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Improving The Electrical Output Power of Photovoltaic Modules by Using Different forms of cooling pipes

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Abstract

The Renewable energy especially photovoltaic panels (PV) are very important issue to produce the electricity at MENA region (The Middle East and North Africa). A continouse high performance for electrical output helps the outback area for home lighting or heating in winter season. Therefore, to improve a fixed photovoltaic performance by using different pipes cooling techniques (serpentine, & pancake shapes) attached on the backside of PV module. The paper reported the electrical performance (electrical output power) of a photovoltaic module by using water as a cooling fluid. Besides that, the thermal behavior analysis introduced by the difference in temperatures of cooling water and the module temperature. The thermal results exposed that, for the PV module temperature with serpentine and pancake cooling pipes decreased about 11.6 % and 16.59 % compared with (STC) Standard Temperature Condition (PV without cooling). In addition, the difference in water temperature increased about 3.8 % and 5.8 % for two different forms. That leads to enhancement in the module daily output power up to 8.9 % by using the pancake compared with serpentine cooling shape.

Keywords: Photovoltaic/Thermal (PV/T) Hybrid Sysetm; Cooling systems; Mat-lab; Solidworks.

1. Introduction

The significance of a photovoltaic module appears in the countries has a long time Sun appear period (hrs/day) [1], it absorbs the solar irradiance and convert it into electricity that can be used in many applications [2], the photovoltaic has a lot of benefits it is environmental friend, without pollution while operating, low cost and maintenance needed, higher output power rather than other renewable energy systems [3].

The photovoltaic efficiency is affected by the temperature status, if the photovoltaic panel temperature increases, the efficiency decrease. Jailany et al. [4] provided comparison for an experimental work using a fixed PV system forced by air and water as cooling fluids. The results show increased in the electrical efficiency of a photovoltaic panel by using water about 9.89%, decreasing the photovoltaic temperature by 22.77%.

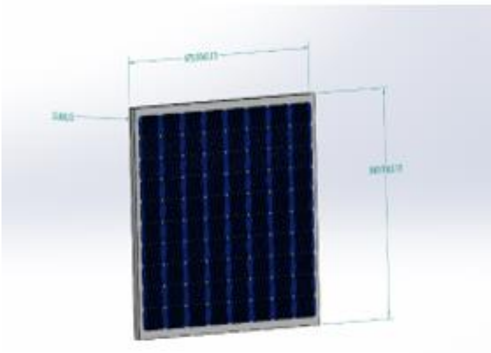
Navid et al. [5] intrduced a dual PV/T system producing both heat and electricity using backside heat exchanger to cool the PV panel, the results show decreasing in PV module temperature by 20% which increase the output power about 12%. Afroza Nahar [6] presented a computitional study for a 3D model using numerical analysis (Comsol Multiphysics) to study the PV performance by using a pancake shape pipe contact to the PV backside with thermal paste, the results show the PV module temperature decreased about 8°C compared with the system without cooling and the PV electrical efficiency increased by 2% with different inlet velocity from 0.0009 to 0.05 m/s.

A. Bayoumi [7] produced a numerical model using finite element method to compare the PV system by using different cooling shapes, materials and pipes' diameter, the result showed the best material was a copper due to it most suitable thermal conductivity, ¼ inch pipe's diameter had the maximum output power, serpentine pipe shape was the most efficient heat transfer.

In this work, a comparision between an attached backside pipes prevouis shape (serpentine shape) and a new shape (pancake shape) are presented for cooling PV modules by using water as a cooling fluid. The purposed in experimntal work is a capablity of enhance the PV module electrical output power performance. The results of three PV systems (without cooling and with cooling by two forms of shapes) will prove the effectiveness of the best shape.

2. PV/T SETUP DESCRIPTION

The three fixed PV modules made of a poly-crystalline are shown in Figure 1. The engineering drawing was done by solid-works. The setup has been done to test three photovoltaic panels fixed systems with one PV without cooling STC (Standard Temperature Condition) and two different cooling shapes serpentine shape, and pancake shape.



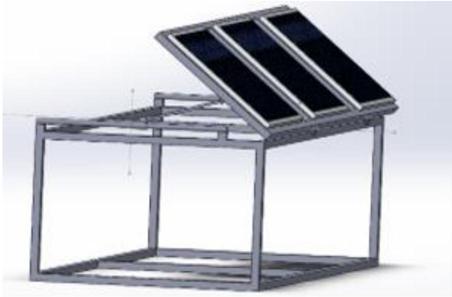


FIGURE 1: The PV module, and Three fixed PV poly-crystalline system produced by Solid-works.

A Poly-crystline PV panel with the maximum output power of a single module is 50 watts as shown in Table 1. The system is fixed at 30 degree inclination angle towards south to the equator to receive the maximum irradiance all over the year in Egypt [8, 9]. Square cross section structure steel is used to fabricate the required frame as shown in Figure 2.

Table 1: PV Specifications

Parameters	Specifications
Model	MTM-CHINA
Dimensions	670 X 540 X 25 mm
P_{max}	50 Watts
V_{max}	18 Volts
I_{max}	2.86 A
V_{OC}	21.6 Volts
I_{SC}	3.17 A
$T_{operating\ cell\ Temperature}$	25 °C

FIGURE 2: General view for the implemented system.

Various shapes of the pipes are bonded by thermal paste (Type: ARCTIC MX-5 Extremely High Thermal Conductivity) on the copper plate with the same area of PV panel with a thickness of 0.001 m. The chosen area of the copper plate is cantered at the back of the PV module, since this provides the highest cooling surface area [10]. The copper plate bonded under the PV panel allows the fluids moving inside the pipes to decrease the module temperature.

Figure 3 shows all suggested shapes have a dimension of 0.011 m and 0.012 m for inner and outer diameters, respectively. Figure 3a shows the first backside water pipe structure, serpentine shape, with length 8.1 m. Figure 3b shows the second type, pancake shape, with length 6.18 m. All shapes were fabricated with a circular entrance and inlet with same average velocity of 0.04 m/s to reach approximately an almost equal pressure drop and flow distribution [5, 11].

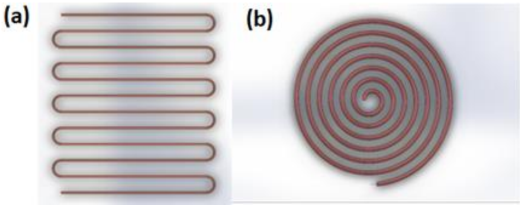


FIGURE 3: A general view for experimental setup.

The three modules in the experimental work were working simultaneously, whereas two tanks and pumps where attached to each module with backside pipes for water cycle. The sensors used to collect the data from PV/T system are infrared thermometer (IR) to measure the surface temperature of the PV module at different five points to calculate the average temperature of the panel, also a two analog thermometer used to measure the inlet and the output temperatures for the fluid cooling used. The pump used to circulate the water a (DC source 12V with 0.4 A) maximum (4.8 Watt) and the flow range (1 to 18 L/min).

This pump is used especially for the PV modules (take the source from PV panel) to decrease the power consumption. The pump intake the water from a cylindrical vertical (12.5-liters) water tank with internal dimension (200 mm diameter × 400 mm height) is fabricated and insulated to store the cooling fluid. The output power electric circuit consists of resistors with different ranges, connected to the voltmeters which measure the PV output power values, and solar meter is used to measure the solar irradiance as shown in Figure 4. The period to collect the experimental data in August 2021 from 6:00 am to 6:00 pm [12, 13, 14].

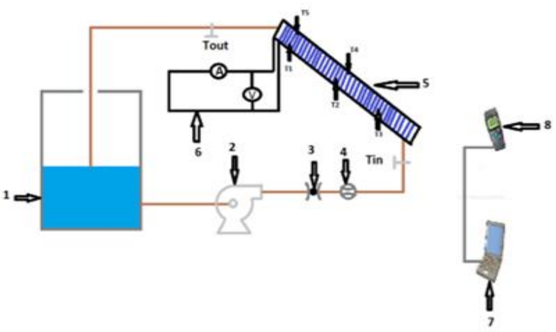


FIGURE 4: A general view for experimental setup consists of: (1) Water tank, (2) DC pump, (3) Ball valve, (4) water flowmeter, (5) A polycrystalline solar panel, (6) I-V analyzer, (7) Laptop, (8) Solar meter, (T_1), (T_2), (T_3), (T_4), and (T_5) infrared thermometer (IR) to measure the surface temperature of the PV module at different five points to calculate the average temperature of the panel.

3. THEORETICAL WORK

In order to prove the laminar of fluid inside the pipes, the Reynolds number is found 1250 for two different shapes. The liquid flow take the time needed to absorb heat from the PV panel. Therefore, flow rate inside the pipes for all shapes is chosen to be 1.2 L/min to decrease the total temperature of the PV module and the power consumption of the system. Reynolds number was calculated for different shapes by equation (1) as follow [15]:

$$R_e = \frac{v_{avg}\, D}{\upsilon} \qquad (1)$$

Where: v_{avg} is the average velocity inside the channel (m/s), D is the channel dimeter (m), and υ is .Kinematic viscosity of fluid (m^2/s).

The pressure drop was calculated using the Darcy–Weisbach equations [16] and were found to be 198.7, and 259.2 Pa, respectively. As shown in equation (2):

$$\frac{\Delta P}{L} = f_D \, \frac{\rho}{2} \, \frac{(v_{avg})^2}{D} \qquad (2)$$

Where: ΔP is the measured pressure drop (Pa), F_D is Darcy Friction factor, ρ is the fluid density (kg/m^3), and L is the pipe length (m).

In order to extract the heat by coolant water, the removed heat was measured equation (3) to calculate the temperature difference of water Δ T as follow [16]:

$$Q^{\cdot} = m^{\cdot} C_P \Delta T \qquad (3)$$

Where: Q. is removable heat (Watt), m. is mass flow rate (Kg/s), and Δ T is the temperature difference between inlet and outlet fluid (K).

The waves of sun irradiance are increased the Silicon PV panel. This hot body (PV module) passes on its heat to the copper plate and pipes (external and internal) by conduction. At last the cooling liquid (water) are heated by convection. The overall heat transfer coefficient for the amount of heat gained to the PV is figured by equation (4), (5), and (6) [17]:

$$\frac{1}{U_o A} = \frac{t_{th}}{K_{Si} A} + \frac{t_{th}}{K_{Cu} A} + \frac{\ln(\frac{r_{in}}{r_{out}})^2}{2 \pi K_{Pipe} L} + \frac{1}{h_f a} + \frac{1}{h_{air} a} \quad (4)$$

$$A = l \times w \quad (5)$$

$$a = 2\pi r L \quad (6)$$

Where mass flow rate is calculated by equation (7) [18]:

$$m^{\cdot} = \rho\, v_{avg}\, \pi D_i^2/4 \quad (7)$$

For electrical modelling, PV module efficiency η_{PV} is calculated by dividing the output electrical power (at maximum power output) by the total input power under AM1.5G standard [7]. The short current is calculated by equation (8) [19]:

$$I = I_{sc} - I_{01}\left(e^{\frac{q(V+IR_s)}{KT}} - 1\right) - I_{02}\left(e^{q(V+IR_s)/2kT} - 1\right) - \left(\frac{V+IR_s}{R_{SH}}\right) \quad (8)$$

Where: I_{sc} is the short circuit current (A), I_{01} is the dark saturation Current (A), q is The electron charge (1.6×10^{-19} Coulomb), V is Voltage (Volt), I is the current (A), R_s is the series resistance (ohm), K is Boltzmann constant ($1.38 \times 10^{-23} m^2 . kg . s^{-2} . K^{-1}$), T is the temperature (K), I_{02} is Reactive current (A), and R_{SH} is the shunt resistance (ohm).

The open circuit voltage is given by equation (9) as follow [20]:

$$V_{oc} = n\, \frac{KT}{q} \ln[\frac{I_{PV}}{I_{01}} + 1] \quad (9)$$

Where: V_{oc} is the open circuit voltage (V), n is Ideality Factor, and q is the electron charge (1.6×10^{-19} C).

The solar cell efficiency can be represented as a variation in the solar output electrical power, the module surface area, and solar irradiance shown in equation (10) [21].

$$\eta_{PV} = \frac{Pout}{Pin} = \frac{V_{oc} I_{sc} FF}{q_{rad}\, A} \quad (10)$$

Where: η_{PV} is PV efficiency (%), Pout is the maximum power output (Watt), Pin is the total optical input power (Watt), FF is Fill factor (%), qrad is the irradiance energy (W/m2), and A the total surface area (m2).

4. RESULTS AND DISCUSSION

In order to enhance the current and voltage of the PV modules, water passed underlying pipes. The investigation of the output power depends on specific parameters like the quantity of sunlight falling on the surface of PV modules, the location of setup [22], etc. but the most important parameters are the cooling water flow rate [6, 23] and the module operating temperature [24, 25].

Despite of the area of cooling technique increasing the system performance, the enhancement of the output power was not acceptable. The increase of flow rate is another parameter that affects the PV module performance. Figure 5 shows the effect of diversified flow rates for two different structures.

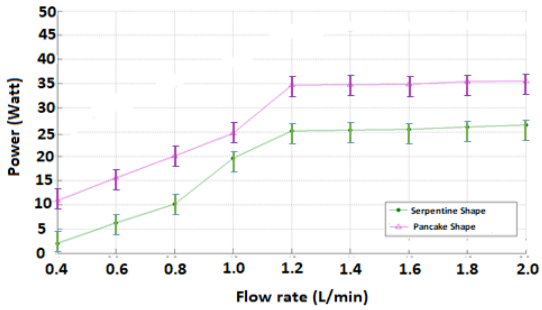


FIGURE 5: A comparison between power versus different flow rates for different shapes of pipes.

The change of flow rates measured at a specific time of 12:00 PM (Higher irradiance point at setup location), the output power was enhanced up to 26 Watt and 36 Watt for 1.2 L/min flow rate of the serpentine shape and pancake respectively. The increase of the output power for all shapes after 1.2 L/min was about the range of 1 to 2 Watt, on the other hand, this increased power consumption for the pumping system about 2.2 Watt. Therefore, the best flow rate was found to be 1.2 L/min in order to avoid any losses in the output power of PV/T system. Besides that, the increase of flow rate affected on the PV module performance that the flow inside the pipes changed to be turbulent flow and fluid inside the pipes have no time to reject utmost heat from the modules. The water was laminar flow and the heat extracted was the same, that lead to the power output generated from the PV was the same output.

Figure 6 shows the solar irradiance ranges from 200 W/m^2 to 1150 W/m^2 in the area of experimentation at 10th of Ramadan city, Egypt (30° 29'E 31° 74'N) [14] and the readings collected every 30 minutes.

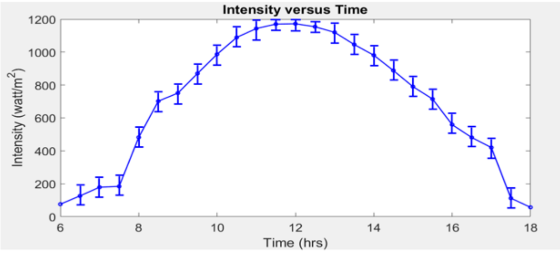


FIGURE 6: Experimental readings of sun irradiance curve during day time.

Figure 7 represents the decrease of PV temperature due to different cooling techniques verses day time. Two different cooling shapes (serpentine shape, and pancake shape) are compared with standers temperature condition (STC), when the sun irradiance reached 1136 w/m2 at 12 pm, The STC temperature increased to 58.22 °C, the serpentine shape temperature run to 52.06 °C, and the pancake shape temperatue enhanced to 48.56°C. the three curves show that the pancake pipes better than STC by the temperature difference about 9.66° C.

The decrease in the PV temperature around 16.59 %, and accordingly it better than serepentine shape by the temperature difference almost 3.5 °C, The decreese in PV temperature nearly 6.72%. this graph proof that the pancake investegated the PV module temperature due to it has the largest area of cooling with the same PV module dimensions.

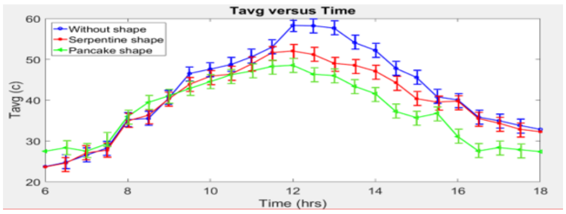


FIGURE 7: the comparison between modules temperatures verses day time (without cooling, serpentine shape, and pancake shape).

Figure 8 shows the comparison between the differance between the inlet and outlet water temperatures verses day time (serpentine shape, and pancake shape), in the same day to collect the results, the serepentine shape increased the temperature difference between inlet and outlet water nearly 3.8 °C, while the pancake boosted this increase in the temperature difference around 5.6 °C, so the pancake increased the water output temperature than the serepentine shape about 1.8 °C.This goes back to that the pancake shape has largest heat transfere area, then that lead to increase in the electrical performance of PV modules.

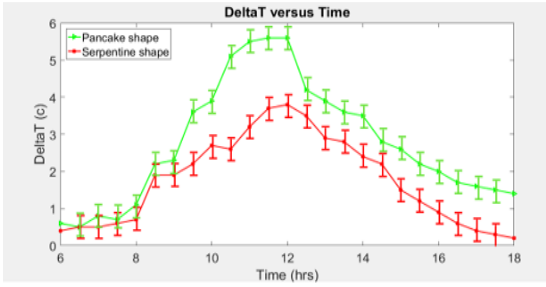


FIGURE 8: the comparison between the differance between the inlet and outlet water temperatures verses day time (serpentine shape, and pancake shape).

Figure 9 shows the comparison between the output power verses day time curves for STC, serpentine shape, and pancake shape on the same day to collect the results, STC has the output power about 36.21 Watt, the serepentine shape has the output power around 39.64 Watt, and the pancake investegate the output power to 44.8 Watt, so the best cooling shape which increases the PV output power is the pancake. it enhanced the output power nearly 17.35% more than the serepentine shape that reached to 8.5%.

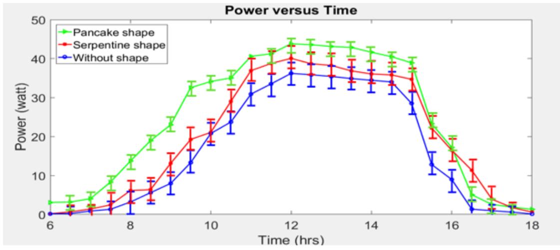


FIGURE 9: the comparison between the output power verses day time (without cooling, serpentine shape, and pancake shape).

5. CONCLUSION

This study demonstrates the effect of an active cooling system with water a as a cooling fluid. Two different shapes of pipes (serpentine and pancake) were presented with the insertion of a structured targeting maximum thermal heat transfer and output power of the PV/T system. The main conclusions are summarized as follow:

- The results showed that the module temperature with serpentine and pancake shapes decreased about 11.6% and 16.59% compared with STC conditions.

- The investegation in the differance between input and output water temperatures show the increasing around 5.6 °C for pancake shape compared with the serpentine shape of pipes 3.8 °C.
- This increase reflects on the maximum output power which reaches to 39.64 Watt for serpentine shape and 44.8 Watt for a pancake shape.
- The collected data and the results show that, the pancake shape is the best PV/T system performance compared with the PV/T system using serpentine shape as a cooling pipes.

6. REFERENCES

[1] Bayoumi A, Abdo G M, Emara A A 2021 *Output Power Boosting of a Photovoltaic Panel Based on Various Back Pipe Structures: a Computational Study* (IOP Conf. Series: Materials Science and Engineering) pp. 1172.

[2] Sudhakar K, Mamat R, 2019 *Artificial Leaves: Towards Bio-Inspired Solar Energy Converters (*Comprehensive Renewable Energy, Volume 1) pp 657:677

[3] Sieckera J, Kusakanaa K, Numbib P B 2017 *A review of solar photovoltaic systems cooling technologies* (Renewable and Sustainable Energy Reviews, Durban, South Africa) pp 192:203.

[4] Jailany A T, Abd El-Al A. Rashwan M. A 2016 *Effect of Water Cooling on Photovoltaic Performance* (Misr Journal of Agricultural Engineering 1 33) pp. 257-268.

[5] Navid Khordehgah, Alina Zabnie, and Hussam Jouhara 2020 Energy Performance Analysis of a PV/T System Coupled with Domestic Hot Water System (College of Engineering, Design and Physical Sciences, Brunel University London, London) doi:10.3390/chemengineering4020022.

[6] Nahara A, Hasanuzzamana M, Rahim N A 2017 *A 3D comprehensive numerical investigation of different operating parameters on the performance of a PVT system with pancake collector* (Journal of Solar Engineering, ASME) pp. SOL-16-1239.

[7] Bayoumi A, Nosier M A, Abdelatiff O E, Mahmoud N A 2016 *Modeling and simulation of photovoltaic/thermal hybrid system using different back-pipe structures* (International Conference on Computer Engineering & Systems ICCES, Cairo, Egypt) pp. 489-494.

[8] Hossam El din A A, Ahmed Hamza C F G, Alin H 2014 *Effect of Ambient Temperature on The Performance of Different Types of PV Cells at Different Locations in Egypt* (Sixteenth International Middle East Power Systems Conference MEPCON'14, Egypt) pp. 331-339.

[9] Khalafallah O. Kassem 2020 *Total Solar Radiation and Ideal Incline Angles of a South-Facing Solar Panel in Qena/Egypt* (Scientific & Academic Publishing ISSN: 2163-2634 Volume 11) pp. 10-17

[10] Bayoumi A, Abdellatif S O, Mahmoud I M, Sahbel A 2014 *novel technique for maximizing the thermal efficiency of a hybrid pv/t system using pulse width modulation* (International Journal of Research in Engineering and Technology pISSN: 2321-7308 Volume: 02 Issue: 08) pp. 437-441.

[11] García M A, Balenzategui 2004 *Estimation of photovoltaic module yearly temperature and performance based on nominal operation cell temperature calculations* (Renewable energy 29 (12)) pp. 1997-2010.

[12] Karami N, Rahimi M 2014 *Heat transfer enhancement in a PV cell using Boehmite nanofluid* (Energy Conversion and Management, Vol. 86) pp. 275-285.

[13] Abdulrahman Th. Mohammad Zuhair S. Al-Sagar, Ali Nasser Hussain, Majid Khudair Abbas Al Tamimi 2021 *Prediction of PV Solar Panel Output Characteristics Using a Multilayer Artificial Neural Network (MLANN)* (IOP Conf. Series: Materials Science and Engineering) pp. 1105.

[14] Bayoumi A, Abdellatif S O, Mahmoud I M, Sahbel A 2013 *Novel Technique for Maximizing the Thermal Efficiency of a Hybrid PV/T System using Pulse Width Modulation* (International Journal of Research in Engineering and Technology, Vol. 2, Issue 8) pISSN: 2321-7308.

[15] Panagiotis Kosmopoulos, Stelios Kazadzis, Hesham El-Askary 2020 *The Solar Atlas of Egypt* (Ministry of Electricity and Renewable Energy), pp. 130.

[16] Hussain F, Othman M, Sopian K, Yatim B, Ruslan H, Othman H 2013 *Design development and performance evaluation of photovoltaic/thermal (PV/T) air base solar collector* (Renewable and Sustainable Energy Reviews 25) pp. 431-441.

[17] Jing D, Hu Y, Liu M, Wei J, Guo L 2015 *Preparation of highly dispersed nanofluid and CFD study of its utilization in a concentrating PV/T system* (Solar Energy, Vol. 112) pp. 30-40.

[18] Makki A, Omer S, Sabir H 2015 *Advancements in hybrid photovoltaic systems for enhanced solar cells performance* (Renewable and Sustainable Energy Reviews, Vol. 41) pp. 658-684.

[19] Hesan Ziar, Patrizio Manganiello, Olindo Isabella, Miro Zeman 2021 *Photovoltatronics: intelligent PV-based devices for energy and information applications* (Journal of Energy and Enviromental Science Volume 1) pp. 106-126.

[20] Abdellatif S, Kirah K, Ghannam R, Khalil A S G, Anis W 2015 *Enhancing the absorption capabilities of thin-film solar cells using sandwiched light trapping structures* (Applied optics, 54 (17)) pp. 5534-5541.

[21] Van Sark W, Reich N. H, Müller B, Armbruster A, Kiefer K, Reise C 2012 *Review of PV performance ratio developmen*t (World Renewable Energy Congress) pp. 4795-4800.

[22] Adel El-Menchawy H., Bassioni H. A., Abdelaziz Farouk 2011 *Mohamed Photovoltaic Systems in Existing Residential Building in Egypt* (International Journal of Scientific and Engineering Research Volume 2 issue 7) pp.1-11.

[23] Firdaus Basrawi, Anuar M N A F, Ibrahim Thamir K, Amir A. Razak 2020 *Experimental analysis on the effect of cooling surface area and flow rate for water cooled photovoltaic module* (IOP Conference Series Materials Science and Engineering) pp. 863-870.

[24] Wojciech Lubon, Grzegorz Pełka, Mirosław Janowski, Leszek Paja K, Michał Stefaniuk, Jarosław Kotyza, Paweł Reczek 2020 *Assessing the Impact of Water Cooling on PV Modules Effciency* (MDPI Journal of Energies) doi:10.3390/en13102414.

[25] Syed M. Islam, Chem V.Nayar, Ahmed Abu-Siada, Md Mubashwar Hasan 2018 *Power Electronics for Renewable Energy Sources* (Fourth Edition springles) pp. 783-827.