OUTDOOR EXPERIMENTAL COMPARISON BETWEEN PV CELL AND COMBINED SYSTEM PV-TEG

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ABSTRACT: *Solar energy is considered one of the promising technology. However, still has many factors affecting the efficiency of the output power of the solar systems, such as collector temperature and rapid changes in irradiance. Many researchers have applied different active cooling methods; to solve the heat problem in the Photovoltaic cell which required external power. In this research paper, the main objective is to convert the unwanted temperature and convert it into electrical power, simultaneously to cool down the photovoltaic panel without using external power. The design of the thermoelectric generator and 5w photovoltaic panel attached to heat-sink had been designed and fabricated to be. The experimental investigation had been carried out to analyze the temperature impact on the combined system photovoltaic cell-Thermoelectric Generator. Outdoor results showed 2.5 % improvements in the average PV cell efficiency when TEG was applied to the system.*

Keywords: PV cell; Thermoelectric; TEG; PV/TEG.

1. INTRODUCTION

Renewable energy could take several forms such as wind, solar, thermal, and hydroelectric energy. Solar energy considered one of the fastest-growing technology all around the world, and it is easy to be installed [1], it has been presented in (United Nations Development Programme) that the amount of the solar irradiance received from the sun is more than twice the total world energy consumption. Furthermore, solar energy help to reduce pollution, help in maintaining global warming, and reduce the cost of fuel. The output power of the photovoltaic cell (PV cell) decreases as the temperature increases. From this point of view, the temperature can be reduced and converted into electricity.

Most of the studies related to combining photovoltaic cell/Thermoelectric Generator (PV/TEG) systems have been made in theoretical aspects [2], or applying extra energy to reduce the temperature of PV cell such as water cooling methods [3] which is not an energy efficiently platform. Attaching the thermoelectric model into the back of the photovoltaic panel could harvest the temperature[4], at the same time the heat of the PV cell could be converted into electricity.

It was well known that the rise in PV cell temperature causes a linear decrease in their efficiency [3] Every 1 °C surface temperature rise of the PV cell represents a decrease in the overall efficiency by 0.5% [5]. Therefore, temperature rise, cause in the reduction of the solar energy absorbed by the PV cells, which are converted into electrical energy. At the same time, PV cells operate in the nonlinear form [6] where open-circuit voltage and output power changes rapidly with the change of weather condition. This causes a drop in the overall output power; therefore, the objective of this research is to convert the unwanted heat of the PV cell by attaching a thermoelectric module and heat-sink in the bottom side of the PV cell to harvest heat and convert it into power. And to compare the output power efficiency of the standalone PV cell setup and the combined system PV-TEG.

MONO-CRYSTALLINE PV CELL

Table 1. represent the electric data of the PV cell. The main elements of the PV cell are the maximum power voltage and the maximum power current. Which can be reached at the optimum irradiances and temperature. Matlab Simulink has been used to plot the (I-V and P-V) graph of the specified PV cell as shown in Fig 1. As shown in Table 1. Maximum voltage is 6v, maximum current is 0.75 A. the highest irradiance the highest output voltage and current. When the temperature exceeds 25 C output power voltage decreases linearly with the increases of the temperature Equation (1) and Equation (2) calculates the diode current and the thermal voltage of one PV cell.

$$I_d = I_o[\exp\left(\frac{V_d}{V_T}\right) - 1] \quad (1)$$

$$V_{T=}\ KT \div V \quad (2)$$

Table: 1 Electrical specification for PV panel.

Item	Specification
Peak power Watts (Pmax)	4.5
Number of cells	12
Maximum power voltage (Vmax) V	6
Maximum power current (Imax) A	0.750
Open Circuit Voltage (Voc) V	7.2
Short Circuit Current (Isc) A	0.850
Size	165*165*3mm

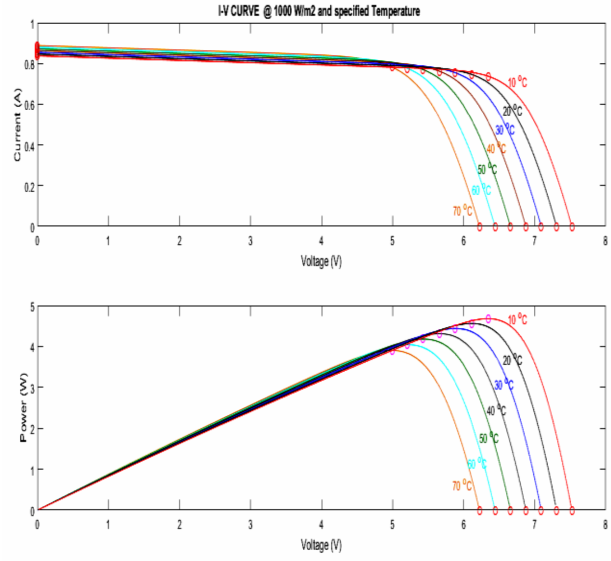


Fig (1) I-V and P-V curves of PV cell.

2. Methodology

Two PV cells were used in this research. The combined design was fabricated using aluminum as meatal for the case. 4 TEGs have been used in this design (TELBP1-12656-0.45). As shown in Fig. 2 the design of the PV/TEGs has 4 views. The top view shows the PV cell (18.5 x 18.5 cm) attached together with the TEGS. The side view shows the length of the PV/TEG model 7.3 cm. the front view shows the output wires of the TEGs, as it has been connected in series-parallel each tow set connected in series and then both sets connected in parallel to increases the output current. The bottom side which represents the heat-sink. Fig.3 represents the overall design and concept of the PV/TEG model, where the heatsink is the main element to reduce the temperature from the model.

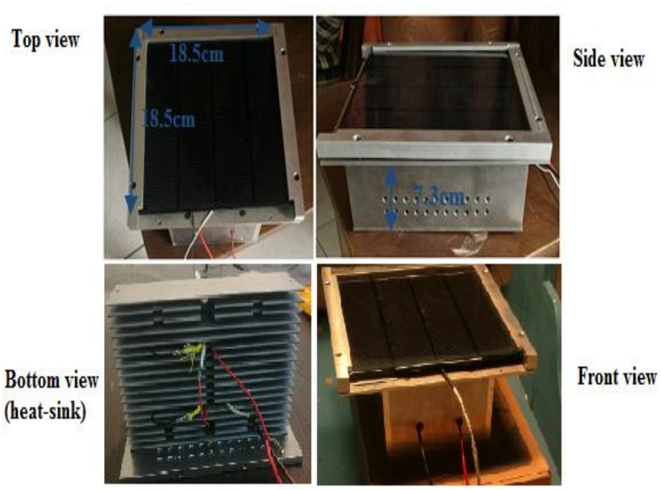


Fig (2) Top and side view of PV/TEG.

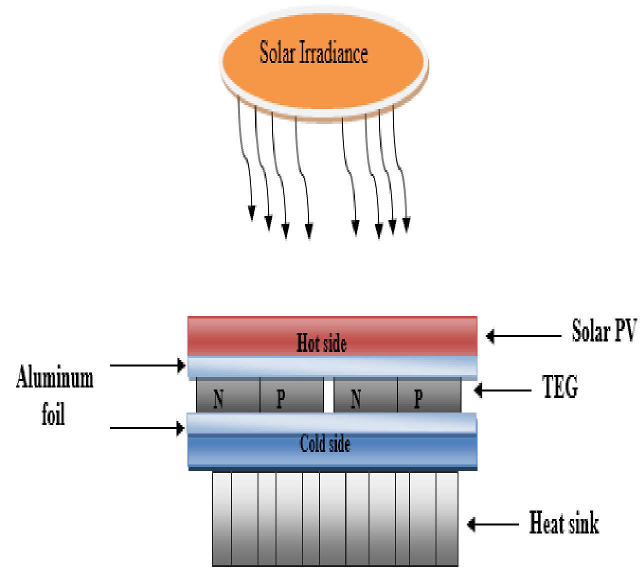


Fig (3) PV/TEG model.

To increase the output current of the TEGs a parallel electrical connection was implemented as shown in Fig. 4. Two sets of TEGs were connected in series therefore, each set connected in parallel. Based on the Seebeck effect theory TEGs were placed in-between the PV cell and the heatsink, the PV cell represents the hot side and the heatsink represents the cold side of the TEGs. There were precisely three main measurement parts; the first part was to measure the temperature of the PV cell. Therefore; output voltage and current were measured to calculate the output power of the model. The second part was to specify the unit measurements of power and temperature. Lastly, the third part was to set up the display for the measured data using LCD technology. SD memory was used to store all the measured data. The system has been designed by using Arduino Uno as the main microcontroller; which is responsible for measuring and recording the data of output power and temperature. Temperature sensors have been placed in the top and bottom sides of the TEGs to determine the temperature values at the hot and cold sides of the TEGs. Data were saved into the memory with a step-time of 5 seconds, for more accuracy. The output power of each model was stored in the memory card in the same time. By using 2 current sensors (ACS712) and 2 voltage sensors. solar meter type (TES 1333R) was used in data collection to measure the irradiance in W/m^2.

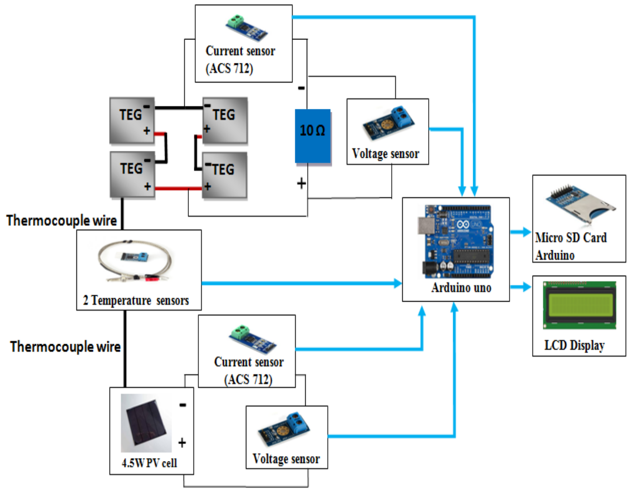


Fig (4) Schematic of TEG connection and PV cell.

3. Electrical Efficiency of PV Cell

Equation (3) represents the electrical efficiency of the PV cell. Where; the electrical efficiency of the PV cell has been calculated based on the power coming out from the module. The size of the PV cell 165*165*3mm is the main element of the equation. In this experiment, the efficiency of the PV cell was calculated for the two models. The efficiency of the PV cell combined with TEGs, and efficiency of the standalone model.

$$\eta_{electrical\ PV} = \frac{P_{max}}{P_i} = \frac{I_{max} \times V_{max}}{Incident\ solar\ radiation \times Area\ of\ solar\ cell}$$

$$= \frac{V_{oc} \times I_{sc} \times FF}{I \times A_c} \quad (3)$$

Where (FF) is fill factor

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} = \frac{I_{max} \times V_{max}}{V_{oc} \times I_{sc}} \quad (4)$$

4. EXPERIMENTAL SETUP

Outdoor experiments have been conducted in Kuala Lumpur KDU University College Gleamarie. As shown in Fig. 5 Solar energy monitor has been used to measure the output power of the PV cell. The outdoor experiment has been carried out for 8 operational hours. Data has been recorded using the SD card every 20 minutes. Fig. 6 presents the measured data of irradiance. The change in weather conditions has played an important role in the outdoor experimental results as shown in Fig. 6. At 12:20 pm irradiance is low because there were clouds suddenly appeared which has highly affected the solar irradiance. Fig. 5 displays the connection of the measurement tools to validate the results which were stored in the SD card. Two voltmeters were used to accurately measure open circuit voltage and short circuit current of the PV cell. While solar energy monitor was connected to the PV/TEG module to display the reliable data of power. Two temperature sensors were used to measure the hot side and cold side generated heat of PV/TEG. While one temperature sensor was used to measure the temperature of the PV cell stand-alone module. Irradiance data was measured using a solar meter (TES 1333R).

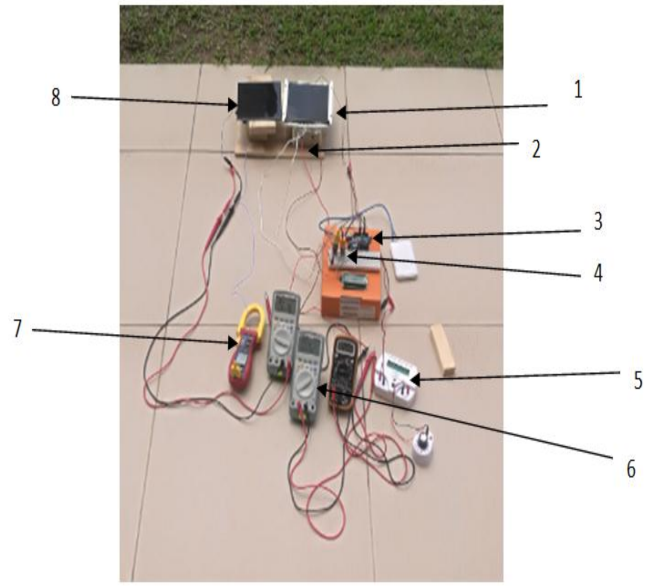


Fig (5) Outdoor experimental setup (1) PV-TEG, (2) output of TEGs, (3) Arduino Uno, (4) temperature sensors, (5) solar energy monitor, (6) voltmeter, (7) temperature sensor, and (8) PV cell.

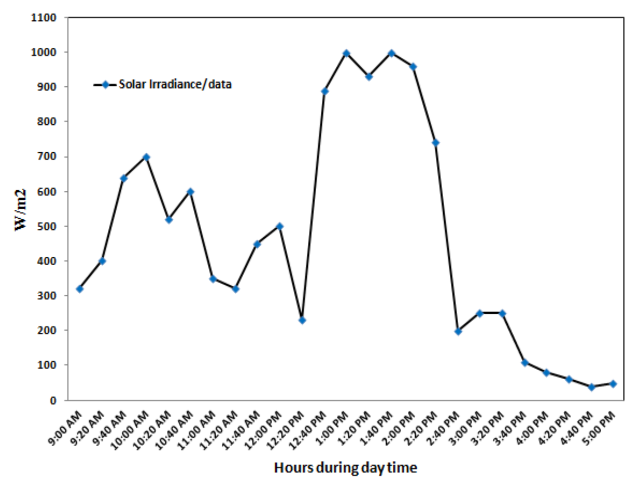


Fig (6) Irradiance/data.

5. RESULTS AND DISCUSSION

The outdoor test was carried out on two PV cells. Observed results were divided into two parts PV/TEG results and TEGs results. Measurements of irradiance and temperature were recorded for the two modules at the same time. As shown in Fig. 7 the temperature readings for both independent modules. The maximum temperature of PV/TEG was 75 °C at 2:00 pm. At the same time, the maximum temperature of PV cell without applying TEG was recorded to be 84 °C.

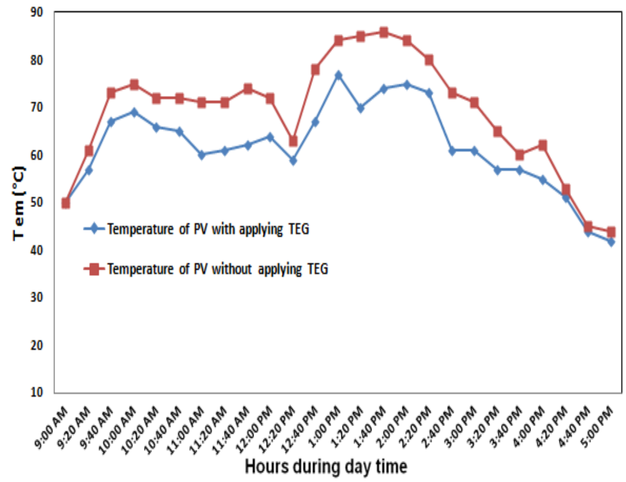


Fig (7) Temperature of PV cell with and without applying PV/TEG.

TEGs RESULTS

TEGs output power was measured and analyzed based on the data of the output current and voltage. A load resistor of 10 Ω was connected to the output terminals of TEGs. The maximum output power of TEGs was 8 mW. While the maximum current generated was 20 mA. Outside factors such as cloudy weather have a strong impact on the performance of TEG. Fig. 8 represents the output power of the TEGs. Solar radiation affects the performance of both TEGs and PV cell as shown in Fig. 8. From 11:40 am output power of TEGs started to increase rabidly until it reached 8mW. After that output power started to decrease gradually at 12:00 am. As presented in Fig. 9 temperature at the hot side (Th) started to increase gradually at 11:40 am.

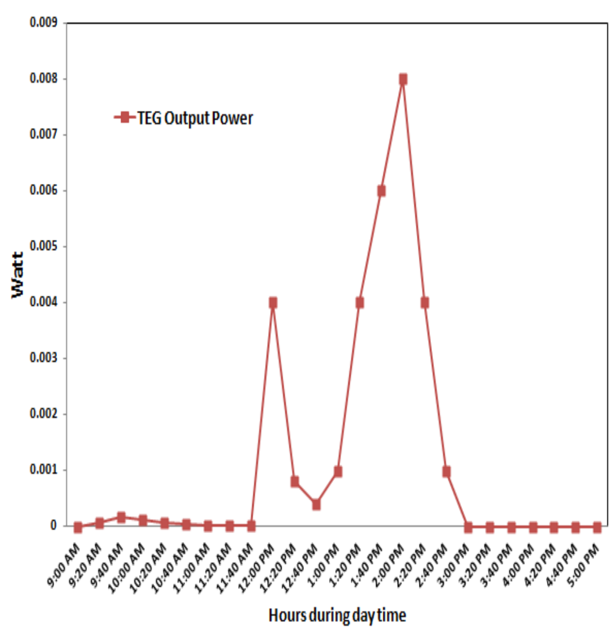


Fig (8) TEG output power.

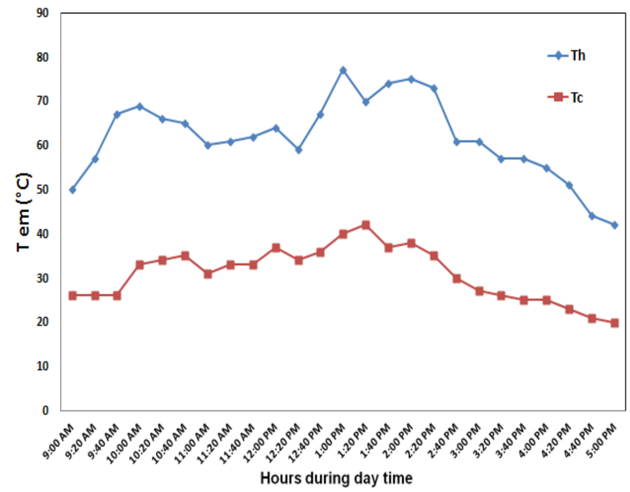
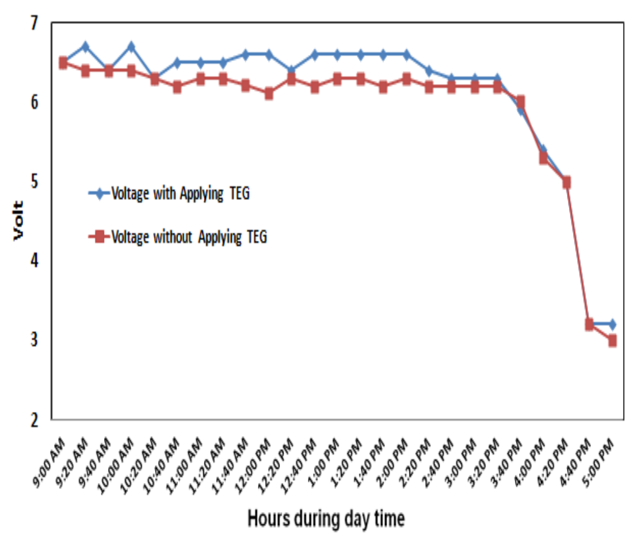


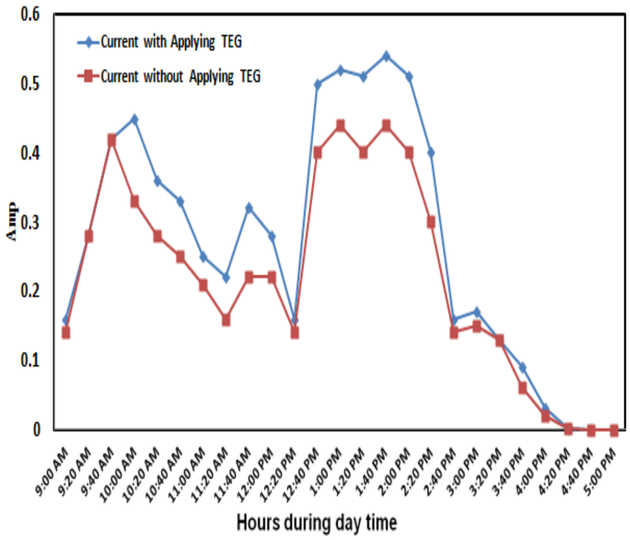
Fig (9) Temperature at the hot and cold side of the TEG Module.

PV/TEG RESULTS

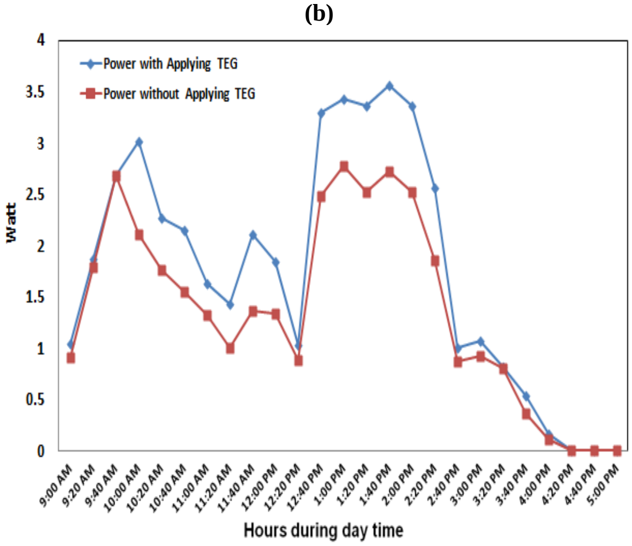
In this part, two PV cells were tested. One of the PV cells was attached to the PV/TEG model, the second one was a standalone model. Fig. 10 part (a) (b) and (c) display the measurements of short circuit current, open-circuit voltage, and output power of PV cell with and without applying PV/TEG respectively. Improvements in output power were observed and improved up to 0.903 W when the irradiance was 700W/m^2. The average efficiency of the PV cell improved by about 2.5% when TEG was applied to the system. Maximum efficiency of 18 % of the PV cell has been reached at 2:40 pm. The average power differences between the PV cell standalone system and PV cell with applying TEG were 0.36W.



(a)



(b)



(c)

Fig (10) PV cell temperature and output voltage, current, and power comparison with and without PV/TEG.

6. CONCLUSION

In this research, the PV/TEG model has been fabricated and tested. Outdoor experiments under the direct sun have been carried out on the combined PV/TEG system. It was observed that the reduction in the heat of the PV cell leads to maximize the output power of the PV panel. Outdoor results have shown 2.5 % increments in the average efficiency of the PV cell when TEG was applied to the system. Experiments Observation has shown that the power generated by the TEGs reached 0.0192 W; therefore, the contribution of the TEGs model in terms of power is slightly small, at the same time TEG attached to heat-sink improves the output power efficiency. For future recommendations, and in order to accomplish a significant increment to the output power of the PV cell, extra TEGs are recommended. In addition, passive cooling methods could be effective through the use of TEGs. It can be used Central Composite Design in RSM [8] for optimization. Many researchers are looking toward waste to energy (WtE) using incineration [9] and pyrolysis [10]. Thus, the PV/TEG is able to be added into the process to convert the waste energy into electricity.

7. ACKNOWLEDGEMENT

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8. REFERENCE

[1] Abbasov and Elnur, "Sustainable Solution for Increasing the Share of Solar Photovoltaic Usages on Residential Houses in Azerbaijan," *Environ. Res. Eng. Manag.*, vol. 71, no. 714, pp. 11–18, 2016.

[2] D. Enescu and F. Spertino, "Applications of Hybrid Photovoltaic Modules with Thermoelectric Cooling," *Energy Procedia*, vol. 111, no. September 2016, pp. 904–913, 2017.

[3] F. Schiro, A. Benato, A. Stoppato, and N. Destro, "Improving photovoltaics efficiency by water cooling: Modelling and experimental approach," *Energy*, vol. 137, pp. 798–810, 2017.

[4] R. Bjørk and K. K. Nielsen, "The performance of a combined solar photovoltaic (PV) and thermoelectric generator (TEG) system," *Sol. Energy*, vol. 120, pp. 187–194, 2015.

[5] J. Siecker, K. Kusakana, and B. P. Numbi, "A review of solar photovoltaic systems cooling technologies," *Renew. Sustain. Energy Rev.*, vol. 79, no. May, pp. 192–203, 2017.

[6] S. Selvan, P. Nair, and Umayal, "A review on photovoltaic MPPT algorithms," *Int. J. Electr. Comput. Eng.*, vol. 6, no. 2, pp. 567–582, 2016.

[7] A. O. M. Zain, C. H. Shen, S. Govinda, F. Y. C. Albert, and A. A. M. Al-Talib, "Matlab Design and Power Analysis of MPPT Controller for Solar PV Using Perturb and Observation Algorithm," *Adv. Sci. Lett.*, vol. 24, no. 11, pp. 9001–9005, 2018.

[8] Y. Kah Yung, H.S. Chua, M. J. K. Bashir, F.Y.C. Albert, Sunil Govinda. "Central Composite Design (CCD) for Parameters Optimization of Maximum Power Point Tracking (MPPT) by Response Surface Methodology (RSM)". *Journal of mechanics of continua and mathematical sciences*, Special issue No : 1,1 March 2019.

[9] H.S.Chua, Mohammed J.K Bashir, K.T. Tan, Chua. H. S "A Sustainable Pyrolysis Technology for the Treatment of Municipal Solid Waste in Malaysia". Paper presented at the conference proceedings of 2018 International Conference on Environment (ICENV 2018) for Journal of Environmental Chemical Engineering, DEC, 2018.

[10]C. Huang Shen, M.J.K Bashir , K.T.Tan, L.P.G. Joceyln, F.Y.C. Albert. "Design and Implementation of A Laboratory-Scale Pyrolysis Combustor for Biomass Conversion," Sci.Int.(Lahore),30(1),81-84 ,2018