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APPLICATION OF TEMPERATURE DEPENDANCES OF PARAMETERS IN A SINGLE-DIODE FIVE-PARAMETER MODEL OF SOLAR PANELS

Current economic developments promote the application of solar panels. This results in more companies producing solar panels with quite different specifications. On the other hand, the specifications provided by the manufacturers generally do not contain the full information to be able to calculate the output of the solar panels in different usage conditions. For this reason, we are in the process of building a solar panel model that allows to calculate the output of the solar panels in different usage conditions based on the general data provided in datasheets of commercially available panels.

Previously we provided the methodology of building a solar panel model from the data provided in datasheets of solar panels. In this article, we refine the proposed methodology and apply it on a solar panel BP4180T produced by BP Solar. The output of the refined model is compared with the results of the previous model and with the datasheet data of the solar panel of interest.

The analysis of the obtained results shows the applicability and repeatability of the proposed model.

Keywords: solar panel modelling, PV cell, testing system, solar energy, physical losses in solar panels.

Introduction. A solar panel can be modelled as a single-diode circuit in parallel with a current source, where the diode is the result of the semiconductor material of the solar cell [1-3]. For achieving results closer to real data, more complicated models have been developed for solar panels. Among them, the most used model for characterizing the solar panel performance is the so-called physical loss mechanism, also known as the single-diode five-parameter model (Fig. 1).

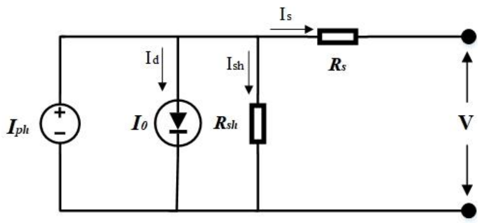


Fig. 1. The physical loss model of a solar panel with one diode and two resistors

This model uses one diode and two resistors to describe the electrical losses inside the solar panels. The series resistance represents the energy dissipated in the form of heat in the electric circuit and the shunt resistance represents the current that takes a shortcut to the end instead of going through the desired path. To describe other existing defects in the solar panel such as non-uniform dipping, a diode is included in the model.

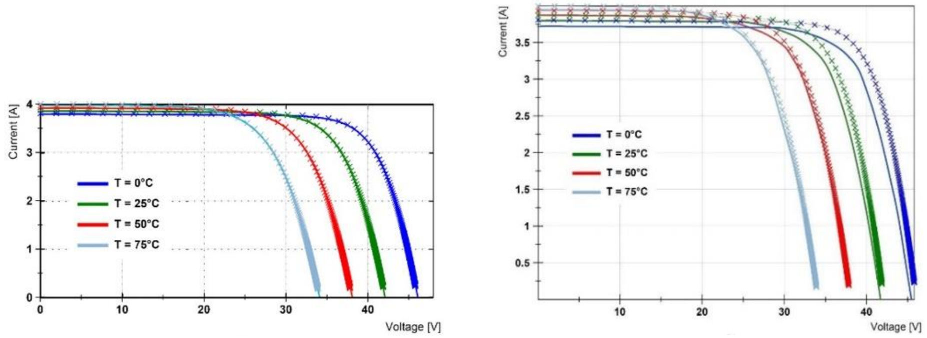
Based on solar panel's one diode two resistors physical loss model, the general current-voltage characteristics of a PV panel can be written as:

$$i = I_{ph} - I_0\left(e^{\frac{v+R_S}{n_S V_t}} - 1\right) - \frac{v+iR_S}{R_{sh}} \text{ [4].} \tag{1}$$

The following characteristics are usually presented in datasheets of commercial Solar panels: $V_{OC(STC)}$ (open circuit voltage), $I_{SC(STC)}$ (short circuit current), $P_{MAX(STC)}$ (maximum power), Temperature coefficient of I_{SC}, Temperature coefficient of V_{OC} and I-V (current-voltage) characteristic curves for different temperatures.

However, this information is not sufficient to estimate the expected power output of the Solar panel for the given illumination and temperature conditions. One needs to have the model of the Solar panel to be able to perform these calculations.

Model Discussion. In article [4], there is a mechanism on how to obtain solar PV model's parameters values through datasheet data. For this purpose, the article provides a Flowchart. Based on these principles, instead of long mathematical calculations, we have built a computerized model in a MULTISIM environment [5]. The new model generates outcomes identical to ones presented in [4]. We compared the data generated by the model with the results of measurements of the parameters of the solar panel presented in the datasheet (Fig. 2). We demonstrated that although the simulation and measurement results are in general agreement, there is a significant deviation between simulation and measurement results. Hence, the output of this model does not repeat the data presented in the datasheet of solar PV [5], which means that this model has some accuracy limitations.



a) b)

Fig. 2. Comparisons of the output of previous models [1][4] with measurement results: a- simulation results (cross markers) compared to the results in [4] (solid lines), b- simulation results (cross markers) compared to the measurement results from datasheet (solid lines)[1]

To find the limitations of the model and improve it, some research has been carried out. The thorough inspection of the model showed that in equations [2-5] the temperature dependencies of I_{sc}, V_{oc}, I_o were taken into account, but temperature dependences of resistors R_s, R_{sh} weren't taken into account [5]:

$$V_{oc}(T) = V_{oc} + k_v(T - T_{STC}), \tag{2}$$

$$I_{sc}(T) = I_{sc}\left(1 + \frac{k_i}{100}(T - T_{STC})\right), \tag{3}$$

$$I_0(T) = \left(I_{sc}(T) - \frac{V_{oc}(T) - I_{sc}(T)R_s}{R_{sh}}\right) e^{-\frac{V_{oc}(T)}{n_s V_t}}, \tag{4}$$

$$I_{ph}(T) = I_0(T) e^{\frac{V_{oc}(T)}{n_s V_t}} + \frac{V_{oc}(T)}{R_{sh}}. \tag{5}$$

In fact, for every material the electrical resistance has some dependence on temperature, therefore we are suggesting that this model's resistors should also be encountered as being dependent on temperature [6]. With this assumption, we took a linear dependence on temperature for the resistances in model (6):

$$R(T) = R_{STC}(1 + \alpha(T - T_{STC})). \tag{6}$$

With the presented equation (6), a new model for BP-MSX120 solar panel has been built [6]. To obtain I-V characteristics of the solar panels at different temperatures we have changed the values of serial and shunt resistances according to (6). To define the temperature coefficient α, we went through the cycles of the algorithm/flowchart from [4] (Fig. 3) to find R_s and R_{sh} resistances of PV panel for each temperature point. In [4], the authors went through that cycle once, for only one temperature they have found one value for R_s and one for R_{sh}, then they used those values for each temperature point [4]. In contrast, we went through the steps of the cycle for each temperature [6].

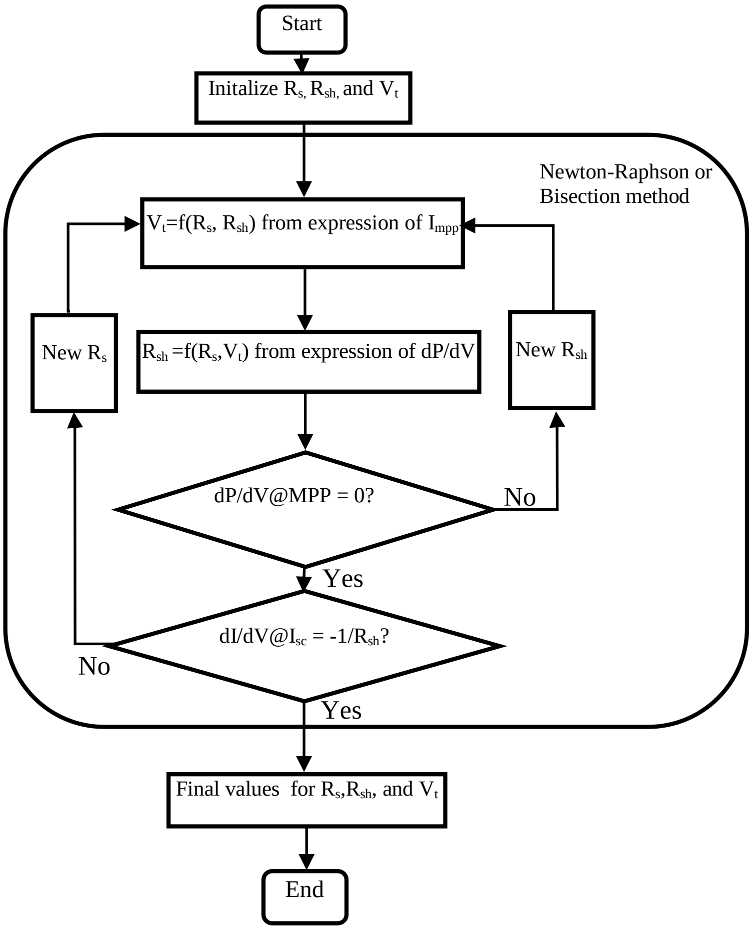


Fig. 3. A flowchart for determination of the PV panel model parameters [4]

With these steps we have obtained an average value of temperature coefficient α=-0,002. This value of temperature coefficient is in the range of TCR (temperature coefficient of resistance) of silicon [7-9]:

$$TCR = \frac{R_2 - R_1}{R_1(T_2 - T_1)}, \quad (7)$$

which is equal to 0.007 for pure silicon but may vary between (±0.001 – 0.008) $℃^{-1}$ for semiconductors with different doping concentrations [10, 11]. For undoped polysilicon films the TCR is about -0.025 $℃^{-1}$ [12]. As a result, we obtained the data shown in Fig. 4.

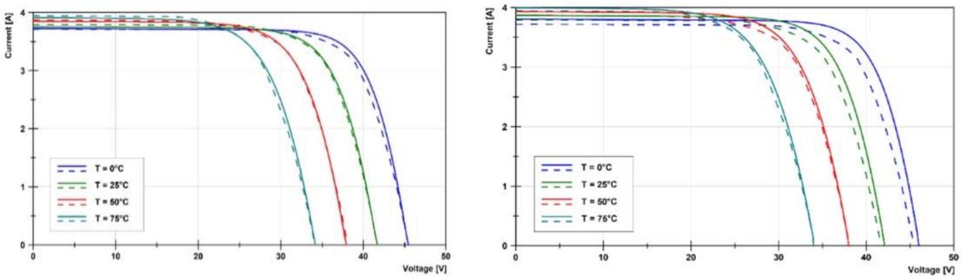


Fig. 4. Comparisons of the "new" model [1] and the "old" model [4] with actual results for BP-MSX120 solar panel [5]: a- simulation results (solid lines) considering temperature dependence of serial and shunt resistances ("new" model) compared to the datasheet values (dashed lines) of BP-MSX120 solar panels, b- simulation results (solid lines) considering temperature independence of serial and shunt resistances ("old" model) compared to the datasheet values (dashed lines) of BP-MSX120 solar panel

In Fig. 4a, the datasheet data (dashed lines) compared with our modeling results (solid lines), which includes temperature dependences of serial and shunt resistances of the model.

In Fig. 4b, the datasheet data (dashed lines) compared with the result of the simulation (solid lines) where the temperature dependences of serial and shunt resistances of the model are not taken into account.

The comparison of Fig. 4a and b clearly demonstrates that the model now is significantly improved.

To evaluate the model improvement, we have calculated the root mean square deviation (RMSD) of modeling results from datasheet values for "old" and "new" models (Table 1).

Table 1

The calculated RMSD values of I-V curves obtained by measurement and simulation (BP-MSX120)

T, °C	Root Mean Square Deviation	
	datasheet data VS existing model	datasheet data VS introduced model
0^0C	0.094	0.079
25^0C	0.046	0.034
50^0C	0.087	0.087
75^0C	0.072	0.072

Table 1 indicates that the introduction of new temperature dependences improves the model accuracy and brings the output of the model closer to the measurement results.

The comparison of the maximum power points (MPP) resulting from measurements, from "new" model and from "old" model is presented in Table 2.

Table 2

The output power at MPP of BP-MSX120 solar panels

T, °C	Power at Maximum Power Point, *W*		
	datasheet	introduced model	existing model
0^0C	125.4914	129.1214	134.0488
25^0C	113.9456	115.1346	120.0760
50^0C	103.3572	103.1626	105.5378
75^0C	89.8748	89.9456	91.2999

We calculated the MPP of solar PV because it is one of the most important parameters of Solar PV panels. It is as important as Isc and Voc. That means, if MPP of the curves does not match with the datasheet, the results that we obtained are not correct, even when the values of Isc and Voc match with the values of those given by the datasheet BP-MSX120 solar panel.

Simulation and Results. To prove the consistency of the newly proposed model, we decided to apply this model to another commercially available Solar panel – BP Solar BP4180T.

Using the formulas of article [1], and the parameter detection algorithm given in the same article, we have found Rs and Rsh. Then, by the method we have proposed, the temperature dependances of series and shunt resistances obtained.

Then, we carried out the "new" and "old" model simulations for different temperatures and plotted the corresponding IV curves on Fig. 5 and 6.

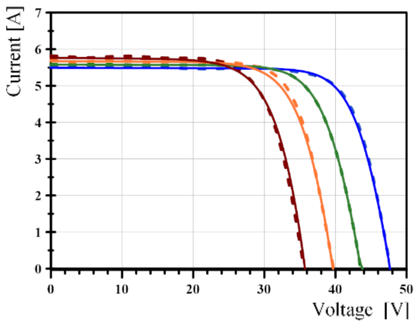


Fig. 5. Simulation results (solid lines) considering the temperature dependence of serial and shunt resistances ("new" model) compared to the datasheet values (dashed lines) of BP4180T solar panels

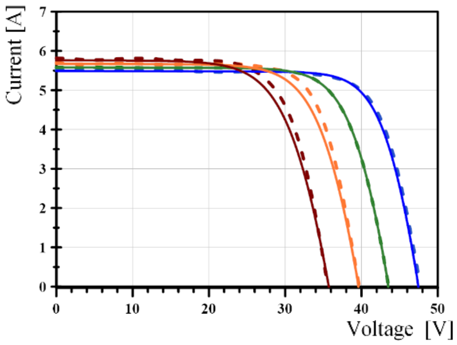


Fig. 6. Simulation results (solid lines) considering the temperature independence of serial and shunt resistances ("old" model) compared to the datasheet values (dashed lines) of BP4180T solar panels

The comparison of Fig. 5 and Fig. 6 clearly demonstrates that the model is improved when the temperature dependances of series and shunt resistances are encountered. This means that the proposed model works for BP4180T solar panel as well.

To show more accurately the data improvement, we calculated the root mean square deviation (RMSD) for BP4180 solar panel at different temperature conditions (0, 25, 50, 75). First, we compared the deviations between the "new" model simulation results and the datasheet data, then we compared the deviations between the "old" model simulation results and the datasheet data (Table 3).

Table 3

The calculated RMSD values of I-V curves obtained by measurement and simulation (BP4180T)

T, ^0C	Root Mean Square Deviation	
	datasheet data VS existing model	datasheet data VS introduced model
0^0C	0.07902	0.07759
25^0C	0.08640	0.08640
50^0C	0.08755	0.08752
75^0C	0.09877	0.09867

Then we calculated the maximum power points for all IV curves and compared the results with datasheet values (Table 4). As can be seen, the output of the "new" model is closer to the datasheet data than the output generated from the "old" model.

Table 4

The output power at MPP of BP4180T solar panels

T, °C	Power at Maximum Power Point, W		
	datasheet	introduced model	existing model
0^0C	200.3549	199.8877	199.4987
25^0C	182.8636	179.2859	179.2859
50^0C	166.9706	161.8130	158.8646
75^0C	145.0250	144.0908	138.3472

Conclusion. In this work, we applied the proposed by us new model to another solar panel. Following the same algorithm as in previous works, performing calculations and modeling, we got the model output for BP4180 solar panels for different temperatures. We compared the IV curves obtained by the new model with the curves of the datasheet, then we compared the curves of the old model with the curves of the datasheet. As a result, a clear improvement of the model is noticeable when we introduce the temperature dependence of serial and shunt resistances of the solar panel model.

Thus, it is shown that the new model proposed for the simulation of solar panels generates results much closer to the measurements than the old model does.

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ԱՐԵՎԱՅԻՆ ՎԱՀԱՆԱԿԻ ՄԵԿ- ԴԻՈԴ ՀԻՆԳ -ՊԱՐԱՄԵՏՐ ՄՈԴԵԼԻ ԿԻՐԱՌՈՒԹՅՈՒՆԸ՝ ՀԱՇՎԻ ԱՌՆԵԼՈՎ ՋԵՐՄԱՍՏԻՃԱՆԱՅԻՆ ԿԱԽՎԱԾՈՒԹՅՈՒՆՆԵՐԸ

Ներկայիս տնտեսական զարգացումները նպաստում են արևային վահանակների կիրառմանը: Սա հանգեցնում է նրան, որ ավելի շատ ընկերություններ արտադրում են արևային վահանակներ՝ միանգամայն տարբեր բնութագրերով: Սակայն արտադրողների կողմից տրամադրված բնութագրերը հիմնականում չեն պարունակում ամբողջական տեղեկատվություն, որպեսզի հնարավոր լինի հաշվարկել արևային վահանակների ելքը օգտագործման տարբեր պայմաններում: Ուստի այժմ արևային վահանակների մոդելի կառուցման փուլում ենք, երբ հաշվարկվում է արևային վահանակների ելքը տարբեր պայ-մաններում՝ հիմնվելով վահանակների տեխնիկական փաստաթղթերում ներկայացված ընդհանուր տվյալների վրա:

Նախկին աշխատանքներում ներկայացրել ենք արևային վահանակների մոդելի կառուցման մեթոդաբանությունը՝ արևային վահանակների տեխնիկական փաստաթղթում

ներկայացված տվյալների հիման վրա: Այս հոդվածում ցույց են տրվում առաջարկվող մեթոդի կրկնելիությունը և կիրառումը այն BP4180T արևային վահանակի վրա, որ արտադրում է BP Solar -ը: Կատարելագործված այս մոդելի արդյունքները համեմատվել են նախորդ մոդելի արդյունքների և արևային վահանակի տեխնիկական փաստաթղթում ներկայացված տվյալների հետ:

Ստացված արդյունքների վերլուծությունը ցույց է տալիս առաջարկվող մոդելի կիրառելիությունը և վերարտադրելիությունը:

Առանցքային բառեր. արևային վահանակի մոդել, ֆոտովոլտային վահանակ, թեստավորման համակարգ, արևային էներգիա, ֆիզիկական կորուստներ արևային մարտկոցներում:

А.Т. СИМОНЯН, О.А. ПЕТРОСЯН, С.Т. МУРАДЯН

ПРИМЕНЕНИЕ ОДНОДИОДНОЙ ПЯТИПАРАМЕТРИЧЕСКОЙ МОДЕЛИ СОЛНЕЧНОЙ ПАНЕЛИ С УЧЕТОМ ТЕМПЕРАТУРНЫХ ЗАВИСИМОСТЕЙ

Текущее экономическое развитие благоприятствует использованию солнечных батарей. Это приводит к тому, что все больше компаний производят солнечные панели с совершенно разными характеристиками. Однако спецификации, предоставляемые производителями, обычно не содержат полной информации, позволяющей рассчитать мощность солнечных панелей в различных условиях использования. Именно поэтому необходимо создать модель солнечной панели, которая позволит нам рассчитать мощность солнечных батарей в различных условиях, основываясь на общих данных, представленных в технической документации панелей.

В предыдущих работах нами была предложена методика построения модели солнечной панели на основе данных, представленных в техническом документе солнечной панели. В этой статье продемонстрирована повторяемость предложенного метода и применяемость его к солнечной панели BP4180T производства BP Solar. Результаты этой улучшенной модели сравнены с результатами предыдущей модели и с данными, представленными в техническом документе интересующей солнечной панели.

Анализ полученных результатов показывает применимость и повторяемость работы предложенной модели.

Ключевые слова: моделирование солнечных панелей, фотоэлектрические элементы, система тестирования, солнечная энергия, физические потери в солнечных панелях.