# Design of Photovoltaic Solar Cell Model for Stand-alone Renewable System



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***Abstract*** **- In the future, more and more pressure will be given on renewable smart applications. One type of renewable energy is the solar energy. A photovoltaic solar cell or a module is often used in mobile applications as energy source. More and more applications are covered with solar cell or module as the energy source. A simple and accurate mathematical model that describes properties of the photovoltaic solar cell is required for present-day dynamic development. The paper deals with the proposal of a model of PV solar cell and module. Proposed model is verified by the simulation using Matlab. The influence of the temperature and the solar irradiation on photovoltaic module is investigated and compared to the I-V characteristics of photovoltaic solar module Sharp, that were used as a source of the photovoltaic cell parameters. Proposed model can be used in research as a part of a simulation of stand-alone power system.**

***Keywords*** **- mathematical model, renewable energy, photovoltaic solar cell, module, simulation, Matlab, equivalent circuit.**

## I. INTRODUCTION

Renewable energy has not only a big potential in mobile technologies. Shortly, the miniaturizing resources of fossil fuels, as coal, oil and gas, will increase the portion of renewable energy usage in the world. It is free, clean and sustainable source of electrical energy [3].

Photovoltaic (PV) solar power is the one of the most potential renewable energy source, especially in mobile applications. In the past, PV energy was used in the space industry or in calculators. Research in the last decades has increased the efficiency of PV solar cell. A new concept is the thin-film technology. In this case, the PV solar cell is made by one or more thin layers on substrate. More layers allow higher usage of the solar spectrum. Today, the highest efficiency 44.7 % of PV cell was demonstrated by Fraunhofer Institute for Solar Energy Systems [7]. Nowadays, a solar power is used as the energy source in the grid connected power systems, the battery chargers or the street lighting [6], [9], [10].

The voltage and current output values of the PV cell are mainly depended on the solar irradiation, on the cell temperature, on the cell materials, on the cell position considering to the sun and shadows or on the cloudiness [2], [6].

## II. MATHEMATICAL MODEL

### A. *PV Solar Cell*

There are many types of the equivalent PV solar cell circuits. These circuits are differing only by the number of the circuit components. The simplest one is the single diode equivalent circuit of the PV solar cell contains a current source connected in parallel with a diode, a series $R_s$ and a parallel (shunt) $R_{sh}$ resistance. The series resistance is an important parameter, especially for irradiances and cell temperatures far from the reference condition. The equivalent circuit is shown in Fig. 1 [1], [2], [3], [4], [5].

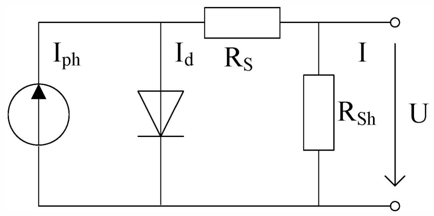


Fig. 1. Equivalent circuit of PV solar cell.

For the ideal condition, $R_s$ is very small ($R_s = 0$) and $R_{sh}$ is very large ($R_{sh} = \infty$). Then, the Circuit is described by Kirchhoff's current law equation:

$$I = I_{ph} - I_d \tag{1}$$

I - Output current of solar cell,
$I_d$ - Diode current,
$I_{ph}$ - Light-generated current.
The diode current is described by Shockley diode equation:

$$I_d = I_0 \left( e^{\frac{qU}{nkT}} - 1 \right) \tag{2}$$

$I_0$ - The diode leakage current density in the absence of light,
q - Electron charge,
U - Voltage of solar cell,

n - Ideality factor,
k - Boltzmann's constant,
T - Temperature of the PV cell.
Where the leakage current $I_0$ is:

$$I_0 = I_{sc}\left(\frac{T}{T_{ref}}\right)^3 e^{\frac{qE_g}{nk}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)} \tag{3}$$

$I_{sc}$ - Short circuit current of the PV cell,
$T_{ref}$ - Reference temperature,
Eg - Band gap energy of the semiconductor.

$$I_{ph} = \frac{\phi}{\phi_{ref}}\left(I_{scr} + \alpha_{isc}\left(T - T_{ref}\right)\right) \tag{4}$$

$\Phi$ - Solar irradiation,
$\Phi_{ref}$ - Reference solar irradiation,
$\alpha_{isc}$ - Short circuit current temperature coefficient of the PV cell,
$I_{scr}$ - Short circuit current of the PV cell at reference temperature.

The theoretical I-V characteristic of the PV solar cell is shown in Fig. 2. The maximum power point voltage $U_{mpp}$ and the maximum power point current $I_{mpp}$ are defining the point of the maximum power output [2].

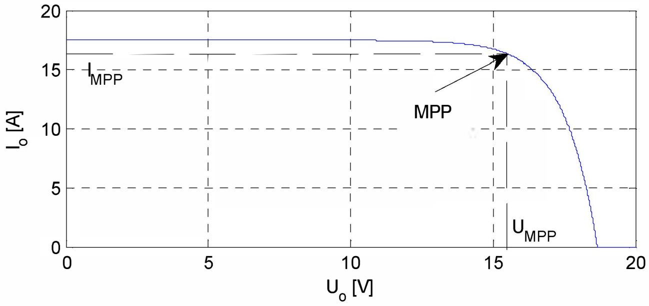


Fig. 2. Theoretical I-V characteristics of PV solar cell

## B. *PV Module and Array*

The output power of the one single PV solar cell is very small value from 0,5 to 0,6 V. In the practice, the PV solar cell is used very occasionally. Mostly, the PV modules are be used. The cells can be organized in series or in parallel. The number of the cells defines the output voltage and current of the PV solar module. The PV Module output voltage is increased by increase the number of the cells connections in series and output current is increased by increase the number of the cells connections in parallel. This procedure is shown in Fig. 3.

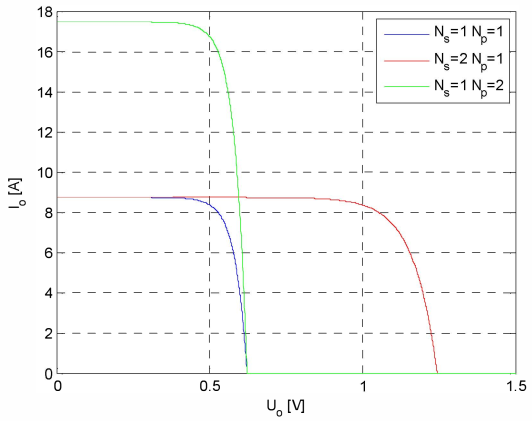


Fig. 3. Number of cells influence on output parameters.

Equations of the PV module are based on PV solar cell equations (1-4). Numbers of cells in parallel $N_p$ or in series $N_s$ are added.

$$I = N_p I_{ph} - N_p I_d \tag{5}$$

$$I_d = I_0\left(e^{\frac{qU}{nkT}} - 1\right) \tag{6}$$

$$I_0 = I_{sc}\left(\frac{T}{T_{ref}}\right)^3 e^{\frac{qE_g}{nN_s k}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)} \tag{7}$$

$$I_{ph} = \frac{\phi}{\phi_{ref}}\left(I_{scr} + \alpha_{isc}\left(T - T_{ref}\right)\right) \tag{8}$$

The influence of number of cells on equivalent circuit components is shown in Fig. 4.

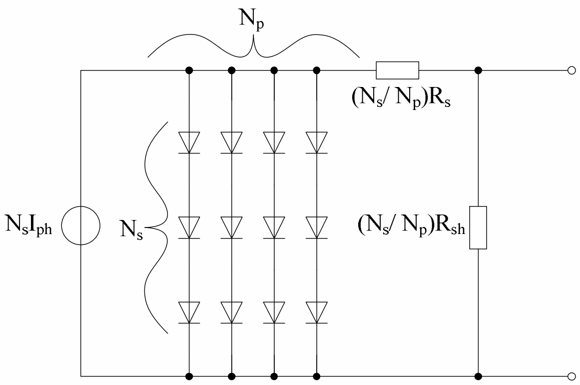


Fig. 4. Cells influence on PV solar module equivalent circuit components.

The highest output power can be achieved by a PV array that is created by the connection of two or more PV modules.

## III. SIMULATION

The proposed mathematical model of the PV solar panel was verified by the simulation. The technical specifications of the PV solar module Sharp NU-245(J5) 245Wp were used [8]. Technical details and I-V characteristics of Sharp module are shown in Fig. 5.

Solar module Sharp NU-245(J5) 245Wp

$N_s$=60
$N_p$=0
$U_{oc}$=37,5V
$I_{sc}$=8,73A
$U_{mpp}$=30,5V
$I_{mpp}$=8,04A
Noct=47,5°C
$\alpha_{isc}$=0,053

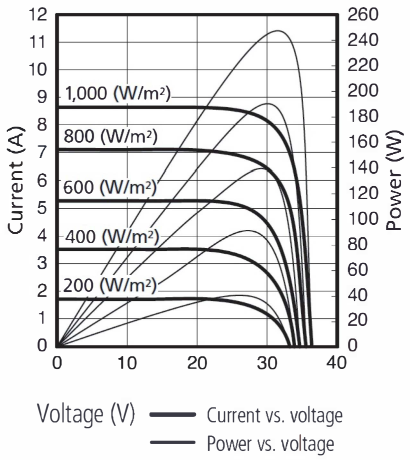


Fig. 5. Sharp NU-245(J5) 245Wp specifications and I-V characteristics.

Simulated I-V characteristic of PV module is in Fig. 6. Results were very accurate compared to I-V characteristics from datasheet in Fig. 5.

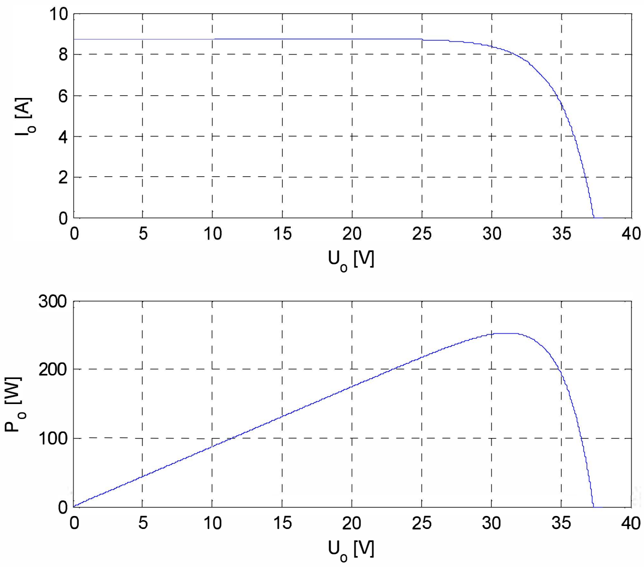


Fig. 6. Simulated PV module I-V and P-V characteristics.

The verified mathematical model has been used for other simulation, where operational conditions were changed. The solar irradiance was changed in the range from 200 to 1000 $Wm^{-2}$. The simulated waveforms of the output current and the power are in Fig. 7 and 8. With the increase of irradiation, the output current rises and, the open circuit voltage becomes partially smaller. The maximum power point was much smaller with the decrease of the solar irradiation.

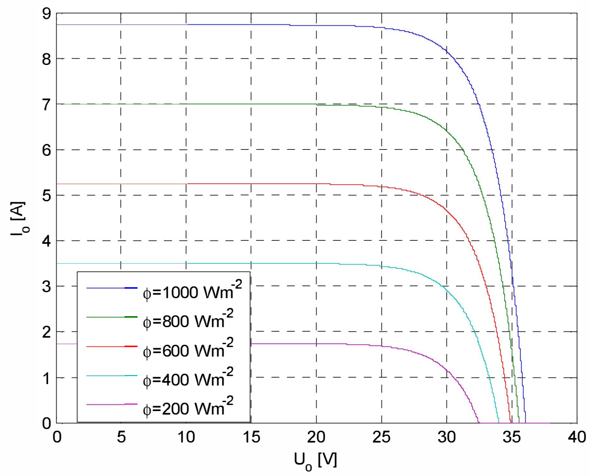


Fig. 7. Solar irradiation I-V characteristics.

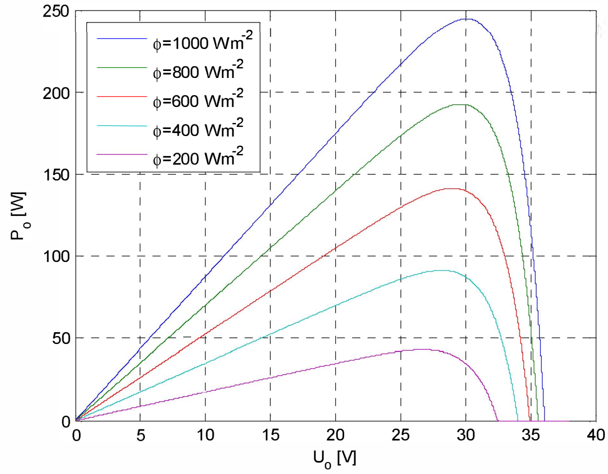


Fig. 8. Solar irradiation P-V characteristics.

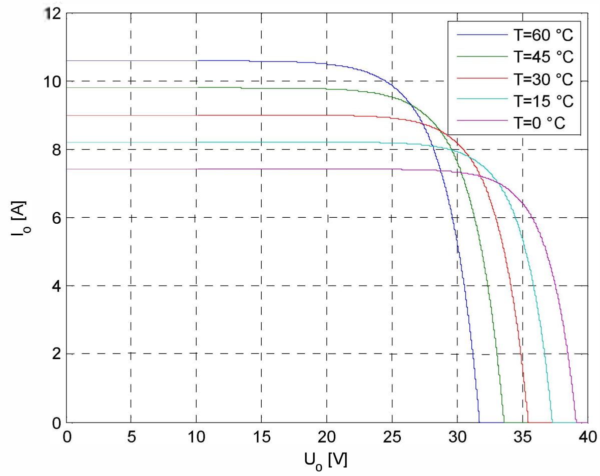


Fig. 9. Temperature I-V characteristics.

The simulation of the influence of temperature on the PV solar module has been also simulated. The temperature of the PV module was changed in the range from 0 to 60 °C. The simulated I-V characteristics showed that with the increase of the temperature, the decrease of the output current and the increase of the open circuit voltage is visible. Simulated results are shown in Fig. 9 and 10.

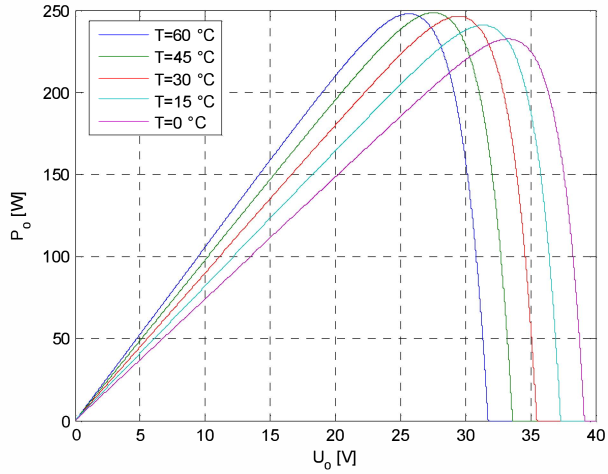


Fig. 10. Temperature P-V characteristics.

## IV. Conclusion

The usage of PV solar energy is growing in the world. The main disadvantage is the dependence on weather conditions. Mathematical model was proposed to simulate this dependence. This model of the PV solar module was based on fundamental circuit equations of PV solar cell. Simulations in Matlab were used for verification. The accuracy of the model was confirmed by comparison between the Sharp NU-245(J5) 245Wp datasheet and the simulated I-V characteristics. The influence of the temperature and the solar irradiation was investigated. The solar irradiation influence was bigger than temperature especially when we focus on the decrease of the solar irradiation. The impact on the output power was much heavier. The proposed simple model of the PV solar module is enough accurate and shall be used for development and simulation of a stand-alone power system.

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## References

[1] T.U. Townsend, "Simplified Performance Modeling of a Direct-Coupled Photovoltaic Systems," Master's Thesis, University of Wisconsin-Madison, 1989

[2] A. Luque, S. Hegedus, "Handbook of Photovoltaic Science and Engineering, 2nd Edition," Wiley, december 2010, ISBN 978-0-470-72169-8

[3] E. Mboumboue, D. Njomo, " Mathematical Modeling and Digital Simulation of PV Solar Panel using MATLAB Software," International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 9, September 2013, ISSN 2250-2459

[4] A.D. Hansen, P. Sørensen, L.H. Hansen, H. Bindner," Models for a Stand-Alone PV System," Risø National Laboratory, Roskilde, December 2000, ISBN 87-550-2774-17

[5] R. Šul, P. Fibich, M.Frívaldský, M," Analysis of PMMT Operation for Renewable (PV/FC) Energy Source," In: Advances in Electrical and Electronic Engineering (AEEE), No. 1-2, Vol. 7/2008, Slovakia, ISSN : 1336-1376, pp. 103 -105.

[6] J. Turček, M. Hraško, J. Altus, " Photovoltaics in Present Days and Their Coexistance with Power System, " Communications – Scientific letters of the University of Zilina, 2A/2011, Vol. 13. , , 2011, p.: 109. - 113., 1335-4205

[7] http://phys.org/news/2013-09-world-solar-cell-efficiency.html

[8] http://www.sharp-electronics.ie/cps/rde/xchg/ie/hs.xsl/-/html/product-details.htm?product=NUR245J5&cat=46000

[9] Y. Flicker, F.A. Himmelstoss, "Analysis of a Possible Battery Charger Topology," CSL Communications- Scientific Letters of University of Zilina, Vol 15, No. 3, 2013 pp. N/A, ISSN 1335/4205

[10] J. Perduľák, D. Kováč, I. Kováčová, M. Ocilka, A. Gladyr, D. Mamchur, I. Zachepa, T Vince, J. Molnár, " Effektive Utilization of Photovoltaic Energy Using Multiphase Boost Converter in Compare with Single Phasse Boost Converter," CSL Communications – Scientific Letters of University of Zilina, Vol. 15, No.3, 2013, pp. N/A, ISSN 1335-4205

[11] B. Dobrucký, M. Pokorný, M. Beňová, M. A. R. Abdalmula, " Modelling of Power Converters Using Z-transform," CSL Communications – Scientific Letters of University of Zilina, Vol. 15, No. 3, 2013, pp. N/A. ISSN 1335-4205

[12] P. Chlebis, A. Havel, P. Vaculik, Z. Pfof, "Modern Instruments for increasing the Efficiency of the Energy Transfer in Electric Vehicles," In 14th International Power Electronics and Motion Control Conference (EPE-PEMC), Ohrid, Macedonia, 2010, pp. 89-93, ISBN 978-1-4244-7854-

[13] L. Grman, M. Hrasko, J. Kuchta, "Single Phase PWM Rectifier in Traction Application," Journal of Electrical Engineering – Elektrotechnický časopis, Volume: 62, Issue: 4 Pages: 206-212 Published: JUL-AUG 2011

[14] J. Dudrik, J. Oetter, "High–Frequency Soft-Switching DC-DC Converters for Voltage and Current DC Power Sources," Acta Polytechnica Hungarica, ISSN: 1785-8860, Vol. 4, n. 2, 2007, pp. 29-46.