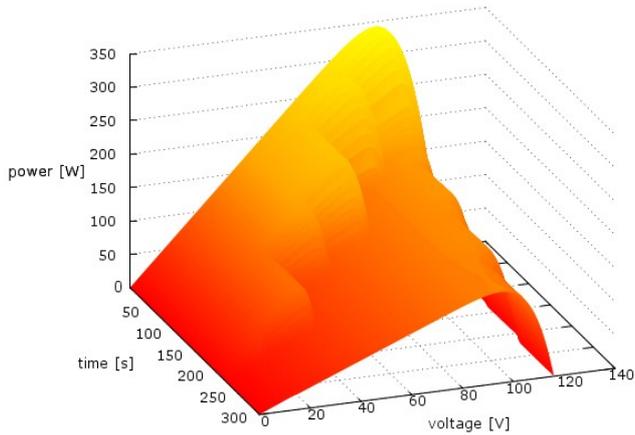


Fig 12: Power curve caused by shading in figure 8

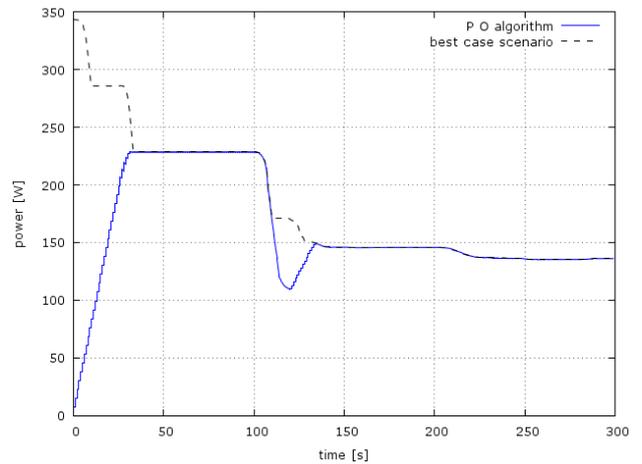


Fig 14: Power curve obtained with the tracker with pertrube and observe search algorithm

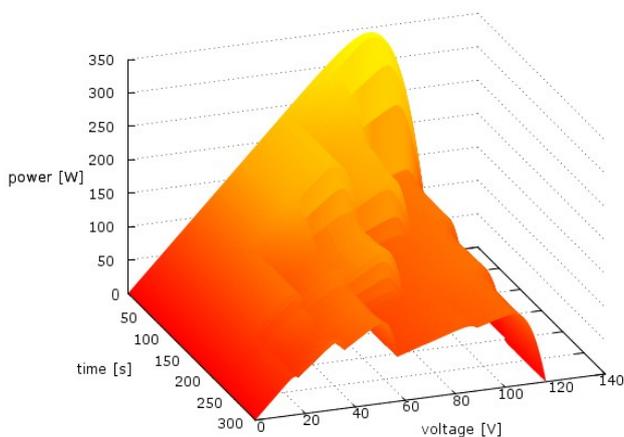


Fig 13: Power curve caused by shading in figure 9

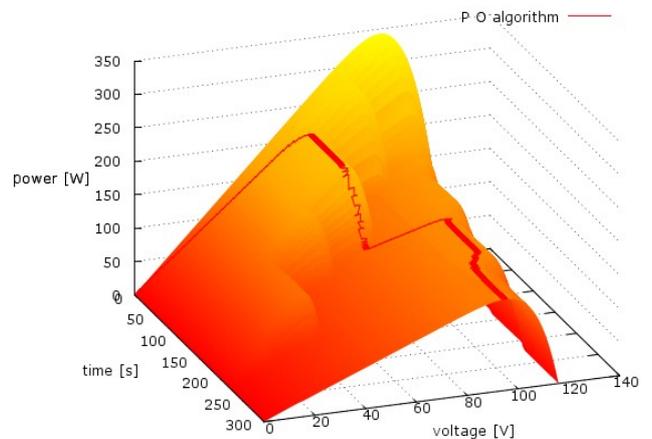


Fig 15: Power curve obtained with the tracker with pertrube and observe search algorithm – 3d mode

in sunlight, and the slow growth, observed on the curve plotted by the solid line are due to temperature changes during the simulation. We can see that the total change in voltage caused by shading for the classical approach is 4V while the simulation of the proposed software is 2.5V. The difference comes directly from temperature changes during the simulation. Similar changes can be observed for the maximum power points.

Figure 8 shows a pattern of shading caused by the shadow of a tree. The image is shifted on the surface of the panel as it is in reality, i.e., the movement of the shadow on the plane is described by a quadratic function. In order not to obscure the graph, the characteristic covers only a half of the time required for the shadow pattern to completely cross the panel. The resulting characteristic $P = f(V, T)$ is shown in Figure 12. In the chart you can see the emergence of several local maxima. The global maximum point of the characteristics changes in step with the changes of sunlight and temperature of the panel caused by shading.

Figure 9 shows a pattern of shading caused by the shadow of a building. The image has been moved across the surface of the panel as in the previous case, i.e., the movement of the shadow on the plane is described by a quadratic function. In order not to obscure the graph, the characteristic covers only a half of the time required for the shadow pattern to completely cross the panel. The resulting characteristic $P = f(V, T)$ is shown in Figure 13.

All curves show the appearance of local maxima, in accordance with our expectations. In addition, the change of the position of the global maximum point of power can be observed.

The software provides an opportunity to make a simulation of the maximum power search algorithms. For the purpose of the article pertrub and observe search algorithm with fixed step was used. The algorithm is described thoroughly in [6].

The algorithm can be presented classically, in the power-to-time domain, Figure 14, or in a 3D mode Figure 15. Classic mode is more convenient for numerical analysis of algorithms. In this mode, tracking errors of the maximum power search algorithm is readily apparent. 3D mode is better suited for the presentation of the algorithm and in all cases when you want to observe the algorithm on several levels simultaneously.

Figures 14 and 15 illustrate the workings of the pertrub and observe search algorithm for the shading caused by the cloud. In the first image you can see the tracking error of the point of maximum power after 110 seconds of time. The simulator provides the values of actual voltage, current, open circuit voltage, short-circuit current and the temperature of each module at any point in time to

maximum power search algorithm. With this information you can simulate any maximum power search algorithm.

4. Conclusion

The validity of proposed method is verified by simulation result. In the simulation result, a photovoltaic array is modelled and the changes in PV array output characteristics according to presence of the bypass diode, shading patterns are shown.

The simulation technique imitates the behavior of a photovoltaic array in real shading conditions. Thanks to loading the possible patterns of shading images, we can accurately test the previous and new maximum power point search algorithms. Due to the modular structure of the program, it is possible to change the model of a photovoltaic panel, which makes the simulation of the entire PV system much easier.

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Janusz Mroczka is a professor of electronic and photonic metrology at Wroclaw University of Technology. He was born in Poland in 1952. In 1991, he received the higher doctor's degree (habilitation) for a thesis in metrological problems of scattered light application on particle size distribution investigation in dispersed solutions, from the same university. Since 1998, he has been the head of the Chair of Electronic and Photonic Metrology at Wroclaw University of Technology.

His research interests are concentrated on physical and mathematical modeling in complex measurements, inverse problem, intelligent measuring devices, scattering radiation spectral and polarization analysis, and multisensor data fusion and time-frequency representations in data processing.

Professor Mroczka is a member of SPIE, a member of the Polish Physical Society, and President of the Committee for Metrology and Instrumentation at the Polish Academy of Science. Since 2010, he has been a Corresponding Member of the Polish Academy of Science



Mariusz Ostrowski is a PhD student in Chair of Electronic and Photonic Metrology at Wroclaw University of Technology. Since 2010, he has worked on modeling and optimization process of obtaining energy from photovoltaic sources.

His main interests are computer science, electronics of renewable energy, power sources and fuel cell.