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ACTIVE VERSUS PASSIVE COOLING SYSTEMS IN INCREASING SOLAR PANEL OUTPUT*

Raja Harahap, Suherman Suherman**

Universitas Sumatera Utara, Medan, Indonesia

Abstract

Energy availability will remain an issue whole years as energy is the primary human need to live in this planet. Fossil energy is no longer the primary choice as its availability decreases every year, although it dominates the energy source used today. Solar cell is increasingly installed throughout the world even dough initial cost is still expensive for many developing and poor countries. For them who have connected the solar system generators to grid, sunlight to electrical conversion efficiency is the primary concern. On the other hand, system output optimization such as by using maximum power tracking method and cooling system are non material efficient solutions. Maximum tracking system may be costly as mechanical system should be developed well for large solar system. Cooling system on the other hand, is much simpler but limited in efficiency increment. Even dough, beside efficiency increment, the cooling system assists system to avoid excessive surface temperature, which in some cases may lead to panel destruction. The active cooling system requires some electric current from the solar panel output to enable cooling system works. The system achieves better surface temperature reduction than passive cooling system, but the current absorption should be as low as possible to avoid deficiency. This work proposed water based cooling system energized by batteries and compared the output performance to passive cooling system. The result shows that the periodic water sprinkler results better temperature decrement about 13.6% higher power than passive cooling system for sprinkler period of 20 minutes and sprinkle duration of 20 second. The performance decreases when sprinkler period is set 60 minutes. By using the applied water tank, water is available up to 24 hours for sprinkle period of 20 minutes but last longer for 60 minutes. Horizontal sprinkler position results larger cooled area than vertical position which generates 2.45% higher output power.

Keywords: active cooling system, automatic sprinkler, passive cooling system, solar cooling system

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** Corresponding author: email: suherman@usu.ac.id

1. Introduction

In some tropical countries such as Indonesia, sunlight is available all day whole years. Sunlight is the main energy source that energizes lives on earth. Since several decades, sunlight is converted into electrical energy by means of semiconductor technology. Sunlight carries photon and heat (Ahmad et al., 2019). Photon energy is able to excite electrons within some semiconductor materials that enable electric current flows in microscopic scale. By arranging the microscopic materials into a large exposed surface, the current flows in sufficient amount to generate electricity. This engineered material is referred to as solar cell. In turn, solar cell is stacked to form larger arrangement put into a strong and compact frame to make a solar panel. Solar panel is now available to generate energy from few miliwatts to several hundred watts for single frame. The international renewable energy agency projected by the late 2020, there are 583.5 GW solar panels installed around the world (IRENA, 2020).

In order to work perfectly, solar panel should be exposed to sunlight as maximum as possible. Many solar panel installations are placed on an open area where no trees or building obstructs sunlight (Malvoni et al., 2020). In order to maximize sunlight exposure, large scale solar panel installation is often equipped by mechanical system that enables the panel to follow the sun position by using the maximum power point tracking system (MPPT) (Mansouri et al., 2019). MPPT has been an interest topic for many researchers where many algorithms are built to achieve maximum power output, such fuzzy logic (Rezk et al., 2019), perturb and observe (Pilakkat and Kanthalakshmi, 2019), grey wolf optimization (Wan et al., 2019) to sensor less MPPT (Li et al., 2019). The primary challenge on MPPT system is the mechanical mechanism that may require overhead power that may not fit small scale installation as power consumption may reduce the system efficiency.

Small scale solar systems are often installed in the roof of houses and buildings. Most system is in fixed position without the MPPT mechanical support. In such conditions, system does not work at maximum exposure. As results, efficiency relies on the solar cell performances. Cooling system is considered as the most suitable for small scale solar panel installations. As aforementioned in previous paragraph, sunlight comes to earth carrying heat. Heat itself is convertible for energy source, such as in heater electric generation system. However, this is not the solar panel design for. Heat is disturbing in solar panel installation. Heat increases solar panel surface temperature. The 1ºC increase in surface temperature is projected to decrease solar panel efficiency by 0.5% (Penmetsa and Holbert, 2019). This causes output voltage and current drop. In some cases, since small scale solar panel installation is often on top of houses that close to trees, burnable materials on top of solar panel surface may cause solar panel is burnt (Hadj, 2020). Since solar panel temperature may achieve more than 70ºC during peak exposure, cooling system may avoid both efficiency decrement as well as panel damage.

Cooling system is very helpful to maintain solar panel performance as system efficiency in current product is less than 22.5% (Dullweber et al., 2020). Cooling system maintains solar cell efficiency that has been achieved by semiconductor material so that it is not aggravated by operational temperature increment. There have been many researches on active and passive cooling systems (Rakino et al., 2019). The active word is referred to the use of electrical energy to perform cooling system. The energy source can be from the generated energy or independently supplied from battery or alternative power source (Rathour et al., 2019). The active cooling system usually employs fan or pump to flow water (Mah et al., 2019) or air (Fatoni et al., 2019) to the solar panel surface to reduce its temperature. The flows can be either at the front of solar panel, or at the back of the panel so that it does not block incoming sunlight. Active water cooling system collects the flowing water and pumping it to be re-sprinkled to solar panel.

The passive cooling system means no electrical properties used in cooling system. Passive cooling system uses heat-sink materials such as aluminum heat-sink or water heat-sink (Suherman et al., 2019). The aluminum heat-sink can be either round pins (RPHS) or straight fins (SFHS). Combination of active and passive cooling system also exists, and so the aluminum and water combination (Suherman et al., 2019).

2. Proposed active cooling system

The challenge when applying water-based active cooling system is that it requires an electric pump to re-use water to keep water available in cooling tank. Electric pump consumes the generated electricity from solar panel which apparently reduces the conversion efficiency. Since the active cooling system is used mainly in a small scale solar panel installation in houses or buildings that is not efficient to use MPPT, the water supply is actually available in place. Especially in tropical country such as Indonesia, the rainy days are not rare and the rain fall rate is overwhelming in most area, water supply is not a concern.

Therefore, this paper proposes water-based cooling system that avoids water pumping so that the electric current consumption can be reduced. As matter of fact, cooling system does not require water flowing through the solar panel surface all the time. The water flow can be adjusted periodically with a determined duration. Moreover, continuous water flow on solar panel surface may result sunlight intensity reduction that may decrease the radiation received by solar cell. Therefore, this paper also proposes the automatic valve control that opens and closes periodically as programmed in its software. By controlling the time and the amount of water flow, the refill time can be predicted. Fig. 1 illustrates the designed water-based active cooling system.

The water tank is supplied by either using rain water or tap water. If the water pipe installation is at bottom of the water tank, the time required to refill (t_{refill}) the water tank is determined by Equation 1, where V is water tank volume (m^3) and Q is cooling flow rate (m^3/s). Since the cooling debit is depending on the flowing duration (d in second) within period of T (in second, s) and the drain debit, q (m^3/s) as in Equation 2.

$$T_{result} = V/Q \quad (1)$$

$$Q = q \cdot d/T \quad (2)$$

The drain debit can be calculated by using tank discharge formula in Equation 3 (Streeter et al., 1998). The δh/δt is the time rate change from initial water height (h_1) to h_2 *and A* is the area of water tank with diameter D as depicted in Fig. 2.

$$q = A \cdot \partial h/\partial t \quad (3)$$

The time equation is derived based on orifice cross-sectional area, a in m^2, *t*ank cross-sectional area, A in m^2, orifice discharge coefficient, C: $0 < C < 1.0$. C depending upon the orifice geometry, orifice diameter, d in m, tank diameter, D in m, and gravity about 9.8 m/s^2 as shown in Equation 4 (Streeter et al., 1998). By using Equation 3 and 4, the tank debit q changes over time depending upon the water height, h.

$$t = (D^2 / d^2 \cdot C) \cdot \left(\sqrt{h_1} - \sqrt{h_2}\right) \cdot \sqrt{\frac{2}{g}} \quad (4)$$

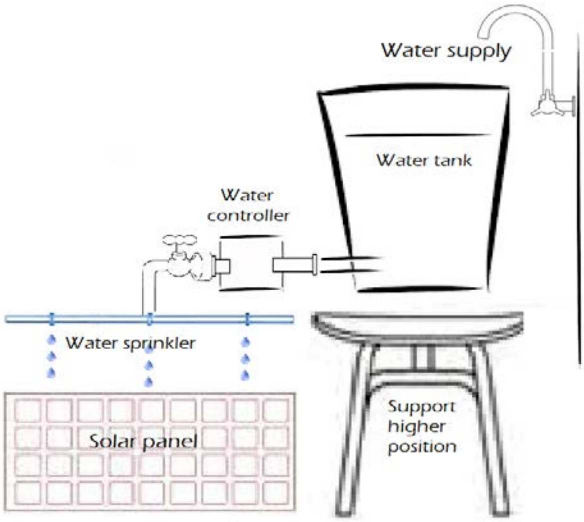


Fig. 1. Designed cooling system

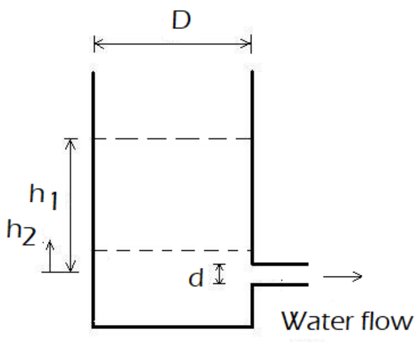


Fig. 2. Tank drain model model

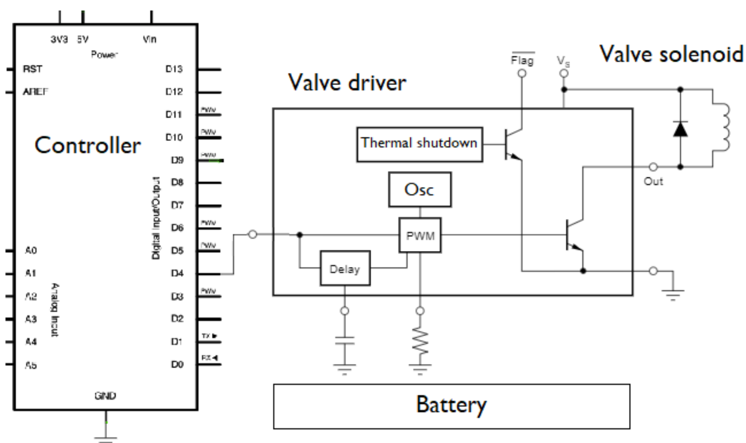


Fig. 3. Valve controller diagram

Meanwhile the water controller is designed by using electronic circuit. The primary parameter is active duration, d and active period, T. The controller activates the water pipe based on period timer and duration timer. When period timer is trigger, the duration timer is activated. Duration timer triggers output D4 to be high. D4 is connected to solenoid driver. Solenoid driver activates the water flow for predetermined duration. Batteries supply current for controller, driver and solenoid. The valve controller diagram is shown by Fig. 3.

3. Measurement method

Measurements were performed on July 22-27, 2020 in location of 3.5658287, 98.6254532. Measurements were performed with combination sprinkler period of 20 and 60 minutes and sprinkler durations of 20 seconds. The compared passive cooling system is aluminum heat-sink combined with water-contained cooling system as proposed in previous work (Rakino et al., 2019) as depicted in Fig. 5.

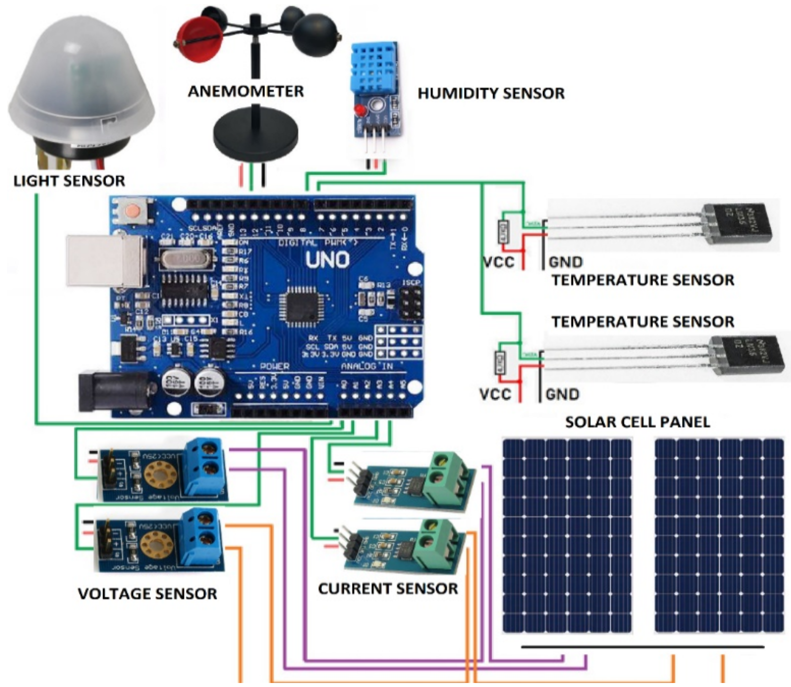


Fig. 4. Measurement circuit

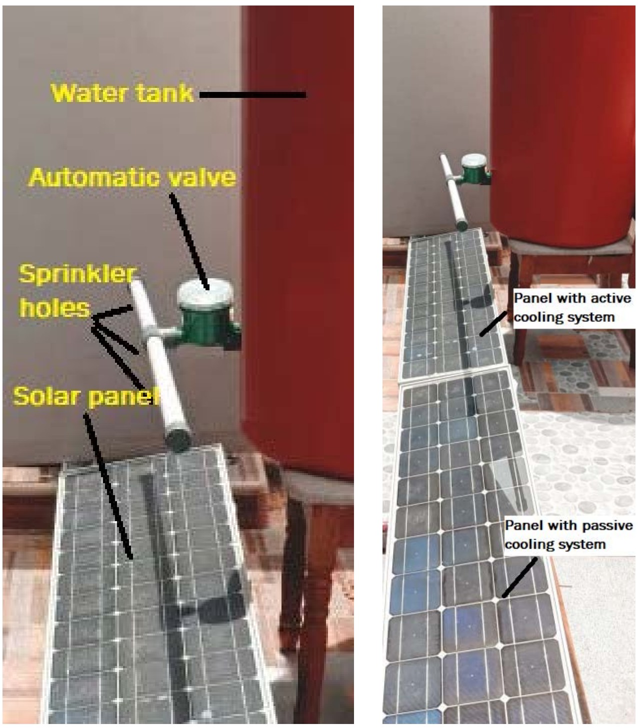
Fig. 5. Solar panel with passive cooling device

In order to evaluate the water-based active cooling system and its impact to output power and to compare its performance to passive cooling system, the experiment is performed by using the 12 Volt 50 WP solar panel modules. To measure the current, voltage and power generated by the solar panel, as well as energy consumed by the water controller, a measurement circuit is devised by using the Arduino control system as depicted in Fig. 4. Some sensors including voltage, current, temperature, light intensity, humidity and wind speed are controlled by ATmega microcontroller within Arduino board. The measurement is initially validated by using a standard voltmeter and ampere meter.

4. Resutls and discussion

Fig. 6a shows the system realization for the water-based active cooling system. The water tank uses a plastic container with average diameter of 66 cm and water height of 95 cm. The container can be replaced by a bigger tank depending upon the size of the cooled panel and the intended water tank water supply. The measurement position is set as in Fig. 6b to compare the proposed active and the existing passive cooling system.

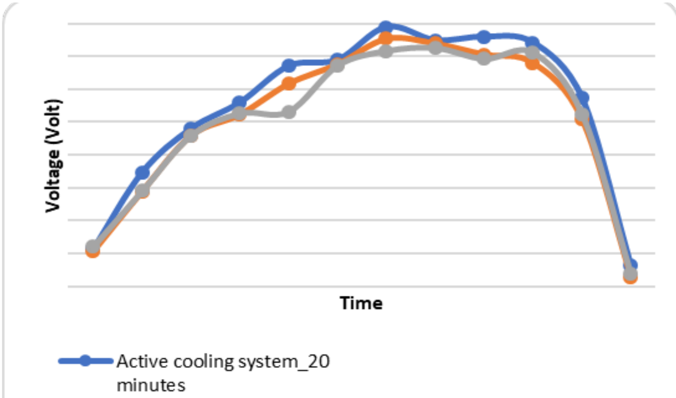
Measurement from 7.00 am to 18.00 pm results voltage, current and power output as plotted in Fig. 7. Voltage rises from about 8.5 V in the early morning to almost 12 V in midday. Voltage then decreases to almost 8 V in the afternoon. The 20 minutes sprinkler period performs the best as voltage higher than other cooled panels. The water cooling system works effectively during midday when sunlight intensity is high. The 60 minutes sprinkler period is able to perform better than passive cooling system only during midday.



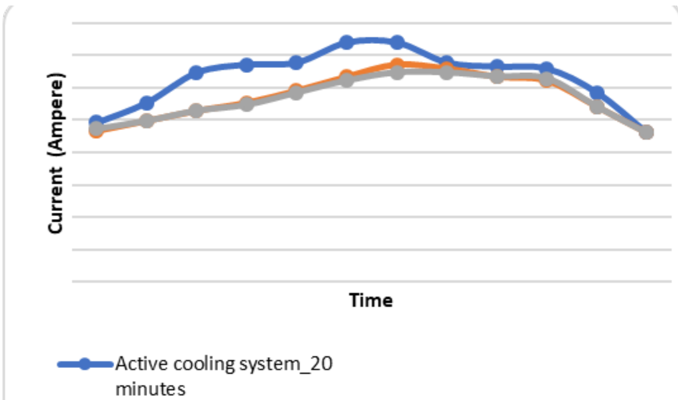
(a) (b)

Fig. 6. Active and passive cooler measurement set up (a) The proposed active cooling system, (b) Active versus passive cooling system

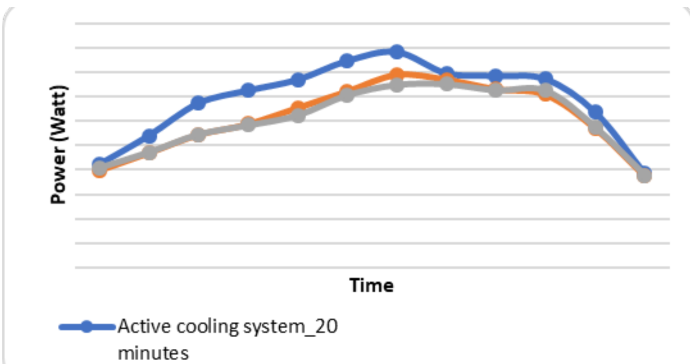
In the early noon and afternoon, passive cooling system is better than 60 minutes sprinkle period. In average, the 20 minutes sprinkle period of water based active cooling system achieve 2.087%, 11.02% and 13.56% higher voltage, current and power than the compared passive cooling system.



(a) Output voltage



(b) Measured current



(c) Output power

Fig. 7. Solar panel output for active and passive cooling systems

Meanwhile, the average power consumption for 11 hours of experiment is shown in Fig. 8 where the 20 minutes sprinkler period consumes in average 1.68 W, the 60 minutes sprinkler period consumes 1.08 W and the passive cooling system has no electric requirement. The proposed active cooling system has lower power consumption than the proposed cooling systems in (Rathour et al., 2019) and (Mah et al., 2019).

The active cooling system in horizontal position causes more water spread over the panel surface. The horizontal position results higher power generated by the solar panel. In average, solar panel with horizontal position cooling position generates about 2.45% higher power than the solar panel with vertical sprinkler position (Fi. 9).

Since water flowing from water tank to solar panel, period and duration of water sprinkling determine how long water will drain. In tropical country, where the experiment was conducted, the average rain rate for the last 10 years achieves 2397 mm per year and average rainy day is 213.64 days a year (BMKG, 2020), which is accountable to fill water tank by using the rain water. However, water tank filling by using water tap can also be done.

The prediction and experiment results of how long water will last in the tank are shown in Fig. 10. Mathematical simulation predicts the water tank water is 10 cm leftover in about 28.5 hours, while the experiment gets 24.2 hours. The error is caused by the shape of the water tank and the chosen discharge coefficient.

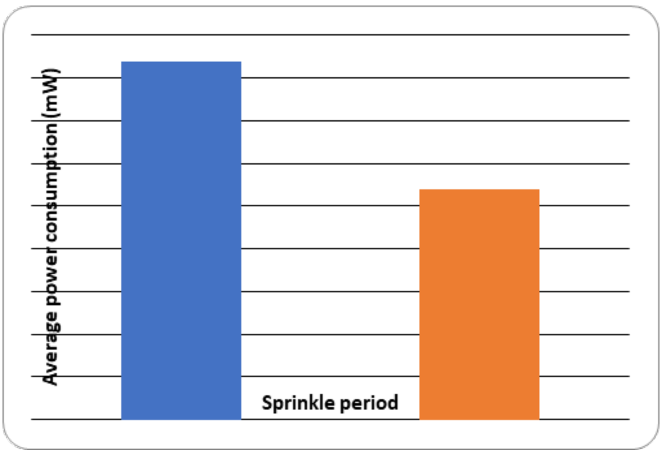


Fig. 8. Power consumption comparison

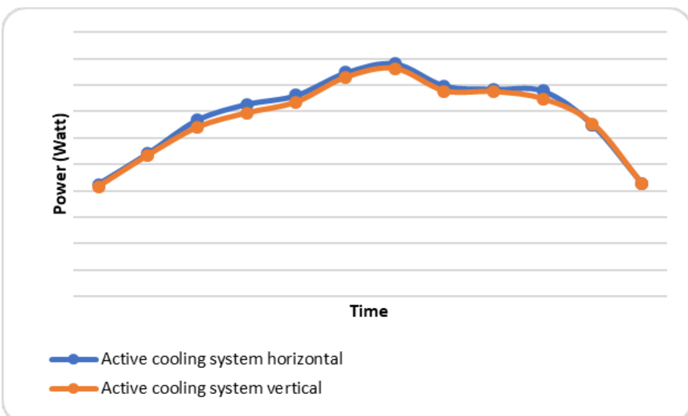


Fig. 9. Horizontal versus vertical sprinkle

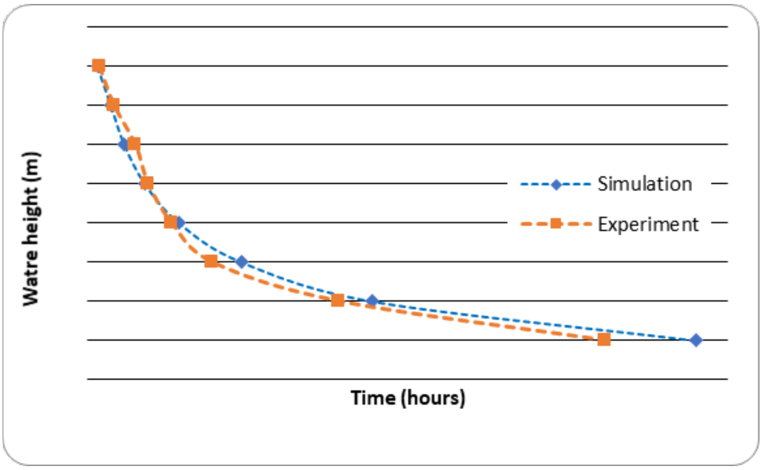


Fig. 10. Water tank drain time

5. Conclusions

This paper has reported the assessment of proposed water based active cooling system that flow water on solar panel surface by using automatic sprinkler with adjusted period and duration. The 20 minutes sprinkler period has successfully increases higher voltage, current and power output of the solar panel about 2.087%, 11.02% and 13.56% subsequently than the compared passive cooling system. The horizontal cooling system position produces better performance than the vertical position. Sprinkler period should be carefully chosen as larger period reduces its effectiveness. However, shorter period requires more water, as the evaluated water tank is predicted last about 28.5 hours for 20 minutes period and 85.5 hours for 60 minutes period. It is suggested that the automatic sprinkler works only when sunlight intensity is strong.

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References

Ahmad Z., Noma T., Paek S., Cho K.T., Taguchi D., Iwamoto M., Manaka T., Nazeeruddin M.K., Touati F., Al-Muhtaseb S.A., (2019), Stability in 3D and 2D/3D hybrid perovskite solar cells studied by EFISHG and IS techniques under light and heat soaking, *Organic Electronics*, **66**, 7-12.

BMKG, (2020), Rainfall Analysis and Nature of August 2020 Rains, (in Indonesian), *BMKG | Meteorological, Climatological, and Geophysical Agency*, https://www.bmkg.go.id/iklim/informasi-hujan-bulanan.bmkg?p=analisis-curah-hujan-dan-sifat-hujan-agustus-2020&tag=&lang=ID.

Dullweber T., Stöhr M., Kruse C., Haase F., Rudolph M., Beier B., Jäger P., Mertens V., Peibst R., Brendel R., (2020), Evolutionary PERC+ solar cell efficiency projection towards 24% evaluating shadow-mask-deposited poly-Si fingers below the Ag front contact as next improvement step, *Solar Energy Materials and Solar Cells*, **212**, 110586.

Fatoni E.K.A., Taqwa A., Kusumanto R., (2019), Solar Panel Performance Improvement using Heatsink Fan as the Cooling Effect, *Journal of Physics: Conference Series*, **1167**, 012031

Hadj M., (2020), The Fire Risk in Green Building Caused by Photovoltaic Installations, In *Smart Energy Empowerment in Smart and Resilient Cities, Lecture Notes in Networks and Systems*, Hatti M. (Ed.), Springer International Publishing, Cham, 462-469.

IRENA, (2020), *Renewable capacity statistics 2020*, International Renewable Energy Agency, Abu Dhabi, United Arab Emirates, On line at: https://www.irena.org/publications/2020/Mar/Renewable-Capacity-Statistics-2020.

Li X., Wen H., Hu Y., Jiang L., (2019), Drift-free current sensorless MPPT algorithm in photovoltaic systems, *Solar Energy*, **177**, 118-126.

Mah C.-Y., Lim B.-H., Wong C.-W., Tan M.-H., Chong K.-K., Lai A.-C., (2019), Investigating the Performance Improvement of a Photovoltaic System in a Tropical Climate using Water Cooling Method, *Energy Procedia*, **159**, 78-83. DOI:

Malvoni M., Kumar N.M., Chopra S.S., Hatziargyriou N., (2020), Performance and degradation assessment of large-scale grid-connected solar photovoltaic power plant in tropical semi-arid environment of India, *Solar Energy*, **203**, 101-113.

Mansouri N., Lashab A., Sera D., Guerrero J.M., Cherif A., (2019), Large Photovoltaic Power Plants Integration: A Review of Challenges and Solutions, *Energies*, Multidisciplinary Digital Publishing Institute, **12**, 3798.

Penmetsa V., Holbert K.E., (2019), Climate Change Effects on Solar, Wind and Hydro Power Generation, In *2019 North American Power Symposium (NAPS)*, 1-6.

Pilakkat D., Kanthalakshmi S., (2019), An improved P&O algorithm integrated with artificial bee colony for photovoltaic systems under partial shading conditions, *Solar Energy*, **178**, 37-47.

Rakino S.A., Suherman S., Hasan S., Rambe A.H., Gunawan, (2019), A Passive Cooling System for Increasing Efficiency of Solar Panel Output, *Journal of Physics: Conference Series*, IOP Publishing, **1373**, 012017.

Rathour R.S., Chauhan V., Agarwal K., Sharma S., Nandan G., (2019), Cooling of Solar Photovoltaic Cell: Using Novel Technique, In *Advances in Fluid and Thermal Engineering*, *Lecture Notes in Mechanical Engineering*, Saha P., Subbarao P.M.V., Sikarwar B.S. (Eds.), Springer, Singapore, 521-529.

Rezk H., Aly M., Al-Dhaifallah M., Shoyama M., (2019), Design and Hardware Implementation of New Adaptive Fuzzy Logic-Based MPPT Control Method for Photovoltaic Applications, *IEEE Access*, Institute of Electrical and Electronics Engineers Inc., **7**, 106427-106438.

Streeter V.L., Wylie E.B., Bedford K.W., (1998), *Fluid mechanics*, 9th ed, WCB/McGraw Hill, Boston.

Suherman S., Sunarno A., Hasan S., Harahap R., (2019), Water and Heat-sink Cooling System for Increasing the Solar Cell Performances, *EAI Endorsed Transactions on Energy Web*, **7**, 10.

Wan Y., Mao M., Zhou L., Zhang Q., Xi X., Zheng C., (2019), A Novel Nature-Inspired Maximum Power Point Tracking (MPPT) Controller Based on SSA-GWO Algorithm for Partially Shaded Photovoltaic Systems, *Electronics*, Multidisciplinary Digital Publishing Institute, **8**, 680.