TEMPERATURE EFFECTS IN SOLAR SYSTEMS WITH INCREASED DEGREE OF EFFICIENCY

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ABSTRACT: *Influence of temperature on photovoltaic solar systems with increased degree of efficiency is analyzed in the paper. Results of the analysis indicate possibilities and ways to increase energy efficiency of renewable solar photovoltaic systems. Results of temperature dependence of power are analyzed and comparisons with experimental results and modeling results of solar panels are performed. It is shown that by regulation of temperature can be provided increase of power in the range of operating temperatures of the solar system. Results of mathematical modeling and experimental results are presented in the paper.*

1. INTRODUCTION

Improvement of the energy efficiency degree of solar systems can be achieved using the systems to track the movement of the Sun and the achievement of maximum radiation in the solar module. The intensity of solar radiation falling on the surface area of the photovoltaic (PV) module is the largest if it falls at a orthogonal angle. Although the lack of such systems is additional energy consumption for motion the module, it is still less than the gain in the total generated energy that is achieved.

A additional and further possible way of increasing the efficiency of solar systems is the using temperature control of solar panels. Control of the effects of the temperature on the solar system in order to enhance the efficiency of solar modules is achieved by influenced on the basic parameters such as short circuit current, open circuit voltage and control of output power. The application of the systems for monitoring and control of the temperature of solar modules can significantly contribute to increasing the efficiency of solar systems.

The solar cells of the same or similar characteristics are connected in series and/or parallel, encapsulated in the casing and forming photovoltaic solar modules. Each individual solar cell has an output voltage value of about (500-600) mV. The cells are connected in series to obtain the needed output voltage and in parallel to obtain the needed output power.

2. TEMPERATURE MODEL OF PHOTOVOLTAIC MODULE

In the application are the various models of solar components. In addition to the basic model it is used a model that contains a light-controlled power generator $I_{ph}(E) = K_E \cdot E$ (photo-generated current), equivalent parallel loss resistance *Rp* (equivalent shunt resistance), and the equivalent series resistance R (of order of mΩ at the output on which is created a voltage drop [1].

Using the inverse saturation current of *pn* junction I_S (dark saturation current) and temperature equivalent voltage V_T it is given the following current-voltage characteristics (I_C is the cell current and V_C is voltage on the cell):

$$I_{C1} = K_E E - I_{SC1}(T)\cdot(e^{\frac{V_c + I_{C1}\cdot R_S}{\eta_1\cdot V_T}} - 1) - \frac{V_c + I_{C1}\cdot R_s}{R_p},\ V_T = kT/q. \quad (1)$$

where T is temperature, η_1 is the correction factor and k is Boltzmann constant ($k = 8{,}62\cdot 10^{-5}$eV/K.).

By modifying and partially simplifying it follows that the dependence of cell current I_{C2} on cell voltage V_C is given as:

$$I_{C2} = K_E E - I_{SC1}(T)\cdot(e^{\frac{V_C + I_{C2}\cdot R_S}{\eta_1\cdot V_T}} - 1) - I_{SC2}(T)\cdot(e^{\frac{V_C + I_{C2}\cdot R_S}{\eta_2\cdot V_T}} - 1) - \frac{V_C + I_{C2}\cdot R_s}{R_p}. \quad (2)$$

In the open circuit, when the current is equal zero, then the operating cell voltage is given by $V_C = V_{OC}$:

$$0 = K_E E - I_{SC1}(T)\cdot(e^{\frac{V_{OC}}{N_s\eta_1\cdot V_T}} - 1) - \frac{V_{OC}}{R_p} \quad (3)$$

The expanded form of the power dependence on the temperature is given in the form [1]:

$$P_C(T) = V_C\cdot\left\{\left[I_C + \alpha_{ph}(T - T_o)\right]\cdot\frac{\lambda}{100} - I_{ST}\cdot e^{-\frac{E_g(0)}{kT}}(e^{\frac{V_C}{\eta V_T}} - 1)\right\} \quad (4)$$

where the PV module illumination is λ =1000W/m^2.

One of approaches for obtaining the optimum value of the correction coefficient is conditioned by obtaining maximal power. At the point of maximum power (MPP) the current is I_{mpp} and voltage is given by V_{mpp}:

$$I_{mpp} = K_E E - I_{SC1}(T)\cdot(e^{\frac{V_{mpp} + I_{mpp}\cdot R_S}{N_s\eta_1\cdot V_T}} - 1) - \frac{V_{mpp} + I_{mpp}R_S}{R_p}. \quad (5)$$

At the maximum power point is [2] :

$$\left[\frac{\mathrm{d}(V_C I_C)}{\mathrm{d}V_C}\right]_{mp} = \left[V_C\frac{\mathrm{d}I_C}{\mathrm{d}V_C} + I_c\right]_{mp} = 0 \quad (6)$$

The power of the solar cell as a function of the voltage of cells at a temperature T as a parameter is shown in Figure 1. The obtained given resulting diagrams are created with the following values: E=1000 Wm^{-2} (full line - red color), E_1=750 Wm^{-2} (dotted line - blue color) and E_2=500 Wm^{-2} (dashed line - pink color).

For comparison and verification of obtained results it was done monitoring and recording of the solar module by the thermovision imaging camera. It was monitored, observed and noticed the temperature distribution in different parts of the photovoltaic module. It can be seen that the module temperature is not equal in every point, and that the temperatures can vary for (3-4) ^{0}C going from the edges to the centre of the module. In Fig. 2 it is shows the thermal recording of the surface of the photovoltaic module of type Solaris H250 obtained by thermovision imaging camera of type Fluke Ti100.

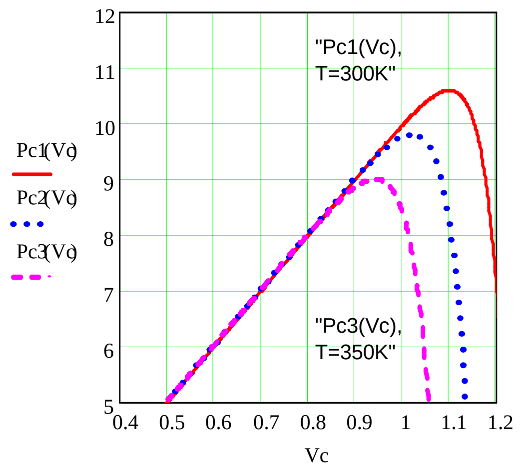

Figure 1: Power of solar cell as a function of voltage of cell at temperature T as a parameter.

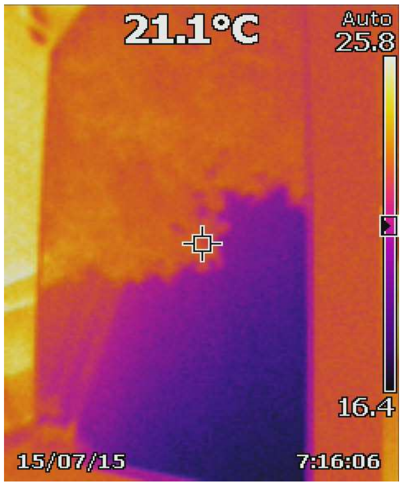

Figure 2: Thermovision record of the surface of the photovoltaic module.

3. TEMPERATURE MATLAB/SIMULINK MODEL OF PHOTOVOLTAIC MODULE

For the purposes of modeling of the photovoltaic modules in the real operating conditions, where is changing the ambient temperature and the intensity of the radiation, the model of solar cell and thus model of the photovoltaic module without an analysis of the effecst of temperature and radiation intensity is not sufficiently accurate. Such models are based on the information that manufacturers provide at standard test conditions, which are often very different from the variable conditions in which the system works.

As in typical solar cells with power of 2W the voltage is approximately 0.5 V then it is used a series of parallel-serial connected cells. When the number of serially connected PV cells is N_s then the current-voltage characteristic is given by [1,3]:

$$I_C = K_E E - I_{SC1}(T)\cdot(e^{\frac{V_C + I_C\cdot R_s}{N_s \eta_1 \cdot V_T}} - 1) - \frac{V_C + I_C R_s}{R_p}. \qquad (7)$$

In the basic simplified model with N_p parallel connected cells and N_s serially connected cells it is obtained [2]:

$$I_C = N_p I_{ph} - N_p I_{SC}(T)\cdot(e^{\frac{V_C}{N_s \eta_1 \cdot V_T}} - 1). \qquad (8)$$

The improvement can be obtained using of the model of "behavior" of the photovoltaic module, which takes into account the effects of temperature and radiation intensity on the voltage and current of photovoltaic module:

$$T_C - T_a = G\cdot\frac{N_{OCT} - T_o}{E_n} \qquad (9)$$

where G is radiation intensity given in W/m^2, T_C is temperature of the solar cell, T_a is temperature of the ambient. Value N_{OCT} depends on the type of module. During testing a large number of modules is obtained value for NOCT = 48^{0}C [2].

The cell temperature inside the module is then calculated using a measured back-surface temperature and a predetermined temperature difference between the back surface and the cell [3,4]:

$$T_C = T_m + \frac{E}{E_o} \cdot \Delta T \ , \tag{10}$$

where T_C is cell temperature inside module (in °C), T_m is measured back-surface module temperature (in °C), E_o is reference solar irradiance on module (1000 W/m2), ΔT is temperature difference between the cell and the module back-surface at an irradiance level of 1000 W/m^2. This temperature difference is typically 2 to 3 °C for flat-plate modules in an open-rack mount. Computation of short circiut current depending on impinging radiation G_a and temperature of cell T_C :

$$I_{SC} = C_1 \cdot G + K_1 \cdot (T_C - T_o) \tag{11}$$

Short circuit current of the module, depending on the intensity of radiation and temperature is given by the following expression:

$$I_{SCM} = \frac{I_{SCMr}}{E_o} \cdot G + \left(\frac{\mathrm{d}I_{SCM}}{\mathrm{d}T} \right) \cdot (T_C - T_r) \tag{12}$$

and the open circuit voltage is given by the approximate relation:

$$V_{OCM} \approx V_{OCMr} + \left(\frac{\partial V_{ocM}}{\partial T} \right)_G \cdot (T_C - T_r) + V_T \cdot \ln \frac{I_{SCM}}{I_{SCMr}} \tag{13}$$

Computation of open circuit voltage depending on impinging radiation G_a and temeprature of cell T_C:

$$V_{OC} \approx V_{OCo} + C_{3G} \cdot (T_C - T_o) - K_2^{-1} \exp \left(\frac{G_a - G_{ao}}{K_3} \right) \tag{14}$$

where K_1, K_2 and K_3 are the constants of proportionality for different materials.
The mathematical basis of the model of PV module to search for point of maximum power is given by following expresions:

$$I_{mM} = I_{mMr} \cdot \frac{G}{G_r} + \left(\frac{\mathrm{d}I_{SCM}}{\mathrm{d}T} \right) \cdot (T_C - T_r) \tag{15}$$

$$V_{mM} = N_s \cdot V_T \cdot \ln \left(1 + \frac{I_{SCM} - \mathrm{I}_{mM}}{I_{scM}} \cdot (e^{\frac{V_{OCM}}{N_s \cdot V_T}} - 1) \right) - I_{mM} \cdot R_{sM} \tag{16}$$

On the basis of given analysis, the new model of the photovoltaic module H250 in the MATLAB/Simulink package is proposed where were taken into account the effects of radiation intensity and temperature on the output values of the photovoltaic module (Figure 3). It were used the basic data provided by the manufacturer of the module at short-circuit current (I_{SC}=1,56A, V_{OC}=21,5V, P_{max}=25W). Module photo-current is $I_{ph}(E) = [K_E \cdot E + K_i (T - 298)] \cdot \lambda / 1000$ where the short-circuit current temperature coefficient is $K_i = 0.0017$A/°C [5,6].
Due to the current of photogeneration which is dependent on the intensity of illumination and also temperature dependent it is obtained a more complete model of the temperature dependence in the form:

$$I_{C2} = [K_E E + K_i (T - T_o)] - I_{SC1}(T) \cdot (e^{\frac{V_C + I_{C2} \cdot R_s}{\eta_1 \cdot V_T}} - 1) - \frac{V_c + I_{C2} \cdot R_s}{R_p}$$
$$- I_{SC2}(T) \cdot (e^{\frac{V_C + I_{C2} \cdot R_s}{\eta_2 \cdot V_T}} - 1). \tag{17}$$

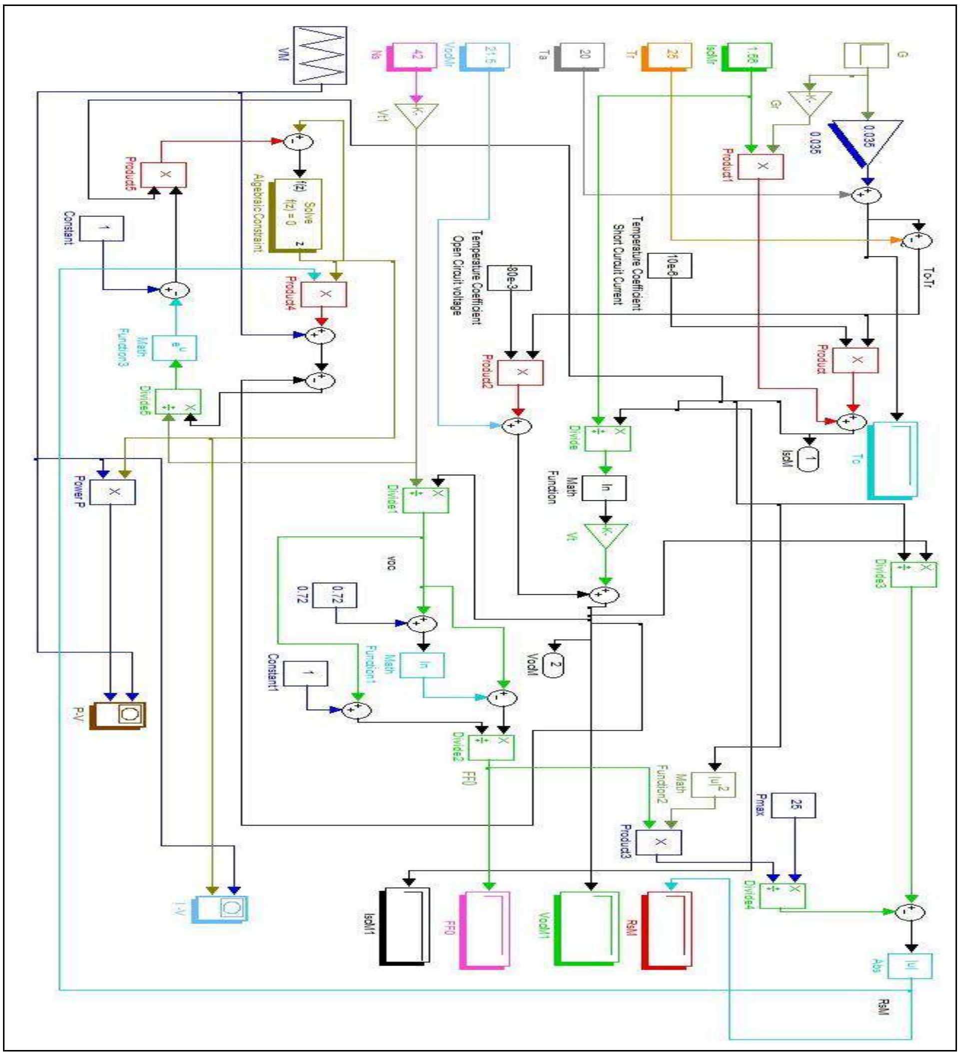

Figure 3: New model of photovoltaic module H250 in Matlab/Simulinek.

Figure 4 shows the results of modeling for photovoltaic module H250 of power 25W.

3. CONCLUSION

In the paper are analyzed the effects of temperature on the current, voltage and power of the photovoltaic module and is proposed a new temperature model of the photovoltaic module in the software package Matlab/Simulink. The simulation results were compared with the measured values. It is shown that with increasing temperature of photomodule can significantly to be reduced its efficiency. The dominant influence of temperature is on the open circuit voltage, whit which that impact is transferred to the output generated power of photovoltaic module. To confirm the obtained results it was performed temperature recording of the module by thermovision imaging camera

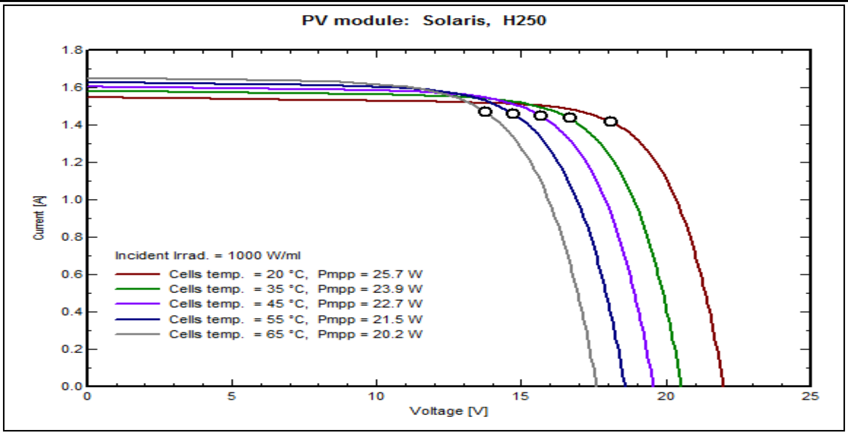

Figure 4: Results of modeling of current-voltage characteristic.

In order to increase the efficiency of solar systems it is desirable that in the solar systems with increased energy efficiency monitor and control the temperature of solar modules. To achieve maximum efficiency, ie. to achieve an optimum between the supplementary obtained energy and the energy used for control of temperature of module (cooling module), it is necessary to construct an adequate system for measuring adequate temperatures and for required cooling of the solar modules and the entire system. Such a system should measure and monitor the following temperatures: ambient temperature, the temperature of the cells on the surface of the module, the back-surface module temperature, the temperature in the center of the module and the temperature in the periphery of the module. It also should have the adequate structure of the system for cooling modules with adequate fluid for cooling. Based on the above mentioned temperature monitoring the system would adequately control the system for cooling and the fluid for cooling. Depending on the specific concrete design and implementation of such a system it is possible to achieve a significant increase in the energy efficiency of solar systems.

4. REFERENCES

[1] F. Softić, Z. Bundalo, A. Stjepanović: Povećanje energetske efikasnosti solarnih izvora energije korekcijom temperature, *9th International Scientific Conference RIM2013*, October, 2013..

[2] H. L. Tsai, C. S. Tu, Y. J. Su: Development of generalized photovoltaic model using MATLAB/SIMULINK, Proceedings of the World Congress on Engineering and Computer Science WCECS2008, San Francisco, USA, October, 2008.

[3] D. L. King, W. E. Boyson, J. A. Kratochvil: Photovoltaic array performance model, Sandia National Laboratories Albuquerque, New Mexico, November, 2003.

[4] C. Y. Huang, H. C. Sunga, K. L. Yen: Experimental study of photovoltaic/thermal (PV/T) hybrid system, Int. Journal of Smart Grid and Clean Energy, 2012.

[5] P. Sudeepika, G. M. G. Khan: Analysis of mathematical model of PV cell module in Matlab/Simulink environment, Proceedings of International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 3, Issue 3, March, 2014.

[6] M. M. Adeli, F. Sobhnamayan, S. Farahat, M. A. Alavi, F. Sarhaddi: Experimental performance evaluation of a photovoltaic thermal (PV/T) air collector and its optimization, Journal of Mechanical Engineering, 2012.