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Enhancement the Performance of PV Panel by Using Fins as Heat Sink

Abstract*- In this paper, theoretical and experimental study of the performance enhancement of PV panels has been presented by utilizing fins for cooling module's temperature at climate conditions operation. To satisfactory cool off for the solar panel as a passive technique, heat sink which has a rectangular variable cross section fins (ribs) attached on the back side of the panel. Analytical thermal model is formulated for heat dissipation from heat sink in order to predict PV panel temperature. A comparison between experimental and theoretical results was carried out for solar panels without and with fins, in order to investigate the proposed thermal model and study the effect of operating temperature on the power output from the panel. The results shows that using fin cooling technique causes a significant dropped in average solar panel temperature about 5.7°C and an enhancement in the average of module output power about 15.3%.*

Keywords*- heat sink, passive cooling technique, fins, solar panel*

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1. Introduction

The solar energy technology has many advantages as well as disadvantages comparing with other sources of traditional energy [1,2]. The potential advantages are such as; It works in noiseless and clean environment,(do not result any undesired waste like radioactive or toxic waste materials), reliable system, good performance, a long life system with expected life extending between 20 and 30 years with low cost maintenance. while its disadvantages are; non-uniform cooling so it need to attach with a necessary absorber system, low efficiency, the production and investiture cost are expensive, not suitable for integrating with present building's roof; and need a large space for producing the required energy.

Photovoltaic solar cell produces electricity, when the solar radiance inform of photons is received. Photons with special wavelengths (which have energy about 1.1 eV) are converted into electricity, and above the threshold are given in the form of heat within the PV cells [3]. This accumulated heat must be efficiently dissipated to protect the solar cell performance from an adverse effect of excessive high temperatures. This undesirable energy can be partly avoided by using a convenient technique of heat extraction [4]. Many researchers had been inspected and proposed various methods to enhance the Photovoltaic panels performance taking in account decreasing the installation costs. Different solutions to reduce the PV panel operating temperature are supported by specialized publications. Many works were done for enhancing heat transfer from the rear side of panel using passive cooling techniques, and found to be more economical when compared to the artificial forced convection enhancement methods. One arrangement to enhance convection heat transfer is by attaching extended surfaces on the rear surface of the solar panel [5]. The author used heat sinks consisting from a cylindrical pin fins attaching at the rear of a panel to be cooled naturally. A hybrid system (PV/T), type's water collector is found the most efficient methods. Solar panel was configured with heat collecting equipment that transported a part of incident solar energy as a thermal energy, by cold water in a closed loop system, [6]. Other research has been carried using a type of lightweight TiO_2 P_25 catalysts to degrade Methylene blue dye in water by solar light. This mixture (dye and catalysts) flows above the pc-Si panel and absorbs only Ultraviolet and Visible light which are the requirements of pc-Si cells to generate electricity [7]. Another method was used extended surfaces (attaching heat sink at the rear) to cool the hot solar panel [8]. Many types of fin were used to offer an additive area for heat dissipation by convection and radiation due to increasing the surface area of heat exchange, [9].

In present work, a thermal model is formulated and it has evaluated by experimental results, for enhancing the cooling process of PV panel by attaching an extended surface configuration (heat sink) on its back. Theoretical and experimental performance results are compared with the experimental performance results of traditional photovoltaic panel.

2. Mathematical Formulation

I. Heat sink performance analysis

The dimensions of a multi layers PV panel, which is considered in present work, is shown in Table 1, with thermal characteristics of its consisted layers. Heat sink with variable cross section ribs is attached at the rear of the panel with dimensions shown in Figure 1.

Table1: Properties and dimensions of solar panel layers

Layer	t, m	k, W/m.K	α	ε
Glass	0.0032	1.0	0.05	0.91
EVA	500×10^{-6}	0.35		
PV Cells	180×10^{-6}	148	**0.85**	0.9
Rear contact	350×10^{-6}	120	0.8	
Tedlar	0.0001	0.2	0.5	

It was made from a high conductivity metal (Aluminum), in order to improve heat transfer process from the PV panel Newtown law for Cooling was modified by reference [10] for heat transfer from heat sink to be as:

$$\dot{Q}_{hs}= (h_{conv}+h_{rad}).(A_b+\eta_f N_f A_f)(T_b-T_{am}) \quad (1)$$

Or

$$R_{hs}=\frac{1}{(h_{con}+h_{rad}).(A_B+\eta_f N_f A_{e,f})} \quad (2)$$

Fin efficiency is inserted to compensate the variation of temperature along fin surface. The efficiency of the fin depends on its geometry. the equation of a trapezoid profiles fin (the used fin in present work) has been pointed in reference [10].

All fin parameters are defined in Fig (1&2).

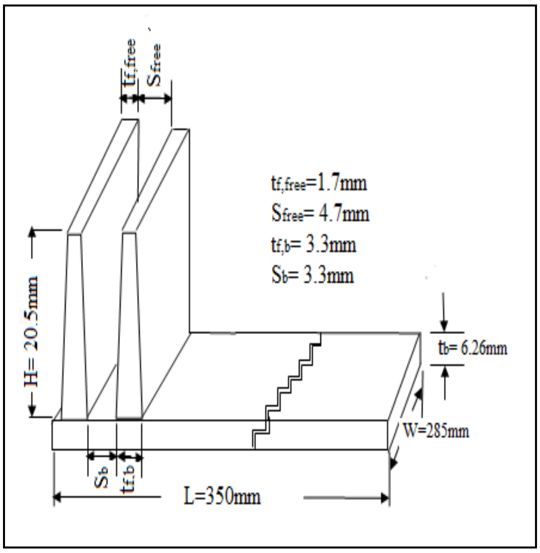

Figure 1: Heat sink parameters

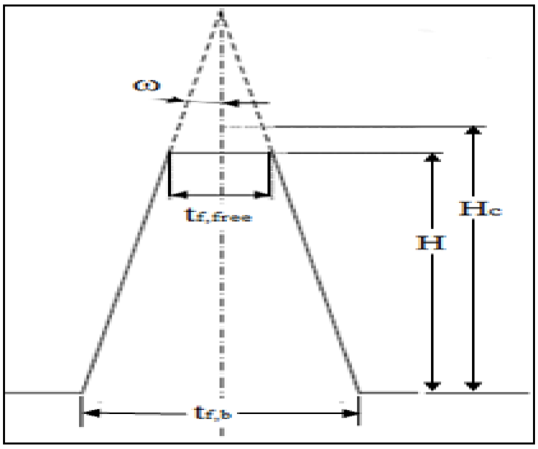

Figure 2:The profile of trapezoidal fin

Ref. [11] proposed to use a composite solution for convection coefficient (h_{con}) with heat sink including developing and fully developed flow conditions, as follows:

$$h_{conv}=\frac{Nu_{com}.k}{S_{av}} \quad (3)$$

where

$$Nu_{com}=\left[\left(Nu_{fd}\right)^{-3}+\left(Nu_{dev}\right)^{-3}\right]^{\frac{-1}{3}} \quad (4)$$

All fluid properties were determined at film temperature (T_{film})

The correlation formulas that used to calculate fully developed flow and developing flow Nusselt Numbers were mentioned in reference [11].

In order to determine the equivalent radiation coefficient (h_{rad}), reference [12] proposed the following equation:

$$h_{rad}=\frac{\dot{Q}rad}{(A_b+N_f Af)(T_b+T_{am})} \quad (5)$$

Thermal radiation rate ($\dot{Q}_{rad}$)from heat sink and the rate of heat transfer from channel surfaces ($q_{ch,r}$) are simplified by [12] . And with using the approximation (linearization) which was mentioned in [5], ($\dot{Q}_{rad}$) becomes as follow:

$$\dot{Q}_{rad}= (N_f-1).\dot{Q}_{ch,rad}+(Ad)\,\sigma\epsilon T_{am}^3(T_b-T_{am}) \quad (6)$$

While $$\dot{Q}_{ch,rad}=\frac{\sigma(S_{av}+2H)LT_{am}^3(T_b-T_{am})}{\frac{1-\varepsilon}{\epsilon}+\frac{1}{F_{ch-sur}}} \quad (7)$$

$$Ad= N_f\left(L.t_{f,free}+2.H.\left(\frac{t_{f,free}+t_{f,b}}{2}\right)\right)+2.H.L+2.t_{f,b}(L+w), \quad (8)$$

$$F_{ch-sur}=1-\frac{2\bar{H}\left[(1+\bar{L}^2)^{0.5}-1\right]}{2\bar{H}.\bar{L}+(1+\bar{L}^2)^{0.5}-1}, \quad (9)$$

Where $\bar{H}=\frac{H}{S_{av}}$ and $\bar{L}=\frac{L}{S_{av}}$

So, the equivalent radiation coefficient (h_{rad}) for heat sink (equation 5) is simplified to be as follows:

$$h_{rad} = \frac{(N_f - 1).\frac{\sigma(s_{av}+2H)LT_{am}^3}{\frac{1-\varepsilon}{\epsilon}+\frac{1}{F_{ch-sur}}} + (Ad)\,\sigma\epsilon T_{am}^3}{(A_p + N_f A_f)} \quad (10)$$

II. Heat balance for PV panel with heat sink

The flow energy through the module components (PV and heat sink elements) to the surroundings is considered as one-dimensional and steady state model. In the present work, the solar system was assumed in a steady state; because the module was during a very short period of time, all parameters that affecting the PV modules performance like the received irradiation intensity and climate condition may be assumed to be steady, that means the variation rates of inclusive heat losses from the solar module to the surroundings can be assumed to be small, and that lead to assume the rate of heat transfer and panel's temperatures are constant at any instant during their performance. The significant heat flows are; the solar energy intercepted by the PV panel ($\dot{Q}_s$), electrical generated power, E_c, and the removed heat($\dot{Q}_{rem}$) from the PV panel including the heat transports by conduction ($\dot{Q}$cond) between the solar cells and panel's layer toward the two sides of the panel (front and rear).Then, heat is dissipated from the front (glass) side by convection $\dot{Q}_{conv,f}$and radiation $\dot{Q}_{rad,f}$ and from heat sink($\dot{Q}_{h,s}$) at rear side of PV panel to the surroundings, see figure 3.

Therefore, the heat balance is: $\dot{Q}_s = E_c + \dot{Q}_{rem}$ (11)

$\dot{Q}_s = \tau_g\ G_s Ap\ bc$ (12)

$E_c = \eta_p \tau_g\ Ap\ bcG_s$ (13)

η_p is the panel efficiency define as [13]:

$\eta_P = \eta_{ref}(1\text{-}0.0041(T_c\text{-}T_{ref}))$ (14)

PV panel's reference efficiency (η_{ref}), as it was mentioned in nameplate of used solar panel, is equal to 15% at reference temperature (25°c). During heat transfer process, each component of module has a thermal resistance, depending on its material's properties. Figure 3 shows the thermal network for these thermal resistances. The removed heat($\dot{Q}_{rem}$) is;

$\dot{Q}_{rem} = \dot{Q}_{rem-fro} + \dot{Q}_{rem-re}$ (15)

Where

$\dot{Q}_{rem-fro} = \dot{Q}_{conv,fro} + \dot{Q}_{rad,fro} = U_{fro}\,(T_c - T_{am})$ (16)

And $\dot{Q}_{rem-re} = \dot{Q}_{hs}$ (17)

While

$$U_{fro} = \left(\sum R_{Th-rem-fro} + R_{eq-fro}\right)^{-1} \quad (18)$$

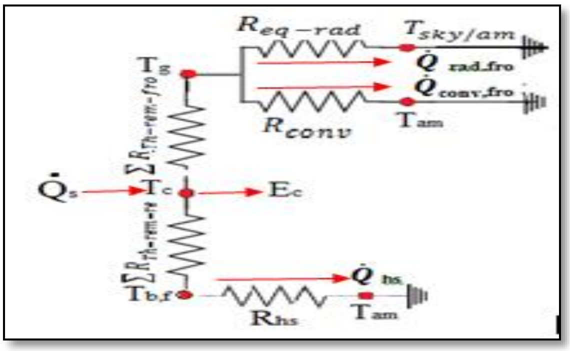

Figure 3: Thermal network

$$\sum R_{Th-rem-fro} = \left(\frac{t_c/2}{ApK_c} + \frac{t_{EVA}}{ApK_{EVA}} + \frac{t_g}{ApK_g}\right) \quad (19)$$

$$R_{eq-f} = \left[\frac{R_{eq-rad}+R_{conv}}{R_{eq-rad}*R_{conv}}\right]^{-1} \quad (20)$$

The fourth power equation of radiation is simplified using the approximation mentioned in [5] to be as:

$$\dot{Q}_{rad,fro} = F_{[fro-(sky/G)]}\ \varepsilon_g\ \sigma\ ApT_{sky/am}^3\ (T_g - T_{sky/am}) \quad (21)$$

So,

$$R_{rad,sky/G} = \frac{1}{4F_{[fro-(sky/G)]}\varepsilon_g\sigma\ ApT_{sky/am}^3} \quad (22)$$

$$R_{eq-rad} = \left[1/R_{rad-sky} + 1/R_{rad-G}\right]^{-1} \quad (23)$$

The shape factor formula for front surface of the panel with sky and ground are mentioned in reference [14] and the formula for calculating sky temperature (T_{sky}) is reported in reference [15].

$$Q_{conv,fro} = h_{conv}\ Ap\ (T_g - T_{am}) = \frac{(Tg - Tam)}{R_{conv}} \quad (24)$$

The convection coefficient is calculated by [16]:

$h_{conv} = 2.56V_{air} + 8.55$ (25)

At the rear half side of panel, the overall heat transfer coefficient becomes as follows:

$$U_{rem-re} = (\sum R_{Th-rem-re} + R_{hs})^{-1} \quad (26)$$

$$\sum R_{Th-rem-re} = \left(\frac{t_c/2}{Ap.K_c} + \frac{t_{EVA}}{Ap.K_{EVA}} + \frac{t_{Ted}}{Ap.K_{Ted}} + \frac{t_{b-f}}{Ap.K_{b-f}}\right) \quad (27)$$

And, the R_{hs} is as demonstrated above.

So, the removed heat from rear face is:

$\dot{Q}_{rem\text{-}re} = U_{rem\text{-}re}\,(T_c - T_{am})$ (28)

U_{rem-re} : The overall heat transfer coefficient at the rear side of panel

$\sum R_{Th-rem-re}$: The summation of thermal resistance from solar cell to the base of fins

When the terms, which are mentioned in energy balance, are compensated, T_{cell} can be calculated as:

$$T_c = \frac{\tau g\, GsAp\, bc - 0.165\, \tau g\, bc\, ApGs + T_{am}U_{fro} + T_{am}U_{rem-rear}}{-0.000615 + U_{fro} + U_{rem-rear}}$$

(29)

3. Experimental Setup

The experimental arrangements were prepared to investigate the fins cooling effect on the solar panel performance. Figure (4Aand 4B) displays the experimental setup which consist of two 10 W panel (polycrystalline type), having an active area (A_p) 0.09975m^2. The panel gives maximum output current and voltage 0.59A and 22V respectively at standard conditions (radiance of 1000W/m^2 and temperature of 25°C). In order to cool PV panel in a passive manner, heat sink made up of aluminum fins (horizontal rib) are used which is joined to the panel's backside by a thermal gel, as shown in figure 4. The heat sink which was used in this study, originally prepared as a cooling element for electrical equipment. The heat sink included 52 variable rectangular cross section fins; all dimensions are illustrated in figures 1 and 2. The panels was tilted by an angle of 32.1 deg with the horizon towards the south [17], the present work was done in Baghdad which is located at 33° 19' N, 44° 25' E, [19] .

The experiments were conducted in 3 June 2017.

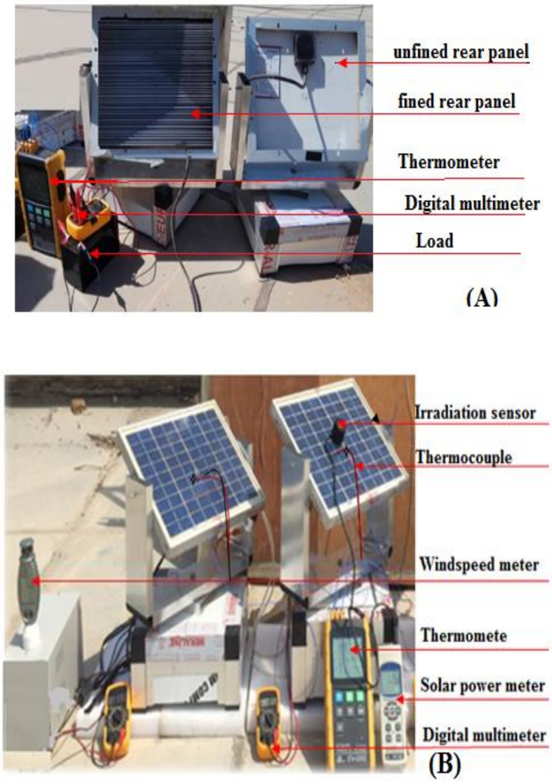

Figure 4: (A) Rear sides of the PV panels with and without heat sink, (B) Experimental set.

Panel's temperatures were measured by a temperature recorder (LUTRON BTM-4208SD type) with accuracy about ±0.3 °C. Thermocouples were placed at front and rear sides for two panels (with and without heat sink), to measure their temperatures.

Solar irradiance was measured by pyranometer (SPM 1116SD type). As well, the current and voltage were measured by using a digital multimeter type (Fluke 179). Local wind velocity was measured at a high of 2 m over the panel location. The experiments were conducted from 9.00 am to 5.00pm and the data registered at every 20 min for without and with heat sink concurrently. The experiment was repeated more than one time in different dates to confirm the results. All devices have been previously calibrated.

4. Results and Discussion

The five locations of the measured temperatures on the front surface of the solar panel are presented in Figure 5.

These locations are distributed to be one sensor location at the center and the other four, at the middle of the top, down, left and right distances from center location of the panel. These five temperatures are plotted and shown in Figure 6. It is as noted that there is a very low difference between them, which confirms the uniformity temperature on the panel. In the present work, the average temperature (T average) of the module has been considered as a panel temperature (Tc) which has been accustomed to be used in the present work.

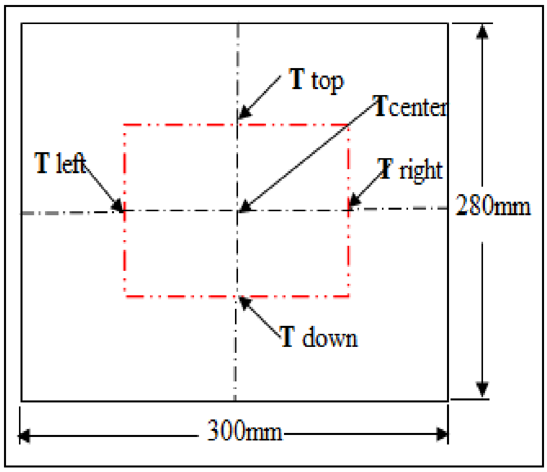

Figure 5: The locations of Temperature sensors

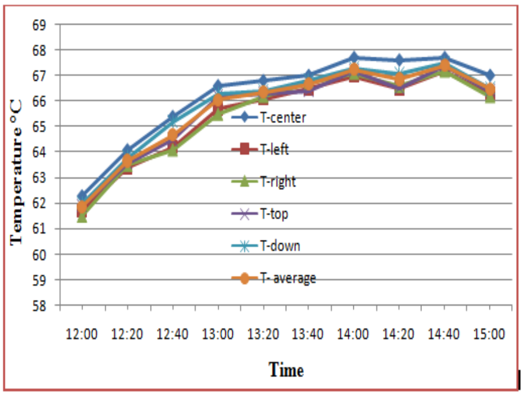

Figure 6: Measured temperatures at 5 locations

I. Thermal characteristics

For Thermal performance comparisons, it have been accomplished by using the constantly temperature data (at every twenty Minute) of PV module without and with heat sink and ambient temperature during the period of proceeding measurements. Figure 7 shows the temperature of solar module which was calculated by equation (35) and that experimentally measured It is noticed that there are a good accuracy between the measured and predicted temperature. The average measured and predicted temperatures during operating time (from 9:00 to 16:00) were 54.1°C and 52.51°C respectively with difference does not exceed 3% between them. Therefore, the present thermal model can be used to exam thermal performance of using various geometry of finned surface as a passive cooling technique for solar panel.

The constantly differences of ambient temperature and module temperature with and without heat sink are represented in Figure 8. The maximum temperature of ambient is measured about 49° C at 2.00 PM in 2nd-July-2017. Figure 8 shows the profile of the temperatures distribution of solar module. The profiles are almost identical for two cases which have been studied i.e., measured temperature with cooling and plain solar panel.

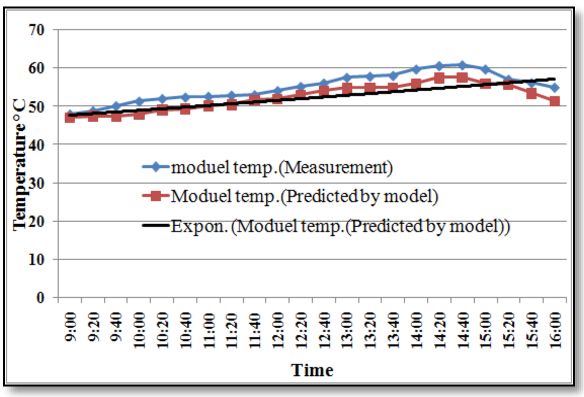

Figure 7: The temperature of module with heat sink as predicted and measured vs. time

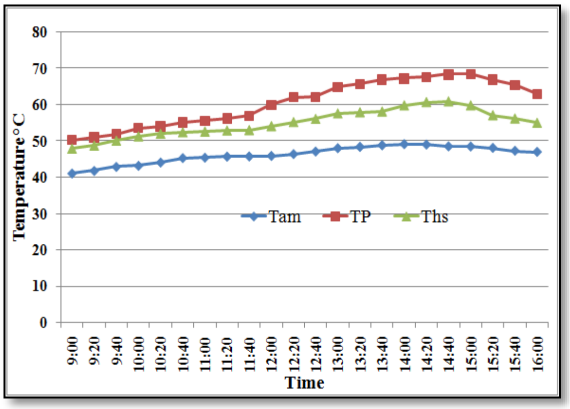

Figure 8: Ambient and different cases panel temperatures vs. time

This detects the reliable performing of the solar module at different functioning conditions.

It is also observed in Figure 8 that the temperature of solar panel is always greater than that for ambient during the period of measuring. The maximum temperature for the module without cooling is about 69 °C and it is reduced to be about 61 °C with using heat sink at the same time (about 3.00 PM). This corresponds with a reduction in average temperatures of module in two cases (it was 60.6°C for plane panel and 54.9°C for panel with heat sink) about 9.4%; this enhancement is attributed to the increasing in the surface of heat exchange, which is provided by using finned surfaces at the back side of module.

II. The Effects on Electrical Properties

Figure 9 &10 show the experimental results for output current and voltage of a plane panel and another panel combined with heat sink. The comparison between two modules performances (with and without heat sink) show that the output current increases slightly at decreasing module temperature (with cooling) but the voltage increases significantly when module temperature decreases.

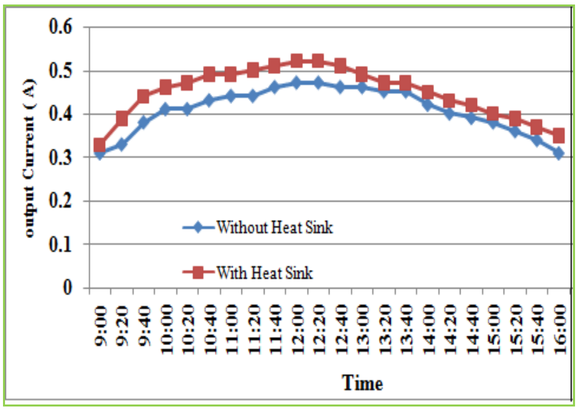

Figure 9: Solar panel output current with and without heat sink.

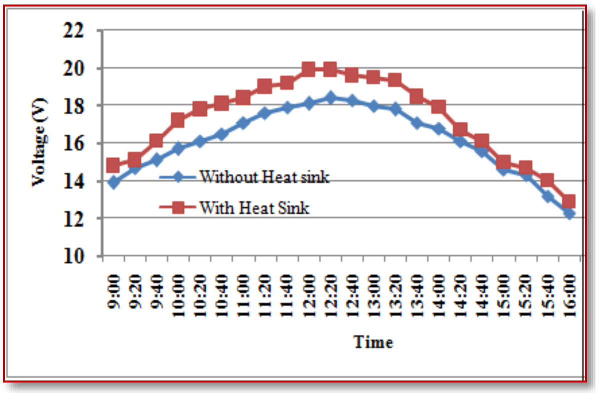

Figure 10: Solar panel output voltage without and with heat sink.

The cooling causes to increase the average output current and voltage from 0.4A and 16v to 0.452A and 17.3v with enhancements about 9.6 % and 7.5% for the gained current and voltage respectively.

As it is shown, the existing of heat sink as a passive cooling technique has an observed effect at the beginning hours of operation time. And then, the effect is gradually receding due to increase in the ambient temperature (which restricts the heat transfer process) and decreasing in solar radiation intensity, these factors are caused to reduce electrical power output. This result is clearly shown in Figures 11.

Figure 11 shows the variation of output power along operating time of plane solar panel and another combines with heat sink. To show the effects of panel temperature and ambient temperature on the output power of two arrangements, they are also presented in Figure 11. It is deduced that the gained power increases when the solar panel is equipped with cooling arranging due to its effects in decreasing module temperature. A maximum power of 10.4W is gained with the solar panel, which is conjoined with a heat sink, while the output power will be least without cooling arrangement, (at a value 8.75W). This corresponds with an enhancement in the average of module output power about 15.3% in the case of using the proposed cooling system (it was 6.7W for plane panel and 7.9 W for panel with heat sink); this enhancement is attributed to decrease the solar panel temperature. It is denotes that the panel temperature has a significant effect in the PV system output power as shown in Figure 11. The effects of efficiency variations of solar module vs. time for two module arrangements are depicted in Figure 12 along with the ambient and panels temperatures . It is indicated that the panel give a higher efficiency when the solar panel is connected with finned surface.

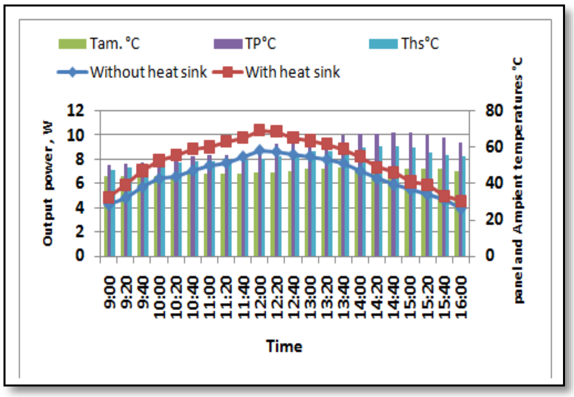

Figure 11. Solar panel output power in case of with and without heat sink and the temperatures of plane panel(T_p), panel with heat sink (T_{hs}) and ambient(T_{am}) vs. time.

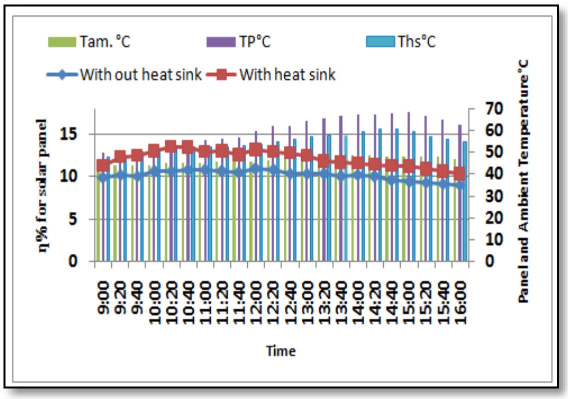

Figure 12. Solar panel efficiency in case of with and without heat sink and the temperatures of plane panel (T_p), panel with heat sink (T_{hs}) and ambient(T_{am}) vs. time.

A maximum efficiency about 13.2% is gained with using heat sink, while the maximum efficiency is about 10.93% for panel without cooling arrangement. This is an indicator for the importance of the module temperature, which has a significant effect in the efficiency, as well as output power of PV system. The high temperature causes an excitation for phonons, which menaces the electron's uniform movement, and this impedance minimizes the module efficiency [18].

5. Conclusions

A simple cooling system (finned surface structure) is joined to a flat PV modules in order to reduce the module's temperature which leads to increase the electrical yield (power output) and enhance the conversion efficiency of the module. The following conclusions have been derived:

1-The temperature of solar panel without cooling is constantly greater than ambient temperature over the time of operation with 69

°C as a maximum temperature and 60.6°C as an average temperature.

2-The maximum solar panel temperature is reduced to 61 °C and about 54.9°C as an average value with using heat sink as a passive cooling system. This corresponds with a reduction to about 9.4% in the temperature of module that is attributed for the extension in the surface area of heat transfer at the backside of the module.

3-There is a good accuracy for the results of thermal proposed model for predicting the module temperature (solar panel with a heat sink) with discrepancy does not exceed than 3% with the measured values at the same state. The thermal model can be used as an available tool to test other heat sink geometries.

4-Cooling the solar panel by fins (heat sink) affects the production of voltage and current, which causes ultimately an increasing in the average output power about 15.3% than that of the plane solar panel and enhancing its average efficiency about 19.3%.

Nomenclature

A: The surface area of heat transfer, m^2
Ad: All surface's areas those radiations not exchange with other surfaces of fin (m^2).
Af : Outer surfaces area of fin. m^2.
bc: the backing factor
Cp: heat capacity (J/kg. °C),
F: The shape factor.
G: irradiation (W/m^2),
H: height of the ribs (0.025 m);
H_c: corrected height of rib, m
h: the coefficient of heat transfer ($W/K\cdot m^2$),
I: output current, A.
V: output voltage, volt
k: thermal conductivity (W/K·m).
L: length of heat sink base and the length of the ribs, m.
N: number of items.
Nu: Nusselt number,
P: output power, W.
Pr: the Prandtl number
$\dot{Q}$: The rate of heat transfer (W)
Re: Reynolds number, ($Re=\frac{V_{air}\cdot S_{av}}{\gamma}$).
$\sum R_{Th}$: The summation of thermal resistance
Rhs: Thermal resistance of heat sink from outer surface of the base to the surroundings
S: step between ribs, m.
T : Temperature, K
t: thickness, m.
U: The overall heat transfer coefficient
V_{air} : wind speed. m/s
W: width of heat sink base, m.

Greek Symbols

η: Efficiency, %.
α: Absorption coefficient
ε: body emissivity
μ : Dynamic viscosity (kg/m·s)
τ: transmission coefficient

Subscripts

am: ambient
av: average
b: base
c: cell
ch : Channel surface
co: corrected
com: composite
conv :convection
dev : developing flow
EVA : Ethylene Vinyl Acetate
e, f : The extended outer surface area of fin
eq : Equivalent.
f : Fin ,
free: Free end of fin
f,b: According to fin and base
fro : Front
fd: fully developed
G: ground.
g:glass.
hs : heat sink
p: panel
r: rear
rad: radiation
re: rear side of panel
ref: reference .
rem: removed heat
s: solar
sky: sky
sur : surrounding.
Ted : tedlar

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