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# EFFECT OF OPERATIONAL TEMPERATURE ON VOLTAGE GENERATION OF PHOTOVOLTAIC PANEL AND A REVIEW TO COOLING SYSTEMS

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**Abstract-** Photovoltaic (PV) solar panel receives radiations from the sun. One part of those radiations is transformed into electricity. The photons in the solar radiation collide with the electrons in the photovoltaic cell thus electricity is produced. External factors such as operational temperature influence this electricity production by the PV module. This paper presents a system of solar panel designed in MATLAB-Simulink software and the results are shown and discussed. The rise of operational temperature *T* decreases PV module electrical efficiency. To protect PV module against this undesired impact of the temperature, PV solar panel cooling methods are analyzed and suggested in this work.

**Keywords:** PV Solar Panel, Photons, Temperature, Cooling Systems.

## 1. INTRODUCTION

For a long time, fossil fuels have been used to produce electricity. Unfortunately, this form of energy releases greenhouse gases which are harmful to our mother nature. Furthermore, utilization of fossil fuels accelerates the phenomenon of "global warming". In addition, the pollution of the atmosphere causes some parts of the world to be uninhabitable.

The emission of $CO_2$ gas into the atmosphere and the increase of the Earth average temperature can lead to serious unpredictable and irreversible consequences such as the appearance of the hole in the ozone layer, melting of the ice at the North Pole, the increase in sea level, floods, multiplication of earthquakes, unexplained plate tectonics, lack of rain, climate change, droughts, forest fires and erosions. At this stage, the decarbonization of the global economy and the energy transition towards clean and sustainable energies are crucial to save our planet [1].

Aware of the situation, in 2015 the Paris $COP_{21}$ set limitations such as lowering the average temperature increase to below 1.5 °C until 2050 [2]. The electric solar panel produces electricity throughout the day. In fact, it transforms part of the solar radiation it receives from the sun into electricity. An increase in the operational temperature *T*, causes a decrease of the PV module efficiency. To demonstrate this effect, a system of PV module is concepted in MATLAB-Simulink software in this paper [3]. The designed system contains the temperature *T* and irradiance *G* subblock. Results are presented and discussed.

Karakilic, et al. [4] Affirmed that not only temperature but also solar irradiation causes a decrease in PV electrical efficiency. Over the years researchers have developed several PV module cooling methods in order to protect PV module against the effect of the operational temperature.

Tripanagnostopoulos and Tonui [5] developed a concept of PV cooling technique that has less use of materials. To achieve that two different techniques of attached metal sheet and perforated rear wall of an air-channel are done. Ambient air is the suitable working fluid to accomplish minimal use of material concept.

Duell, et al. [6] studied the light transmission and module temperature on structured glasses on the PV module. Grooves, pyramids, inverted pyramids and lightly textured glasses are the objects of the experiment. They also mentioned that the velocity of the wind plays a fundamental role in the cooling effect because higher wind speed causes the PV module temperature to decrease [6].

Hawlader, et al. [7] investigated on with and without of an active cooling technique implemented on the hybrid solar approach consisted of array of duct positioned in parallel at rear side of the PV panel. To facilitate uniform airflow distribution, inlet/outlet manifold was used.

Akbarzadeh and Wadowski [8] mentioned the problem of uniform distribution of solar radiations received on the surface of the PV cells. As a solution, they proposed to develop reflecting surfaces so that the cells could be uniformly irradiated. In other part to participate to the dropping of the photovoltaic cell temperature, thermosyphon cooling technique is tested to the system. The results are discussed [8].

Elminshawy, et al. [9] investigated on the earth-to-air heat exchanger (EAHE) which in the first step cool the ambient air and then in the second step uses the pre-cooled ambient air to cool the back of the photovoltaic panel. Performance of PV module is reported [9].

Harahap, et al. [10] worked on an active cooling technique which basically consists of flowing water on the front side of the PV panel. They declared an enhancement of efficiency is obtained. Results of the experiment are shown and discussed.

Najafi, et al. [11] proposed the Peltier effect cooling process in order to decrease the solar cell surface temperature. Basically, using thermoelectric cooling module attached at the rear side of the solar cell simultaneously lead to a decrease of the solar cell surface temperature in addition to the optimization of the maximum output power of the system. At the end of the investigation, the results are analyzed and discussed.

Elminshawy, et al. [12] explained the buried water heat exchanger (BWHE) integrated with PV concentrator system. Water is used as a working fluid. The influence of this cooling technique is conducted on the reducing surface temperature of PV cell, the generated electrical power (GEP), electrical and thermal efficiency. The flow rate of cooling water and the results are shown and discussed.

Chenkenbah, et al. [13] proposed a solution of using Fuzzy Logic Controller for the PV system which encounters partial shading issues that cause a decrease in electrical efficiency.

## 2. THEORICAL KNOWLEDGES

Figure 1 illustrates one diode PV cell circuit [14].

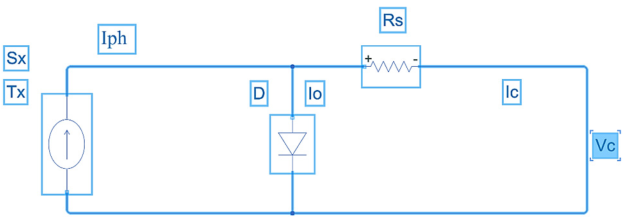


Figure 1. One diode PV cell circuit [14]

The above model is an equivalent electrical circuit of PV cell and from this model output voltage of the single cell $V_c$ and output current of the single cell $I_c$ are obtained.

A mathematical equation of the PV cell parameters which depend on the operational temperature $T$, are demonstrated in Equation (1) which $V_{OC}$ is a highest tension that can be possibly supplied from one PV cell. Its expression is:

$$V_{oc} = \frac{nKT}{q \ln\left(\frac{I_l}{I_o} + 1\right)} \tag{1}$$

The Equation (1) explicitly indicates that $V_{OC}$ depends of the operational temperature $T$. The fill factor $FF$ determines the maximum power and it is calculated using the following formulation:

$$FF = \frac{P_m}{I_{sc}.V_{oc}} = \frac{I_m.V_m}{I_{sc}.V_{oc}} \tag{2}$$

where, $\eta$ is the efficiency of a solar cell, it can be computed using the equation:

$$\eta = \frac{P_m}{P_{in}} = \frac{I_{sc}.V_{oc}.FF}{P_{in}.A} \tag{3}$$

The Equations (2) and (3) explicitly indicates that electrical efficiency and fill factor depend on $V_{OC}$ which depends on the operational temperature $T$. $V_c$ is the PV cell output voltage. It is calculated using the equation:

$$V_c = \frac{A_1.K.T_c}{e} \ln\left(\frac{I_{ph} + I_o - I_c}{I_o}\right) - R_s.I_c \tag{4}$$

PV cell current $I_c$ is found by using the equation:

$$I_c \cong I_{ph} - I_o.\left\{e^{\frac{e}{K.T_c}(V_c + R_s.I_c)} - 1\right\} \tag{5}$$

The Equations (4) and (5) indicate that the output voltage of the cell $V_c$ and output current of the cell $I_c$ depend on the temperature of the cell $T_c$ which depends on the operational temperature $T$.

The equations above showed that all the characteristics of photovoltaic cell depend on the operational temperature $T$.

## 3. SIMULATION IN MATLAB/SIMULINK

To demonstrate the influence of temperature on the electric efficiency of PV module a system has been created using MATLAB/Simulink software. Figure 2 shows the conception of $V_c$ subblock and $I$ followed the equation in (4) to concept the below $V_c$ subblock in MATLAB. The parameters used to create $V_c$ subblock are explained in Table 1.

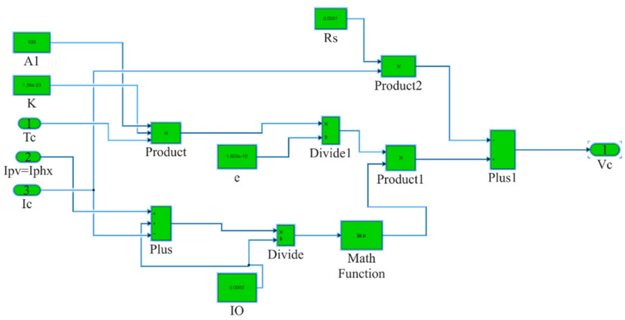


Figure 2. The $V_c$ subblock

Table 1. Parameters of $V_c$ subblock [15]

| Parameters | Values |
|---|---|
| $A_1$ | 100 |
| $K$ | 1.38e$^{-23}$ J/°K |
| $T_c$ | 20 °C |
| $R_s$ | 0.001 Ω |
| $e$ | 1.602e$^{-19}$ C |
| $I_{ph}$ | 5 A |
| $I_o$ | 0.0002 A |

Next step is to create temperature and irradiance subblock. To achieve that, $C_v$ is the voltage coefficient and $C_i$ is the current coefficient. The equations for $C_v$ and $C_i$ are shown as:

$$C_{TV} = 1 + \beta_T\left(T_a - T_x\right) \tag{6}$$

$$C_{TI} = 1 + \frac{\gamma_T}{S_c}\left(T_x - T_a\right) \tag{7}$$

$$C_{SV} = 1 + \beta_T \alpha_s \left( S_x - S_c \right) \quad (8)$$

$$C_{SI} = 1 + \frac{1}{S_c} \left( S_x - S_c \right) \quad (9)$$

Above Equations (6)-(9) have been used for the creation of the temperature and irradiance subblock in Figure 3.

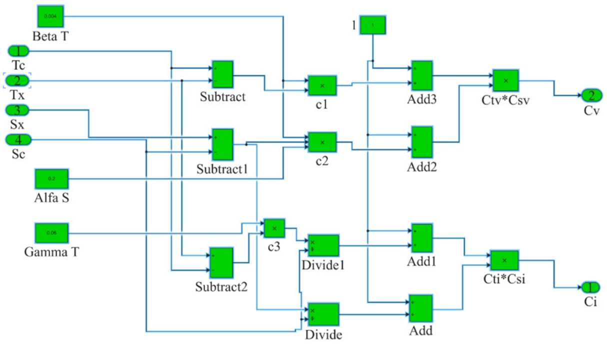


Figure 3. Temperature and irradiance subblock

The parameters used to create temperature and irradiance subblock are explained in Table 2.

Table 2. Parameters of $C_I$ and $C_V$ formulas [15]

| Parameters | Values |
|---|---|
| $T_x$ | $T$=28 °C, $T_2$=80 °C and $T_3$=100 °C |
| $T_a$ | 20°C |
| $S_x$ | 75.34 W/m$^2$ |
| $S_c$ | 100 W/m$^2$ |
| $\beta_T$ | 0.004 |
| $\alpha_S$ | 0.2 |
| $\gamma_T$ | 0.06 |

All the mathematical Equations (1)-(9) are inspired of and taken from Altas [15].

## 4. RESULTS AND DISCUSSION

In this part, performance and response of the system that has been designed in MATLAB/Simulink is presented. Only the $T_x$ values are changed in order to show the effect of the temperature. The other parameters remain the same as $N_s$ = 100, $N_p$ = 90 and $S_x$ = 75.34 W/m$^2$. In Figures 4-9, *V-I* and *V-P* curves for different $T_x$ values are illustrated.

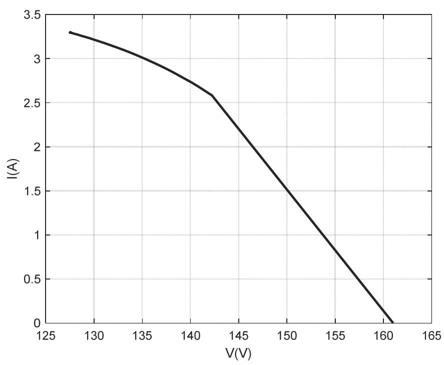


Figure 4. The *V-I* curve for $T$ = 28 °C

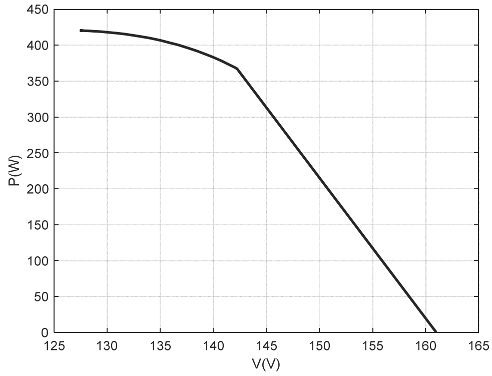


Figure 5. The *V-P* curve for $T$ = 28 °C

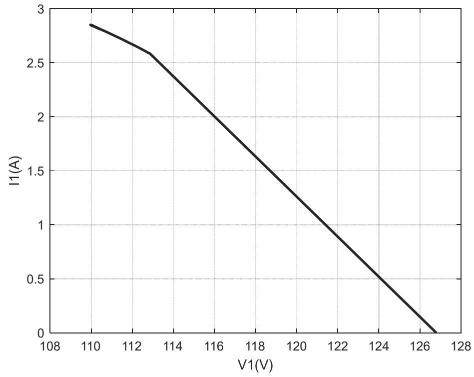


Figure 6. The *V-I* curve for $T_1$ = 80 °C

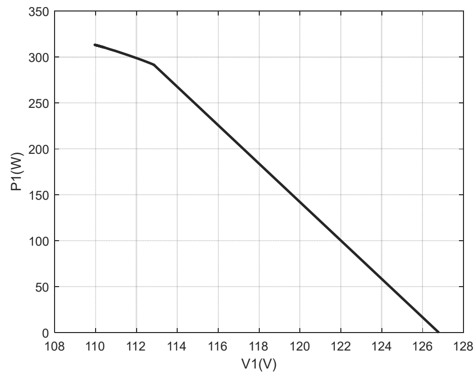


Figure 7. The *V-P* curve for $T_1$ = 80 °C

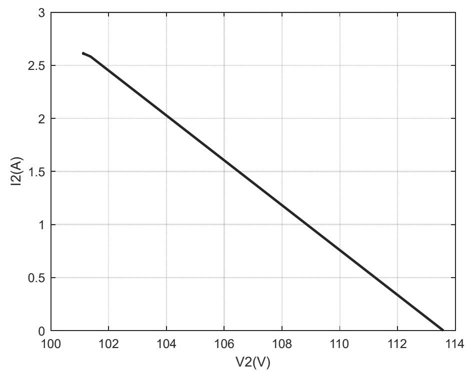


Figure 8. The *V-I* curve for $T_2$ = 100 °C

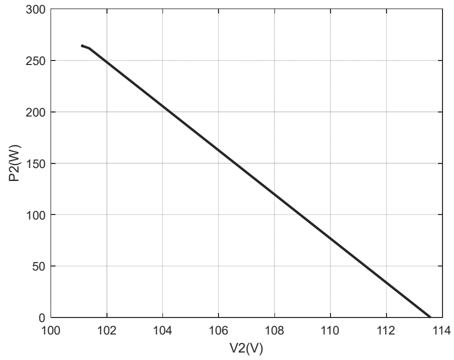

Figure 9. The $V$-$P$ curve for $T_2$ = 100 °C

In the Figure 10, all the $V$-$I$ characteristics are gathered in a same axis to draw an explicit conclusion. In the Figure 11, all $V$-$P$ characteristics are gathered in a same axis to draw an explicit conclusion.

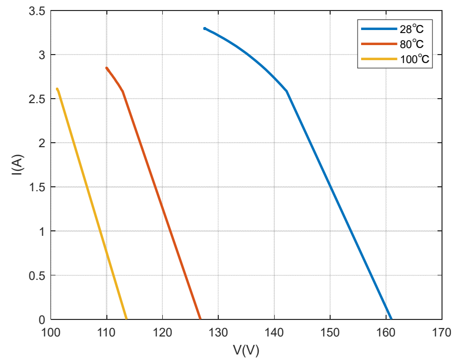

Figure 10. The $V$-$I$ curves for $T$ = 28 °C, $T_1$ = 80 °C and $T_2$ = 100 °C

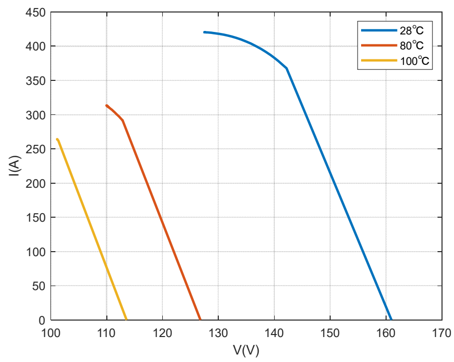

Figure 11. The $V$-$P$ curves at $T$ = 28 °C, $T_1$ = 80 °C and $T_2$ = 100 °C

From $V$-$I$ and $V$-$P$ curves at various temperatures, it is concluded that; when the operational temperature $T_x$ increases, the values of voltage $V$ and power $P$ decrease. However, the values of current $I$ are increasing slightly. The ambient temperature $T_x$ has an effect on the electric production of the PV panel. Any change in atmospheric ambient temperature affects the behavior of PV panel. The impact of temperature on the electric production of the PV panel is presented in this paper. Solar irradiation is also another external factor to influence the efficiency of PV panel. It was concluded that current and power increase with the increase of operational solar irradiation. However, the voltage increases slightly in the polycrystalline technologies [4].

## 5. A REVIEW TO THE COOLING METHODS

With a view to overcome the effect of the temperature rise on the efficiency of the PV panel, several cooling methods are developed in the literature. Some of these techniques are given in this section.

### 5.1. Fan and Pump Cooling Approaches

Irwan, et al. [16] studied the effect of a fan and pump cooling methods. The cooling process in the two systems are same. When the operational temperature $T$ starts to increase the temperature sensors LM 35 detect the problem and send immediately the analog data to the circuit of commands.

The Midi Logger GL220 records the data send by the temperature sensors. In the next step, the microcontroller PIC18F4550 commands the DC brushless fan to ventilate the rear side of the solar module and hence the PV system starts the cooling procedure in order to eliminate the effect of rising temperature. In the water pump cooling system, the microcontroller PIC18F4550 commands the DC pump to sprinkle water on the top layer of the PV panel and begins to cool the system. The results of the comparison are discussed.

### 5.2. Ground-Coupled Central Panel Cooling System

Sahay, et al. [17] researched about a financially inexpensible PV module cooling technique. Suitable for huge central panel, the ground-coupled central panel cooling method is a technique driven by a heat exchanger.

The cooling process begins when the blower creates a forced convection of the air. It moves the ambient air into the entrance pipe of the ground-coupled heat exchanger. The pipe takes the warm air down in the ground where its temperature is dropped. it uses the Earth's relatively constant temperature to dissipate the heat from the warm air. The cool air goes out of the nozzles located on the rear part of the solar panel [17].

### 5.3. Floating Tracking Cooling Concentrating System

In general, PV plants encounter limitations such as thermal drift (temperature influence), the availability of lands that is not occupied by buildings and the expensive price of the tracking system. Cazzaniga, et al. [18] proposed a solution to solve the limitations encountered by PV plants. Floating Tracking Cooling Concentrating System (FTCC) is one way to produce electricity from PV panels and to cool the system.

Basically, the FTCC technology is a floating PV module which are built on a platform that is supported by a polyethylene tubes. The platform is constructed on rafts that float on the surface of lake or artificial basins. Three different configurations of the FTCC technology on the surface of lake are discussed and analyzed. Not only for the cooling aspect of the panels by water sprinklers, FTCC also provides other features such as a tracking system and concentrating system composed by reflectors which concentrate the solar radiation to increase the production.

### 5.4. Hybrid Photovoltaic/Thermal System Sing Zn-H2O Nanofluids Cooling Technique

Hussein, et al. [19] examined the impact of water and Zn-$H_2O$ nanofluids in the hybrid solar photovoltaic system which is simply a solar photovoltaic system connected to the collector. The major problem in this system is the heat accumulated in PV cells. The working fluid is used to extract heat from PV cells and that way to decrease the temperature and thus to participate in the cooling manner of the solar module. The objective of the collector is to transfer heat out of a solar module to water or Zn-$H_2O$ nanofluids. Shaped in a form of serpentine, the collector is built at the back side of the solar module.

Zn nanoparticles are used to enhance thermal conductivity, which means to improve heat transfer. The heated water is replaced by fresh new water by convection and that way the cycle of cooling technique continues. The heated water can be used for domestic appliances. The Zn-$H_2O$ nanofluids with five different concentration ratios of 0.1, 0.2, 0.3, 0.4 and 0.5% are analyzed and the outcome are shown and discussed in [19].

### 5.5. Pin Fin-Heat Sink Cooling Technique

Hamza, et al. [20] reported that thermoelectric heat sink (THS) can be used to remove heat from PV module surface and rejected outside. Air flows naturally between the fins. Absorbed heat is dissipated in the pin fin-heat sink. Cooled and fresh air comes from inlet and absorbs and dissipates the heat.

In a consequence, the top layer temperature of PV module is decreased. To indlcate which design has the best cooling process on the PV panel the original, circular, square and triangular carved different geometrical configurations of the pins on the heat sink are analyzed and the results are discussed.

### 5.6. Forced Water Circulation Cooling Technique

Arefin, et al. [21] explained the hybrid PV module cooling system associated with the flate-plate collector. Water is used in this cooling system because it has the highest specific heat. The cooling process begins when water flows in the upper surface of solar panel through PVC pipes and absorbs heat from front surface and then is pushed by a DC pump to get to the collector. The collector is the device produce thermal energy from the solar radiations. Different mass flow rate of the water is examined and the results are discussed.

## 6. CONCLUSIONS

External factors such as operating temperature of the location has an impact on the PV module electrical efficiency. In fact, the rise in ambient temperature causes the decrease in voltage, power and efficiency of the PV module. In order to protect PV panel against this temperature effect, PV module cooling techniques such as direct current brushless fan and water pump cooling systems are developed as a solution. Some of the cooling methods are reviewed in this paper.

## NOMENCLATURES

### 1. Acronyms

| | |
|---|---|
| PV | Photovoltaic |
| COP21 | Conference de Paris |
| DC | Direct Current |
| FTCC | Floating Tracking Cooling Concentrating System |
| THS | Thermoelectric Heat Sink |
| EAHE | Earth-to-Air Heat Exchanger |
| BWHE | Buried Water Heat Exchanger |

### 2. Symbols / Parameters

$A_1$: Curve fitting factor
$K$: Boltzmann constant
$T_c$: Temperature of the PV cell
$R_s$: Series resistance of the PV cell
$e$: Electron charge
$I_o$: Reverse saturation current of the diode
$I_{ph}$: Photocurrent
$T_x$: Ambient temperature of the PV cell
$T_a$: Reference PV cell operating temperature
$S_x$: Ambient solar irradiation of the PV cell
$S_c$: Benchmark reference irradiance on the surface on the PV cell
$V_c$: Output voltage of the single cell
$I_c$: Output current of the single cell

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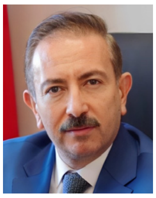

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