STUDY OF A PHOTOVOLTAIC SYSTEM WITH MPPT USING MATLAB^{TM}

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Abstract*: In this paper a photovoltaic (PV) system is analyzed using Matlab. First, a Matlab code is written in order to obtain the I-V and P-V curves at different values of solar irradiation and cell temperature. The results were compared with the experimental data of a commercial PV module, USP 150. Then, the code was implemented in Simulink and, along with a MPPT algorithm and a DC-DC converter, the whole system was simulated.*

1. INTRODUCTION

In the last years, the use of alternative energy sources in electricity supply systems has rapidly increased. The increasing interest for renewable energies is due to the increasing concerns about fossil fuel deficit, high oil prices, global warming, and damage to environment and ecosystem. Also, another advantage of renewable energies is that it is suitable for electrifying remote areas where the electric grid does not reach and it is also becoming an economically viable renewable power source for distributed generation.

Solar energy, wind energy, hydro-power, bio-gas energy etc. are the most popular renewable energy sources. Research and development in each of these areas is being carried out in all parts of the world, out of which the solar energy is one of the cleanest and the least expensive one. [1] Abundance and sustainability of solar radiant energy are important factors that characterize the energy through the PV (photovoltaic) effect among the renewable energy resources. Regardless of the intermittency of sunlight, solar energy is widely available and completely free of cost. Despite of the high initial cost and low efficiency, PV system has small operation and maintenance costs as it is a stationary source of energy fabricated from

semiconductor material. [2] The output characteristics of PV module depends on the solar irradiation, the cell temperature and output voltage of PV module. Since the PV has a nonlinear current-voltage (I-V) characteristic, it is vital to model the PV unit for MPPT (maximum power point tracking) in PV-based power systems, [3].

2. PV MODEL DEVELOPMENT

A PV module consists of a number of solar cells connected in series and parallel to obtain the desired voltage and current output levels. Mostly commercial modules consist of 36 or 72 cells.

During darkness, the solar cell is not an active device and it works as a diode with a p-n junction. It produces neither a current nor a voltage. As sunlight strikes a solar cell, the incident energy is converted directly into electrical energy without any mechanical effort. Transmitted light is absorbed within the semiconductor, by using this light energy to excite free electrons from a low energy status to an unoccupied higher energy level. When a solar cell is illuminated, excess electron-hole pairs are generated throughout the material, hence the p-n junction is electrically shorted and current flows. [4]

The simplest equivalent circuit of a solar cell is a current source in parallel with a diode. (Fig. 1) The output of the current source is directly proportional to the light falling on the cell (photocurrent I_L).
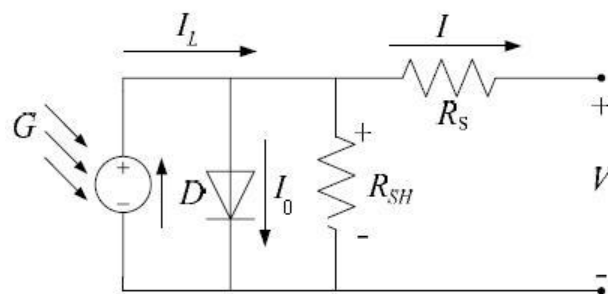

Fig. 1 – The equivalent circuit of a PV cell

The symbols in Fig. 1 are defined as follows: G − solar irradiation, I_L − photocurrent, D − diode, I_0 - the diode saturation current, R_{SH} − the shunt resistance, R_S - series resistance, I − the net current of the solar cell and V − the voltage of the solar cell.

Shunt resistance R_{SH} corresponds to the leakage current to the ground (is commonly neglected) and the series resistance R_S represents the internal losses due to the current flow. In an ideal cell, $R_{SH}=R_S=0$.

The net current of the cell is the difference of the photocurrent, I_L and the normal diode current I_0:

$$I = I_L - I_0 (e^{\frac{q(V+IR_S)}{nkT}} - 1) \qquad (1)$$

where:

- $q = 1.6 \times 10^{-19}$ [C] – the electron charge;
- $k = 1.38 \times 10^{-23}$ [J/K] – the Boltzmann's constant;
- T - the cell temperature [K];
- n – the diode quality factor.

The temperature dependence of the photocurrent I_L and the saturation current of the diode I_0 [5]:

$$I_L = I_L(T_1) + K_0(T - T_1) \qquad (2)$$

$$I_L(T_1) = I_{SC}(T_{1,nom}) \frac{G}{G_{nom}} \qquad (3)$$

$$K_0 = \frac{I_{SC}(T_2) - I_{SC}(T_1)}{T_2 - T_1} \qquad (4)$$

$$I_0 = I_0(T_1) \times (\frac{T}{T_1})^{\frac{3}{n}} e^{\frac{qV_g(T_1)}{n\,k\,(\frac{1}{T}-\frac{1}{T_1})}} \qquad (5)$$

$$I_0(T_1) = \frac{I_{SC}(T_1)}{(e^{\frac{q\,V_{oc}(T_1)}{n\,k\,T_1}} - 1)} \qquad (6)$$

$$R_S = - \frac{dV}{dI_{Voc}} - \frac{1}{X_V} \qquad (7)$$

$$X_V = I_o(T_1) \frac{q}{nkT_1} e^{\frac{qV_{oc}(T_1)}{nkT_1}} - \frac{1}{X_V} \qquad (8)$$

$$V_{oc} = \frac{nkT}{q} \ln \left(\frac{I_L}{I_0}\right) = V_t \ln\left(\frac{I_L}{I_0}\right) \qquad (9)$$

where

- I_{sc} – is the short circuit current [A];
- V_g is the band-gap energy of the semiconductor used in the cell [eV];
- V_{oc} - open circuit voltage [V].

3. SIMULATION AND RESULTS

In this paper a PV module fabricated by Udhaya Semiconductors Limited is analyzed. Table1 presents the specifications of the USP150 PV module standard test conditions (STC), which means an irradiation of 1000 W/m^2 with an AM1.5 spectrum at 25° C . The values were obtained from the manufacture's datasheet.

Table1. Parameters of the USP150 module

Maximum Power	*150 W*
Open Circuit Voltage (Voc)	*43 V*

Maximum power point voltage (Vmpp)	*33,5 V*
Short circuit current (Isc)	*4,9 A*
Maximum power point current (Impp)	*4,5 A*
No. of cells	*72*
Configuration	*24 V*
Maximum system voltage	*1000 V*
Type of Solar Cell	*mono-Si*

In order to analyze the solar cell behavior at different solar irradiation or temperature, a code was written in Matlab which use the solar script developed by González-Longatt in [5]. The screen shot of the code is presented in Fig. 2.

```
% Behavior at different solar irradiation or temperature of USP150 PV module
data = xlsread('USP150.xlsx', 'Data', 'A:B'); %Read curve's points from the Excel file
dataU = data(:,1);% Extract Voltage of the PV module
dataI = data(:,2);% Extract Current of the PV module
clear data

% Cell computation
dataUcelula=dataU/72;% Voltage of the solar cell
Va =dataUcelula';
Ia0=solar(Va,1,25); %Current of the solar cell

% Panel computations:
Ns = 72; % Number of cells serially connected in a panel [].
Va0 = 0:0.01:0.665; % Voltage vector of one cell [V]
Ia1 = solar(Va0,1,25); % Compute current from voltage vector [A]
Va1 = max(Ns*interp1(Ia1, Va0, 0:0.001:ceil(max(Ia1)*100)/100, 'linear', 'extrap'), 0);
Ia2 = solar(Va0,1,50);
Va2 = max(Ns*interp1(Ia2, Va0, 0:0.001:ceil(max(Ia2)*100)/100, 'linear', 'extrap'), 0);
Ia3 = solar(Va0,0.8,25);
Va3 = max(Ns*interp1(Ia3, Va0, 0:0.001:ceil(max(Ia3)*100)/100, 'linear', 'extrap'), 0);
Ia4 = solar(Va0,0.5,25);
Va4 = max(Ns*interp1(Ia4, Va0, 0:0.001:ceil(max(Ia4)*100)/100, 'linear', 'extrap'), 0);
Ia5 = solar(Va0,0.2,25);
Va5 = max(Ns*interp1(Ia5, Va0, 0:0.001:ceil(max(Ia5)*100)/100, 'linear', 'extrap'), 0);
RelativeError=abs((dataI-Ia0')./dataI);
```

Fig. 2 – The code written in Matlab in order to analyze the behavior of PV module

Below are presented the results of the Matlab code: Fig 3 presents the I-V curve of solar cell at STC and at different values of the temperature, Fig. 4 presents the P-V curve at different irradiation values and temperatures, Fig. 5 presents the I-V curve of the PV module at different values of temperature and solar irradiation and Fig. 6 presents the relative error between the I-V curve provided by the manufacturer and the I-V curve obtain with the Matlab code.
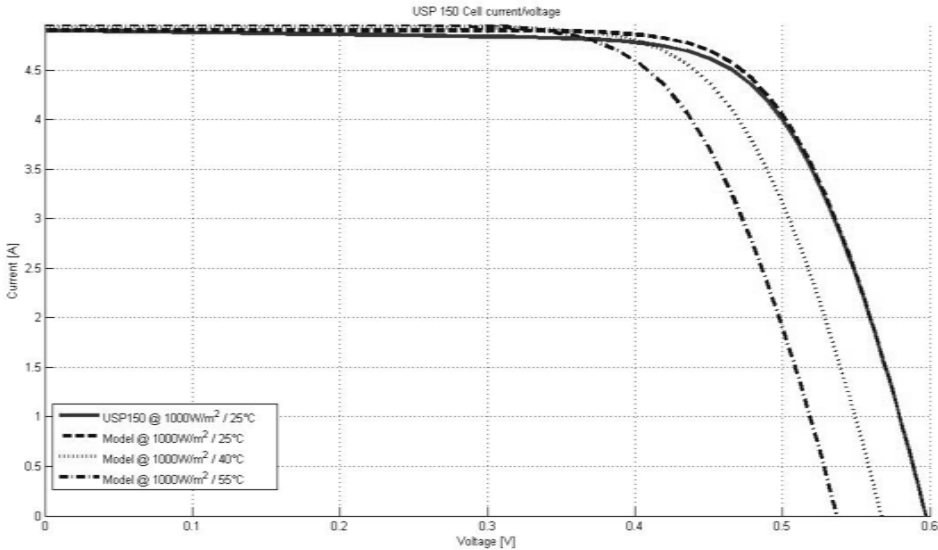
Fig. 3 – The I-V curve of the solar cell obtained with the Matlab code
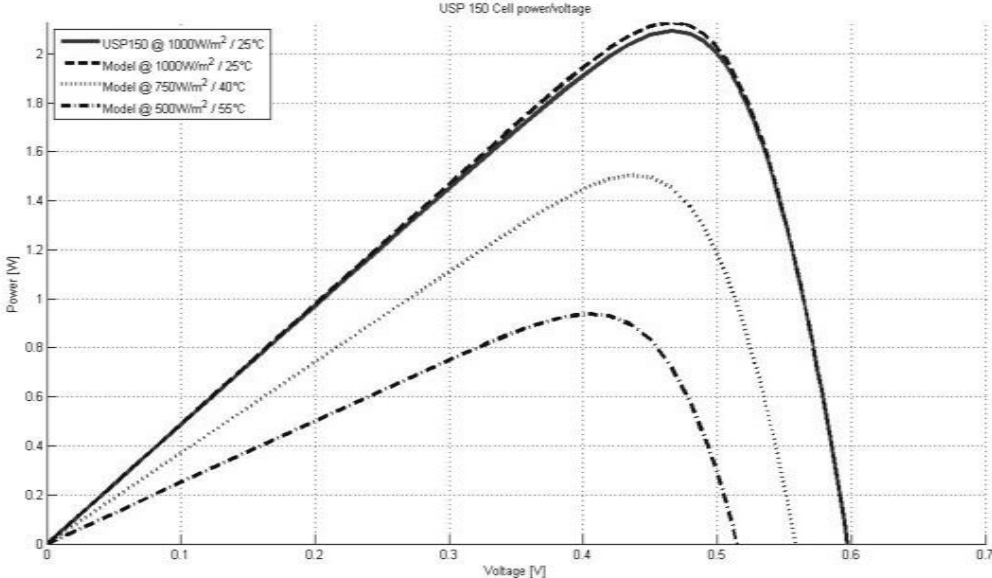

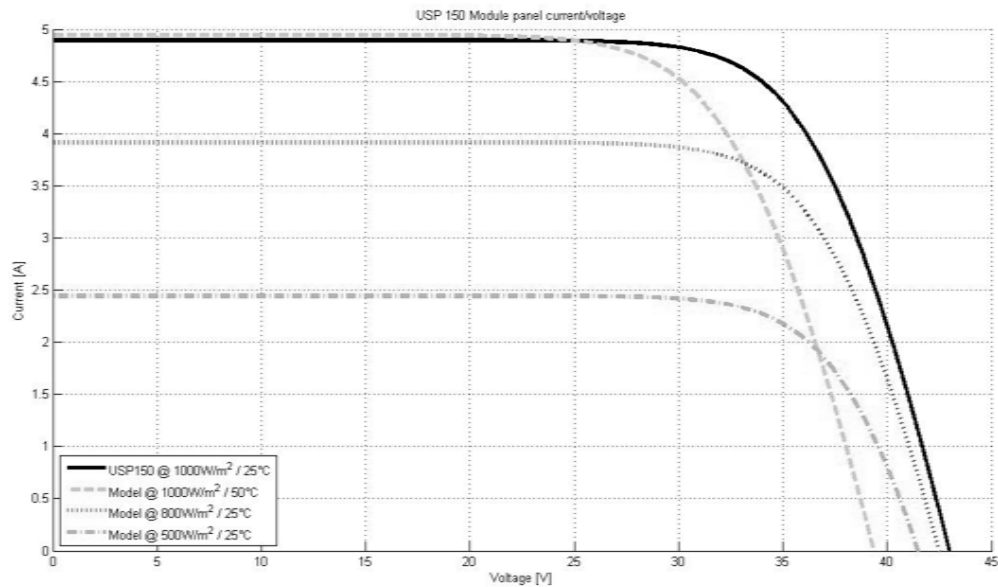*Fig. 4 – The P-V curve of the solar cell obtained with the Matlab code*

Fig. 5 – The I-V curve of the PV module obtained with the Matlab code
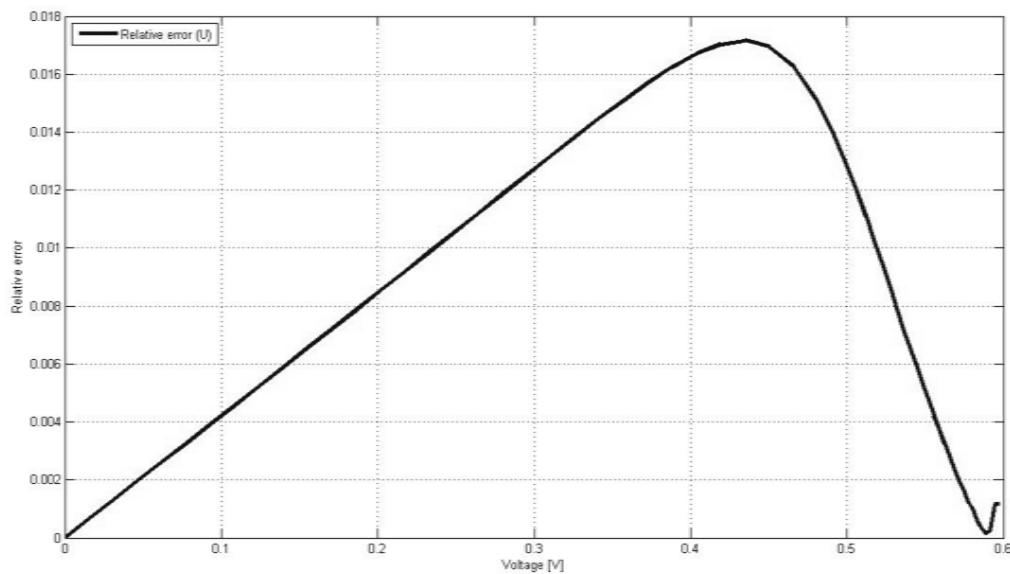

Fig. 6 – The relative error between the real and obtained I-V curve

With the variation of irradiation and temperature, the power output of PV module varies continuously. The maximum power point tracking (MPPT) algorithm is used for extracting the maximum power from the solar PV module and transferring that power to the load. By changing the duty cycle of the PWM control signal, the load impedance as seen by the source varies and matches the point of the peak power of the source so as to transfer the maximum power. The perturbation and observation (P&O) method has been widely used because of its simple feedback structure and fewer measured parameters. The peak power tracker operates by periodically incrementing or decrementing the solar array voltage. If a

given perturbation leads to an increase (decrease) in array power, the subsequent perturbation is made in the same (opposite) direction. In this manner, the peak power tracker continuously hunts or seeks the peak power conditions. [6] The flow chart of the P&O algorithm is shown in Fig. 7
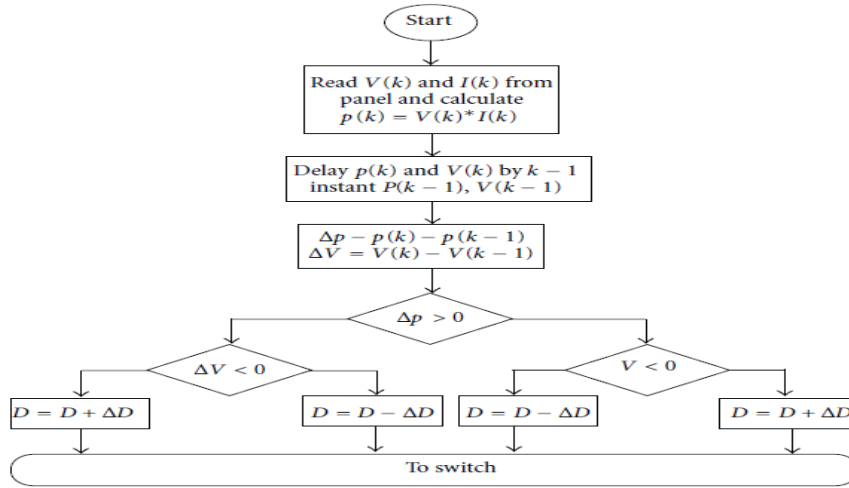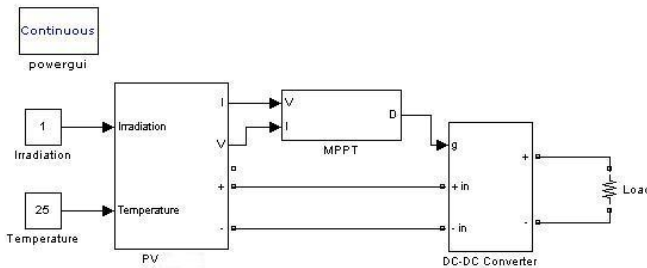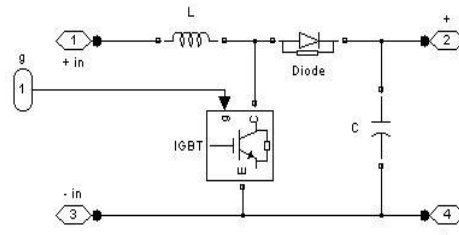

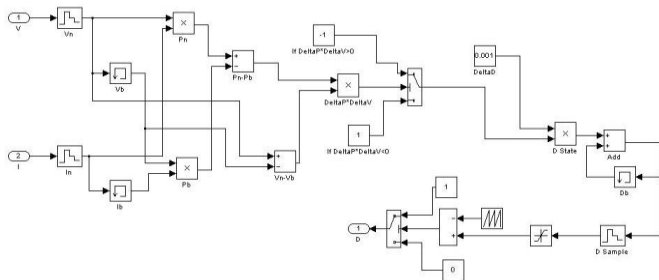*Fig. 7 – The flow chart of the P&O algorithm*

In Fig. 8 is presented the PV system created in Matlab – Simulink.
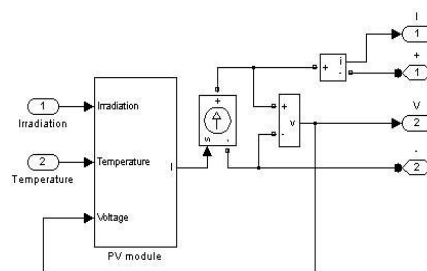

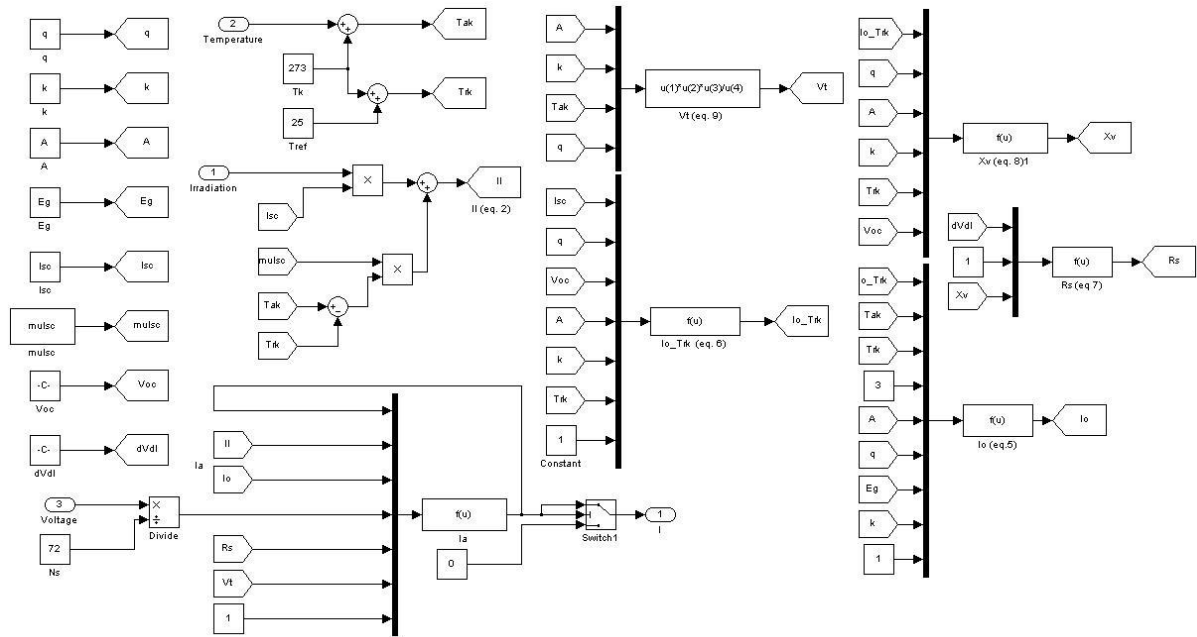*a)   The PV system created in Simulink*

b) The DC-DC converter subsystem

b)   The MPPT subsystem

d) The PV subsystem

e) The PV module subsystem

Fig. 8 –The PV system created in Matlab - Simulink

Fig. 9 presents the voltage at the input and output of the DC-DC converter obtained after the simulation.
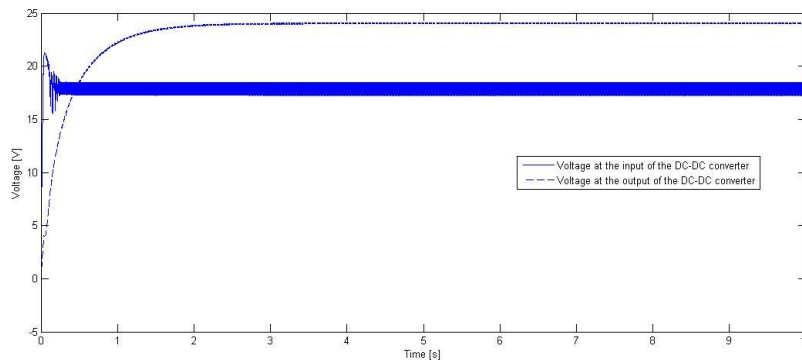

Fig. 9 –The voltage at the input and output of the DC-DC converter

3. CONCLUSIONS

In this paper, a Matlab code was written in order to analyze the behavior of a commercial PV module and the results were compared with the data from manufacture's datasheet. Then, it was implemented in Matlab-Simulink, along with a MPPT algorithm and a DC-DC converter. The inputs of the developed model using SimPowerSystems toolbox are solar irradiation and PV array operating temperature. The purpose of the MPPT is to adjust

the solar operating voltage close to the MPP under changing atmospheric conditions. The DC-DC converter provides a constant voltage output.

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