Experimental Investigation of Module Temperature Effect on Photovoltaic Panels Efficiency

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(Received : 21.03.2016 ; Accepted : 20.05.2016)

ABSTRACT

A Photovoltaic module efficiency is mainly depend on the ambient temperature, module temperature, incoming solar radiation intensity and photovoltaic material composition. In the present work, the effect of module temperature on the photovoltaic (PV) panel efficiency was investigated experimentally. Incoming solar radiation on the PV surface (I), ambient temperature of the panel (Ta), back surface temperature of the panel (Tp), voltage and current are the main parameters measured during the experiments. In the experimental system the area that PV module placed have been adjusted four different ambient air temperature as 10, 20, 30 and 40 °C. PV module efficiencies are calculated with using obtained experimental data. According to the computations the module efficiency was 12.07% for the 14.9 °C of Tp while it was found as 10.7% for the 51.3 °C of Tp. It was observed that increasing of PV module temperature decreases efficiency.

Keywords: Energy, Solar energy, photovoltaic module temperature, efficiency, zenith angle.

Modül Sıcaklığının Fotovoltaik Panellerin Verimine Etkisinin Deneysel Olarak İncelenmesi

ÖZ

Bir fotovoltaik (PV) modülün verimi esas olarak ortam sıcaklığına, modül sıcaklığına, güneş ışınım şiddetine ve fotovoltaik malzemenin bileşimine bağlıdır. Sunulan bu çalışmada modül sıcaklığının PV panelin verimine olan etkisi deneysel olarak incelenmiştir. PV yüzey üzerine gelen güneş ışınım şiddeti (I), panelin bulunduğu ortam sıcaklığı (Ta), panel arkası sıcaklık (Tp) gerilim ve akım değerleri deney süresince ölçülen ana parametrelerdir. Deneylerde PV modülün bulunduğu ortam 10, 20, 30 ve 40 °C olmak üzere dört farklı sıcaklık değerine ayarlanmıştır. Deneysel çalışmadan elde edilen veriler kullanılarak PV modülün verimi hesaplanmıştır. Yapılan hesaplamalara göre 14.9 °C panel arkası sıcaklığı (Tp) için % 12.07 olan modül verimi Tp=51.3 °C için %10.7 olmuştur. PV modül sıcaklığının artışı verimi düşürdüğü gözlemlenmiştir.

Anahtar Kelimeler: Enerji, Güneş enerjisi, Fotovoltaik modül sıcaklığı, verim, zenit açısı

1. INTRODUCTION

Energy is an indispensable part of today's society. Countries are faced to increasing energy requirements with depleted energy sources. Besides, environmental problems resulted use of fossil-based energy sources, has led to the search for new energy sources. In this way solar energy is quite important assigned in renewable energies with its endless light and heat sources. Today, solar cells utilizing solar energy to electrical energy are produced and the efficiency of the systems developed in this direction is being investigated. Photovoltaic systems are commonly used all around world as shown themselves to be one of the most promising applications for dealing with electricity generation [1-4]. Generally, a typical PV module converts only 4-20% of the incoming solar radiation into electricity depending upon the type solar cells and climatic conditions [5, 6]. Therefore a big part of the incoming solar energy is extracted as heat and the temperature of PV module which is a parameter that has great influence in the behavior of a PV system is increase [7]. Hanlin and Stein [8] have modeled the module temperature of PV system using a transient heat-flow model. Single day of measured module temperature has used simultaneous non-linear least squares regression and optimized then tested for accuracy using a year's worth of data for one location. Environmental conditions on module temperature of selected PV system in Singapore have analyzed by the Ye et al. [9].

Cooling of PV panels is providing a significant efficiency increases [10-12]. As it was reported in Bahaidarah et. al. [13] the efficiency of the PV module is mostly depend on operation temperature. It was mentioned in their paper active cooling method applications has increased the PV module efficiency about 9%. Their claims will be verification when the Ceylan et al [14] study was read. They have investigated different PV/T systems to cool photovoltaic modules. In experimental study simple spiral pipe recirculated water inside was placed to the back surface of PV module to provide cooling effect as a heat exchanger. The cooled module efficiency was reported as 13% whereas uncooled was 10% at the end of the study. In another work which was investigated experimentally by Teo et al. [15] an active cooling

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Digital Object Identifier (DOI) : 10.2339/2016.19.4 569-576

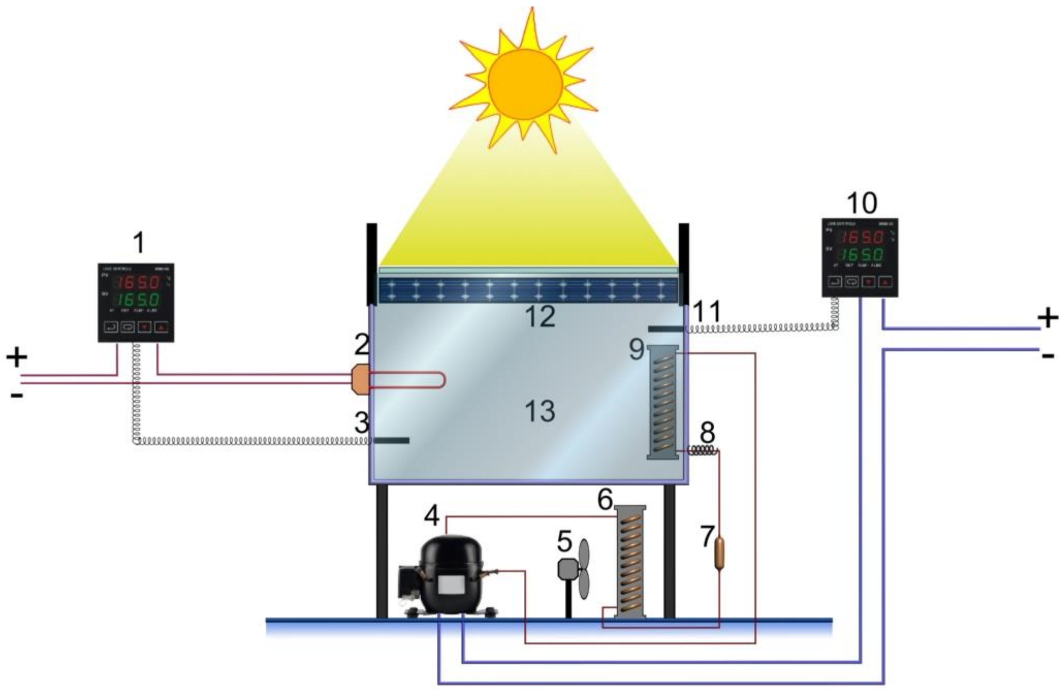
method was developed for PV modules. Temperature profile obtained experimental tests had been compared with simulation model and it was said to be an excellent agreement between simulation model and experimental results in the paper. Agrawal et al [16] has investigated performance of PVT solar air collector. Electrical and thermal efficiency of the PVT systems was reported as %12.4 and %35.7 respectively at the end of the study. Another study was performed which is resulted in 8.4 % and 42% electrical and thermal performances by Solanki et al. [17].

Motivated by the above studies the main objective of the present study is to determine module temperature effect of the PV- module performance. For this purpose an experimental test rig was designed and produced. In the experimental test rig the ambient temperature of the PV module placed area was set to different temperatures. The ambient temperature values have tried to be a constant temperature with heating and cooling operations by using process control equipment's. For heating process electrical resistances were used while vapor compression refrigeration cycle system was used for cooling process. Solar radiation intensity, ambient temperature of PV module, back surface temperature of the PV module, voltage and current are the main measured parameters in the experimental tests. Obtained results by using experimental measured data were used to calculate the efficiency of the PV module and presented with graphical and tabular form. The paper is organized as follows: The experimental procedure is described in the next section followed by a discussion of the results of the experimental studies in Section 3 ending with a conclusion in Section 4.

2. MATERIAL AND METHOD

Photovoltaic solar panel is positioned into a closed chamber in order to observe the changes in the temperature of the PV module. Closed chamber was surrounded with glass material. Indoor temperatures are fixed by four different temperature values. To obtain constant temperatures values in indoor, cooler and heater equipment's were used. For heating and cooling process electrical heater and simple vapor-compression refrigeration cycle system was used. It has been possible to hold desired constant temperatures with using PID control equipment. A schematic diagram of the experimental apparatus used in this work is shown in Figure 1 and the photograph is shown in Figure 2.

Incoming solar radiation intensity on the PV module numbered as 12 in the Figure.1 was measured with solarmeter. Indoor environment temperature numbered as 13 was adjusted at desired temperature values with using number 2 and cooling equipment numbered as 4-5-6-7-8-9 in the figure. When temperature of the indoor environment decreases under the set value number 1 (automatic control equipment) activates the number 2 to get the desired temperature. Similar case has occurred for reverse namely, when temperature of the indoor environment rises above the set value, number 10 activates the cooling system to get the desired



1. Process control equipment (for heater), 2. Electrical heater, 3. Temperature sensor, 4. Compressor, 5. Fan, 6. Condenser, 7. Dryer, 8. Capillary tube, 9. Evaporator, 10. Process control equipment (for cooling) 11. Temperature sensor, 12. Photovoltaic module.

Figure 1. Schematic view of the experimental test rig [4, 18].

temperature. This process is work automatically in the experimental setup. Digital thermostats were used to activate the heating and cooling systems. In the experiments solar radiation, ambient air temperature of the PV module, back surface temperature of the PV module was measured and recorded to a personnel computer.

Figure 2. Photograph of the experimental system.

Solar radiation incoming the PV module converts to electrical energy and stored in accumulator. Stored electrical energy works the LEDs light placed in the experimental systems. Specification of the experimental component are given in Table 1.

the PV module is produced. For crystal silicon almost 0.0045/K is taken [19, 20]. The electrical efficiency of the PV module is given as follows:

$$\eta_m = \eta_c . \tau_g . \alpha_c . \delta_c \tag{2}$$

where; τ_g, α_c and δ_c are the transparency for the PV module glass, absorptivity of the solar cell and packing factor. The values for these are taken as 0.90, 0.95 and 0.90, respectively [19, 21].

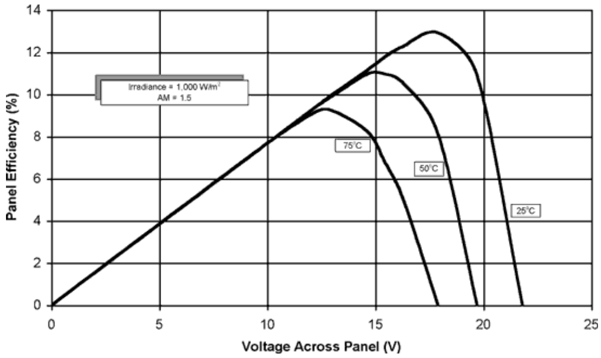


Figure 3. Standard test conditions efficiency of the PV module.

In addition that, a simple program that helps to locate PV modules in any place and time which is based on incoming solar angle was developed on the purpose of performing experimental test conditions. PV panels can be tested at 1000 W/m^2 solar radiation and 1 or 1.5 air mass values. Air mass (AM) definition is as follow,

$$AM = \frac{1}{cos\emptyset} \tag{3}$$

where cosφ is the solar zenith angle.

The main objective of this developed program is to calculate the solar zenith angles (φ) of predicted days. Solar zenith angle can be defined as follow:

Table 1. Specification of the experimental components.

Experimental components	Features
Condenser	1/4 hp
Evaporator	1/5 hp
Compressor	12/24 V 70 W
Accumulator	SP 127 (12V 7AH/20 HR)
Sheet Centrifugal Fans	18/120, 275 m^3/h flow rate 220 V 85 W
Kyocera crystalline silicon solar module	10 W
Multimeter	JT-830LN
Haenni digital solar meter	Model-130 1500W/m2, sensitivity ±1.5%
Lae Dijital termostat and TT-T-ECHNI-C Thermometer, sensitivity ±0.05%	

Using the obtained data by experimental measurements the PV module efficiency has been calculated. According to [4, 19, and 22] PV module cell efficiency can be defined as;

$$\eta_c = \eta_0 \left[1 - \beta\left(T_p - 25\right)\right] \tag{1}$$

where; η_0 is standard test conditions efficiency (I=1000 W/m^2 and Tc=25 °C) which has value 0,13 as can be seen in Figure 3. T_p and β are the panel temperature and electrical efficiency thermal coefficient respectively. β value depends on the features of the materials from which

$$cos\emptyset = (sinL \times sin\delta) + (cosL \times cos\delta \times cosh) \tag{4}$$

where;

L, δ and h are the Latitude degree, declination angle and hour angle respectively. Declination angle described as follow:

$$\delta = 23.45 sin\left[360\frac{284+i}{365}\right] \tag{5}$$

where *i* is defined number of days since the start of the year. The predicted experiment hour is defined as *h* and calculated with the following equation.

$$h = (AST - 12) \times 15 \quad (6)$$

where; AST is areal (local) solar time. A screenshot of the created program is shown in Figure 4.

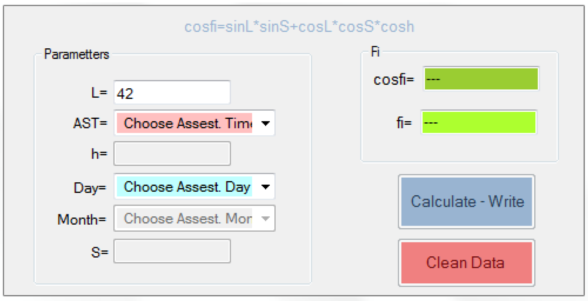


Figure 4. A screenshot of the developed program.

The angle of PV module can be adjusted for a specific region and time zone with the help of this program in order to obtain highest efficiency from PV module. For instance, the zenith angle can be calculated by developed program for experiments on 14^{th} , 15^{th} and 16^{th} days of July between 14:00 and 18:00 in the prevailing weather conditions of Karabük (L=42°) city of Turkey. The calculated zenith angels for these assumptions are shown in Table 2.

$$w_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \cdots\cdots\cdots\cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{\frac{1}{2}} \quad (7)$$

where R is a given function of the independent variables x1, x2, x3,., xn, w_R the uncertainty in the results. Through calculations, the uncertainty values of efficiency are less than 6%.

3. RESULTS AND DISCUSSION

A series rigorous tests were conducted on the designed and manufactured experimental setup to observe module temperature effect to the PV panel efficiency. Experiments were performed outdoor conditions regardless of the change of zenith angle. In the experiments incoming solar radiation intensity (I, W/m^2), ambient temperature of PV panel (Ta), back surface temperature of module (Tp), current and voltage values were measured and recorded in a personnel computer. Following graphs were plotted as a result of obtained measurements. The ambient air temperature of the PV panel has adjusted four different temperature as 10, 20, 30 and 40 °C. These values has tried to be kept constant during the experimental time.

Table.2 Computed solar zenith angles.

i	*δ*	*AST*	*h*	*L*	*cosφ*	*φ*	*AM*
195	21.6746	14	30	42	0.8452	32.305	1.1831
195	21.6746	15	45	42	0.7354	42.653	1.3597
195	21.6746	16	60	42	0.5924	53.670	1.6879
195	21.6746	17	75	42	0.4258	64.793	2.3480
195	21.6746	18	90	42	0.2471	75.692	4.0464
195	21.6746	19	105	42	0.0683	86.078	14.6202
196	21.5173	14	30	42	0.8441	32.418	1.1846
196	21.5173	15	45	42	0.7342	42.753	1.3619
196	21.5173	16	60	42	0.5911	53.764	1.6917
196	21.5173	17	75	42	0.4243	64.889	2.3564
196	21.5173	18	90	42	0.2454	75.793	4.0746
196	21.5173	19	105	42	0.0664	86.187	15.0375
197	21.3536	14	30	42	0.8430	32.536	1.1862
197	21.3536	15	45	42	0.7330	42.856	1.3641
197	21.3536	16	60	42	0.5897	53.863	1.6957
197	21.3536	17	75	42	0.4227	64.989	2.3652
197	21.3536	18	90	42	0.2436	75.898	4.1043
197	21.3536	19	105	42	0.0645	86.301	15.5003

In the present work, the measurement uncertainties of temperature are ±0.05, which contains a measurement error of ±0.5 °C by thermocouples. The uncertainty in the solar radiation measurement is 1.5%. The uncertainties of efficiency which are calculated by directly measured values such as temperature, incoming solar radiation are generally denoted as ∂_x described as follow.

The back surface temperatures of the PV module at 10 °C ambient temperature that are varied incoming solar radiation intensity are shown in Figure 5. It can be clearly seen from Figure 5, instantaneous variations of solar radiation intensity were occurred. These variations has been taking place because of the fact that the weather conditions are cloudy/partially cloudy.

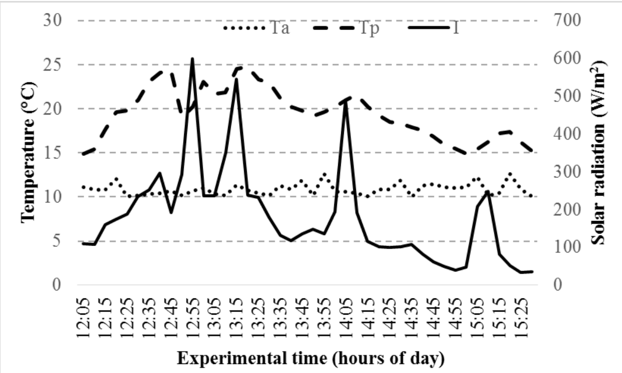


Figure 5. Variations of Tp depends upon solar radiation intensity, Ta=10 °C.

In addition, these variations influenced on the back surface temperatures of the PV module directly. Solar radiation intensity and back surface temperature values decreased and increased proportionally. The back surface temperatures are varied between 14.9 and 24.8 °C during test period.

The back surface temperatures of the PV module at 20 °C ambient temperature that are varied incoming solar radiation intensity are shown in Figure 6. It can be clearly seen from Figure 6, instantaneous variations of solar radiation intensity were occurred at the beginning of test. Although the small variations were observed on the solar radiation intensity after the 50th minutes of the test and it tends to decrease. These variations influenced on the back surface temperatures of the PV module directly. Solar radiation intensity and back surface temperature values decreased and increased proportionally. The back surface temperatures are varied between 22.3 and 32.8 °C during test period.

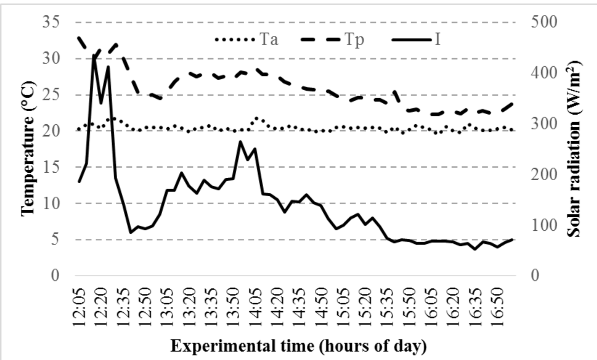


Figure 6. Variations of Tp module depends upon solar radiation intensity, Ta=20 °C.

The back surface temperatures of the PV module at 30 and 40 °C ambient temperatures that are varied incoming solar radiation intensity are shown in Figs 7 and 8 respectively. When Figure 7 was examined it is seen that back surface temperatures are varied between 31.9 and 47.5 °C during test period. In a similar manner back surface temperatures are varied between 40.7 and 51.3 °C for Ta=40 °C as shown in Figure 8.

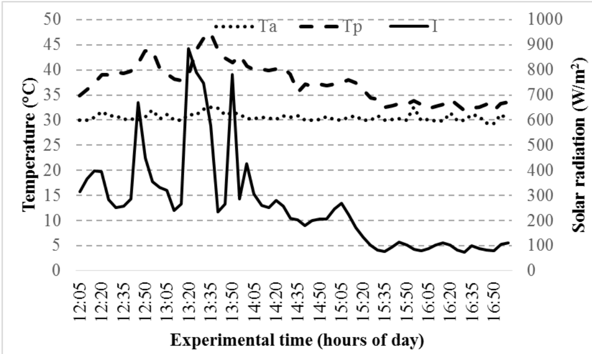


Figure 7. Variations of Tp depends upon solar radiation intensity, Ta=30 °C.

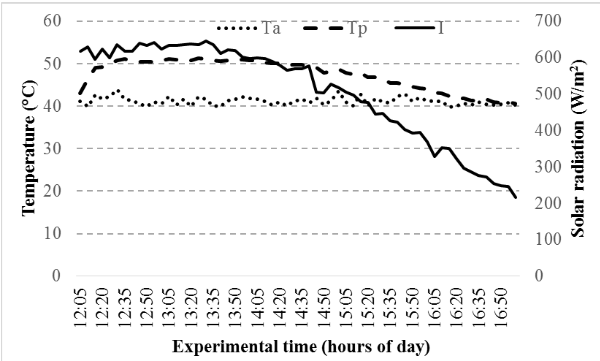


Figure 8. Variations of Tp depends upon solar radiation intensity, Ta=40 °C.

Measured current and voltage values for each set temperatures are averaged and tabulated in Table 3. The measured voltage values were varied between 12.01and 12.82 V, whereas current values were changed between 0.08 and 0.1 A.

Table 3. Current and voltage values.

Ta (°C)	Tp* (°C)	Current (A)*	Voltage (V)*
10	19.4	0.08	12.820
20	25.8	0.09	12.521
30	37.4	0.1015	12.179
40	47.4	0.1038	12.011

*Average values of measurements.

Efficiency values changing with Tp has shown in Figure 9 for different Ta. It is clear to say from the figure increasing of Tp has caused to decrease efficiency for all Ta values.

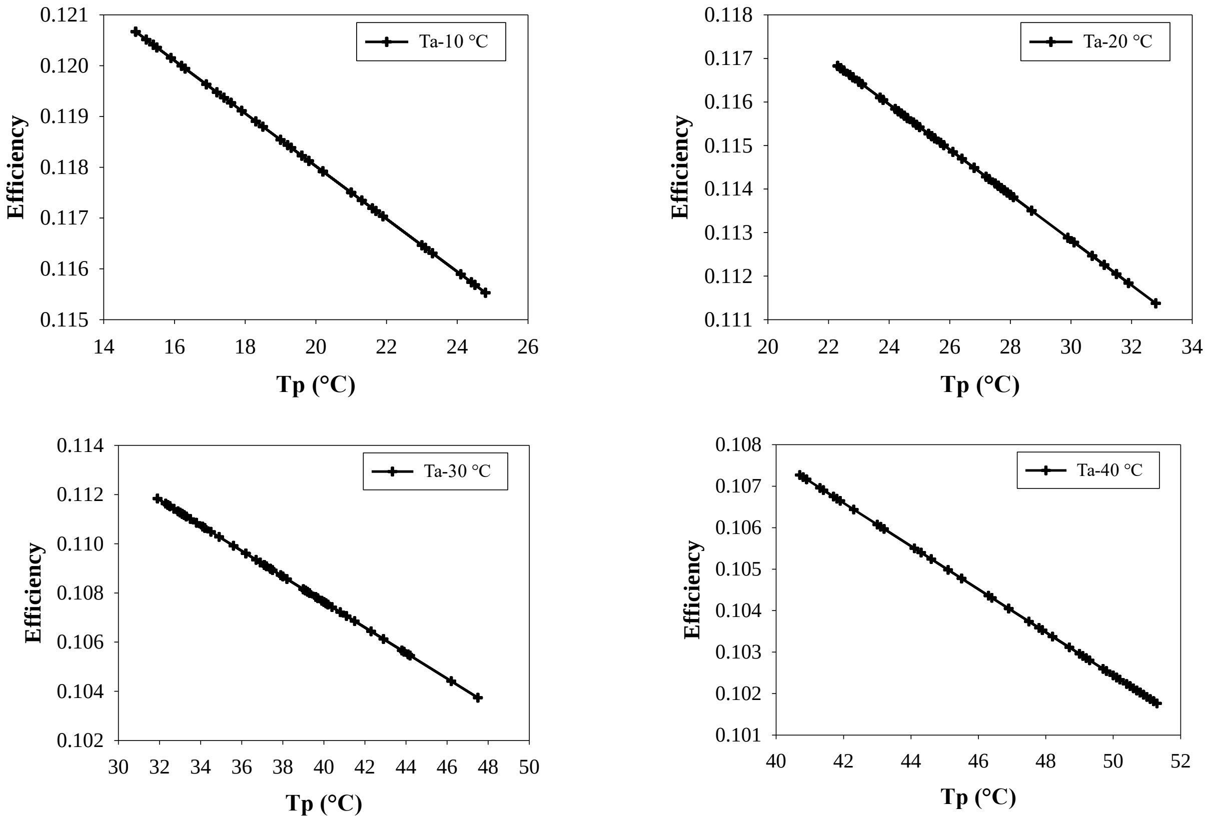


Figure 9. Variations of efficiency with Tp.

The ambient temperature of the PV module at 10 °C, the efficiency of PV module was varied between 12.07% and 11.57% for Tp =14.7 and 24.8 °C respectively. The lowest efficiency value has been calculated as 10.17% in the situation where ambient temperature is 40 °C for the Tp=51.3 °C. As it was reported in the previous studies [6, 22] increasing PV module temperatures decreases electrical efficiency and computed efficiency values in this work was found in good agreement with previous published results as given Table 4.

Table 4. Comparison of the efficiency values with previous published results.

Study	Type of cell	Electrical Efficiency (%)
Present	Crystalline silicon	10.27-11.94
Ceylan et al. [14]	Crystalline silicon	10.15
Moradi et. al. [23]	Crystalline silicon	10.00–15.00
Evans D.L. [24]	Mono Crystalline silicon	15.00
Truncellito and Sattolo [25]	Mono Crystalline silicon	11.00
Chow [26]	Mono Crystalline silicon	12.0

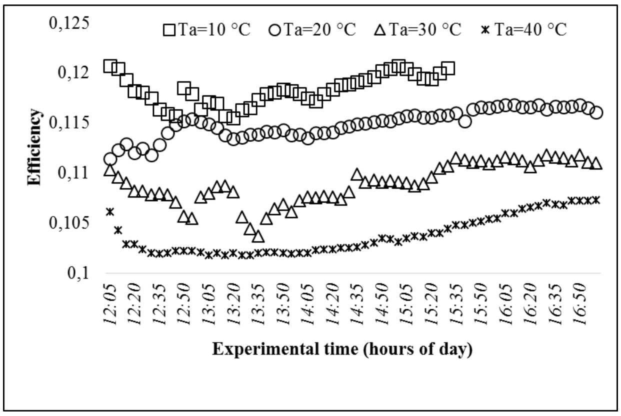


Figure 10. The PV module efficiencies during the experimental time for different Ta values.

Variations of efficiency values versus experimental time has been shown in Figure 10. It is clear to see decreasing efficiency values with increasing ambient temperatures. While the average module efficiency was computed as %11.94 for Ta=10 °C, it was computed as %11.30, %10.81 and %10.27 for Ta=20, 30 and 40 °C respectively. Changing module efficiency during the experimental time is resulted from variations of incoming solar radiation intensity on the PV module surface.

4. CONCLUSION

An experimental approach of a PV system is studied regarding its temperature and efficiency. The system is tested under the climatic conditions of Karabük, Turkey. The measured and calculated values obtained from the results of this work are discussed as follows:

- ✓ The ambient air temperature is a very important factor in terms of photovoltaic module temperature.
- ✓ As the solar radiation increased, temperature of PV module has also increased which is directly effect to photovoltaic *module* electrical efficiency to decrease according to Figure 9.
- ✓ The solar zenith angles can be obtained for any desired time and places with the recommended program.
- ✓ An effective way to increase efficiency of a PV module is to reduce the operating temperature of PV module. This may be performed by using active and passive cooling techniques of the PV module during the process.

ACKNOWLEDGEMENT

The authors would like to thank the Karabük University Scientific Research Projects Unit, Karabük/TURKEY for providing the financial supports for this study under the KBÜ-BAP-13/2-YL-037 project.

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