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KARAKTERIZACIJA PARAMETARA **ELEKTRIČNO**G MODELA FOTONAPONSKOG MODULA

PARAMETER CHARACTERIZATION FOR ELECTRICAL MODEL OF PHOTOVOLTAIC MODULE

Igor Petrović, Zdravko Petrović, Stanko Vincek

Prethodno priopćenje

Sažetak: *U smislu upravljanja proizvodnjom električne energije fotonaponskim modulom važno je znati sa koliko energije raspolažemo u određenom trenutku. Električni teret ili distributivna mreža preuzimaju ovako proizvedenu energiju. Električni model fotonaponskog panela može se koristiti kao izvor informacija za regulaciju toka energije od fotonaposnkog panela prema teretu ili mreži, a ne obratno. Za svaku radnu točku sustava postoji optimalno opterećenje koje će preuzeti upravo svu električnu energiju koja je dostupna u tom trenutku. Budući da se opterećenje u većini slučajeva ne može proizvoljno mijenjati potrebno je osigurati tok energije kroz pretvarač upravljačkim sustavom, odnosno postavljanjem pretvarača u radnu točku maksimalne radne snage (MPP) fotonaponskog panela. U ovom članku prikazani su utjecaji promjene pojedinih parametara električnog modela fotonaponskog panela na izlaznu karakteristiku struje i napona.*

Ključne riječi: *FN modul, električni model, radna točka MPP*

Preliminary notes

Abstract: *In terms of PV module electrical energy production management it is important to know how much energy is available at any given time. Electrical load or distributive grid is consuming this produced energy. The electrical model of PV module can be used as a source of information for regulation of energy flow from PV module towards the load or the grid, and not the other way around. There is an optimal load for every operating point of the system, which will consume all of available electrical energy at a given moment. It is necessary to ensure the energy flow through the converter using the converter control system since the load cannot be arbitrarily altered, by setting the operating point of converter to maximum power point (MPP) of PV module. In this paper the influence of single parameter is presented for electrical model of PV module on output characteristic of current and voltage.*

Key words: *PV module, electrical model, operating point MPP*

1. INTRODUCTION

The usage of PV technology became very spread in terms of energy production. From the aspect of possibilities of energy production it is commonly considered as one of the most popular “green” energy providers as in [1]. PV modules life cycle is also one of the main issues of present, as in [2]. Therefore, the modeling efforts are focused on obtaining every possible increase in electrical energy production available, as for example in [3] or [4]. The most dominant influences on PV module/plant energy production are irradiation and temperature. Therefore, a lot of research is provided especially for the irradiation modeling improvements, as provided in [5]. Also, it is important to give attention to location and specific climate conditions of the PV module/plant while modeling the irradiation, as in [6].

The electrical model of PV module allows insight in electrical behavioral when electrical load is varied. These behavioral preferences are the most important aspect of MPP tracking in electrical converters used for providing the PV energy to electrical load and/or distribution grid. If PV module is not regulated in MPP operating point for current conditions, it will reduce efficiency of electrical energy production.

2. PV MODULES

The modelling in this research is based on the most commonly used PV cell model called Single Diode Model (SDM) as presented in Figure 1. The model consists of a current source which provides a photon current IL and is present when a PV cell is exposed to light. This photon current is the fundamental current in PV cell, caused by a photovoltaic effect. When the PV cell is not illuminated by the light it acts like a conventional diode that does not depend on any light parameters [7]. Behavior of a PN diode is described through a current–voltage characteristic which is based on the Shockley equation (1).

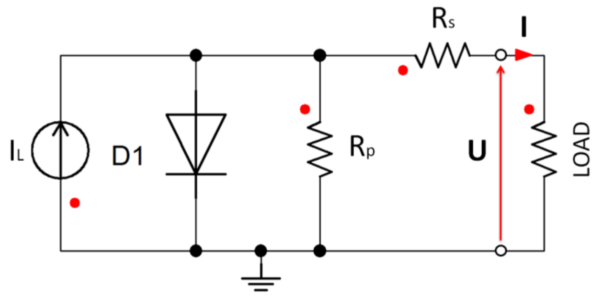

Figure 1. Electrical model of PV module

$$I = I_L - I_0 \cdot \exp\left(\frac{U + I \cdot R_s}{m \cdot U_T}\right) - \frac{U + I \cdot R_s}{R_p} \qquad (1)$$

Where U_T is temperature equivalent voltage (thermal voltage) and can be described with equation (2). The voltage U is the voltage between anode and cathode of a PN diode, the current I_0 is a saturation current which flows when PN junction is reversed polarized, and m is ideality factor (values from 1 to 2) which is in close correlation with diode forward voltage value.

$$U_T = \frac{k \cdot T}{q} \qquad (2)$$

Where k is Boltzmann constant of 1.380650×10−23 J/K, q is electron charge of 1.602176×10−19 C and T is temperature in Kelvins.

The current I_0 exists due to minority carriers (voids) in region N and minority carriers (electrons) in region P, and it is directed from N to P region. A current-voltage (I-U) characteristic of a diode is very temperature dependent, as can be seen from Shockley equation. The saturation current I_0 and thermal voltage U_T change with the change of temperature respectively. Diode current I_D will increase with temperature increase because of I_0 but at the same time it will decrease with the increase of thermal voltage U_T. The increase of the saturation current has a stronger impact then the increase of thermal voltage, and therefore the diode current I_D increases with the increase of temperature and constant diode voltage U_D. Single diode model of a PV module also include the most common parasitic resistances, series resistance and shunt resistance respectively [8]. Series resistance in a PV module has three causes. Primarily, the movement of carriers (current) through the emitter (N region) and base (P region) of the PV module. Secondly, the contact resistance, introduced between the metal contact and the silicon. Finally, the resistance of the top and rear metal contacts of the PV module. The main impact of series resistance is the fill factor reducing, although its excessively high values may also reduce the short-circuit current. Series resistance RS varies with the reciprocal of the irradiance. Shunt resistance RP is parallel leakage resistance and is typically large. The low shunt resistance causes power losses in PV module by providing an alternate current path for the light-generated current. Such a diversion reduces the amount of current flowing through the PV module junction and reduces the voltage of the PV cell. The effect of a shunt resistance is particularly severe at low light levels, since there will be less light-generated current. Therefore, the loss of this current to the shunt has a larger impact on final output current. In addition, the impact of a parallel resistance is large at lower voltages where the effective resistance of the PV module is high. This component can be neglected in many applications except for low light conditions. The output PV module current is final as provided in (1).

Figure 2. Sample of PV module

Table 1. PV module nominal data

PV module parameter	Nominal value
Model	DSP-10M
P_M	10 (±3%) W
U_M	9.00 V
I_M	1.11 A
U_{PH}	10.80 V
I_{KS}	1.28 A
T_{noct}	-45 – 80 °C
U_{max}	60 DC V
Dimensions	284 x 350 x 17 mm
Standard test conditions	AM = 1.5; H = 1000 W/m^2; T = 25 °C

The number of cells in a PV module can be reached by comparing the open-circuit voltage with the conducting voltage of a diode U_0 (0.6 V) as provided in equation (2). Therefore, the number of cells N must be implemented in the thermal voltage U_t, along with m which is the diode ideality factor and depends on the type, doping density and quality of the semiconductor material. The usual value of m for this PV module is 1.3.

$$N = \frac{U_{PH}}{U_0} = \frac{10.80}{0.6} = 18 \qquad (2)$$

3. ELECTRICAL MODEL OF PV MODULE

Modeling of PV module I-U characteristics, like presented in Figure 2., is basically an adjustment of parameters used in equation (1) in order to produce exponential function exactly as real PV module I-U characteristic.

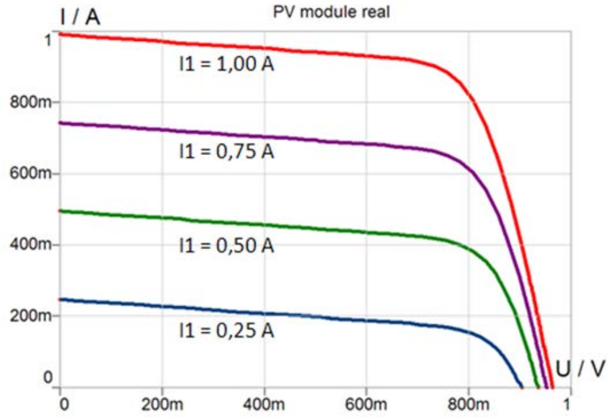

Figure 3. Sample exponential I-U characteristics of PV module

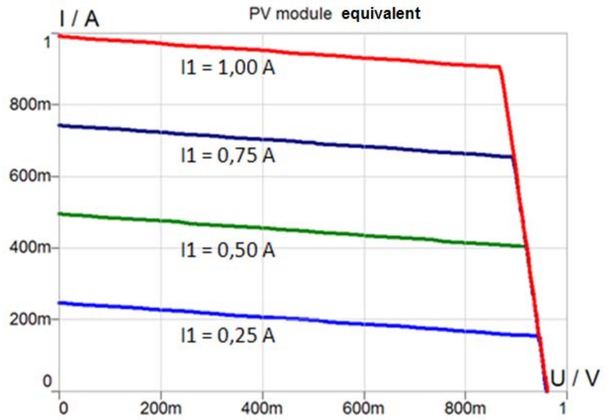

Figure 4. Sample linear I-U characteristics of PV module

The real PV module can be described by exponential function as presented in Figure 3, or in simplified case as two linear functions as presented in Figure 4. Linear model will introduce some errors which are the most prominent in the surroundings of MPP (maximum power point). Since the MPP is the optimal operating point, the exponential function should be used in any serious research of PV module.

The influence of changing single parameter in electrical model for PV module is simulated trough Excel calculation as presented in Figure 5. These characteristics present PV module output I-U characteristic when all parameters except one are fixed. The calculations of characteristics are generally made for PV module current, and PV module power is then calculated from these characteristics.

The calculation procedure is divided in two loops which are searching for the solution on current and voltage couples that comply with provided exponential function regarding the parameters in equation (1). The outer loop is the voltage search which is given for range from 0 V to 0.8 V, which is just above U_0, in 0.01 V raster. For each of these voltages the associated current is calculated using inner loop for range from 0 A to 1 A, which is the maximum I_L used in this simulations. The result values are saved when the appropriate couple of current and voltage is reached, and the outer loop is progressing to the next step.

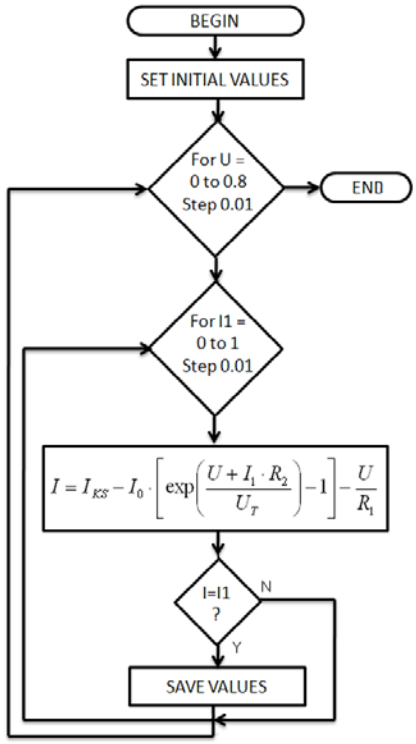

Figure 5. Modeling of PV module in VB for MS Excel

4. RESULTS FOR PARAMETER ADJUSTMENT IN PV MODULE OF ELECTRICAL MODEL

The modeling of PV module output characteristic is provided from Excel model. The serial resistance of PV module is presenting the voltage drop on output connection of PV module. If the resistance is low, it will not change the output voltage significantly from the voltage on internal diode. The original exponential voltage is rapidly decreasing when the serial resistance is increasing, as presented in Figure 6. The output power is also reducing if the serial resistance is increasing, since the losses on the serial resistance are increasing, as presented in Figure 7. The serial resistance is commonly from 0.01 Ω to 1 Ω.

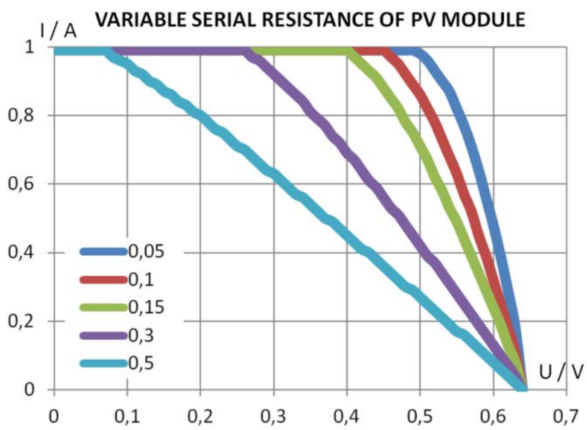

Figure 6. I-U characteristics for variable values of R_s and fixed R_p = 10 Ω i I_L = 1 A

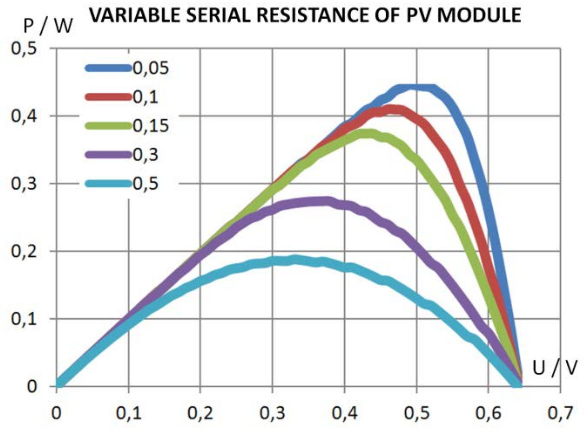

Figure 7. P-U characteristics for variable values of R_s and fixed R_p = 10 Ω i I_L = 1 A

The parallel resistance of PV module is presenting the current losses inside the PV module. If the resistance is high, it will not change the output current significantly from the internal source current. The original current is rapidly decreasing when the parallel resistance is decreasing, as presented in Figure 8. The output power is also reducing if the parallel resistance is decreasing, since the internal losses on the parallel resistance is increasing due to increase of current, as presented in Figure 9. The parallel resistance is commonly from 100 Ω to 300 Ω.

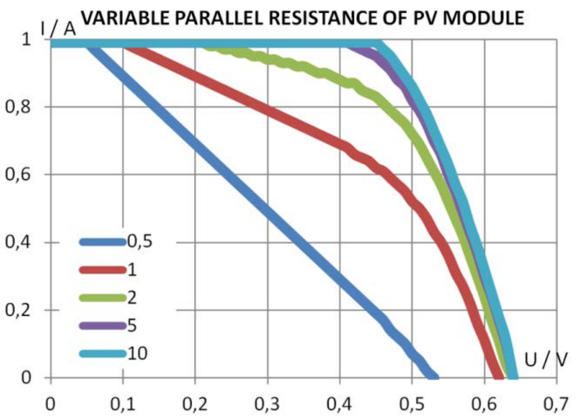

Figure 8. I-U characteristics for variable values of R_p and fixed R_s = 0,1 Ω i I_L = 1 A

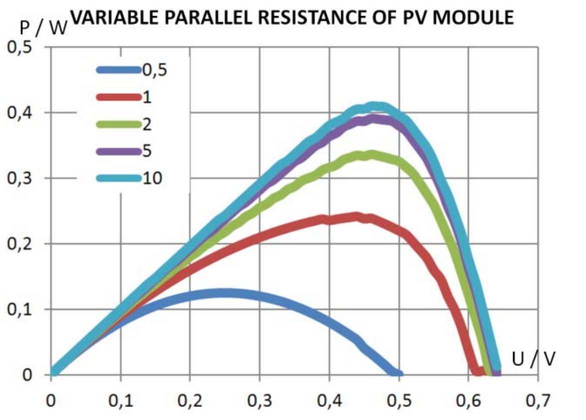

Figure 9. P-U characteristics for variable values of R_p and fixed R_s = 0,1 Ω i I_L = 1 A

The internal source current of PV module is presenting the current available from the PV module for specific irradiation on PV module surface. If the irradiation is high, it allows significant internal source current. The internal source current is linearly decreasing when the irradiance is decreasing, as presented in Figure 10. The output power is also linearly reducing if the irradiance is decreasing, since the lower current is available at the same output voltage, as presented in Figure 11. The internal source current is related to nominal PV module short-circuit current.

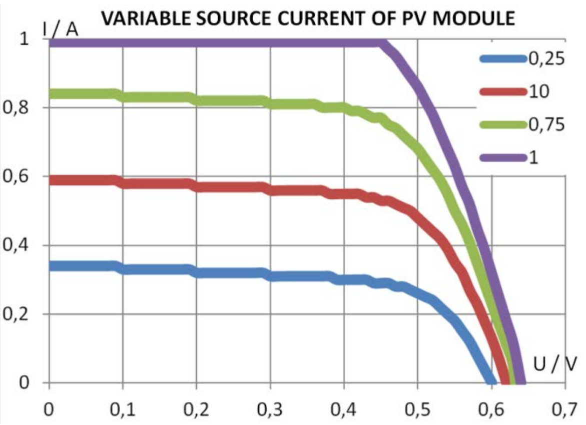

Figure 10. I-U characteristics for variable values of I_L and fixed R_p = 10 Ω i R_s = 0,1 Ω

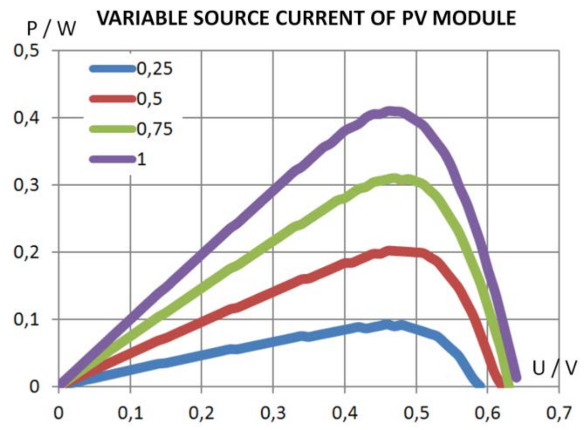

Figure 11. P-U characteristics for variable values of I_L and fixed R_p = 10 Ω i R_s = 0,1 Ω

5. CONCLUSION

The electrical model of PV module is used to describe all electrical effects which are taking place inside PV module while solar energy is converted into electrical energy. Each element in model represents one physical property of PV module, and must be understood as representation of such a property. The current source is presenting available solar energy and diode is presenting a PN junction inside the PV cells. The serial and parallel resistors are not really applied in PV module, but rather represent current losses (parallel resistor) and voltage losses (serial resistor) inside the PV module regarding the ideal state. These parameters are fully enabling PV module state description and energy resources. Therefore, it is the best way to perform MPP tracking with energy converter. The main prerequisite is good parameterization of all elements used in electrical model of PV module. The measuring system must enable good data on solar irradiance and ambient temperature, and output electrical values of voltage, current and power.

6. REFERENCES

[1] Razykov, T. M.; Ferekides, C. S.; Morel, D.; Stefanakos, E.; Ullal, H. S.; Upadhyaya, H. M.: Solar photovoltaic electricity: current status and future prospects, Solar Energy, Vol. 85, No. 8 (2011) 1580-1608

[2] Raugei, M.; Frankl, P.: Life cycle impacts and costs of photovoltaic systems: current state of the art and future outlooks, Journal of Energy, Vol. 34, No. 3 (2009) 392-399

[3] Petrović, I.; Šimić, Z.; Vražić, M.: Advancements in PV plant energy production prediction with model improvement based on measured data, Journal of International Review of Electrical Engineering (I.R.E.E.), Vol. 8, No. 2 (2013) 832-838

[4] Petrović, I.; Šimić, Z.; Vražić, M.: Advanced PV plant planning based on measured energy production results – Approach and measured data processing, Journal of Advances in Electrical and Computer Engineering, Vol. 14, No. 1 (2014) 49 – 54

[5] Badescu, V.: Modeling Solar Radiation at the Earth's Surface - recent advances, Springer, 2008

[6] Shayani, R. A.; Gonçalves de Oliveira, M. A.: A New Index for Absolute Comparison of Standalone Photovoltaic Systems Installed at Different Locations, IEEE transactions on sustainable energy, Vol. 2, No. 4 (2011) 495-500

[7] Ma, J.; Ting, T. O.; Man, K. L.; Zhang, N.; Guan, S.-U.; Wong, P. W. H.: Parameter Estimation of Photovoltaic Models via Cuckoo Search, Journal of Applied Mathematics, Vol. 2013, (2013) 1-8

[8] de Blas, M. A.; Torres, J. L.; Prieto, E.; Garcıa, A.: Selecting a suitable model for characterizing photovoltaic devices, Renewable Energy, Vol. 25, No. 3 (2002) 371-380

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