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REGULAR ARTICLE

Impact of Active and Passive Cooling on Photovoltaic Modules Performance's

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The limitation of the efficiency of photovoltaic modules comes mainly from the thermal or optical (transmission) losses. Overheating of silicon photovoltaic panels due to excessive solar radiation and high ambient temperatures is a major problem. This paper focuses on analyzing the effect of heat losses on photovoltaic module performance. In order to determine the electrically sensible parameter that is the cause of the degradation in solar cell performance as a function of temperature, we will first conduct a simulation study to investigate the effects of temperature on the physical and electrical characteristics of PV modules. Following this, we conducted an experimental study to demonstrate the significance of an active cooling system in comparison to a passive one. A circuit based on the Arduino board has been developed to automate this cooling procedure.

Keywords: Solar cell, Passive cooling, Active cooling, Arduino, Efficiency.

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1. INTRODUCTION

The future of economic growth mostly depends on the availability of sustainable energy from affordable, accessible, and environmentally friendly sources. Energy plays a significant role in determining public health, climate change, and security. Despite being regarded as a basic human need, access to electricity is still extremely unequal in the twenty-first century [1].

According to the majority of forecast experts, commercial primary energy consumption is expected to increase by two by 2030 and by three by the end of 2050. Nevertheless, a significant portion of electricity generation comes from burning non-renewable resources: (Nucleaire 5.9 %, Gas naturel 20.9 %, Charbon 26.5 %, and Petroleum 34 %) [2].

Due to the rising costs of conventional energy sources (fossiles) and the depletion of their resources, photovoltaic energy is becoming more and more popular as an alternative energy source. She has several advantages, including her potential for abundance, its renewable nature, its non-polluting nature, and its availability in varying amounts throughout the world. Thermalization or transmission losses are the main causes of the observed decrease in efficiency and physical defects in solar modules [3].

Understanding how photovoltaic modules react to temperatures – which in desert areas can reach 63 °C – is crucial when installing them in various locations [4]. Accordingly, the temperature of the solar panels is raised to 75 °C, which results in a 25 % decrease in performance.

The study of the effect of temperature on photovoltaic modules and cooling solutions allows us to quantify the thermal losses in the solar cell and PV modules, improve the performance of PV modules operating under these conditions and choose the most appropriate material in the manufacture of PV modules that ensures optimal operation in the climatic conditions of the chosen site.

In general, the cooling methods that are employed can be either passive, active, or hybrid (a mix of passive and active methods). Active cooling approaches rely on forced convection to transfer heat and require a temperature sensor, a mechanical pump to ensure continuous circulation of the colporteur fluid, and an electrical circuit to control this process. Because passive cooling methods are relatively easy to use and don't require external power, they can be implemented at a relatively low cost [5].

2. EFFECTS OF TEMPERATURE ON A PV MODULE'S PERFORMANCE

The photovoltaic module is the basic element of any solar PV installation. One crucial parameter for assessing the performance of PV modules is temperature. The characteristics of photovoltaic modules are extremely sensitive to temperature changes; in terrestrial

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applications, they are typically exposed to temperatures ranging from 10 to 50 °C. Typically, photovoltaic modules are made of semi-conducting materials. The voltage in the open circuit of these materials depends on the lighting current and the operating temperature of the PV module, which can be found using the following formula [6]:

$$V_{OC} = \frac{A \times K_B \times T}{q} ln\left[1 + \frac{J_L}{J_0}\right] \quad (1)$$

Where J_L is the illumination current of the solar cell or PV module, J_0 the saturation current, K_B: Boltzmann constant, q: the electric charge, A: is a constant.

On the other hand, the open circuit voltage can be given, as a function of the energy band gap of the semiconductor material, as follows:

$$\mathrm{V}_{OC} = \frac{E_g}{q} - \frac{\mathrm{KT}}{q}\left(\frac{\mathrm{j}_{sc}}{\mathrm{j}_{00}}\right) \quad (2)$$

Where: E_g is the band gap energy of the semiconductor material and j_{00} is a saturation current density pre-factor [7]. The band gap energy is in turn given by the Varshni equation:

$$E_g(\mathrm{eV}) = \mathrm{E_{g0}} - \alpha\, \mathrm{T}^2 / (\mathrm{T} + \beta) \quad (3)$$

Where T is the absolute temperature in Kelvin, E_{g0} is the band gap at T= 0°K. β and α are two constants.

On the other hand, the efficiency of the photovoltaic module is a function of the open circuit voltage:

$$\eta = \frac{Pout}{Pin} = \frac{V_{CO} \times Icc \times FF}{Pin} \quad (4)$$

Where: Pin is the incident light power in W/m^2, FF is the fill factor, I_{cc} is the short-circuit current, and V_{co} is the open-circuit voltage of the PV module.

3. THE VARIOUS ACTIVE AND PASSIVE SOLUTIONS USED FOR COOLING PV MODULES

As the temperature of the PV module rises, its performance decreases over time. In order to effectively prevent an excessive rise in temperature, numerous cooling systems have been developed and researched. There are many different cooling techniques used to cool solar cells, including passive cooling, active cooling, cooling with phase-changing materials (PCM), and cooling with PCM combined with other additives like nanoparticles or porous metal. Our work focuses on cooling methods for photovoltaic (PV) panels, including both active and passive ones [8].

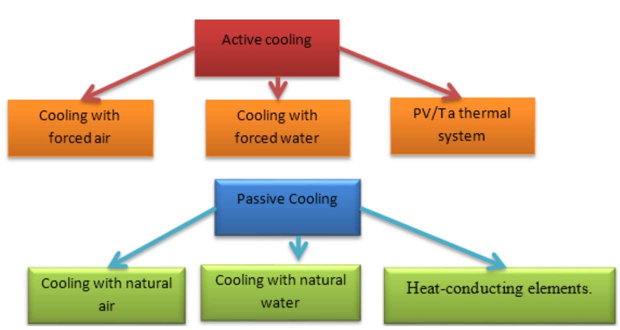

Fig. 1 – Different Cooling Methods

4. METHODS

The effect of temperature on the solar cell will be simulated in this section. To do this, we used the simulation program SCAPS-1D, which allowed us to simulate how the cell would behave as the temperature rose. The simulation was conducted under a fixed 1000 W/m^2 radiation exposure with resistance series null and infinite shunt resistance. The construction of the solar CIGS cell under the SCAPS-1D solar simulator is shown in figure [9]. The variation of characteristics I–V with temperature variation is of interest in this simulation.

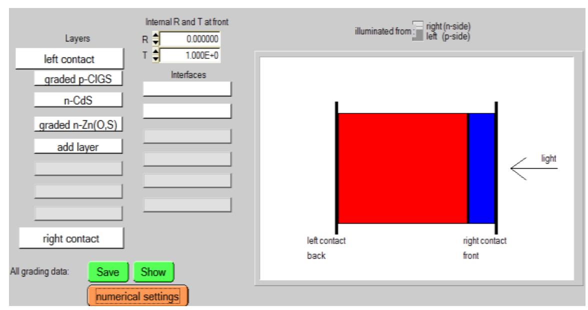

Fig. 2– Structure of the CIGS solar cell under the SCAPS-1D solar simulator

After performing the simulation of the solar cell at different operating temperatures, the results obtained are shown in Figs. 3-6. It is observed that the performance of the solar cell decreases with increasing temperature, except for the short-circuit current, which shows a slight increase. The excitation of electrons by photon absorption is caused by the intensification of thermal induction. However, the band gap width, corresponding to the energy required to transfer electrons from one band to another, may slightly decrease with increasing temperature. This causes a slight increase in the short-circuit current, as can be observed in the characteristic graphs of a CIGS cell (Figs. 3 and 4).

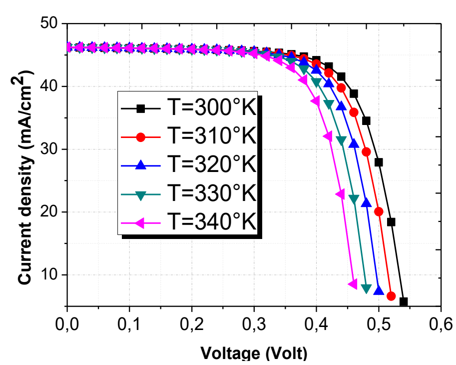

Fig. 3– Variation of the *J-V* characteristic of the CIGS solar cell as a function of temperature variation

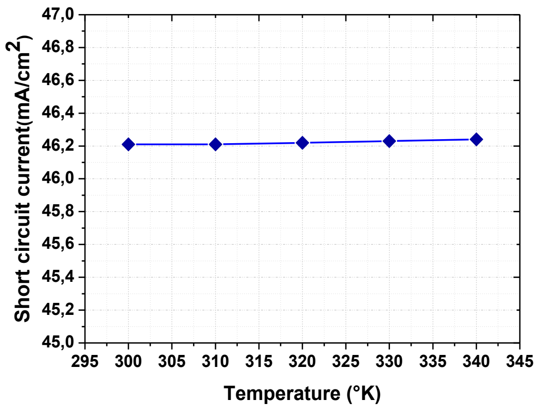

Fig. 4 – Effect of temperature on short-circuit current of CIGS solar cell

The increase in the solar cell's temperature also results in a decrease in the open circuit tension (V_{co}). This last decreases with temperature by around 0.002V/°C (Fig. 5). The open circuit tension is highly sensitive to temperature. A decrease in the overall performance of the solar cell may result from the reduction in open circuit tension combined with an increase in temperature.

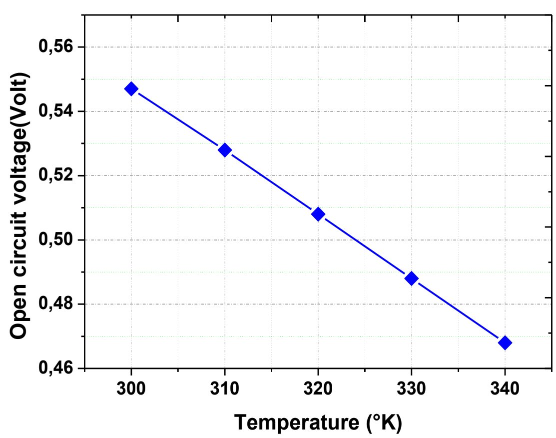

Fig. 5– Effect of the temperature on the open circuit voltage of CIGS solar cell

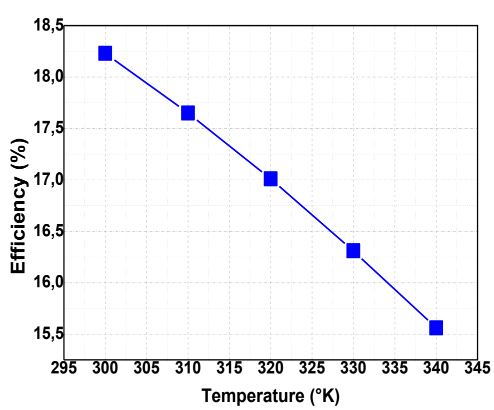

Fig. 6– Effect of the temperature on the efficiency of CIGS solar cell

In this experimental section, we conducted a comparative analysis of the heating of a photovoltaic cell under the following different conditions: without cooling, with passive cooling, and active cooling using cold air. In all these cases, we studied the evolution of the open-circuit voltage as the temperature increases, because this factor is directly related to the temperature of the solar cells, as demonstrated by the mathematical relationship (Eq. 1) and the simulation results present in the first section. The lighting and the heating of the solar cell were provided by a 100-watt lamp. A thermocouple was connected to a Multimeter was used to measure the temperature of the solar cell. The results of the tests are shown in the Fig. 7.

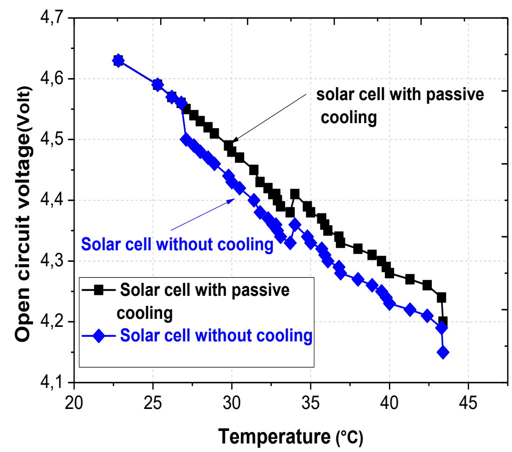

Fig. 7– Comparison of open-circuit voltage variation of solar cell with and without passive cooling

The behavior of the Si solar cell with and without passive cooling is contrasted in Fig. 7. This graphic shows that the open circuit voltage increases with passive cooling. In other words, an increase in the Si solar cell's performance based on temperature change.

A comparison between the solar cell with passive cooling and the same solar cell with active air cooling is made in this section. To achieve this, a circuit based on an Arduino card has been developed that allows the control of the active cooling cycle of the solar cellule with cold air, i.e., the control of a fan to cool the solar cellule according to an optimal operating temperature.

The Arduino-Uno card and the active air-cooling system (ventilator) must ensure the following functions:

– the measurement of the solar cell's operating temperature;

– the ventilator starts to work if the operating temperature rises beyond 40 °C;

– the ventilator stops if the solar cell's temperature reaches 25 °C following the cooling cycle;

– the cellule's temperature is shown on an LCD screen throughout operation.

The temperature sensor is connected to the Arduino board with three pins, the first two are V_{cc} (5 Volt) and GND (0 Volt) for the sensor power supply, the third pin is connected to the analog input of the Arduino board (A0).

This pin of the LM35 sensor represents the sensor output (OUT) in voltage, at the Arduino board, the value captured by the pin (A0) in voltage is converted by the Arduino board into temperature according to the following formula:

value=analogRead(an1);

Temp=(value×5×100)/1023;

The Arduino card's program enables it to compare the temperature recorded by the sensor with reference temperatures. If the recorded temperature is higher than the predetermined threshold (40°C), the card sends a signal to the ventilator to begin cooling via broche 10 with a 5 V tension. The generated signal flows to the transistor 2N2222's base via the resistance (R). This last enables the relay to be closed and the ventilator to start

Table 1 – Description of the electrical components of the control circuit based on the Arduino card

Components	Functioning
Potentiometer:	Adjusting the LCD screen brightness
An LCD display:	Solar cell operating temperature display
Arduino UNO board:	Command interface
LM35 Temperature Sensor:	Solar cell operating temperature detection
Relay G2R 14-AC120 :	Fan operation control switch
DC Fan:	Cooling the solar cell
2N2222 Transistor:	Amplification.
1N4004 Diode:	Protection
100Ω Resistor:	Transistor polarization
Solar cell Si	Conversion of the light into the electrical energy.

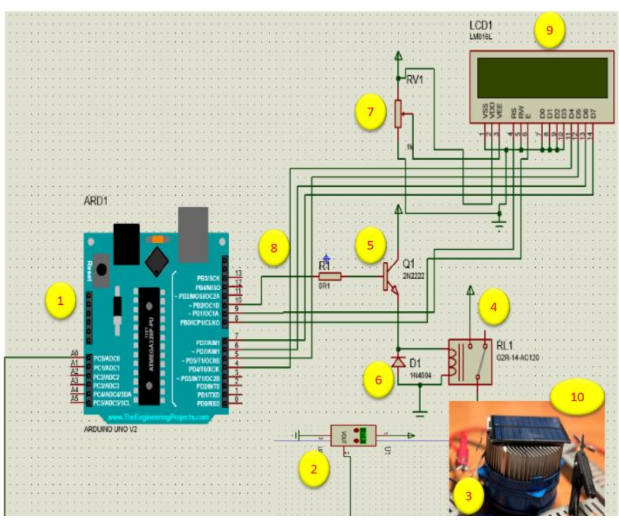

Fig. 8– Synoptic schemes for the Arduino card with the circuit for commanding the solar cell cooling system. 1: Arduino Card, 2: Temperature sensor LM35, 3: Fan, 4: Relay G2R 14-ac120, 5: Transistor 2N2222, 6: Diode 1N4004, 7: Potentiometer, 8: Resistor, 9: LCD, Solar cell

cooling the solar cell until the sensor reaches 25°C. The Arduino card then sends another interruption to the relay to end the cooling cycle Fig. 8. The Table 1, presents a description of the electrical components of the control with the Arduino card.

According to the results, which are shown in Fig. 9, cooling with active circulation of cold air allows the solar cell to quickly restore these performances (improvement of open circuit tension) in comparison to passive cooling.

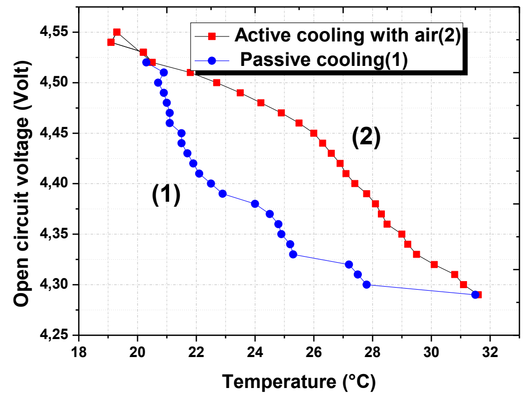

Fig. 9– Comparison of open circuit voltage variation of a solar cell with passive cooling and active cooling

5. CONCLUSION

We examined the impact of temperature on solar cells in this work and showed how temperature increases have a negative impact on the behavior of these cells. Therefore, we have suggested ways to address this issue by employing both passive and active cooling strategies. An investigation into how solar cells behave when temperatures rise has been conducted through simulation. The results produced by the solar simulator SCAPS-1D show that the cells' electrical performance deteriorates due to a decrease in open circuit tension, which is directly related to the material's properties (energy gap). Experiments have confirmed the simulation results obtained, confirming the same behavior of the solar cellule against temperature increase. Several tests have been conducted on a solar cell in Si: without cooling, with passive cooling (Finned radiator), and with forced air. The sum of the results clearly demonstrates the contribution that cooling makes to the improvement of open circuit tension, which in turn enhances solar cell performance. Accordingly, a circuit based on an Arduino card has been developed to offer an automatic cooling solution. With the help of the developed program, we were able to control the solar cell's temperature by using a continuous current ventilator. This facilitates the integration of these solutions into autonomous photovoltaic systems. We envision the large-scale implementation of this cooling technique using standard-sized solar panels to monitor and control electricity generation.

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Вплив активного та пасивного охолодження на продуктивність фотоелектричних модулів

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Обмеження ефективності фотоелектричних модулів пов'язане головним чином з тепловими або оптичними (пропускальними) втратами. Перегрів кремнієвих фотоелектричних панелей через надмірне сонячне випромінювання та високі температури навколишнього середовища є серйозною проблемою. Ця стаття зосереджена на аналізі впливу теплових втрат на продуктивність фотоелектричних модулів. Щоб визначити електрично чутливий параметр, який є причиною погіршення продуктивності сонячних елементів як функції температури, ми спочатку проведемо моделювання впливу температури на фізичні та електричні характеристики фотоелектричних модулів. Після цього ми провели експериментальне дослідження, щоб продемонструвати важливість активної системи охолодження порівняно з пасивною. Для автоматизації цієї процедури охолодження була розроблена схема на основі плати Arduino.

Ключові слова: Сонячний елемент, Пасивне охолодження, Активне охолодження, Arduino, Ефективність