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BOOK 1

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An Approach to Model Parameter Extraction of Photovoltaic Module

Elissaveta Dimitrova Gadjeva, Dimitar Yordanov Shikalanov and Georgi Georgiev Valkov

Abstract - **An approach to model parameter extraction of photovoltaic module is developed. The extraction procedure is of direct type without using optimization approach. The basic model parameters of the model at nominal temperature are obtained based on the datasheet characteristics. The temperature coefficients of the temperature-dependent model are also calculated. A validation of the model is performed based on experimental data for the solar array and the accuracy of the extraction procedure is investigated.**

Keywords – **Photovoltaic cell, Photovoltaic Module, Computer Model, Parameter extraction, PSpice Simulator**

I. INTRODUCTION

The development of adequate computer models of photovoltaic cells and arrays is of significant importance for the investigation and optimization of PV power systems. Photovoltaic models of PV cells and modules are developed in [1-5]. Temperature dependent models of PV cells and modules are proposed in [5-7]. An improving of the model is achieved in [7] by iterative adjusting the model parameters. In this way the simulated IV curve and the experimental data are matched at three remarkable points of the characteristics.

Methods and algorithms for parameter extraction of photovoltaic modules by taking the manufacturer specified data are developed in [6-7].

An approach to model parameter extraction of photovoltaic (PV) module is developed in the present paper. The extraction procedure is of direct type without using optimization approach. The model parameters at nominal temperature are obtained based on the datasheet characteristics. The temperature coefficients of the temperature-dependent model are also calculated. A validation of the model is performed based on experimental data for the solar array and the accuracy of the extraction procedure is investigated. The extraction procedure is realized in the *Cadence PSpice* and *Cadence Probe* environment.

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II. MODELING OF PHOTOVOLTAIC MODULE

The equivalent circuit of the photovoltaic module is shown in Fig. 1.

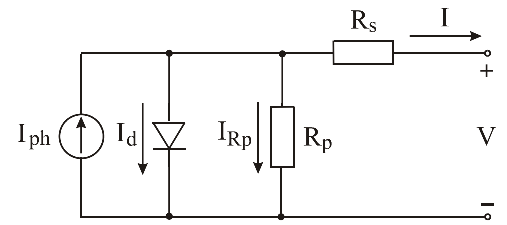


Fig. 1. Equivalent circuit of PV module

The current I is expressed by the following equation:

$$I = I_{ph} - I_o\left(e^{\frac{q(V+IR_s)}{AkT}} - 1\right) - \frac{V + IR_s}{R_p} \qquad (1)$$

or

$$I = I_{ph} - I_o\left(e^{\frac{V+IR_s}{A_1}} - 1\right) - \frac{V + IR_s}{R_p}, \qquad (2)$$

where

$$A_1 = AN_sV_T \quad ; \quad V_T = \frac{kT}{q}. \qquad (3)$$

I_{ph} – photo generated current, I_o – dark saturation current, R_p – shunt resistance, R_s – series resistance, A – diode ideality constant, N_s – number of cells connected in series, $q = 1.6\times10^{-19}$ C – electronic charge, $k = 1.38\times10^{-23}$ J/K – Boltzmann's constant, T – ambient temperature in Kelvin.

II. EXTRACTION PROCEDURE

The input data for the extraction procedure are: the open circuit voltage V_{oc}, the photo generated current I_{ph}, the IV characteristic from the datasheet.

1. *Determination of* R_p

$G_p = 1/R_p$ is obtained for low voltages from the flat part of IV curve (Fig. 2), where the diode current I_d and the voltage across R_s are neglected. From (1)

$$I \approx I_{ph} - \frac{V}{R_p}, \quad (4)$$

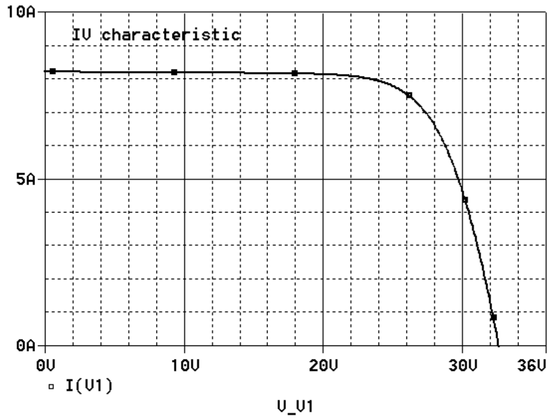


Fig. 2. IV characteristic

$$G_p = \left(\frac{dI}{dV}\right)_{V=0} \quad ; \quad R_p = \frac{1}{G_p}. \quad (5)$$

The derivative G_p is calculated in the range $[0,V_1]$, which defines the flat part of the IV characteristic. The function E_1 is defined in the form:

$$E_1 = \begin{cases} 0 \text{ if } V \le V_1 \\ 1 \text{ if } V > V_1 \end{cases}. \quad (6)$$

The experimental data for IV characteristic are introduced in the *PSpice* model tabularly as input data (Fig. 2).

R_p is obtained according to (5) using the following macros in the graphical analyzer *Probe* (Fig. 3):

```
E1 = 0.5*(sgn(v(1)-1)+1)
Rp = max(-1/d(I(V1))*E1)
```

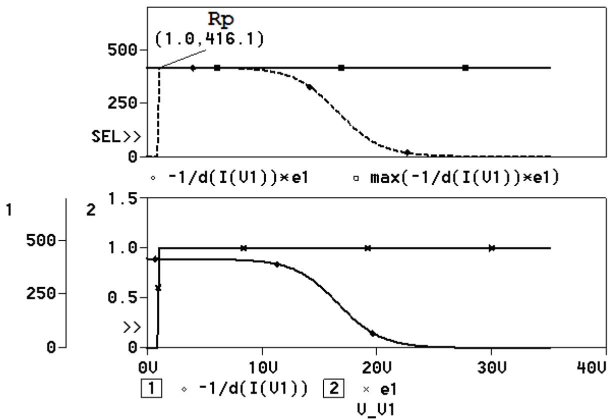


Fig. 3. Determination of R_p

2. *Determination of* I_o

The following equation is obtained from (1) for $I = 0$ and $V = V_{oc}$:

$$0 = I_{ph} - I_o\left(e^{\frac{V_{oc}}{A_1}} - 1\right) - \frac{V_{oc}}{R_p}. \quad (7)$$

I_o is obtained from (7) in the form:

$$I_o = \frac{I_{ph} - \frac{V_{oc}}{R_p}}{e^{\frac{V_{oc}}{A_1}} - 1}. \quad (8)$$

I_o is calculated according to (8) using the following macro in *Probe* (Fig. 4):

```
Io = (Iph-Voc/Rp)/(exp(Voc/A1)-1)
```

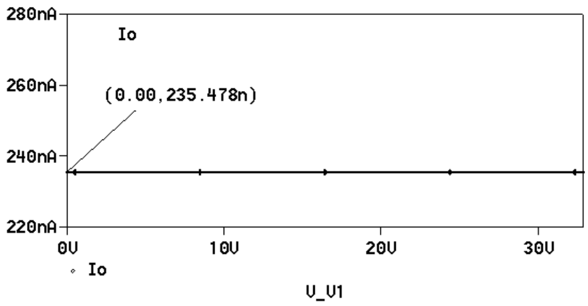


Fig. 4. Determination of I_o

3. *Determination of* R_s

R_s is obtained using the slope of the IV characteristic near V_{oc}. The following equation is used:

$$V = R_s I + V_d, \quad (9)$$

where V_d is the diode voltage.

After differentiation of (9) with respect to I, the equation

$$R_s = R_{sV} - R_{sd} \quad (10)$$

is obtained, where

$$R_{sV} = \left.\frac{dV}{dI}\right|_{V=V_{oc}} \quad ; \quad R_{sd} = \left.\frac{dV_d}{dI}\right|_{V=V_{oc}}. \quad (11)$$

R_{sV} is obtained from the IV characteristic:

$$R_{sV} = -\left.\left(\frac{dI}{dV}\right)^{-1}\right|_{V=V_{oc}}. \quad (12)$$

R_{sd} is obtained from the diode equation:

$$R_{sd} = -\left.\left(\frac{dI}{dV_d}\right)^{-1}\right|_{V=V_{oc}} \quad (13)$$

or

$$R_{sd} = \frac{A_1}{I_{oc} e^{\frac{V_{oc}}{A_1}}}. \quad (14)$$

R_s is calculated according to (10-14) using the following macros in *Probe* (Fig. 5):

```
Rsd = A1/(Ioc*exp(Voc/A1))
RsV = min(-1/d(I(V1))))
Rs=RsV-Rsd
```

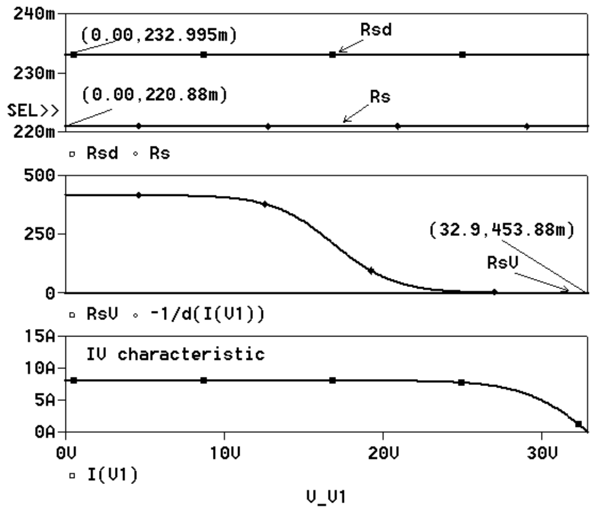


Fig. 5. Determination of R_s

4. Determination of temperature coefficient K_V

The temperature dependence of the open circuit voltage $V_{oc,T}$ has the form [7]:

$$V_{oc,T} = V_{oc} + K_V \Delta T \ , \tag{15}$$

where

$\Delta T = T - T_n$; T_n – nominal temperature (298^{o}K); T – ambient temperature (^{o}K); V_{oc} – open circuit voltage at temperature T_n ; $V_{oc,T}$ – open circuit voltage at temperature T.

The coefficient K_V is obtained using (15) in the form:

$$K_V = \frac{V_{oc,T} - V_{oc}}{\Delta T} \ . \tag{16}$$

K_V is calculated according to (16) using the following macro in the graphical analyzer *Probe*:

```
KV=(VocT-Voc)/(T-Tn)
```

5. Determination of temperature coefficient K_I

The temperature dependence of the short circuit current $I_{sc,T}$ has the form [7]:

$$I_{sc,T} = I_{sc} + K_I \Delta T \ , \tag{17}$$

where

$I_{sc,T}$ - short circuit current at temperature *T*, I_{sc} - short circuit current at temperature T_n .

The coefficient K_I is obtained using (17) in the form:

$$K_I = \frac{I_{sc,T} - I_{sc}}{\Delta T} \ . \tag{18}$$

K_I is calculated from (18) using the following macro in the graphical analyzer *Probe*:

```
KI=(IscT-Isc)/(T-Tn)
```

The temperature dependence of the current $I_{o,T}$ has the form:

$$I_{o,T} = \frac{I_{sc,T}}{e^{\frac{T_n V_{oc,T}}{A_1 T}} - 1} \ . \tag{19}$$

III. Validation of the Extraction Procedure

The datasheet parameters of the solar array KC200GT [7] shown in Table 1 are used as input data.

TABLE 1. PARAMETERS OF THE KC200GT SOLAR ARRAY AT 25^{o}C

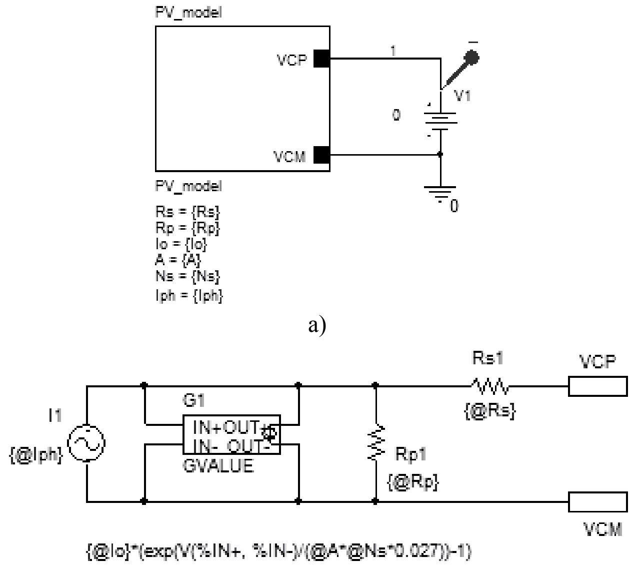
V_{oc}	32.9V
I_{sc}	8.21A
I_{ph}	8.214A
I_{mp}	7.61A
V_{mp}	26.3V
P_{max}	200.143W
N_s	54

The extracted parameters are presented in Table 2. The extracted parameter values obtained in [7] are also given for comparison.

TABLE 2. EXTRACTED PARAMETERS

Parameter	Extracted value	Extracted value in [7]
R_p	416.1 Ω	415.405 Ω
R_s	0.22088 Ω	0.221 Ω
I_o	235.478 nA	237.8 nA
K_V	-0.123V/K	-0.123V/K
K_I	0.003A/K	0.0032A/K

The *PSpice* macromodel of the PV module defined as a parameterized block is shown in Fig. 6.



a)

b)

Fig. 6. *PSpice* macromodel of the PV module defined as a block (a) and parameterized subcircuit (b)

The simulated IV and power characteristics are shown in Fig. 7 and Fig. 8 respectively.

The modeled values for V_{oc} and I_{sc} are presented in Fig. 7. The modeled values for the maximum power P_{max}, current I_{mpp} at P_{max} and voltage V_{mpp} at P_{max} are shown in Fig. 8.

The simulated values for V_{oc}, I_{sc}, P_{max}, I_{mpp} and V_{mpp} are compared with the values given in the datasheet. They are presented in Table 3. The relative errors of the corresponding parameters are also given.

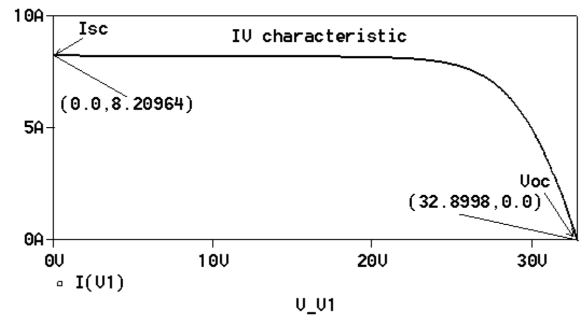


Fig. 7. Simulated IV characteristic

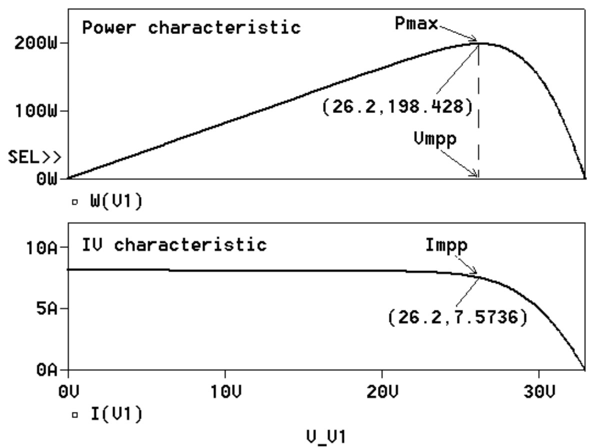


Fig. 8. Simulated power characteristic

TABLE 3. COMPARISON RESULTS

Parameter	Datasheet value	Modeled value	Relative error,%
V_{oc}	32.9V	32.8998V	6.079×10^{-4}
I_{sc}	8.21A	8.20964A	4.385×10^{-3}
I_{mpp}	7.61A	7.5736A	0.3469
V_{mpp}	26.3V	26.2V	0.38
P_{max}	200.143W	198.428W	0.857

The simulated IV characteristic $I(V)$ is compared with the experimental IV characteristic $I_m(V)$ given in [7] and the relative error ε_I is calculated:

$$\varepsilon_I = 100\left|\frac{I(V) - I_m(V)}{I_m(V)}\right|. \qquad (20)$$

The obtained relative error is less then 0.4%. The simulation results of the model with extracted parameters match very closely the measured data.

IV. CONCLUSION

A computer-aided procedure for model parameter extraction of photovoltaic module has been developed. The model parameters at nominal temperature, as well as the temperature coefficients of the temperature-dependent model are calculated based on datasheet characteristics. A validation of the model with the extracted parameters is performed using experimental data for the solar array. The obtained relative error of the simulated IV characteristic is less then 0.4%.

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REFERENCES

[1] H-L., Tsai, Ci-Siang Tu, Yi-Jie Su. *Development of generalized photovoltaic model using MATLAB/SIMULINK*, Proceedings of the World Congress on Engineering and Computer Science 2008, WCECS 2008, October 22 - 24, San Francisco, USA, 2008.

[2] I.H., Altas, A.M., Sharaf. *A photovoltaic array simulation model for Matlab-Simulink GUI environment*, International Conference on Clean Electrical Power,. ICCEP '07. 21-23 May 2007,pp. 341 – 345, Capri, 2007.

[3] R. Hernanz, C. Martín, J.J. Belver, L. Lesaka, Z. Guerrero, E. Puelles Pérez. *Modelling of photovoltaic module*, International Conference on Renewable Energies and Power Quality, (ICREPQ'10) Granada (Spain), 23th to 25th March, 2010.

[4] D. Sera, R. Teodorescu, P. Rodriguez. *PV panel model based on datasheet values*, IEEE International Symposium on Industrial Electronics, ISIE 2007,June 4-7 2007, Vigo, Spain, ISBN: 978-1-4244-0754-5, pp. 2392-2396, 2007.

[5] R.K. Nema, Savita Nema, Gayatri Agnihotri. *Computer Simulation Based Study of Photovoltaic Cells/Modules and their Experimental Verification*, International Journal of Recent Trends in Engineering, Vol 1, No. 3, May 2009

[6] A. El Shahat. *Maximum Power Point Genetic Identification Function for Photovoltaic System*, International Journal of Research and Reviews in Applied Sciences IJRRAS vol. 3, n.3, pp. 264-273, June 2010.

[7] M.G.Villalva, J.R. Gazoli, E.R. Filho. *Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays*, IEEE Transactions on Power Electronics, v. 24 , n. 5, 1198 – 1208, May 2009.