NUMERICAL MODELLING OF A PV CONCENTRATOR SYSTEM BASED ON A DUAL-DIODE CELL MODEL TAKING INTO ACCOUNT COOLING BY A HEAT SINK

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ABSTRACT: The first part is described PV concentrator system. This system generates electricity and heat from the incoming solar radiation. The second part is double exponential model of the solar cell with temperature dependence, based on a dual-diode model of the solar cell; the model is implemented in theMatlab/Simulink software package. An equivalent circuit of the model includes a photocurrent source, two diodes, and a series and parallel resistance. The effect of temperature on each element is taken into account. The third part is made implement in Simscape and PDEtool. It is considered the heat transfer between the parts of the installation. Fourth part is presented combined model.

Keywords: PV System,Concentrators, Thermal Performance

1 INTRODUCTION

The factor limiting the widespread usage of solar energy is the cost of these energy systems. Cost reduction of photovoltaic power generation systems is possible by cost decreasing of photovoltaic modules (PV) or increasing of efficiency, the same being valid also for the solar cells themselves.

An effective method of increasing the efficiency is the application of a concentrator. Concentrated systems use mirrors or lenses to concentrate a large area of incident sunlight onto a small area. Systems operate most efficiently in concentrated sunlight, as long as the solar cell is kept cool through use of heat sinks. The design of photovoltaic concentrators introduces a very specific optical design problem, with features that makes it different from any other optical design. It has to be efficient, suitable for mass production, capable of high concentration, insensitive to manufacturing and mounting inaccuracies, and capable of providing uniform illumination of the cell. For example one can use a concentrator like a parabolic dish concentrator. The parabolic mirror concentrators focus the sunlight to a single point, where the solar cell has to be located.

Concentrator solar power increases the energy flux density coming to the surface of the PV module, thereby increasing efficiency and electricity generation of the module. In addition to increasing the generation of electricity, the silicon module is heated; it is resulting an efficiency loss and possibly in delamination effects of the module or deterioration of ohmic contacts of the PV cell, if heated to a temperature above 120 ˚C. Therefore, for a reliable system measures for cooling the system of the silicon module have to implement. One can use a passive or an active cooling system. For an active system liquid cooling is a possibility. The heat transferred by the coolant can be used for further purposes (e.g. for heating water for further usage). So one gets a combined system that can allow both to produce electricity and heat.

Application of concentration and a tracker improves a solar system effectively, because one receives a more uniform generation of electricity from sunrise to sunset.

Numerical modelling of a PV concentrator system is designed with the help of MATLAB.

MATLAB is a mathematical package of great potential. MATLAB works with matrix data and enables to create a custom calculated program. MATLAB is an operating environment and a programming language. Simulink is a standalone toolbox in MATLAB. Simulink can be used together with the MATLAB and other toolboxes, as well as individually. Simulink implements the principle of visual programming: the user uses the library to construct the model, configures the solver and calculation step. MATLAB/Simulink allows creation of blocks, programs and libraries. MATLAB and Simulink are graphical displays of simulation results.

2 DESCRIPTION OF THE PV CONCENTRATOR SYSTEM A HEAT SINK

In Russia it is not urgently necessary to use an alternative energy system everywhere, because Russia has a large amount of traditional energy resources: oil, coal, gas, hydro and nuclear resources. Also, the infrastructure of energy department is well developed.

Therefore the authors see a prospect for alternative energy usage for small villages and private houses in distant and remote terrain (for example, villages in a taiga, houses of forestry officers in national parks).

The installation is a hybrid system which converts solar energy into electricity and heat. The sunlight falling on the silicon photovoltaic modules is converted into electricity. Heat production is carried out by cooling of photovoltaic modules.

Low Concentrator is added to the system to increase energy production. The concentrator is represented as a parabolic reflector.

Coming radiation flux falls on the concentrator and is reflected on the photovoltaic module. The plane of the solar module is perpendicularly oriented to the flow of the reflected radiation. Direct light is not incident on a photovoltaic module.

For work in the cold season it is possible to use the additional cover (which is transparent to the direct sun rays and impervious to the reflected radiation within the system), which will protect the concentrator and photovoltaic modules from precipitation and reduce the outflow of heat into the environment.

To increase the power it can be used tracking system, such as the system developed earlier [1].

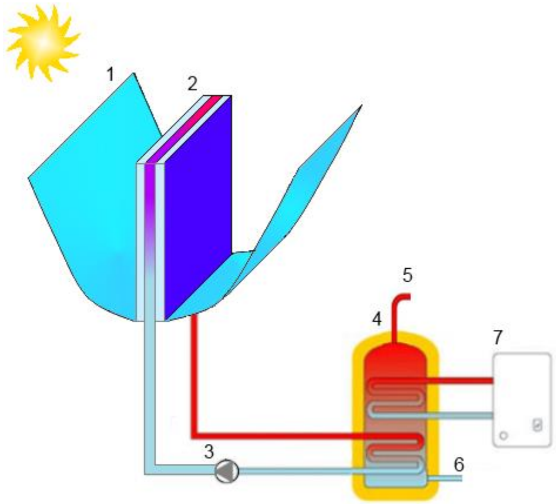

Figure 1:PV concentrator system with a heat sink: 1 – Concentrator; 2 – PV module; 3 – Pump; 4 – Tank; 5 – Output;6 – Input; 7 – Boiler.

2.1 Photovoltaic modules

Photovoltaic module consists of two panels arranged in parallel to each other. Between the two photovoltaic modules is cooled liquid. Flowing between the photovoltaic modules the liquid is cooling them and heating itself.

2.2 The concentrator

The concentrator consists of two parabolic reflecting surfaces. The concentrator can be made of any material that approaches the economic and operational tasks, such as metal or plastic with a reflective coating.

The mathematical model takes into account the influence of the concentrator as a multiplier for solar radiation.

2.3 The cooling system

The cooling system is a typical thermal solar system.

As a cooling liquid can be presented of any coolant with a high value of specific heat capacity.

It is possible to use two methods of fluid flow:

1. Water enters from top of the system and is drained down by a pump and gravity.

2. Water is pumped from the bottom and is moved upward by the pump (in case of a small thickness of the channels also by expanding when heated)

By the type of channels:

1. The coil (one or more)

2. Many small direct channels arranged vertically / along the PV

In the top heating is less due to the lower concentration of light in a border zone with the environment.

3 DOUBLE-EXPONENTIAL MODEL OF PV

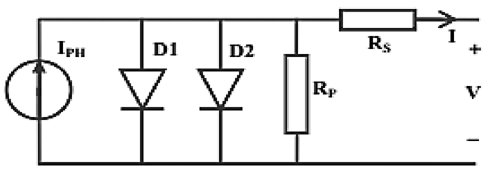

Figure 2: Equivalent circuit for a double-exponential model

The circuit (fig.2) consists of a current source, diodes, and a serial and a parallel resistance. The current source simulates the occurrence of the photocurrent in a cell under illumination. The first diode is connected in forward direction in parallel to the current source. The saturation current can flow through the diode when affected by the bias due to excessive concentrations of electrons in the n- region of the cell and the concentration of holes in its p-region. The parallel photovoltaic cell resistance arises due to the reverse resistance of the n-p-transition and various conductive films or contamination on the cell surface or local small shunts. It is also connected in parallel to the current source. Series resistance represents contacts (mainly semiconductor-metal contact resistance) and the resistance of the semiconductor material from which the solar cell is manufactured (the resistance of each of the p- and n-regions of the cell) [2].

The single diode equation assumes a constant value for the quality factor N. In actual practice, the quality factor is a function of the voltage across the device. At high voltage, when the recombination in the device is dominating in the surface layer and bulk regions, the quality factor is close to one. However, at lower voltages, recombination in the junction dominates and the ideality factor approaches two. The junction recombination is modeled by adding the second diode in parallel to the first and setting the quality factor typically to two [2, 3].

The mathematical equation of the model is [2, 3]:

$$I = I_{ph} - I_S\left(\exp\left(\frac{V + I\cdot R_S}{N\cdot V_T}\right) - 1\right) - \qquad (1)$$
$$- I_{S2}\left(\exp\left(\frac{V + I\cdot R_S}{N_2\cdot V_T}\right) - 1\right) - \frac{V + I\cdot R_S}{R_P}$$

where

Iph is the solar-induced current,

*Is*is the saturation current of the first diode,

I_{S2} is the saturation current of the second diode,

$V_T$is the thermal voltage,

N is the quality factor (diode emission coefficient) of the first diode,

N2 is the quality factor (diode emission coefficient) of the second diode,

Rs and Rp are the serial and parallel resistances of the cell,

V is the voltage across the solar cell electrical ports.

The parameters in the double-exponential model depend on the solar radiance and temperature of the cell.

The Simulink-model (fig. 3) implements equation (1) and builds the output V-I and V-P characteristics (fig.4). Model features:

The voltage is set by uniformly time-varying signals. The current values are calculated for a definite voltage value at each step. The calculation stops when the current value reaches 0. This function is performed by the block «Stop Simulation». «Stop Simulation» compares the current value with 0 at each calculation step. When reaching the equality, the simulation ends.

The data is stored in the pv.mat file. The data is stored in an array of four lines: the first line is the simulation time, the second line is voltage, the third line is current, and the fourth line is power. The stored data can be loaded in the Workspace for later processing.

The temperature effect is taken into account when modeling the photocurrent and diode saturation current. Possible differences in the parameters of the diodes in the equivalent circuit are taken into account, as they have a significant impact on Voc and power output.

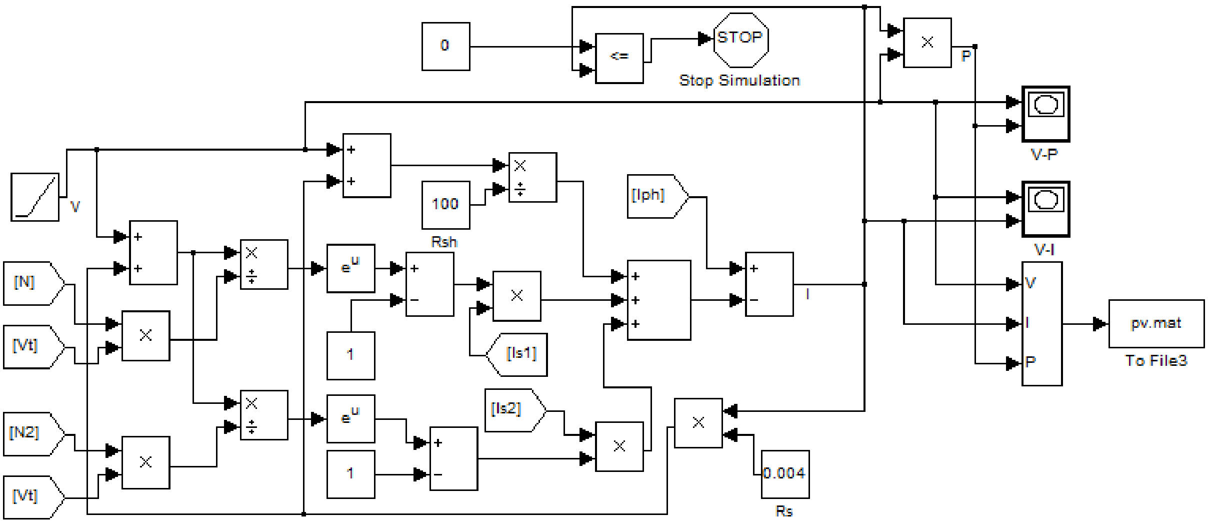

Figure 3: Simulink-model

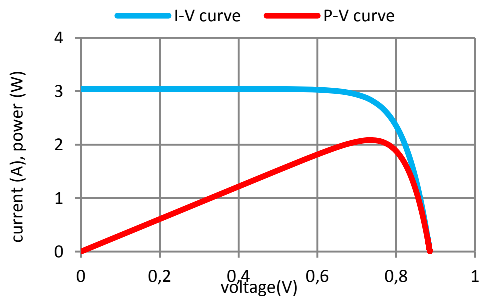

Figure 4:I-V and P-V curves

4 THE THERMAL MODEL

The thermal model is based on the heat transfer from hot to cold bodies. The model takes into account the heat flow from the heat protective glass flow and heat energy directly to the photovoltaic cells.

For each model the same thermal characteristics of substances were used.

4.1 The Simscape model

Simscape model is presented for a single PV module, as it is assumed that each element makes the same contribution.

The model is based on the transfer of heat from one layer to another on the basis of heat transfer. 3 blocks use for each layer: 2 blocks set heat transfer between the layers and 1 block given mass of layer. PV layer has a direct heating radiation from the sun and heat from the previous layers.

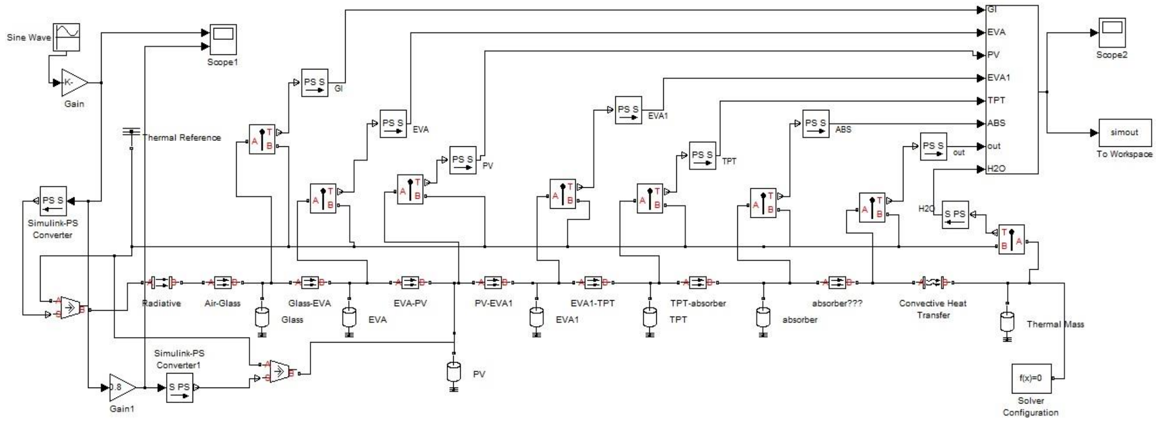

Figure 5: Simscape model

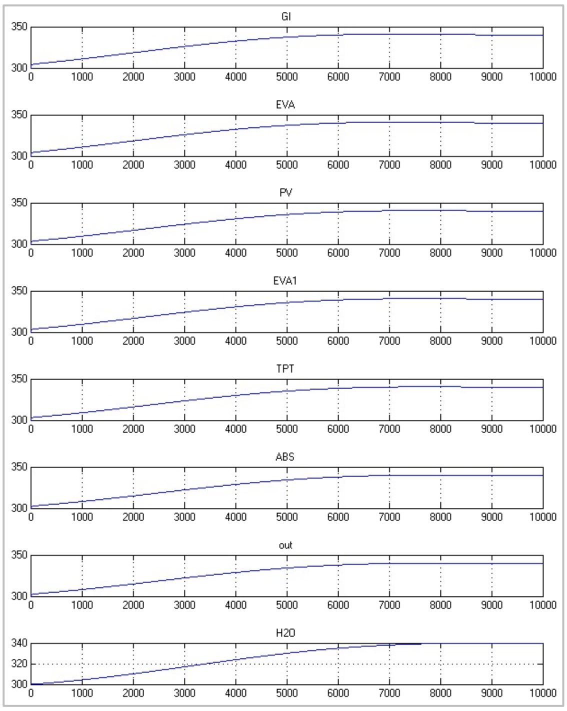

Figure 6: Measurements of temperature per elements

4.2 The PDE model

PDE model shows the temperature distribution in a two PV and cooling liquid.

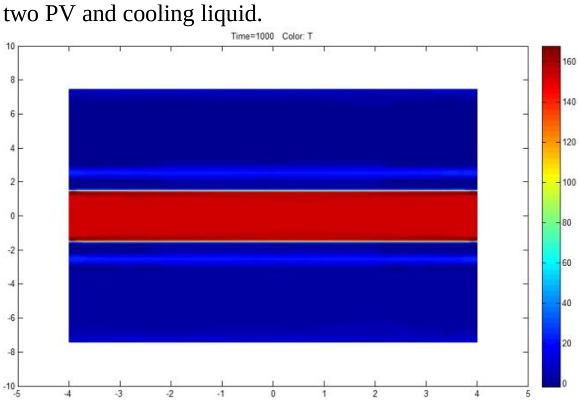

Figure 7: Model of PDEtool with dimensions and structure is approximated to real.

5 THE COMBINED MODEL

Let's combine the photovoltaic and thermal models. Since it is the same toolbox, then additional settings are not required.

In the thermal part the calculated temperature value is transmitted to the module and the electric part, wherein on the basis of this temperature the operating current and voltage is determined.

The result of the simulation is shown below.

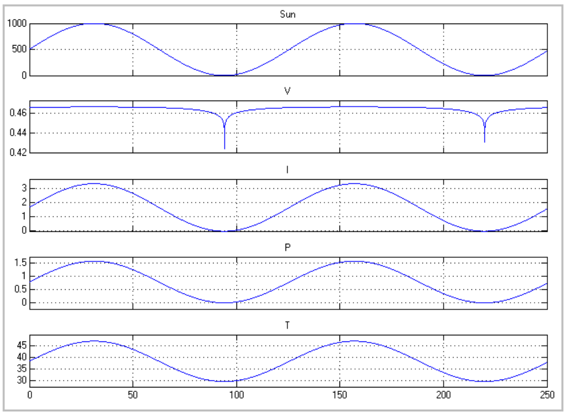

Figure 8: Measurements of temperature and electrical parameters

6 CONCLUSION

The Simulink PV model has been created in Simulink toolbox based on the double exponential model of the photovoltaic cell. This model takes into account the non-linearity of PV. The developed model is based on mathematical equations and an equivalent circuit, which includes a photocurrent source, two diodes, series and parallel resistors.

The model for the proposed range of the equivalent circuit elements, irradiance and temperature as model inputs, with the corresponding values of voltages, currents, and power as outputs is presented.

The thermal model was constructed based on the heat transfer between the layers.

The combined model was designed with the help of electric and thermal models. This model calculates the temperature and electrical characteristics of the photovoltaic panel.

7 ACKNOWLEDGMENT

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