Passive thermal regulation of Photovoltaic module temperature using Truncated fins

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***Abstract* – Photovoltaic "PV" module efficiency decreases as the operating temperature increases over a certain limit. Cooling PV module temperature is essential in order to increase its electrical performance and maintain the PV module working at low operating temperature. Adopting heat dissipation option appears more practical in terms of energy consuming, cost, maintenance, and simplicity. Therefore, in this paper, a passive thermal regulation technique with using extended surface area "truncated fins" and planar reflector has been evaluated. To obtain higher solar radiation intensity on the top surface the PV module, both top and bottom angles of the planar reflector has been changed from (0-90^o) and the optimal angle was found 60^o. ANSYS, FLUENT, CFD software was employed to perform the computational fluid dynamics analysis to predict the PV module temperature reduction. To properly cool the PV module, a parametric study in terms of fin thickness, fin height, number of fins, and fin pitch has also been investigated. The bare PV module temperature without fin cooling has been numerically calculated using Engineering Equation Solver (EES). Meanwhile, Design of experiment (DOE)/Response surface method (RSM) was used to determine the optimum number of fins, fin height and fin thickness that reduce the PV module temperature and improve its electrical performance. The simulation results showed that due to truncated fin cooling, the temperature of the PV module dropped significantly from 64.3^{o}C to 44.14^{o}C with temperature difference of 20.16^{o}C and the efficiency was improved by 9.2%under natural convection.**

Keywords: passive cooling, electrical efficiency, Aluminum fins, Design of expert/ response surface method, optimum design for thermal regulation

I. INTRODUCTION:

Many researchers have investigated and proposed several techniques to optimize the performance of PV module in order to minimize the installation cost. Natural convection becomes one of the important topics concerning thermal and mass transport processes involved in various types of applications. For instance, in case of a simple 3-D rectangular enclosure, very only limited research and development "R&D" have been carried in last two decades in comparison to 2-D studies which were restricted mainly due to the limitations of the high memory and high PC's specifications as well [1]. Effective cooling of PV module not only enhances its electrical performance, but also increases the life period of the PV cells as the thermal stress decreased, [2-4]. The undesirable heat in PV module can be avoided by applying efficient heat dissipation [5-7] or heat recovery options [8-10]. [11-13] studied several passive cooling techniques in conjunction with rectangular enclosures as a domain. A combined PV/T concept was proposed to reduce the thermal stress of PV module by recovering the heat of high PV module temperature and use it for thermal applications. PV/T system does not succeed in penetrating the market due to technical, cost and size barriers. Hence, it would be more appropriate if the R&D community refocuses its efforts again on the heat dissipation option instead of the costly heat recovery option to regulate the high PV module temperature[14]. An efficient heat transfer with using fins has been studied by [1, 15]. The ideal solution for the heat transfer through a fin can be simplified to one dimension (1D) and steady state. In this ideal solution, the temperature differ in one direction and the fin base temperature is the temperature at the attachment with what is being cooled [11]. Convection dispersion equation and solved analytically in (1D) under variety of different conditions has been studied by [12]. Meanwhile, [13] numerically solved the convection dispersion equation by different methods including finite difference, finite elements, quasi-linearization, and probabilistic/statistical methods. Optimally fin sizing can be done when the total fin volume is kept constant and only one of the physical dimensions is changed [16].

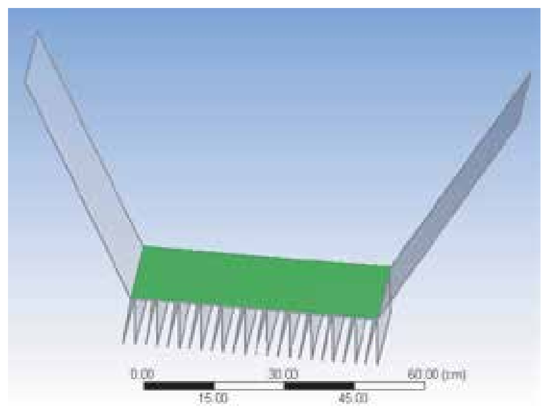
Through passive cooling of PV module with using extended surface area "different fin configurations" is cheap and can provide enough cooling. PV cooling using fins can be considered as an economic choice. Therefore, further R&D on these issues is essential.

II. LITERATURE REVIEW:

Passive cooling of PV panels can be divided into three main categories: air-cooling, water-cooling, and conductive cooling. In several cases, however, passive cooling can replace active cooling, in order to save the installation costs [17]. Different passive heat extraction techniques were reviewed. [18] investigated immersing a PV module directly in a liquid under different water depths. The results showed that the PV conversion efficiency increases by 15% at 4cm water depth. This improvement in the conversion efficiency has been attributed to annulment of thermal drift and due to less reflection. In the same context, [7] studied experimentally cooling the PV panel by submerged it in distillated water at different depths has been investigated. The results revealed that the improvement in the efficiency of the PV module could be observed with increasing water depth; the maximum value for the efficiency about 22% was obtained at a depth of 6cm. Phase change material (PCM) has been used in many thermal management systems. Improving PV performance by using yellow petroleum jelly as phase change material has been carried out by [19]. Petroleum jelly (called as vaselinum flavum) is a semi-solid material consisting of hydrocarbon, which has quite wide applications, ranging from cosmetics, medical, to machinery and has a melting temperature range of 42–55^{o}C. Two (10-Watt-peak mc-Si PVs) were directly compared with each other. The maximum solar irradiation for the “PV on-roof “ experiment was 1120W/m^2, and the maximum temperature for the upper and underneath surface was 60 and 58.8^{o}C, respectively. At the same time, the top and bottom surface temperature of PV/PCM was 55.7^{o}C and 54.3^{o}C. The results indicated that Vaseline flavum suppresses PV surface temperature around 4.3^{o}C at its maximum temperature. They concluded that passive cooling using PV/PCM module was found suitable to be applied in BIPV. [14] fabricated 6 PV module strips each containing single row of 6 mc-Si solar cells (44.5W_p) and mounted in 6 V-trough channels. The V-trough walls were designed from a thin single aluminum metal sheet to achieve better heat dissipation from the cells under concentration. In this design the V-trough angle was chosen to be 20^{o} for which the transmissivity was calculated to be about 75% and the surface area available for heat dissipation in the concentrator V-trough PV module was found 4 times higher than the case when V-trough walls were not used for cooling. In this study, they reported that 58.5% higher sunlight reaches the cell due to V-troughs are achieved. Despite of this light concentration in the V-trough, the cell temperature remains same as that of a cell temperature in a flat plate PV (60^{o}C) as against to 80^{o}C without heat sink effect under 750W/m^2. [20] investigated the effect of using passive aluminum heat sink on the performance parameters of silicon solar cells. Thermal grease was used between the heat sink and the back surface of the PV cell in order to improve the thermal conductivity of a thermal interface by compensating irregular surfaces of the components. Two similar pc-Si PV cells with and without aluminum heat sink under different ambient temperatures and various illumination intensities up to 1sun using solar simulator were studied. Under three implemented values of solar irradiance (400, 600 and 800W/m^2), the results showed that the amount of heat dissipated from the PV cell with and without fins were (5.49, 9.06 and 12.03W) and (4.54, 6.91 and 9.61W), respectively. Meanwhile, they reported that at low intensity level (200W/m^2), the passive cooling technique is inefficient due to the low temperature difference was (1.1^{o}C) between fins and the surrounding air. In addition, they mentioned that under higher intensity levels such as 400, 600 and 800W/m^2, the level of cooling improved up to (20.09, 31.1 and 25.2%), respectively.

III. PROPOSED DESIGNS AND GRID INDEPENDENCE TEST (GIT)

The proposed approach in this paper is to employ an aluminum planer reflector augmented PV module with truncated fin which has been drawn using 3-D design modeler as shown in Fig.1(a). Meanwhile, Fig.1 (b) showed the designed passive cooling system with enclosure as an air domain and Fig 1.(c) illustrates the meshing of the proposed system.



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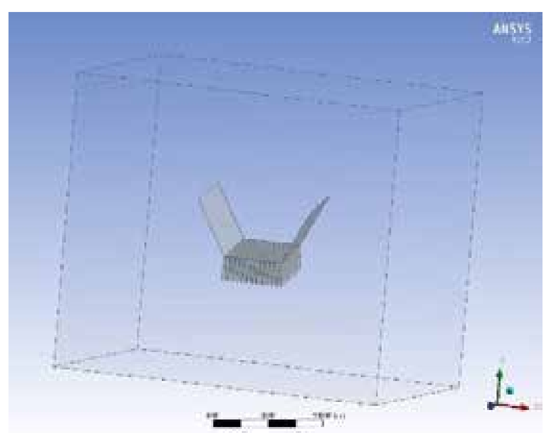

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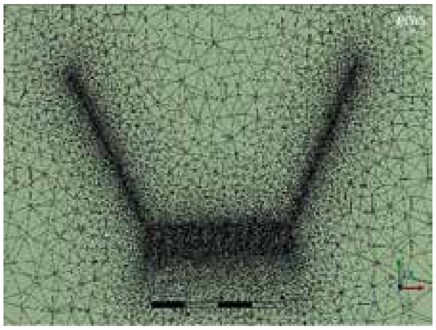


(c)

Fig.1 (a) PV module with truncated fins, (b) Design with enclosure as an air domain, (c) Meshing of the proposed truncated fin design

In this study, the GIT has been carried out to determine the suitable face sizing meshing for all geometries. The discretization grid was unstructured and non-uniform. From Fig.2 we can conclude that the face sizing (5mm) was chosen as the best in terms both accuracy and higher orthogonal quality about (0.17).

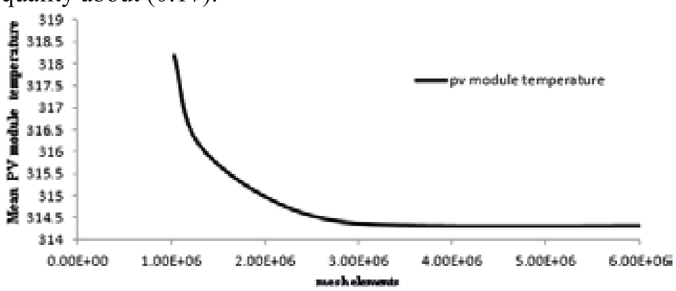


Fig.2 Mean PV module temperature over mesh face for GIT

IV. MATERIAL AND METHOD

Table.1 summarized the material in terms of PV module type, absorber thickness, tilt angle, ambient temperature solar radiation and the assumed working conditions. Meanwhile, Table.2 illustrates the specifications and the geometry design dimensions used in the simulation process. Design of experiment/Response Surface Method (RSM) was used as a method to optimize the parameters affected the output response "Mean PV module temperature". Optimizing each of fin length; fin height, fin thickness, fin pitch, absorber thickness and tilt angle were obtained from ANOVA analysis. For numerical simulations, truncated fin geometry was drawn using design modeller and the computational domain meshed with control volumes built around each grid using ANSYS 17.2, CFD, and conducted using steady state pressure based solver. The partial differential governing equations for mass and momentum are solved for steady incompressible flows. Velocity-pressure coupling was affected through the Semi-Implicit Method for Pressure-Linked Equations algorithm, while second order upwind schemes were selected for the solutions.

TABLE 1
SPECIFICATION OF PV MODULE WITH ASSUMED WORKING CONDITIONS

Ambient temperature	T_a	298 K
PV length	L	0.67m
PV width	W	0.53m
Collector area	A_c	0.3551m^2
Al/ reflector dimension		0.67*0.53m
Aluminum fins thickness	L_f	2mm
Fin conductivity	k_f	204W/m k
Aluminum plate thickness	L_{Al}	2mm
PV module reference efficiency	η	12%
Thermal conductivity of aluminum	k_{al}	148W/m-k
Maximum power at STC	P_{max}	40W±5%
Open circuit voltage at STC	V_{oc}	21.6V
Short circuit current at STC	I_{sc}	2.57A

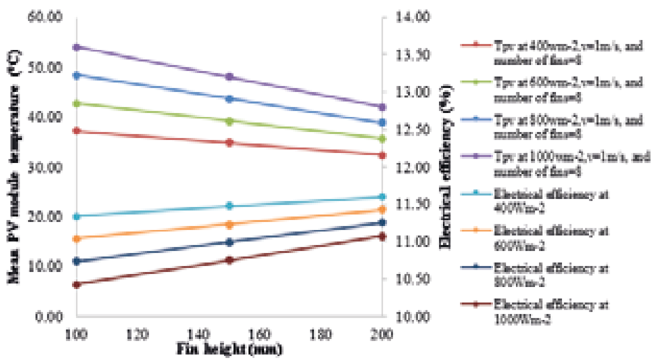
TABLE 2
SUMMARIZED THE SPECIFICATIONS OF PROPOSED DESIGN

Type	Design specifications and geometry details
PV module with Aluminum heat sink and truncated fins	1-Solar irradiance varies from 400-1100Wm^{-2} 2-The air velocity changes from 0.5-1.5m/s. 3- Fin thickness was 2mm and fin height varied between 100-200mm. 4- number of fins varies from 8-10-12 fins 5- Tilt angle varies from 10-15-20^o. 6- Fin pitch for 8 fins was 75.5mm, 58.7mm for 10 fins, and 48mm for 12 fins.

V. RRESULTS AND DISCUSSION

1. Effect of Truncated Fins Parameters on PV Module Performance

Influence of varying truncated fin height from (100–200mm) and solar irradiance from (400-1000Wm^{-2}) on the PV module temperature reduction and its efficiency at different number of fins changed from (8-12) was investigated as shown in Fig 3. The results revealed that the PV module temperature was decreased from 54.04^{o}C at 1000Wm^{-2}, number of fins=8 with fin height 100mm into 42.11^{o}C at 1000Wm^{-2} with 8 fins and fin height was 200mm. While, as a number of fins increased from 8 to 10 fins, the PV module temperature decreased from 52.07^{o}C at 1000Wm^{-2}, number of fins=10, and fin height 100mm into 40.14^{o}C at 1000Wm^{-2}, number of fins=10, and fin height 200mm. Meanwhile, the PV module temperature reduced from 50.10^{o}C at 1000Wm^{-2}, number of fins=12 and fin height 100mm into 38.17^{o}C 1000Wm^{-2} at number of fins=12 with fin height 200mm. This means that the PV module temperature was significantly affected by increasing number of truncated fins and height of fins.



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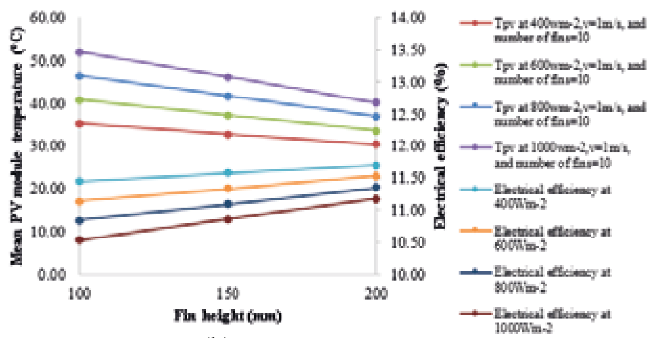

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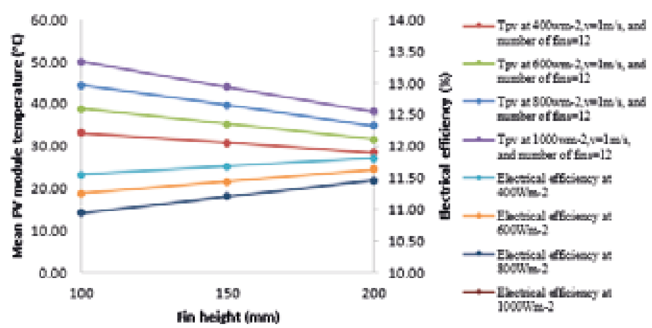

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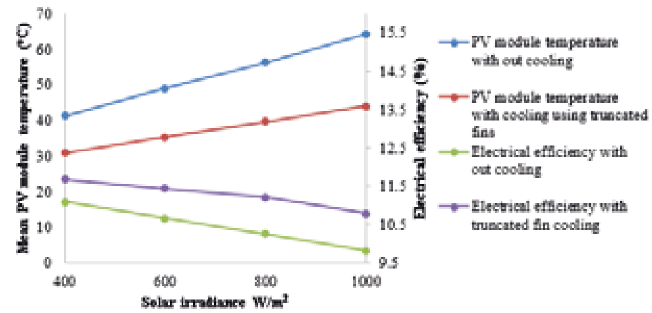
Fig 3 Effect of truncated fin height and solar irradiance on PV module temperature and its electrical efficiency at number of fins (a) 8 fins, (b) 10 fins, and (c) 12 fins

Moreover, Fig 4(a) shows the reduction in the mean PV module with truncated fins compared to non-cooling PV module. The results showed that the PV module temperature reduced from 64.3°C without cooling to 44.14°C at fin height 150mm and number of fins=12 with a temperature difference about 20.16 °C. From anther hand, the electrical efficiency was enhanced from 9.81% without cooling fins into 10.79% with cooling using truncated fins. Fig 4(b) shows the effect of increasing number of truncated fins on the PV module temperature reduction at solar irradiance 1000W/m^2 and optimum fin height 150mm. from other hand, the results revealed that the PV module temperature decreased from 42.11°C to 38.17°C as number of fins increased from 8 to 12 fins. Meanwhile, the effect of truncated fin pitch on the PV module performance improvement at solar irradiance 1000W/m^2, wind speed 1m/s, and fin height 200mm is shown in Fig.4(c). The results showed that when the fin pitch increases from 42-75mm this leads to decrease the truncated fins number from 12 to 8 fins which increases the PV module temperature from 38.17-42.11°C.



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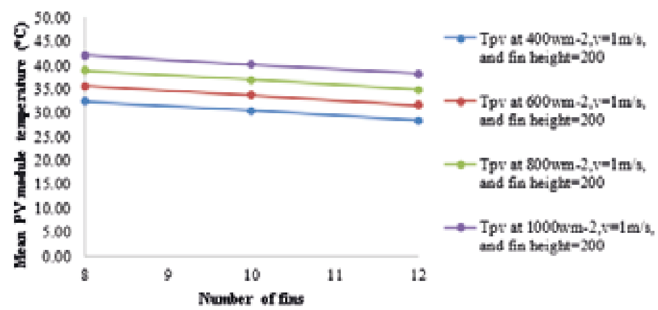

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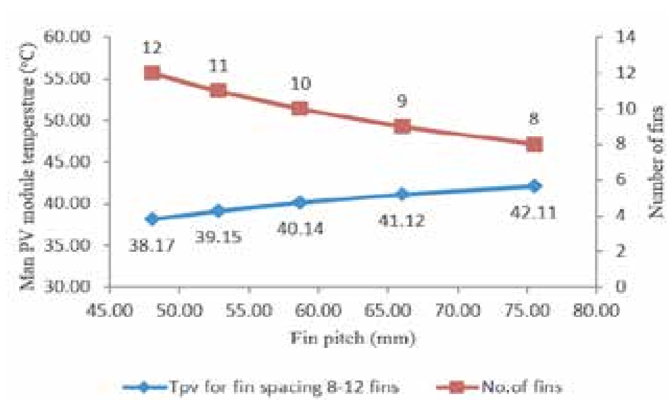

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Fig 4 (a) comparison of mean PV module temperature reduction with and without cooling (b) effect of increasing number of fins on PV module temperature and (c) effect of fin pitch on PV module temperature reduction

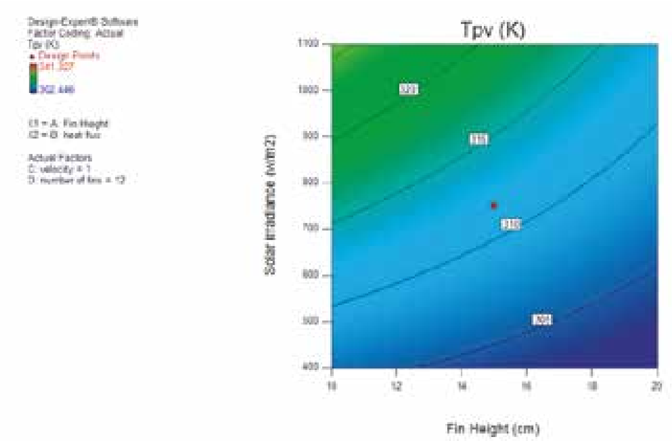
2. Respond Surface Method Results for truncated fins using ANOVA Analysis by DOE

The variation levels for the important four factors affected the passive cooling of PV module performance with planar reflector and truncated fins are shown in Table 4.

TABLE 4
INPUT FACTORS AND RESPECTIVE VARIATION RANGES

Factors	Name	Units	Type	Min	Max	Mean
A	Height of fin	mm	Numeric	10	20	15
B	Number of fin	----	Numeric	8	12	10
C	Wind speed	m/s	Numeric	0.5	1.5	1
D	Solar irradiance	Wm^{-2}	Numeric	400	1100	750

Figure 5 (a,b) shows the contour plot for the factors (fin height, number of fins, and solar irradiance) that improve the PV module performance. It can be concluded that those factors had a significant effect on PV module temperature reduction.



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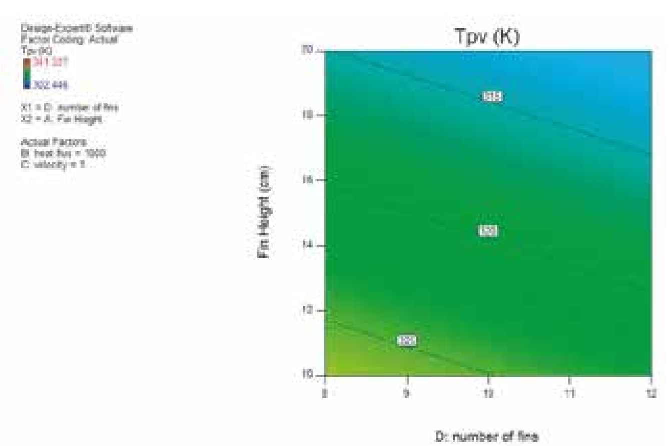

(b)

Fig 5 (a) effect of solar irradiance and truncated fin height (b) effect of truncated fin height and number of fins on the mean PV module temperature reduction

VI. CONCLUSIONS

The performance of PV module has been simulated by using 3-D CFD, FLUENT. From the analysis carried out, the results revealed that the truncated fins has better performance in decreasing the PV module temperature when compared to conventional PV module without cooling. Furthermore, it was found that thickness of aluminum fins above 2mm showed a negligible effect on the PV power and efficiency. In addition, the optimum number of fins (8-12) and the height of fins (100-200 mm) are 12 and 150 mm respectively. Finally, the PV temperature reduction achieved by the back plate extended surface (truncated fins) was 44.14^{o}C with temperature difference about 20.16^{o}C when compared to the reference PV module.

ACKNOWLEDGMENT

The authors would like to honestly thank the National University of Malaysia for the provision of the grant TRGS/1/2014/UKM/01/11/1 to support this work.

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