Testing the Efficiency of Solar Cells at Different Ambient Temperatures

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Abstract

Solar panels, known as popular sources of energy, have grown and developed significantly from day to day. Although they don't use energy produced from classical (fossil) energy sources, these systems have a huge potential to overcome even the biggest energy problems and therefore they are subjected to this research. However, in order to produce enough energy to meet consumer demands, it is necessary to achieve rational use. In this regard, this paper examines the effects of ambient temperature on the efficiency of the photovoltaic conversion process, whereby the obtain results contribute to make a real estimate that will enable the most rational production of electricity. The goal of this paper is to examine the temperature characteristics of commercial samples of photovoltaic cells whose application is decorative night lighting. In addition to experimental realization, the analysis of the process is supported by LabVIEW-simulation.

Keywords: ambient temperature, photovoltaic (PV) cell, energy efficiency, virtual instrumentation

Introduction

The production of electricity by the photovoltaic panels is one of the most eco-friendly way to produce energy. Aside from that, it should be noted that solar panels are suitable for places located at a great distance from the electrical power transmission system. The photovoltaic generator usually consists of a number of independent modules. To increase the power and voltage, multiple individual solar cells are connected, nearly always in series, thereby forming photovoltaic (PV) module. The direct conversion of solar energy into electricity is the result of the process known as photovoltaic effect. This effect is characteristic of semiconductors that create a p-n junction. Lighting of these semiconductors creates the electron-hole pairs (free charge carriers) and thus generates electricity. In most electrical circuits, the symbol of photovoltaic cell is a diode in combination with a current generator and resistors, as shown in Figure 1. The current generator is an analogy of solar radiation, where the symbols of the resistors are as follows: R_s - electrical resistance of wires, R_p - internal resistance of the equivalent current generator and R - load.

The basic equation for the current-voltage curve of a solar cell, that can be derived from the Figure 1, is given as:

$$I = I_{ph} - I_0\left(e^{\frac{q(V+R_S I)}{nkT_C}} - 1\right) - \frac{V + R_S I}{R_{Sh}} \qquad (1)$$

where I_0 is the saturation current of the cell [A], V is the output voltage [V], q=1.6·10^{-19} C is the elementary charge, k=1.38·10^{-23} J/K is the Boltzmann constant, n is the ideality factor of the p-n junction and T_c is the ambient temperature of the cell [K].

The ambient temperature can be calculated by the equation

$$T_c = \frac{T_{noct} - 20}{80} G + T_a \qquad (2)$$

where T_{noct} is the nominal operating cell temperature[K], G is the solar irradiance [W/m^2] and T_a is the ambient temperature [K].

The real-time simulation of the measurements in LabVIEW

Due to limited number of technical specifications, several assumptions of the photovoltaic cells characteristics are made on the basis of the measurement results that are obtained. Monitoring system is responsible for controlling the amount of energy produced by the photovoltaic system in real time, as well as to provide an accurate forecast of the efficiency changes of the conversion process as a result of the temperature changes.

The block diagram of the virtual instrument in LabVIEW made for the aim of this paper is shown in Figure 2. The graphs shown in figures 3 and 4 represent the characteristic I-V and P-V curve of a solar cell. Also, the maximum power point (MPP) of a PV cell is shown in figures, that is calculated as the product of the current and the voltage equal the greatest value. As can be seen further in the paper, these curves are slightly different from the curves obtained by experimentally measuring cells at different temperatures. Furthermore, the value of the maximum power that is obtained from the simulation at every temperature within the range differs from measured values less than one percent.

Experimental measurements and discussion

Illuminance measurements are made by lux meter (model MASTECH MY-68), whereby the measured value of illuminance by a source of light, after a stabilization period of 10 minutes, is equal to 2229 lx. The ambient temperature of the PV cells is controlled by temperature chamber (model BINDER). The experiment was performed using a temperature range +10°C to +60°C for every 10 degree rise in temperature. It should be noted that for each temperature there is a stabilization period of ten minutes before reading measuring instruments. In doing so, the following parameters were measured: open circuit voltage and short circuit current. In order to enable variability of the load resistance, a decade resistance box is connected to the electrical circuit. At the same time, the resistor adjusts to certain values that are adopted, and then, gradually, using multimeters (which are from the MASTECH model) the values of the measured currents and voltages at different resistances in the circuit are read. The procedure is carried out five times for different values of temperature. It is clearly seen from Table 1 that the temperature has a significant impact on the values of voltages and currents measured using digital multimeters and thus on the efficiency of the PV cell. Increasing the temperature of the photovoltaic cells leads to a decrease in the maximum power output that can be delivered by the PV cells, as well as to a decrease in the voltage of the open circuit. The short-circuit current remains constant or changes slightly with temperature change. These changes are represented in the tables and graphs below. To illustrate, it can be noticed that open circuit voltage at a temperature of 10 ℃ is 4,95 V and the maximum power is 2,44292 mW. On the other side, the open circuit voltage at a temperature of 60 ℃ is 3,54 V and the maximum power is 1,823 mW. The graphs that represent these measurements results are shown in figures 5 and 6, respectively.

Description and technical characteristics of the measuring instruments

Figure 7 shows the measuring instruments with which the experimental measurements were carried out. In order to be able to carry out the measurements at different temperatures, a BINDER chamber (see Fig. 8) was used to simulate the different ambient conditions. A digital multimeter (type MASTECH MY-68) was used to read the values of voltages and currents in the measurements (see Fig. 9). In order to obtain the value of the intensity of the illuminance, a luxmeter was used (type MASTECH MS6610) as shown in fig.10. The decade resistor that is used in the measurements is shown in Figure 11 and it has the role of the load in the electrical circuit that is powered by the photovoltaic generator. As mentioned above, in this way, at different load values can be obtained different values for output voltage and current of the PV cells.

As can be seen from the technical specifications of the digital multimeter that was used for measuring voltages and currents, the values for the absolute errors are given in the form: $\Delta = \left(A_{pv}\% + B_{dig}\right)$, as is shown in Table 2 and 3, respectively. The absolute error as well as the accuracy class of the instrument can be determined if we take into account the values of the voltage and current at the maximum power point (MPP) of PV cells. If the measured value of the direct voltage at the MPP is U=3,14 volts, then the absolute error and the accuracy class of the digital voltmeter can be calculated as:

$$\Delta = \pm\left(\frac{0{,}3}{100}\cdot 3{,}14 + 2\cdot 1\cdot 10^{-3}\right) = 11{,}42\ \text{mV} \qquad (3)$$

$$\gamma = \frac{\Delta}{U_{mp}}\cdot 100 = \frac{11{,}42\,\text{mV}}{3,\ 26\,\text{V}}\cdot 100 = 0{,}35\% \qquad (4)$$

On the other hand, if the measured value of the direct current is I=779 mA, then the absolute error and the accuracy class of the digital ammeter can be calculated as:

$$\Delta = \pm\left(\frac{2}{10000}\cdot 778 + 5\cdot 1\cdot 10^{-3}\right) = \ 5{,}16\ \text{mA} \qquad (5)$$

$$\gamma = \frac{\Delta}{U_{mp}}\cdot 100 = \frac{5{,}16\,\text{mA}}{10\,\text{A}}\cdot 100 = 0{,}05\% \qquad (6)$$

Conclusion

Of all the facts presented in this paper, as well as of the results obtained from the measurements that were performed, it can be easily seen that the temperature is of great importance for the electricity obtained from photovoltaic panels. Thus, in order to achieve maximum utilization of solar energy, it is necessary to pay attention on several conditions in which the conversion takes place, because otherwise electric energy that is produced will be significantly below the expected value. It should be noted that the photovoltaic panel used in this paper has unknown specifications. During the experiments, the influence of humidity was neglected, which also contributes to the final outcome of the tests, and thus to the final results obtained. It can be concluded that the results obtained by the simulation in LabVIEW correspond to the measured parameters of photovoltaic cells. It means that this simulation could be used to predict the voltage and the maximum power that are produced by PV cells at different ambient temperatures. Finally, as a hallmark of this paper, it can be concluded that the measurements conducted, as well as their analysis, are a "living" witness that the efficiency of solar panels is closely related to temperature.

References

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Figure 1: Electrical equivalent circuit of PV cell

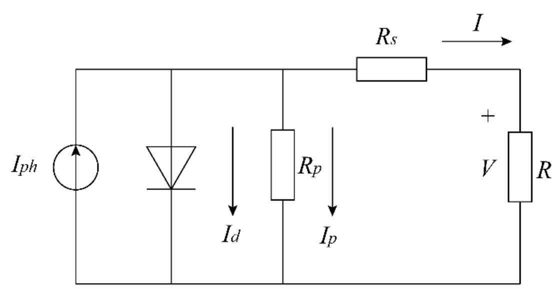

Figure 2: The block diagram of the virtual instrument in LabVIEW

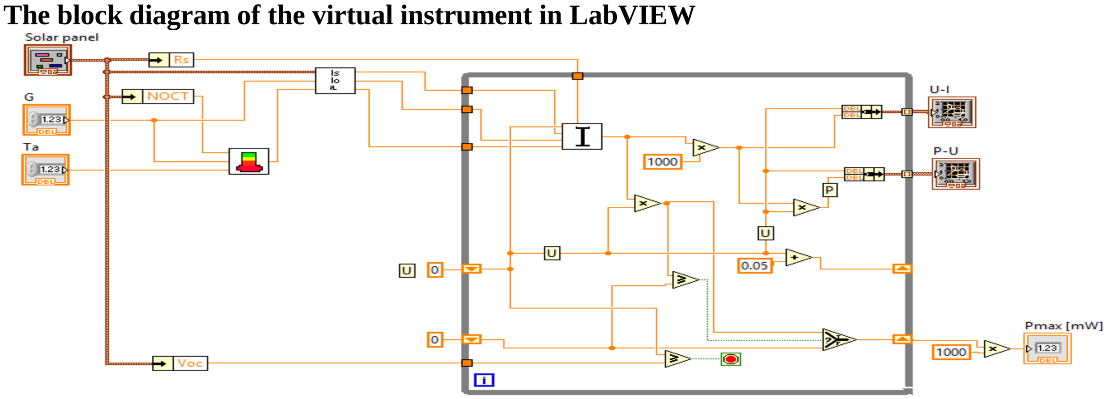

Figure 3: *I-V* and *P-V* curve of a solar cell at temperature of 60°C

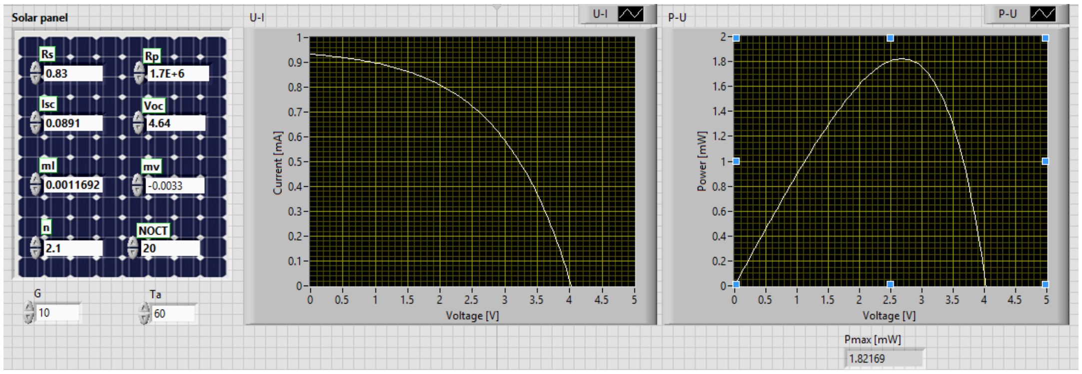

Figure 4: ***I-V*** **and** ***P-V*** **curve of a solar cell at temperature of 20°C**

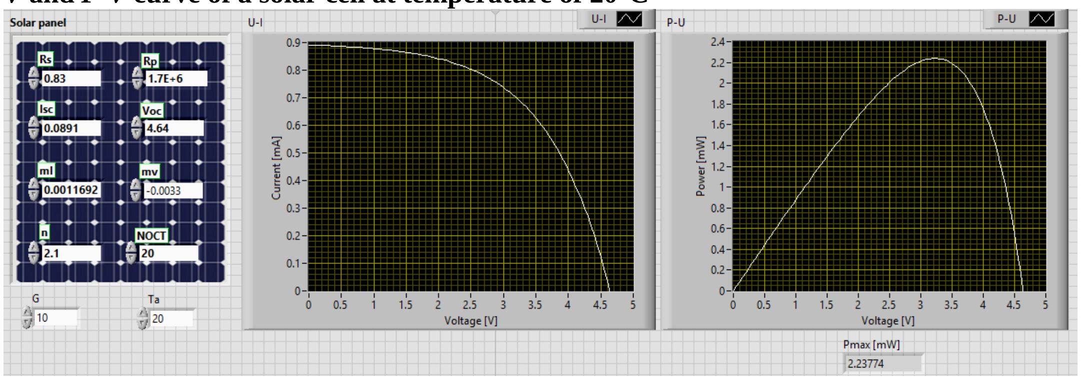

Figure 5: ***I-V*** **curve of a solar cell at different temperatures**

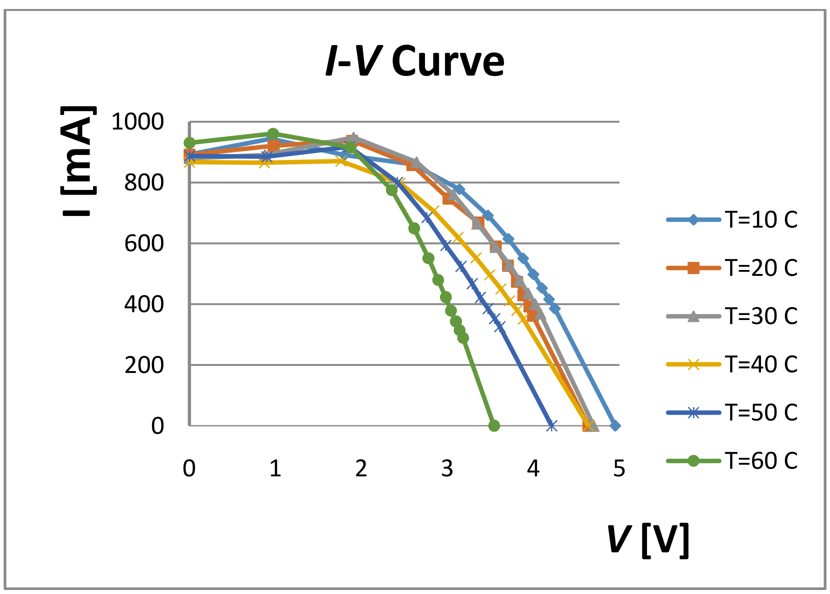

Figure 6: *P-V* curve of a solar cell at different temperatures

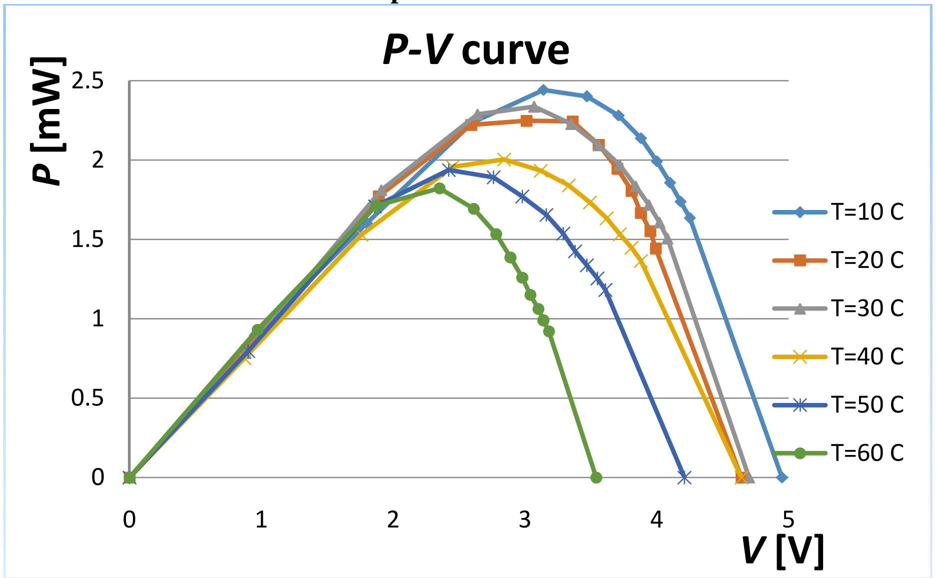

Figure 7: Overview of conditions and measuring instruments

Figure 8: A temperature chamber

Figure 9: A digital multimeter

Figure 10:A luxmeter

Figure 11: A decade resistor

Table 1: Measured currents and voltages at different resistances and temperatures

T=10 °C			
R_p [kW]	*V* [V]	*I* [mA]	*P* [mW]
Short circuit	0	892	0
1	0,95	944	0,8968
2	1,8	890	1,602
3	2,6	860	2,236
4	3,14	778	2,44292
5	3,47	692	2,40124
6	3,71	615	2,28165
7	3,88	551	2,13788
8	4	498	1,992
9	4,1	453	1,8573
10	4,18	416	1,73888
11	4,25	385	1,63625
No load	4,95	0	0

T=20 °C			
R_p [kW]	*V* [V]	*I* [mA]	*P* [mW]
Short circuit	0	891	0
1	0,98	921	0,90258
2	1,89	938	1,77282
3	2,59	858	2,22222
4	3,01	747	2,24847
5	3,36	668	2,24448
6	3,56	589	2,09684
7	3,7	526	1,9462
8	3,81	474	1,80594
9	3,88	430	1,6684
10	3,95	393	1,55235

11	3,99	362	1,44438
No load	4,64	0	0

T=30 °C

***R_p* [kW]**	***V* [V]**	***I* [mA]**	***P* [mW]**
Short circuit	0	880	0
1	0,88	890	0,7832
2	1,91	948	1,81068
3	2,64	867	2,28888
4	3,07	761	2,33627
5	3,35	665	2,22775
6	3,56	588	2,09328
7	3,72	529	1,96788
8	3,84	478	1,83552
9	3,94	436	1,71784
10	4,02	400	1,608
11	4,08	369	1,50552
No load	4,7	0	0

T=40 °C

***R_p* [kW]**	***V* [V]**	***I* [mA]**	***P* [mW]**
Short circuit	0	867	0
1	0,87	865	0,75255
2	1,76	870	1,5312
3	2,45	799	1,95755
4	2,84	706	2,00504
5	3,12	620	1,9344
6	3,33	553	1,84149
7	3,49	497	1,73453
8	3,62	451	1,63262
9	3,72	412	1,53264
10	3,81	380	1,4478
11	3,88	352	1,36576
No load	4,64	0	0

T=50 °C

***R_p* [kW]**	***V* [V]**	***I* [mA]**	***P* [mW]**
Short circuit	0	887	0
1	0,9	885	0,7965
2	1,86	918	1,70748
3	2,42	801	1,93842
4	2,76	685	1,8906
5	2,98	594	1,77012
6	3,16	524	1,65584
7	3,29	467	1,53643
8	3,38	422	1,42636
9	3,47	385	1,33595
10	3,55	353	1,25315

11	3,61	327	1,18047
No load	4,21	0	0

T=60 °C

R_p [kW]	*V* [V]	*I* [mA]	*P* [mW]
Short circuit	0	930	0
1	0,97	961	0,93217
2	1,87	915	1,71105
3	2,35	776	1,8236
4	2,61	649	1,69389
5	2,78	552	1,53456
6	2,89	480	1,3872
7	2,98	423	1,26054
8	3,04	379	1,15216
9	3,1	343	1,0633
10	3,14	315	0,9891
11	3,18	290	0,9222
No load	3,54	0	0

Table 2: Absolute errors of the voltages

	Range	Resolution	Error
DC voltage	326 mV	0.1mV	$\Delta = \pm(0{,}5\% + 2dig)$
	3.26 V	1mV	$\Delta = \pm(0{,}3\% + 2dig)$
	32 V	10mV	$\Delta = \pm(0{,}3\% + 2dig)$
	326 V	0.1V	$\Delta = \pm(0{,}3\% + 2dig)$
	1000V	1V	$\Delta = \pm(0{,}5\% + 2dig)$

Table 3:Absolute errors of the currents

	Range	Resolution	Error
DC current	326 µA	0.1µA	$\Delta = \pm(1{,}2\%. +3dig)$
	3260 µA	1µA	$\Delta = \pm(1{,}2\%. +3dig)$
	32.6 mA	10µA	$\Delta = \pm(1{,}2\%. +3dig)$
	326 mA	0.1 mA	$\Delta = \pm(1{,}2\%. +3dig)$
	10A	10 mA	$\Delta = \pm(2{,}0\%. +5dig)$