# EFFECT OF FORCED AIR COOLING ON EFFICIENCY OF PHOTOVOLTAIC MODULE

***A.T. Jailany and *M. I. Morsy**

## ABSTRACT

*A photovoltaic is a system that converts solar energy into an electric power. During generation electricity from solar energy using photovoltaic modules, high surface temperature is caused by the absorption of thermal energy which leads to a decrease the efficiency of the module. In this study, an air-cooling unit was developed for a photovoltaic module to study the effect of air velocity on increasing the cooling rate of the surface of the module and the increasing in the efficiency of the model and compared to another model under normal conditions with no cooling. The study also discussed the use of experimental results in the conclusion of mathematical models to calculate the best cooling air speed required to obtain the best performance of the photoelectric module. Results showed that the use of forced air in the cooling process of the photovoltaic module caused an increase in energy production efficiency by 9.45 to 19.31 at different air speeds of 1.1 to 2.4 m / s. The highest efficiency gain was obtained at 19.31% at 2.4 m / s where the surface temperature of the model approached the recommended standard operating temperature. Also, a microcontroller PIC16F877A control system was used to regulate the PV module surface temperature to keep suitable constant temperature to the surface of the module. The test results were compared to the test results of the PV module under normal condition.*

**Keywords:** *Photovoltaics, Energy saving, Solar Energy.*

## INTRODUCTION

A considerable number of settlements are remote from the grid electricity supply and do not have any commercial source of electricity. Photovoltaic (PV) system, have been a promising alternative **(Kolhe M. 2009).**

A part of solar radiation incident is absorbed by PV module as thermal energy causing. An increase in PV module temperature which decreases the efficiency of electricity generation **(Saira I., Saira A. et al., 2016).**

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Increasing the efficiency and the power output depends largely on reducing the PV surface temperature, which allows the greatest benefit from the whole system. It was found that water cooling decreased the PV surface temperature by 4 to 5 $^{o}$C, and increased the efficiency by 7 to 12%. **Timothy J. S. et al. 2018** reported that the temperature of PV modules can be decreased by reductions in heat generation waste. The heat generation waste can be reduced by:

a) reflecting unusable light from the cell.
b) cooling the back side of PV modules.
c) cooling the exposed surface of PV module.

**Waithiru Ch. L. 2018** reported that cooling PV modules by floating the PV on water improved its performance. The efficiency was recorded more than 14.69% at an annual mean yearly temperature 21.9 $^{o}$C. Also, that approximately two-thirds observed of the annual yield produced by floating PV system obtained when the module surface temperature was under 40 ◦C compared with the reference PV module which was operating in surrounding air.

Spraying water over the **PV** exposed surface significantly increases the system efficiency by 9.27 % and another benefit of using water spraying is to continuously clean the panels so the cost of cleaning can be saved **(Jailany A. T.; Abd El-Al A. et al., 2016**). The effect of using PV modules under a high temperature of 68 $^{o}$C causes electrical efficiency drop significantly to 8.6% **(Teo H.G., Lee P.S. b, et al. 201**2).

PV/Thermal concept is necessary to increase overall efficiency of all PV system by making use of waste heat energy generated in PV module **(Tonui, J. K. et al. 2007).**

**Kolhe, M. et al. 2012** reported that the drop-in efficiency of concentrated photovoltaic system (CPV) was due to the temperature rise of the solar cell. With the increased air flow rate, more heat can be extracted from the CPV module and it can help in reducing the cell temperature and hence in increasing the cell electrical efficiency.

**El-Seesy et al. 2012** made an attempt to cool down the PV cell with a thermosyphon effect polycrystalline silicon module, with a total area of 0.260 m$^{2}$, along with a copper sheet and tubing installed on the back of the module, and a thermosyphon air system with air capacity of 80 liters. The increase of relative efficiency gained was 19 %.

**The main objectives of this study are to determine:**

1- the effect of forced air cooling along the back side of PV module on its performance,
2- the optimum air velocity at which highest increasing in efficiency occurred.

## MATERIALS AND METHODS

Experiments were conducted at the Renewable Energy Laboratory, Department of Agricultural Engineering and Biosystems, Faculty of Agriculture, Alexandria University.A physical model of a PV system was developed. The system consists of PV module with an air-cooling system attached to the back of the first PV module. PV modules specifications are shown in **Table (1)**. The air-cooling system consists of duct of the same surface area as the exposed surface of the module installed to the back in which air is forced by a DC fan **(Figure 1,2)**.

**Table 1.** Technical Specifications of experimental PV modules.

| Parameter | Value |
|---|---|
| Open Circuit Voltage, $V_{OC}$ | 21.5 Volt |
| Short Circuit Current, $I_{SC}$ | 0.35 Amp |
| Power output | 5 Watt/Panel |
| Max. System Voltage, $V_{OC}$ | 21.5 × 4 = 86 Volt |
| Dimensions of PV module | 45 cm × 15 cm |
| PV model | GP-5 |

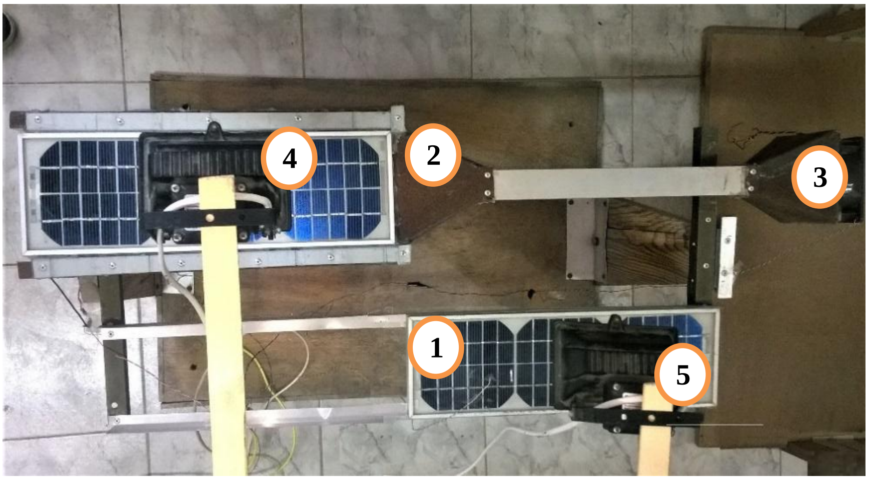


**Fig. 1.** Experimental PV system

(1) PV module without air cooling. (2) PV module with forced air cooling. (3) DC fan. (4,5) 2x150w halogen detectors.

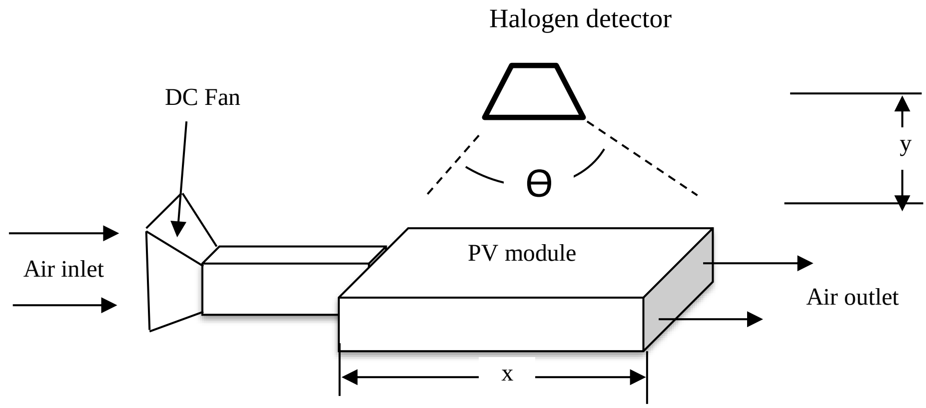


**Fig. 2.** Experimental PV system sketch.

The air velocity is controlled by changing dc voltage value using DC voltage adapter **NEVA-103**. Air velocity was measured each voltage value using thermo anemometer **VA893 (Figure 3)** at three points of the air outlet from the cooling duct installed on the back of the PV module to measure the actual velocity of air passing through the duct area section. The data was recorded, and air flowrate was calculated using equation (1) and given in **Table 2:**

$$M_{air} = A \ x \ v_{air} \qquad (1)$$

Where:

$M_{air}$= Air flow rate (m$^3$/sec),

A = net cross section area of air duct (m$^2$) (0.0075 m$^2$).

$v_{air}$ Air average velocity (m/s).

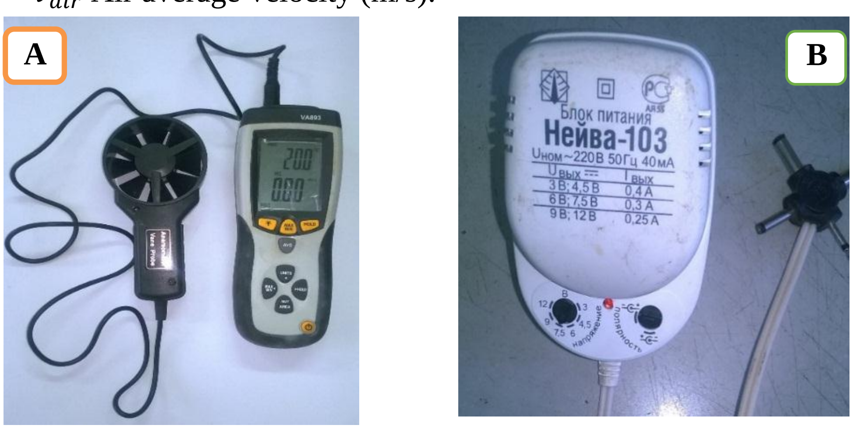


**Fig. 3.** (A) Thermo anemometer **VA893, (**B) DC voltage adapter **NEVA-103.**

**Table 2.** Calculated fan power at deferent measured air velocity

| Voltage (V) | Current (Amp.) | Air Velocity (m/sec) | Air Flow rate (m3/sec) | Fan Power (w) |
|---|---|---|---|---|
| 3.00 | 0.90 | 0.20 | 0.0015 | 2.70 |
| 4.50 | 0.90 | 1.10 | 0.0083 | 4.14 |
| 6.00 | 1.25 | 1.60 | 0.0120 | 7.50 |
| 7.50 | 1.25 | 2.00 | 0.0150 | 9.375 |
| 9.00 | 1.28 | 2.20 | 0.0165 | 11.52 |
| 12.00 | 1.28 | 2.40 | 0.0180 | 15.36 |

Constant radiation on photovoltaic was provided by halogen detectors with a capacity of 150 watts to ensure the stability of the effect of exposed radiation intensity falling on the modules as shown in **Figure 1,2.** The detector was installed at the height of the individual coverage from the surface of the module to ensure that there are no light interference between modules. The height of the halogen detector from the model surface was calculated as follow:

$$y = (\frac{X}{2})/tan\frac{\theta}{2} = 45tan\frac{60}{2} = 40\ cm \qquad (2)$$

Where: y: hight of the halogen detector from module surface,

x: the length of the largest dimension of the module **(Figure 2).**

The voltage and temperatures of solar panels were automatically measured using a data logger DL2 version 5.0, Data-T Devices Cambridge-England. PC software (Ls2Win) was first used to program the logger. Thermocouples type T (Copper-constantan) were fixed on the surface of each panel, at its air inlet and air outlet to measure the temperature. On the other side they connected to the data logger.

To connect the data logger with the PV modules, two resistances were connected between the logger and modules to obtain tested voltage. On the other side the logger was connected to a PC using a serial cable as shown in the schematic diagram in **Figure (4)**. The logger operates with voltage less than 5 volt, so according to the manual of the logger, the resistances Rs and Rsp were used to adjust the voltage, $V_{PV}$ of logger and the diode was used to protect the circuit. The value of voltage $V_{PV}$ was calculated using the following equation (**Jailany A. T.; Abd El-Al A. et al., 2016)**:

$$V_{PV} = V_1\left(\frac{R_{SP}}{R_S}\right) \qquad (3)$$

Where: $R_S$ is module series resistance (Ohm), $R_{SP}$ is module parallel resistance (Ohm), $V_1$ is measured voltage by data logger.

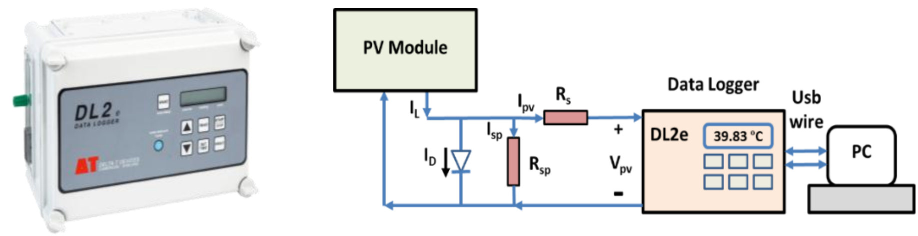


**Fig. 4.** Schematic diagram shows the connection of data logger with computer and PV modules (**Rashwan M. A.; Jailany A. T. et al., 2015)**

A microcontroller PIC16F877A control system was used to regulate PV surface temperature. The microcontroller unit was developed to control DC fan during cooling process. **Figure (5)** shows the microcontroller schematic and circuit of electronic temperature control unit that was used to construct the control unit. Control unit consists **PIC16F877A**, temperature sensor thermocouple **Type T**, LCD screen to view module surface temperature and relay to switch on/off DC fan.

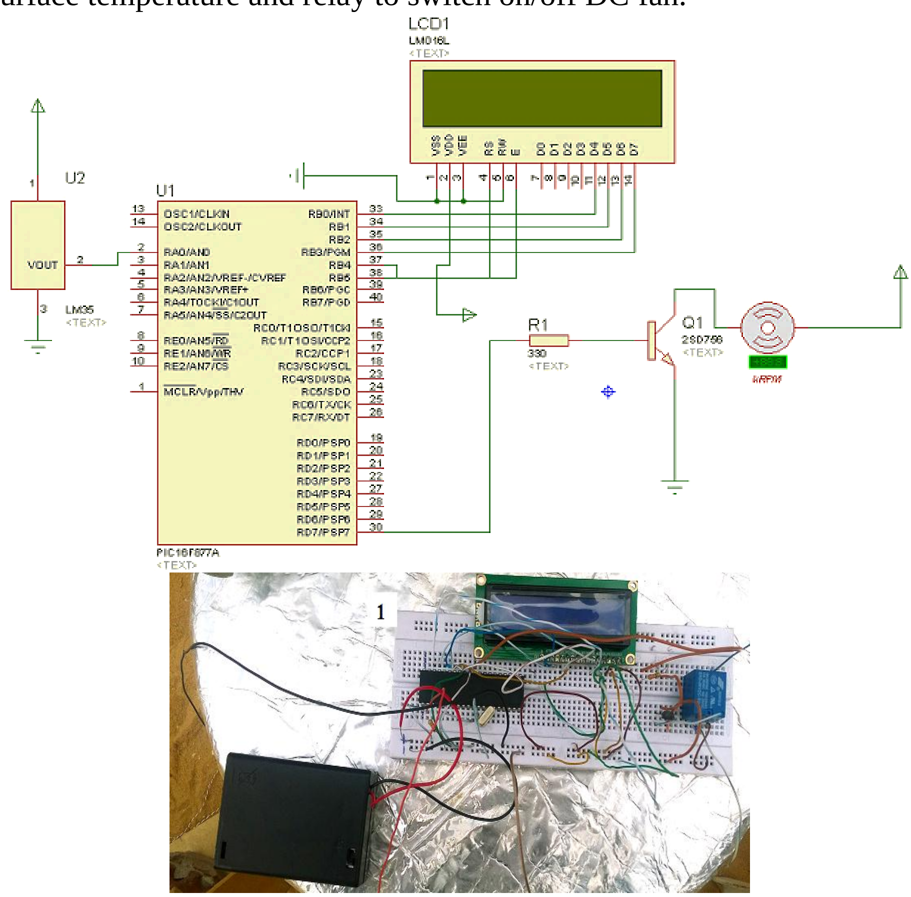


**Fig. 5.** Microcontroller schematic and circuit of temperature control unit

## RESULTS AND DISCUSSION

The values of the generated open circuit voltages from the PV modules were monitored Under the constant intensity of radiation generated by halogen detector with a change in the air velocity at different levels to study their effect on energy production.

The temperature of the module surface and the open circuit voltage of the PV were measured and recorded every minute at constant intensity of radiation and deferent air velocities.

**Figure 6** shows the relationship between time of exposure and PV surface temperature at different air velocities. It was observed that the stability of the temperature values was achieved at different time intervals according to the air-cooling velocity. The shortest time to reach the stability occurred at an air velocity of 2.4 m/sec. The results showed that by increasing the velocity of the air inside the cooling system, the temperature of the surface gradually decreases over time until it reaches the stability stage. PV module surface temperature decreased from 51.2 $^{o}$C to 25.8 $^{o}$C at by increasing air velocity from 0 to 2.4 m/sec. The standard temperature recommended for operation under Standard Test Conditions (**STC)** was obtained at air velocity of air 2.4 m/sec. Also, the results showed that increasing air velocity from zero to 2.4 m/sec decreased the temperature of the surface of the PV module from 51.2 to 25.8 as given in the **Table 3**.

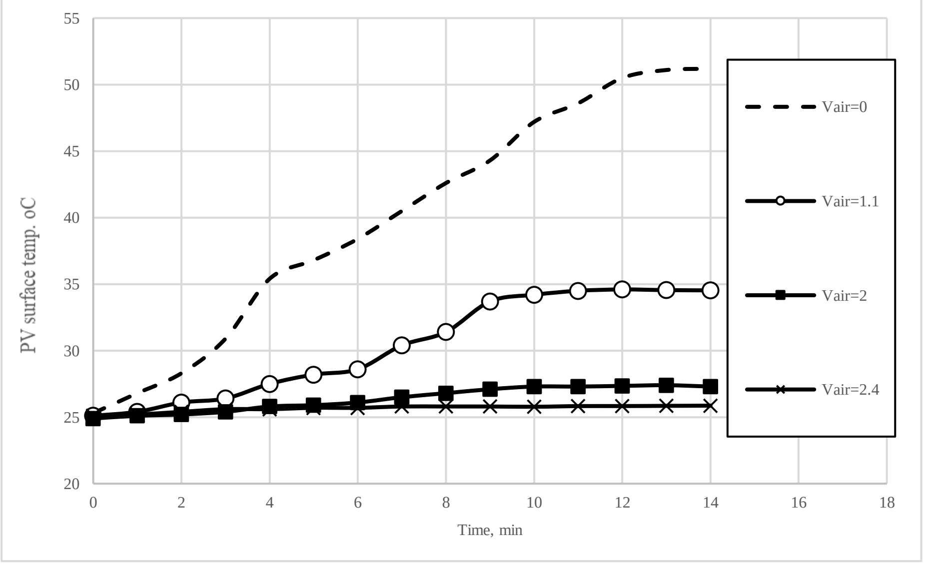


**Fig. 6.** Effect of air velocity on PV module surface temperature

**Figure 7** shows the relationship between time and PV module open circuit voltage **$V_{oc}$** at different air velocities. It was observed that the stability of the voltage values was achieved at different time intervals according to the air-cooling velocity exhibited in the model. The shortest time lag to reach the stability occurred at the air velocity of 2.4 m/sec. For each air velocity the open circuit voltage of the module gradually increased until it reached the stability stage. Results showed that by increasing the velocity of the air inside the cooling system, the open circuit voltage increased. PV module open circuit voltage increased from 17.45 to 20.82 volt by increasing air velocity from 0 to 2.4 m/sec. Also, increasing air velocity from zero to 2.4 m/sec increased open circuit voltage by as shown in the **Table 3**.

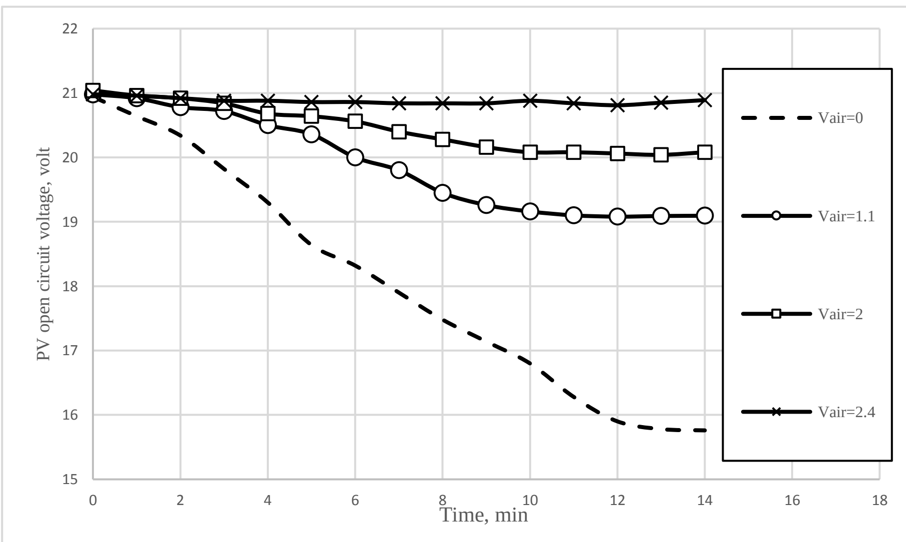


**Fig. 7.** Effect of air velocity on PV module open circuit voltage.

Regression analysis was used to obtain a relationship between open circuit voltage and air velocity and PV module surface temperature and air velocity, the results are shown in **Figure 8, 9**.

$$V_{oc} = f\ ( v_{air}, T_{surface}) \qquad (4)$$

Where: $V_{oc}$ : PV open circuit voltage,

$v_{air}$: forced air-cooling velocity,

$T_{surface}$: PV module surface temperature.

There was a linear relationship between the open circuit voltage of the PV module and the velocity of the of air as follows:

$$V_{oc} = 1.3629\, v_{air} + 17.488 \qquad R^2 = 0.99 \qquad (5)$$

A second-degree relationship was found between PV surface temperature and the velocity of air passage of as follows:

$$T_{surface} = 3.0935\, v_{air}^{\ 2} - 18.06\, v_{air} + 51.224 \qquad R^2 = 0.99 \qquad (6)$$

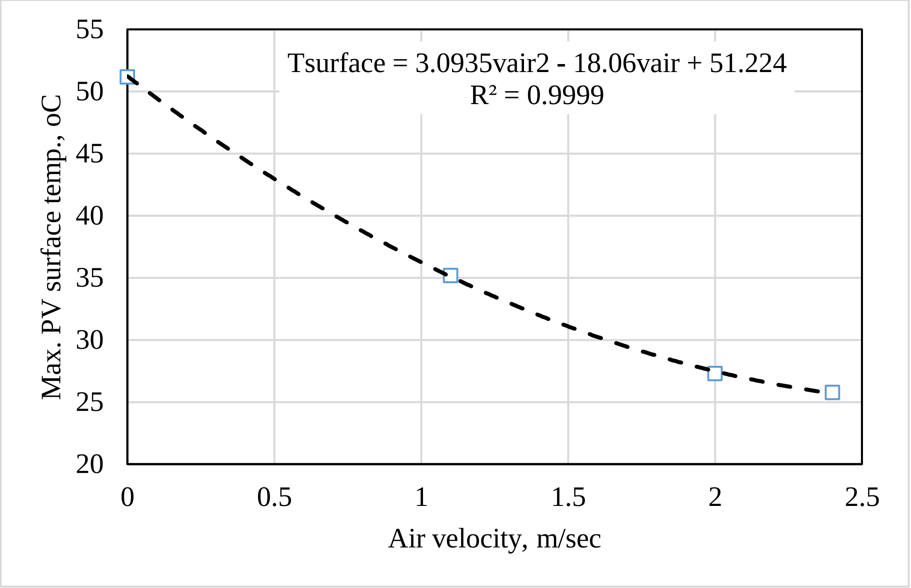


**Fig. 8.** The relationship between air velocity and PV module surface temperature.

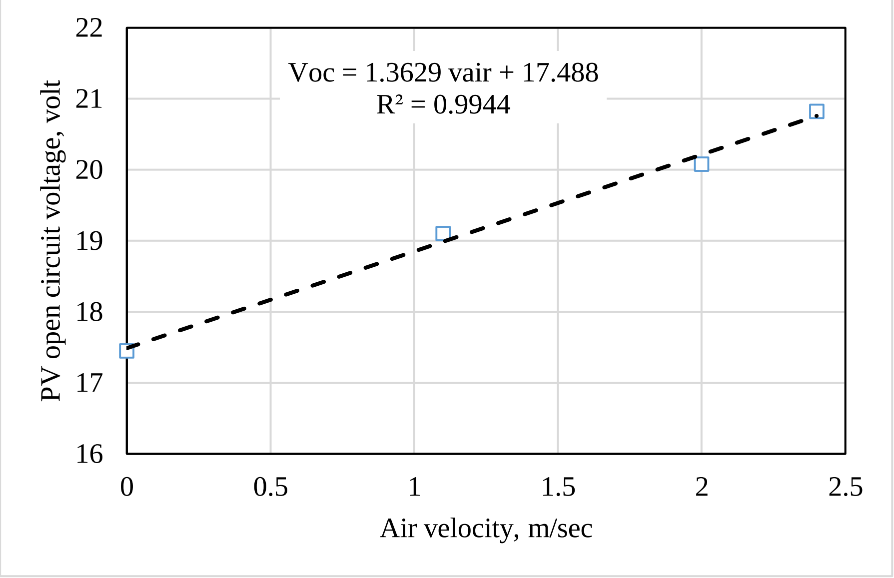


**Fig. 9** The relationship between air velocity, PV open circuit voltage.

Since the maximum value of the open circuit voltage $V_{oc}$ which can be obtained from equation (5) should not exceed $V_{oc\_STC}$ under the Standard Test Conditions (STC) for the module, the equation can be written as follows:

$$v_{air} = \frac{V_{oc} - 17.488}{1.3629} \qquad V_{oc} \leq V_{oc\_STC} \tag{7}$$

$V_{oc\_STC}$: open circuit voltage at standard test conditions.

To calculate the maximum surface temperature of the model at air velocity $v_{air}$, equation (6) can be used.

In order to calculate the maximum actual power capacity $\mathbf{P_{max}}$ of the module under the operating conditions (**The German Solar Energy Society**), the following equations are used:

$$V_{max} = (\text{from } 0.75 \text{ to } 0.9)\ V_{oc} \tag{8}$$

$$I_{mp} = (\text{from } 0.85 \text{ to } 0.95)\ I_{sc} \tag{9}$$

$$P_{max} = V_{max} \times I_{max} \tag{10}$$

*Where:*

$V_{max}$ : maximum PV voltage at maximum power point (MPP).

$I_{mp}$: maximum PV current at maximum power point (MPP).

$I_{sc}$ : short circuit current of PV.

The increase in PV module efficiency (Table 3) at different air velocities can be calculated using experimental open circuit differentials at each air velocity using the following equation:

$$\Delta\ Efficiency = \frac{V_{oc\_cool} - V_{oc\_control}}{V_{oc\_control}} \tag{11}$$

**Table 3. Energy analysis.**

| **Vair , m/sec** | **$T_{surface}$, °C** | **$\Delta T_{surface}$, %** | **$V_{oc}$, volt** | $\Delta\ Efficiency$ % |
|---|---|---|---|---|
| 0 | 51.2 | 0 | 17.45 | ----------- |
| 1.1 | 35.2 | -31.25 | 19.1 | 9.45 |
| 2 | 27.3 | -46.88 | 20.08 | 15.07 |
| 2.4 | 25.8 | -49.61 | 20.82 | 19.31 |

A microcontroller unit was developed to control DC fan during cooling process.. Microcontroller programming flow chart is shown in **Figure (10)**. The microcontroller program compares the measured temperature of the module surface ($T_{module}$) to the PV surface temperature calculated from the equation (6) which is calculated as a result of running the fan at a certain velocity.

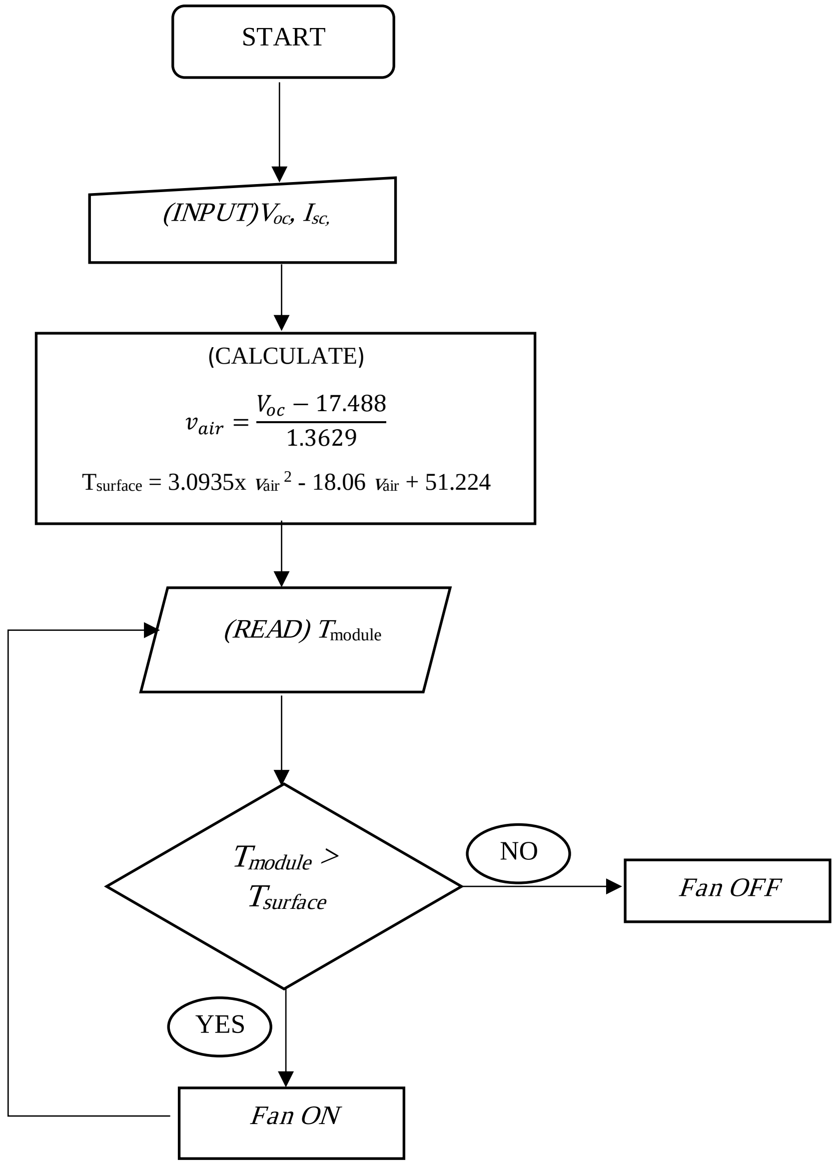


**Fig. 10.** Microcontroller programming flow chart

## CONCLUSION

In this study, was investigated the application of using air for cooling system of a photovoltaic module. Results illustrated high efficiency of the cooling process which consequently led to boosting the energy production efficiency increased as air velocity increased. The efficiency increased from 9.45% to 19.31% as air velocity increased from 1.1 to 2.4 m/sec. Experiments also showed relatively higher stability of the PV surface temperature and output open circuit voltage values after different periods of time. The standard temperature recommended for operation was obtained at low surface temperature of the module at the velocity of air 2.4 m/sec which was associated with an efficiency increase of 19.31%.

A mathematical model was derived based on the experimental results to calculate the optimum cooling air velocity according to the PV module specifications. The model is used to predict the maximum allowed PV surface temperature and the maximum power at certain air velocity.

Finally, a control unit was developed to regulate the fan based on the previously developed mathematical method. Such model enables the possibility of turning the fan off when the temperature of the model surface reaches the surface temperature calculated based on the air velocity and the open circuit voltage. On the other side, the fan will be on when the temperature exceeds the calculated surface temperature which helps avoid running the fan for long periods and thus improve energy saving.

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## الملخص العربى

# تأثير التبريد بدفع الهواء على كفاءة النموذج الكهروضوئي

**احمد تركي جيلانى* و محمد ابراهيم نصر***

ترتفع درجة حرارة النموذج الكهروضوئي اثناء عملية انتاج الطاقة الكهربية كنتيجة لامتصاص الطاقة الحرارية من الاشعاع الشمسى الساقط على النموذج مما يؤدى الى انخفاض كفاءة انتاج الطاقة. فى هذه الدراسة تم انشاء وحدة تبريد بالهواء لموديول كهروضوئي لدراسة تأثير سرعة الهواء على زيادة معدل التبريد لسطح النموذج و معدل الزيادة فى كفاءته مقارنة بنموذج اخر تحت الظروف التشغيل العادية بدون تبريد.

**الأهداف الرئيسية لهذه الدراسة هي تحديد:**

١- تأثير التبريد بدفع الهواء على الجانب الخلفي من الوحدة الكهروضوئية على أدائها،
٢- سرعة الهواء المثلى التي يحدث فيها أعلى زيادة في الكفاءة.

***مدرس بقسم الهندسة الزراعية و النظم الحيوية – كلية الزراعة (الشاطبى) – جامعة الاسكندرية.**

أظهر استـخدام الهواء في عملية تبريد سـطح النموذج الكهروضـوئي كفاءة عالية ، مما أدى إلى رفع كفاءة إنتاج الطاقة في حدود ٩,٤٥ إلى ١٩,٣١عند سرعات هواء مختلفة من ١,١ إلى ٢,٤ متر / ثانية.

وتم الحصــول على أعلى زيادة في الكفاءة ١٩,٣١ ٪ عند ســرعة هواء ٢,٤ متر / ثانية حيث أقتربت درجة حرارة سطح النموذج من درجة الحرارة القياسية الموصى بها للتشغيل و هى ٢٥ درجة مئوية.

كما تطرق البحث الى استخدام النتائج التجريبية فى استنتاج نموج رياضى لحساب افضل سرعة هواء تبريد لازمة للحصول على افضل اداء للنموذج الكهروضوئي.

و ايضـــا تم تصـــميم وحدة تحكم الى باســـتخدام PIC16F877A للتحكم فى تشـــغيل و ايقاف المروحة خلال فترة انتاج الطاقة الكهربائية لتجنب التشغيل المستمر للمروحة دون جدوى.