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Modeling of photovoltaic power supply source

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ABSTRACT

In the following article a development of photovoltaic power plant simulation model in Matlab is presented. Based on this model, the behavior of existing photovoltaic power plant is simulated. The simulation results are compared with measured data from real photovoltaic power plant.

Keywords: PV module, single-diode model, simulation model, verification, Matlab.

INTRODUCTION

One of the most important points concerning the energy policy worldwide is the stable development and use of non-traditional and renewable energy sources to receive electrical energy. Such an inexhaustible and free energy source is the sun. The sun energy does not render harmful influence to the environment and does not cause ecological problems in the process of its transformation to electrical energy (like prevailing un-renewable energy sources like carbon fuels). One of the ways to transform directly the sun energy into electrical is by using photoelectrical systems, built of photo elements – photovoltaic (PV) cells [1].

For effective use of sun energy with PV systems reliable and precise enough models of PV modules are needed to achieve their *I-V* and *P-V* characteristics and to determine the maximum power point (MPP) [1 - 3]. This gives the opportunity to predict the behavior of designed PV installations in different values of sun radiation, temperature and loading. When modeling, equivalent electrical schemes are used – models of PV modules with a single diode and with two diodes [1, 3 - 5]. The two-diode model gives better results when sun radiation is low (low voltages), but it has more parameters for estimation with long and complex iterative procedure [3 - 5].

A single-diode model was used in this article. The equivalent electrical scheme of the most often used single-diode model of PV module is shown at Fig. 1 [1 - 3, 6, 7]. The photo element is shown as photo current generator *Iph* when it is irradiated with light; in the first approximation its electrical scheme can be modeled with a current generator and a diode, connected in parallel. Two resistors are included in the scheme – *Rs* is a serial

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resistor and it shows the resistance of every single PV cell and contact resistances; *Rsh* is a shunt resistor and it models all leakage currents as a result of structural and manufacturing diode defects, heat diffusion and carriers' recombination, etc.

EXPERIMENTAL

Volt-amper characteristics of the module, based on the scheme on Fig. 1, can be described with the following basic equation:

$$I = I_{ph} - I_D - I_{sh} \tag{1}$$

where

$$I_D = I_0 (\exp(\frac{(V + R_s)q}{AkT}) - 1);$$

$$I_{sh} = \frac{V + IR_s}{R_{sh}}; \quad V_t = \frac{N_s AkT}{q}$$

and I_{ph} - generated from the sun radiation current, I_0 - diode dark saturation current, V_t - thermal voltage of the PV array, k - Boltsman constant (k = 1,38.10^{-23} J K^{-1}), q - electron charge (q = 1,6.10^{-19} C), A - diode ideality factor, Ns - number of PV cells, connected in series, T - module temperature [K], I and V - module output current and voltage, respectively.

The generated from the module photocurrent depends linearly on the sun radiation and module temperature as it is shown in the equation below [6]:

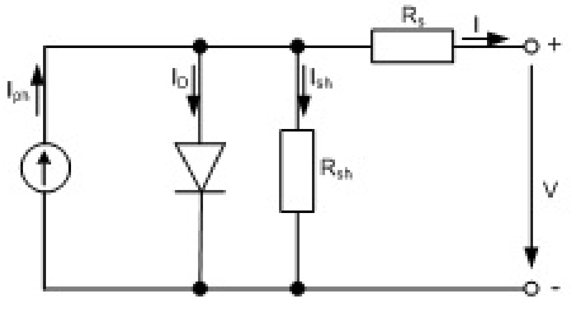

Fig. 1. Equivalent electrical scheme of photovoltaic module.

$$I_{pv} = (I_{pv,n} + K_I \Delta_T) \frac{G}{G_n} \tag{2}$$

where

$I_{pv,n}$ - generated from the module photocurrent in standard conditions (temperature 25°C and sun insolation 1000 W m^{-2});

K_I - short current cell temperature coefficient;

$\Delta_T = T - T_n$ - difference between work and standard temperature (T_n = *25°C*);

G - sun insolation (W m^{-2});

G_n - nominal sun insolation (G_n=*1000 W m*$^{-2}$).

Module data sheet gives information about the nominal photocurrent, which is the maximal current value $I_{sc,n}$ through a load or device. When single diode model is used, the approximation $I_{pv} \approx I_{sc}$ is made, because the value of series resistance R_s is dozens of times smaller than shunt resistance R_{sh} [8]. Then equation (2) becomes as follows:

$$I_{sc} = (I_{sc,n} + K_I \Delta_T) \frac{G}{G_n} \tag{3}$$

Two equations are used for dark saturation current value calculation – first the nominal saturation current $I_{0,n}$ is calculated using equation (4) and then the dark saturation current I_0 by equation (5):

$$I_{0,n} = \frac{I_{sc,n}}{\exp(\frac{Voc,n}{AkTN_s}) - 1} \tag{4}$$

$$I_0 = I_{0,n} (\frac{T_n}{T})^3 \exp(\frac{qEg}{Ak} (\frac{1}{T_n} - \frac{1}{T})) \tag{5}$$

where $V_{o,n}$ - module open circuit voltage from datasheet;

E_g - bandgap energy of the semiconductor

($E_g \approx 1.12eV$ for polycrystalline Si at 25°C).

Equation (6) is used to calculate the output module power:

$$P = (P_{\max} + \mu(T_m - T_n)\ \frac{G}{G_n} \qquad (6)$$

where

$T_m = T_{air} + \frac{(NOCT - 20)}{800})$ - cell temperature;

NOCT – normal work cell temperature (*NOCT = 49°C*);

T_{air} - air temperature;

μ - power temperature coefficient (μ *= -0.0048 W °C*$^{-1}$).

Based on equations (3) to (6), a simulation model of the photovoltaic module was developed using Matlab/Simulink. Input data for the model are module temperature, air temperature, sun insolation, diode ideality factor and some module datasheet values (open circuit voltage, short circuit current, number of series connected cells). By expert opinion diode ideality factor is suggested to be set at 1.3.

The simulation model is shown in Fig. 2. All model subsystems are shown as follows: short current calculation subsystem (Fig. 3), nominal saturation current determination subsystem (Fig. 4), dark saturation current subsystem (Fig. 5) and output module power subsystem (Fig. 6).

Model output power results were compared and verified with real measured data from photovoltaic power plant in village Blato, Dupnitsa,

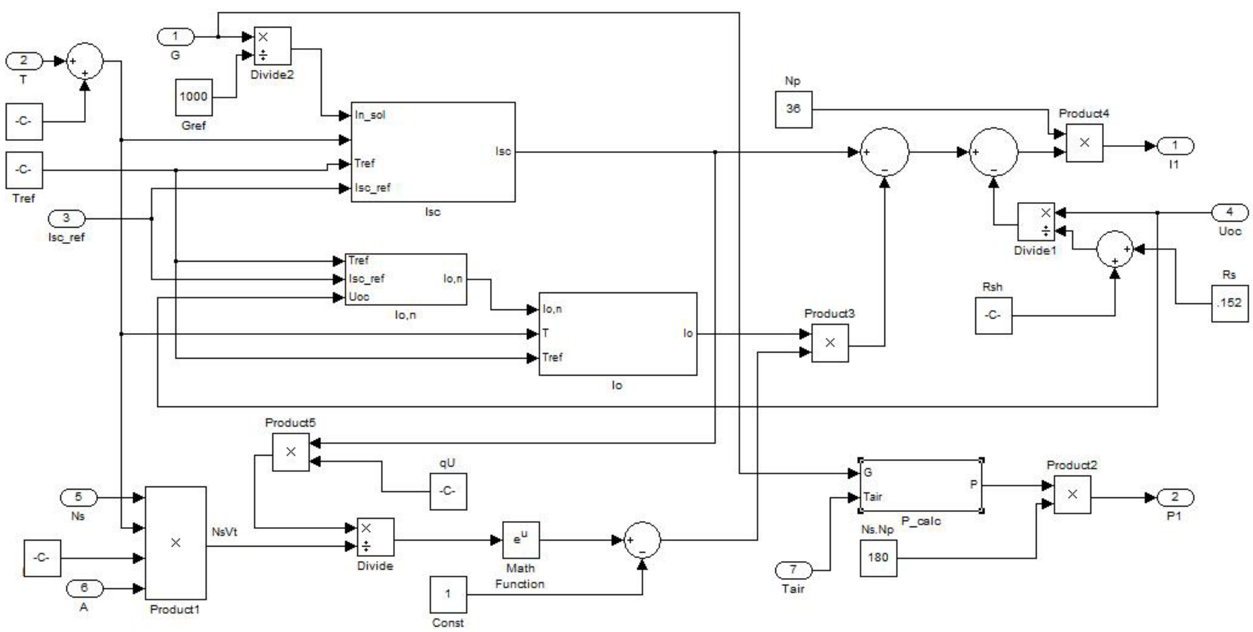

Fig. 2. Common view of photovoltaic module simulation model.

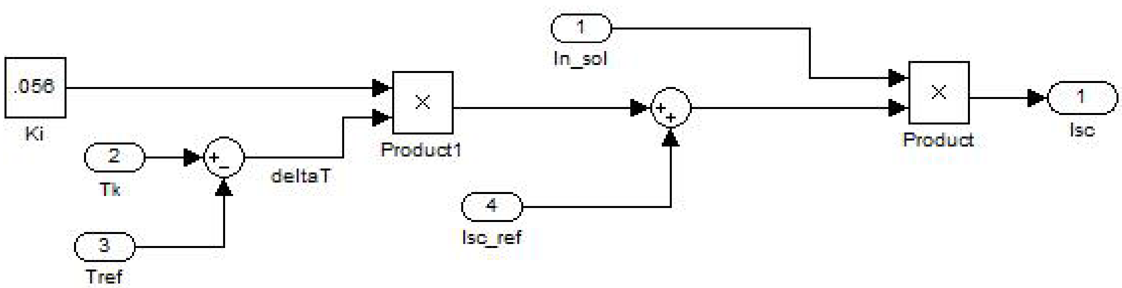

Fig. 3. Module short current determination subsystem.

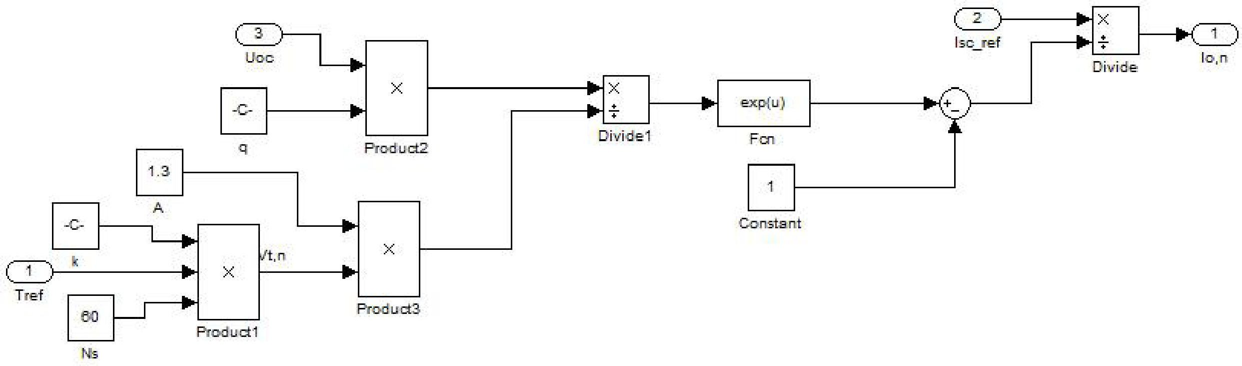

Fig. 4. Module dark saturation current calculation subsystem.

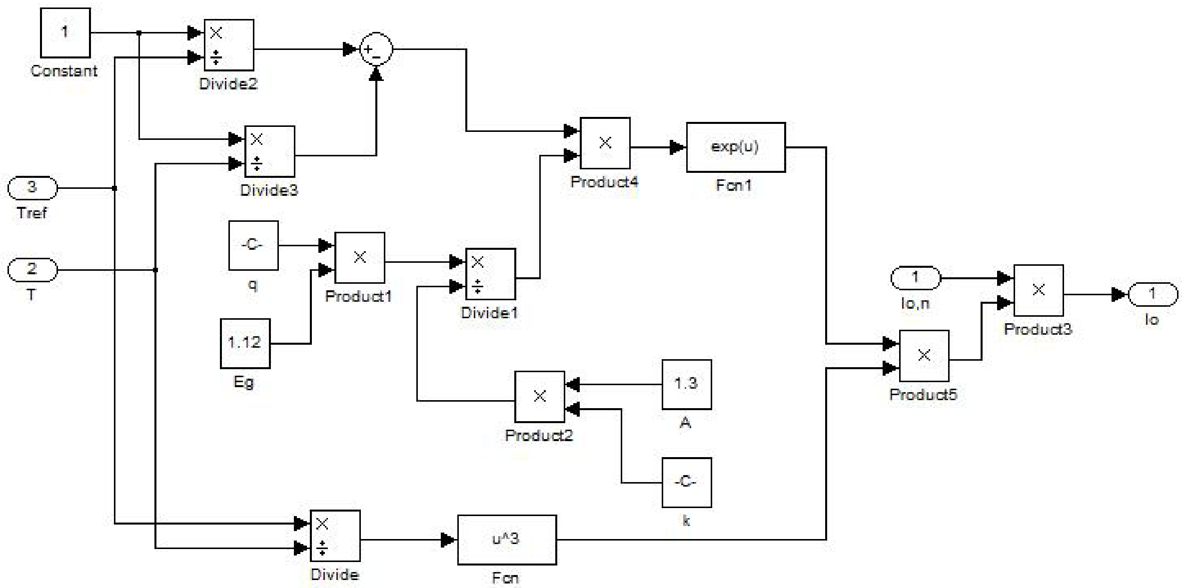

Fig. 5. Module dark saturation current determination subsystem.

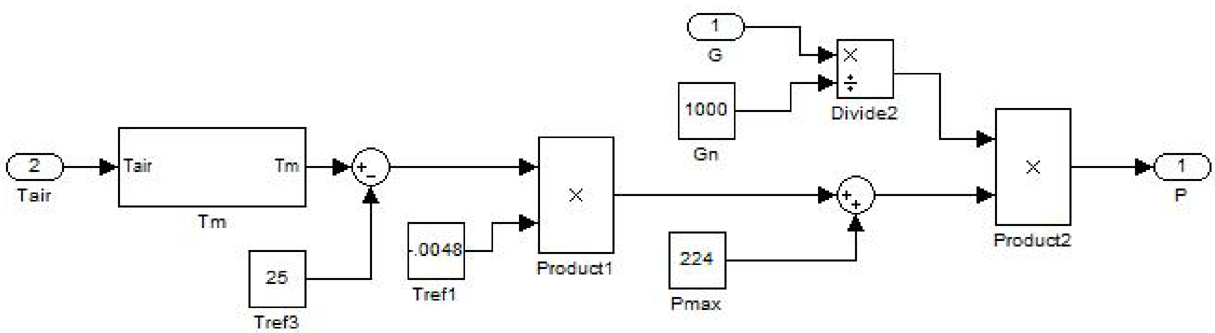

Fig. 6. Module output power calculation subsystem.

Kyustendil district. Measurements were made at 11.12.2016 and 16.09.2017. The power plant consists of 180 photovoltaic modules Hyunday (array of 36 parallel and 5 series strings) and 360 photovoltaic modules CSUN (array of 72 parallel and 5 series strings). Total output power of the plant is 180 kW. The specific place to build the plant and the feature of the area (pine forest

Table 1. Modules datasheet and calculated resistances.

Module	Voc [V]	Isc [A]	Pmax [W]	Ki [mA/K]	Ns [-]	Rs [Ω]	Rsh [Ω]
Hyunday	37,1	8,1	224	5,6	60	0,152	211,65
CSUN	36,8	8,59	240	4,5	60	0,106	154,29

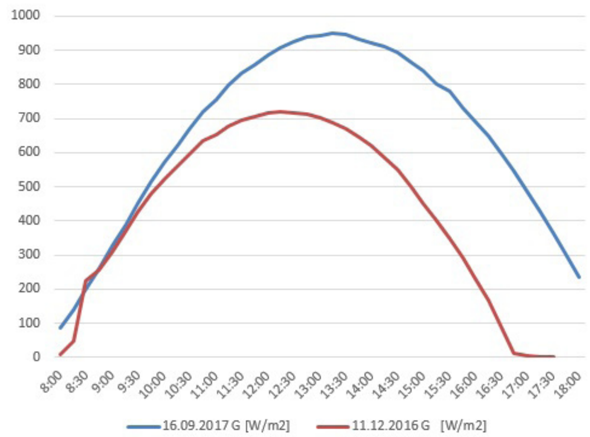

Fig. 7. Sun insulation curves for both measurement days.

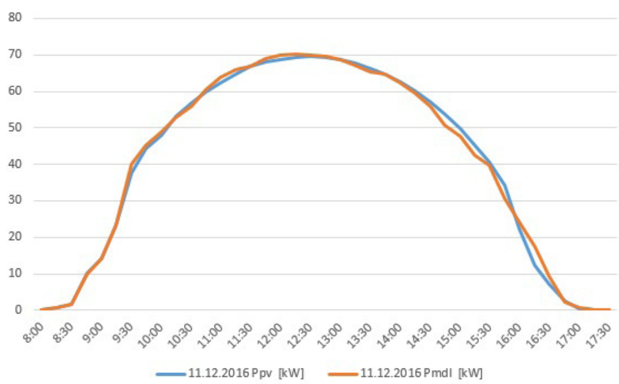

Fig. 8. Simulated (Pmdl) and measured (Ppv) module output power for 11.12.2016.

40 m right of the power plant) does not cause any shading, so there are no bypass diodes in the model. An algorithm was used for series and shunt resistances determination for both PV module types [9]; the results and modules` datasheet values are shown in Table 1.

The sun insulation for both measurement days is shown on Fig. 7; the comparison between measured and simulated output power is shown in Fig. 8 and Fig. 9, for 11.12.2016 and 16.09.2017, respectively.

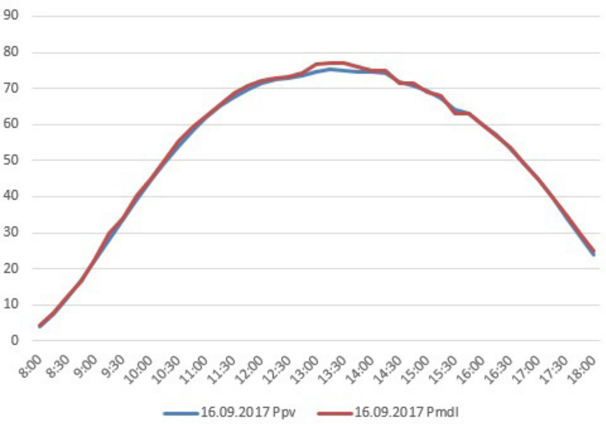

Fig. 9. Simulated (Pmdl) and measured (Ppv) module output power for 16.09.2017.

CONCLUSIONS

The development of a simulation model of photovoltaic power plant using Matlab is presented. The model was verified with existing photovoltaic plant. This model gives opportunities for future researches and also for energy yield (efficiency) and output power prediction for already built photovoltaic sources with different type PV modules.

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