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BUILDING A TOOL TO SIMULATE SOLAR CELLS AND PHOTOVOLTAICS ARRAY WITHIN SINGLE-DIODE MODEL

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Abstract:

In this research, we study and develop a tool for simulation of a Solar Cell (SC) and a Photovoltaics array (PV-Array) under MATLAB/GUI. The SC and PV-Array are modeled as a single-diode model at different values of ideality factor. The characteristic of the current equations of SC and PV-Array are solved by the iterative Newton-Rapson algorithms. This algorithm is used to build a simulation tool under MATLAB/GUI environment. Some basic simulation characteristic curves of the SC and PV-Array such as current-voltage (I-V) and power-voltage (P-V) obtained were in good agreement with the corresponding experimental data of solar cells reported in some previous works. The simulation tool was also used to investigate some kind of SC and PV-Array at different factors of temperature, solar-irradiation, series resistance (R_s) or shunt resistance (R_{sh}).

Keywords:

Solar Cell, PV Array, Solar cell and PV Array modeling, Solar cell and PV Array simulation.

Tóm tắt:

Trong bài báo này, chúng tôi nghiên cứu và phát triển công cụ phần mềm để mô phỏng đặc tính của pin mặt trời (tế bào pin và dàn pin) trong môi trường MATLAB/GUI. Pin mặt trời được mô hình hoá theo sơ đồ thay thế 1-diode với các thông số đầu vào khác nhau. Phương trình đặc tính mô tả quan hệ dòng và áp của pin mặt trời được giải bằng phương pháp lặp Newton-Rapson. Thuật toán lặp được phát triển thành công cụ mô phỏng trên nền MATLAB/GUI. Công cụ này được dùng để mô phỏng lại một số đặc tính cơ bản của pin mặt trời đã được công bố như đặc tính dòng điện - điện áp (I-V) và đặc tính công suất-điện áp (P-V) và cho kết quả phù hợp. Các đường đặc tính khác khi thay đổi nhiệt độ, cường độ bức xạ, điện trở nối tiếp (R_s) và điện trở song song (R_{sh}). cũng được mô phỏng.

Từ khóa:

Tế bào pin mặt trời, dàn pin mặt trời, mô hình pin mặt trời, mô phỏng pin mặt trời, MATLAB/GUI.

1. INTRODUCTION

Electric energy is required for the large number of things from home to cars to companies. The traditional electric energy got from coal, natural gas, nuclear energy,

hydraulic etc. Due to the crisis of traditional energy sources, the other sources of energy need to find out. Solar energy is a good option because of it is free, clean, and abundant in most places

throughout the year. The electricity output from solar cell is greatly depending on the weather conditions and fluctuating in nature.

In order to exploit this energy efficiently, it is necessary to study the operation of solar cells under the influence of the environment. There are some tools, which are used to simulate SC and P- array such as: the solar cell block and the PV array block in the library of MATLAB [1,2]. There also are some studies on the Maximum Power Point Tracking for SC or PV-Array system to optimize their operations [3-5].

In this study, we have modeled a solar cell and programmed to building a tool within this model to simulate the characteristics of SC and PV-Array. After that, this tool is used to investigating the effect of temperature, intensity of solar radiation on performance of the solar cell and comparing the simulated results with the measured results in practice.

2. SINGLE-DIODE MODEL OF SOLAR CELL AND THE SOLVING ALGORITHM

Single-diode model of solar cell

A formal solar cell consists of semiconductor junctions that form electron-hole pairs when bombarded by photons. This structure creates an energy source liked a diode that generates, rather than consumes, power. The steady-state characteristics of the SC can be modeled as a current source (I_L), diode, and shunt resistance (R_{sh}) when operated under even distribution of light. The equivalent circuit of a formal SC can then be

expressed by Figure 1 [4-7].

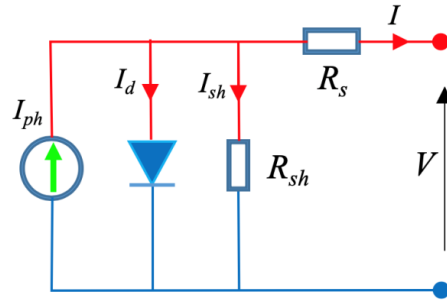


Fig. 1. The equivalent circuit of solar cell

The relationship between the current (I) and the voltage (V) as follows:

$$I = I_{ph} - I_0 \cdot \left[e^{\frac{V+I.R_s}{V_T}} - 1 \right] - \frac{V+I.R_s}{R_{sh}} \quad (1)$$

where: I_{ph} is Photon current; I_0 is the cell saturation of dark current [A]; V is the cell output voltage [V]; R_s is series resistance; R_{sh} is parallel resistance.

The thermal voltage V_T can be calculated by equation:

$$V_T = \frac{A.k.T}{q} \quad (2)$$

Where: $q=1.610^{-19}\text{C}$ is the electron charge, $k=1.3810^{-23}\text{ J/K}$ is the Boltzmann constant, A is the ideal factor of the $p-n$ junction, T is the cell operating temperature [K], which can be calculated as shown in following equation:

$$T = T_a + \frac{T_{noct}-20}{800} \cdot G \quad (3)$$

where T_{noct} is nominal operating cell temperature [K] given by the PV module manufacturer, G is solar irradiance [W/m^2], and T_a is ambient temperature [K].

Newton-Rapson's algorithm

Equation (1) takes the form $I = f(V, I)$; to solve this equation we use the Newton-

Rapson's method:

$$I_k = I_{k-1} - \frac{f(I_{k-1})}{f'(I_{k-1})} \quad (4)$$

where: I_k is the current value at after k time iterations step; I_{k-1} is the current value current value at after $(k-1)$ time iterations step. f' is derivative of f , which is derived from below expressions.

The solving equations for 1 cell as following (in which I_{ph} is replaced by short circuit current (I_{sc}):

$$f(I) = I \left(1 + \frac{R_s}{R_{sh}} \right) - I_{sc} + I_0 \cdot \left(e^{\frac{q \cdot (V + I \cdot R_s)}{A \cdot k \cdot T}} - 1 \right) + \frac{V}{R_{sh}} \quad (5)$$

$$f'(I) = \frac{\partial f(I)}{\partial I} \quad (6.a)$$

$$f'(I) = \left(1 + \frac{R_s}{R_{sh}} \right) + \frac{q \cdot R_s}{A \cdot k \cdot T} \cdot I_0 \cdot e^{\frac{q \cdot (V + I \cdot R_s)}{A \cdot k \cdot T}} \quad (6.b)$$

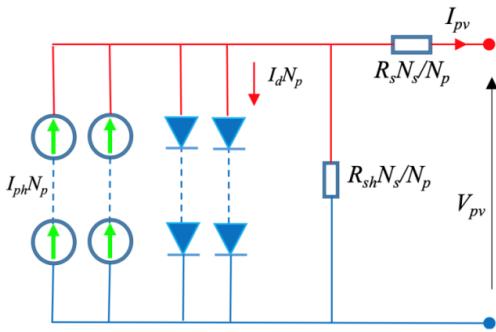


Fig. 2. The equivalent circuit of PV-array

When a PV-array consists of N_s solar cell are connected in series (*a string*) and N_p string are connected in parallel, the equivalent model of PV-Array is shown in Figure 2.

The parameters of equivalent circuit of PV-Array such as photon current, diode

current, series resistance, parallel resistance, should be:

$$I_{ph,pv} = N_p \cdot I_{ph}$$

$$I_{d,pv} = N_p \cdot I_d$$

$$I_{o,pv} = N_p \cdot I_o$$

$$V_{pv} = N_s \cdot V$$

$$R_{s,pv} = \frac{N_s}{N_p} \cdot R_s$$

$$R_{sh,pv} = \frac{N_s}{N_p} \cdot R_{sh} \quad (7)$$

The solving equation for PV-Array as following:

$$f(I) = I \left(1 + \frac{R_{s,pv}}{R_{sh,pv}} \right) - I_{sc,pv} + I_{o,pv} \cdot \left(e^{\frac{q \cdot (V_{pv} + I \cdot R_{s,pv})}{A \cdot k \cdot T}} - 1 \right) + \frac{V_{pv}}{R_{sh,pv}} \quad (8)$$

$$f'(I) = \frac{\partial f(I)}{\partial I} \quad (9.a)$$

$$f'(I) = \left(1 + \frac{R_{s,pv}}{R_{sh,pv}} \right) + \frac{q \cdot R_{s,pv}}{A \cdot k \cdot T} \cdot I_{o,pv} \cdot e^{\frac{q \cdot (V_{pv} + I \cdot R_{s,pv})}{A \cdot k \cdot T}} \quad (9.b)$$

The function of current can be expressed as when $V=0$, $I=I_{sc}$; so that the initial value should be $I = I_{sc}$.

When the voltage and current values are obtained through equation (1), the power of the solar cell is calculated by following equation:

$$P = V \cdot I \quad (10)$$

3. BUILDING SC AND PV-ARRAY SIMULATION TOOL UNDER MATLAB/ GUI

The purpose of single-diode modeled was for examining the characteristics of SC and PV-Array when their parameters and environment conditions is changed, etc.

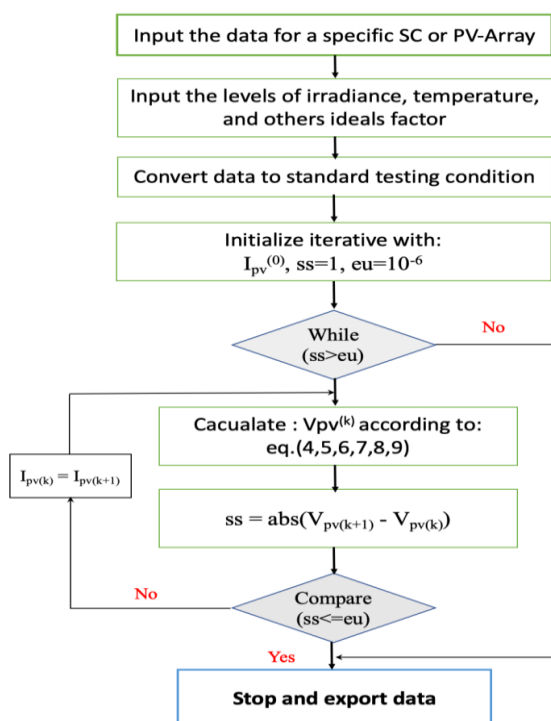


Fig. 3. Flowchart of the proposed iteration Newton-Rapson's algorithm for I-V curve

Figure 3 shows the flowchart of the iteration algorithm to solve I-V characteristic of SC and PV-Array by Newton-Rapson's method. After calculating I-V characteristics, the P-V characteristic can be obtained by equation

(10). The MATLAB/GUI framework has been used to program for building a SC and PV-Array simulation tool in this model.

Figure 4 shows the main windows of SC and PV-Array simulation tool. The left window shows the input data of SC and PV-Array. The user could input data of simulated SC and PV-Array in both ways of manually-input via edit-box or prepared-input via list-box which included some SCs or PV-Arrays. The data of SCs and PV-Arrays in the list-box were prepared in an excel file, which was attached in the simulation package and the user can also modify. To confirm the achieve characteristics of simulation tool similar to real experimental curves of SC and PV-Array, some extra input data should be considered: the cell temperature coefficient, environment temperature, solar radiation, etc. The right window shows I-V and P-V curves of SC and PV-Array, which is plotted by simulation tool. The output data of simulation tool also can be exported to excel file to plot by others scientific software such as Igor or Origin, etc.

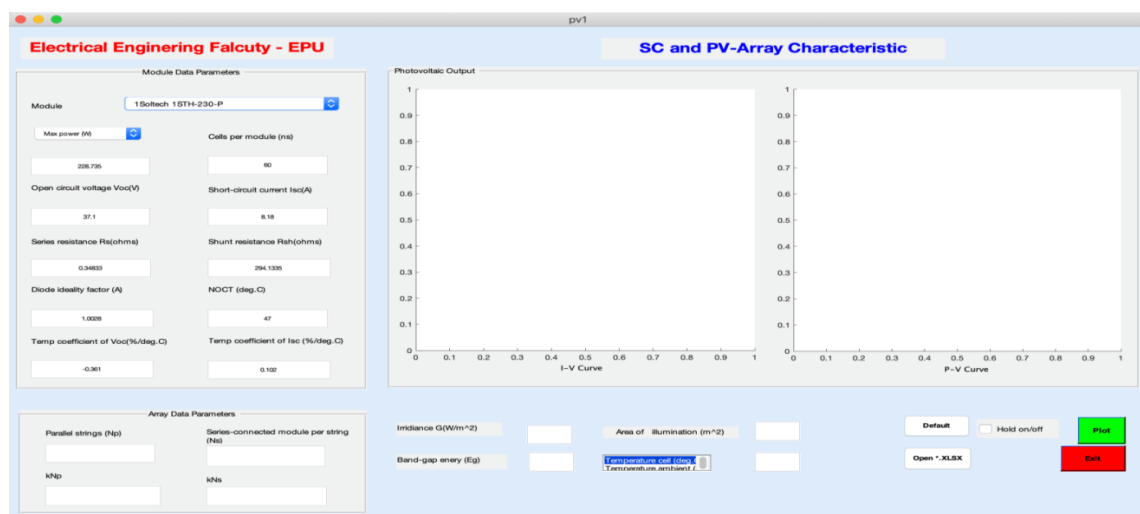
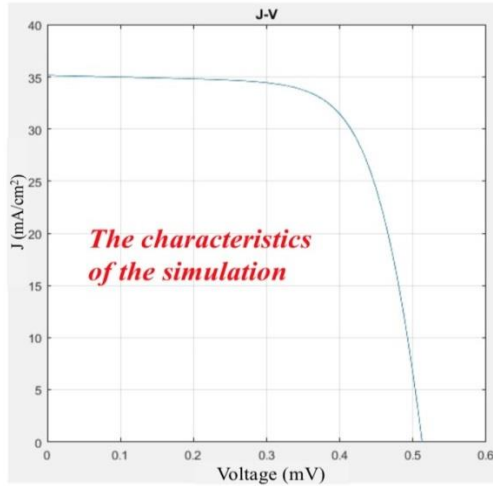


Fig. 4. Main interface of SC and PV-Array

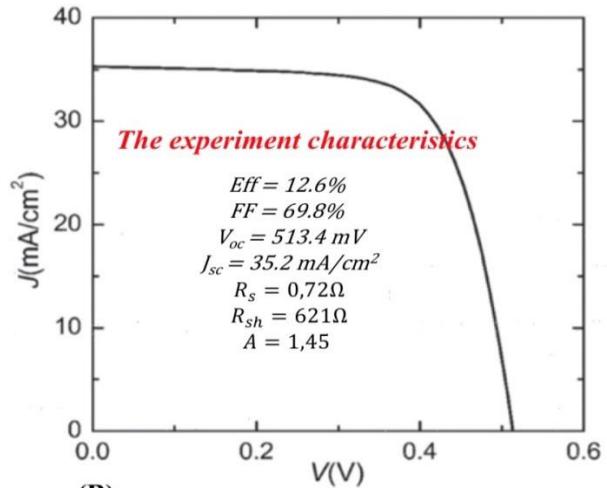
4. RESULTS

In order to test the calculation ability and reliability of the proposed tool, the results have been compared with some published actual measured results with the same

parameters. The results show that the simulation results and actual results match. Here are comparing characteristics of the simulation tool and the experiment characteristics.



(A)

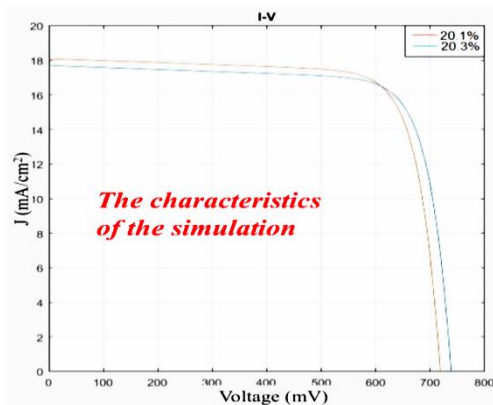


(B)

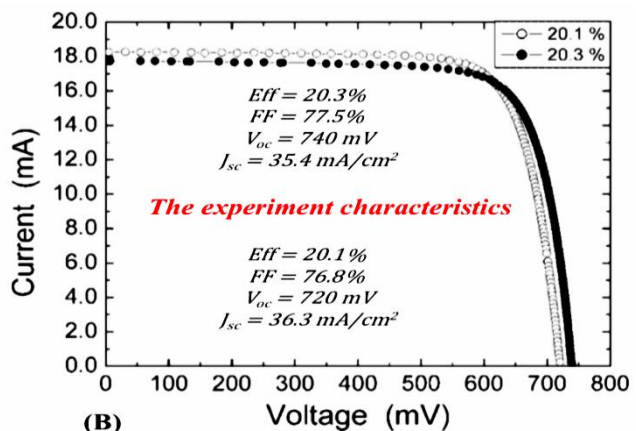
Fig. 5. Compare I-V characteristic of SC from the simulation tool (A) to experiment data (B) [8]

Figure 5 shows the results about I-V characteristics of the proposed tool (Fig. 5A) comparing to the experiment characteristics of the CZTS solar cell (which have conversation efficiency of 12.6%) published by W. Wang et al (Fig. 5B) [8]. The figure shows that the simulation curve has been in good agreement with the experiment curve.

Figure 6 shows the result of I-V characteristics of the simulation (Fig. 6A) comparing to the experiment characteristics of the CIGS solar cell (which have conversation efficiency of 20.1% and 20.3%) published by P. Jackson, et al. (Fig. 6B) [9]. The deviation between these curves is negligible.



(A)



(B)

Fig. 6. Comparing I-V characteristic of SC from the simulation tool (A) to experiment data (B) [9]

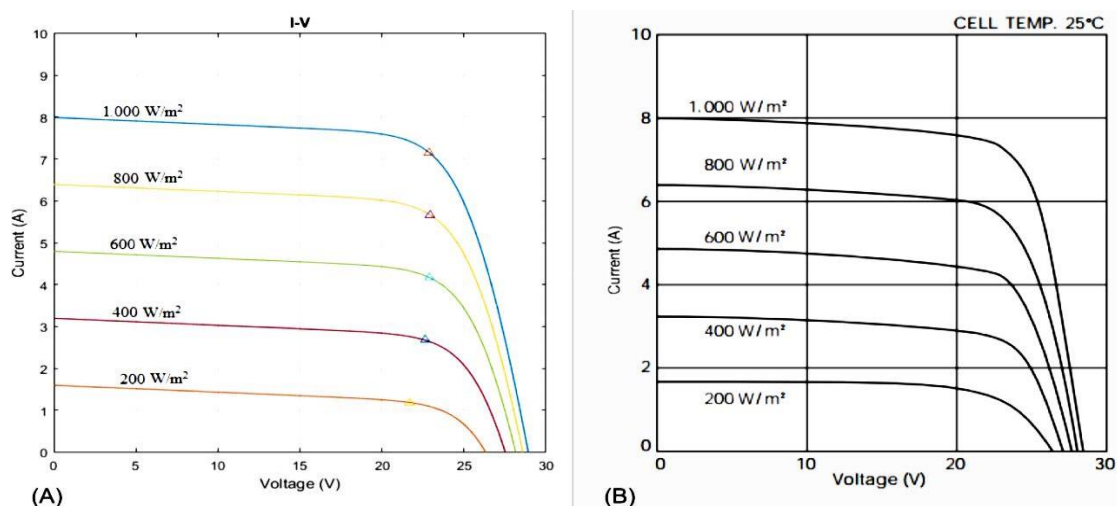


Fig. 7. Compare I-V characteristics of PV module under difference radiation of the simulation tool (A) to experiment data (B) [10]

Figure 7 shows the result of I-V characteristics of the simulation (Fig. 7A) at various radiations of 200, 400, 600, 800 and 1000 W/m² comparing to the testing characteristics of the silicon solar cell reported by published by KYOCERA International Incorporated for module

KC170GT (Fig. 7B) [10]. These characteristics have been in good agreement.

Figure 8 shows the simulation result of 1Soltech 1STH-230-P module [11] under difference environment temperature of 25°C, 45°C, 65°C.

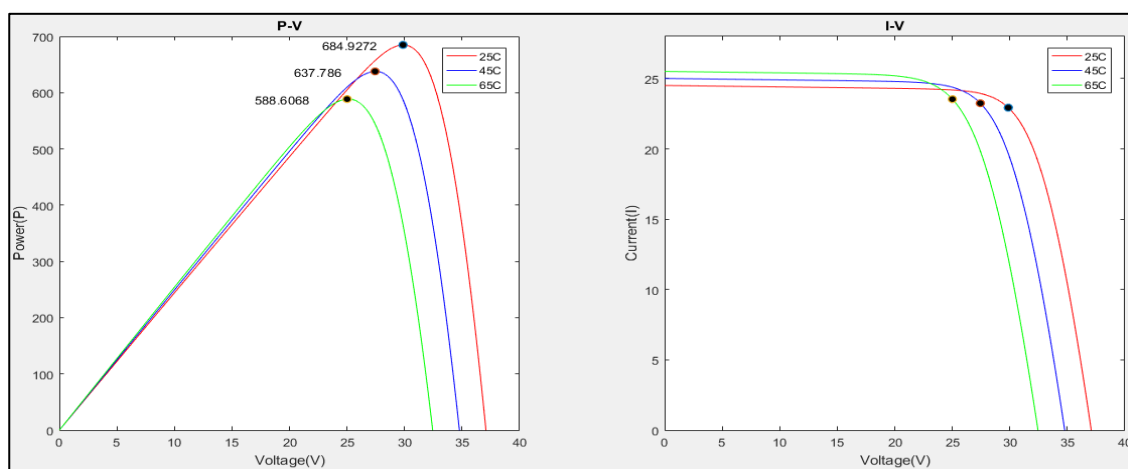


Fig. 8. P-V and I-V characteristics of PV module under difference environment temperature of 25°C, 45°C, 65°C

5. CONCLUSIONS

Studying the characteristics of solar cells requires a lot of time and money from

research and manufacturing to measurement and evaluation. The simulation tool gives the easy way to

simulate I-V and P-V characteristics of SC and PV-Array under different input conditions. The results of the simulation have been verified by comparison with the published results of some types of solar cell such as Silic, CIGS, CZTS. This tool not only allows to perform the

described functions but also is the basis for further studies such as: simulating the PV with different kind of configuration, tracking the maximum power point of the solar cell and PV array, and optimizing PV array configuration, etc.

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Biography:



Pham Anh Tuan received his MSc in electrical engineering from Hanoi University of Science and Technology - Vietnam (HUST) in 2006. He became a lecturer at the Electrical Engineering Faculty of Electric Power University since 2009. He received his PhD in materials science from HUST in 2017. He was awarded best price from HUST for the PhD thesis of "Research and fabrication of CIGS and CZTS solar cells".

His research interest includes Solar cell materials and Photovoltaics system simulation.

